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January 29, 2021

Stacie R. Beyer
Planning Manager
State of Maine, Department of Agriculture, Conservation & Forestry
Land Use Planning Commission
22 State House Station
Augusta, Maine 04333-0022

Re: Third-Party Review of Technical Feasibility and Financial Practicability Assessment, Pickett Mountain Mine Project, Wolfden Mt. Chase LLC Rezoning Petition / SWCA Project No. 61402

Dear Ms. Beyer:

SWCA Environmental Consultants (SWCA) has undertaken a third-party peer review for technical feasibility and financial practicability of the Wolfden Mt. Chase LLC (Wolfden) Pickett Mountain Project in support of a State of Maine Land Use Planning Commission (LUPC) application to rezone a portion of Penobscot County to allow for development of an underground mineral deposit.

This letter report presents the results of SWCA's review. Should you have any questions pertaining to the information provided, please contact me at (720) 840-4703 or via email at Andrew.Harley@swca.com.

Sincerely,

Andrew Harley, Ph.D.
Mining Director
Senior Geochemist/Senior Soil Scientist

Attachments

OBJECTIVES

The following two documents were submitted by Wolfden in support of the LUPC rezoning application.

- The petition submitted by Wolfden to LUPC.[1]
- A National Instrument 43-101-compliant Preliminary Economic Assessment (PEA).[2]

The documents were reviewed for feasibility and impacts of the mining operation. Based on the level of data associated with these reports, the documents were reviewed to identify, based on collective experience in the mining industry and working on similar projects, issues that may affect the technical and financial viability of this project. The work did not include detailed design reviews and engineering analysis but rather an assessment based on a general understanding of mining principles.

The following areas were assessed to identify potential areas that may put the project at risk.

- Mining engineering: general mining strategies were reviewed, especially those pertaining to impact to land development, including tailings management, transportation and infrastructure, and general mine development strategies.
- Mine dewatering: evaluation of available groundwater data and adequacy of water availability and impacts to processing and water treatment.
- Management of mine waters and process waters: water issues impacting mine viability include variation in predicted and actual water volumes and underestimating water treatment costs. Volcanogenic massive sulfide (VMS) can have potential contaminants of concern, especially arsenic, and potential issues related to tailings management, water management, and impact on concentrate.
- Reclamation and closure: the potential closure issues were reviewed, including water management, habitat restoration, and long-term monitoring and management.
- For financial practicability, the following potential impacts to project viability were reviewed.
    - Infrastructure costs: plans to use existing infrastructure were reviewed to ensure sufficiency and that plans for new infrastructure are realistic. Expected capital and operating costs were also reviewed to ensure that they are reasonable. Specific focus was given to water and energy as the most critical key supplies to evaluate.
    - Marketing: the economic and financial viability of the project will depend on both a) the ability of the owner to sell the products to customers, which will be determined by the quality (chemical composition) of each of the products and the logistics required to deliver to market; and b) the metal prices for those products. Data reviewed included the metal products that the project will produce, and the quality of each of the planned metal products was assessed to confirm the marketability of each.
    - Project schedule: the project schedule will depend on the petitioner coordinating and performing, directly or through contractors, the different development and construction activities necessary for the project to achieve commercial production. The mine development strategy and high-level schedule were reviewed in terms of scope of

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[1] Wolfden Mt. Chase LLC (Wolfden). 2020. *Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit*. Thunder Bay, Ontario: Wolfden Mt. Chase LLC.

[2] Wolfden Mt. Chase LLC (Wolfden). 2020. *Preliminary Economic Assessment, Picket Mountain Project, Penobscot County, Maine, USA*. Thunder Bay, Ontario: A-Z Mining Professionals Ltd. Effective date September 14, 2020; filing date October 29, 2020.

activities, schedule and sequencing for the individual activities, and overall project timeline.

- Project economics: the financing plan and other evidence presented by the petitioner will indicate the expected financial practicality of the project. The macroeconomic, technical, and commercial assumptions components of the financial model were reviewed, as were the financing assumptions used by the petitioner in order to present the financial practicality of the project in the petition.
- Project financing: current conditions of the junior mining market will be used in conjunction with the requirements of the mining financing community to make an assessment of the challenges and opportunities for the petitioner to achieve either a divestment to a major mining company or to secure financing that would enable the project to become a mine.
- Socioeconomic considerations: concurrent with the review of the financial model in the project economics (above), estimates provided by the petitioner were reviewed for reasonableness in the event the project becomes a mine.

TECHNICAL TEAM AND APPROACH

The following senior-level review teams were engaged to provide review and evaluation of the project.

- SWCA Environmental Consultants (SWCA)
- Engineering Analytics, Inc.
- Linkan Engineering (Linkan)
- Montgomery & Associates
- Sunrise Americas LLC

Each team was provided with the documents to provide an assessment of the project overall and for their specific disciplines. Mining engineering strategy was reviewed primarily by Engineering Analytics. Linkan was the primary lead for water management, with support from SWCA on the geochemical and water balance. Montgomery & Associates reviewed mine dewatering with input from Linkan and SWCA regarding water balance. Sunrise Americas reviewed the financial viability of the mine.

Technical memoranda were prepared following independent review of the documents by each team and were used as a basis for this overall assessment report. Team technical memoranda are attached as follows.

- Attachment A: Review of the PEA for the Pickett Mountain Project, Engineering Analytics
- Attachment B: Wolfden Mining Rezoning Petition and Preliminary Economic Assessment Technical Review, Linkan Engineering
- Attachment C: PEA Review, Montgomery & Associates
- Attachment D: Assessment of Geochemistry, Soils, and Reclamation, Pickett Mountain Project, Wolfden Mt. Chase, SWCA
- Attachment E: Assessment of Financial Practicality, Sunrise Americas

PROJECT DESCRIPTION AND CONTEXT

Pickett Mountain is a high-grade base metal deposit primarily composed of zinc, lead, copper, silver, and gold as economic minerals of interest. The intended process is to excavate valuable in-situ minerals (ore) from underground via drilling and blasting into manageable-sized fragments that can be loaded into underground trucks and hauled to the surface to be stored on a temporary stockpile for milling (crushing and grinding to a fine dust) and concentrating. Milling and concentrating will occur continuously at a nominal rate of 1,200 tonnes per day (tpd). The concentrator will use flotation technology to separate the valuable minerals (concentrate) from the non-valuable minerals (tailings). Three concentrates will be produced in sequence—copper, lead, then zinc—with each dewatered and stored separately for transportation to a selected smelter outside the state of Maine. Transportation will be facilitated using truck and trailer combinations with optimized capacity for the amount of concentrate produced. Waste byproduct (tailings) will be dewatered and thickened for delivery via trucks and dozers to an approved Tailings Management Facility (TMF) where the tailings can be shaped and contoured. Water from the dewatering of the tailings and concentrates will be recirculated in the processing plant. The TMF will be lined in such a way as to ensure that any decant water, precipitation, or other water introductions will be collected and not allowed to come in contact with the water table below. The total footprint of the TMF is expected to be approximately 78.4 acres built in five sections sequentially over the life of the operation. Each section will be approximately 15 acres and will be operated and then closed as the next section opens in order to manage the reclamation process on an ongoing basis and minimize risks and exposure. All water collected from the TMF will be pumped back into the milling circuit described above along with some make-up water. The milling process is expected to have a net negative water balance, such that some fresh groundwater will be required to keep the entire milling and concentrating process working and none of these waters will be discharged to the environment.

Project Context with Respect to Development of Volcanogenic Massive Sulfide Deposits

VMS deposits occur in a variety of tectonic settings but are typically related to precipitation of metals from hydrothermal solutions circulating in volcanically active submarine environments. VMS deposits are major sources of zinc, copper, lead, silver, and gold, and significant sources for cobalt, tin, selenium, manganese, cadmium, indium, bismuth, tellurium, gallium, and germanium. Some also contain significant amounts of arsenic, antimony, and mercury. Because of their polymetallic content, VMS deposits continue to be one of the most desirable deposit types for security against fluctuating prices of different metals.[3] There are close to 850 known VMS deposits worldwide with geological reserves of over 200,000 tonnes, with successful mine development in a variety of environments. Successful development of VMS deposits includes the Greens Creek underground mine in Alaska.

Volcanic-associated massive sulfide deposits are among the most likely of all deposit types to have associated environmental problems, particularly acid mine drainage. VMS deposits have high iron- and base-metal-sulfide mineral contents and are hosted by rocks with low buffering capacity. These minerals are unstable under normal oxidizing near-surface conditions and represent potential sources of highly acid and metal-rich drainage, especially in areas disturbed by surface mining or tailings disposal. Associated high abundances of potentially toxic trace metals, including arsenic, bismuth, cadmium, mercury, lead, and antimony, are present in some deposits, particularly those associated with felsic volcanic or sedimentary source rocks.

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[3] Galley, A.G., M.D. Hannington, and I.R. Jonasson. 2007. Volcanogenic massive sulphide deposits. In *Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods*, edited by W.D. Goodfellow. Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5:141–161.

Mining methods have a large influence on the potential environmental impacts of massive sulfide deposits. Both open-pit and underground methods have been used to mine VMS deposits in historic and modern operations. Local climatic and hydrologic conditions influence the acid-generating capacity of deposits. Most massive sulfide deposits contain a large excess of iron-sulfide minerals relative to valuable base-metal sulfide minerals. The nature of ore processing and the method of deposition of the sulfide-mineral-rich tailings and waste rocks are critical parameters that influence the scope of environmental impacts associated with mining massive sulfide deposits. Fine-grained and intergrown sulfide minerals may require very fine grinding, which can result in highly reactive tailings, for beneficiation. Many modern mines discharge fine-grained sulfide-mineral-rich tailings into surface tailings ponds underlain by a number of impermeable linings. Some active underground mines are able to dispose of essentially all tailings by backfilling and cementing mined stopes; consequently, surface contamination is virtually eliminated. Base-metal sulfide minerals are typically separated by flotation; some surfactants used in the process are toxic. Most of these surfactants are recycled and relatively minor amounts are discharged to tailings ponds.

Soluble sulfate salt minerals derived from weathering and oxidation of sulfide minerals in mine dumps and tailings piles represent a potential source of metal contamination and acid generation. Extremely fine grinding required for beneficiation of VMS ore may enhance airborne transport of lead-arsenic-cadmium-antimony-bearing dust. This phenomenon is most probable in semi-arid to arid regions in which strong winds prevail.

Tailings ponds below mills are likely to contain high abundances of lead, zinc, cadmium, bismuth, antimony, and cyanide and other reactants used in flotation and recovery circuits. Highly pyritic-pyrrhotitic orebodies that are exposed to oxidation by air circulating through open adits, manways, and exploration drill holes may evolve sulfur dioxide gas; in some cases, spontaneous combustion can cause sulfide ore to burn. Tailings that contain high percentages of non-ore iron sulfide minerals have extremely high acid-generating capacity. Surficial stockpiles of high-sulfide mineral ore are also potential sources of metal-rich mine water.

Project Context with Respect to a Preliminary Economic Analysis

A preliminary economic assessment is defined as a study that includes an economic analysis of the potential viability of a project's mineral resources. Preliminary economic assessments are completed before prefeasibility and feasibility studies and are an important step in determining whether a company should develop a mineral resource project.

Generally, PEAs will include base case information on the capital costs associated with bringing a project into production, an estimate of how the mine will operate once it is built, how much metal and money it will produce and at what operating cost. The PEA helps mining companies understand risks and uncertainties associated with a project. The study can be part of exploration with both open-pit mining and underground mining and should include a mine plan. More specifically, a PEA tends to have information on pre-production capital costs, life-of-mine sustaining capital, mine life and cash flows, as well as details on processing and production methods and rates.

PROJECT TECHNICAL FEASIBILITY

The proposed development is considered in line with the technical requirements of an underground development of a VMS deposit, specifically regarding the following.

- Acceptable narrow vein mining techniques.
- Mine inflows of groundwater are manageable under normal mining conditions.

- Waste rock segregation and returning to backfill mine workings, with and without cementation depending on geotechnical needs.
- Flotation mineral processing techniques to separate and concentrate metals for sale and to remove deleterious components from tailings, and to recycle reagents as appropriate.
- Adoption of dry stacking for tailings management.
- Application of appropriate water treatment techniques suitable to anticipated water quality associated with mineral processing and waste management.

As this is a PEA-level design, there are considerable issues that require additional assessment and detailed design during feasibility level studies and during the permitting phase, including the following.

- Additional drilling will be required to update the current indicated and inferred mineral resources to measured and indicated categories (Measured & Indicated mineral resources) and, subsequently, to prepare a mineral reserve that can be used to develop a mine plan.
- Segregation of waste rock has been proposed. Additional testing will be required to develop segregation criteria, materials handling, and suitability for backfilling. These data are required to ensure suitable waste management will be temporarily stored at the surface.
- Similarly, geochemical testing of material that will be placed back underground is required to ensure that deleterious constituents will not leach into groundwater in which it is contact.
- Additional metallurgical studies will be required to optimize production which will also impact tailings management and water treatment design parameters.
- The process flow diagram is based on a packaged treatment system using generic performance data. This package system will require optimization for the site-specific water.
- Solids removal will be required prior to the ultra-filtration process to optimize water treatment performance and reduce backwash volumes. Sludge levels may be high and require an appropriate management plan.
- Reverse osmosis concentrate will require additional treatment to ensure precipitation within the storage tank.
- Cyanide management within tailings will require management possibly thought detoxification or ensuring that residual concentrations within the tailings cannot be released into the environment.
- Extremely fine grinding required for beneficiation of VMS ore may enhance airborne transport of metal-bearing dust that will require management during the dry period.
- Management of pyrite during mineral processing has been minimally discussed in the PEA. Clarification of pyrite management following mineral processing is required.
- Liner and capping design is required to minimize leachate loss from these facilities. This will need to be undertaken with an updated soil survey to ensure that facilities are sited appropriately to minimize impact to water resources.
- Groundwater and surface water baseline data will be required.
- Groundwater pumping tests will need to be conducted to determine the hydraulic properties of rocks to confirm groundwater inflows.
- A strict water balance will need to be maintained to maximize use of water produced during mining.

While these issues may appear to be limiting, these are not unusual for a project of this magnitude and can be addressed by engineering controls and good management. A review of the Maine Mining Rules[4] indicates rigorous design requirements that are consistent with other state regulations within the United States, and include an Environmental Impact Assessment as per §3.9(G). These rules will ensure that the detailed design for the proposed project will conform to industry standards and minimize impacts to natural resources. Additionally, development of underground VMS deposits is well understood and examples of effective developments of similar scale include the Greens Creek and Red Dog projects in Alaska.

The site is technically viable, provided that detailed engineering designs, and waste management and operational procedures are in line with industry standards.

PROJECT FINANCIAL FEASIBILITY

The proposed development is considered in line with the financial requirements of an underground development of a VMS deposit, specifically the following.

- Neither the power nor road infrastructure are expected to present any development difficulties.
- The estimated capital expenditure for the new transmission line from the regional grid is considered reasonable based on industry benchmarks.
- Electrical power cost is generally consistent with the delivery and supply rates for industrial customers published by the state regulator, the Maine Public Utilities Commission.
- The quantities of make-up water are relatively small due to the recycling, and errors in the assumptions would not be expected to have a material impact on the economic evaluation.
- Capital estimates for the road upgrades are relatively small in the overall capital expenditures for the project.
- Smelter charges used for assumptions in the economic evaluation were based on input from major smelters including a large, diversified resource conglomerate and commodity trader, for life of mine feed at international benchmark terms.
- Wolfden has confirmed that it expects to negotiate long-term offtake agreements with smelters.
- Copper, lead, and zinc prices used to calculate incomes from the sale of concentrates are reasonable; although similar to current prices, they are at the higher end of long-term price forecasts used within the industry to evaluate projects.
- Although the PEA has not stated smelter destinations, the road and shipping transportation costs to deliver concentrates to the smelters are considered reasonable when benchmarked against other projects and mines and considering likely smelter destinations.
- Smelter charges (deductions) for processing concentrates are reasonable and in line with standard deductions and charges applied in the industry.
- The schedules indicated or implied in the PEA and Zoning Petition for the feasibility phase, and subsequent construction and commissioning phases, appear reasonable.
- The results of the economic analysis confirm that the project could be developed into a viable, small to medium-sized mining operation; the sensitivity analysis confirms that the project returns will be reasonably robust to variances in the key assumptions.

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[4] Maine Department of Environmental Protection. 2017. Chapter 200: Metallic Mineral Exploration, Advanced Exploration and Mining. Available at: http://www.maine.gov/sos/cec/rules/06/096/096c200.docx. Accessed November 2020.

- Wolfden has demonstrated the ability to raise financing to fund development work, with an estimated $14 million invested into the project, including the acquisition of the property.
- The involvement of a major mining company, Kinross Gold, which currently owns 9.6% of Wolfden, can be considered a third-party endorsement of the project, and a demonstration of the ability for management to attract interest from different sources of finance.
- The strategy of Wolfden to raise new funding for the project is considered both standard and reasonable for junior mining companies.

As this is a PEA-level design, there are considerable issues that require additional assessment and detailed design during feasibility level studies, including the following.

- The environmental and other permitting requirements for water have not been considered in this assessment of financial practicality of the project.
- The assumption of the build-own-operate arrangement for the proposed water treatment plant results in a reduced capital expenditure for the construction phase; however, it will not reduce the financing requirement for the project since Wolfden will be expected to provide a corporate guarantee to the supplier for the risk of any failure to use the service.
- The PEA assumes that the concentrate will be transported to the nearest deep-water port via a local logistics contractor, however there is no reference to the location of this port, nor to the destination smelters.
- No market studies have been presented and need to be undertaken during pre-feasibility and feasibility studies.
- The PEA and Zoning Petition make no reference to the timeline for Wolfden to arrange financing for the construction and commission phases, except by implication in the Gantt chart; such financing process can begin prior to completion of the feasibility study and would be expected to continue following completion of the same study.
- The capital expenditures presented in the PEA exclude costs such as tax and duties, financing costs, and legal costs.
- The results of the economic analysis presented in the PEA exclude the royalty that would be paid to Altius Minerals.
- Potential penalties have not been included in the economic analysis since the test work is at the scoping level and is not sufficiently advanced to allow any meaningful estimates.
- Further test work will be required to more accurately determine the chemical composition of the concentrates to be produced by the project, and to confirm the suitability of the concentrates for treatment and refining at the smelters.
- These net present values are significantly higher than the market capitalization of Wolfden, reflecting the use of low discount rates in the PEA and the fact that the market has factored in the risk profile of the project.

In summary, the PEA has been relied on for assessment of infrastructure requirements, and estimates of capital and operating costs for such infrastructure; the descriptions in the PEA are considered reasonable and, since the project would benefit from existing infrastructure (roads, regional grid system) and key supply resources (water, electricity) in the proximity to the project, any errors in the assumptions would not be expected to have a material impact on the economic evaluation.

CONCLUSIONS

Several documents for the Wolfden Mt. Chase LLC Pickett Mountain Mine Project have been prepared to support the land use rezoning application, including the application itself and a preliminary economic assessment. At this stage, all project components are preliminary in nature and will become more detailed as the project develops. Given the level of effort for this stage of development, and compared with similar deposits, the proposed development is technically feasible with the understanding that significant detail is still required for the design of individual mine components in accordance with the State of Maine rules and regulations for development of this project. The estimates and assumptions presented in the rezoning application and preliminary economic assessment to support the financial practicality of the project are considered reasonable at this stage of development; more detailed evaluation, including establishing a mineral reserve, and conducting detailed engineering and negotiating firm contracts to improve the accuracy of capital and operating cost estimates, will be required during the next stages to confirm the economic viability of the project.

The principal challenges for the project to realize the values presented in the PEA are:

- confirming at a feasibility level the scoping level assumptions that have been used in the PEA, including the need to establish a mining reserve;
- successfully fulfilling permitting requirements; and
- arranging project financing and/or introducing a partner.

Finally, Wolfden continues to fund exploration drilling to target extensions to the existing deposits and new discoveries; if successful, this would be expected to improve the financial practicality of the project and make the project return more robust.

ATTACHMENT A

Review of the PEA for the Pickett Mountain Project,
Engineering Analytics, Inc.

Engineering Analytics, Inc. ▪ 1600 Specht Point Rd. ▪ Suite 209 ▪ Fort Collins, CO 80525 ▪ Ph 970.488.3111 ▪ Fax 970.488.3112

Technical Memorandum

To:	Andrew Harley, PhD.	From:	Jason Andrews, P.E.
Company:	SWCA Environmental Consultants	Date:	December 4, 2020
EA No.:	111115		
Re:	Review of the PEA for the Pickett Mountain Project		
Reviewed by:	Daniel Overton, P.E.		

1.0 INTRODUCTION

Engineering Analytics, Inc. (EA) was requested to review the mine engineering aspect of selected sections of the Preliminary Economic Assessment (PEA) for the Pickett Mountain Project. The PEA was prepared by A-Z Mining Professionals Limited for Wolfden Resources. This review was conducted in consideration of the Land Use Planning Commission (LUPC) approval criteria provided below:

- 1b - no undue adverse impact on existing uses or resources or a new district designation is more appropriate for the protection and management of existing uses and resources.
- 2a - Positive and negative impacts resulting from the change in use and development of the area. Such impacts may include, but are not limited to, impacts to regional economic viability, Maine’s natural resource-based economy, local residents and property owners, ecological and natural values, recreation, and public health, safety, and general welfare.
- 2b - Positive and negative impacts upon associated transportation routes and other infrastructure
- 2c - Potential for future reclamation and beneficial use of the affected area, following closure of the site.
- 3a - Potential short and long term socioeconomic impacts, both positive and negative, upon the immediate area and communities likely to be affected by the proposed activities and resulting from the construction, operation and closure of the proposed activity
- 3b – Potential impacts on services
- 3c – Potential impacts on existing infrastructure
- 3d – Potential impacts to existing uses and natural resources

EA's reviewed the sections of the PEA provided in Table 1 were reviewed in performing our scope of work:

Table 1: PEA Sections Reviewed

4.0 Property Description and Location
5.0 Accessibility, Climate, Local Resources, Infrastructure and Physiography
6.0 History of the Property
7.0 Geological Setting and Mineralization
7.1 Regional Geology
13.0 Mineral Processing and Metallurgical
14.0 Mineral Resource Estimate
15.0 Mineral Reserve Estimates
16.0 Mining Methods
16.2 Underground Mine Design
16.3 Geotechnical Considerations
16.4 Mine Access and Level Development
16.5 Rock Handling
16.6 Underground Services and Infrastructure
16.7 Mining Methods
16.8 Dilution and Extraction
16.9 Mining Operations
16.10 Mining Equipment
16.11 Mine Backfilling
16.12 Ventilation
16.13 Development and Production Schedules
16.14 Mine Surface Infrastructure
16.15 Grade Control
16.16 Underground Personnel
17.0 Recovery Methods
17.1 Conceptual Process Flowsheet
17.2 Process Design Criteria
17.3 Reagents
17.4 Process Make-Up Water
17.5 Material Balance
18.0 Infrastructure
18.12 Materials Pads
18.12.1 Rock Dump - Clean
18.12.2 Rock Dump - Acid Generating
18.12.3 Ore Pad and Temporary Stockpile
18.22 Tailings Management Facility
20.0 Environmental Studies, Permitting and Potential Impacts
20.1 Regulatory Framework
20.2 Mine Permitting Stages and Status
20.3 Environmental Studies and Impact Studies and Impact Assessments
25.0 Interpretation and Conclusions

EA has also reviewed the Petition to Rezone Portion of Township 6 Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit dated January 26, 2020 and revised June 30, 2020 for conformance with the PEA data.

EA's review was completed with the understanding that this PEA to support the petition to rezone and that a mine permit application will be submitted at a later date for detailed review.

EA's comments to the assigned sections are provided in Table 2 below. Only the sections that EA had comments on are provided in Table 2.

2.0 ASSESSMENT OF REASONABLENESS

EA has reviewed the PEA as it relates to mine engineering. We have determined that the information put forth in the sections we reviewed are based on reasonable estimates. The proposed facilities and technologies are similar to those used in the industry at other mines in similar climates.

3.0 ISSUES AND POTENTIAL CHALLENGES

During EA's review there are a few items that could pose challenges. The tailings management facility is a very conceptual at this stage of the project. The proposed method for dry stacking the tailings is used in the mining industry and is reasonable. However, management of tailings is an important part of the mine life cycle that requires detailed design.

The water usage and sources are discussed in general terms. The PEA indicates that they will have suffect water for mining activities and appears reasonable. Additional details for the water usage and water source will be needed for the site water usage for startup, operations and closure. The management of water consumes a lot mine operations time and efforts. A detailed water balance will be needed to determine water treatment, storage, and usage needs during the year.

4.0 CONCLUSIONS

The information put forth in the sections EA reviewed appear to be based on reasonable estimates. At this stage of the project there are additional details that would be needed for a mine permit application. However, the assumptions provided in the PEA support the concept that this project is feasible from a mine engineering standpoint.

Table 2: Comments on PEA in Support of Rezoning Petition

Comment Number	Section Number	Page Number	Comment
1.	Section 4.0 Property Description and Location	15	A discussion of nearest residences/structures would be helpful to determine impact to others. Additional discussion of the impacts and agreements regarding "surface rights leases on the south side of Pleasant Lake" should be discussed.
2.	Section 5.3 Local Resources	16	This section addresses the local resources and outlines roads, a town and rail line. It does not address how they will use the local resources and the impacts that the mine might have on those resources, including fire, police, solid waste, etc. These items should be addressed. The impact to local natural resources should be also be addressed.
3.	Section 5.4 Infrastructure	16	This section addresses the existing infrastructure that includes roads and electrical. A statement as to the capacity of the existing roads to support the additional mine traffic should be included and potential needs for road upgrades should be included. A statement regarding the ability for the existing utilities to support the mine should also be included.
4.	Section 5.5 Physiography	17	It would be useful to discuss surface water bodies and potential impacts to those structures.
5.	Section 7.1 Regional Geology	23	The resolution of Figure 7.2 is hard to read the geology of the region. Please improve the resolution.
6.	Section 15.0 Mineral Reserve Estimates	107	This section has not been completed. Please update.
7.	Section 16.5 Rock Handling	112	The rock handling section does not provide any detail about how the rock will be sorted or stored during the life of the mine. Additional detail should be provided about rock sorting and storage or provide a reference in the report to the sections that address this. Waste rock handling and associated ARD can be a problem if not managed correctly.
8.	Section 16.6 Underground Services and Infrastructure	112	The water supply section indicates that water will be obtained from a water storage pond and water pumped from the mine. The mine dewatering section indicates that they anticipate pumping about 1,420 m^3 of water from the mine each day or 518,300 m^3 per year. The service water needs are projected to be 401,000 m^3 per

Comment Number	Section Number	Page Number	Comment
			year. Thus, during full time operation the project has enough water to operate. However, additional detail should be provided to support their water source availability prior to full mine development. At full mine development it appears that they will have an excess of about 100,000 m^3 of water per year. Information should be provided to address where the source of the water before the shaft is developed and how the excess water is managed during full time operations. The control of and access to water is integral for development and operations.
9.	Section 16.14 Mine Surface Infrastructure	133	The mine surface infrastructure talks about a well for potable water needs. Some discussion should be provided regarding potable water needs and project well production levels.
10.	Section 18.3.1 Main Pad Preparation	143	The amount of drilling and blasting costs to level the pad was calculated. However, the costs to crush and place the material is not included in the costs. Please include these costs or reference where they are located.
11.	Section 18.5 Potable Water System	144	A potable water system should be identified.
12.	Section 18.12.1 Rock Dump -Clean	145	Section 18.12.2 calls out the liner thickness. Update this section to reflect the liner thickness.
13.	Section 18.22.2 Design Criteria	150	This section should include seismic design criteria.

ATTACHMENT B

Wolfden Mining Rezoning Petition and Preliminary Economic Assessment Technical Review,

Linkan Engineering

MEMORANDUM

DATE: November 24, 2020

TO: Andrew Harley, SWCA

FROM: James J. Gusek and David A. Myers

SUBJECT: Wolfden Mining Rezoning Petition and Preliminary Economic Assessment Technical Review

REFERENCE NO.: 96.01_504

INTRODUCTION

At the request of SWCA, Linkan Engineering (Linkan) reviewed two documents associated with the rezoning of a land parcel in Penobscot County, Maine for the development of an underground metal mine and its associated surface disturbances including a dry stack tailings facility. The Linkan review focused on technical issues related to the potential to contaminate ground and surface water and the mitigation plans proposed in the two documents:

- Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit, and
- Preliminary Economic Assessment (PEA) Pickett Mountain Project

Linkan's comments follow. For convenience, the page number locations of Linkan's comments are cited below and they are also imbedded in the two Adobe Acrobat™ bookmarked PDF files that SWCA provided to Linkan. Page numbers referenced below refer to the location of the page in the total page count in the document (Adobe Acrobat™ page count) and not the page number listed at the bottom of the page (that was not consistently provided).

LINKAN ENGINEERING'S COMMENTS TO *PETITION TO REZONE PORTION OF TOWNSHIP 6, RANGE 6 PENOBSCOT COUNTY, MAINE FOR DEVELOPMENT OF AN UNDERGROUND METALLIC MINERAL DEPOSIT*

Linkan Comment #01, Page 163

There is no real basis for estimate of mine dewatering flow rate. The water management plan needs to have flexibility in case flows are higher. There does not appear to be a specific plan to deal with large storm events.

Linkan Comment #02, Page 163

The water quality of the seepage into the mine workings deteriorates over time as previously submerged or isolated sulfide rock (i.e., pyrite) is exposed to the mine atmosphere containing oxygen. This is an inevitable condition that either needs a mitigation plan to prevent it from happening or a water treatment plant capable of treating the additional loading or both.

Linkan Comment #03, Page 164

Removing the bacterial component of pyritic dissolution is also an effective strategy for preventing acid generation, but is not mentioned. Acidophilic microbes such as *Acidithiobacillus Ferrooxidans* accelerate the kinetics of pyrite oxidation and the generation of acid rock drainage (ARD) by several orders of magnitude. This aspect of ARD production has been well understood for almost 70 years (Leathen et al., 1953).

Linkan Comment #04, Page 164

Oxidation can still occur w/o Oxygen. If ferric iron (Fe^{+3}) is present in the water in contact with pyrite, oxidation can occur even though the pyrite is submerged. Ferric iron is produced in the pyrite dissolution process and can self-sustain to a degree. When the ground water rebounds after mine dewatering pumping is suspended, it might be necessary to neutralize the rising mine pool with alkalinity to minimize the presence of ferric iron in the pore spaces in contact with sulfide-bearing mine waste.

Linkan Comment #05, Page 164

Bactericides can also be effective in minimizing pyritic oxidation. Low concentrations of common anionic surfactant bactericides such as sodium lauryl sulfate, can minimize acid generation kinetic rates (Kleinmann and Ericson, 1983). Diluted milk has also been found to be an effective acidophilic bactericide (Jin, et al., 2008).

Linkan Comment #06, Page 164

The longer the acidic waste rock stays on the surface, the more acidic the backfill material might become. Preventing pyritic oxidation by removing oxygen and/or water or applying a bactericide during operations could minimize ARD generation in backstowed waste rock until closure, which would minimize the presence of ferric iron in the rising mine pool.

Linkan Comment #07, Page 164

General Comment

While Wolfden did not acknowledge the role of bacteria in the generation of ARD, it appears that they are cognizant of the problem and have taken appropriate measures (i.e., controlling water and air contact and addressing ARD in an active treatment plant) to deal with it both during operation and at closure. The use of ARD-preventive bactericides, a proven technology, might be a reasonable strategy to include in the plan.

Linkan Comment #08, Page 166

Tailings & waste rock co-disposal underground is a good idea. If there are reactive sulfides in the stope walls, after backstowing they would be placed in intimate contact with the very moist co-disposed tailings and that would cut off the oxygen supply. This is as close to pre-mining conditions as one could expect.

Linkan Comment #09, Page 166

Submergence of tailings is an acceptable practice, however it should be validated with some simple kinetic testing using drill core. The testing should be conducted in concert with planned acid-base accounting. Also, some residual flotation reagents are organic (such as A325, M200, and A343 [Table 17.2 in the PEA] which are xanthates and organic collectors). These will eventually turn the mine pool anoxic as they degrade. While arsenic is present in the waste rock and tailings as arsenopyrite and tetrahedrite which contains antimony, it is unlikely that these two constituents (As & Sb) would be mobilized by the anoxic conditions in the mine pool.

Linkan Comment #10, Page 166

Sub-aerial tailings deposition will encourage acid formation due to exposure to water and air. A plan for suppression of bacterial growth is needed.

Linkan Comment #11, Page 166

What happens to snowmelt? This is Maine... Consider a temporary sealant to increase runoff and avoid infiltration, especially on the 20% side slopes. A water-based polymer sealant was used successfully on a mine waste repository in Idaho at the end of the construction season to reduce infiltration. The photo is courtesy of Pacific Inter-Mountain Distribution LLC, Kalispell, Montana.

Figure 1 Spraying temporary sealant on a mine waste repository

Linkan Comment #12, Page 166

The final tailings might be finer than 400 mesh (37 microns) according to the PEA executive summary. Smooth drum rolling is an appropriate compaction method. We agree that this compacted material is likely to produce a very low permeability condition. However, dust control might be a problem during the drier months and the finer grained material is likely to contain a significant fraction of respirable dust.

Linkan Comment #13, Page 168

General Comment

An ARD mitigation plan should be in place during mine operations and not just for closure. The plan should include minimizing water and air exposure to pyritic waste rock piles such as spray-on sealant (say at the end of the fall season) and/or the inclusion of a bactericide to suppress microbial kinetics. Implementing these technologies would not add a significant cost component. As there will be a geomembrane cap as part of the closure design (i.e., complete encapsulation), the potential for ARD generation appears to be very small.

Linkan Comment #14, Page 169

Returning the RO reject back to the WTP feed tank will cause a build-up of salts and potentially gypsum to form in the system. A plan to remove sulfate is needed or a disposal plan for the brine. This is not a lot different than many larger mines…but they have very large tailings ponds to put the reject into.

Linkan Comment #15, Page 169

The proposed Process Flow Diagram seems credible (with possible exception of RO brine management – Linkan Comment #14). Linkan's experience is that well mixed round reaction tanks followed by lamella or other type of clarifiers and then Microfiltration followed by RO gives a robust system with consistent results.

Linkan Comment #16, Page 221

It is not reasonable to expect that all drainage water will no longer require treatment after 1 year. There should be a passive system to polish the final drainage water, and the WTP should be retained for a time as a contingency plan.

LINKAN ENGINEERING'S COMMENTS TO *PRELIMINARY ECONOMIC ASSESSMENT (PEA) PICKETT MOUNTAIN PROJECT*

Linkan Comment #01, Page 14

The grain sizes of the concentrates and the tailings are reported to be from 14 microns (µm) to 37 µm. This is very small compared to established norms by many mining operations. For comparison, talcum powder exhibits a "…a median diameter of 26.57 µm with a range of particle sizes from 0.399 µm to 100.237 µm" (Gilbert, et al., 2018).

The assumptions used to determine dry stacking (or sub-aerial tailings deposition) capacities and characteristics need to be vetted from experience/data with similar materials. Dry stacked tailings storage will reportedly reduce the tailings moisture content to about 20%; dust control may be an operational issue in drier seasons but there are numerous technologies available such as spray-on sealants to mitigate this potential problem. This would not be an issue at closure as the tailings storage facility (TSF) will be capped.

Linkan Comment #02, Page 18

The presence of arsenic and antimony in the concentrates infers their presence in the tailings. Immobilization of these constituents in the final tailings and presumed exposed surfaces in the underground mine workings should be a priority. This is discussed in more detail in other comments.

Linkan Comment #03, Page 19

There appears to be adequate room for locating a runoff catchment basin.

Linkan Comment #04, Page 20

Complete geochemical characterization testing is a good idea, but it should also include a microbial testing component for the presence/ absence of acidophilic bacteria in the core samples collected from the site during the exploration program. Older samples should be tested prior to more-recent core samples.

Linkan Comment #05, Page 20

As revealed elsewhere in the PEA (Linkan Comment #06), the deposit contains high concentrations of pyrite and the tailings will exhibit a very fine grain size (Linkan Comment #01). Low dry stacked tailings permeability values notwithstanding, the tailings will likely be very geochemically reactive and prone to produce acid rock drainage (ARD). Amending the closure cover design to eliminate the low permeability geomembrane component is probably not a good plan.

Linkan Comment #06, Page 38

The presence of pyrite (FeS_2) and calcite ($CaCO_3$) in the ore constitute two end points on the ARD potential spectrum. The more calcite present in the mine waste, the less likely ARD will form. This would be confirmed in follow-up testing (Linkan Comment #04).

Linkan Comment #07, Page 39

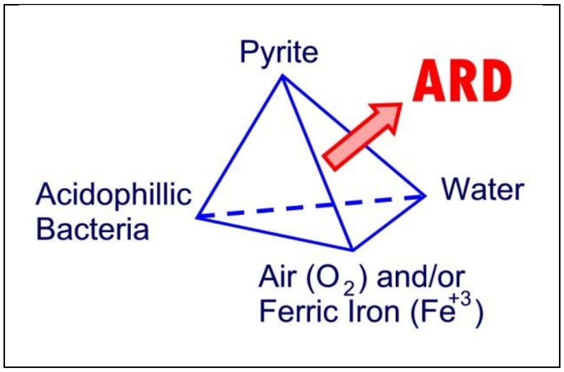
The level of pyrite in the ore (45% to 65%) will increase in the tailings when the minerals of value (chalcopyrite [Cu], galena [Pb], and sphalerite [Zn]) are recovered. By inspection, this elevated level of pyrite in the mine waste has an almost certain likelihood of generating ARD if mitigation measures (discussed elsewhere in the PEA) are not implemented. The arsenopyrite, tetrahedrite, and tennantite in the ore (and presumably the tailings) are potential sources of arsenic and antimony contamination. Mitigation measures are discussed elsewhere in the PEA.

Linkan Comment #08, Page 93

The smallest grain size distribution of the tailings sample used in this test was 325 mesh or 44 µm. Text in Section 1.4, Processing, states that regrinding to 14 µm would be necessary to produce a suitable lead concentrate. Vacuum filtration of 14 µm materials should be demonstrated. Vacuum filters with diatomaceous earth precoat are often used for very fine material.

Linkan Comment #09, Page 139

Backfilling the stopes with mine waste and tailings (Section 16.11.1) is a good idea. The technique should be called out as "co-disposal" which is the term commonly used. Surrounding coarser-grained mine development waste (which may or may not be acid generating) with tailings that presumably contain pyrite with a grain size of about 14 µm is an efficient use of space and geochemically sound as the moisture retention/field capacity of the tailings should keep the backfill moist (cutting off the oxygen supply leg of the ARD tetrahedron shown below) and have very low permeability.



Linkan Comment #10, Page 151

Table 17.2 includes sodium cyanide and multiple organic reagents such as xanthate (A325) used in the froth flotation circuit. The ultimate fate of these reagents should be discussed in the water treatment section. Are these reagents retained in the concentrates (which are shipped off site) or the tailings? It would be easy to add this information as an extra column or two in Table 17.2.

Linkan Comment #11, Page 156

This is a reasonable approach for collecting ARD. Materials above the liner might include a carbonate component to passively neutralize any ARD prior to its draining to the holding pond.

Linkan Comment #12, Page 157

The water management system (page 157) does not discuss the water quality requirements for process water. If all or some of the collected water is clean enough to be directly recycled without treatment, it could save treatment costs.

Linkan Comment #13, Page 157

Recommend that the proposed infiltration fields for excess water not be called septic fields…suggest Rapid Infiltration Basin (RIB).

Linkan Comment #14, Page 157

The WTP is designated to be designed for 120 gpm, and there does not seem to be adequate background for this number. On page 125 it says that the underground dewatering requirement is 1,420 m^3/day, or 260 gpm. On page 157 the text says, "the collected surface water, along with mine discharge water, is pumped to a raw water collection pond. This water is then treated through a water treatment facility". – this makes it seem that the WTP must be significantly larger than 120 gpm. Also, the WTP needs to be sized larger to "catch up" after rain events.

Linkan Comment #15, Page 158

Linkan's experience is that well mixed round reaction tanks followed by lamella or other type of clarifiers and then Microfiltration followed by RO gives a robust, system with consistent results.

Linkan Comment #16, Page 158

The RO reject is shown as going to "Waste/Concrete". RO reject disposal can be a severe problem, and this should be defined better.

Linkan Comment #17, Page 160

The tailings moisture will be controlled with pressure filtration, referencing Mine Paste, 2020. Did this test work use a tailing sample with a minimum grain size of 14 µm?

Linkan Comment #18, Page 161

The tailings volume is conservatively assumed to not include underground backfill.

Linkan Comment #19, Page 161

The design criteria need to include considerations for dust control. The very fine-grained dry stack tailings, even after moisture control, will quickly desiccate in dry weather and could pose a blowing dust problem. This could be managed with water sprays or a spray on water-based polymer which was discussed in Comment No.'s 9 and 10 in the Zoning Petition document.

Linkan Comment #20, Page 164

Over time, the grasses and shrubs will yield to a forest similar to the one surrounding the site. This is inevitable. The random soil layer for the root zone might be adjusted to accommodate for this.

Linkan Comment #21, Page 164

The contact water chemistry improvement timeline might be accelerated through the use of temporary sealants (see Linkan Comment #11 in the Rezoning Petition document) until the final cover is completed.

Linkan Comment #22, Page 177

Sequentially closing up to five TMF cells is a good plan; it provides an opportunity to adjust the closure of subsequent TMF cells based on the performance of earlier closure events.

REFERENCES CITED

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END

MEMORANDUM

DATE: December 2, 2020

TO: Andrew Harley, SWCA

FROM: James J. Gusek and David A. Myers

SUBJECT: Wolfden Mining Rezoning Petition and Preliminary Economic Assessment Technical Review

REFERENCE NO.: 96.01_504a (addendum)

INTRODUCTION

At the request of SWCA, Linkan Engineering (Linkan) reviewed one additional document and one updated version of a previously reviewed document associated with the rezoning of a land parcel in Penobscot County, Maine for the development of an underground metal mine and its associated surface disturbances including a dry stack tailings facility. The Linkan review focused on technical issues related to the water treatment mitigation plans proposed:

- New Document - Ltr_Wolfden_Responce_AdInfoRequest.pdf
- Updated Document - Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit, Revised June 30, 2020

Linkan's comments follow. Comments start at #23 as this is an addendum (addition) to the previously submitted Memorandum, same subject, dated NOV 24th, 2020, that ended with comment #22. References to the sections that pertain or connect with the reviewed document are provided for each comment.

Linkan has also provided a summary opinion on whether the information provided indicates that the mine is at least feasible for the purpose of rezoning to allow for detailed design and permitting to take place.

LINKAN'S COMMENTS TO: WOLFDEN RESPONSE INFO REQUEST

Linkan Comment #23, (Comment #7 Waste Disposal)

The process flow diagram is based on a packaged Suez treatment system using generic performance data. This package system is not optimized for the site specific water (not available yet) so there will be changes. Typically some type of solids removal step is in front of ultra-filtration (UF) process to optimize performance and reduce backwash volumes. Sludge levels could be high so more thought about sludge handling may be needed. Also a comment is made that the, "Reverse osmosis (RO) concentrate will flow to a storage tank for decant and solids removal." Some measure of additional treatment is needed for RO concentrate (brine) to precipitate. This is not included and not trivial.

Linkan Comment #24, (Comment 11 State Agency Review Comments, Answer 4 Streams and Wetlands)

The statement that, "The liner below and capping and closure of the TMF will prevent any leachate from infiltrating into the groundwater below" is a bold promise assuming industry standards. Liners and caps are almost never perfect so it is probably more correct to state that it will prevent significant infiltration. To say more than this would require justification about how this system is better than industry standard.

LINKAN'S COMMENTS TO: PETITION TO REZONE…, REVISED JUNE 30, 2020

On review of the text associated with Linkan's previous comments there is not any substantive changes that need to be made to the comments.

SUMMARY OPINION

Overall the documents were fairly well detailed for the expected level of project development. The rezoning requestor, Wolfden Mt. Chase LLC, has covered a fairly broad range of potential issues that will drive water treatment challenges during the active life of the project and after closure. We did not find any major category gaps in the documents.

There are many issues that still must be resolved based on more realistic water quality and flow rate predictions. This would include a more refined water treatment process that is specific to the site water (with a more definitive effluent quality), more details on how wastes will be handled (precipitates, sludges, brine, etc.), and a representative closure model that can be relied on. In this process we would assume that the issues we have discussed in our comments could be resolved.

In summary the documents that Linkan reviewed indicate that Wolfden Mt. Chase LLC, has covered the main categorical issues that will be faced with the water treatment aspects of the mining project. Both water treatment during active mining and source control measures for closure will not be trivial especially with the no impact goals stated for discharge. We believe these issues can be mitigated and the goals met if good planning, testing/proving, engineering, and execution is done behind adequate funding and good management. Thus the water treatment aspects of the project appear feasible for the purpose of rezoning.

END

ATTACHMENT C

PEA Review,
Montgomery & Associates

MONTGOMERY
& ASSOCIATES
Water Resource Consultants

Groundwater experts since 1984

TECHNICAL MEMORANDUM

DATE: November 23, 2020 **PROJECT #:** 1683.01

TO: Andrew Harley, SWCA

FROM: Chris Cottingham, Dexter Race, Paul Pettit

PROJECT: PEA Review, Wolfden Resources, Picket Mountain Project,

SUBJECT: PEA Review

Montgomery & Associates (M&A) has read the A-Z Mining Professionals, LTD, Preliminary Economic Assessment Pickets Mountain Project, Prepared for Wolfden Resources Corporation, September 14, 2020. Additionally, M&A reviewed Wolfden Mtn. Chase, LLC, Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit. M&A has reviewed these materials to assesses the following:

1. The veracity of the proposed operation.
2. The viability of the mining project and an assessment of impacts, both positive and negative.
3. A determination if there is enough information to justify a rezoning for mining.

M&A determines that there is enough information and that a professional standard has been met in the preliminary economic assessment (PEA) to justify a rezoning of the property for mining.

SPECIFIC FINDINGS

The specific findings are as follows:

Regional Geology

Geologic units from surface:

Chesuncook Dome

- Trout Valley Fm (mudstone-siltstone)
- Traveler Rhyolite
- Matagamon SS (sandstone)
- Seboomook Fm (sandstone-mudstone)

- Frost Pond Shale
- West Branch Volcanics
- Ripogenus Fm (sandstone)
- Dry Wall Volcanics

NW flank Shin Pond/Stacyville quads

- Metagaman SS (sandstone)
- Seboomook Fm. (sandstone-mudstone)
- Unnamed intermediate to mafic volcanics
- Unnamed calcareous siltstone
- Unnamed limestone
- Unnamed siltstone-sandstone
- Unnamed conglomerate-sandstone-siltstone
- Wassataquoik Chert
- Stacyville Volcanics

Cross section of the deposit and associated lithotypes

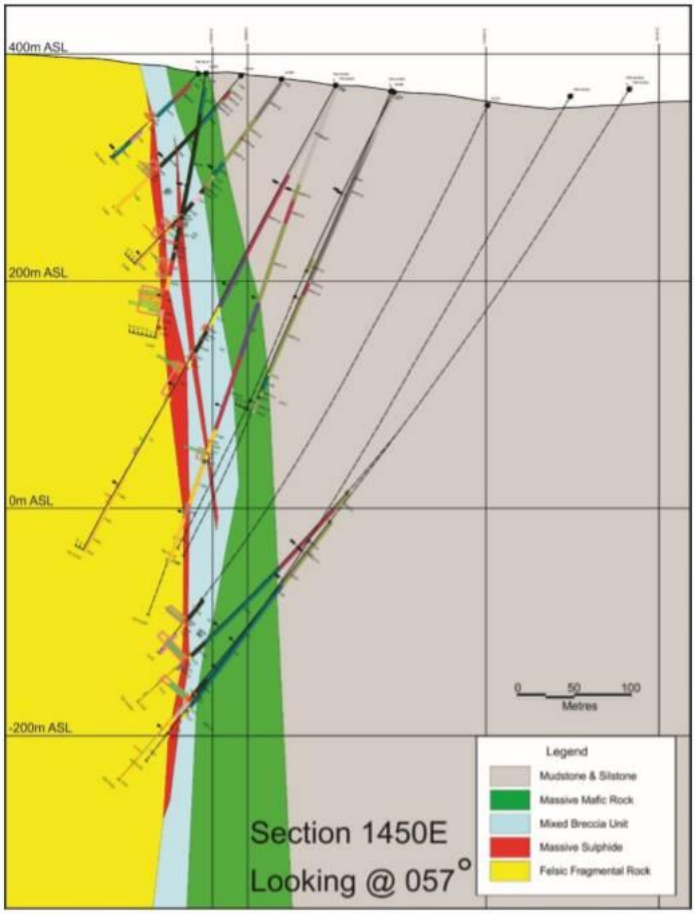

Figure 7.5 Cross Section of the Pickett Mountain Deposit

Dewatering and Water Management

Although there is little to no groundwater data provided in the material reviewed, groundwater is expected to be encountered during mining. Dewatering wells are planned for the initial phases of mining to reduce the water managed during mining prior to the completion of underground piping infrastructure. The projected water produced by underground mine development activities for the project is 1,160 cubic meters (m^3) per day or 260 gallons per minute (gpm). The service water required for the mine would be 401,000 m^3 per year or 201.55 gpm. This rate of inflow (260 gpm) is easily managed underground under normal mining conditions and would meet the service water requirements stated above.

Underground, water is planned to be managed through a series of sumps and baffles. Water will be segregated by water quality and will ultimately be pumped to the surface through a series of pipelines and stored in surface ponds for use as service water. This is a standard and acceptable water management practice.

FUTURE WORK TO BE CONDUCTED

As mentioned in the PEA, hydrologic studies need to be conducted to confirm the proposed dewatering method, evaluate the TSF site, and confirm location(s) for a supply well(s).

Specific Water Data Needs Recommendations

1. No groundwater elevation data has been provided in the PEA. This will need to be collected as part of the baseline environmental studies.

2. Pumping tests will need to be conducted to determine the hydraulic properties of the rock. This is will allow the project hydrogeologist to confirm the inflows to be experienced during mining and verify that they will be manageable and will meet the service water needs.

3. Tailings characterization has not been completed and are recommended to confirm assumptions for the underground mining method and tailings foundation stability.

4. Waste rock characterization has not been completed. The water quality implications should be studied as part of the overall baseline environmental studies.

5. No background water chemistry is included in the PEA. However, the potential for water chemistry issues is acknowledged (As, TDS etc), and a subsequent water treatment plant is mentioned.

6. The PEA recommends that all environmental baseline studies be completed as they are necessary to meet state and federal permitting requirements.

FINDINGS AND CONCLUSIONS

1. The water portion of the PEA appears to be completed to a professional standard and is based on reasonable and verifiable data as it exists to date.

2. The water management portions of the mining project appear to be viable and potential water quality or quantity impacts are acknowledged and planned to be studied.

3. The PEA meets the professional standard to justify the rezoning of the property for mining.

4. Two factors contribute to the confidence in water management at this site: 1) The need to maintain a strict water balance in order to maximize the use of water produced during mining for service water, and 2) the recognition and dedication to build a water treatment facility.

ATTACHMENT D

Assessment of Geochemistry, Soils, and Reclamation, Pickett Mountain Project, Wolfen Mt. Chase

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TECHNICAL MEMORANDUM

To: Michael Lychwala
SWCA Environmental Consultants
8 Science Park Road
Scarborough, Maine 04074

From: Andrew Harley, Senior Geochemist/Senior Soil Scientist

Date: December 1, 2020

Re: **Assessment of Geochemistry, Soils, and Reclamation, Pickett Mountain Project, Wolfden Mt. Chase / SWCA Project No. 61402**

SWCA Environmental Consultants (SWCA) has reviewed the following two documents submitted by Wolfden Mt. Chase LLC (Wolfden) in support of a State of Maine Land Use Planning Commission (LUPC) application to rezone a portion of Township 6, Range 6 of Penobscot County to allow for development of an underground mineral deposit known as the Picket Mountain Project.

- The petition submitted by Wolfden to LUPC (Wolfden 2020a)
- A National Instrument 43-101-compliant Preliminary Economic Assessment (PEA) (Wolfden 2020b)

SWCA has reviewed the documents to evaluate the technical feasibility of the geochemical, soils, and reclamation components of the project, given the preliminary development stage of this project. SWCA understands that additional studies are planned and that Wolfden will obtain a Maine Department of Environmental Protection (MEDEP) Metallic Mining Permit under Chapter 200 rules (MEDEP 2017) if rezoning is approved.

ENVIRONMENTAL GEOCHEMISTRY

Pre-mining geochemical characterization is of critical importance to evaluate potential impacts over the life of a mine, and to develop suitable mitigation strategies. Impacts can be physical, chemical, and biological in nature. Characterization activities include pre-mining baseline conditions and the identification of risks specifically related to the manner in which the ore will be mined and processed, how water and waste products will be managed, and the final configuration of the post-mining landscape.

Current Status and Information

The project consists of a massive sulfide deposit, described as fine-grained with potentially acid-producing minerals including pyrite (iron sulfide), sphalerite (zinc sulfide), galena (lead sulfide), and chalcopyrite (copper iron sulfide). The minerals, when exposed to air and water, react to form acidic leachate and drainage. Acidic materials can be offset through neutralizing minerals, as described in Acid-

Base Accounting (ABA) procedures. Neutralizing minerals noted in the PEA include calcite and felsic rocks. Other minerals of concern include tetrahedrite (copper antimony sulfosalt) and arsenopyrite (iron arsenic sulfide) that can potentially release antimony and arsenic into the environment. Assessment of ABA or potential metal leachate production are not reported.

Whole rock geochemistry results are based on digestion and analysis by inductively coupled plasma optical emission spectrometry (ICP OES) and are discussed in the PEA. Concentrations of zinc, lead, copper, silver, and gold are presented within the PEA. Sulfide results, commonly reported during the preliminary feasibility stage, are not mentioned in the PEA, although the data likely exist given the analytical technique.

Waste rock produced during underground development will be returned to backfill mined-out stopes to prevent caving. Primary stopes will be backfilled with cemented rockfill while secondary stopes will contain uncemented rockfill. Assessment of geochemical suitability for waste rock to be relocated below ground has not been provided.

Prior to backfilling, waste rock will be stored in two rock dumps: a clean rock dump and an acid-generating rock dump. Details regarding construction are limited, with mitigation strategies including berms, drainage collection, and in the case of the acid-generating rock dump, liners and potentially a holding pond. Similarly, stockpiles of ore will be developed with a design similar to the acid-generating rock dump. Proposed methods for segregation between the clean and acid-generating waste rock have not been discussed.

Metallurgical testing has been undertaken to evaluate processing requirements to produce a concentrate for sale. The other component of processing is the residual material from which the concentrate has been removed. This material is referred to as tailings and will be disposed in an aboveground facility as described below. Based on the geological composition of the ore, the tailings will likely contain fine-grained, reactive sulfide that can potentially produce acidic and metal leachate. A master composite sample submitted for metallurgical testing contained 27.4% total sulfur, although 21.0% of the sulfur presented as sulfate indicating that some oxidation had occurred. Floatation techniques were used to collect the remaining sulfides; however, 2.5% sulfide sulfur will remain within the tailings that will report to the tailings management facility (TMF). Additionally, reagents used in testing, including cyanide, may end up in the tailings. Characterization of reagent impacts to tailings have not been reported.

Tailings management will be via dewatering and pressure filtration to generate a filter cake to be placed into a dry stack TMF. While geochemical testing of tailings actually stored at the site has not been reported, engineering controls of any potential leachate include a containment system constructed of low permeability soil fill, a geomembrane liner, and a drainage collection layer. A berm will be constructed along the toe of the TMF to anchor the geomembrane liner and to create a collection ditch for contact water.

Water quality baseline data, both surface water and groundwater, have not been reported for the project and will be required for feasibility and permitting-level efforts.

Assessment of Reasonableness

The level of environmental geochemical testing and reporting is less than would be expected for a PEA-level document. Data of interest include sulfur data for waste rock characterization and management, geochemical characterization of tailings material, and initial water quality data. However, as these are costly programs it is understandable that the proponent has not invested in these without rezoning approval. The level of effort certainly indicates that the proponent is aware of these issues and will address these during more detailed design and permitting of the project. The proponent has invested effort into water management and water treatment designs, again indicating an awareness of potential issues on this project. The concentration of sulfides reporting to the TMF will need to be further monitored as metallurgical testing continues.

Issues and Potential Challenges

As the project progresses, increasing levels of environmental geochemical testing will be required as per MEDEP Chapter 200 §5.20(E) with guidance such as the *Global Acid Rock Drainage Guide* (International Network for Acid Prevention 2014), and development of a Reactive Mine Waste and Designated Chemical Material Management System as per MEDEP Chapter 200 §5.20(G). Characterization will include static testing of development rock and tailings material and kinetic testing of tailings material and rock to be placed underground including cemented and uncemented components. Additionally, a water quality monitoring plan is required as per MEDEP Chapter 200 §3.9(C). As permitting will take 2 to 3 years following rezoning, this gives sufficient time to complete appropriate baseline and environmental studies.

The design and operation of a filter cake disposal facility is dependent on tailings to the specified consistency. The main challenges to tailings management include variations on tailing development that require additional reworking, drying, or re-processing before deposition and that winter conditions may impact dewatering efficiency, requiring temporary storage. Although this is of more engineering and operational concern, the geochemical nature of the material will inform operational decisions.

SOILS

Current Status and Information

A soil suitability evaluation undertaken by Wood Environment & Infrastructure Solutions, Inc. (Wood) (2020a) identified five soil suitability classes.

- Generally Suitable: Well drained (>16 inches to water table), deep (>40 inches) bedrock, slopes less than 15%.
- Limited Suitability: Poorly drained (7–16 inches to water table), moderately deep (20–40 inches), slopes less than 15%.
- Unsuitable: Poorly drained (<7 inches to water table), shallow (<10 inches) bedrock.
- Unsuitable – Wet: Hydric soils or mapped wetlands.
- Unsuitable Steep: Slopes >15%.

Based on these criteria, the site was divided into six areas based on broad landscape areas with similar soil characteristics (Wood 2020a:Figure 5).

- Area 1: This area is in the northeast portion of the site and slopes range from 3% to 10%. Soils in Area 1 are loams to silt loams, with bedrock greater than 16 inches. Soils are well drained to moderately well drained. Seasonal high-water table is generally greater than 15 inches below grade. The TMF and processed wastewater dispersal facility is to be located in Area 1.
- Area 2: The northern and northwestern section of the rezone area is characterized by gentle to moderate slopes and soils are loams to silty loams with a seasonal high-water table or restricted layer less than 16 inches. As such, the soils are poorly drained and contain long slopes with shallow groundwater during normal conditions.

- Area 3: The western section has moderate slopes and loam to silty loam, well-drained soils with bedrock approximately 10 to 20 inches deep. Development of the main pad is proposed in Area 3.
- Area 4: The central section has slopes ranging from 0% to 8% with some moderate slopes of 8% to 15%. The loam and silt loam soils over glacial till or bedrock result in poorly drained soils. Wetlands are prevalent in this area. Development in this area is proposed to consist of material storage pads including laydown areas for equipment, cold storage pad, containment pads for waste rock, low grade ore, and native topsoil and gravel from the grading of other development areas (i.e., main pad, TMF).
- Areas 5 and 6: This portion of the central section has a complex terrain with steep slopes, shallow ledges, and bedrock outcrops. Where silt loam soils are present, bedrock generally occurs at depths of 10 to 20 inches. The low-grade ore pad is proposed for Area 5.

A wetland delineation survey (Wood 2020b) identified 34 wetlands and eight vernal pools within the proposed rezoning area. Development is proposed such that no impacts will occur to vernal pools, delineated wetlands, and streams, with a 75-foot buffer observed on these resources. In the event that impacts cannot be avoided, compensation features will be developed. The final grading plan will include enhancement of these features during reclamation and closure activities.

Assessment of Reasonableness

As with any mining development, the soil assessment identified a mixture of soil types and suitability. Generally, soils that can be considered suitable for development, or with limited suitability that can be corrected through engineering design, exist within the proposed rezoning area. The soil limitations observed include shallow bedrock conditions, and areas with a seasonal high-water table. Areas of steep slopes, greater than 20%, occur in small amounts as part of the landscape and should be avoided when possible. Areas with a high-water table include jurisdictional wetlands, and the lower slope positions with somewhat poorly drained soils are also present and should be avoided when possible. Prior to any development, more detailed surveys to better identify the most appropriate areas for site development are required prior to permitting.

Issues and Potential Challenges

The most common limitations in the preliminary site plan areas are generally shallow bedrock and poorly draining soils with a high-water table at or near the surface. These poorly drained soils present limitations for roadway, parking, and laydown area construction; tailings storage facility construction and operations; building and foundation construction; and wastewater disposal construction and operations. Wood (2020a) has proposed the following hierarchy to overcome these limitations.

- Locating and maximizing development on areas with better drained soils where practical.
- Siting development areas to maximize use of the existing infrastructure including existing roads.
- When development must occur on soils that have limitations, employ the appropriate construction techniques.

Wood (2020a) has also outlined design criteria for the State of Maine to meet regulatory requirements, design criteria, and construction standards.

CLOSURE AND RECLAMATION

Current Status and Information

The proposed mine is designed to operate with a limited footprint throughout all phases of the project.

At the end of the mine life, buildings will be demolished and disposed. The underground portal will be closed to prevent access to underground workings while also allowing for bat entry and habitat. The site will be regraded to approximate original contours. Salvaged topsoil will be distributed for plant-growth media prior to revegetation.

Closure cover for the TMF will include a composite liner system with drainage layer and soil cover for vegetation growth. The soil cover is designed with 1.5 feet of subsoil and topsoil, and replanted with small grasses and shrubs. TMF constraints include maximum height of 22 feet to be less than the height of the trees, setback from wetlands greater than 75 feet, and setback from the project boundary greater than 400 feet.

The water management system for management of site drainage water during closure and post-closure will be maintained in place until water concentrations are at acceptable levels to meet regulatory guidelines.

Assessment of Reasonableness

The preliminary closure and reclamation components are consistent with industry standards. Closure of the TMF is proposed to be progressively reclaimed which allows for evaluation of closure cover performance that can allow for modifications of the reclamation protocols as required. As concurrent closure of the TMF will occur during operations, risks to the State will also be minimized as total disturbed areas will be reduced. A final closure plan will be developed in compliance with MEDEP Chapter 200 §5.24 rules as the mining plan evolves and is finalized. The reclamation plan will include a detailed cost estimate and the associated surety bond will be filed prior to commencement of operations.

Issues and Potential Challenges

The preliminary closure and reclamation components are consistent with industry standards with the following considerations.

- Material placed underground requires testing to ensure no impact to groundwater.
- Topsoil salvage for reclamation is discussed as final soil cover for regrowth and local borrow areas have been identified for subsoil. A material balance will be required to ensure that sufficient topsoil is salvaged and borrow material is available for reclamation.
- The TMF will provide the greatest long-term risk at closure to ensure that fine-grained, highly reactive sulfide minerals are not exposed to air and/or water. Seepage and geotechnical studies will be required to ensure that the TMF is designed and constructed appropriately.
- Final design for TMF closure will be in compliance with MEDEP Chapter 200 rules and the cover design appears reasonable for grasses and shrubs. Given that the climax species in the area are trees, consideration will be required for ensuring that forest encroachment does not occur during the long term with deep-rooted vegetation disturbing liners and capping materials.

CONCLUSIONS

The review of available preliminary data has identified that several potential issues related to environmental geochemistry, soils, and reclamation and closure that will require additional investigations to ensure that the project is technically feasible. These include a robust geochemical testing program, and refined soil mapping as the facility siting is finalized. In addition, financial reclamation plans are to be refined and costed. These requirements are well documented within MEDEP Chapter 200 rules.

However, the basis of any project is to limit the negative impact to natural resources, especially water resources. While preliminary in nature, the key issues have been identified and will be developed further as detailed planning progresses to final design and permit approval. The preliminary design presented in the LUPC petition and the PEA has been developed to minimize these impacts through engineering controls such as water management and treatment, and appropriate use of liners and capping. The site will be graded to maintain, as close as possible, original contours, and the largest surface feature, the TMF, will be sited to not exceed the height of existing trees.

SWCA considers the project components received during this scope to be industry standards and that the mine can be developed such that impacts are minimized during operation, closure, and post-closure.

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ATTACHMENT E

Assessment of Financial Practicality
Sunrise Americas LLC

PICKETT MOUNTAIN PROJECT, WOLFDEN MT. CHASE LLC

ASSESSMENT OF FINANCIAL PRACTICALITY

NOVEMBER 2020

Prepared for SWCA Environmental Consultants for the purpose of including in a “Technical Feasibility & Financial Practicability Assessment” of the proposed Pickett Mountain metallic mineral mine to be submitted to the Land Use Planning Commission (LUPC) of the Department of Agriculture, Conservation and Forestry of the State of Maine.

Prepared by: Sunrise Americas LLC
Date: November 30, 2020

1 INTRODUCTION

The Pickett Mountain polymetallic mining project in northeastern Maine ("Pickett Mountain" or "Project") is owned 100% by Wolfden Mountain Chase LLC ("WMC"), a wholly-owned subsidiary of Wolfden Resources Corporation ("Wolfden"), a Canadian mining company listed on the Toronto Venture Exchange.

Getty Oil discovered the Pickett Mountain copper-lead-zinc deposit in 1979. After a succession of owners, WMC purchased the Project in late 2017 and proceeded to advance exploration and development work at the property. On September 14, 2020, Wolfden announced the results of a preliminary economic assessment ("PEA") for the Project and, on October 29, 2020, filed a technical report on the Project for the purposes of the NI 43-101 requirements of Canadian securities law.

On January 26, 2020, WMC submitted a "Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit" ("Zoning Petition") with the Land Use Planning Commission ("LUPC") of the Department of Agriculture, Conservation and Forestry of the State of Maine.

This report has been prepared for SWCA Environmental Consultants for the purpose of including in a "Technical Feasibility & Financial Practicability Assessment" of Pickett Mountain to be submitted to LUPC.

This report has relied solely on the assessments, reports, plans and reference sources submitted to-date by the petitioner, WMC, during the application process. The sources for such information were the following:

Wolfden Mt. Chase LLC - Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit - January 26, 2020 (Revised June 30, 2020);

- Wolfden Resources - Preliminary Economic Assessment, Pickett Mountain Project – Effective date: September 14, 2020; and
- Wolfden Resources – Website - www.wolfdenresources.com - Press Releases & Financial Statements.

More detailed references to the sources of the information reviewed by the author can be found in the contents of this report together with a complete list of References in Section 8.

Glossary and Abbreviations of Terms

Ag	silver
Au	gold
C$	currency of Canada
Cu	copper
g/t	grams per tonne
k	thousand
km	kilometre
m^3	cubic metre
Mt	million tonne (metric)
MW	megawatt
MWh	megawatt hour
NSR	net smelter return
oz	ounces (troy)
Pb	lead
PEA	Preliminary Economic Assessment
t	tonne (metric)
tpy	tonnes per year
US$	currency of the United States of America
USA	United States of America
WMC	Wolfden Mountain Chase LLC
Wolfden	Wolfden Resources Corporation
Zn	zinc

2 INFRASTRUCTURE & KEY SUPPLIES

2.1 Infrastructure Requirements

The Project is located in northeastern Maine, about 33 miles from the Canadian border and about 42 miles due west of the town of Woodstock, New Brunswick. Access to the Project for State Highway 11, and from State Highway 11 there are paved primary and secondary highways with access to Interstate 95 at Island Falls, about 22 miles from the Project (Source: PEA, Section 4.0).

The area is well supported by local infrastructure, including well maintained roads, highways, and access to rail in the town of Sherman Station 17 miles from the Project; as well, the (regional) electric grid runs along Highway 11 (Source: PEA, Section 5.4).

The development plan for the Project requires the availability of key infrastructure to support the construction and operation of the mine as follows:

Water	The concentrator requires 3,033m^3 per day of water. After recycling 89%, the net make-up fresh water is 325m^3 (Source: PEA, Section 17.4).
Power	The Project would be connected to the regional grid system (NPCC) through a new 14.6-mile transmission line that a power supplier would construct (Source: Zoning Petition, Project Description). The mine operation will require about 6MW electrical demand (Source: PEA, Section 18.4) which will be supplied by a licensed competitive supplier.
Roads	The Project is located in a logged area that has access roads used by foresters to reach timber lots. The rights-of-way has been established and the roads require upgrading to meet safety standards for higher volumes of traffic that will occur with construction and operation of a mine (Source: PEA, Section 18.1). The access road from the paved Highway 11 to the mine site will need to be upgraded to ensure safe reliable access year-round (Source: PEA, Section 18.2).

Mine site infrastructure, such as the site pad for the construction and operating areas and power distribution lines that step down from the main substation, are considered part of the construction of the mining facilities required to extract and process the ore.

All other infrastructure requirements, such as the port for shipment of concentrates to smelter destinations, will rely on existing infrastructure already operated by third parties who would provide such facilities on a services basis.

2.2 Current Status of Development Work & Information Reviewed

The development work conducted to prepare the PEA included assessment of key infrastructure requirements and estimates of the capital expenditures to develop the infrastructure. The level of the evaluation is not stated however it is assumed that these are to a scoping study level, consistent with level of the PEA.

- Wolfden and its consultants have assessed the requirement for a potable water system that includes the process water system that needs to meet or exceed dissolved solids that may interfere in the extraction process. The water needs to be drawn from an authorized site by the state of Maine to a suitable tank, and from the tank be distributed after being treated for organics, total dissolved solids, as well as metal ions (Source: PEA, Section 18.5). No information is provided on the cost of the state of Maine delivering the water or on the expected quality of the water.
- Wolfden and its consultants have had discussions with Emera Power, the predecessor to power supplier Versant Power, who provided an indicative price of US$7 million to deliver 6MW electrical power to the main substation at the mine site (Source: PEA, Section 18.4). The mine will have standby diesel generators of 3MW electrical demand to ensure safety of the operation during a power disruption (Source: PEA, Section 18.19). The electrical power cost delivered to the Project is estimated at US$85/MWh (Source: PEA, Section 21.2.1). No information is provided on the scope and precision of the estimates of the power requirements.
- Wolfden and its consultants have assessed the condition of the local roads and access road, and the upgrade requirements are as described in Section 2.1.

The development plan includes construction of a water treatment facility. The structure for the development assumes a build own operate (“BOO”) arrangement that would be owned by a specialist third-party developer and operator, and includes a reverse osmosis unit to ensure the water quality meets state environmental standards (Source: PEA, Section 18.17). The cost of the service is estimated at US$1.74 per tonne (Source: PEA, Section 20.2.3). No information is provided on the source of the estimated cost.

2.3 Assessment of Reasonableness

The author has relied on the PEA for description of the existing road conditions, for the assessment of the new water and power infrastructure requirements, and road upgrade requirements, and for all estimates of capital expenditures and operating costs for such infrastructure.

The estimated capital expenditure for the new transmission line from the regional grid is considered reasonable based on industry benchmarks, and the electrical power cost is generally consistent with the delivery and supply rates for industrial customers published by state regulator, the Maine Public Utilities Commission.

The quantities of make-up water are relatively small due to the recycling, and errors in the assumptions would not be expected to have a material impact on the economic evaluation. Similarly, the capital estimates for the road upgrades are relatively small in the overall capital expenditures for the Project.

The assumption of the BOO arrangement for the proposed water treatment plant results in a reduced capital expenditure for the construction phase (instead, it is assumed the Project will pay a fixed capital charge for the supplier to receive a return on its investment), however it will not reduce the financing requirement for the Project since Wolfden will be expected to provide a corporate guarantee to the supplier for the risk of any failure to use the service.

2.4 Issues & Potential Challenges

Neither the power nor road infrastructure are expected to present any development difficulties.

The environmental and other permitting requirements for water have not been considered in this assessment of financial practicality of the Project.

2.5 Conclusions

The key infrastructure requirements have been identified and capital costs to develop have been estimated by Wolfden and its consultants.

The PEA has been relied on for assessment of infrastructure requirements, and estimates of capital and operating costs for such infrastructure; the descriptions in the PEA are considered reasonable and, since the Project would benefit from existing infrastructure (roads, regional grid system) and key supply resources (water, electricity) in the proximity to the Project, any errors in the assumptions would not be expected to have a material impact on the economic evaluation.

3 MARKETING

3.1 Marketing Plan

Based on scoping level metallurgical test work, it is planned that the Project will produce three concentrates, a copper concentrate, a lead concentrate and a zinc concentrate, that will be sold to smelters handling such products. Silver and gold by-products report principally to the copper concentrates, then to the lead concentrates (Source: PEA, Section 13.3.3).

The life-of-mine production tonnages for the three base metals are stated, but the annual production of the metals and the corresponding tonnes of concentrate are not presented in the PEA; estimates of annual tonnages of: (a) metal contained in the concentrates and (b) concentrate are calculated based on assumptions used in the economic analysis (Source: Wolfden Resources, Press Release, September 15, 2020):

Copper	3,495 tonnes per year copper in concentrate
	14,092 tonnes per year copper concentrate
Lead	10,278 tonnes per year lead in concentrate
	20,193 tonnes per year lead concentrate
Zinc	29,928 tonnes per year zinc in concentrate
	51,868 tonnes per year zinc concentrate

The concentrate products require transportation by road to a port, and subsequent transportation by shipping vessel to destination ports used by the smelters to receive concentrates.

The concentrate products will be subject to deductions and charges imposed by the smelters for smelting and refining of the concentrates, including any charges for other payable metals contained in the concentrates and penalties for certain elements considered contaminants by the smelters.

The Project will be expected to negotiate long-term offtake (delivery and sales) agreements for each of the concentrate products in order to ensure customers for the products and to satisfy the likely requirements of financiers.

3.2 Current Status of Development Work & Information Reviewed

In order to develop a preferred processing circuit for recovery of the metals, Wolfden has reviewed the test work originally performed at Lakefield Research for previous owners Getty Mining (1984) and Chevron Resources (1988), and has undertaken its own scoping level metallurgical test work during 2019 conducted by Resource Development Inc. (RDI) with the primary objective of determining metal recoveries and flotation concentrate grades from the mineralized material. The scoping level test work has indicated that a sequential flotation process will produce marketable grade copper, lead and zinc concentrates (Source: PEA, Section 13). The projected recoveries for the three metals, 80.5% for copper,77.5% for lead and 89.5% for zinc, and their respective concentrate grades, 24.8% for copper, 50.9% for lead, and 55.7% for zinc, were used to calculate the production schedules that were included in the economic evaluation (Source; PEA, Section17.5).

The PEA assumes that the concentrate will be transported to the nearest deep-water port via a local logistics contractor (Source: PEA, Section 19.2). There is no reference to the location of this port, nor to the destination smelters.

Estimates of commodity prices for the metals contained in the concentrates, and estimates for concentrate transportation costs and smelter charges have been used to prepare the mine plan and input to the economic analysis of the Project.

- The commodity prices for the metals contained in the concentrate are presented in Table 19.1 of the PEA and input to the economic analysis are based on industry consensus pricing provided by Wolfden (Source: PEA, Section 1.8). The sources and methodology used to determine these prices are not stated. No market studies were conducted (Source: PEA, Section 19.1).
- Transportation costs of US$40 per tonne of concentrate have been used for assumptions in the economic analysis to cover handling on site, transportation to a port, port handling and transport by ship to smelter (Source: PEA, Section 21.6). These services would be provided by a local logistics contractor (Source: PEA, Section 19.2). There is no reference to the source for these estimates.
- Smelter charges used for assumptions in the economic evaluation were based on input from major smelters including a large, diversified resource conglomerate and commodity trader, for life of mine feed at international benchmark terms (Source: PEA, Section 19.2).

Wolfden has confirmed that it expects to negotiate long-term offtake agreements with smelters (Source: PEA, Section 19.2).

3.3 Assessment of Reasonableness

Based on the results of the test work used to prepare the conceptual process flowsheet (Source: PEA, Section 17.1) and material balance (Source: PEA, Section 17.5), the chemical composition of the lead concentrate and zinc concentrate, including the concentrate grades, should be suitable for treatment and refining at smelters, and would be expected to receive standard smelter charges for the products.

Based on the same test work, the concentrate grade of 24.8% copper is slightly below the typical minimum concentrate grade of 25% copper accepted by smelters. If the final process flowsheet does not increase the concentrate grade of the copper above the minimum, this does not mean that the product cannot be marketed, however it may be subject to smelter terms that are not considered international benchmark terms.

The annual tonnages of each of the concentrates are not considered significant in terms of creating challenges for road and shipping logistics, nor would they be expected to have any material impact on the availability of smelter capacity. There are smelters operating in North America for each of the three metals, and Europe and Asia could be alternative smelter destinations, although these would be expected to result in higher transportation costs.

The commodity prices for the metals contained in the concentrates, and estimates for concentrate transportation costs and smelter charges have been used to prepare the economic analysis of the Project in the PEA.

- Copper, lead and zinc prices used to calculate incomes from the sale of concentrates are reasonable; although similar to current prices, they are at the higher-end of long-term price forecasts used within the industry to evaluate projects. The sources and methodology used to determine the industry consensus pricing is not known.
- Although the PEA has not stated smelter destinations, the road and shipping transportation costs to deliver concentrates to the smelters are considered reasonable when benchmarked against other projects and mines, and considering likely smelter destinations.
- Smelter charges (deductions) for processing concentrates are reasonable and in-line with standard deductions and charges applied in the industry. Potential penalties have not been included in the economic analysis since the test work is at scoping level and not sufficiently advanced to allow any meaningful estimates.

For the purposes of ensuring customers for the concentrates and for the purposes of securing financing, it would be expected that long-term offtake contracts will be negotiated with the smelters. Wolfden has confirmed this is part of the marketing plan.

3.4 Observations & Potential Challenges

The author of the PEA has identified high levels of arsenic and antimony in the test work samples for the copper concentrate; these are considered deleterious elements by the smelters and may be subject to penalties or even result in the product not being accepted by smelters. Since the test work is at scoping level and further test work is planned that will provide additional information on the impurities, including investigation of possibilities to blend the ores from different areas of the mine to keep the impurities below penalty levels, this is highlighted but not considered a fatal flaw (Source: PEA, Section 13.4).

A recent trend is containerized transportation of concentrates, where the concentrate is placed in a container at the mine and delivered to the customer in a sealed form, thereby avoiding multiple transfer points, reducing environmental impact, and avoiding loss of product. It is expected that Wolfden will consider this option during the feasibility phase when the products are better defined and smelter destinations are identified.

3.5 Conclusions

The key factors impacting the marketing of the concentrates to be produced by the Project have been identified and assessed by Wolfden at a scoping level. Based on the information reviewed, the marketing plan and assumptions appear reasonable.

Further test work will be required to more accurately determine the chemical composition of the concentrates to be produced by the Project, and to confirm the suitability of the concentrates for treatment and refining at the smelters. Since the process flowsheet remains under review and has not been finalized, this confirmation will not be possible until further development work has been completed. At this stage, it is premature for the Project to advance any discussions with potential customers (smelters) until the final products are better understood and samples can be provided to the smelters.

4 PROJECT SCHEDULE

4.1 Development Timeline

Wolfden and its consultants have prepared a PEA which provides a scoping level assessment of the development plan to advance the Project through a feasibility phase, and subsequent construction and commissioning phases to achieve commercial operation.

The development plan is based on an underground mining operation and processing plant with a sequential flotation circuit that will process 1,200 tonne per day of ore to produce three separate metal concentrate products.

The development timeline is based on completion of a feasibility study, including establishing a mining reserve and securing all required permits, to enable a feasibility study to be completed. In addition, it will be necessary to arrange all contracts, including the EPC or EPCM contract, and secure financing for the construction and commissioning phases.

4.2 Current Status of Development Work & Information Reviewed

The Zoning Petition and PEA provide the most recent updates on the current status of the Project in terms of the development work completed.

- The final version of the Zoning Petition is dated June 30, 2020.
- The PEA was prepared effective September 14, 2020.
- Further development work will require a mining reserve to be established, all permits to be secured and a feasibility study to be completed to enable financing to be arranged and an investment decision to construct and operate a mine.

Feasibility Phase

The PEA does not provide information on the timeline to complete the feasibility work however the Zoning Petition includes a high-level Gantt chart showing a three (3) year timeline to complete approval of rezoning, baseline study work and final approval of a mining permit (Source: Zoning Petition, Project Description - Phase 4).

Wolfden has made no public statements on the timetable to advance further development work at the Project.

Construction Phase

The PEA indicates a pre-production period of 21 months (Source: PEA, Section 21.1.4). There is no information provided on the timeline for individual construction activities or the commissioning phase required to achieve commercial production. The PEA indicates that working capital estimates are based on four months of operating costs which implies a four-month period for commissioning from mechanical completion to commercial production.

The high-level Gantt chart in the Zoning Petition shows a similar two-year timeline to complete construction, including mine production ramp-up and commissioning, and achieve commercial production. Most of the construction activities have a timeline of no more than 12 months from the full notice to proceed issued to contractors for construction, except for the excavation of ventilation raise to the surface, installation of the electric substation and interconnection to the regional grid, and construction of the concentrator and supporting facilities, which the Gantt chart indicates would be completed within the two-year timeline for construction (Source; Zoning Petition, Project Description – Phase 4).

Neither the PEA nor the Zoning Petition make reference to the timeline for Wolfden to arrange financing for the construction and commission phases.

4.3 Assessment of Reasonableness

Feasibility Phase

The author of the PEA has described the need to conduct additional drilling and establish a mining reserve, to complete metallurgical and other work programs and enter into contracts that will be required to complete a feasibility study. Although no schedule is provided in the PEA for completion of these development activities, assuming funding is available, it should be possible to complete the work within the three-year timeframe indicated to secure all permits indicated in the Gantt chart in the Zoning Petition. No assessment is made in this report of the likelihood of Wolfden to secure all permits within that schedule.

The PEA and Zoning Petition make no reference to the timeline for Wolfden to arrange financing for the construction and commission phases, except by implication in the Gantt chart; such financing process can begin prior to completion of the feasibility study and would be expected to continue following completion of the same study.

Construction Phase

The PEA indicates a pre-production period of 21 months and, by inference, a further 4-month timeline for commissioning to achieve steady-state operations and commercial production. The author has relied on the PEA on for the estimated schedule however, although the Project is at an early development stage and more detailed work needs to be completed to refine the schedule, the construction and commissioning schedule appears reasonable.

4.4 Observations & Potential Challenges

All mining development projects are faced with technical, commercial, legal, permitting, financing and other challenges, which combined are unique for each project. Many of these activities are interdependent, and difficulties to meet timetables to complete the various development activities and programs will often result in delays to project schedules.

A different set of challenges are presented with the construction and commissioning of a mining project however, if a project has a completed feasibility study, arranged financing and has made an investment decision, this will be a strong indication of that the project is solid since the subsequent phases will have been reviewed in detail by third-parties, such as independent engineers, financiers and regulatory environmental and other authorities.

The Project can be considered in the same situation. A PEA has been completed which outlines the potential to develop a technically and economically viable mining operation. There are challenges to maintain the timetable, complete the feasibility study and reach an investment decision – most notably the challenges to secure all necessary permits, to secure continued funding for the development work, and to arrange financing for the construction and commissioning phases – but these are typical for a mining development project and would not be considered fatal flaws at this stage of the development schedule.

4.5 Conclusions

The schedules indicated or implied in the PEA and Zoning Petition for the feasibility phase, and subsequent construction and commissioning phases, appear reasonable.

The complexities of advancing a mining project to an investment decision, including the requirement to schedule many different interdependent development activities and programs, often result in delays to the project schedule.

5 PROJECT ECONOMICS

5.1 Assessment of Financial Practicality of a Mining Project

Assessment of the financial practicality of a mining project requires an economic evaluation, including developing an economic model using a financial computer software with inputs for key parameters and assumptions for expected macroeconomic conditions, capital expenditures, production, operating performance and costs, closure costs and bonding requirements, and tax and financing costs. In addition, the economic model will be used to assess the sensitivity of the project economics to variations in the values estimated for the key parameters and to assist in the risk assessment of the project. Inputs for the economic model will be based on internal estimates, principally using technical assumptions developed from both in-house and third-party work and reviews, and external estimates, principally for macroeconomics and commercial assumptions provided by recognized institutions, corporations or industry specialists. As a project advances towards an investment decision, inputs will include firm quotes for capital equipment, and capital and operating cost estimates derived from commercial terms in contracts entered into by the mining company.

During the feasibility phase, the mining company will continue economic evaluation of the project and, if public companies, will likely periodically report the results in regulatory filings in the form of a PEA, prefeasibility study or feasibility study. Other groups, such as analysts for brokerage houses, regulators and other parties interested in the project may make independent evaluations, which will typically be private or with restricted access.

As the mining project advances, other groups such as potential investors and/or financiers will likely make detailed due diligence and assess the financial practicality of the project. Although the results from such investigations are unlikely to become public, the decisions made by such groups based on their evaluations will provide good indications of the financial practicality as assessed by groups willing to invest into the project.

5.2 Current Status of Development Work & Information Reviewed

The PEA includes a Section 22 titled “Economic Analysis”. Although the methodology to prepare the economic evaluation is not specifically stated, the section references the calculation of expected cash flow estimates, and provides the results and financial analysis. The Zoning Petition provides a general description of the preparation of a cash flow (economic) model to evaluate the cost estimates and produce economic forecasts (Source: Zoning Petition, Appendix A-B3a).

The economic analysis includes estimates of metal prices and some key parameters for production and capital costs (Source: PEA, Section 22), which can be referenced back to estimates determined in other sections of the PEA.

Production Estimates

The potentially mineable underground resource used in the economic analysis is estimated at 4.2 million tonnes at a grade of 8.56% Zn, 1.11% Cu, 3.40% Pb, 0.79 g/t Au and 88,8 g/t Ag. The PEA relies on indicated mineral resources (approximately 48.7% of the total resource) and inferred mineral resources. The author of the PEA notes that the inferred mineral resources are considered highly speculative geologically (Source: PEA, Section 22).

Schedules for mine production and ore throughput to the processing plant were prepared for the PEA. The mine ore throughput planned is 1,200 tpd, or 432,000 tpy (Source: PEA, Section 16.13). The metallurgical recoveries, and capital and operating cost estimates are considered to be at least PEA level accuracy (Source: PEA, Section 22).

Capital & Operating Costs Estimates

The PEA states that the initial capital expenditures totaling US$147.4 million and sustaining capital totaling US$100.0 million are based on budget pricing from supplier from critical components, consultants, contractors, studies and local benchmarks, and a review of other Canadian projects. Further, that capital expenditure estimates are within +/- 40% and include working capital and contribution to the Financial Assurance Trust fund (Source: PEA, Section 21.1.11). The same section provides more specific details on the sources of the estimates for individual cost areas. It is assumed that initial underground construction, ramp-up and operation of the underground for up to 3 years will be conducted by mining contractors (Source: PEA, Section 19.2).

The working capital is estimated at US$11.5 million based on 4 months of estimate operating costs (Source: PEA, Section 21.1.9).

The all-in operating costs of US$93.08 per tonne of ore production are based on US and overseas prices from suppliers and other similar type projects for consumables and parts. The source or basis for the cost of electricity and fuels are not stated. Labor rates are based on local rates where available, and/or contractor costs in the region and country for similar types of work (Source: PEA, Section 22.1). The same section provides more specific details on the sources of the estimates for individual cost areas.

The author of the PEA states that the overall level of accuracy of the study is +/- 40% (PEA, Section 22.2).

No contracts currently exist for construction, operation, supplies or consumables, however budgetary quotations and estimates have been provided by potential candidates for input into the economic analysis (Source: PEA, Section 19.2).

Economic Evaluation – Results & Analysis

The PEA includes summary tables for the results and analysis. The expected life-of-mine returns for the Project are presented for revenues net of marketing costs (transportation and smelter charges), undiscounted cash flows, net present returns at 5% and 8% discount rate, the internal rate of return and the payback period, on a real (not inflated) pre-tax and after-tax basis (Source: PEA, Section 22.2). All results are presented in United States dollar terms.

The PEA does not include tables to illustrate the production, capital and operating costs, and cash flows for the Project on an annual basis. The Zoning Petition includes annual cash flow estimates for employment, consumables, services and energy to show the amount and schedule of expenditures within the local communities (Source: Zoning Petition, Appendix A-B3a).

The PEA includes sensitivity analysis of the impact of percentage changes to the key parameters (mining grade, recovery, smelter charges, metal prices, operating costs and capital costs) on the net present value at 8% discount rate and the internal rate of return (Source: PEA, Section 22.3).

In addition, a corporate presentation by Wolfden Resources includes an estimate of the unit revenue value of a tonne of ore produced, a standard metric used to analyze the value of a project (Source, Wolfden Resources, Corporate Presentation, October 30, 2020).

5.3 Assessment of Reasonableness

The author has relied on the PEA for the assumptions for the key technical parameters, together with any observations and concerns expressed in the same document.

The economic analysis in the PEA is not based on a mining reserves, which would require more certainty on the mineral resources (i.e., it would not include inferred mineral resources) and the technical and economic assumptions included to develop the block model for the mine plan; however, this methodology is standard and acceptable based on the current status of the Project as an early stage development project at a PEA level.

The National Instrument 43-101 Standards of Disclosure for Mineral Projects issued by the Canadian Securities Administrators consider the confidence in inferred mineral resources is insufficient to allow the meaningful application of technical and economic parameters or to enable an evaluation of economic viability worthy of public disclosure. However, Wolfden has met the criteria to disclose the results of an economic analysis by stating that the economic assessment is preliminary in nature, that it includes inferred mineral resources

The sources of the estimates used to prepare the assumptions for the key capital and operating costs, and commercial parameters are considered standard for economic analysis in a PEA.

- As described in Section 3.3, the copper, lead and zinc prices used to calculate incomes from the sale of concentrates are reasonable; although similar to current market prices, they are at the higher-end of long-term price forecasts used within the industry to evaluate projects.
- The PEA has been relied on for the estimates for capital costs and operating costs used in the economic analysis; these are considered generally within industry benchmark ranges for an underground mine and flotation plant at the planned production levels. The relatively low infrastructure capital costs reflect the proximity and availability to key supplies such as water and power.
- As described in Section 2.3, the estimates used for transportation costs and smelter charges are considered reasonable.

The methodology used to prepare the economic analysis, including the use of real terms and discount rates, and the output measures of value (net present value, internal rate of return, payback) are considered standard for the mining industry. A minimum discount rate for a base metal project would be 8% (the PEA includes valuations at 5%), and reasonable arguments can be made that a higher discount rate should be used to reflect the risk profile of the Project.

Since annual production and cash flows are not presented in the PEA, the author has prepared a simplified financial model using the key parameters indicated in Section 2.20 of the PEA to confirm that the results of the economic analysis presented in the PEA have been correctly calculated and appear reasonable.

5.4 Observations & Potential Challenges

The capital expenditures presented in the PEA exclude costs such as tax and duties, financing costs, and legal costs. These exclusions are highlighted but, at this early stage of the development of the Project, these are not a focus and can be estimated as the development work is advanced.

The results of the economic analysis presented in the PEA exclude the royalty that would be paid to Altius Minerals (see Section 6.2).

As described in other sections, the financial practicality of the Project will depend not only on the results of the feasibility study but will depend on the ability of Wolfden to successfully fulfil permitting requirements and arrange project financing and/or introduce a partner.

5.5 Conclusions

These results of the economic analysis confirm that the Project could be developed into a viable, small to medium-sized mining operation; the sensitivity analysis confirms that the Project returns will be reasonably robust to variances in the key assumptions.

These net present values are significantly higher than the market capitalization of Wolfden, reflecting the use of low discount rates in the PEA and the fact that the market has factored in the risk profile of the Project.

The principal challenges for the Project to realize the values presented in the PEA are: (a) confirming at a feasibility level the scoping level assumptions that have been used in the PEA, including the need to establish a mining reserve, (b) successfully fulfilling permitting requirements and (c) arranging project financing and/or introduce a partner.

Finally, Wolfden continues to fund exploration drilling to target extensions to the existing deposits and new discoveries; if successful, this would be expected to improve the financial practicality of the Project, and make the Project return more robust.

6 FINANCIAL CONSIDERATIONS

6.1 Junior Mining Companies & Financing for Mining Projects

A mining development project requires funding for: (a) the feasibility phase to complete the work and studies necessary to appraise the technical and economic viability of the project and make an investment decision, and subsequently (b) the construction and commission phases of the project until it becomes a commercially operating mine.

For junior mining companies, the ability to successfully fund the development phases of a mining project will depend on many factors including, but not limited to, the quality and viability of the mining project, the relationship of management with brokerage houses, financial institutions, investments funds and other groups accustomed to investing into the mining industry, the ability of management to raise funding at specific times in the project development schedule, the market environment for both metals and the overall economy, and the general vagaries and sentiment of the investment community at any point in time. The challenges for a junior mining company to fund the development of a mining project become acutely difficult when seeking to financing the construction phase, when financiers will not only consider the economic viability of the project but will consider a wider range of criteria including the likely requirement for the company to have the financial capacity to manage issues such as project capital cost overruns, and to provide corporate guarantees in the event the mining project cannot be commissioned.

The financing plan will be further influenced by the strategy of the junior mining company; in some cases, the company will focus on its core exploration and technical skills to advance a project before seeking a partner or divesting to a company with the technical and financial capacity to develop the mine; in more rare cases, the other cases, the junior mining company can develop those capacities and seek to develop the mine itself.

6.2 Current Financial Status of Wolfden Resources & Information Reviewed

The Project was acquired by Wolfden in November 2017 from a private seller for US$8.5 million. The assets included timberland and all minerals, mining, subsurface and surface rights owned by the seller in an area referred to as the Pickett Mountain property, which included the Pickett Mountain base metal deposit. (Source: Wolfden Resources, Press Release, November 16, 2017).

The acquisition was financed through: (a) the granting of a 1.35% royalty interest in the future gross revenues from the Project for US$6 million to Altius Minerals, and (b) a non-brokered private placement (share purchase) in Wolfden made by Altius Minerals for gross proceeds of C$5.1 million, equivalent to US$4.0 million at the closing date (Source: Wolfden Resources, Press Release, November 16, 2017). The surplus of funds from these transactions was used to conduct exploration and development work on the Project during 2018 (Source: Wolfden Resources, Financial Statements, Fourth Quarter 2018).

Since the acquisition, Wolfden has been successful to raise funds to advance development work on the Project. In December 2017, the company raised C$675k (US$537k) from a non-brokered private placement; in March 2019, the company raised C$2.5 million (US$1.9 million) from a non-brokered private placement with Kinross Gold, a major Canadian gold company with mines in Nevada, and; in January 2020, the company raised an initial C$3.0 million (US$2.3 million) by selling forward timber from the Pickett Mountain property (Sources: Various Wolfden Resource Press Releases).

As of June 30, 2020, Wolfden Resources (consolidated) had a cash balance of C$2.9 million (US$2.1 million), and current assets of C$3.0 million (US$2.2 million. The company has only C$259k (US$199k) current liabilities and no debt to financial institutions. The royalty held by Altius Resources is a contingent liability payable only if and when Wolfden commences operations at the Project.

In terms of future expenditures, the Project is considered at an early development stage with further development work required to establish a mining reserve, obtain all permits required, prepare a feasibility study and make an investment decision, and subsequently to construct and commission a mine operation (see Section 26).

- The author of the PEA estimates that US$3-5 million will be required to complete a feasibility study for the Project, excluding drilling costs (Source: PEA, Section 26).

  WMC indicates the expenditure during the feasibility phase may be US$10-15 million (Source: Zoning Petition, Wolfden letter dated November 13, 2020). This second estimate is considered the most realistic.

- The author of the PEA estimates that US$147.4 million will be required for initial capital costs and working capital to achieve commercial production (Source: PEA, Section 21.1.6). Based on benchmarking of the capital costs and the unit capital cost (US$340 per tonne of annual ore production), the estimate is considered reasonable.

In the Zoning Petition, Wolfden references the requirement to continue to raise funds through further private placements and, when possible and appropriate, to consider partnering to improve the ownership capacity to finance the Project or divest the Project to a larger mining company to continue development work (Source: Zoning Petition, Exhibit H – Financial Capacity; Wolfden letter dated November 13, 2020).

As of November 24, 2020, Wolfden has 129. 9 million shares issues (148.4 million shares on a fully diluted basis, a share price of C$0.205 (US$0.16) and a market capitalization of C$26.7 million (US$20.5 million). Since the Project is substantially the principal asset of Wolfden, the current market value of the Project is approximately US$17.0-18.5 million.

6.3 Assessment of Reasonableness

Wolfden has demonstrated the ability to raise financing to fund development work, with an estimated US$14 million invested into the Project, including the acquisition of the property (Source: Wolfden Resources, Financial Statements, 2017-2020).

Further, Wolfen was able to raise US$1.9 million from Kinross Gold in March 2019 (Source: Wolfden Resources, Press Release, March 29, 2019). The involvement of a major mining company, which currently owns 9.6% of Wolfden, can be considered a third-party endorsement of the Project, and a demonstration of the ability for management to attract interest from different sources of finance.

Based on the current liquidity of Wolfden described in Section 6.2 and the future expenditure requirements estimated by the author of the PEA, Wolfden will need to secure new financing to complete a feasibility study for the Project. Although financing in the junior market space is currently challenging, especially for non-precious metal investment opportunities, base metals prices have proved resilient since the initial weeks of the COVID-19 pandemic and prices for the three base metals that would be produced by the Project have increased significantly in the past months: as of November 24, 2020, the copper price is US$3.30 per pound, the lead price is US$0.99 per pound, and the zinc price is US$1.24 per pound, representing increases of 20%, 10% and 21% respectively since December 31, 2019. These increases in prices for the base metals will have a positive impact on any financing initiative pursued by Wolfden.

The strategy of Wolfden to raise new funding for the Project, as referenced by the company in the Zoning Petition, is considered both standard and reasonable for junior mining companies; the author has not evaluated the likelihood of Wolfden to raise such funds in the future.

6.4 Observations & Potential Challenges

As described in Section 6.1, the ability of a junior mining company to fund the construction phase of a mining project is challenging. There are examples of junior mining companies, such as Bema Gold (Kupol, Russia) and Gibraltar Mines (Lomas Bayas, Chile), who have successfully funded development projects through to mine operations; others, such as Baja Mining (Boleo, Mexico) and Apex Silver (San Cristobel, Bolivia), have successfully funded development projects but failed to achieve commission of mining operations; and many others have funded development projects but failed to finance the construction of mining projects.

The challenge to finance the construction and commissioning phases of the Project is highlighted but, at this early stage of the development of the Project, no assessment can be made of the likelihood of Wolfden arranging financing and/or introducing a partner to the Project to support these future development phases.

6.5 Conclusions

Wolfden acquired the Project in late 2017, and has been successful to raise the financing necessary to advance the Project and complete a PEA (estimated expenditure to June 30, 2020, is US$14 million).

Wolfden requires an estimated US$10-15 million (WMC estimate) to complete a feasibility study and, subsequently, it will require an estimated $147 million plus financing costs to construct and commission a mine operation. No assessment can be made of the likelihood that Wolfden can raise such financings however the potential strategies to raise financing described by WMC in the Zoning Petition are considered standard and reasonable.

7 VALUE OF PROJECT FOR LOCAL COMMUNITY & STATE OF MAINE

7.1 Value of Mining Projects to Local Communities & States

It is a requirement of the rezoning petition that the petitioner provide assessment of the potential economic benefits of a project. Such application should outline details and potential impacts of the plan, including outcomes such as economics and anticipated impacts on the environment, population, economy, infrastructure.

7.2 Current Status & Information Reviewed

The Zoning Petition includes assessment prepared by WMC of the short-term and long-term socioeconomic impacts of the Project.

WMC states that the project will provide direct and substantial economic benefit to the local communities in the form of job skills training, primary wages to local employees, wages that are spent in the local economy, an increase in property tax revenue, and indirect wages at secondary jobs that help support the mining operations (mechanical equipment repair, vehicle maintenance, road maintenance, solid waste management, and other specialized services (Zoning Petition, Economic Development).

The Zoning Petition describes the preparation of a cash flow model to evaluate the cost estimates and produce economic forecasts. The cash flow model has been used to evaluate socioeconomic considerations, such as employment, consumables, services and energy, to estimate the amount and schedule of expenditures within the local communities (Source: Zoning Petition, Appendix A-B3a). Potential tax benefits are highlighted but not stated.

In the Zoning Petition, WMC has presented estimated investment in the local communities of $164.5 million, $230.6 million in the impacted counties, $413.4 million in the state of Maine and US$477.8 million in the USA. These estimates are categorized by four cost-types: employment, supplies, energy and services. Other potential indirect economic benefits of local hiring of $44.4 million are highlighted in the petition. About 25% of the estimated investment will be made during construction phase and 70% during operations.

7.3 Assessment of Reasonableness

The author has made comment on the planned infrastructure, estimated capital investments, expenditure for mine site and marketing costs, and overall projected economic returns elsewhere in this report.

The author has relied on the information provided by WMC in Zoning Petition for the estimates of economic investment in the local community, impacted counties and the state of Maine and in the USA. Based on the intention of Wolfden to prioritize the use of local employment and local services, the estimates generally appear reasonable.

The author has made no assessment of the cost-benefit of the Project, nor the tax benefits to the state of Maine and the USA, nor the strategic impact to the USA of the Project developing US-produced supply of base metals and precious metals.

7.4 Observations

The assessment by WMC in the Zoning Petition does not include estimates of potential indirect benefits that may occur with the development of a mine in northeastern Maine, such as economic multipliers.

7.5 Conclusions

The estimates of economic investment in the local community, impacted counties, the state of Maine and the USA presented by WMC in the Zoning Petition appear reasonable. These estimates would be expected to be evaluated in more detail during the preparation of the feasibility study and permitting applications.

8 REFERENCES

Wolfden Mt. Chase LLC - Petition to Rezone Portion of Township 6, Range 6 Penobscot County, Maine for Development of an Underground Metallic Mineral Deposit - January 26, 2020

Wolfden Resources - Annual Information Form for the Year Ended December 31, 2019 - April 28, 2020

Wolfden Resources - Consolidated Financial Statements for the years ended December 31, 2019 and 2018 - April 15, 2020

Wolfden Resources - Condensed Consolidated Interim Financial Statements for the three and six months ended June 30, 2020 and 2019 - August 24, 2020

Wolfden Resources - Management's Discussion & Analysis of Financial Condition and Results of Operations Form 51-102F1 for the years ended December 31, 2019
and 2018 - April 15, 2020

Wolfden Resources - Management's Discussion & Analysis of Financial Condition and Results of Operations Form 51-102F1 for the three and six months ended June 30, 2020 - August 24, 2020

Wolfden Resources - National Instrument 43-101 Technical Report - Pickett Mountain Project, Resource Estimation Report - January 7, 2019

Wolfden Resources - News Release – November 17, 2017 - Wolfden Completes Financing and Purchase of the Pickett Mountain Base-Metal Property in Penobscot County, Maine, USA

Wolfden Resources - News Release - March 29, 2019 - Wolfden Completes $2.5M Financing with Kinross Gold Corporation

Wolfden Resources - News Release - January 15, 2020 - Wolfden Secures USD 4.5M in Non-Dilutive Funding

Wolfden Resources - News Release - February 19, 2020 - Wolfden Applies for Rezoning at Pickett Mt. Project

Wolfden Resources - News Release - July 28, 2020 - Wolfden Announces Positive Update on its Pickett Mt. Project Rezoning Process

Wolfden Resources - News Release - August 11, 2020 - July 28, 2020 - Wolfden Announces Update on Pickett Mt. Exploration Program in Maine

Wolfden Resources - News Release - September 14, 2020 - Wolfden Announces Robust Preliminary Economic Assessment for Pickett Mt. Project in Maine

Wolfden Resources - News Release - November 2, 2020 - Wolfden Files NI-43-101 Technical Report for the Pickett Mt. Project in Maine

Wolfden Resources - News Release - November 5, 2020 - Wolfden Reports Encouraging Drill Results at Pickett Mt. Project in Maine

Wolfden Resources - Preliminary Economic Assessment, Pickett Mountain Project - October 29, 2020

Wolfden Resources - Presentation (November 1, 2020) - "One of America's Highest Grade Deposits"

Wolfden Resources - Website - www.wolfdenresources.com

Additional Support Documents for NRCM Report

Bald Mountain Mining Risks: Hidden from the Public

This pdf provides documents secured through Freedom of Access Act requests to the DEP, and other support materials. For further information, see footnotes in the report footnotes.

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OPINION OF TECHNICAL AND ECONOMIC ASPECTS OF WASTE MANAGEMENT BALD MOUNTAIN PROJECT

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EXECUTIVE SUMMARY

Introduction and Objective of Review

The Bald Mountain Project, located in north-central Aroostook County, Maine, is being evaluated by Boliden Resources Inc. The deposit consists of gold bearing gossan overlying copper and zinc bearing massive sulfide zones.

Recovery of the resource is proposed by open pit mining to produce about 0.6 million tons per year of gossan ore for two years followed by up to 1.75 million tons per year of massive sulfide ore for about 13 years. Cyanidation would be used in the gold extraction process and cyanide may be used to enhance selectivity in the copper and zinc flotation process. A total of about 1.2 million tons of gossan tailings, 22 million tons of massive sulfide tailings and 39 million tons of mine rock would be produced.

The project is located in an area with significant timber harvesting and high quality groundwater and surface waters. It is proposed to locate the tailings and mine rock facilities over about 20 to 30 acres of wetlands. Bald Mountain Brook has its headwaters in the proposed tailings impoundment and mine rock storage pile area. Bald Mountain Brook drains into Clayton Stream about 1.5 miles from the impoundment. Both streams are Class A streams with a low dissolved solids content, particularly in the spring freshet period when most of the flow is from melting snow.

The review includes a preliminary assessment of the acid generation characteristics of the tailings, mine rock and pit walls, development of conceptual waste management and reclamation plans, evaluation of the water balance, effects on wetlands, groundwater and surface waters, and an evaluation of the potential to achieve environmental standards.

Acid Generation Characteristics of the Tailings and Mine Rocks

The tailings are massive sulfides and clearly potentially acid generating if exposed to both air and water. The ore deposit contains up to 50% sulfides, occurring principally as pyrite and pyrrhotite. Core samples of the ore are stored by Boliden Resources Inc. in freezers to prevent oxidation prior to metallurgical testing. This may be indicative of the reactivity of some of the massive sulfide rock. Material with a high pyrrhotite content can exhibit rapid oxidation characteristics. Acid-base accounting tests performed on the mine rocks as part of this study have demonstrated that the 13 million tons of foot wall mine rock and 12 million tons of massive sulfide mine rock would be potentially highly acid generating. The 6 million tons of hanging wall mine rock and the 8 million tons of glacial till are expected to be non-acid generating.

The status of current technology regarding the control of acid generation from sulfidic wastes is that the exclusion of oxygen through placement of reactive wastes under water is the most promising long-term means of limiting acid generation. The mine waste management plan for the Bald Mountain Project should be to place all acid generating tailings and mine waste under water, either during operation or on decommissioning. However, while the rate of acid generation is greatly reduced by placing the waste underwater, this does not halt the oxidation process entirely. The extent to which acid generation and metal leaching may occur and the resulting impact on the environment at the Bald Mountain Project site cannot be quantified at this stage. Minimizing the impact of acid generation during operation may be achieved by a combination of measures. These include measures to inhibit the acid generation process, for example addition of alkali material, measures to minimize infiltration and migration of the products, and allowance for collection and treatment of drainage.

For the purpose of this review it has been assumed that the tailings would not be classified as a hazardous waste, based on the results of previous laboratory leachate quality testing, and would therefore not be subjected to waste handling and storage criteria applicable to hazardous wastes. This would need to be confirmed prior to finalization of the mine waste management plan.

Proposed Waste Management and Reclamation Plan

A conceptual mine waste management and reclamation plan has been developed with the principal objective of providing the required environmental protection of natural water resources at the site in the most economical and practical fashion. The proposed waste management plan consists of:

Tailings

- Using separate, synthetically lined tailings impoundments for the storage of gossan and massive sulfide tailings. The gossan tailings would be expected to contain higher levels of cyanide and placement of these tailings in a separate impoundment upstream of the main embankment would provide added control of cyanide migration and reduces initial capital costs.

- Installing a drainage system under the liners to collect and discharge groundwater to a monitored seepage collection pond. This is required in order to prevent the build-up of water pressure beneath the liner during operation which may damage the synthetic geomembrane.

- Installing a drainage layer above the membrane liners to enhance drainage from the tailings and to provide a hydraulic 'high permeability' envelope around the tailings. The objective of this layer is to reduce the hydraulic gradient through the tailings mass and hence the potential for contaminated seepage through leaks in the synthetic liner in the long term.

Mine Rock

- Using non-acid generating till and hanging wall rock for embankment and cover construction purposes.
- Placing massive sulfide mine rock below water in the flotation tailings impoundment as it is mined.
- Stockpiling foot wall rock over a natural or compacted till liner. Acid generation in this material during operation would be limited by blending in a small percentage of finely crushed limestone and covering the dump as it is developed to reduce both oxygen entry and leaching.
- Backfilling all potentially acid generating mine rock from the temporary stockpile to the pit on completion of mining and flooding the pit. The quality of the pit water would be controlled during backfilling to achieve alkaline conditions with the objective of controlling dissolved contaminants.

Pit Walls

- Placing a till cover against all potentially acid generating pit walls (foot wall rock) located above the water level in the pit on completion of backfilling. Long term stability to the till cover would be provided by means of a rock buttress constructed from hanging wall waste.

Water Management

- Collecting, monitoring and treating the water from the pit, mill, tailings impoundment and mine rock piles prior to discharge to surface waters or land applied.

The reclamation plan would consist of:

- Covering the tailings with a till layer and flooding the impoundment to form marshland conditions in which a continuous zone of saturated till overlies the tailings.
- Covering the non-acid generating mine rock remaining in the surface rock piles with till and revegetating the covered piles. No acid generating mine rock would remain on the surface.
- Flooding the pit to submerge all backfilled potentially acid generating mine rock. Vegetation would be established on unflooded till surfaces.

Alternative Tailings Impoundment Sites

A number of alternative sites have been identified in previous studies. Apart from wetland considerations none of the sites offer any advantage over the selected site. These were reviewed, and evaluations made of their potential for the waste quantities currently proposed. All of these sites have considerable disadvantages with respect to groundwater seepage control and maintenance of a water cover on decommissioning and, in addition, would be considerably more costly to develop. They would result in environmental impacts over a much greater area and potentially impact additional watersheds. None of these sites are considered to be preferable to the selected site.

Water Balance

A water balance determination for the proposed mine development and waste management plan resulted in an average annual excess of 490 USgpm with 70% of the tailings water being recycled to the mill and 180 USgpm with 90% of the tailings water being recycled to the mill. These quantities were obtained assuming average precipitation conditions and assuming that drainage from the pit and foot wall rock dump is an inflow to the impoundment water balance. All evaluations allowed for staged diversions to minimize water capture. The importance of the recycle percentage is apparent as is the need to minimize the contributory area. These calculated excesses are considerably greater than those determined in the previous study by Barr Engineering. The difference is substantially accounted for in the assumption that recycle cannot be 100%.

Mine Water Treatment and Discharge Alternatives.

The mean annual dilution ratios of discharged treated mine waters into Bald Mountain Brook and Clayton Stream range between about 0.5 and 1.5 in Bald Mountain Brook and between 3 and 8 in Clayton Stream, when compared with the mean average annual mine water flows. To achieve 'no degradation' in Bald Mountain Brook requires treatment to water quality standards not achievable with present technology. The development of land application sites for such substantial flows will require large application areas. The fate of accumulated metals will be a concern. Further studies are required in order to identify alternative appropriate instream standards. Additional studies are also required to identify water management and treatment strategies to achieve such standards.

In our opinion, the only scenario under which permitting could be achieved would be to obtain variances which would allow treated water discharge which, with dilution in Clayton Stream, would still be protective of the local ecosystem. Based on our appreciation of current technology and site conditions, it will not be possible to achieve drinking water quality standards in Clayton Stream at the confluence with Bald Mountain Brook, under the proposed mine development plan. A site specific analysis could yield alternative in-stream criteria greater than background water quality.

Groundwater and Surface Water Quality

In addition to controlled discharges there will be non-point-source discharges resulting from drainage which escapes the perimeter ditching via either surface or groundwater routes. These losses will contribute to the degradation of water quality in Bald Mountain Brook.

To minimize such losses during operation a synthetic membrane liner is proposed for both tailings impoundments, installed directly onto compacted till to form composite liners, together with drainage layers above the liner to reduce water head on the liner. Seepage losses from the mine rock storage piles would be minimized by their placement on a till liner. No losses would occur from the pit during operation. These measures should be sufficient to control losses to very small values during operation and groundwater and surface water degradation should not represent a fatal flaw during this period, assuming seepage losses can be collected and treated effectively.

After closure the mine rock will be placed in the pit which will flood and discharge to Bald Mountain Brook through surface overflow and near-surface groundwater. The leaching of the backfilled rock waste and the contamination of highwall seepage with oxidation products are concerns and may represent a fatal flaw. Additional test and modelling work will be required to demonstrate the long term quality of this discharge. The tailings geosynthetic liner is expected to degenerate over the very long term (possibly 50 to 100 years). The till portion of the composite liner would remain over the very long term. The purpose of the high permeability 'hydraulic envelope' is to minimize contaminant migration from the low-permeability tailings mass. The effectiveness of this system in the long term cannot be quantified or demonstrated at this stage.

Waste and Water Management Costs

The total estimated gross capital cost for construction of the mines waste and water management facilities is $35.7 million ($1.56 per ton of ore mined) for the "base case". Taking account of staged construction and discounting costs at 12%, the present value of this cost is $25.2 million ($1.10 per ton of ore mined). Total estimated gross operating and closure costs are $26.4 million and $24.8 million, respectively.

Potential Technical and Economic Flaws

While an evaluation of the permitting requirements for the project development are excluded from the scope of work for this study, it is our opinion that, under the proposed mine development plan, the technical issues related to water quality may represent fatal flaws.

The maintenance of water quality in the downstream surface waters of Bald Mountain Brook and Clayton Stream is a possible fatal flaw. During operations the quantity and quality of treated water discharge is sufficiently large that it will be difficult, with the dilution flows available, to prevent degradation of these streams to levels where their ecosystems are not deleteriously effected. Following decommissioning the release of untreated seepage from the tailings and (particularly) the pit will also result in reduced water quality. While the impacts of these long term releases could not be established with confidence in a review of this nature, it is our opinion that it will be difficult to demonstrate low impacts. Further, based on our understanding of current technology and site conditions, it will not be possible to maintain drinking water quality standards in Clayton Stream at the confluence with Bald Mountain Brook, under the proposed mine development plan.

Conclusions and Recommendations

There are technical concerns with the proposed mine development and waste management plan as described in this review document. These concerns relate primarily to the maintenance of water quality in the downstream environment both during operations and post decommissioning. These concerns may prove to be fatal flaws unless it can be demonstrated that these issues can be addressed by technically and economically feasible means, incorporating appropriate contingencies and factors of safety against failure. This may be achieved through either:

- further evaluation of the existing plan, or
- modification of the current mining and waste management plan.

The following recommendations derive from this conclusion:

i) Perform additional testing and evaluations to confirm, by qualitative results, the validity of the technical concerns and obstacles to permitting.

ii) Identify the operating conditions and site conditions required at mine decommissioning to eliminate, or minimize, the concerns with regard to water quality in receiving waters.

iii) Evaluate alternative mine and mill development strategies that would meet these conditions or objectives, i.e., adopt a "design for closure" approach. Some of the alternative strategies that could be considered include:

  - reducing the size of the pit and hence waste and tailings areas,
  - underground mining,
  - backfilling tailings in underground workings,
  - placement of all potentially acid generating mine rock in the tailings impoundment in combination with revised pit configuration,
  - alternative mill processes to maximize recycle and minimize water balance excess.

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OPINION OF TECHNICAL

AND

ECONOMIC ASPECTS OF WASTE MANAGEMENT

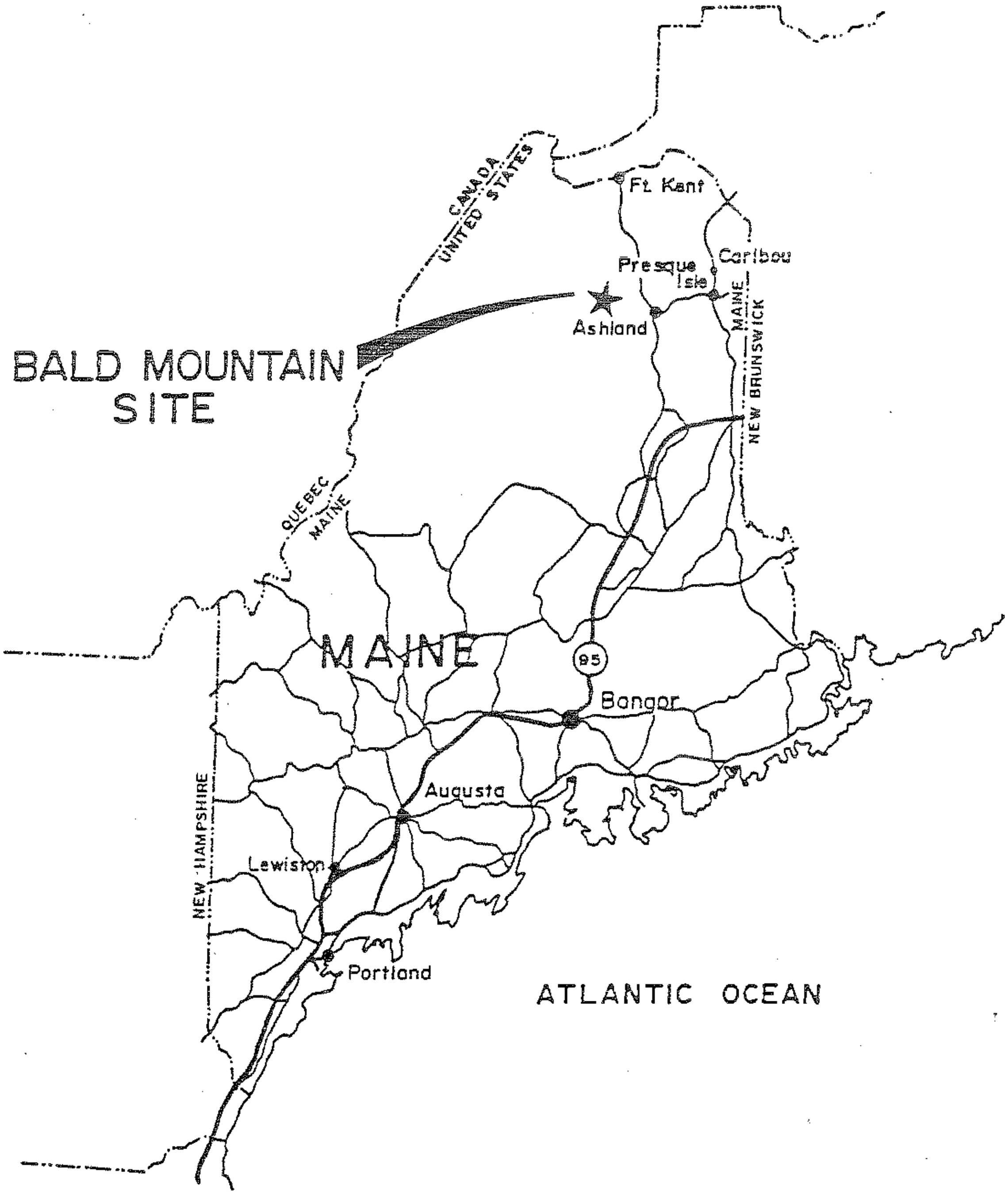
BALD MOUNTAIN PROJECT

1.0 INTRODUCTION

Boliden Resources Inc. (Boliden) is studying the feasibility of developing the Bald Mountain Project in north-central Aroostook County, Maine (Figure 1.1). Boliden has contracted Steffen Robertson and Kirsten (SRK) to conduct an initial review of the technical and economic aspects of waste management and permitting.

The workscope for this study is defined in proposal No E5342 from SRK dated April 6, 1990 and provided for the following tasks:

- Reassess the potential for acid rock drainage (ARD)
- Identify available ARD control techniques
- Carry out a preliminary tailings impoundment water balance
- Evaluate the feasibility of water treatment
- Perform a preliminary assessment of site hydrology, geohydrology, surface water quality and the potential environment impact
- Develop preliminary costs for all major waste management components
- Develop preliminary waste management and reclamation plans and prepare a report.



BOLIDEN RESOURCES INC.	BALD MTN. PROJECT	DATE JUNE 1990
PROJECT SITE LOCATION		PROJ. NO. 80701
		APPROVED
		NO. 1.1
STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers		

2.0 DESCRIPTION OF THE PROJECT

The Bald Mountain ore deposit is located approximately 14 miles (22 km) north-west of the town of Ashland in north-central Aroostook County, Maine. The deposit consists of two types of ore: a gold-bearing gossan zone overlying a copper and zinc bearing massive sulfide zone. Boliden Resources Inc. holds the mineral rights to the Bald Mountain deposit and plan to submit mining and other required permit applications. An open pit mine is proposed for the recovery of the gold, copper and zinc ores (Figure 2.1). Approximately 1.2 million tons of gold-bearing ore from the gossan zone would be processed during the first two years of operation at a rate of approximately 0.6 million tons per year. Following mining of the gossan zone, approximately 22 million tons of massive sulfide ore would be mined and processed at a rate of up to 1.75 million tons per year to recover copper and zinc for a period of about 13 years. Cyanidation would be used in the gold extraction process and cyanide may be used as a depressant in the copper and zinc flotation process. The overall waste to ore stripping ratio is approximately 1.7 to 1 resulting in approximately 39 million tons of mine rock. Acid generation, due to the natural oxidation of sulfide minerals contained in the tailings, open pit walls and some of the mine rock, would need to be controlled during both the operating and post decommissioning period to prevent adjacent surface and groundwaters from being adversely affected.

3.0 SITE CHARACTERIZATION

3.1 Topography

The topography of the project site is shown in Figure 2.1 and the surrounding area is shown on Figure 3.1. The ore-body occurs on the west side of No-Name Ridge, a peak that rises from the surrounding valleys at an elevation of about 900 ft. to a crest elevation of 1,500 ft. This peak is one of a chain that trends north-south through the project area. The chain is dissected by a series of valleys, the axes of which generally trend southwest on the west side of the chain and southeast or east on the other. Two valleys to the east of the mine peak have axes tending northwest to southeast. The orientation of the valleys along the chain of peaks reflects the underlying geology: a series of linear features, joints and faults or other geological discontinuities.

To the west of the chain, the ground slopes down along flatter valleys to a more level area where Clayton Lake and Big Machias Lake are found. To the northwest, the area drains along Clayton Stream to the Fish River and then into Fish River Lake. This lake fills a north-south depression, probably a part of the extensive series of linear features that dominate the surrounding topography.

To the southeast of the chain, the area flattens with only a few major peaks between the project site and Portage Lake. Just to the east, on the foothills of the chain, is Greenlaw Pond. This feeds into Greenlaw Stream, Sterling Brook and, ultimately, the Great Machias River.

The area to the northeast of the chain is dominated by Carr Pond Mountain and adjacent peaks. In amongst them nestles Bishop Pond. This drains into Bishop Pond Stream and then into Carr Pond. Carr Pond occupies an east-west depression formed by linear features.

3.2 Mine Development

The open pit would be situated on the west flank of No-Name Ridge. The limits of the ultimate pit would have maximum and minimum elevations of approximately 1,140 and 880 feet, respectively. The ultimate pit would have a floor elevation of approximately 180 feet.

The pit would be developed as a series of benches and material quantities by bench level, based on 1.0% copper and 1.83% zinc cutoffs, respectively, are summarized in Table 3.1. However, the specifics of the mine plan, particularly in the early years when the various waste storage facilities are being developed using mine rock, may depend to a significant degree on the construction scheduling requirements of the waste storage facilities.

TABLE 3.1

Open Pit Quantities by Bench Level

PIT 8 - ULTIMATE PIT - 1.0% CU & 1.83% ZN CUTOFFS

01-May-90

		ORE															WASTE					
	TOTAL	GOSSAN			ZINC MS			CU MS			CU MS +ZN			STRINGER			GOS WAST	MS WASTE			TILL	VOLCANIC
BENCH	TONS	TONS	AU	AG	TONS	CU	ZN	TONS	CU	ZN	TONS	CU	ZN	TONS	CU	ZN	TONS	TONS	CU	ZN	TONS	TONS
1125	25,316	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	25,316	0
1100	159,130	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	159,130	0
1075	348,014	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	348,014	0
1050	642,387	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	642,387	0
1025	1,025,108	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	978,092	47,018
1000	1,428,345	0	0.000	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	1,139,014	289,331
975	2,015,461	2,407	0.078	1.6	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	2,407	0	0.00	0.0	1,249,709	760,938
950	2,590,455	60,168	0.073	0.9	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	14,440	0	0.00	0.0	1,318,745	1,197,102
925	2,971,901	312,676	0.094	1.5	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0	50,642	0	0.00	0.0	1,242,888	1,365,595
900	3,320,151	435,620	0.128	2.9	71,429	0.16	2.2	5,102	1.23	0.3	56,122	1.22	1.3	0	0.00	0.0	31,288	142,857	0.34	1.4	822,757	1,754,978
875	3,521,861	274,368	0.148	3.6	163,265	0.20	3.2	102,041	2.23	0.2	163,265	1.49	1.3	25,316	1.23	0.1	24,067	418,367	0.40	1.2	122,538	2,228,634
850	3,578,758	120,337	0.141	3.1	193,878	0.16	3.6	387,755	2.66	0.2	193,878	1.63	1.1	36,166	1.21	0.1	7,220	588,853	0.45	1.3	0	2,050,671
825	3,598,028	0	0.000	0.0	239,796	0.18	3.5	744,898	2.66	0.2	127,551	1.38	1.2	39,783	1.22	0.1	0	678,571	0.47	1.3	0	1,767,429
800	3,454,762	0	0.000	0.0	311,224	0.23	3.3	790,816	2.43	0.2	137,755	1.31	2.0	50,633	1.32	0.0	0	704,082	0.48	1.3	0	1,460,252
775	3,264,117	0	0.000	0.0	352,041	0.20	3.4	836,735	2.21	0.2	107,143	1.27	1.7	36,166	1.42	0.3	0	647,959	0.47	1.4	0	1,284,073
750	3,104,915	0	0.000	0.0	377,551	0.24	3.7	841,837	2.19	0.2	61,224	1.12	0.8	39,783	1.65	0.4	0	683,673	0.48	1.3	0	1,100,847
725	2,963,094	0	0.000	0.0	392,857	0.22	3.5	831,633	2.27	0.2	86,735	1.33	0.7	32,550	1.79	0.4	0	760,204	0.46	1.3	0	859,115
700	2,816,166	0	0.000	0.0	372,449	0.18	3.3	795,918	2.45	0.2	127,551	1.56	0.8	39,783	1.75	0.1	0	846,939	0.48	1.4	0	633,526
675	2,642,490	0	0.000	0.0	408,163	0.16	3.1	744,898	2.54	0.2	102,041	1.52	0.8	50,633	1.64	0.1	0	882,653	0.58	1.2	0	454,102
650	2,468,123	0	0.000	0.0	408,163	0.13	3.0	647,959	2.13	0.2	127,551	2.73	0.8	72,333	1.61	0.1	0	841,837	0.57	1.1	0	370,280
625	2,302,126	0	0.000	0.0	377,551	0.16	3.0	663,265	1.89	0.2	107,143	3.02	0.7	57,866	2.21	0.1	0	846,939	0.57	1.0	0	249,362
600	2,092,030	0	0.000	0.0	295,918	0.16	3.1	678,571	1.91	0.2	66,327	1.30	0.7	65,099	2.17	0.1	0	790,816	0.57	1.0	0	195,299
575	1,887,949	0	0.000	0.0	275,510	0.22	3.2	724,490	1.80	0.2	45,918	1.77	0.9	57,866	1.58	0.1	0	581,633	0.60	1.0	0	202,532
550	1,697,688	0	0.000	0.0	188,776	0.26	3.0	704,082	1.87	0.3	45,918	1.86	0.9	72,333	2.00	0.1	0	494,898	0.64	1.0	0	191,681
525	1,498,063	0	0.000	0.0	71,429	0.25	2.9	642,857	1.72	0.3	96,939	1.93	1.3	68,716	1.87	0.0	0	433,673	0.66	0.9	0	184,449
500	1,334,991	0	0.000	0.0	56,122	0.28	3.3	596,939	1.67	0.3	132,653	1.99	0.8	79,566	1.88	0.0	0	321,429	0.68	0.7	0	148,282
475	1,148,734	0	0.000	0.0	45,918	0.24	3.6	540,816	1.77	0.3	127,551	1.95	0.7	54,250	1.99	0.0	0	250,000	0.72	0.7	0	130,199
450	970,356	0	0.000	0.0	0	0.00	0.0	489,796	1.82	0.3	96,939	1.92	0.7	43,400	2.40	0.0	0	224,490	0.74	0.8	0	115,731
425	817,489	0	0.000	0.0	0	0.00	0.0	403,061	1.79	0.3	56,122	1.84	0.7	28,933	3.19	0.0	0	224,490	0.83	0.8	0	104,883
400	702,919	0	0.000	0.0	0	0.00	0.0	336,735	1.65	0.3	51,020	1.65	0.8	54,250	1.81	0.0	0	163,265	0.85	0.7	0	97,649
375	548,760	0	0.000	0.0	0	0.00	0.0	311,224	1.76	0.3	66,327	1.40	0.8	39,783	1.73	0.0	0	66,327	0.86	0.8	0	65,099
350	437,807	0	0.000	0.0	0	0.00	0.0	229,592	1.92	0.2	66,327	2.05	0.8	57,866	1.63	0.0	0	15,306	0.93	1.1	0	68,716
325	318,522	0	0.000	0.0	0	0.00	0.0	168,367	2.05	0.2	45,918	2.58	0.7	39,783	1.67	0.0	0	10,204	0.98	0.9	0	54,250
300	240,700	0	0.000	0.0	0	0.00	0.0	153,061	2.02	0.2	10,204	1.67	0.6	32,550	1.55	0.0	0	5,102	0.68	0.7	0	39,783
275	154,353	0	0.000	0.0	0	0.00	0.0	127,551	2.11	0.2	5,102	1.51	0.8	18,083	1.46	0.0	0	0	0.00	0.0	0	3,617
250	98,230	0	0.000	0.0	0	0.00	0.0	76,531	1.90	0.1	0	0.00	0.0	14,467	1.18	0.0	0	0	0.00	0.0	0	7,232
225	20,408	0	0.000	0.0	0	0.00	0.0	20,408	1.87	0.1	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	0	0
200	5,102	0	0.000	0.0	0	0.00	0.0	5,102	4.38	0.0	0	0.00	0.0	0	0.00	0.0	0	0	0.00	0.0	0	0
Total:	62,214,810	1,205,776	0.122	2.6	4,602,041	0.19	3.3	13,602,040	2.09	0.2	2,311,224	1.74	1.0	1,207,957	1.77	0.1	129,964	11,624,567	0.55	1.1	8,048,590	19,482,651

1,205,776 = GOSSAN ORE

4,602,041 = ZINC ORE

17,121,221 = TOTALCU ORE

39,285,772 = TOTAL WASTE

Related to the mine development would be the production of gossan and sulfide tailings, glacial till, gossan mine rock, sulfide mine rock, hanging wall mine rock and foot wall mine rock. The expected tonnage of each of these materials and notes on whether they are expected to be acid generating are shown in Table 3.2. The tailings tonnages shown in Table 3.2 do not reflect final product (or concentrate) recovery which is expected to be approximately 6% of the total tonnage. The tonnage of tailings placed in the impoundment would therefore be approximately 94% of the values shown in Table 3.2. The acid generation potential of the mine wastes is discussed in detail in Section 5.0 of this report. It is the acid generation potential of these various materials that governs their management and reclamation. The conceptual waste management plan is briefly summarized here and described in more detail in Section 6.0. In particular, materials which have the capacity to generate acid would either be placed directly inside the tailings impoundment or temporarily on a till pad until the pit is completed and this waste can be backfilled to the pit. Mine rock which has a net neutralizing potential would be used in the construction of drains and embankments or would be placed downstream of the embankment used to confine tailings.

TABLE 3.2
Summary of Materials Produced as a Result of Mine Development For 0.73% and 1.00% Copper Cut-off Grades

Material	Quantity (Tons) 0.73% Copper	1.0% Copper	Acid Generating Potential
Gossan tailings	1,210,000	1,210,000	yes (assumed)
Sulfide tailings	29,820,000	21,720,000	yes
Glacial till	8,050,000	8,050,000	no
Gossan mine rock	130,000	130,000	yes (assumed)
Massive Sulfide mine rock	5,890,000	11,620,000	yes
Hanging wall mine rock	8,240,000	6,300,000	no
Foot wall mine rock	17,340,000	13,200,000	yes

The gossan tailings are a product of a process which requires quantities of cyanide greater than the copper/zinc extraction process, and should be separated from the sulfide tailings in a lined impoundment. This impoundment would be located such that any leakage from the gossan tailings through the liner would be contained during operation. The location of the gossan impoundment is at the upstream end of the overall impoundment area, thus maximizing the length of possible seepage paths and taking advantage of the natural attenuation and degradation of cyanide. The embankment used to confine the gossan tailings would be constructed using glacial till and mine rock. Drains, placed beneath the liner, would consist of quarried, non-acid generating rockfill or hanging wall mine rock.

The sulfide tailings are believed to have a strong potential to generate acid. These tailings would be deposited in a lined impoundment. A confining embankment would be constructed using glacial till, and hanging wall mine rock.

The glacial till would be used to construct confining embankments for tailings impoundments, a temporary base pad, if needed, for storage of foot wall mine rock and a permanent pad to facilitate the early placement of massive sulfide mine rock inside the limits of the sulfide tailings pond. During operation, excess glacial till would be placed downstream of the sulfide tailings dam in a stockpile. A portion of this till would be used to cover the tailings surface in order to promote the development of marshland conditions. Till would also be used to develop fillets to cover those portions of the pit walls which are potentially acid-generating and for other reclamation purposes.

Gossan mine rock would be used in the construction of the embankment used to confine the gossan tailings.

Massive sulfide mine rock would be deposited in the tailings impoundment along with all the sulfide tailings.

Hanging wall mine rock would be used in the construction of drains beneath the two lined tailings impoundments and in the construction of embankments.

Foot wall mine rock is potentially acid generating and would therefore be placed temporarily on a glacial till pad so that drainage can be captured and, if contaminated, treated. At closure, the foot wall mine rock would be backfilled to the open pit below the final water elevation.

3.3 Alternative Tailings Disposal Sites

3.3.1 Initial Site Selection

In 1980 and 1981, Steffen Robertson and Kirsten (SRK) carried out a study to select, evaluate and rank alternative tailings disposal sites. The study resulted in the identification of 45 potential tailings disposal sites, the locations of which are shown on Figure 3.1.

An analysis was performed in which the potential sites were assessed in the context of potential fatal flaws. A fatal flaw is defined as a site characteristic which is sufficiently unfavorable or severe that, on its own, would eliminate the site as an alternative for tailings disposal. Typical fatal flaws established as part of this analysis comprised embankments with a volume of greater than 6.7 million cubic yards; access distances of greater than 9 miles; upstream catchments of greater than 5.4 square miles; access routes where two or more streams have to be crossed; and impoundments where more than three saddle dykes are required.

The analysis indicated that fatal or severe flaws affect most of the 45 sites. The sites which had no apparent fatal or severe flaws and, therefore, warranted further consideration, were Moose Site (Site 6), High Site (Site 7) and Logging Road Site (Sites 8 and 45). Conceptual designs were completed for each of these sites and preliminary costs of construction, operation and decommissioning were estimated. The sites were then ranked on the basis of visibility, land use, operation, environmental effects and cost, with the following result:

Ranked First	High Site
Ranked Second	Moose Site
Ranked Third	Logging Road Site

3.3.2 Site Selection Based on Wetlands Avoidance

In 1988 and 1989, International Engineering Company, Inc. (IECO) carried out another site selection study with a view to avoiding wetlands. Conceptual designs were prepared for the four impoundment alternatives (High Site 1, High Site 2, High Site 3 and Bull Hill Site) shown on Figure 3.2. The designs were based on storage of 7.5 million cubic yards of tailings, except for High Site 1 which was also assessed on the basis of 15 million cubic yards of storage. A description of each of these sites is included below and a summary of their characteristics based on the IECO analysis is included in Table 3.3.

- High Site 1

The site would be developed by constructing a single cross-valley embankment. To keep the embankment out of marshy areas as much as possible, the dam axis was located across a small knoll at the west end of the site. Studies by others indicate that this valley site supports a 20 to 30-acre wetland area.

- High Site 2

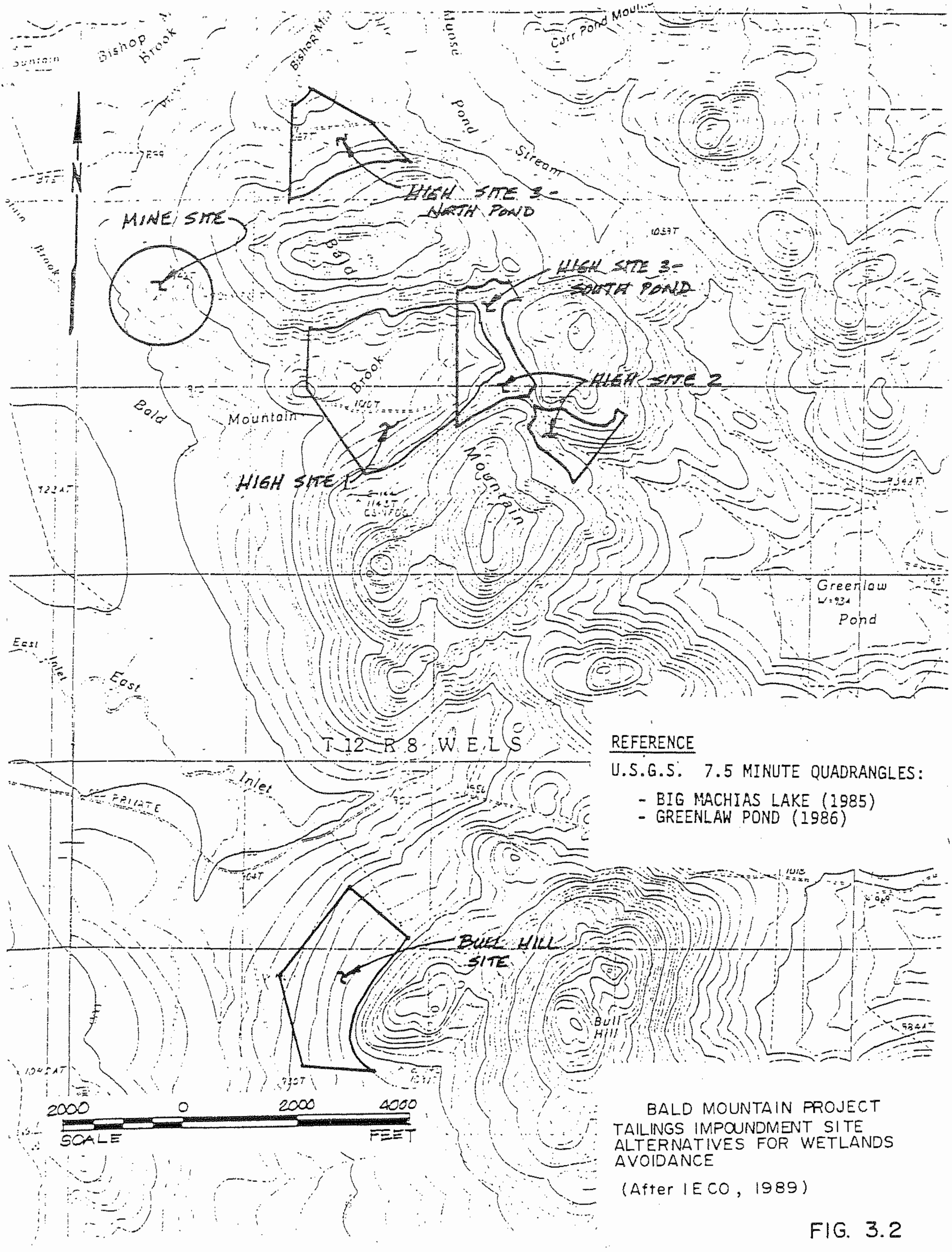
This site was located to avoid wetlands almost entirely. The west dam was located east (upstream) of the wetlands affected by High Site 1. To develop sufficient storage capacity, dams would be required in the northeast saddle and southeast of the southeast saddle.

- High Site 3

This alternative consists of two impoundments: a south impoundment in the High Site with a maximum tailings level at El. 1152 (the approximate elevation of the northeast saddle) and a north impoundment located north of No-Name Ridge.

- Bull Hill Site

This site is located on the west flank of Bull Hill, about 2.3 miles south of the mine site. The Bull Hill alternative is a side hill alternative and therefore consists of a three-sided impoundment.



REFERENCE

U.S.G.S. 7.5 MINUTE QUADRANGLES:

- BIG MACHIAS LAKE (1985)
- GREENLAW POND (1986)

BALD MOUNTAIN PROJECT
TAILINGS IMPOUNDMENT SITE
ALTERNATIVES FOR WETLANDS
AVOIDANCE

(After IECO, 1989)

FIG. 3.2

TABLE 3.3

Tailings Impoundments For Avoidance of Wetlands Summary of Physical Characteristics (After IECO, 1989)

				HIGH SITE 3			
	HIGH SITE 1	HIGH SITE 2	SOUTH POND	NORTH POND	TOTAL	BULL HILL SITE	HIGH SITE 1
1) Storage Capacity (million c.y.)	7.5	7.5	2.5	5	7.5	7.5	15
2) Impoundment Area (acres)	118	92	44	58	102	91	165
3) Maximum Tailings Elevation (ft.)	1,078	1,178	1,152	1,142	---	1,083	1,112
4) Embankment Dam							
A. Volume (c.y.)	1,085,000	4,080,000	1,385,000	2,380,000	3,765,000	5,158,000	2,357,000
B. Length (ft.)	2,840	5,330	2,810	4,370	7,180	6,500	3,160
C. Maximum Height (ft)	103	175	110	110	110	130	137
D. Crest Elevation (ft.)	1,088	1,187	1,160	1,151	---	1,090	1,122
5) Drainage Basin Area (acres)	367	185	107	135	242	134	367
6) Drainage Basin Area/Impound. Area	3.1	2.0	2.4	2.3	2.4	1.5	2.2
7) Storage Capacity/Embank. Volume	6.9	1.8	1.8	2.1	2.0	1.5	6.4
8) Straight Line Distance to Mine (miles)	0.6	1.3(avg.)	1.0	0.8	---	2.3	0.6

3.3.3 Review of Alternative Sites Based on Current Design Criteria

3.3.3.1 Design Parameters

The required storage capacity in the overall tailings impoundment was evaluated for two copper cut-off grade cases, namely 0.73% and 1.00%. A summary of material tonnages for these two cases is shown in Table 3.2. The storage requirement for 0.73% copper cut-off is for 1.2 million tons of gossan tailings, 29.8 million tons of sulfide tailings and 5.9 million tons of potentially acid generating sulfide mine rock. At estimated settled densities of 80, 130 and 177 pounds per cubic foot (pcf), respectively, these translate to 1.1 million, 17.0 million and 2.5 million cubic yards, respectively, or a total of 20.6 million cubic yards. Allowing for a 10% contingency, the total volume of material would be 23 million cubic yards. The required storage capacity for 1.00% copper cut-off grade is approximately 20 million cubic yards. A storage requirement of 23 million tons was assumed for the purpose of evaluating alternative sites. It was assumed in the current assessment that mine rock and till would be used to construct the embankments and that, based on the likelihood that a synthetic liner would be required, a 60 mil HDPE liner would be used to line the tailings impoundment.

The issue of gossan tailings and the potential need for a second impoundment has been ignored for purposes of this comparison of alternative sites.

3.3.3.2 Preliminary Design

The designs prepared by IECO (1989) have been used as the basis for evaluating and costing tailings disposal at the four sites. Impoundment capacity curves prepared previously by IECO have been extrapolated to determine the approximate embankment crest elevation required to store 23 million cubic yards of waste. A copy of the extrapolated curves is included in Appendix A. The embankment layouts prepared by IECO were modified to reflect these crest elevations (Appendix A) and the volumes of the respective embankments were computed. The results of these calculations are summarized below:

Site	Embankment Crest Elev (ft)	Embankment Volume (Cu. yd.)	Embankment Volume to Storage Ratio
High Site 1	1148	2,974,000	0.13:1
High Site 2	1274	16,692,000*	0.72:1
High Site 3	1237	17,065,000*	0.74:1
Bull Hill Site	1178	19,049,000	0.82:1

* Total of two embankments

Based on the ratios of embankment volume to storage, the High Site 1 has the most efficient storage.

3.3.3.3 Estimated Costs

The cost of constructing the impoundments at High Sites 1, 2, 3 and Bull Hill Site have been estimated. Cost estimates prepared by IECO, plus a 10% increment for inflation, form the basis of the current estimates. Other factors in the preparation of the current estimates are as follows:

- Assume the entire embankment is constructed prior to the start of mining.
- Assume the embankments are constructed entirely of mine rock and till from the open pit development. In fact, for all cases except High Site 1, approximately 12 million cubic yards of borrow will be required to construct the final embankments, possibly at lower costs than are noted in Appendix A, but with greater disturbance.
- Assume the cost of cutoff and foundation grouting will be eliminated from all cases.
- Assume that a 60 mil HDPE liner at 60¢/square foot will be required in all cases.

A summary of the cost estimates, prepared only for the purpose of comparing the alternative sites, is provided in Table 3.4.

TABLE 3.4
Summary of Estimated Costs for Embankment
Construction at Alternative Tailings Impoundment Sites

Site	Total Estimated Cost*	Unit Cost of Disposal**
High Site 1	$24.3 million	$0.69/ton
High Site 2	$85.1 million	$2.43/ton
High Site 3	$79.7 million	$2.28/ton
Bull Hill Site	$112.2 million	$3.21/ton

* Prepared from the IECO estimates, for comparative purposes only
** For 35 million tons of tailings and potentially acid generating mine rock

3.3.3.4 Evaluation of Alternative Sites

The following is a discussion of the advantages and disadvantages of the alternative sites.

High Site 1

Advantages:

- close to mine and therefore has a likelihood of a smaller environmental impact in the event of

a rupture of the tailings pipeline.
- requires no additional borrow to construct the confining embankments
- drainage impact affects only one brook
- lowest capital cost, by a substantial margin
- operating cost would, by virtue of its location, be relatively low
- catchment area sufficient to ensure water cover can be maintained

Disadvantages:
- 20 to 30 acres of wetland affected
- Bald Mountain Brook impacted

High Site 2

Advantages:
- relatively close to mine and therefore has a likelihood of a smaller environmental impact in the event of a rupture of the tailings pipeline
- operating costs would be similar to that of High Site 1, with slightly higher waste haulage and tailings pumping costs

Disadvantages:
- drainage impact affects multiple brooks and groundwater systems
- a need to develop borrow areas to complete construction of the confining embankments
- high capital cost
- assured water cover may not be possible in dry years

High Site 3

Advantages:
- relatively close to mine and therefore has a likelihood of a smaller environmental impact in the event of a rupture of the tailings pipeline
- operating costs would be only slightly higher than that of High Sites 1 and 2

Disadvantages:
- two impoundments instead of one, which compounds potential operating and environmental problems
- drainage affects multiple brooks and groundwater systems
- high capital cost (only sightly less than High Site 2)
- need to develop borrow areas to complete construction of the confining embankments
- assured water cover may not be possible in dry years

Bull Hill Site

Advantages:

- no apparent advantages (early evaluations of the site indicated that there may be reduced impact on wetlands at the Bull Hill Site, however, recent studies have shown that this is not the case)

Disadvantages:

- distant from the mine resulting in likelihood of greater environmental impact in the event of a pipeline rupture
- highest capital cost, reflecting the high ratio of embankment volume to waste volume
- need to develop borrow areas to complete construction of the confining embankments
- additional haul road and pipeline construction, hence site disturbance
- additional operating costs for tailings pumping and mine rock haulage
- assured water cover may not be possible in dry years

In summary, High Site 1 stands out as the best site in terms of cost, suitability for controlling acid generation and minimizing the impact to one watershed. The Bull Hill Site has the potential to impact a large area in the event of a pipeline rupture. Furthermore, water cover in dry periods is not assured and it has by far the highest capital and operating costs with an incremental cost of at least $4.00 per ton over High Site 1. It is anticipated that such an incremental cost is likely to represent a fatal flaw for the development of this site. High Sites 2 and 3 are similar in that they both potentially impact multiple brooks and groundwater systems. This risk to more than one ground or surface water system may be a fatal flaw to permitting. Their capital and operating costs are at least $2.00 per ton higher than High Site 1 but lower than the Bull Hill Site. In conclusion, High Site 1 is the site most worthy of further consideration and is, therefore, the site used for the assessments discussed in this report.

3.4 Geology and Soils

The geology of the site is described, in detail, in the report "Bald Mountain Site, Surficial Geology of Proposed Tailings Impoundment Areas" by Jordan Gorrill Associates (JGA), dated January 1981. It is summarized below. Where possible, conclusions based on subsequent geological studies have been introduced.

3.4.1 Regional Geomorphology

The mildly metamorphosed volcanic province of Aroostook County is a maturely dissected plateau surface. The ridge and hill forming rocks are almost exclusively siliceous volcanic and volcaniclastic rocks, while slopes and valleys tend to be underlain by graphitic shales and micritic mudstones. Major topographic lineaments have been linked to structural control in a previous study. Subsequent identification of folding of volcanics on Bishop Mountain was made using aerial photography.

It would appear that the local bedrock topography is little changed from preglacial times. This contention is supported by the lack of major glacially scoured basins, the lack of deranged bedrock controlled drainage, the remnant natural topography and the lack of asymmetrical bedrock hills.

3.4.2 Regional Bedrock

The bedrock geology in the vicinity of the project is summarized on Figure 3.3, adapted from a figure prepared by Superior Mining Co. (SMC). It shows that the area is typically characterized by various volcanics (flow, fragmentals and tuffs) and, in the portion of Bald Mountain Brook which flows essentially northwards, a band of graphitic shale (Su). There is little structural data available in the area, primarily because of the extensive till cover. Faults which have been mapped are situated in the vicinity of the proposed open pit. Lineaments were mapped by JGA and are shown on Figure 3.3.

3.4.3 Regional Soils

The surficial geology is summarized on Figure 3.4 prepared by SMC. It shows that the soils in the area are typically comprised of tills, of which there are three types, and swamp deposits made up of peat, organic silt and clay and organic-free silt and clay. Although they are not shown on Figure 3.4, small, apparently inactive talus piles are common downslope of cliffs and steep outcrops.

Three tills were identified in the study area. Their presence and properties are important as they would serve as a "natural liner" when present. They can be re-worked to avoid permeable zones and used in combination with synthetic liners to form a much more secure "composite" liner. The lower till (Qtg), grey to brownish grey in color, displays fine fissility, has a pronounced clay fraction and is composed chiefly of slate clasts. Grain size distributions of this till indicate a characteristic curve with a distinctively high percentage of silt/clay. It appears to be relatively impervious, having an estimated field permeability of 10^{-6} cm/sec based on USGS field classifications. Owing to physical similarities and stratigraphic position, this till is correlated with the St. Francis till. This till is rarely found at depths shallower than 10 feet and it is presumed that the St. Francis till is present where the till is 15 feet or thicker. There are no data concerning the maximum thickness of this till or the presence of older units underlying it.

The upper till (Qtb) is brown, olive brown or chocolate brown in color. It is composed of clasts from many different rock units including cherts, graywackes, shales, volcanic rocks from basic to acidic, slates and a certain modest amount of phaneritic plutonic rocks. It is generally stoney with a moderate silt fraction and is somewhat pervious in places, owing to the distribution of lenticular bodies of immaturely washed sands and gravels. The till is correlated with the Mars Hill till and represents the latest Wisconsin glacial event in northern Maine. A comparison of the grain size distribution curves between the Mars Hill and St. Francis tills show a distinct increase in the fine fraction (minus #200 sieve) percentages. The color distinction between the St. Francis and the Mars Hill till seems to be a function of relative clast and matrix lithologies and bulk permeability. The greater permeability of the Mars Hill till has led to effective oxidation of iron-and-carbon-bearing shales, cherts and basalts. Oxidation may also be exacerbated by fluctuations in the seasonal high water table.

There is good evidence from texture, structure and compaction that both an ablation and a lodgement facies are represented in the Mars Hill till. Grain size distributions show that the ablation facies is somewhat better sorted than the lodgement facies. Although no stratification was observed in the field, the ablation till was definitely affected by limited selective action of meltwater during deposition. The ablation till lacks fissility and is consistently looser and more friable than the underlying lodgement till.

The third till unit, designated Qtw on Figure 3.4, is a relatively clean well sorted and permeable superglacial till. The precise mode of emplacement of this till is yet unclear. However, it is believed to be derived from the Mars Hill till.

Water contents of all three tills are low to moderately low (8 to 19 percent on a dry weight basis) with highest values generally associated with the more clay rich tills. This reflects the high porosities and low permeabilities associated with the clay fractions. Plasticity indices for all analyzed tills cluster closely in the low plasticity range.

Swamp deposits composed of muck, silt and some clay occur as a result of organic accumulation in bedrock depressions and other poorly drained areas. Although no section through the swamps has yet been obtained, they are believed to be relatively shallow deposits, probably less than 10 feet thick.

3.4.4 Bedrock Geology and Soils at Tailings Impoundment

The bedrock geology in the vicinity of the open pit and tailings impoundment is summarized on Figure 3.5. It indicates that, beneath most of the tailings impoundment, is a bedrock unit comprised of fragmental and massive volcanic rocks of andestic to basaltic composition; fragmental volcanics (dominantly lapilli and block fragmental) and massive volcanics which are locally pillowed. In the extreme east and west edges of the impoundment area are found fragmentals and tuffs of rhyolitic to calcitic composition intermixed with minor volcanic rocks.

Site specific investigations indicate the site of the tailings impoundment is underlain by thin to moderately thick (greater than 50 feet) glacial till. At the surface, the till is brown in colour, stoney with a moderate silt fraction, and somewhat pervious in places, due to the presence of lenticular bodies of sands and gravels. It is correlated with the Mars Hill till. For soil depths below about 15 ft, the St. Francis till is believed to occur. This is grey in color with a pronounced clay fraction, and is relatively impervious. It is composed mainly of slate clasts.

Linear east-west tending knobs on the north, south and east sides of the valley are bedrock controlled. The bedrock consists primarily of tuff overlying basaltic rocks of varying types and character.

The lineaments indicating geological contacts and faulting, defined by JGA are shown on Figure 3.3. It is apparent that there is a strong set of southwest northeast tending faults which may have a considerable influence on the groundwater flows in these directions.

3.5 Surface Water

The surface water characteristics of the project area and the regional stream systems were described by Woodward-Clyde Consultants (1982) and by the U.S. Geological Survey (USGS, 1989). The following description of the surface water system focuses specifically on the project drainages and the areas immediately downstream of the project.

The main surface water drainage in the project site is Bald Mountain Brook (Figure 3.3), over which the tailings impoundment will be situated. Bald Mountain Brook drains into Clayton Stream about 1.5 miles west and slightly north of the tailings impoundment area; Clayton Stream flows approximately 3.5 miles north of the project area before discharging into the Fish River. The project site is essentially at the headwaters of the Fish River drainage basin. Bald Mountain Brook and Clayton Stream are designated as Class A streams and Fish River is designated as a Class AA water of the State of Maine.

Precipitation at the project site is approximately 40 inches per year. Annual runoff is approximately one half of the precipitation, or 20 inches per year. The majority of the balance of the precipitation is removed by evaporation and evapotranspiration (Woodward-Clyde Consultants, 1982).

In late 1978, a surface water gauging station (WCC station 2) was installed on Bald Mountain Brook just downstream of the proposed impoundment. The gauge location is shown on Figure 3.3. As indicated, its catchment and that of the tailings pond are approximately equal. The gauging station catchment area is 358 acres; the impoundment catchment area will be approximately 417 acres. Data from this station indicate that for a three year period of record, the mean annual discharge of the stream was 0.74 cfs. Flow is perennial from this point on the stream to approximately 0.4 miles to the east (upstream). A large part of this segment and the remainder of the drainage consists of wetlands, and has a number of mapped springs and seeps.

Water quality at the project site is good. The USGS installed and subsequently monitored a gauging station on Bald Mountain Brook from 1979 through 1984 (Figure 3.3). The results indicate that the waters have a relatively high dissolved oxygen content, very low total dissolved solids (TDS), and have trace metals present in extremely low concentrations. Selected chemical data for Bald Mountain Brook is shown in Table 3.5. The USGS station indicated an average annual flow for the entire Bald Mountain Brook watershed (1.73 square miles) of 3.25 cfs for water years 1983 and 1984.

3.6 Groundwater

Much of the groundwater information developed to date was by Woodward-Clyde Consultants (1982). IECO (1989a) and Budo (1988a,b) performed additional specialized studies in the impoundment and pit areas, respectively. A summary of the groundwater characteristics of the site, based on the results of investigations through 1988, appears in Budo (1988c).

The major soil and rock units identified at the site include glacial till, a country rock (bedrock), the massive sulfide ore, a vuggy (porous) massive sulfide ore, and gossan. The gossan, massive sulfide

TABLE 3.5
Surface Water Quality For Bald Mountain Brook
(After USGS (1989))

Parameter	Number of analyses	Mean	Range
Temperature (°C)	53	7.7	0.0-20.0
Turbidity (NTU)	53	2.7	0.5-15.0
Color (Platinum cobalt units)	49	50	20-90
Specific conductance (micS/cm)	50	57	18-185
Dissolved oxygen (mg/L)	51	11.0	7.2-13.7
pH (standard units)	49	6.7*	6.0-7.8
Alkalinity (mg/L as $CaCO_3$)	54	16	2-40
Total solids, residue at 105°C (mg/L)	38	72	33-119
Total ammonia nitrogen (mg/L as N)	12	<0.01	<0.01-0.03
Total nitrogen NO_2+NO_3 (mg/L as N)	13	0.12	<0.01-0.42
Total phosphorus (mg/L as P)	39	0.01	<0.01-0.04
Total cadmium (mg/L as Cd)	8	0.002	0.002-0.002
Total chromium (mg/L as Cr)	10	0.007	<0.005-0.02
Total copper (mg/L as Cu)	53	0.003	<0.001-0.016
Total iron (mg/L as Fe)	50	0.256	<0.05 -0.92
Total lead (mg/L as Pb)	23	0.010	<0.001-0.03
Total zinc (mg/L as Zn)	50	0.008	<0.001-0.02
Total aluminum (mg/L as Al)	7	0.256	0.1 -0.36

* Mean of pH readings

ore, and vuggy massive sulfide ore are contained mostly within the limits of the pit area. The glacial till and bedrock are more extensive over the site area, and are the stratigraphic units of concern for dewatering and groundwater protection.

3.6.1 Glacial Till

Glacial till overlies the bedrock surface throughout much of the project area. However, groundwater aquifers associated with glacial till are not significant. In general the till is thin or missing in areas of bedrock highs and is as much as 130 feet thick in areas that represent erosional channels in the old bedrock surface. Although there are occasional sandy or gravelly zones, these are commonly discontinuous and are, for the most part, of little significance. Typically, there is a zone that will transmit some water into borings or pits at a depth of 3 to 16 feet, but it is too small and discontinuous to be considered a viable resource. Through the tailings impoundment valley the thickness of the till averages approximately 30 feet. The till there tends to be absent above elevations of approximately 1150 ft. In the valleys it serves as a confining unit to the fractured bedrock aquifer.

The till was tested at several locations in the tailings impoundment valley for engineering properties. Field tests for permeability show the till is relatively impermeable because of the large amount of silt and clay sized particles in the matrix. Field permeabilities indicate an average permeability on the order of $1x10^{-6}$ cm/sec. However, reworked samples of till can achieve permeabilities on the order of $1x10^{-8}$ cm/sec.

3.6.2 Bedrock

In the vicinity of the proposed mine and tailings impoundment, the significant aquifer appears to be that of the fractured surface of the bedrock. This aquifer ranges from confined to unconfined conditions through the general mine area, based largely on the thickness of the overlying glacial till. Field testing in the impoundment area for foundation assessments indicate that the fractured bedrock extends 50 to 80 feet below the contact with the till. Below this depth, fractures tend to infill and/or close, and permeability is reduced. The permeability within the fractured bedrock is in the order of $1x10^{-3}$ cm/sec, based on packer tests by IECO (1989a) and a pumping test by Budo (1988b). The pumping test indicated inter-connection of fractures within the bedrock to a depth of 50 to 80 feet; therefore, it would appear that this zone may form a potential seepage migration pathway away from the proposed impoundment.

There was no documentation reviewed which indicates that the bedrock has been hydraulically tested below a depth of approximately 80 feet below ground surface. Despite this, previous investigators conclude that this zone is essentially impermeable (Woodward-Clyde Consultants, 1982; Budo, 1988a). A bulk mass permeability in the order of $1x10^{-5}$ cm/sec is considered representative of this formation. The potential exists that there are additional southeast northwest tending faults such as are encountered in the pit area and shown on Figure 3.3. These may form preferential groundwater flow paths.

Previous estimates of pit dewatering flows have been based on the assumption that the bulk rock mass is intact below the ultimate pit bottom elevation (approximately 180 feet MSL). However, two major faults and at least two other faults are known to intersect the mine pit. These faults may extend into the small drainage valley west of the pit and could provide a means of underflow from the valley to the mine pit when the water table is lowered. Because the faults are potential pathways for groundwater movement, they have the potential to deliver greater volumes of water to the pit than has been previously estimated. This, in turn, would affect the water balance of the project. Although not a fatal flaw, the actual characteristics of the faults should be defined in subsequent evaluations. Additionally, the presence of faults should be investigated in the impoundment area, as they could be critical to any potential seepage movement.

Groundwater flows at the site are generally parallel to the surface topography. Recharge is estimated to be 3 inches per year. Based on this, the tailings impoundment area has a balanced recharge and outflow at the mouth of the valley of approximately 70 gpm (Budo, 1988). A potentiometric surface of the area was presented by Woodward-Clyde Consultants (1982), and others (IECO, 1989; Budo 1988).

Most of the groundwater quality data for the project site was recorded for the period 1973 to 1982. Four water quality stations (boreholes A, B, C, and D) were established early in the water quality monitoring program and were sampled beginning in October 1978. A number of other stations (piezometers 1002, 1006, 1007, 1013, 1014, and 1015) were sampled later in the program. The locations of the stations are shown in Figure 3.3. The groundwater quality summary is shown on Table 3.6.

The quality of groundwater in the project area is generally low in total dissolved solids (TDS). The total mineral content of the water is low; TDS, sodium, chloride, and sulfate are well below recommended levels. The groundwater could be classified as moderately hard to hard. Refer to Woodward-Clyde Consultants (1982) for a detailed description of water quality.

TABLE 3.6
Groundwater Quality Summary

Water Quality Parameters	A	B	C	D	1002	1006	1007	1014
General Constituents (mg/l unless otherwise noted)	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
pH (units)	6.7	6.9	6.5	6.3	7.7	8.3	7.6	7.8
Temperature (°C)	9.3	7.2	8.5	8.1	19.1	15.6	15.2	15.4
Redox Potential	-	-	-	-	-26	-153	-69	-76
Specific Conductance (micmhos/cm at 25°C)	183	231	164	129	274	150	164	250
Total Dissolved Solids	145	191	122	103	204	103	112	170
Total Suspended Solids	208	29.6	10.5	14.7	48	2	2	2
Turbidity (NTU)	38.7	8.1	4.1	3.2	3.7	0.6	1	1
Color (Apparent, APHA)	-	-	-	-	40-50	<5	5	5
Alkalinity	68	81.6	29.1	17.3	95.5	71.2	70	65
Hardness	104	137	83	50.6	122	56	80	83
Dissolved CO_2	1.7	6.4	8.4	6.6	1.8	0.1	1.8	0.9
Dissolved Oxygen	4.2	5.9	7.2	6.4	6.3	4.8	6.5	5.4
COD	-	-	-	-	980	25	25	25
Common Ions (mg/l)								
Calcium	33.4	30.7	16.5	7.3	38.8	20.2	24.4	26.2
Magnesium	7.5	41	7.2	4.8	6.0	1.8	2.8	3.6
Sodium	3.7	6.4	3.5	3.3	17.1	16.4	3.8	23.8
Potassium	0.51	0.72	0.57	0.6	1.06	0.56	0.58	0.8
Bicarbonate	35.8	42.3	13.4	8.4	54.7	42.1	39.2	37.6
Carbonate	N	0.9	N	N	0.2	0.5	0.1	0.1
Sulfate	32.2	43.2	49	39	40	4	12	22
Chloride	1.9	2.2	1.6	1.9	0.5	1.2	0.6	18.8
Silicon	-	-			18	8.9	10.4	9.6
Trace Metals (micg/l)								
Aluminum	-	-	-	-	203	286	364	256
Arsenic	121/0.8*	413/204	404/1.54	423/106	1	1	1	1
Cadmium	1.1/.59	1.1/.55	0.8/0.44	.9/.5	0.3	0.2	0.1	0.2
Chromium	5.8/2.8	4.6/2.2	1.72	8/2.5	1	1	1	1
Copper	45/15	29/4.7	7.8/3.2	56/5.3	1	1	1	2
Lead	3.8/2.1	2.4/2.0	2.6/1.9	3.2/1.7	1	4	1	2
Mercury	.6/.49	1.2/.73	.7/.5	1.7/.73	1	0.2	0.2	0.2
Nickel					7	4	1	1
Zinc	428/186	112/23	58/36	483/114	1	15	5	8

* Mean trace metal values indicate both total and dissolved concentrations (e.g., 121/.8).
N = not detected Source: Woodward-Clyde Consultants (1982)

4.0 PERMITTING REQUIREMENTS

4.1 Introduction

This section presents a list of permits and approvals which would be required to develop the Bald Mountain Project. Evaluation of the attainability and time period that will be required for permitting is specifically beyond the scope of this report, as is discussion of the environmental issues.

4.2 Significant Permits/Approvals

4.2.1 Environmental Impact Statement (EIS)

The Army Corps of Engineers (COE) and/or the U.S. Environmental Protection Agency (EPA) may require the preparation of an Environmental Impact Statement (EIS). An EIS for the Bald Mountain Project may take up to two years to complete.

4.2.2 National Pollutant Discharge Elimination System (NPDES) Permit

This permit deals with the discharge of water to natural water resources and is issued at both the state and federal level (review) by the Department of Environmental Protection (DEP) and reviewed by the EPA. NPDES permits are issued for 5-year periods.

4.2.3 Section 404 - Dredge and Fill/Wetlands

This permit is required where wetland disturbance may occur and is issued by the DEP and COE/EPA. It will be necessary to refer to the Federal Manual for Identifying and Delineating Jurisdictional Wetlands in defining the wetlands at the Bald Mountain Project site according to current standards.

4.2.4 Landfill/Solid Waste Management Permit

This permit would be required to obtain approval for sites to be used for the disposal and storage of tailings and mine rock. The permit is issued by the DEP, Bureau of Solid Waste Management.

4.2.5 Natural Resources Protection Act

This permit is required for any disturbance of soil within 100 feet of a water body or for any stream diversion and is issued by the DEP, Bureau of Land Quality Control.

4.2.6 Land Use Regulation (Rezoning) Law

This approval is required for rezoning current land use status to one which allows surface mining as a permitted use. This permit is controlled by the Land Use Regulation Commission (LURC), normally issued at the county level in most states. However, Maine regulates some of its larger rural areas at the state level.

4.2.7 Site Location of Development Law

For this permit the applicant must demonstrate that there will be no unreasonable effect on runoff/infiltration relationships, surface water and groundwater quality and quantity and adequate erosion and sedimentation control. The permit is issued by the DEP.

4.2.8 Prevention of Significant Deterioration (PSD)/Various State Air Quality Construction and Operation Permits

Permits relating to air quality emission may be required for stationary sources (such as crushers, etc.), mobile sources (haul roads, etc.) and toxic emissions. Emissions of 250 tons per year trigger the PSD level review. These permits are issued by the DEP and EPA.

5.0 ACID MINE DRAINAGE POTENTIAL

5.1 Introduction

This section discusses the acid generation potential of the different materials that would be produced during mining. Based on the available geological information and previous test work conducted on behalf of Superior Mining Company, acid generation may occur from the tailings, from some of the mine rock and from the pit walls.

For the purpose of this study, the tailings have been assumed to be acid generating in the long term and hence require measures to prevent an impact on receiving waters. The control of acid generation could be provided by maintaining the tailings under a water cover, i.e., in a saturated condition in the long term. There is still considerable uncertainty about the long term effectiveness of dry covers. While a proposed design incorporating a dry cover may not be a fatal flaw, it would be considerably more difficult to demonstrate low long-term environmental impacts. Since there appears to be little advantage in selecting a dry cover, this option is not considered further.

The results of toxicity tests on tailings samples are presented and discussed in Section 6.1.1. It has been assumed, for the purpose of this study, that the tailings would not be classified as a hazardous waste under the new mining regulations.

The objectives of this part of the study are to evaluate the acid generation potential of the mine rock and pits walls. The work carried out for this study, as described below, includes the following:

- an evaluation of the results from a laboratory test program carried out during 1980/81,
- a laboratory test program carried out for this study, and
- evaluation of feasible measures to minimize the environmental impact due to acid generation.

5.2 Results of Previous Acid Generation Prediction Testing

A study of the acid generation potential of tailings and mine rock from the Bald Mountain Project was carried out by the Colorado School of Mines Research Institute for the Superior Mining Company during 1980 and 1981 (Colorado School of Mines Research Institute, 1980 and 1981). The test program evaluated the acid generation potential by means of a series of column leach tests conducted on tailings samples and composite samples of core representing the mine rock. Two samples of flotation tailings were prepared for the tests, one containing a high pyrite content (35.1% S) and the other a high pyrrhotite content (42.6% S). Five composite rock samples were prepared from the borehole core. The samples were composited from sections of core of comparable sulfur content obtained from different boreholes. A description of the rock type of the samples was not recorded. However, an examination of the borehole logs indicates that the core samples used were all siliceous volcanics from the foot wall, except for one sample which was foot wall andesite. Acid-base account tests are not discussed in the reports and presumably these were not conducted. The behavior of the materials was studied under two conditions:

- samples subjected to wetting and drying over a 14-day cycle (submerged for 7 days, air-dried for 7 days), and
- samples fully submerged for the entire duration of the testing.

The samples were kept at approximately 68°F during the tests and 5 ml of acid mine drainage from an unspecified source (an existing tunnel) were added to each column with the intention of inoculating the samples with sulfide-oxidizing bacteria. This presumably also served to partially pre-acidify the samples although the pH and chemistry of the added water were not recorded.

Meaningful interpretation of the results from both the tailings and mine rock tests is difficult due to the lack of acid-base account data and the shortcomings in the test procedure. However, certain observations can be made from the test results.

5.2.1 Mine Rock Samples - Wetting and Drying Tests

A total of ten column tests were run, two columns for each composite rock sample, under wetting and drying conditions. The results show evidence of acid generation in these tests. The pH of the leachate, drawn from the columns 316 days after the start of the tests, ranged between 2.4 and 4.2 in eight of the ten tests performed. In the remaining two tests, conducted on the same composite sample, pH values of 8.0 and 8.4 were recorded after 316 days. The maximum concentrations of sulfate, copper and zinc in the leachate were as follows:

Parameter	Max. Concentration (mg/L)
SO_4^{2-}	4240
Cu	240
Zn	950

5.2.2 Mine Rock Samples - Submerged Tests

A total of five column tests were conducted, one column per composite sample, under submerged conditions. The pH of the leachate showed a definite increase, as the tests progressed, in three of the five tests conducted with pH values, after 7 days, of between 6.8 and 7.1 and between 8.9 and 9.4 after 316 days. In the remaining two tests the leachate exhibited relatively low initial pH values (4.5 and 4.2 after 7 days) with similar values after 316 days (4.4 and 4.8, respectively). The concentration of sulfate in leachate withdrawn from the columns after 312 days was a maximum of 792 mg/L and, on average, 29% of that in the columns undergoing wetting and drying tests, after the same period. Copper and zinc concentrations in the leachate after 368 days were below 0.01 mg/L and 0.02 mg/L, respectively, except in the two tests on samples exhibiting low initial pH values. The maximum copper and zinc concentrations in these tests after 368 days were 14 mg/L and 173 mg/L, respectively.

5.2.3 Tailings Samples - Wetting and Drying Tests

A total of four tests were conducted on tailings samples subjected to wetting and drying conditions, two tests on each of the two tailings composite samples. The pH of tailings water extracted from the base of the columns after 276 days ranged between 8.0 and 8.1 for three of the tests, with a value of 3.8 for the fourth test. While the pH values remained relatively stable for the duration of the bulk of the tests, rust-brown discoloration of the tailings surface was reported, indicating sulfide oxidation having taken place on the surface during the tests. In the test that produced leachate with a pH 3.8 after 276 days, this rust-brown discoloration was observed in the column, between the glass wall and the sample, and in the glass wool packing in the base of the column. The sulfate concentration in the water extracted after 14 days was approximately 2,300 mg/L in all four tests, reducing to an average of approximately 200 mg/L after 117 days and remaining at this level until the end of the tests.

5.2.4 Tailings Samples - Submerged Tests

A total of four tests were carried out on submerged tailings samples, two tests on each of the two tailings composite samples. The pH of the test solution increased in all the submerged tailings tests, from an average initial pH of 8.5 to an average final pH of 9.4. The sulfate concentration in the water extracted during the early stages of the test was in excess of 3,000 mg/L in all four tests, reducing to approximately 200 mg/L in the later stages of the tests.

5.2.5 Conclusions Drawn from the Test Results

The following observations can be made from the results of the test program conducted by the Colorado School of Mines Research Institute:

- The samples of mine rock tested generated acid under the test conditions of alternate wetting and drying. Maximum copper and zinc concentrations in the leachate after 368 days were 240 mg/L and 950 mg/L, respectively in these tests.

- Column samples recovered from two of the five composite samples exhibited relatively low initial pH values (4.2 to 4.7 after 7 days) in both the wetting/drying and submerged tests. This is probably an indication of sulfide oxidation having occurred in the material prior to the tests.

- In the tests conducted on submerged rock samples, the values of pH generally increased as the tests progressed. This was probably due to a combination of reduced rate of acid generation and the presence of soluble alkali minerals. Sulfate concentrations of up to 792 mg/L (29% of wetting/drying test results, on average) were recorded in the leachate from these tests. These relatively high sulfate levels are considered to be due to either sulfate generated prior to the test and mobilized when the samples were submerged, or to oxidation under submerged conditions.

- Visual discoloration on the surface of the tailings samples indicates evidence of acid generation during the tests in which tailings samples were subjected to wetting and drying. The leachate was extracted from the base of the samples in all tests. The products of acid generation were not detected in the leachate from tests where acid generation was limited to the surface of the tailings sample. The products of acid generation would not be expected in leachate from these tests, considering the nature of the material and the period over which the tests were run. In one test, where visual evidence of acid generation (rust-brown discoloration) was observed down the side and at the base of the column, a pH value of 3.8 was recorded.

- Insufficient data are available from the tests carried out by the Colorado School of Mines Research Institute, concerning the test procedure and results, to enable quantification of the reduction in acid generation rates due to submergence of the tailings and rock samples.

5.3 Acid Generation Prediction Testing - 1990 Program

5.3.1 Acid-base Account Test Program

A laboratory test program was initiated for this study to obtain an initial evaluation of the acid-base account characteristics of the different types of mine rock that would be mined at the Bald Mountain Project. After discussions with the Boliden project geologist and scrutiny of the geological cross-sections, samples were selected from the existing borehole core for the purpose of conducting acid-base account tests. Samples, each approximately one to two kilograms in mass, were recovered from the various rock types as detailed in Table 5.1. A program consisting of 29 acid-base account tests was conducted on the samples.

The tests were conducted using a modification of the standard Environmental Protection Agency (EPA) acid-base account test procedure (U.S. Environmental Protection Agency, 1978). The procedure used in this study incorporates recent experience and is considered to have advantages over the EPA method which was documented in 1978. Extracts from the EPA test procedure and a technical paper describing the modified test procedure used in this study, and the reasons for these modifications, are included as an Appendix to this report.

5.3.2 Acid-base Account Test Results

The results of the acid-base account test program are presented in Table 5.2. The test data includes paste pH, sulfide-sulfur content of the samples (S%), acid generation potential (AP), neutralization potential (NP), net neutralization potential (NNP), and the ratio of neutralization potential to acid generation potential (NP/AP). AP, NP and NNP are expressed in kg $CaCO_3$ equivalent per tonne of material. The values of NNP and NP/AP are used in the interpretation of the acid-base account test results and characterization of materials as acid generating or non-acid generating. The next level of prediction testing in more detailed studies, namely kinetic laboratory tests, are generally considered for materials with NP/AP ratios less than 3. The information obtained from acid-base account tests is sufficient for the purpose of this preliminary study.

TABLE 5.1

Type and Number of Samples Selected for Acid-Base Account Testing

Material Category	Rock Type	No of Samples
Massive sulfide rock		5
Hanging wall rocks	Chert	3
	Tuff	2
	Andesite	3
Foot wall rocks	Siliceous Volcanics	9
	Stringer Sulfides	3
	Andesite	4
Total		29

5.4 Mine Waste Characterization

The character of the different mine rock types with respect to acid generation potential, based on the acid-base account and leach test results, are described below.

5.4.1 Massive Sulfide Rock

The tests conducted on massive sulfide rock samples indicate sulfur contents of between 26% and 47%, neutralizing potential (NP) of between -18 and 22 kg $CaCO_3$ equivalent per tonne and net neutralizing potential (NNP) of between -829 and -1476, with a mean of -1228 kg $CaCO_3$ equivalent per tonne. This material would clearly generate acid if exposed to the atmosphere and ambient temperatures unless control measures are implemented to inhibit the oxidation reactions. Rapid oxidation should be anticipated in material with a high pyrrhotite content. One of the samples tested exhibited a paste pH of 2.84 and a negative neutralizing capacity (-18 kg $CaCO_3$ per tonne). This probably indicates oxidation of sulfides in-situ, or in the core box, resulting in a material with low pH pore water and containing products of the oxidation reactions. If oxidation has occurred in-situ, this would provide oxidation products for immediate release. Secure short and long-term control measures to inhibit the acid generation process would be required for the tailings and massive sulfide mine rock. The amount of in-situ oxidation and rate of oxidation will have to be investigated during the detailed studies. Approximately 22 million tons of massive sulfide tailings and 12 million tons of massive sulfide mine rock would be produced, assuming a 1% cut-off grade for copper ore.

TABLE 5.2
ACID-BASE ACCOUNT TEST RESULTS

CATEGORY	ROCK TYPE	BOREHOLE	DEPTH (ft)	PASTE pH	S (%)	AP	NP	NNP	NP/AP
						kg CaCO3 per tonne			
Massive sulfide	pyrite	M-34	214-218	2.84	46.6	1458	-18	-1476	<0.1
		M-55	360-363	6.80	39.1	1221	22	-1199	<0.1
	pyrrhotite	M-54	468-475	6.08	26.6	833	3	-829	<0.1
	sphalerite	M-34	319-323	6.38	39.2	1225	5	-1219	<0.1
		M-94	215-220	5.84	46.8	1436	18	-1417	<0.1
Hanging wall	Chert	M-62	269-302	8.33	0.4	12	18	6	1.5
		M-86	148-158	8.30	0.1	4	68	64	16.5
		M-132	170-180	8.34	0.3	11	57	46	5.4
	Tuff	M-61	133-138	8.43	<0.1	<1	25	25	84.0
	(HW/FW contact)	M-31	310-320	7.77	0.7	22	22	1	1.0
	Andesite	M-41	169-174	8.76	<0.1	1	116	116	129.3
		M-93	116-126	8.77	0.1	3	55	53	19.8
		M-133	110-125	8.50	<0.1	<1	181	181	>181
Foot wall	Siliceous volcanics	M-13	347-357	7.91	0.2	6	4	-3	0.6
		M-41	264-268	7.92	3.3	104	17	-87	0.2
		M-31	338-343	8.05	2.8	88	390	301	4.4
		M-44	337-342	8.60	3.6	113	12	-101	0.1
		M-63	315-325	8.14	0.9	28	15	-14	0.5
		M-65	160-175	8.39	0.8	23	10	-14	0.4
		M-87	305-315	6.06	3.6	112	9	-103	0.1
		M-102	255-265	8.31	3.9	122	32	-90	0.3
		M-126	210-220	8.20	3.6	114	12	-101	0.1
	Stringer sulfides	M-36	236-240	8.20	4.5	142	24	-118	0.2
	(siliceous volcanics)	M-88	490-510	7.82	6.4	200	56	-144	0.3
		M-126	265-275	8.43	3.3	104	18	-86	0.2
	Andesite	M-30	97-103	6.37	7.4	231	5	-227	<0.1
		M-42	62-67	8.53	0.8	25	139	114	5.5
		M-63	383-397	8.37	0.8	26	16	-10	0.6
		M-102	145-155	5.65	12.8	400	3	-397	<0.1

NOTES: AP - Acid potential in kg CaCO3 equivalent per tonne
NP - Neutralization potential in kg CaCO3 equivalent per tonne
NNP - Net neutralization potential in kg CaCO3 equivalent per tonne
NP/AP - Ratio of neutralization potential to acid potential

5.4.2 Hanging Wall Rocks

Mine rock from the hanging wall would consist mainly of andesite with lesser amounts of chert and Tuff. The acid-base account test results indicate sulfur contents of up to 0.7% in these geological units. The test results show neutralizing potentials between 18 and 181 kg $CaCO_3$ per tonne with an average value of 68 kg $CaCO_3$ per tonne. The values of net neutralizing potential are all positive for the hanging wall rocks with an average of 62 kg $CaCO_3$ per tonne. The average NP/AP ratio for these materials is expected to be well in excess of 3. The hanging wall rocks are expected to be non-acid generating and should be suitable for use as construction materials. A total of approximately 6 million tons of mine rock would be produced from the hanging wall, assuming a 1% cut-off grade for the copper ore.

5.4.3 Foot Wall Rocks

Mine rock from the foot wall would consist mainly of siliceous volcanics with minor amounts of stringer sulfides and andesite. The acid-base account test results indicate sulfur contents between 0.2% and 12.8% for the foot wall rocks. The test results show neutralizing potentials of up to 390 kg $CaCO_3$ per tonne with an average value of 47 kg $CaCO_3$ per tonne. The net neutralizing potential of the foot wall rocks are all less than zero except for two samples that gave NNP values of 114 and 301 kg $CaCO_3$ per tonne. The average NNP from the test results is -68 kg $CaCO_3$ per tonne and the NP/AP ratios for these materials are generally less than 1. These test results indicate the presence of localized zones containing minerals with high neutralizing potential. The foot wall rocks are expected to generate acid unless measures are implemented to control the oxidation process. Assuming that the neutralizing potential reflected in the test results is available for reaction, it is anticipated that the onset of strong acid generation resulting from biological oxidation at low pH would be delayed. Nevertheless, control of acid generation and/or drainage would be required during mining and a secure long term control measure to inhibit acid generation would be required for mine rock and pits walls containing these rock types. A total of approximately 13 million tons of foot wall mine rock would be produced for the case of 1% copper cut-off grade.

5.5 Conceptual Measures to Control the Impact of Acid Generation

The results of the column leach and acid-base account testing as described in this report indicate that mine rock at the Bald Mountain Project would pose a serious threat to natural water resources unless effective control measures are implemented to limit the rate of sulfide oxidation and acid generation. The total acidity that could potentially be produced from the tailings, massive sulfide mine rock and foot wall mine rock, assuming these wastes were subjected to conditions favorable for acid generation, would consume the alkalinity produced by 43 million tons of $CaCO_3$ before being neutralized. The requirements to control the impact of acid generation from the tailings, mine rock and pit walls both during the operating period and in the long term have been evaluated. The conceptual control measures for each waste type are described below.

5.5.1 Flotation Tailings

The flotation tailings from the Bald Mountain Project would have a high sulfur content and large excess in acid generation potential. However, the tailings would be deposited at high pH (probably in the region of 10 to 11) which, together with the layering of fresh tailings, will prevent acid generation during the life of the operation. Measures would be required to control acid generation after tailings placement stops, and in the long term.

Available evidence indicates that water cover, in the form of either a water pond or a saturated soil/water cover, is an effective means to exclude oxygen entry to the tailings and to control acid generation. The tailings impoundment could be designed and reclaimed such that the entire tailings mass is maintained in a saturated condition in the long term. This could be achieved by establishing either a man-made lake or a saturated soil cover and marshland conditions on the tailings surface. The results of EPA toxicity tests conducted on bench scale tailings samples are presented and discussed in Section 6.1.1.

5.5.2 Hanging Wall Mine Rock

The hanging wall mine rock is non-acid generating, based on the results of the acid-base account tests, and may be used in the construction of the tailings impoundment facilities such as underdrains, embankments, etc.

5.5.3 Potentially Acid Generating Mine Rock

The potentially acid generating mine rock includes the massive sulfide rock and the foot wall rocks comprising siliceous volcanics and andesite.

5.5.3.1 Massive Sulfide Rock

The massive sulfide rock contains up to 50% sulfur and exhibits a very high net acid generation potential. It would be necessary to place this material below water soon after the rock has been mined. The tailings impoundment would provide the storage and the necessary water cover for this purpose. The alkalinity in the tailings water should be sufficient to neutralize any initiating acid generation and precipitate dissolved metals. Resulting water qualities would have to be monitored.

5.5.3.2 Foot Wall Mine Rock

The acid-base account test results show that the siliceous volcanics and andesite mine rock from the foot wall are potentially acid generating. If oxidation of the sulfide minerals is allowed to occur and the acid generation and metal leaching process become established, drainage from this mine rock would contain elements at concentrations exceeding receiving water quality, probably by many orders of magnitude. Data gathered from an operating metal mine in Canada (referred to as "Mine A") is presented as an example of the quality of drainage from an acid generating mine rock storage pile under similar climatic conditions. The average water quality of drainage samples collected from rock dumps at "Mine A" during 1986 and 1987 is shown in Table 5.3.

TABLE 5.3
Average Water Quality of Mine Rock Drainage Samples Collected From "Mine A" During 1986 and 1987

Parameter	Average Value
pH	2.61
Acidity	10,365 mg/L
SO_4	13,946 mg/L
Cu	207 mg/L
Fe	2,180 mg/L
Zn	99 mg/L

A summary of the acid-base account test results for the foot wall rocks at the Bald Mountain Project is shown in Table 5.4, together with results of tests on samples from an open pit at "Mine A", and from mine rock at another operating mine in Canada (referred to as "Mine B"). These results indicate similar acid generation characteristics for the samples tested at these projects. The water quality data from "Mine A" illustrates the need to control the acid generation process.

TABLE 5.4
Summary of Acid-Base Account Test Results from Bald Mountain Foot Wall Rocks, "Mine A" Pit and "Mine B" Mine Rock

Parameter	Bald Mountain		"Mine B"		"Mine B"
	(All values in kg CaCO		per tonne equivalent)		
	Mean	Range	Mean	Range	Range
Neutralization potential (NP)	48	3 to 390	23	0.3 to 184	2 to 213
Acid potential (AP)	115	6 to 400	56	3 to 227	3 to 128
Net neutralization potential (NNP)	-67	-397 to +301	-33	-215 to +153	-38 to +200

It is envisaged that two different control measures would be implemented for this waste, for the following periods:

- during operation of the mine (short term), and
- following mine closure and decommissioning (long term).

During operation of the mine the mine rock would be stockpiled at a suitable location and the drainage from the stockpile collected and treated or disposed of in the tailings impoundment. A suitable stockpile site would be immediately downstream of the tailings impoundment embankment. Additional measures, such as mixing in crushed limestone with the mine rock to inhibit acid generation and a till and/or synthetic cover to minimize infiltration, should be considered to reduce treatment costs and improve drainage water quality. The proposed waste handling activities for the Bald Mountain Project are described in more detail in Section 6.0 of this report.

On closure of the mine, the waste should be placed and stored below water in the long term. This could be achieved by backfilling the mine rock into the open pit at the end of mining and flooding the pit.

5.5.4 Open Pit Walls

During mining, and at mine closure, the massive sulfides and acid-generating foot wall rock would be exposed in the pit walls. The results of seep surveys carried out in the open pits at "Mine A" and "Mine B" are summarized in Table 5.5. This data illustrates the type of water quality that may be expected from the Bald Mountain open pit during operation.

During mining, water entering the pit from groundwater seepage and precipitation would be collected and treated before discharge, or pumped to the tailings impoundment. The pit walls located in the potentially acid-generating foot wall rock would require measures to control acid generation in the long term. Control could be achieved by limiting oxygen entry by flooding of the pit for the rock faces located below the final groundwater elevation in the pit. Rock located above this level would require some other form of acid generation control. It is proposed that a till cover or "fillet" would be placed over these faces. This would require the pit to be backfilled with rock to form a foundation for the till fillet. Both measures achieve control by reducing oxygen to the potentially acid generating rocks. The required activities and quantities are presented in Section 6.0.

TABLE 5.5
Water Quality Results from Seep Surveys at "Mine A" and "Mine B" Open Pits

PARAMETER	MINE A			MINE B		
pH	2.79	to	8.02	6.02	to	8.36
Acidity	2	to	2,040 mg/L	-		
SO_4	270	to	3,670 mg/L	2	to	10,101 mg/L
Cu	0.01	to	17.00 mg/L	<0.002	to	13.8 mg/L
Fe	0.07	to	192.00 mg/L	<0.1	to	2,025 mg/L
Zn	0.01	to	35.60 mg/L	<0.01	to	240 mg/L

The acid generation potential of the gossan tailings and mine rock were not investigated during this study. Further geochemical testing would be required to determine the reaction kinetics and the relative rates of acid generation for the different materials under different test conditions. These kinetic tests may also be used to evaluate the effectiveness of different control techniques.

6.0 CONCEPTUAL MINE WASTE MANAGEMENT AND RECLAMATION PLAN

A conceptual mine waste management and reclamation plan has been developed with the principal objective of providing the required protection of natural water resources at the site in the most economical and practical fashion. The phenomenon of acid mine drainage and the potential for release of water from the tailings impoundment present threats to these water resources, during both the operating period and in the long term, following mine closure. Potential sources of contamination include:

- the mill site and tailings impoundment,
- mine rock storage piles, and
- the open pit.

The mine waste management and reclamation plan presented below has been developed at a conceptual level, in sufficient detail to conduct this fatal flaw evaluation, to determine what may be practically feasible, and to obtain an estimate of the costs involved. Detailed engineering of the structures and facilities has not been carried out. Reclamation of access roads, the mill site and other infra-structure facilities are not expected to represent fatal flaws to the project and are therefore not addressed here. A schematic of the conceptual mine waste management plan during operation and the reclamation plan for these specific areas is shown in Figure 6.1.

6.1 Mine Waste Management During Operation

The estimated total quantities of mine waste that would be produced during mining, for cut-off grades of 0.73% and 1.0% copper, are shown in Table 6.1. The estimated total tonnages of the different waste types that would be produced during mining and the location of placement, or "destination", of these wastes are shown in Table 6.2. The quantities shown in Table 6.2 and discussed below are for a 1.0% copper cut-off grade.

6.1.1 Tailings

The selected tailings impoundment is located at the "High Site" as described in Section 3.3 of this report. The tailings disposal facility would consist of separate impoundments for the gossan and the massive sulfide tailings (see Section 2.0, Figure 2.1). The purpose of two tailings impoundments are as follows:

- to place the cyanide-bearing tailings as far from the main embankment as possible for the purpose of protecting downstream water quality (to allow attenuation and seepage emergence), and

- to facilitate staged construction of the tailings impoundment.

TABLE 6.1
Estimated Total Mine Waste Quantities

Waste Type		Tonnage 0.73% Cu	(Million Tons) 1.00% Cu
Tailings	Gossan	1.2	1.2
	Massive Sulfide	29.8	21.7
Till		8.0	8.0
Gossan Mine Rock		0.1	0.1
Massive Sulfide Mine Rock		5.9	11.6
Hanging Wall Rock	Chert	1.0	1.2
	Tuff	0.3	0.4
	Andesite	6.9	4.7
Foot Wall Rock	Siliceous Volcanics	16.4	10.1
	Stringer Sulfides	0.5	2.8
	Andesite	0.5	0.4
Total Tailings		31.0	22.9
Total Till & Mine Rock		39.6	39.3
Total Waste		70.6	62.2

A study carried out on behalf of Chevron Resources Company during 1989 concluded that the tailings impoundment would need to be lined with a synthetic geomembrane to minimize seepage losses (International Engineering Company Inc., Report M.013, 1989). An evaluation of the impact on surface water quality downstream of the impoundment, carried out as part of this study, confirms the requirement for a composite till and synthetic liner.

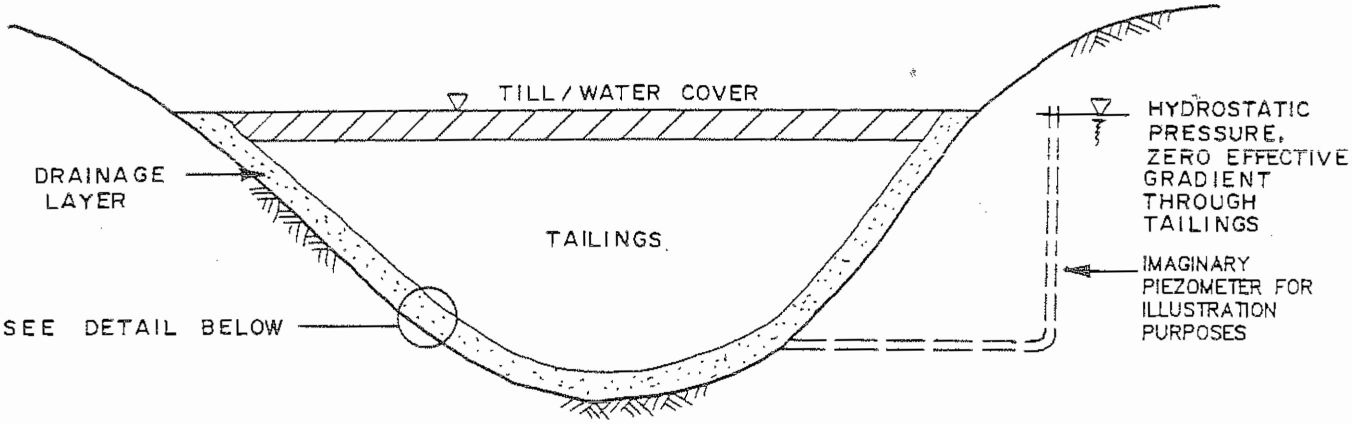
The composite liner would consist of in-situ till, a 60 mil thick synthetic geomembrane liner such as High Density Polyethylene (HDPE), and drainage layers. A schematic section through the proposed composite liner is shown in Figure 6.2. A system of finger drains would be required beneath the synthetic liner in order to prevent the development of excess pore water pressure due to seepage. A build-up of pore pressures beneath the liner could damage the liner during the early stages of the impoundment. The under-drain system would discharge downstream of the tailings embankment where the drainage quality would be monitored. Should the drainage quality deteriorate to the extent that it is not suitable for discharge, for example in the event of a leak in the liner, this flow could be intercepted and pumped to the impoundment.

TABLE 6.2
Waste Management During Mining

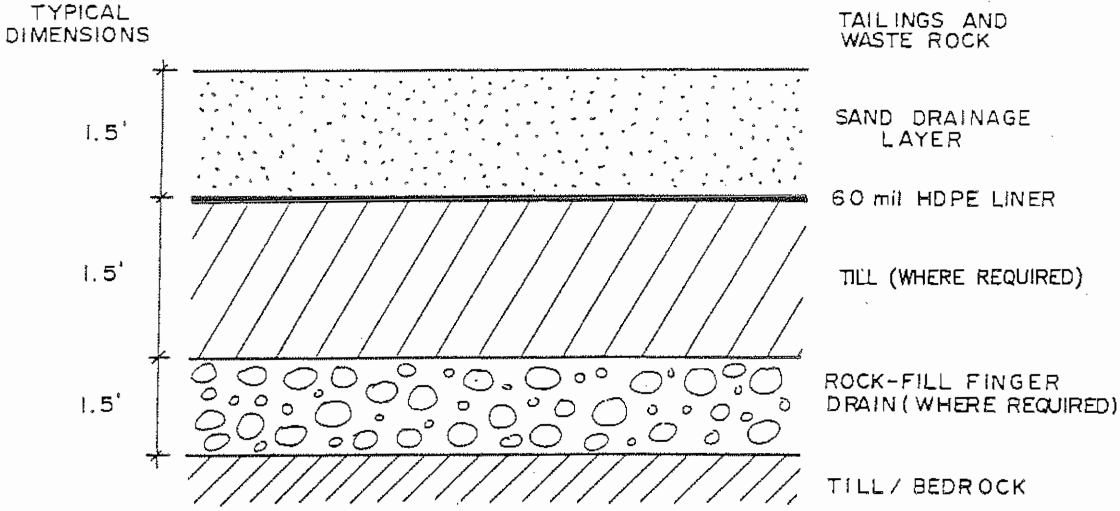
Tonnages (Million Tons) and Waste Destination
Assuming 1% Copper Cut-off Grade

Waste Type	Destination			Total Tonnage
	Stockpile	Construction Material	Tailings Impoundment	
Tailings				
- Gossan	-	-	1.21	1.21
- Massive Sulfide	-	-	21.72	21.72
Till	3.98	4.07	-	8.05
Gossan Mine Rock	-	0.13	-	0.13
Massive Sulfide Mine Rock	-	-	11.62	11.62
Hanging Wall Mine Rock	3.00	3.27	-	6.27
Foot Wall Mine Rock	13.20	-	-	13.20
Total	20.18	7.47	34.55	62.20

The objective of the sand drainage layer above the synthetic liner is to protect downstream water quality in the long term when the synthetic liner fails. The long-term performance of synthetic membranes is uncertain at present, however, gradual and progressive failure of the liner within a period of 50 to 100 years should be anticipated. The function of the drainage layer is to maintain a zone of relatively high permeability immediately above the liner and below the tailings. The drainage layer would extend to the tailings pond surface along the edges of the impoundment, maintaining hydrostatic conditions around the tailings mass. The aim is to minimize the hydraulic gradient through the tailings in the event of a leak in the liner. When leaks develop in the liner, water flow from the surface to the zone of the leak would occur predominantly within the higher permeability zone. Under these conditions, the quality of the water flowing through the leak would be expected to be better than tailings water. This concept has been designed and implemented at the lined tailings impoundment at Kennecott Ridgeway Mining Co.'s Ridgeway Mine in South Carolina (SRK, 1987). Water flow from the tailings mass into the sand drainage layer would occur principally due to excess pore water pressure in the tailings during consolidation. The need for a geomembrane (filter fabric) or careful sizing of the sand in order to prevent clogging of the drainage layer would need to be evaluated during final design.



SCHEMATIC SECTION THROUGH IMPOUNDMENT SHOWING DRAINAGE LAYER CONCEPT



DETAIL SHOWING COMPOSITE LINER

BOLIDEN RESOURCES INC.	BALD MTN. PROJECT	DATE JUNE 1990
		PROJ. NO. 80701
SCHEMATIC SECTION SHOWING THE PROPOSED COMPOSITE LINER		APPROVED
		NO. 6.2
STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers		

Construction of the composite liner is perceived as follows:

- strip vegetation and topsoil from the impoundment site to expose in-situ till,
- excavate and place rock-fill finger drains where required,
- place and compact till over rock drains and bedrock outcrops where these occur,
- place the synthetic liner, and
- place the sand drainage layer above the liner.

The impoundment configuration considered as the "base case" in this study may be summarized as follows:

- a double impoundment system (separate gossan and massive sulfide impoundment),
- a composite till/synthetic liner, and
- a drainage layer above the liner.

Alternatives and variations to the "base case" that were considered include:

- a single impoundment,
- an unlined impoundment,
- a double liner, and
- no drainage layer.

The volume and tonnage of materials required for the construction of the tailings impoundment are detailed in Table 6.3. Mine waste would be used for construction where possible, nevertheless, some natural material, specifically sand for drainage layers, may need to be imported to the site.

6.1.1.1 Gossan Tailings

Approximately $1.2\text{x}10^6$ tons of gossan ore would be milled and processed for gold recovery during the first two years of operation at a milling rate of approximately 1650 tons per day. The gossan tailings would be placed within the lined gossan impoundment as shown in plan in Figure 6.3.

TABLE 6.5
Results of TCLP and Water Analysis Tests on Copper Tailings Conducted by Lakefield Research, 1988

Tailings Water Analysis		TCLP	
Element	Concentration (mg/L)	Element	Concentration (mg/L)
Iron	<0.05	Iron	7.35
Copper	1.63	Copper	23.3
Lead	<0.05	Lead	0.07
Zinc	<0.02	Zinc	3.14
Cadmium	<0.02	Cadmium	<0.01
Chromium	<0.01	Chromium	<0.02
Manganese	0.08	Manganese	3.86
Mercury	0.001	Mercury	<0.001
Cyanide	0.008	Cyanide	0.32
Arsenic	<0.05	Arsenic	2.23
Selenium	0.52	Selenium	<0.2
Chlorine	25.0	Chlorine	0.68
Sulfate	434.6	Sulfate	150.2
Nitrate	11.3	Nitrate	0.60
TDS	1080	TDS	6840
Barium	0.03	Barium	0.33
Sodium	62.0	Sodium	1839.8
Silver	<0.03	Silver	<0.03

The copper concentration shown in the test results is of concern. The form of the copper present and its mobility should be investigated. The elevated copper in the TCLP test result, combined with iron, zinc and arsenic may make the tailings marginal in terms of classification as a hazardous waste. As discussed in Section 6.1.1.1, the EPA limit for arsenic may be reduced and Maine may impose more stringent criteria than those of the EPA. If the limit for arsenic is reduced to 1mg/L, the tailings would be classified as a hazardous waste based on the test results in Table 6.5. This may also be the case if, for example, copper is designated a primary standard in Maine. The test results provided to SRK (Table No. 11: PP-10 Cu Tailing Water Analysis, and Table No. 12: PP-10 Cu Tailings TCLP Water Analysis) and presented in Table 6.5 show inconsistencies, as follows:

- The values reported for chlorine are probably values of chloride,
- The values reported for cyanide should be questioned. Based on experience, values of

1 to 2 ppm cyanide would be expected at the copper concentrations reported.

- The value of selenium in the tailings water analysis (0.52 mg/L) is greater than that in the TCLP test results. The opposite would normally be expected.

Further leach tests are required on samples that are representative of what would be produced in the field.

The massive sulfide tailings would be deposited at an elevated pH (pH>8) and would be maintained in a saturated condition in the long term, thereby limiting the rate of potential acid generation during operation and after mine closure.

6.1.2 Till

The quantity of till that would be obtained from stripping the pit area is approximately 8.0×10^6 tons. This material would be suitable for use in the construction of the tailings impoundments. Till would be used in construction of both embankments (see Table 6.3) and till may be required to be placed over bedrock outcrops in certain areas of the impoundment. Till not used for initial construction would be stockpiled for use in later stages of embankment construction and for reclamation after mine closure. Till stockpiled during stripping of the pit area would be used in the reclamation of the site in the following areas:

- open pit reclamation, and
- reclamation of the tailings impoundment.

The estimated quantity of till required for embankment construction and reclamation exceeds that available from pit stripping. The additional quantity of till required, less than 1 million tons, could be obtained from borrow areas adjacent to the pit and other disturbed areas.

6.1.3 Gossan Mine Rock

Approximately 0.13×10^6 tons of gossan mine rock is expected to be produced during the first two years of mining. This material would be placed within the embankment or in the gossan impoundment. This embankment would be covered by tailings and would be kept saturated in the long term and acid generation is not expected to be a concern for this waste under these conditions.

6.1.4 Massive Sulfide Mine Rock

The massive sulfide mine rock is expected to be potentially highly acid generating and will oxidize and release poor quality drainage within a period of months of mining if the oxidation process is allowed to proceed. The rate of acid generation would be minimized by placing the mine rock directly into the tailings impoundment so that it is submerged below water as soon as possible after it is mined. Careful preparation of a pad on the liner and controlled dump construction would be required to avoid instability and damage to the liner. It is considered that the liner could be suitably protected by constructing a pad on the liner, using till or similar material, followed by an initial low lift of waste material and then conventional end-dumped construction on the prepared base.

6.1.5 Hanging Wall Mine Rock

The results of the acid-base account tests (Section 5.0) indicate that the hanging wall mine rock is not likely to be acid generating and could be used in the construction of the impoundments and embankments. For the purpose of this study, it has been assumed that this material could be used in the following:

- rockfill in the tailings impoundment embankments,
- drainage layers beneath the composite liner,
- reclamation of the open pit to control acid generation from the exposed foot wall rock in the high walls (see Section 6.3.2), and
- possibly in making sand for the protection and drainage layer above the composite liner, as an alternative to importing sand.

A detailed mine plan is not available at this stage, however, it has been assumed that mining of the hanging wall rock could begin at an early stage in the mine plan in order to provide mine rock for construction. The quantity of material required and the sources are shown in Tables 6.3 and 6.2, respectively. Approximately $3x10^6$ tons of hanging wall mine rock would need to be stockpiled during mining to provide the required material for reclamation of the open pit at mine closure. This rock would be used for the construction of a buttress to the till cover that would need to be placed over the exposed potentially acid generating pit walls (Section 6.3.2). The location of the hanging wall mine rock stockpile is shown in Figure 6.5. Run-off from the hanging wall mine rock stockpile would need to be directed to a sedimentation pond for removal of sediments. This is discussed further in Section 6.2.4.

6.1.6 Foot Wall Mine Rock

The results of the acid-base account tests indicate that the foot wall rocks are potentially acid generating. Long term storage of this mine rock under water is essential in order to inhibit the acid generation process (see Section 5.4.2.2). The conceptual waste management plan incorporates stockpiling of this mine rock during mining and then backfilling this to the open pit at mine closure (Figure 6.1). The location of the foot wall rock stockpile is shown in plan in Figure 6.5. If no measures to control acid generation are implemented, it is anticipated that drainage emerging from the stockpile would develop high acidity and metal contents, based on the laboratory tests carried out to date and equivalent conditions at other mines (see "Mine A", Section 5.4). Temporary measures to inhibit the development of acid generation in the stockpile and/or to prevent or mitigate impact on receiving waters would be required during the period of mine operation. Available temporary measures include the following:

- addition of crushed limestone to control the pH within the stockpile, thereby inhibiting the acid generation process,
- placement of a low permeability cover over the stockpile, as construction proceeds, in order to minimize infiltration of precipitation, and
- collection of drainage emerging from the stockpile and either directing this water to the tailings impoundment, or treating the water and disposing of this through land application or discharge to surface waters.

Drainage from the stockpile has been included in the tailings impoundment water balance. It has been assumed that a low permeability cover would be placed over the stockpile during construction and that runoff from 50% of the stockpile area would meet discharge criteria following removal of suspended sediments. The need for limestone to be added to the mine rock would be evaluated following laboratory kinetic geochemical testing.

6.2 Water Management During Operation

6.2.1 Open Pit

Water management in and around the open pit would consist of two components:

- diversion of runoff from undisturbed areas, and
- collection of water within the pit.

Surface runoff from the undisturbed area up-slope of the pit should meet discharge criteria and would be diverted around the perimeter of the pit, or disturbed area, and discharged to Bald Mountain Brook via a settling pond for sediment control.

The water that collects in the pit due to inflowing groundwater seepage and precipitation would not meet discharge criteria (see example of pit water quality from operating mines, Section 5.4). There are two options for management of this water:

- pump to the tailings impoundment,
- pump directly to a treatment plant before disposing of the water through discharge to surface waters or land application.

The most appropriate option would depend on the water quality and the treatment technique adopted. The tailings impoundment water balance model has been set up to accommodate either of these options.

6.2.2 Tailings Impoundment

The tailings impoundment would be constructed in stages in order to minimize inflow to the impoundment and to stage construction capital costs. Runoff from the undisturbed area within the tailings impoundment catchment would be diverted around the impoundment and discharged to Bald Mountain Brook via a settling pond for sediment removal, if required. The staged construction of the impoundment is shown in Figures 6.3 to 6.5. The nominal elevation of diversion ditches and their catchment areas are as follows:

Stage	Nominal ditch elevation (ft)	Catchment area (acres)
I	1100	37
II	1100	136
III	1150	210

A rockfill finger-drain system would be constructed beneath the composite synthetic/till liner in order to collect groundwater seepage entering the impoundment beneath the liner. This system would drain beneath the embankment where water quality could be monitored and the flow directed to the seepage return dam in the event that water quality is unacceptable for discharge, for example, due to a leak in the liner.

6.2.3 Foot Wall Mine Rock Stockpile

Infiltration of precipitation into the foot wall mine rock stockpile would be minimized by placing a till and/or synthetic cover on the mine rock. Runoff from this cover would be directed to a sedimentation pond, the overflow from which should meet discharge water quality criteria. Infiltration into the dump would be collected above the prepared till base. This drainage is not expected to meet discharge criteria due to sulfide oxidation and metal leaching that is expected to occur within the dump. This drainage would be directed to the seepage return dam.. There are two options for management of this water, as for the pit water (Section 6.2.1), as follows:

- pump to the tailings impoundment,
- pump directly to a treatment plant before disposing of the water through discharge to surface waters or land application.

The most appropriate option would depend on the water quality of the drainage water and the treatment technique adopted. The tailings impoundment water balance model has been set up to accommodate either of these options.

6.2.4 Till and Hanging Wall Mine Rock Stockpiles

Approximately $7x10^6$ tons of till and hanging wall mine rock (non-acid generating) would be stockpiled during mining for use in reclamation activities at closure. Runoff from the till is expected to meet discharge criteria following sediment removal.

6.3 Mine Waste Reclamation

The conceptual mine waste reclamation plan for the open pit, tailings impoundment and mine rock storage piles is described in this Section and shown schematically in Figure 6.1. The estimated quantities of material that would require handling at mine closure are detailed in Table 6.6. Reclamation of access roads, the mill site and other infra-structure facilities are not expected to represent fatal flaws to the project and are therefore not addressed here.

TABLE 6.6
Waste Management Following Mine Closure

Tonnages (million tons) and destinations
assuming 1% Copper cut-off grade

	DESTINATION		
Waste Type	Tailings Impoundment Reclamation	Open Pit Backfill	Total
Till	1.0	4.0	5.0
Hanging Wall Mine Rock	-	3.0	3.0
Foot Wall Mine Rock	-	13.20	13.20
Total	1.0	20.20	21.20

6.3.1 Foot Wall Mine Rock Stockpile

The conceptual reclamation plan requires the foot wall mine rock to be backfilled to the open pit, below the final water elevation, at mine closure. The objective of this is to provide a water cover to the potentially acid generating mine rock and to the bulk of the potentially acid generating pit walls. The plan would involve rehandling approximately 13.2×10^6 tons of foot wall rock mine rock. A schematic showing the reclaimed pit is included as Figure 6.7.

The quality of the water draining from the flooded pit will depend on, among other criteria, the success of temporary acid generation control measures applied to the stockpile. It will be necessary to monitor and treat this discharge water for a period until acid products in the mine rock have been flushed out. The need to fill the pit with water during backfilling is discussed in Section 6.3.2.

6.3.2 Open Pit Walls

Till would be required to construct a low permeability cover to the potentially acid generating walls exposed above the final elevation of the backfilled foot wall mine rock as shown in Figure 6.7. In order to support the low permeability till cover and to provide long term stability to the exposed pit walls, a rock buttress over the till cover would be required. This rock would be exposed to wetting and drying conditions and would therefore need to be constructed using inert or non-acid generating rock. Hanging wall mine rock would be suitable for this purpose and approximately $3x10^6$ tons of mine rock has been allocated for this purpose.

It would be necessary to fill the pit with water as quickly as possible following mine closure in order to submerge the mine rock and potentially acid generating pit walls. It may be feasible to drain the ponded surface water in the tailings impoundment to the pit at closure in order to facilitate tailings impoundment reclamation and to provide water to the pit. However, this may result in unacceptable quality of the pit water which would discharge to Bald Mountain Brook through groundwater flow and, ultimately, through surface water discharge from the pit. The tailings impoundment water quality and potential impact on surface waters would need to be evaluated in detail. Approximately $6x10^8$ US gallons of water would be required to cover the foot wall mine rock backfilled in the pit. This volume would be provided by a pond of water with a depth of between 8 and 10 ft over the final tailings impoundment at closure. It would be feasible to direct runoff from the entire tailings impoundment to the pit after closure in order to fill the pit as quickly as possible. Under these conditions the pit would fill with water to the discharge elevation of approximately 900 ft within a period of 6 to 8 years following backfilling. Significant acid generation could occur on the exposed pit walls during this period and it would therefore be necessary to place the buttressed till cover over the potentially acid generating pit walls exposed above the top of backfilled rock (approximate elevation 690 ft). It may be necessary to use fresh water to fill the pit depending on water quality aspects and available volume of tailings water. An extraction permit may be required for this purpose. Lime will need to be added to the pit water during backfilling to prevent mobilization of metals contained within the mine rock and open pit. Nevertheless, water quality may still be a concern due to elevated total dissolved solids (TDS) and possibly other parameters.

6.3.3 Tailings Impoundment

It has been assumed that tailings impoundment reclamation would incorporate construction of a soil/water cover to create marshland conditions on the tailings surface. Till would be useful for this purpose in providing a growth medium and to provide an undulating surface, suitable for development of marshland conditions. Approximately $1x10^6$ tons of till would be required for this purpose.

6.4 Water Management After Mine Closure

Water elevation would need to be controlled in the reclaimed tailings impoundment and backfilled pit after mine closure in order to maintain the reactive materials beneath the water surface.

6.4.1 Tailings Impoundment

The tailings surface would be reclaimed with the objective of establishing a marshland type cover on the impoundment surface (Section 6.3.2). The diversion ditches would be removed and the catchment contributing runoff to this area after reclamation would be 418 acres. The site experiences a net precipitation of approximately 20 inches a year and, under these conditions the reclaimed impoundment would have a net excess in the water balance which would need to be discharged to Bald Mountain Brook. A permanent spillway would be excavated in rock in the right abutment of the impoundment. The spillway could discharge to the reclaimed pit or to Bald Mountain Brook. During periods of low precipitation evaporation may exceed precipitation resulting in a deficit in the water balance. Under these conditions the water elevation may drop below the spillway crest elevation. However, the till cover on the tailings would be sufficient to maintain the tailings in a saturated state, even under extreme drought conditions applicable to this region.

6.4.2 Open Pit

The final water elevation in the flooded pit would be at approximate elevation 900 ft, controlled by the spillway located at the low point on the pit perimeter. The water elevation would be controlled by means of a spillway discharging to Bald Mountain Brook. The depth of water above the potentially acid generating mine rock within the pit would be of the order of 200 ft. This is considered to be more than adequate to ensure continuous water cover over the reactive mine rock.

7.0 TAILINGS IMPOUNDMENT WATER BALANCE

7.1 General Description

A water balance model for the Bald Mountain tailings impoundment has been developed to predict potential discharge and water treatment requirements and to evaluate short and long term storage requirements in the impoundment. Since the water balance is of critical significance to this study, it was evaluated at some depth. The model was developed using a Lotus 123 spreadsheet. Input data can be readily modified to evaluate changes in the overall water balance for changes in climatic data, mill processing circuit, tailings geotechnical characteristics, tailings impoundment location, configuration and size (including diversion ditches), discharge criteria and mine life.

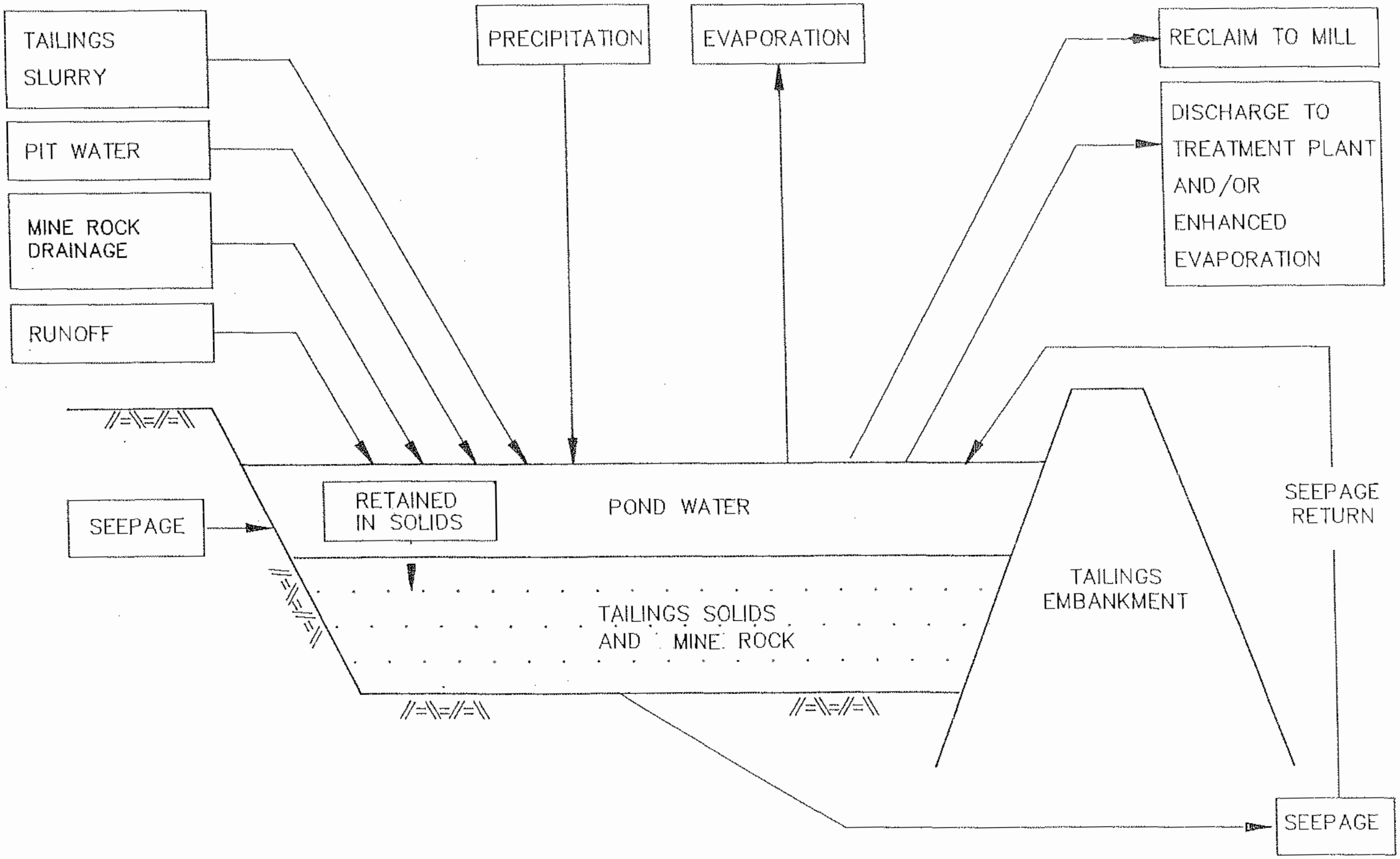
Tailings and waste rock would be deposited in the impoundment constructed at the "High Site 1" located as described in Section 3.3 and shown in Figure 2.1. The alternative tailings impoundment sites were evaluated with preliminary water balance calculations and reported previously by SRK (Report No. 02202/4 July, 1981; and 1982). A cut-off grade of 1% copper has been assumed in the water balance model. The overall impoundment would consist of separate gossan and massive sulfide impoundments as described in Section 6.0.

7.2 Model Description

A schematic diagram depicting the components of the water balance is provided in Figure 7.1. The tailings impoundment would receive water directly from precipitation on the pond surface, runoff from the catchment area, and, in the case of unlined impoundments, from groundwater seepage into the impoundment. The areas of the tailings impoundment subject to precipitation, evaporation and runoff are a function of the configuration of the basin used for disposal. The surface area of the pond over which precipitation and evaporation occur increases as tailings are placed, thereby decreasing the area over which runoff is calculated.

The water balance model was formulated to simulate the operation of the impoundment and the surrounding catchment for a given rainfall rate and tailings deposition rate. The catchment areas and pond surface area were determined from topographical maps and plan layouts of the impoundment, and the basin volume was calculated. Relationships were identified for the measured values of elevation and surface area, and elevation and volume. Thus it is possible to study the rate at which the level of the impoundment increases as tailings are placed, and determine the excess or shortfall of water in the impoundment.

Preliminary water balance calculations and previous studies have shown that the areal extent of the catchment basin is critical to determining the amount of excess water. A staged embankment construction consisting of a series of diversion ditches was assumed, as discussed in Section 6.0 and shown in Figures 6.2 to 6.4, in order to limit the catchment areas of the impoundment over the 15-year life. The total catchment area without diversion ditches is approximately 417 acres. This has been limited, with diversion ditches to:



BOLIDEN RESOURCES INC.

COMPONENTS OF THE TAILINGS IMPOUNDMENT WATER BALANCE

STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers

DATE JUNE, 1990
PROJ. NO. 80701
APPROVED
NO. FIG. 7.1

Stage	Period	Catchment area within ditches (acres)
I	Years 0-2	37
II	Years 3-7	136
III	Years 8-15	210

Drainage from the waste rock dump could be collected and discharged to the tailings impoundment if water quality is such that it is not suitable for discharge. The quality of drainage from the foot wall waste rock stockpile is likely to be such that it would not be suitable for discharge, as discussed in Sections 5.4.3.2 and 6.2. Similarly, precipitation and seepage collected in the open pit is not expected to be of discharge water quality and allowance has been made for these flows to be included in the tailings impoundment water balance model.

Water would be withdrawn from the pond primarily through reclaim water to the mill for reuse. The large surface area of the pond would result in loss of water through evaporation. Water would also be retained in the voids of the tailings solids; a permanent loss to the water circuit. Excess water in the tailings impoundment may be disposed of using various options including :

- enhanced evaporation through spraying or using tailings pond water as coolant in a power plant,
- water treatment and discharge to surface waters, and
- water treatment and land application.

These options are discussed in more detail in Section 8.0.

The water balance model calculates the change in storage based on inflows and outflows from the impoundment on a monthly basis, and the resultant volume and elevation of tailings solids and pond supernatant. Maximum and minimum depths of water in the tailings pond have been defined to limit the pond elevation and to provide sufficient water cover over the tailings solids. If the monthly net inflow results in the pond depths exceeding the criteria, discharge volumes are calculated. If insufficient water cover is predicted, mill reclaim volumes must be reduced.

The total mass inflow into the tailings impoundment consists of a number of possible components:

volume of tailings solids	(T_{solids})
water associated with the tailings	(T_{water})
precipitation on the pond surface	(P)
runoff from the catchment area	(R)
drainage from the waste rock dump	(WR)
water from the open pit	(OP)
seepage into the impoundment	(S_{in})

Thus the total volume flowing into the tailings impoundment at any time is given by the sum of the inflows:

$$\text{Inflows} = T_{solids} + T_{water} + P + R + WR + OP + S_{in} \tag{1}$$

The amount of water that is lost or withdrawn from the tailings impoundment (outflow) could include:

- mill reclaim water (M_r)
- water retained in tailings and waste rock (R_s)
- natural evaporation (E_n)
- enhanced evaporation (cooling water) (E_e)
- planned discharge (D)
- seepage from the impoundment (S_{outh})

The amount of water withdrawn from the impoundment is thus the sum of the outflows at any given time:

$$\text{Outflows} = M_r + R_s + E_n + E_e + D + S \qquad (2)$$

The resulting change in storage within the pond over a given time interval is the difference between inflows and outflows, equation (1) - equation (2).

7.3 Description of Water Balance Components

7.3.1 Tailings (T_{solids}) (T_{water})

Total tailings discharged to the impoundment includes 1.2×10^6 tons of gossan tailings and 21.7×10^6 tons of massive sulfide tailings (1% copper cut-off grade). Processing rates of 1652 tons/day for years 0-2 and 4578 tons/day for years 3-15 were assumed. Results from the pilot plant tests on the gossan and sulfide ores indicated average dry density values of 80 and 130 pcf, respectively (SRK, Technical Engineering Report #6, 1982).

Tailings slurry densities of 45 % solids for the gossan material and 30 % solids for the sulfide material have been assumed (SRK Technical Engineering Report #6, 1982). These pulp density values correspond to water flow rates to the impoundment of 336 USgpm (1.3 m^3/min) and 1779 USgpm (6.7 m^3/min) for the gossan and massive sulfide tailings, respectively.

7.3.2 Precipitation (P)

There are no long-term precipitation records at the mine site itself, however a 30-year record of monthly precipitation is available from the Fort Kent Weather station, 40 miles north of the site. These data were used to calculate average monthly precipitation values for the water balance (SRK Report No. 02202/4, July 1981; 1982) as summarized in Table 7.1. Average annual precipitation was estimated to be 39 in. (1000 mm). The 100-year recurrence interval 24-hour storm was estimated to be 4.9 in. (125 mm).

A frequency analysis was conducted on the 30-year record using the Consolidated Frequency Analysis Package, based on a Generalized Extreme Value Distribution to identify precipitation values for wet and dry year events. Annual precipitation for a 1 in 20 wet year was estimated at 51.2 in. (1300 mm), and 30 in. (736 mm) for a 1 in 20 dry year. These precipitation figures were similar to recorded values in 1954 and 1965, respectively. To calculate the overall water balance accounting for the occurrence of an extreme precipitation event, recorded precipitation values for years representing wet and dry year values (1954 and 1965, respectively) were used in the water balance and are provided in Table 7.1. These were applied to the year with the maximum and minimum discharge requirements, respectively (Cases B and C - see Section 7.4).

TABLE 7.1
Climatic Data used in Water Balance Calculations

MONTH	AVERAGE MONTHLY VALUE (in.)				
	PRECIPITATION			RUNOFF	EVAPORATION
	ave.	1965	1954		
January	2.5	0.9	1.6	0.8	0.4
February	2.3	2.7	2.8	0.6	0.5
March	2.6	0.6	1.0	1.0	1.0
April	2.8	0.9	3.6	5.1	1.7
May	3.2	2.2	5.8	4.3	2.9
June	3.7	1.3	6.8	2.8	3.1
July	4.4	3.4	6.3	1.2	3.5
August	4.1	3.3	7.1	0.8	2.5
September	3.7	4.1	7.9	0.8	1.7
October	3.4	3.9	2.1	1.2	1.2
November	3.5	4.3	2.9	2.0	0.7
December	3.2	2.0	5.6	1.6	0.5
TOTAL	39.4	29.5	53.5	22.4	19.7

7.3.3 Runoff (R)

The average annual runoff for the area was estimated to be 22 in. (560 mm). An average annual runoff coefficient of 0.56 was obtained based on average annual precipitation of 39 in. The estimated average monthly runoff data was developed in previous reports and is summarized here in Table 7.1.

7.3.4 Evaporation (E_n, E_e)

The average annual lake evaporation for the site was estimated to be 19.7 in. (500 mm). Monthly evaporation values were developed from empirical relationships (SRK, 1982) and are presented in Table 7.1. Enhanced evaporation rates through cooling water losses were estimated to be 100 USgpm (provided by Boliden personnel).

7.3.5 Pit Water and Waste Rock Dump Drainage (OP, WR)

The volume of water from the open pit included both precipitation over the actual pit area and seepage into the pit. The pit area contributing to inflow from precipitation has been assumed constant at 40.3 acres and seepage inflow has been estimated to vary linearly over the 15-year life to a maximum of 50 USgpm. Drainage from the waste rock dump was estimated from runoff data (as infiltration and evaporation of precipitation would occur). The dump area was approximated as increasing linearly over years 3 to 15 to a final dump footprint of 50 acres. Within the first two years of operation the gossan waste rock would be utilized for embankment construction and thus there is no inflow to the water balance for these years.

7.3.6 Seepage (S_{in}, S_{out})

The water balance simulations have been conducted assuming the impoundment would be lined and thus there would be no net seepage into or out of the impoundment.

7.3.7 Water Retained in Tailings and Waste Rock (R_s)

The pore water retained within the solid waste in the impoundment is a component included in the water balance outflows. The volume of water retained within the tailings and waste rock was calculated based on assumed void ratios of 1.35, 1.02 and 0.3 for the gossan tailings, massive sulfide tailings and waste rock, respectively.

7.3.8 Mill Reclaim Water (M_r)

The water balance model has been set-up such that the model can be run for any ratio of mill reclaim to tailings water. The water balance has been computed for mill reclaim water ratios of 70% and 90%; a typical range for flotation milling circuits. The reclaim ratio refers to the percentage of the tailings water discharge which is returned to the mill as process water.

7.4 Water Balance Results

The water balance model was run for a variety of cases to evaluate the effect of changes in precipitation, mill reclaim ratio, enhanced evaporation, pit water input and waste rock dump drainage input. The variables for each of the cases are detailed below. The detailed results of Case A (described below) and summary results of all other cases are included as Appendix C. A summary of the mean annual discharge requirements from the water balance is shown in Table 7.2.

Case A
- average precipitation
- mill reclaim ratio 70 %
- enhanced evaporation excluded
- pit water and waste rock dump drainage included

Case B
- low precipitation event
- mill reclaim ratio 70 %
- enhanced evaporation excluded
- pit water and waste rock dump drainage included

Case C
- high precipitation event
- mill reclaim ratio 70 %
- enhanced evaporation excluded
- pit water and waste rock dump drainage included

Case D
- average precipitation
- mill reclaim ratio 90 %
- enhanced evaporation excluded
- pit water and waste rock dump drainage included

Case E
- average precipitation
- mill reclaim ratio 70 %
- enhanced evaporation included
- pit water and waste rock dump drainage included

Case F
- average precipitation
- mill reclaim ratio 70 %
- enhanced evaporation excluded
- pit water and waste rock dump drainage excluded

Case G
- average precipitation
- mill reclaim 70%
- enhanced evaporation; excluded for years 1 and 2, included for years 3 to 15
- pit water and waste rock dump drainage included

Case H
- average precipitation
- mill reclaim ratio; 70% for years 1 and 2, 90% for years 3 to 15
- enhanced evaporation excluded
- pit water and waste rock dump drainage included

TABLE 7.2

Water Balance Results
Summary of Average Annual Discharge (USGPM)

	Cases							
Year	A	B	C	D	E	F	G	H
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	189	189	189	0	89	89	89	0
4	522	522	522	3	422	415	422	3
5	517	517	517	156	416	401	416	156
6	294	294	294	92	209	200	209	92
7	308	308	308	0	199	161	199	0
8	677	677	677	139	576	541	576	139
9	621	621	621	223	493	469	493	223
10	690	690	690	333	590	540	590	333
11	695	695	695	338	595	538	595	338
12	701	701	701	344	601	537	601	344
13	707	707	707	350	607	536	607	350
14	714	714	714	357	613	535	613	357
15	720	720	875	363	620	534	620	363
Mean*	490	490	501	180	402	366	402	180
Mean**	598	598	610	225	495	451	495	229

* Mean of all years
** Mean of years 4-15

8.0 MINE WATER TREATMENT AND DISCHARGE ALTERNATIVES

8.1 Introduction

From the preliminary water balance calculations presented in a report by Barr Engineering Co., 1987, the average daily flow of mine water requiring treatment was estimated at 35 USgpm. The report indicated that the estimate could increase by an order of magnitude. A more recent study by Barr Engineering Co. concluded that, under "average" precipitation conditions, an excess of approximately 106 gallons per minute would occur in the tailings impoundment during operation (Barr Engineering Co., 1988). Due to the potential variability in the mine water flows, further flow estimates have been generated through development of a tailings impoundment water balance, as described in Section 7.0. The results obtained from the water balance calculations indicate a significant increase in the anticipated excess mine water flow. The recalculated excess mine water flows after year 3 of operation, under average precipitation conditions, range from 294 to 720 USgpm with an annual mean of 490 USgpm at 70% recycle of process water, to 92 to 363 USgpm with a mean of 180 USgpm at 90% recycle. The increase in mine water flows has a dramatic impact on the cost and viability of the proposed discharge and treatment options. It may be possible to achieve discharge requirements to between 0 and 260 USgpm at 90% recycle of mill water and enhanced evaporation of 100 USgpm. However, further analysis is necessary to validate these calculations.

With regards to discharge of treated mine water, two scenarios have been advanced. The first involves discharge of treated mine water into either Bald Mountain Brook or an upper reach of Clayton Stream. The second scenario involves land application of treated mine water through spray irrigation. Both the brook and stream are classified Class A according to the State of Maine water quality regulations. According to surveys conducted by Woodward-Clyde Consultants (1982) and Normandeau Associates (1990), both potential surface water receiving systems contain well established invertebrate and reproducing brook trout populations. The water quality of the local surface and groundwater are excellent, with very low levels of metals, hardness, dissolved solids, and nutrients noted in a study conducted by Woodward-Clyde Consultants (1982).

8.2 Surface Water Discharge

Due to the sensitivity of the fishery and the low background levels of hardness and metals, instream criteria associated with the surface waters are very stringent. The State of Maine recently promulgated numerical water quality criteria based on values presented in the USEPA Gold Book (USEPA, 1986) and a hardness of 20 mg/l as $CaCO_3$. The values presented in Table 8.1 are taken from an earlier report prepared by Normandeau Associates, 1990. The numerical criteria are very low, particularly in the case of silver, copper, cadmium, mercury, lead, and zinc.

TABLE 8.1

Selected EPA "Gold Book" Water Quality Criteria* Versus Detection Limits Reported By Woodward-Clyde Consultants(1982) and USGS(1989).

(After Normandeau Associates Inc., 1990)

PARAMETER	ACUTE TOXICITY LIMIT mg/1	CHRONIC TOXICITY LIMIT mg/1	REPORTED DETECTION LIMIT RANGES mg/1
Ag	0.00025	0.00012	0.001-0.10
Al	0.950	0.200	0.09-0.10
As	0.390	0.190	0.001-0.005
Cd	0.0006	0.0003	0.0001-0.005
CN	0.022	0.005	0.010-0.060
Cr VI	0.016	0.011	0.001-0.010
Cu	0.004	0.003	0.001-0.005
Hg	0.002	0.000012	0.0002-0.060
Ni	0.363	0.040	0.001-0.005
Pb	0.011	0.0004	0.001-0.005
Zn	0.030	0.027	0.001-0.010

*Assumes hardness of 20 mg/L

Assuming a mean flow in Bald Mountain Brook of about 335 USgpm, an annual mean low flow for upper Clayton Stream of about 1,800 USgpm, and mean average annual discharge flows ranging from 225 to 598 USgpm, depending upon the degree of recycle, the estimated dilution factors range between 0.5 and 1.5 in Bald Mountain Brook and between 3 and 8 in Clayton Stream. Through development of a more detailed site water balance and application of a controlled hydrograph release system, the dilution factor could increase significantly. In conjunction with dilution, completion of a site specific analysis could yield alternative instream criteria greater than the background water quality, but still protective of the local ecosystem.

The anticipated increase in mine water flows limits the available dilution significantly, and discharge to Bald Mountain Brook is not a viable option under present conditions. Discharge into upper Clayton Stream would require very high levels of treatment efficiency, even though there is increased dilution. It is not probable that the proposed treatment systems (as discussed in Section 8.4) would provide an effluent of acceptable quality to allow discharge into either the stream or the brook, unless reduced instream criteria can be obtained. Development and acceptance of site specific criteria may still not yield achievable end-of-pipe effluent limitations, due to the limited dilution.

The controlled hydrograph release approach involves discharge of treated mine water at such a rate as to maintain a specified minimum dilution based on continuously gauged stream flows. Precedence for the approach in the State of Maine is not known at this time. The approach is utilized in conjunction with industrial discharges in other states (i.e., South Carolina). The surface water discharge option into Clayton Stream is probable only if the above conditions of reduced instream standards can be satisfied and the approach is accepted by the State. The site specific approach will involve additional studies including further stream surveys and specific toxicity tests. At a minimum there would be a requirement for modification of existing instream criteria, development and acceptance of a controlled hydrography release system to maximize dilution, implementation of advanced or tertiary mine water treatment, and adherence to a stringent mine water balance. A detailed engineering and a scientific study would be necessary to verify the validity of these approaches.

8.3 The Land Application Option

The second discharge option involves land application of treated mine water through spray irrigation as discussed by Barr Engineering, 1987. Through a detailed study of the land application option it has been determined that suitable soils exist for percolation of the mine water (Woodard and Curran Inc., 1989). Treatment of the mine water prior to application would be required. The results of the geochemical evaluation included in the study indicates that the cation exchange capacity of the soil could supply the sorption necessary to remove the residual constituents and minimize the potential for groundwater contamination, the primary concern associated with land application. Of secondary concern is the accumulation of undesirable levels of constituents in the native vegetation.

There is precedent for land application of both industrial and municipal wastewaters in the State of Maine. However, the characteristics of the mine water are different from those of other wastewaters and more detailed evaluations of chemical and physical attenuation mechanisms are needed. With regards to land application of treated mine waters, there are permitted and operating systems existing in other states, such as Montana.

The success of the land application option is related to the effluent criteria established by the State of Maine and the volume of mine water requiring disposal. The Barr Engineering report suggested either drinking water standards or background water quality as possible effluent standards. From a review of the anticipated mine water characteristics, it is not probable that treatment to background levels is achievable. Treatment to drinking water standards is not acceptable since the aquatic life criteria are more stringent for several of the parameters of concern.

The preferred approach is to establish effluent limitations on the basis of probable soil attenuation and protection of groundwater. At this point in time, the acceptability of the approach and the probable selection of effluent limitations have not been addressed with the State of Maine.

If the land application approach proves viable based upon derivation of suitable effluent limitations, it would be necessary to provide storage for treated or untreated mine water for up to six or seven months. Storage of untreated mine water would dictate a significant increase in the capacity of the treatment system, since the total volume of mine water must be treated and discharged in about 50% of the time. Based upon the estimated range of daily mine water flows (i.e., 92 to 720 USgpm), the volume of storage required ranges from 20 to 190 million gallons. This approach would require storage capacity within the tailings impoundment or construction of a large lined mine water holding pond.

Another detailed assessment of required and available surface area for land application must be undertaken, since the required acreage would increase significantly due to the anticipated increase in mine water flows. However, unless a significant reduction in anticipated mine water flows is realized, land application is probably not a viable discharge option.

8.4 Selection of Preferred Mine Water Treatment Options

Based on anticipated effluent requirements employing either drinking water standards or background water quality, several treatment options have been postulated by Barr Engineering, 1987. The options included lime treatment, either alone or in combination with filtration, reverse osmosis, or ion exchange. Based on the original anticipated mine water flow of 35 USgpm, the capital costs of the system ranged from $1.8 to 3.1 million. The anticipated annual operating costs ranged from $240,000 to $410,000. These costs are very high compared with the anticipated untreated mine water flows.

However, the water balance calculations indicate that mine water flows requiring discharge could increase to between 200 and 720 USgpm. Conventional treatment including cyanide oxidation and metals precipitation using pH adjustment and flocculent addition would increase the anticipated capital costs to $5,000,000 or more. The annual operating costs could reach $1,000,000. A comparison of approximate costs and effectiveness of treatment for conventional and advanced treatment technologies is illustrated in Table 8.2. For example, this level of treatment using proven technology could achieve a copper effluent value of about 0.10 mg/L. Assuming an instream copper criteria of 0.003 mg/L taken from Table 8.1, a dilution factor of 33 is needed. At the anticipated discharge volumes, the required dilution is not available. A significant relaxation in stream standards or an alternative discharge point far downstream is needed.

Application of advanced technologies beyond the conventional treatment involving either filtration and reverse osmosis or filtration and ion exchange could produce an effluent copper of about 0.05 mg/L. At a minimum, the increased capital costs would be about $1,000,000 to $2,000,000. The annual operating costs would increase by an additional $200,000 to $400,000. The required dilution for copper to reach an instream concentration of 0.003 mg/L would still remain about 16, which is not achievable unless a discharge point far downstream is utilized. A downstream discharge point would require the installation of a pipeline which may need to be buried.

TABLE 8.2
Comparison of Costs and Effectiveness of Different Treatment Technologies
For Illustrative Purposes Only

Level of Technology	Approximate Costs		Effluent Copper	Required Dilution
	Capital	Operating	(mg/L)	
Conventional	$5,000,000	$1,000,000	0.1	33
Advanced	$6,000,000	$1,400,000	0.05	16

The example using copper demonstrates the extreme difficulty and cost in achieving acceptable effluent quality for discharge, under the proposed mine plan. Similar or increased difficulties will be encountered for the metals silver, mercury, lead, cadmium, zinc, and nickel. These metals are of primary concern with regard to both treatment and toxicity. No significant advantage with regards to treatment efficiency is achieved through the use of advanced technologies.

For discharge of treated mine water to be a viable option, more reasonable effluent limitations must be obtained, in conjunction with a decrease in the anticipated mine water flows. In the case of the surface water discharge option, the effluent limitations would be derived from a site specific waste load allocation. In the case of land application, the effluent limitations would be based on considerations of potential groundwater impacts. For example, effluent limitations based on the BAT standards for the Ore Mining and Dressing Industry are achievable and acceptable. Effluent limitations based on either background water quality or the present aquatic life standards, in conjunction with required treatment of elevated mine water flows constitute a probable fatal flaw.

In the event that more reasonable effluent limitations are obtained along with a more favorable mine water balance, a treatment system based on conventional processes is possible. In this case, the treatment system would combine chemical oxidation and precipitation possibly followed by filtration. Reverse osmosis or ion exchange would not be necessary. These latter processes are not preferred due to expense, complexity, and the problems associated with brine or regeneration solutions. The side streams produced from these processes contain very high concentrations of dissolved constituents which can not be continuously disposed of in the tailings impoundment. A mine water treatment system based on the advanced processes is not practical or justifiable. Several operational problems could be encountered during the life of the mine.

In the case of conventional treatment, chemical precipitation would convert the metals to the insoluble hydroxides which could be disposed of in the impoundment along with the tailings. As long as the pH of the solids remains elevated, significant dissolution of the metals would not occur. The capital and operating costs for conventional treatment would be lower relative to the advanced or tertiary treatment options. In addition, conventional treatment processes, such as hydrogen peroxide oxidation for cyanide and lime precipitation for metals, are well known.

One additional area requiring discussion involves the need for increased design capacity for treatment of contaminated seepage in the event of failure of the liner. Based on preliminary hydrological calculations, the potential flow of groundwater which could be contaminated through failure of the liner is about 200 USgpm. Increasing the capacity of the treatment system would not only increase the cost of treatment, but further reduces the viability of both the surface water and land application discharge options.

In the case of the surface water discharge option, the degree of available dilution is reduced and a significant increase in treatment performance is required to meet the instream criteria. In the case of land application, the available storage capacity for untreated mine water is increased dramatically as is the area needed for irrigation. It is not probable that suitable land application area is available to accommodate a combined seepage and mine water flow in the range of 400 to 900 USgpm. Further analysis of this potential fatal flaw is necessary prior to making a final decision.

8.5 Conclusions

Based on a review of the available documents, there are several areas related to the mine water management and treatment systems which may result in a fatal flaw. It is not probable, based upon the current conditions, that either the surface water discharge or land application option are viable based upon the expected treatment cost and efficiency needed to achieve either background surface water quality or aquatic life criteria. In the case of a surface water discharge the available dilution is minimal, while in the case of land application the required surface area and storage volume are excessive. It is not probable that any available conventional or advanced treatment process can achieve background water quality.

In order to allow treatment and discharge of mine water to maintain the internal water balance, alternative site specific effluent criteria must be derived and accepted, along with a significant reduction in the expected mine water flows. The allowable mine water volumes and quality must be determined through further evaluations. Based upon a non-quantitative assessment, a reduction of 50% or greater in the anticipated mine water flow is needed.

The preferred approach would utilize either a controlled hydrograph release in conjunction with site specific criteria and conventional treatment, or land application using conventional treatment and effluent limitations base upon standards similar to the BAT regulations. In both cases significant reductions in the mine water volumes must be realized.

9.0 POTENTIAL IMPACT ON WATER QUALITY

9.1 Water Quality Criteria

9.1.1 Surface Water

The long-term surface water quality criteria for the project, by current regulations, is that Class A streams cannot be degraded in any way from baseline water quality (see Section 4.2.2 and Section 8.0). Without a variance to this regulation, the surface water quality criteria for Bald Mountain Brook would be the approximate baseline water quality presented in Section 3.5 and Table 3.5. The implication is that the discharge of any quantity of water of a quality substantially poorer than that shown in Table 3.5 would not be allowed. Since the water produced by the project would degrade the stream if discharged, untreated, it is necessary to either achieve a zero discharge condition or to treat to a suitable level prior to discharge. Section 8.0 presents a discussion of the feasibility of meeting water quality standards in Bald Mountain Brook and Clayton Stream.

9.1.2 Groundwater

Baseline groundwater quality at the site is discussed in Section 3.6 and summarized in Table 3.6. However, given the siting of the tailings impoundment in the Bald Mountain Brook drainage and the numerous springs and seeps in the impoundment valley which eventually feed the brook, groundwater quality criteria for the tailings impoundment will essentially default to those for surface water quality. For example, if, in the case of a lined impoundment, a leak were to develop in the liner there would be an impact on water quality in the underdrain which feeds Bald Mountain Brook. The primary means of control on groundwater quality should be to create effectively zero discharge facilities. With regard to the open pit, it would similarly be prudent to consider a subsurface release as having an immediate effect on surface water quality. For the purpose of this discussion, the potential impact on surface water quality has been assumed to be the critical issue.

9.2 Water Quality Objectives

The surface and groundwater quality criteria for the project, considered together with the expected tailings water quality and feasibility of treatment, indicate that the tailings impoundment system would essentially have to be a zero discharge facility in order to meet current regulations. The criteria of zero degradation cannot be met through treatment and discharge means (Section 8.0). The results of the tailings impoundment water balance (Section 7.0) indicate that zero discharge is unlikely to be achieved although the discharge may be reduced to less than the net accumulation resulting from the difference between precipitation and evaporation. An alternative approach is to establish in-stream water quality objectives less severe than background water quality but protective of local ecosystems (Section 8.2). Boliden should consider pursuing a variance on water quality criteria to establish appropriate water quality objectives for the project. The implications of proposing alternative water quality objectives on permit applications are discussed in Section 4.2.2 and the technical feasibility of achieving different water quality objectives is discussed in Section 8.0. It is unlikely that acceptable water quality objectives could be maintained in Bald Mountain Brook. It would therefore be necessary to locate the point of compliance for receiving water quality at, or downstream of, the confluence of Bald Mountain Brook and Clayton Stream.

9.3 Potential Impact During Operation

The water quality of surface water in the receiving environment would be impacted by water released from the following areas;

- the tailings impoundment,
- mine rock stockpiles,
- open pit, and
- the general mine site.

Water from the tailings impoundment would need to be treated and discharged as discussed in Sections 7.0 and 8.0. An additional release of water could potentially occur through subsurface and embankment seepage in the case of an unlined impoundment, and through leaks in the case of a lined impoundment. Seepage or leakage from the impoundment would be expected to emerge at the surface within a relatively short distance downstream of the impoundment. A large proportion of this water could be collected and returned to the tailings impoundment during operation, thereby maintaining the required protection of surface water quality during this period.

Runoff and drainage from the till and mine rock stockpiles, water collected in the open pit and runoff from the general mine site would need to be collected and treated before discharge to the environment, as described in Section 6.2. The water management plan during operation would need to be designed and implemented in order to prevent an unacceptable impact during mining. The technical feasibility of different treatment and discharge options is discussed in Section 8.0.

The impacts to the groundwater system which could result from mining include depletion of groundwater reserves in the project area by pit dewatering, and water quality deterioration in the shallow aquifer system via tailings pond seepage. As a number of investigators (Woodward-Clyde Consultants, 1982; Budo, 1988) have indicated that the groundwater volumes removed by mining will be minimal, it would appear that the only groundwater impact of potentially major significance will be that due to tailings pond seepage, as discussed above.

9.4 Potential Long-Term Impact on Water Quality

The long term impact on the surface water system, resulting from decommissioned mine facilities, could occur as a consequence of the following:

- surface runoff from the reclaimed pit,

- seepage of groundwater through the backfilled pit, with discharge to Bald Mountain Brook,
- seepage of groundwater beneath the tailings pond, with discharge to Bald Mountain Brook, and
- runoff from the proposed reclaimed tailing impoundment surface.

While it is expected that the engineered containment measures would minimize the impacts due to each of the above in the post-operational period, these measures may not result in acceptable water quality.

9.4.1 Runoff from the Reclaimed Pit

The plan for reclamation of the open pit is presented in Section 6.3.2. It could take up to 30 to 50 years for the pit to naturally fill with water to the final elevation of 880 ft, assuming the pit is flooded to the elevation of the top of the backfilled mine rock immediately following mine closure. This assumes that the sources of inflowing water to the pit after mine closure would be direct precipitation into the pit, runoff from the pit catchment as well as natural groundwater inflow from the up-gradient direction. This period could be reduced to between 6 and 8 years if the runoff from the tailings impoundment catchment is directed to the pit after closure. During the period of filling groundwater seepage from the pit would be negligible. In the long term the total inflow to the pit is likely to be greater than the outflow due to groundwater seepage and evaporation. This excess in the pit water balance would flow as surface water from the pit to Bald Mountain Brook. The mean annual flow of surface water from the pit is expected to be of the order of 70 to 120 gallons per minute. The quality of this water would depend on a number of factors, principally:

- the extent of sulfide oxidation within the mine rock stockpile prior to backfilling to the pit and the acid generation and metal leaching products contained within the mine rock,
- the extent of on-going acid generation on the pit walls and in the backfilled mine rock.

While measures to control acid generation would be implemented in the short term (i.e., during mining and stockpiling of the mine rock) some acid generation is expected to occur. The mine rock may contain products of the acid generation processes which could be released into the pit water on backfilling. The storage of reactive mine rock underwater reduces the rates of acid generation very significantly, however, the process is not halted entirely. It is possible that near-surface groundwater flow may convey oxygenated water through the upper, fractured zone of the pit walls, allowing acid generation to continue to some extent. While the conceptual waste management plan, as described in Section 6.0, incorporates what are considered to be the most promising, practically achievable measures to minimize the impacts from acid generation, no field data regarding the effectiveness of these measures from similar operations is available. This lack of field data and the uncertainties associated with the currently available modelling techniques make prediction of the quality of surface water flowing from the pit after mine closure extremely difficult. The long term impact of surface flow from the reclaimed pit on surface water quality is therefore a very significant issue of concern.

9.4.2 Seepage of Groundwater from the Backfilled Pit

When the water elevation within the pit has reached its final elevation of approximately 900 ft, the general groundwater gradient in the pit area will be restored to approximately pre-mining conditions. Seepage from the pit would occur through the overburden and upper zone of fractured bedrock. The quantity of flow has been estimated at 2 USgpm. The impact of this flow on surface water quality in Bald Mountain Brook and Clayton Streams is expected to be very small compared to that due to surface runoff from the pit.

9.4.3 Runoff from the Proposed Reclaimed Tailings Impoundment

The conceptual reclamation plan for the tailings impoundment area is described in Section 6.3.3. The source of water to the reclaimed tailings impoundment after mine closure would be direct precipitation and runoff from the catchment area which measures approximately 418 acres in total. The mean annual runoff from the tailings impoundment would be approximately 450 USgpm based on the available climatic and hydrological data. The runoff from this area could be directed to the pit which would take between 6 to 8 years to fill. Under these conditions, runoff from the tailings impoundment area would have no impact on surface water in the receiving environment during this period. The water quality of surface runoff from the till cover over the tailings impoundment would be expected to improve as marshland conditions become established.

9.4.4 Seepage from the Tailings Impoundment

Woodward-Clyde Consultants (1982) and IECO (1989) performed seepage analyses for the tailings impoundment under various containment scenarios. Although there were minor differences in the models used and in the selection of input parameters to the models, the analyses indicated roughly the same order of magnitudes for the unlined condition. SRK has reviewed the analyses, and believes the IECO estimates to be based on more representative parameter values. SRK presents the following evaluation of tailings impoundment seepage for the two containment scenarios: an unlined impoundment and a synthetically lined impoundment. The contingency measures which would have to be implemented should significant quantities of leachate develop are described below. The conceptual design of the drainage system to collect groundwater discharge beneath the tailings disposal area is described in Section 6.0.

9.4.4.1 Unlined Impoundment

After mining ceases, there would be saturated tailings to an approximate elevation of 1140 feet msl. Provided these tailings remain saturated, they will be a source of recharge to the groundwater system. The head created in the tailings will be the source of seepage water to the subsurface. The seepage water will first have to pass through the glacial till material, which underlies the impoundment area, before entering the upper bedrock aquifer. The primary mode of lateral transport of seepage fluid will then be through this bedrock aquifer.

The reclaimed tailings surface will comprise approximately 200 acres. Table 9.1 provides SRK's seepage estimates using Darcy's law for the unlined case, indicating that approximately 160 USgpm of seepage would enter the bedrock aquifer. This estimate was based on the assumption that all of the head loss thought the system is in vertical migration of fluid through the till (no head loss through the tailings), and a hydraulic gradient of 1 through the till. The till permeability was estimated as $1x10^{-6}$ cm/sec (Table 9.1).

TABLE 9.1

Tailings Impoundment Seepage Summary

	Unlined	Lined	
Governing Parameters		Permeation	Pinhole Leaks
Material Controlling Seepage	Glacial Till	Liner	Glacial Till
Permeability of Controlling Material (cm/sec)	$1X10^{-6}$	$1X10^{-12}$*	$1X10^{-6}$ ($1.47X10^{-5}$gpm/ft^2)
Head/Gradient Through Controlling Material	Unit Gradient	50 ft. head per (80/1000) inch** = 7500	50 ft. head
Area Allowing Flow (Acres)	250	250	1 hole/acre = 1cm^2/acre
Seepage per Unit Area ($q = K.i$) (gpm/ft^2)	$1.47X10^{-5}$	$1.1X10^{-7}$	$5.6X10^{-10}$
Seepage From Impoundment (gpm)	160	1.2	0.006

An unlined pond bears an additional risk that there are areas of the impoundment in which the till is absent or fractured, resulting in more direct seepage paths to the bedrock and significantly higher seepage quantities. Since the till is absent in some areas at elevations above approximately 1050 feet (Woodward-Clyde Consultants, 1982), seepage would probably be greater than 160 USgpm. IECO (1989), for example, estimates that 500 USgpm of seepage is possible. Final seepage rates will depend on the amount of till placement on exposed bedrock.

Current groundwater flow through the bedrock out of the mouth of the tailings impoundment valley is estimated to be on the order of 70 USgpm (Budo, 1988, a, b and c), based on an average annual groundwater recharge of 0.25 feet and a catchment area on the order of 460 acres. Thus, the potential seepage from an unlined impoundment is greater than the flow estimated to occur thought the valley. Unless seepage was of almost the same quality as natural surface waters in Bald Mountain Brook this seepage quantity would be considered unacceptable. This type of design would automatically have to provide for a seepage interception system, and would add uncertainty as to whether all of the seepage volume was contained.

9.4.4.2 Synthetically Lined Impoundment

In a synthetically lined impoundment, the equivalent permeability of the liner is so small that potential seepage flows from widespread permeation is negligible. IECO (1989) estimates that 0.9 USgpm of seepage flow would occur beneath the impoundment, using 80 mil HDPE liner. This is essentially a "no release" condition. The significant mode of seepage release could be through tears or punctures, commonly referred to as "pinhole" leaks.

The seepage from pinhole leaks is dependent upon the permeability of the underlying material,, the area of opening(s) in the liner, and the frequency of openings. A standard hole area of 1 sq. cm (diameter = 0.2 inch) and a frequency of holes of one per acre has been used for seepage estimation, following procedures recommended by EPA (1987). This selection in turn was based on interviews with quality assurance personnel which indicate that these are the maximum hole size and frequency which can be expected to exist after quality assurance inspection.

The potential seepage through a standard opening was estimated using formulas developed for estimating soil permeability using open-ended standpipes, because the permeability of the soil will control the rate of seepage flow through the opening. The potential seepage rate can be estimated by (Cedergren, 1977):

$$q = 2KDH$$

where: K = permeability of the soil
q = flow rate
D = diameter of intake area
H = head at the intake

Table 9.1 summarizes the estimated seepage through the impoundment resulting from liner leaks. As indicated, the resulting value of 0.006 USgpm is insignificant. From a water quality standpoint, a synthetically-lined system would therefore appear to be the best available technology for seepage control approaching zero discharge.

9.4.4.3 Collection System for Tailings Seepage Discharge

If tailings seepage were great enough to be detectable, down-gradient of the tailings facility, measures would have to be taken to prevent further migration and minimize degradation to the surface and groundwater quality. As a worst case, this seepage could amount to 160 USgpm (that is, the case of an unlined impoundment) if the liner was to completely deteriorate over time. Significant releases could also occur if there was a "catastrophic" liner failure. A potential control system which could be implemented would be a groundwater pump-back system, with water returned to the tailings pond or directly to the treatment system. Although it is possible that the quality of the seepage water would improve with successive displacements of tailings pore water, there are no data at present to support this conclusion.

Analyses indicate that such a system would consist of approximately twenty wells in a line downstream from, and parallel to, the main axis of the tailings impoundment. Costing for this contingency measure is indicated in Section 10.0.

The backup contingency measures are considered feasible because of the interconnected nature of the fracture system, as determined from pumping tests in the impoundment area (Budo, 1988, a, b or c). However, they could result in having to operate a treatment system indefinitely.

10.0 MINE WASTE MANAGEMENT AND RECLAMATION COSTS

10.1 General

Cost estimates have been prepared for the construction, operation and closure of mine waste and water management facilities at High Site 1. The cost estimates consider a base case, described in Section 6.1.1, as well as two alternatives related to the lining of the tailings impoundment.

These costs, a summary of which is included below in Tables 10.1 and 10.2 with more detailed backup included in Appendix D, are based on the conceptual waste management and reclamation plans. These estimated costs should therefore be regarded as approximate. Should further assessments of the feasibility of the project and/or the next phase of design be undertaken, these costs should be re-evaluated.

10.2 Construction Costs

The estimated construction costs for the base case and two alternatives are summarized in Table 10.1. As described previously, the base case consists of a double impoundment (one for gossan tailings and one massive sulfide tailings and massive sulfide mine rock), a single composite till/synthetic liner for both tailings impoundments, rock underdrains, diversion ditches, outlet structures, a reclaim barge, interception ditches, a seepage collection pond, a pump for a transfer of water which collects in the seepage collection pond to the tailings impoundment and a water treatment facility. The capital cost estimate allows for a very substantial water treatment facility at an estimated capital cost of $5,000,000. This estimate is considered appropriate given the level of treatment required and the present uncertainty in influent water quality. Also included in the capital cost estimate is an allowance for engineering and construction management (10 percent of the contractor's estimated fees). Not included in the capital cost estimates are the cost of mining and loading of the waste materials to be used for embankment construction, nor the tailings and water pipelines. The former is assumed to be included in the mining costs; the latter are assumed to be included in the capital cost of the mill.

The alternatives involve different liners for the tailings impoundments. Alternative 1 is the base case, with selective till placement, a HDPE liner and 18 inches of sand bedding over the synthetic liner. Alternative 2 is no liner at all. Alternative 3 is comprised of a double synthetic liner separated by a "sandwich" of sand.

To minimize the level of effort of the current study, unit costs prepared previously by IECO (1988) have been used to formulate many of the current costs. The IECO unit costs, where used, were increased by 15% to account for inflation.

The capital costs shown in Table 10.1 have been calculated based on total quantities. This is suitable for purpose of comparing the cost of different alternatives that would be similarly staged. The total capital cost for the "base case" could be staged as follows:

STAGE	YEAR	$ (millions)
I	0	4.6
II	2	19.0
III	7	12.1
TOTAL CAPITAL COST		35.7

Assuming the above cost schedule, the present value of the total capital cost is $25.2 million ($1.10 per ton of ore mined), discounted at an interest rate of 12%.

10.3 Operating Costs

The estimated operating costs for the base case and its alternative are summarized in Table 10.2. With respect to the operating costs, the base case consists of discharge of tailings to the tailings impoundment, disposal of sulfide mine rock to the massive sulfide tailings impoundment, disposal of all other waste materials to the area immediately downstream of the confining embankment at the massive sulfide tailings impoundment, recycle of water from the tailings impoundments to the mill and treatment and discharge of excess water from the tailings impoundment. The operating cost estimate allows for water treatment at a cost of between 0.3 ¢/gal and 0.7 ¢/gal, depending on the quantity of water treated.

10.4 Closure Costs

The estimated closure costs for the base case and its alternative are summarized in Table 10.2. The base case consists of dumping the foot wall rock back into the open pit, placing a fillet constructed from till and hanging wall rock against the portions of the pit wall which are potentially acid generating, constructing a discharge structure at the open pit, backfilling the pit with water, covering the tailings with a till cap, shaping the waste areas downstream of the tailings impoundment and revegetation of all disturbed areas. The closure cost includes an estimated cost for lime addition to the pit during backfilling to control the pH of pit water. The cost estimate has been based on the quantity of lime required assuming acidity of 0.1% by mass is contained in the rock. This assumption is not based on test results and is made in order to make allowance for the cost of lime addition. The assumption is based on experience and takes into account limestone addition in the foot wall rock stockpile during operation.

10.5 Conclusion

While we have not built these waste disposal costs into an overall economic evaluation of the project it is apparent that the incremental costs should not of themselves be a fatal flaw with respect to project viability.

TABLE 10.1
Construction Cost Summary

	Alternative 1 (Base Case)	Alternative 2 (No Liner)	Alternative 3 (Double Synthetic)
GOSSAN IMPOUNDMENT			
- Materials and Contracting	$ 3,806,578	$ 1,590,748	$ 5,280,628
- Engineering and Construction Management	$ 380,658	$ 159,075	$ 528,063
- Total Cost	$ 4,187,236	$ 1,749,823	$ 5,808,691
- Cost per ton of gossan ore mined	$ 3.47	$ 1.45	$ 4.82
MASSIVE SULFIDE IMPOUNDMENT			
- Materials and Contracting	$28,656,514	$16,913,314	$40,759,584
- Engineering and Construction Management	$ 2,865,651	$ 1,691,331	$ 4,075,958
- Total Cost	$31,522,165	$18,604,645	$44,835,542
- Cost per ton of massive sulfide ore mined	$ 1.45	$ 0.86	$ 2.06
TOTAL COST	$35,709,401	$20,354,468	$50,644,233
COST PER TON OF ORE MINED	$ 1.56	$ 0.89	$ 2.21

TABLE 10.2
Operation and Closure Costs - Tailings Impoundment & Mine Rock Storage Piles

	TOTAL COST	COST/TON
OPERATING COSTS		
- yearly	$ 1,794,827	
- Total (over 15 years)	$26,430,100	$ 1.15*
CLOSURE COSTS	$24,806,180	$ 1.88*

* cost/ton of ore mined

** cost/ton of foot wall rock

11.0 POTENTIAL TECHNICAL AND ECONOMIC FATAL FLAWS

An evaluation of the permitting requirements and the attainability of the permits needed for development of the project are excluded from the scope of this study.

It is our opinion that, under the proposed mine development plan, there are two areas of substantial technical concern which may prove to be fatal flaws. These concerns relate to water quality in the receiving environment, both during operation and following mine closure.

11.1 Quality and Quantity of Water During Operations

The water balance indicates that excess water quantities in the range of 200 to 600 USgpm may be anticipated, depending largely on the percentage of recycle of tailings water that can be achieved. Recycling rates in excess of 90% will be required to achieve the lower figure. This recycling rate must be investigated further to determine if it is achievable.

With excess water values in the lower ranges there is still a considerably greater quantity than has been considered in previous evaluations. This increased water quantity compounds the difficulty of water discharge. With direct discharge the dilution potential in both Bald Mountain Brook and Clayton Stream is limited and would require high standards of water treatment. Even with site specific water quality standards in Clayton Stream, to limits to protect the stream ecosystem, the required water quality standards will be very onerous. Storage of contaminated waters to allow timed releases and the application of state-of-the-art treatment methods and operating skills would be required if adequate water qualities are to achieved. Given the state-of-the-art, there is considerable doubt as to the reliability with which such high standards could be consistently achieved.

The potential for land application reduces as the quantity of excess water increases. Large areas of land application are required and concerns exist regarding the potential for remobilization and migration of precipitated metals. There appears to be little merit in this form of discharge for the larger flows anticipated at the Bald Mountain Project.

11.2 Quality and Quantity of Water Following Closure

The long-term quality of surface water is likely to be influenced by discharge of water from the tailings cover and from seepage from the tailings impoundment, following deterioration of the geomembrane liner. While these may not represent fatal flaws, water quality has not been quantified in this study and remains a concern. The quality of surface discharges from the flooded pit is of considerably greater technical concern. The mine rock would contain the products of acid generation that would have occurred during the period of exposure on the surface. While the rate of acid generation in the submerged rock may be limited, this together with the potential for leaching of the acid products is not known. The solubility of sludges from lime treatment of acid mine drainage has been demonstrated to be of concern at values of pH below a threshold value which generally occurs between 6 and 7, depending on the nature of the sludge. The porous nature of mine rock and resultant potential for groundwater movement increases the likelihood of leaching. Groundwater entering the pit, through the pit walls under the till cover, may also contain products of acid generation occurring in the covered pit walls, albeit at reduced rates. There is insufficient data to reliably predict the quality of the pit waters. It is our opinion that these waters could be of such a quality that it would not be possible to achieve water quality criteria in Clayton Stream.

11.3 Economic Concerns

The costs determined for the tailings, water and waste rock management, while representing a substantial increment over more conventional plans, do not themselves appear to represent a fatal flaw.

12.0 CONCLUSIONS AND RECOMMENDATIONS

There are technical concerns with the proposed mine development and waste management plan as described in this review document. These concerns relate primarily to the maintenance of water quality in the downstream environment both during operations and post decommissioning. These concerns may prove to be fatal flaws unless it can be demonstrated that these issues can be addressed by technically and economically feasible means, incorporating appropriate contingencies and factors of safety against failure. This may be achieved through either:

- further evaluation of the existing plan, or
- modification of the current mining and waste management plan.

The following recommendations derive from this conclusion:

i) Perform additional testing and evaluations to confirm, by qualitative results, the validity of the technical concerns and obstacles to permitting.

ii) Identify the operating conditions and site conditions required at mine decommissioning to eliminate, or minimize, the concerns with regard to water quality in receiving waters.

iii) Evaluate alternative mine and mill development strategies that would meet these conditions, or objectives, i.e., adopt a "design for closure" approach.

A number of alternative strategies could be considered, including:

- Reducing the size of the pit, and in particular reducing the height of the exposed high wall, thereby also reducing the quantities and areas of the tailings and mine rock stockpile areas.
- Mining the gossan as an open pit and limiting acid generation in the final pit by means of a till cover. Mining the massive sulfide by underground methods which would result in a stable crown pillar with flooded workings. This would reduce the quantity of potentially acid generating mine rock as well as acid generation from the exposed pit slopes above the water table.
- Placing all potentially acid generating mine rock underwater in the tailings impoundment, in combination with a modified mine plan to reduce the area of potentially acid generating rock exposed on the highwall, or a modified pit slope to allow placement of a till cover directly on the pit wall above the flooded water level.
- Evaluating strategies to increase the percentage of recycled tailings water.

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STATE OF MAINE

INTER-DEPARTMENTAL MEMORANDUM

DATE: September 13, 1990

TO: Mining Task Force & Work Group DEPT: Environmental Protection

FROM: Mark Stebbins, QAO DEPT: Environmental Protection

RE: Bald Mountain Tour and Presentation/August 30, 1990

****

Provided below is a summary of the highlights of the Bald Mountain Tour & presentation. (See attachment for attendees.)

Boliden presentation:
J. Cesar - President Boliden
H. Lewis - Chief Environmental/Regulatory Affairs
M. Scully - Chief Geologist
P.M. Sandgren - Mill Manager
M. Robb - Mine Manager

Introduction: J. Cesar

Tentative schedule for the Bald Mountain Project (drafted 4/90).

	No EIS	EIS
Regulations adopted	2/91	2/91
Baseline Complete	6/91	6/91
Applications submitted	7/91	7/91
EIS determination	No	Yes
EIS complete	N/A	5/93
Applications approved	7/92	10/93
Begin construction	10/92	10/93
Begin production	6/93	7/94

Geology of Site: M. Scully

-Ore and Body size is 1200' x 900' x 800', stratabound deposits.
-Type - Massive sulfide ore deposit, submarine Volcanogenic.
-Stratigraphy: 40' - 60' of glacial till.

Hanging Wall: Tuff, Clert, Andesite.
Footwall: Tuff, Breccias, Basalts.
Massive sulfide: Zinc, copper & stringers
Structures: Faulting & folding
Mineralogy: Gossan cap (mine for gold) Goethite, Limonite, Quartz
Zinc - Pyrite, sphalerite, Quartz, Arsenopyrite
Copper - Pyrite, chalcopyrite, Pyrrotite, Quartz
Secondary copper - Pyrite, chalcocite, Arsenpyrite.

Drilling Info:

Past drilling by Superior & Cheveron (1977-1988). Total number of drill holes 508. Cost $8 million. Current drilling by Boliden, 12 holes at a cost of $150,000. Reclamation on all drill sites and other exposed areas by seeding, mulching, fertilizing and liming.

Environmental Affairs: H. Lewis

History: Superior Mining 1978-1983, large-scale study area that included air, land and water resources studies. Reports were never finalized and no permit applications were submitted.

-Cheveron 1987-1989, conducted supplementary baseline studies to fill in data gaps (ground-water, macroinvetebrates, vegetation). Limited agency interaction and no permit applications submitted.

-USGS - (United States Geological Survey) 1979-1984 studied surface water quality, hydrology and meteorology. Data contained in a 1989 USGS Publication.

-Boliden's baseline activities

Air Quality 1 year program that includes the following:
*Wind speed, direction and temperature. Data collection
*PM-10 Monitoring Program - Particulate monitoring less than 10 microns.
*Database for modeling for air emissions license
Cost: $160,000

Surface Water Quality & Hydrology

*Monthly sampling for 1 year for 40-50 parameters. Includes 6 stream sites and 2 lakes sites.
*Storm surveys, spring and fall (collecting water quality info.
*Sediment sampling
Cost: $250,000-$300,000

Ground Water Quality and Hydrology

*Consultant hired - R. Gerber, Inc.
*Quarterly for 1 year/40-50 parameters.
*Monitoring wells in both glacial till/bedrock aquifers.
*Pump tests for GW Modeling
Cost: $250,000-$300,000

Aquatic Ecology

*Aquatic insects
*Fish populations
*Stream habitat
*Fish tish analysis
Cost: $80,000-$120,000

Terrestrial Ecology

*Vegetation cover types
*Threatened plant studies
*HEP baseline assessment
*Deer wintering areas
Cost: $75,000-$100,000

Wetlands

*Field inspection by U.S. Army Corp. of Engineers
*Supplementary soil & vegetation sampling
*Inventory of wetlands around site
Cost: $15,000-$20,000

Other Baseline Studies

*Land-use within a 5 mile radius
*Social economics
*Visual analysis
*Traffic
*Cultural resources
*Noise
Cost: $100,000-$200,000

Potential Permitting Issues

-Wetlands
-Bald Mtn. Brock (Class A flows into a Double A stream)
-Water Management
-Acid mine drainage
-Reclamation on open pit & tailing ponds

Mining operation - Mike Rabb

-Run mine 2 shifts a day, 5 days a week
-Mine gold the first & second year of operation
-Mine copper/zinc in the 3rd year of operation
-Two options on size of mine (tons of ore mined).
    *2 million tons/year (entire deposit) for 13 years
    *750,000 tons/year
-Employ 80-130 people
-No housing units on site
-Mining operations are regulated by Mine Safety & Health Administration (stringent standards on dust control).
-No new roads, upgrade existing roads (Fish River Road)
Power - Need 5 - 13 m. watts
    Options: Powerline from Ashland
             Generation on site

Mining Processing - P.M. Sandgren

-Two different processes for the gold & copper
    Gold: Agitation leaching in vats (Cyanide)
    Copper: Froth Flotation
-Water treatment system & tailings
-Mill water requirements, total 1400-3600 gpm, recycle 1000-2500 gpm. Need additional 400-1000 gpm - of fresh water. Possible sources include runoff - R. GW wells.
Note: Potato processing plant uses 3500 gpm of water.

-Treatment of excess water by the following mechanisms:
*Lime treatment (most common & cheapest)
*Ion exchange
*Reverse Osmosis

-Disposal of excess water
*Steam evaporation
*Spray irrigation
*Disposal to surface waters

-Tailings Pond design: Composite liner
Synthetic liner
Till
Rock fill/finger drains
Till/bedrock

-Issues remaining for mill design
*Processing
*Water balance
*Reagent scheme
*Base for plant design and layout

Notes of Interest

D. Basley, Inland Fisheries, Carr Pond, 75-80 feet deep, cold water game species salmon, togue. Fed by Moose Pond stream which begins on the NE/E side of No Name Ridge. (Ore deposit located.) Moose Pond stream is the major source of smelts for Carr Pond. Eight camps on Carr Pond. Rich Hoppe, Wildlife Biologist, Concern about water fowl in tailings pond and bio-accumalation of metals by animals feeding on vegetation.

Special thanks to Nick Archer and Frank Wezner of the Presque Isle Regional Office for setting up the site visit.

Chronology of Key Events for Boliden Resources, Inc.

December 1989	Boliden Resources, Inc. met with the LURC director to discuss the permitting process for the development of an open pit sulfide mine.
June 1990	DEP accepted pre-application fee for submission of baseline monitoring plans.
July 1990	DEP staff reviewed preliminary Surface Water Monitoring Plan.
July 1990	LURC staff reviewed and offered guidance for proposed scope of Land Use Planning, Traffic, Visual Quality and Socioeconomic Data Collection Program.
July 1990	DEP staff commented on Biological Data Collection Program.
August 1990	MDIF&W staff reviewed and approved Terrestrial Ecology Program.
September 1990	The DEP staff reviewed the Air Quality/Meteorology Monitoring Program for the Bald Mountain Project and approved the monitoring site.
September 1990	Boliden Resources, Inc. presentation and tour of the Bald Mountain Project site in T12 R8 WELS.
October 1990	Boliden Resources, Inc. met with DEP and LURC staff to discuss the Hydrogeologic Work Plan.
November 1990	The DEP and LURC staff reviewed the Hydrogeologic Work Plan and requested the location and depth of monitoring wells be modified.
November 1990	MDIF&W and DEP staff reviewed and offered guidance for implementation of the Aquatic Ecology Work Plan.
December 1990	The MDIF&W commented on the Aquatic and Terrestrial Ecology Work Plan.
December 1990	DEP staff reviewed the Surface Water Baseline Monitoring Plan and rejected the PQL's submitted for the parameters.
January 1991	DEP staff met with Boliden Resources, Inc. to discuss the detection limits.
April 1991	The DEP staff conditionally accepted the revised Surface Water Baseline Monitoring Plan.

August 1991	Rules for Metallic Mineral Exploration, Advanced Exploration and Mining adopted.
September 1991	LURC and DEP staff met with Boliden Resources Inc. to discuss status of baseline plans . Boliden intends to use pre-existing data for surface water hydrology and archaeological studies.
October 1991	Boliden Resources, Inc. submitted to the DEP and LURC pre-existing data collected for soils, wastewater disposal and hydrology.
October 1991	Boliden Resources, Inc. submitted revisions to the Hydrogeologic Work Plan.
December 1991	Boliden submitted, and the DEP staff accepted, pre-existing data collected for surficial geology and soils at the Bald Mountain Project Site.
December 1991	DEP and LURC staff met with Boliden Resources, Inc. to discuss the revisions to the Hydrogeologic Work Plan.
January 1992	DEP and LURC staff approved the revisions to the Hydrogeologic Work Plan.
January 1992	Final air quality baseline results submitted to the DEP.
February 1992	Final surface water baseline monitoring results submitted to the DEP.

Although these work plans were approved in 1990, as of March 9, 1991, Boliden has not yet begun studies for: Aquatic and terrestrial ecology (except for macroinvertebrate data), groundwater monitoring, socioeconomic, traffic, land use, visual quality or noise studies. Some of these programs such as groundwater monitoring will take a year to complete once initiated.

Other Potential Permitting Issues:

- impacts to wetlands
- impact to Bald Mountain Brook (class A stream)
- water management
- acid mine drainage
- reclamation of open pit and tailings pond

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BHK

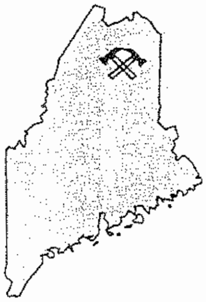
Black Hawk Mining Inc.

Volume 1

APPLICATION
FOR
MINING

Bald Mountain Project

T12R8
Aroostook County, Maine



NNM Resources, Inc.
wholly owned subsidiary of
Black Hawk Mining Inc.
Toronto, Ontario

APPLICATION FOR MINING

Bald Mountain Project
T12R8, Aroostook County, Maine

NNM Resources, Inc.
wholly owned subsidiary of
Black Hawk Mining, Inc.
Toronto, Ontario

prepared for:

Land Use Regulation Commission
Maine Department of Environmental Protection
Augusta, Maine

DECEMBER 1997

EXECUTIVE SUMMARY

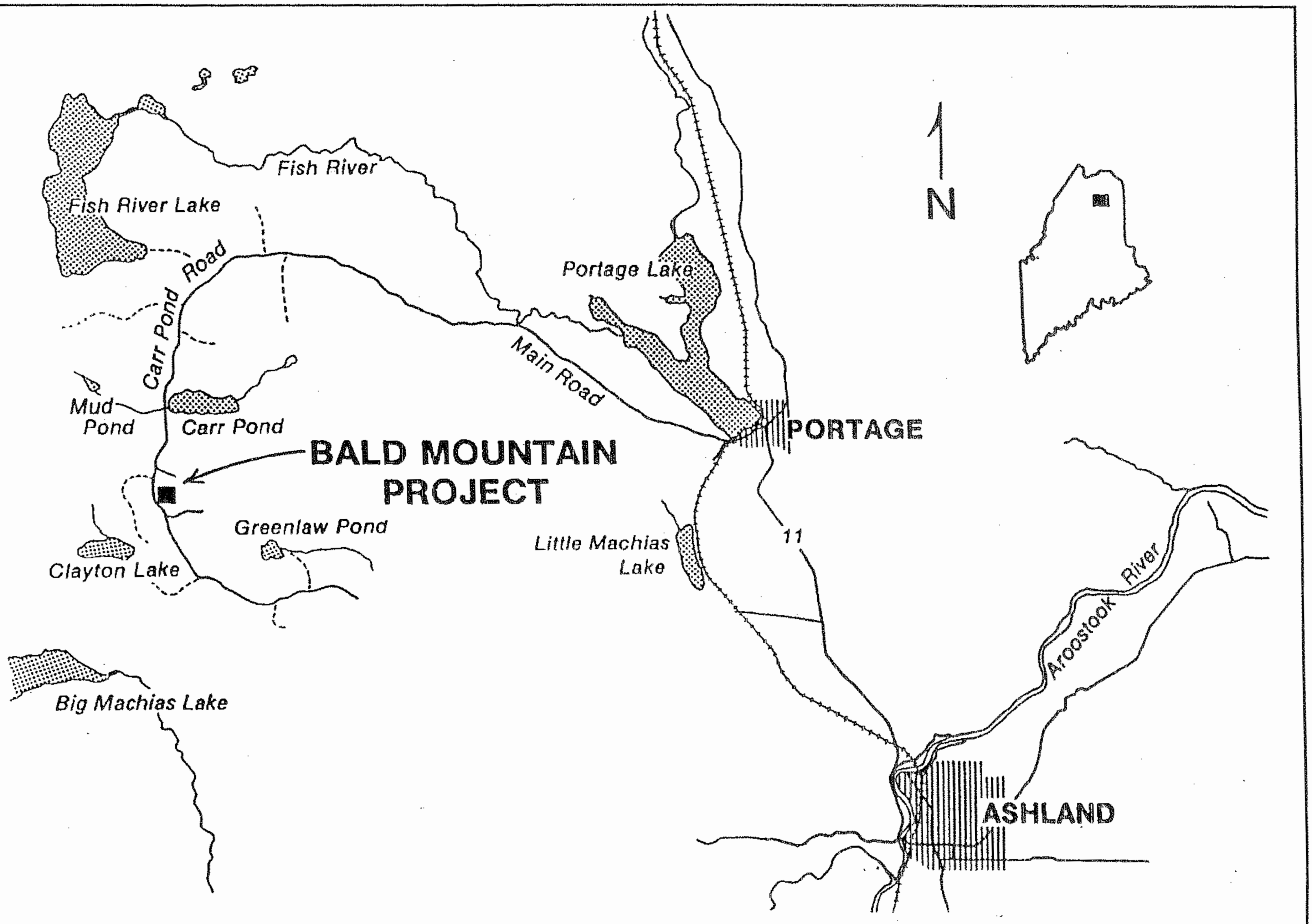
NNM Resources, Inc., a wholly owned subsidiary of Black Hawk Mining Inc. (Black Hawk), is proposing to develop a gold/silver mine in northern Maine known as the Bald Mountain Project. The ore body, discovered in 1977 through a regional exploration program based on geochemical sampling, is estimated to contain 35 million tons of massive sulfide (containing zinc, copper, gold, and silver). The gossan zone contains 1.2 million tons of 0.132 oz/ton gold and 2.94 oz/ton silver and has been naturally oxidized and leached of its zinc, copper and iron sulfides, leaving the gold and silver in a resultant sand-like gossan.

In 1995, Black Hawk purchased all the issued shares of Boliden Resources, Inc., the owner of the mining leases, and renamed the company to NNM Resources, Inc. Black Hawk is submitting this formal application for mining the gossan deposit. This application has been prepared in accordance with Chapter 13 of the Land Use Regulation Commission (LURC) regulations entitled, *Metallic Mineral Exploration, Advance Exploration, and Mining Rules (Rules)*. The application is a joint submittal to LURC and the Maine Department of Environmental Protection (MDEP). Black Hawk's development plans call for:

- removing topsoil and 40 feet of glacial till to expose the gossan zone
- mining of the gossan using standard gravel pit equipment and technology, with minimal drilling and blasting
- crushing and agglomerating the gossan at a production rate of 1,000 tons per day
- placing the agglomerated gossan in a walled (concrete basement) vat
- dissolving and recovering the gold and silver, recycling the leach solution, and washing and draining the agglomerate
- hauling the drained agglomerate to a soil lined landfill (with a leachate collection system) where it is piled, contoured, and covered

The studies performed for this application have identified and developed mitigation, in the most cost effective way, of all potential environmental impacts. This application includes:

- summary of the extensive studies performed at the site by numerous companies since 1979



Scale: as shown Date: Dec. 1997	Figure 1.2 Site Location Bald Mountain Project	**NNM Resources, Inc.** a subsidiary of **Black Hawk Mining, Inc.**

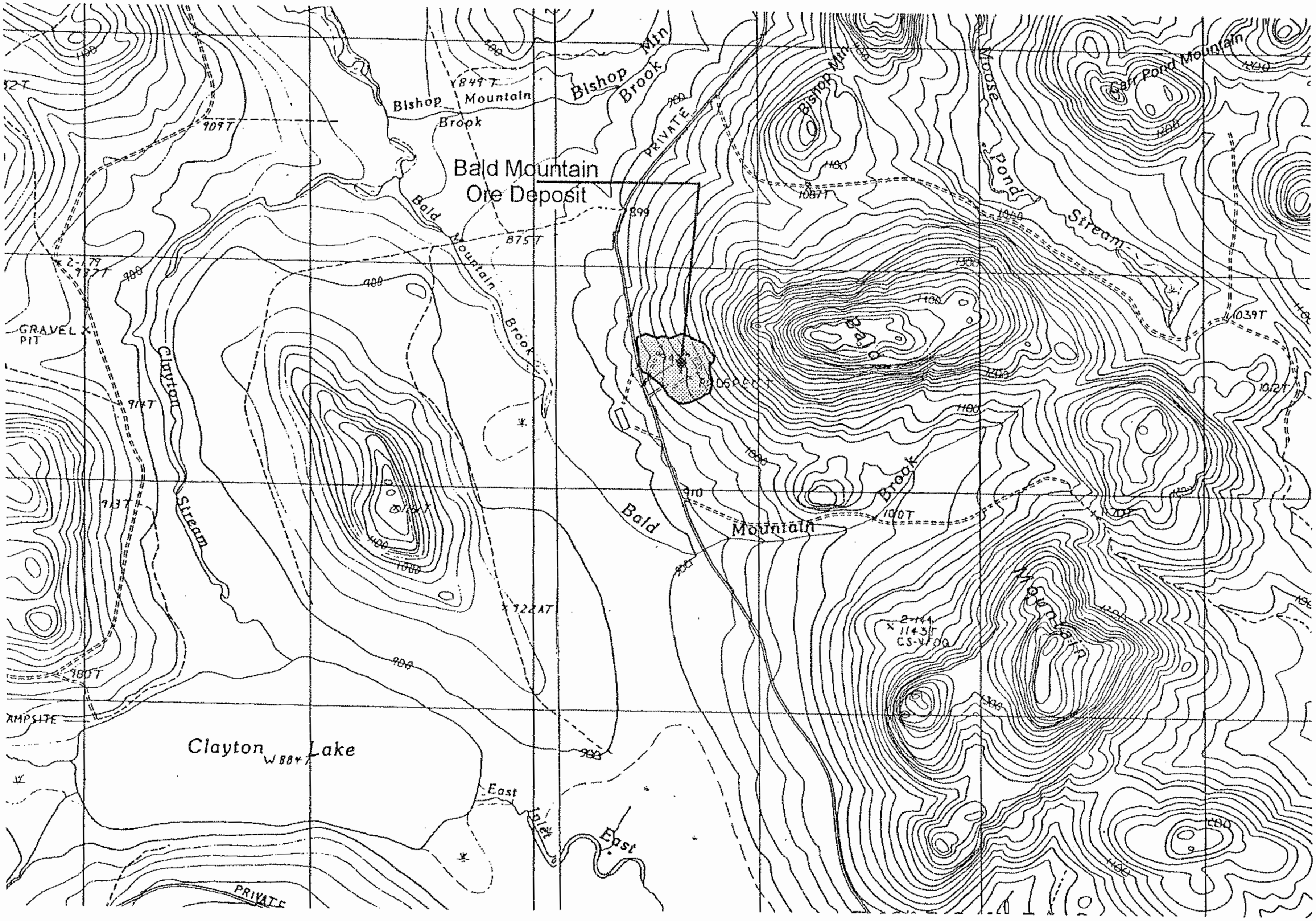


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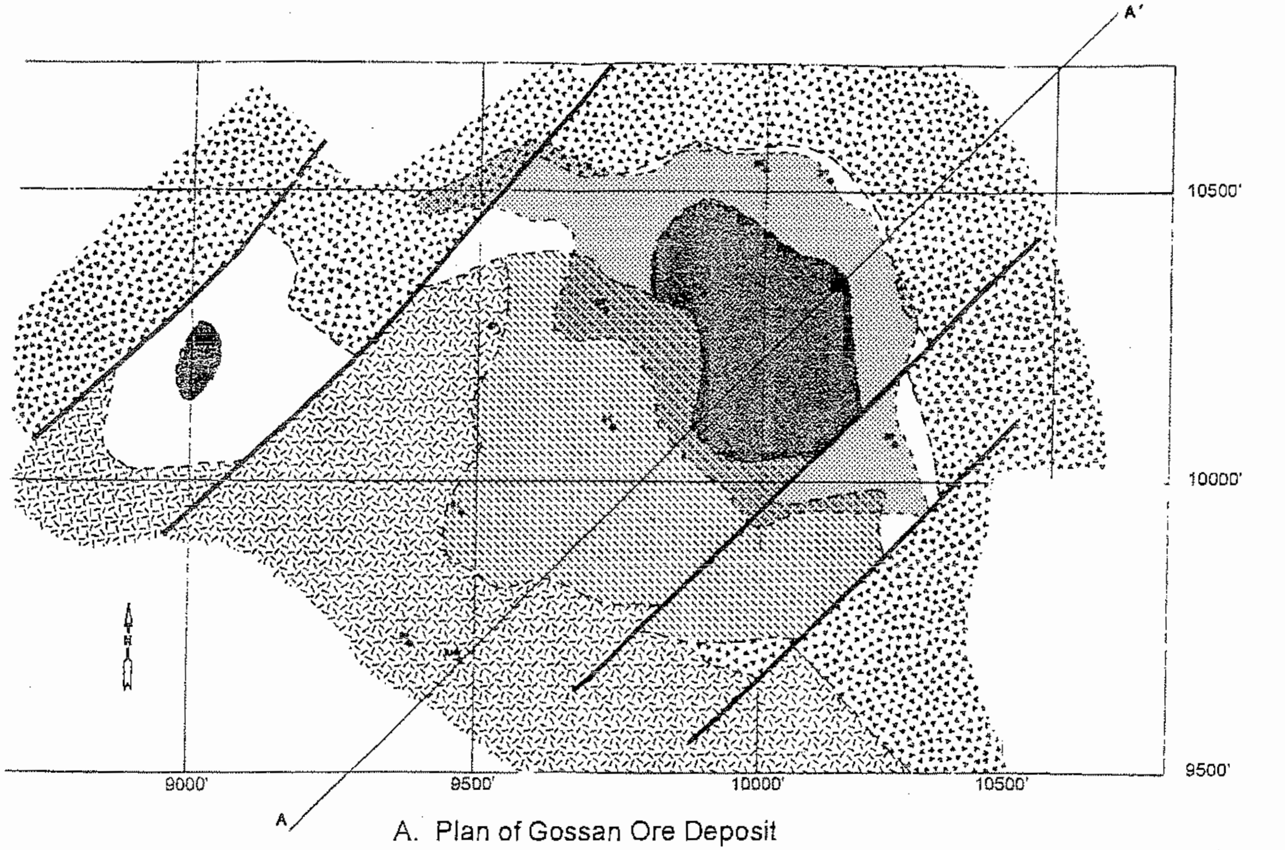
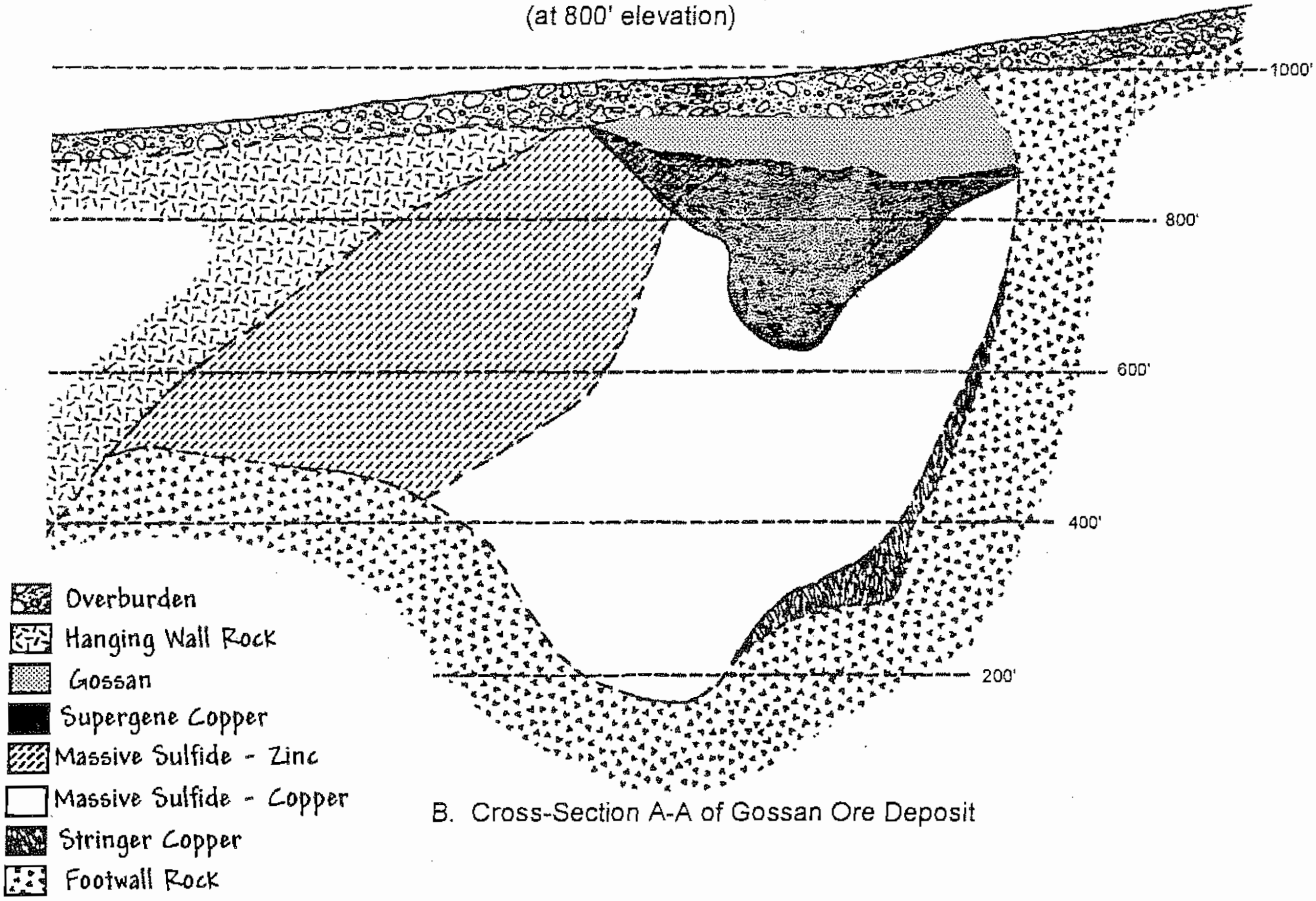
Figure 1.3
Location of Ore Deposit
Bald Mountain Project

NNM Resources, Inc.
a subsidiary of
Black Hawk Mining, Inc.



A. Plan of Gossan Ore Deposit
(at 800' elevation)



B. Cross-Section A-A of Gossan Ore Deposit

Scale: as shown	Figure 1.4 Gossan Ore Deposit Bald Mountain Project	**NNM Resources, Inc.** a subsidiary of **Black Hawk Mining, Inc.**
Date: Dec. 1997		

- results of the Baseline Monitoring Studies
- Environmental Impact Report (EIR)
- description of the extraction and beneficiation process
- mine waste treatment and management plan
- reclamation plan
- site monitoring plan
- description of other operating plans required by the Rules

This application, which includes the EIR, encompasses environmental, physical, cultural, land use, and socioeconomic impacts of the proposed project. It identifies measures for mitigating significant impacts, and proposes site and processing alternatives. The potential for unanticipated failures of the engineering controls at the site have been identified and alternatives for corrective measures presented.

The Mining Application is submitted in several volumes which include the Application for Mining, the Baseline Monitoring Studies, the Environmental Impact Report and companion reports prepared by Black Hawk and others. To support the Mining Application, other applications are submitted including:

- Petition for Rezoning
- Application for Air Emissions License
- Maine Waste Discharge License Application for Surface Waste Water Disposal System

7. MINE WASTE TREATMENT AND MANAGEMENT PLAN

Waste management at the Bald Mountain Project includes agglomerated tailings from the ore processing facility, overburden and waste rock from the mine pit, landfill leachate from the tailings landfill, and excess surface water and groundwater that has accumulated in the mine pit. This section describes the management plan for these wastes as described in Sections 31 through 35 of the Rules. Most of the discussion presented herein relates to the tailings landfill that has been designed in accordance with Sections 32 and 33 of the Rules. Management of other waste units are included at the end of each section in this chapter. Details of the mine waste treatment and management plan are presented in the *Civil Engineering Design Report* (Sevee & Maher, SM.030, 1997) included with in the Companion Reports. A plan view of the landfill is presented in Figure 7.1.

7.1 WASTE CHARACTERIZATION

In accordance with LURC's mining regulations (Section 31.C, Chapter13), a testing program was performed by Boliden (SRK: S.241, 1990; S.246, 1992) and Black Hawk (Wardwell: WA.031, 1997) to characterize the waste materials from the proposed mine and plant known as the Bald Mountain Project. As illustrated in Table 7.1, testing has been performed on all materials at the site including: footwall waste rock for both the gossan mine and massive sulfide mine; hangingwall waste rock materials including chert, tuff, and andesite and footwall rock along the full massive sulfide deposit. Also, ore material including gossan, supergene, and massive sulfide and agglomerated tailings associated with the extraction of gold and silver from the gossan deposit have been tested. Tests include both geochemical tests to evaluate the acid producing potential of the waste materials and geotechnical testing to support the engineering design of the disposal handling facility.

A summary of the test results is presented in the Waste Characterization Report (WA.031 1997) included in the Companion Reports. A summary of the test results is presented in this section.

7.1.1 Material Source

Core samples of the ore and waste rock were obtained from previous drilling programs performed by the various owners on the orebody. Residues from the gossan ore that was processed through a bench scale pilot plant were used for ABA and humidity cell testing.

Two types of gossan ore (goethite and limonite) have been identified based on their mineralogy. Samples of each were tested separately to determine the relative source of extracted mineral. While these minerals were tested separately, there are no plans to isolate the two minerals during the mining and ore processing. As will be demonstrated, there are no differences in the two types of tailings. Therefore, a composite of the two

Table 7.1
Geochemical Testing Details
Acid Generation Potential
Bald Mountain Project, Black Hawk Mining Inc.

Material	Sample	Boring		Tests		
		Number	Depth	TCLP	ABA	Humidity Cell
1. Waste Materials - Gossan Mine						
Tailings[a]	Comp 2	(note 1)			x	
	Comp 3				x	
	Comp 4			x	x	x
Tailings w/ waste rock (M21, M29, M87, M88, M90, M97)[a]	10-90	(note 2)			x	x
	15-85	(note 2)			x	x
	20-80	(note 2)			x	x
Waste Rock						
Gossan Ore[b]	SRK-1A/B	B7	116-131'		x	
		B7	141-156'			
	SRK-2	B7	131-141'		x	
	SRK-3A/B	B6	76-85'		x	
		B6	90-94'			
footwall waste rock[a]	Comp 1	(note 2)			x	
	Comp 5	(note 3)			x	x
	Comp 6	(note 4)			x	x
2. Pit Water Quality						
Gossan Footwall[a]	Comp 5	(note 3)			x	x
	Comp 6	(note 4)			x	x
Gossan Ore[b]	SRK-1A/B	B7	116-131'		x	
		B7	141-156'			
	SRK-2	B7	131-141'		x	
	SRK-3A/B	B6	76-85'		x	
		B6	90-94'			
Gossan Waste Rock[b] (beneath gossan layer)	SRK-4	B7	101-116'	x	x	
	SRK-5	B7	166-176'		x	
	SRK-6	B7	156-166'		x	
	SRK-7	B5	163-173'		x	
Supergene[b]	SRK-8	B2	295-320'	x	x	
Massive Sulfide - Wall Rock[b]						
Zn	SRK-9	B6	104-149'		x	

		Boring		Tests		
Material	Sample	Number	Depth	TCLP	ABA	Humidity Cell
3. Other Tests						
Massive Sulfide Footwall[b]	SRK-13A/C	B2	615-666'	x	x	x
		B7	358-395'			
		B8	127-167'			
	SRK-14A/D	B5	353-390'	x	x	x
		B7	323-390'			
		B8	43-127'			
		B8	167-229'			
Massive Sulfide - Wall Rock[b]						
Zn	SRK-10	B6	377-417'	x	x	x
Cu	SRK-11A/C	B5	205-271'	x	x	x
		B5	256-311'			
		B5	349-404'			
		B7	218-251'			
		C29	598-673'			
Massive Sulfide Waste Rock[c]		(Table 2, SRK 1990)				
pyrite	2 samples				x	
pyrrhotite	1 sample				x	
sphalerite	2 samples				x	
Hanging Wall Rocks[c]		(Table 2, SRK 1990)				
chert	3 samples				x	
tuff	2 samples				x	
andesite	3 samples				x	
Footwall Rocks[c]		(Table 2, SRK 1990)				
siliceaous volcanics	9 samples				x	
stringer sulfides	3 samples				x	
andesite	4 samples				x	

References

a. Lorax (1997), *Assessment of ARD and Metal Leaching Potential of Vat Leaching Residues and Waste Rock*, Bald Mountain Project, Black Hawk Mining, Inc.

b. SRK (1992), *Report on Mine Rock Acid Generation Potential*, Proposed Bald Mountain Project, Boliden Resources Inc.

c. SRK (1990), *Report on the Acid Generation Characteristics of Mine Wastes for the Proposed Bald Mountain Project*, Boliden Resources Inc., August.

Notes: Lorax (1997) samples-

1) tailings: Comp 2-goethite tailings; Comp 3-limonite tailings; Comp 4-composite from 55% goethite and 45% limonite tailings from bench scale tests
2) gossan waste rock composite: M21(32-218'), M29 (31-123'), M87 (32-355'), M88 (48-200'), M90 (28-189'), M97 (25-380')
3) Comp 5: M87 (57-110'), M88 (50-110'), M90 (75-105')
4) Comp 6: M87 (110-189'), M88 (110-190'), M90 (105-177')

samples from the bench test were combined and tested for geochemical and geotechnical characteristics.

7.1.2 Geochemical Testing Program

A program of ABA and humidity tests were performed on the waste rock core, and agglomerated tailings samples to determine their acid generation potential. A summary of the tests is presented in Table 7.1. These tests determine the leachate quality from each of the waste materials, as inferred by the rates of acid generation and metal release. In addition, the tests provide data on drainage water quality for preliminary water treatment estimation used in evaluating water handling procedures for the site (Wardwell: WA.040, 1997).

7.1.3 Summary of Results

ABA and humidity cell testing data are summarized in the Waste Characterization Report (WA.030). Details of the testing program and results are presented in the following reports included in the Waste Characterization Report:

- S.241 Report on the Acid Generation Characteristics of Mine Wastes for the Proposed Bald Mountain Project. Steffen Robinson and Kirsten. Report 80701/2. August 1990

- S.246 Proposed Bald Mountain Project, Report on Mine Rock Acid Generation Potential. Steffen Robinson and Kirsten. Report 80701/3. March 1992

- LX.010 Assessment of ARD and Metal Leaching Potential of Vat Leach Residues and Waste Rock. Lorax Environmental Services, Ltd., November 1997

Tests have already been performed on the gossan ore and waste rock waste (SRK 1992) to evaluate short term water quality in the pit during operations. As mentioned, additional tests were performed by Lorax for Black Hawk on a composite of the agglomerated tailings. Test results for the agglomerated gossan tailings and footwall waste rock were performed by Lorax on the following samples:

- Comp #1 - waste rock
- Comp #2 - goethite tailings from the vat leach process
- Comp #3 - limonite tailings from the vat leach process
- Comp #4 - composite of the goethite and limonite tailings
- Comp #5 - footwall rock sample
- Comp #6 - footwall rock sample

- mixtures of waste rock to tailings at the following ratios
    - 10-90
    - 15-85
    - 20-80

ABA testing on hangingwall samples (i.e. chert, tuff, and andesite) were performed by SRK for Boliden in 1990.

Based on the ABA testing, sulfide-S values are low in the tailings (Comp 2, 3, 4) and do not appear to contain enough reactive sulfur to be potentially acid generating. The lack of acid producing potential for the agglomerated tailings is confirmed by the revised net potential ratios (RNNP) of greater than 8 which are considered to be materials with sufficient buffering capacity (USEPA 1994).

Conversely, waste rock sample (Comp1) and remaining footwall rock (Comp 5&6) contain 0.6% to 2 % reactive sulfur and have RNNP ratios of -18 to -59, both indicating acid producing potential.

The five samples subjected to the ABA testing were examined petrographically and for total metal content. While the gossan tailings contains elevated levels of arsenic, there is a general absence of crystalline forms of iron arsenate (scorodite), suggesting that most of the arsenic is adsorbed to the surfaces of the iron oxyhydroxides.

A analysis of the ABA, petrographic and humidity cell test results for the Bald Mountain Project has produced the following conclusions:

- Vat leach residue samples of gossan ore (i.e. agglomerated tailings) do not appear to contain enough reactive sulphide to be potentially acid generating. These inherent properties, in concert with the added alkalinity from the agglomeration and cyanide leach process, demonstrates that leach residue material will not be a source of acid generation.

- Footwall rock samples contained significant quantities of reactive sulphide. Very little neutralization potential is available in footwall material and these rocks are predicted to be acid generating upon exposure.

- Vat leach tailings, when deposited in the landfill, are predicted to release elevated arsenic levels during periods of active infiltration and seepage. Similarly, elevated concentrations of cyanide, copper, mercury and silver are also expected during the initial flushing of residual metal-cyanide complexes in interstitial waters. Overtime, flushing and aeration through the pile is expected to result in reduced cyanide, copper, mercury and silver concentrations emanating in the seepage. Comparative reductions in arsenic concentrations overtime has not been observed.

While the gossan tailings leach arsenic and other metals, they will be contained in a landfill which includes provisions to collect the leachate which drains from this material. At closure, the landfill will be capped with an impervious composite barrier to prevent infiltration.

In addition to this testing, previous work was performed by Boliden to evaluate the acid producing potential of the hangingwall materials (i.e. chert, tuff, and andesite) that would be encountered during the deeper excavation of the massive sulfide (Table 2, SRK, S.241, 1990). The current mine plan does not anticipate excavation of these materials. Regardless, the initial ABA testing demonstrates that, if encountered, these materials would not be acid producing.

7.1.4 Waste Characterization Conclusions

Agglomerated gossan tailings do not appear to contain enough reactive sulfide to be potentially acid generating. These inherent properties, coupled with the added alkalinity from the agglomeration and cyanide leach process demonstrates that leach residue material will not be a source of acid generation. The sand-like material is drained but is still damp.

Footwall rocks and gossan waste rock contain fairly abundant sulfides mainly as pyrite, as these are the rocks through which the sulfuric ore forming fluids passed to produce the massive sulfide deposit. Sine they have very little neutralizing potential, they are acid producing.

Hangingwall rocks were deposited on top of the orebody after the main ore-forming process was completed. As such, they do not contain elevated levels of sulfides and are not acid-producing.

Based on the ABA and kinetic (humidity cell) testing, the agglomerated gossan tailings are classified as a Group B waste by the Rules. Hangingwall waste rock is classified as Group C mine waste. Footwall waste rock is classified as a Group A waste. The landfill is designed to contain only Group B and C wastes. Only material which passes through the ore processing facility and demolition debris at closure will be brought to the landfill.

7.2 HYDROGEOLOGIC ASSESSMENT

Hydrogeology for the Bald Mountain Project site has been studied in detail during previous years (JGA, 1981; WWL, 1982; W-C, 1982; Budo, 1988; RGGI 1990, 1991 and 1997). These studies were initiated by Superior Mining in 1980 through their consultant Woodward Clyde Consultants. Their work focused on developing the full massive sulfide deposit. A summary of the geologic conditions at the site was prepared by Gerber (G.010, 1990) and submitted by Boliden in 1991.

Three dimensional groundwater modeling for this site, including the present tailings landfill area, was performed for Boliden by R.G. Gerber Inc. in the early 1990's (G.011, 1991). This model was recently updated for Black Hawk by Gerber-Jacques Whitford (G.020 July 1997). This section summarizes the previous studies and the results of the recent modeling performed to evaluate the hydrogeologic conditions at the site. The Gerber reports are included in the Companion Reports for a full discussion of the assumptions and procedures used to evaluate the hydrogeologic conditions at the site. Their work has been incorporated into the landfill design presented in detail in the *Civil Engineering Design Report* (SM.030, 1997).

7.2.1 Hydrogeologic Conditions

The landfill site is underlain by a layer of overburden soil over bedrock. Overburden soil in the landfill area consists of a thin layer of forest duff/root mat underlain by dense glacial till. Based on the explorations made in the landfill area, the glacial till ranges in thickness from not present (bedrock outcrops) to more than 20 feet. The design report presents an overburden thickness map for the landfill area. In-situ penetration testing indicates that the glacial till is dense to very dense. The testing results are consistent with other laboratory tests performed by previous companies investigating the site (S.111, 1982; M.012, 1989). The water table in the till, where present, appears to be an unconfined perched condition caused by localized variations in hydraulic conditions. The majority of available groundwater generally lies in a thin veneer of fractured bedrock.

Based on the site topography and the vertical position of the bedrock encountered in the 1997 borings, the bedrock surface in the landfill area appears to downslope in a generally east to west direction. In the vicinity of the tailings landfill, there appears to be only one significant aquifer, that of the fractured surface of the bedrock. This aquifer ranges from confined to unconfined conditions through the general mine area, based largely on the thickness of glacial till. Local variations in the potentiometric surface appear to have other causes.

Based on the previous hydrogeologic evaluations(J.0050, 1981; WWL.010, 1982; W.170, 1982; SB.013, 1988; G.010 to 011, 1990, 1991, 1997) and on-site piezometric measurements, the landfill area spans the region of groundwater recharge (to the east, upslope side of landfill) and groundwater discharge (to the west, downhill side of landfill). Groundwater phreatic surface map and profile for the landfill are presented in the companion reports (G.020, 1997, SM.030, 1997).

7.2.2 Initial Modeling

Gerber - Jacques Whitford (GJW) previously performed work for the proposed Bald Mountain mine during 1990 and 1991. This work was done under contract with Boliden Resources, Inc. The project was to characterize the hydrology of the mine and waste disposal areas and to predict the impacts of operation and closure of the mine. The project was divided into three components: Hydrogeological Work Plan, Phase I Analysis and Report, and Phase II Analysis and Report. The Hydrogeological Work Plan and Phase I Analysis were completed and reports were submitted to Boliden (G.010, 1990; G.011, 1991).

The Phase I Report was submitted to Boliden on August 22, 1991. The report documented the field work and analysis performed by GJW. The field work included test pits, monitoring well installation, and a photolinear interpretation. The analysis consisted of developing a three-dimensional ground water flow model for the mine region, and simulating the ground water inflow to the active mine. The Phase II analysis, never initiated, would have analyzed the mining related impacts. The details of the initial groundwater model are documented in the Phase I Report (G.011).

7.2.3 Revised Boliden Model

The mine as proposed by Black Hawk is substantially smaller and much shallower than the Boliden proposal. In applying the existing model, it was decided to reduce the regional extent (grid size) of the model and refining the grid resolution in the mine and landfill areas. Other than these changes, and the manner in which the mine is simulated, the new Black Hawk model and older Boliden model are essentially identical (e.g., model layering, hydraulic conductivities, storage coefficients, and recharge).

Several scenarios were simulated using the revised model:

- pre-mine calibration to August, 1982, and 1990 water levels
- mine dewatering, inflow, and adjacent drawdown using the calibrated model
- sensitivity analysis of mine inflow
- particle tracking from the landfill for assumed failure conditions

7.2.4 Hydrogeologic Results and Conclusions

Based on the previous referenced studies, the landfill area is generally situated in a region of both groundwater recharge (east side of site) and groundwater discharge (west side of site). Groundwater phreatic surface map for the landfill, based on the results of MODFLOW simulations and existing site data, and hydrogeologic cross-sections are presented in the modeling report (G.012, 1997).

7.3 ENGINEERING DESIGN

Details of the stockpile and landfill design are presented in the *Civil Engineering Design Report* (SME, SM.030) presented in the companion reports. The Design Report includes a detail discussion of the siting criteria. This section summarizes the design of the tailings landfill, footwall waste rock storage, and handling procedures for excess water at the site.

7.3.1 Tailings Landfill

Landfill Configuration - The tailings landfill (landfill) will occupy approximately 20 acres of the project site as shown on Figure 7.1. The landfill is designed to be constructed and operated as a series of contiguous waste cells which have a combined waste capacity of 1.2-million cubic yards. The footprint will be underlain with a soil liner and leachate collection system to handle infiltration and internal drainage from the landfill.

To minimize leachate generation, the active landfill area will be restricted to a maximum of 4 acres during operations. In addition, portions of the landfill at final grade will be covered with a synthetic interim cover material (SICM) until the permanent landfill cover can be installed. SICM will act to shed essentially all precipitation from the covered portions of the landfill, thereby greatly reducing the quantity of leachate generated in those areas.

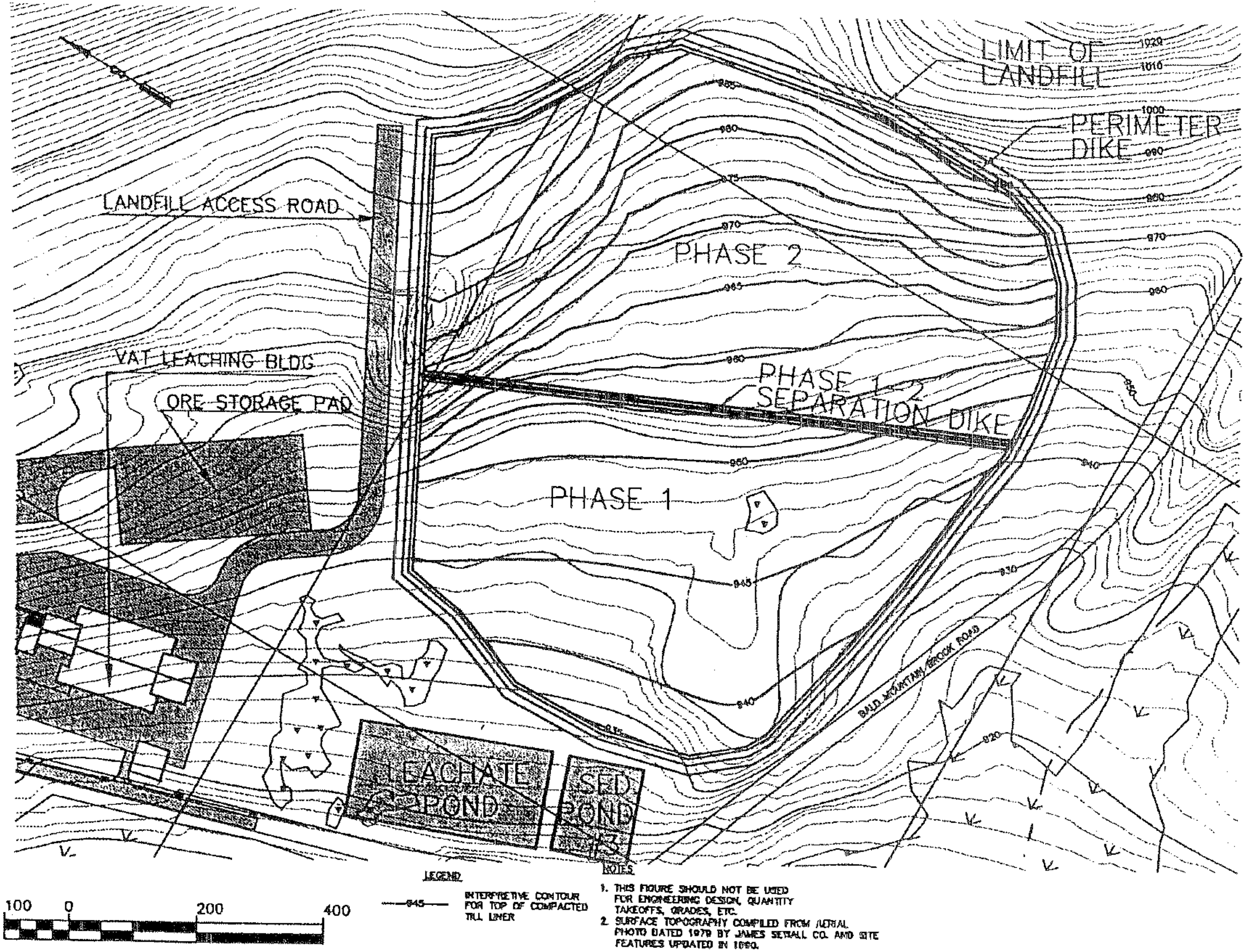
The landfill will be constructed in two adjoining phases as shown on Figure 7.1. The base grading plan for the top of the till liner is also shown on this figure. Together, the two landfill phases will have an approximate waste disposal volume of 1.2-million cubic yards , which is expected to be sufficient to hold the agglomerated tailings and site reclamation debris. Phase 1 of the landfill will be built during the first construction season, and Phase 2 will be built the next year. Figure 7.2 shows the final grading plan for the landfill.

Agglomerated tailings will be hauled from the processing plant to the tailings disposal area using normal earthmoving equipment. Access roads will be built on the tailings to provide mobility. These roads will be cleared of deep snow in winter. All snow on the active cell will remain within the cell footprint. In this way, snowmelt will be contained and collected in the leachate collection system. No tailings or meltwater will leave the active cell area.

Permanent landfill sideslopes will be inclined at angles not exceeding 3H to 1V in order to maintain slope stability. Horizontal benches will be located along the final landfill slopes at 30-foot vertical intervals to form breaks in the overall slope length. The benches will be approximately 30 feet wide and will serve to provide anchorage opportunity of the VLDPE cover and geocomposite drainage net. Drainage ditches will also be installed on the benches to intercept surface runoff and to collect drainage from the geocomposite drainage net. Riprapped sideslope drainage channels located transverse to the landfill final grades will be used to convey runoff collected in the bench ditches to the landfill perimeter. Final sizing of the bench ditches, drainage channels, and geocomposite drainage net will be completed as part of final design.

Landfill Liner - The landfill liner will consist of a 3-foot thick layer of compacted glacial till which exhibits a permeability of $1x10^{-7}$ cm/sec or less. The soil liner will present a barrier to leachate vertical movement equivalent to a 7-year travel time (based on a permeability of $\leq 1x10^{-7}$ cm/sec, hydraulic gradient = 1.0 and effective porosity = 0.25). Because Black Hawk plans to complete the ore processing/landfilling in less than 4 years, the landfill cover will be in-place before hydraulic breakthrough of the liner occurs.

Leachate Collection - The leachate collection system will consist of a network of finger drains comprised of perforated piping surrounded by drainage stone and filter sand. This system is described in detail in Section 8.1.2 of the *Civil Engineering Design Report*



LEGEND

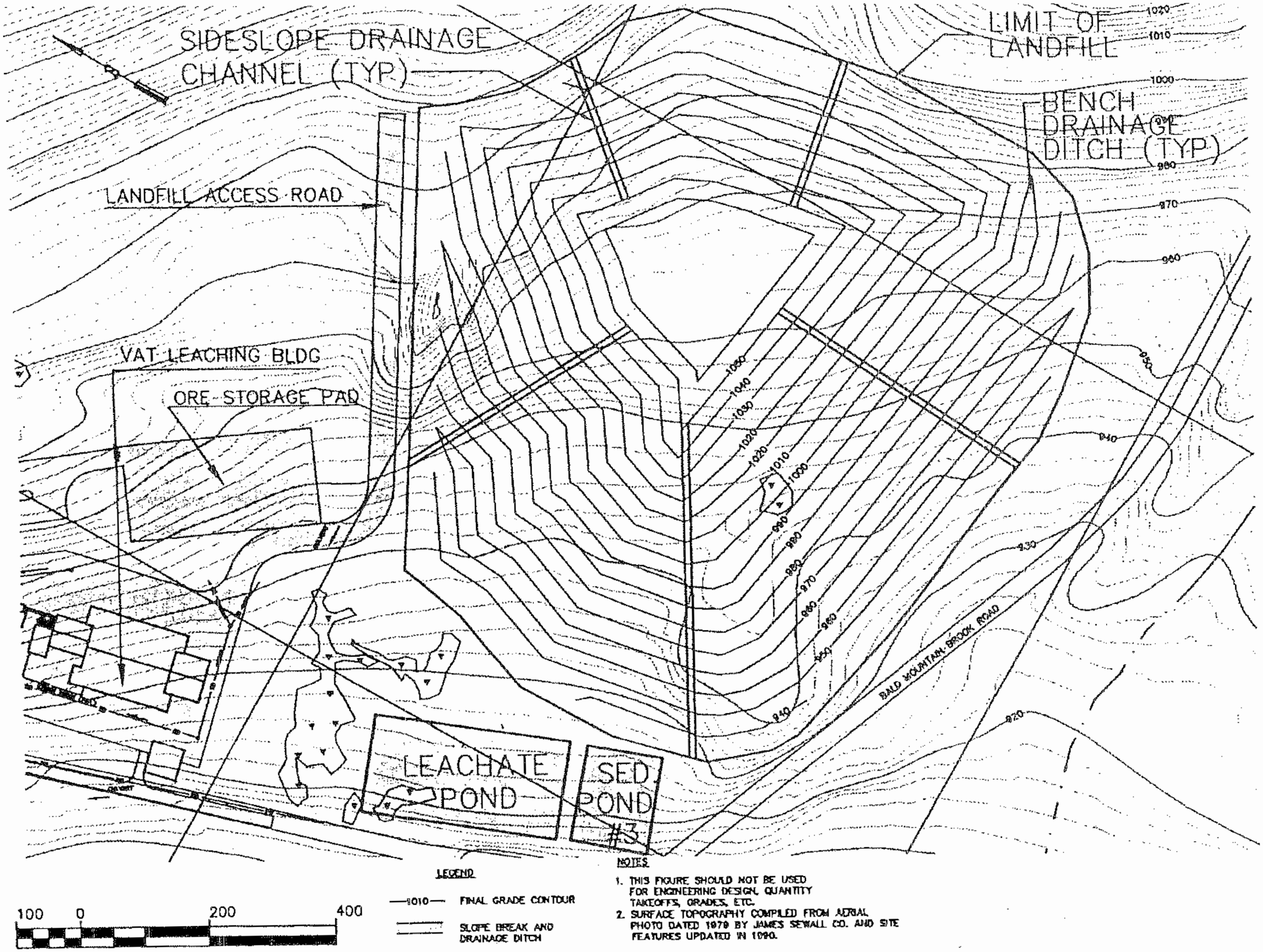
—945— INTERPRETIVE CONTOUR FOR TOP OF COMPACTED TILL LINER

NOTES

1. THIS FIGURE SHOULD NOT BE USED FOR ENGINEERING DESIGN, QUANTITY TAKEOFFS, GRADES, ETC.
2. SURFACE TOPOGRAPHY COMPILED FROM AERIAL PHOTO DATED 1979 BY JAMES SEWALL CO. AND SITE FEATURES UPDATED IN 1990.

(Ref: Figure 6.1, Sevee & Maher, SM.030)

Scale: as shown Date: Dec. 1997	Figure 7.1 Tailings Landfill Site Plan Bald Mountain Project	**NNM Resources, Inc.** a subsidiary of **Black Hawk Mining, Inc.**



NOTES

1. THIS FIGURE SHOULD NOT BE USED FOR ENGINEERING DESIGN, QUANTITY TAKEOFFS, GRADES, ETC.
2. SURFACE TOPOGRAPHY COMPILED FROM AERIAL PHOTO DATED 1979 BY JAMES SEWALL CO. AND SITE FEATURES UPDATED IN 1990.

(Ref: Figure 6.2, Sevee & Maher, SM.030)

Scale: as shown Date: Dec. 1997	Figure 7.2 Final Grading Plan, Tailings Landfill Bald Mountain Project	**NNM Resources, Inc.** a subsidiary of **Black Hawk Mining, Inc.**

(SM.030, 1997). The finger drains will be augmented by collection header pipes, inlet structures, and vertical drains. Post-closure leachate management will be use gravity drainage since permanent electricity, necessary for pumping, to the site is not planned. All leachate piping, inlet structures, and manholes will be constructed of HDPE. Leachate collected in the leachate pond will be pumped to the ore processing facility to be reused as process water. Procedures for handling leachate in the event of plant shut-down are presented in the design report. At the end of ore processing, leachate remaining in the leachate pond will be treated by destroying the cyanide. If CN contents are reduced to 0.2 mg/L or less, the water will be discharged through the land application area. If CN concentrations are higher, the water will be stored and shipped off-site for disposal at an approved facility.

7.3.2 Waste Rock

Acid producing waste rock from the footwall will remain in the mined out pit area. Non-acid producing waste rock from the hangingwall will be stored in the area of the till stockpile for use during reclamation.

Mine waste rock will be separated and handled according to its acid-producing potential. As shown on Figure 5.7, the spatial distribution of the hangingwall and footwall types is well defined from drilling information. All four types of waste materials (i.e. till, footwall rock, hangingwall rock, and gossan) will be easily distinguished based on visual inspections of their lithologies along the active excavation face. Consequently, management of excavation and haulage operations (in order to direct material to their appropriate storage piles) will be relatively straight forward based on the visual discrimination between these rock types in the mine pit. The excavation activities will be planned by the on-site engineering and geology staff. They will communicate their plan to the operations supervisor on a daily basis to control the transportation and storage of materials.

The northeast corner of the mine pit, where footwall and hangingwall rock are in contact as illustrated in Figure 5.7, will require more careful material assessment. Exposed pit wall rock will be visually inspected for sulfide content and will be handled accordingly. Due to the low levels of sulfide necessary for acid generation, a program of ABA testing will be performed on the blast hole chips to help determine the acid producing potential. Any acid producing rock will be identified based on the detail geologic inspection and ABA test results and remain in the pit for future burial and submergence.

7.3.3 Process Water and Landfill Leachate

All the vat leach solution will be recovered, stripped of its gold and silver content, and returned to the vat leach circuit.

All the water draining from the tailings landfill, as well as site runoff and pit inflow, will be collected and reclaimed to the process-water balance. If there is an excess water balance, the water will be treated on-site to meet environmental quality guidelines and then discharged.

7.3.4 Excess Water Collection and Treatment

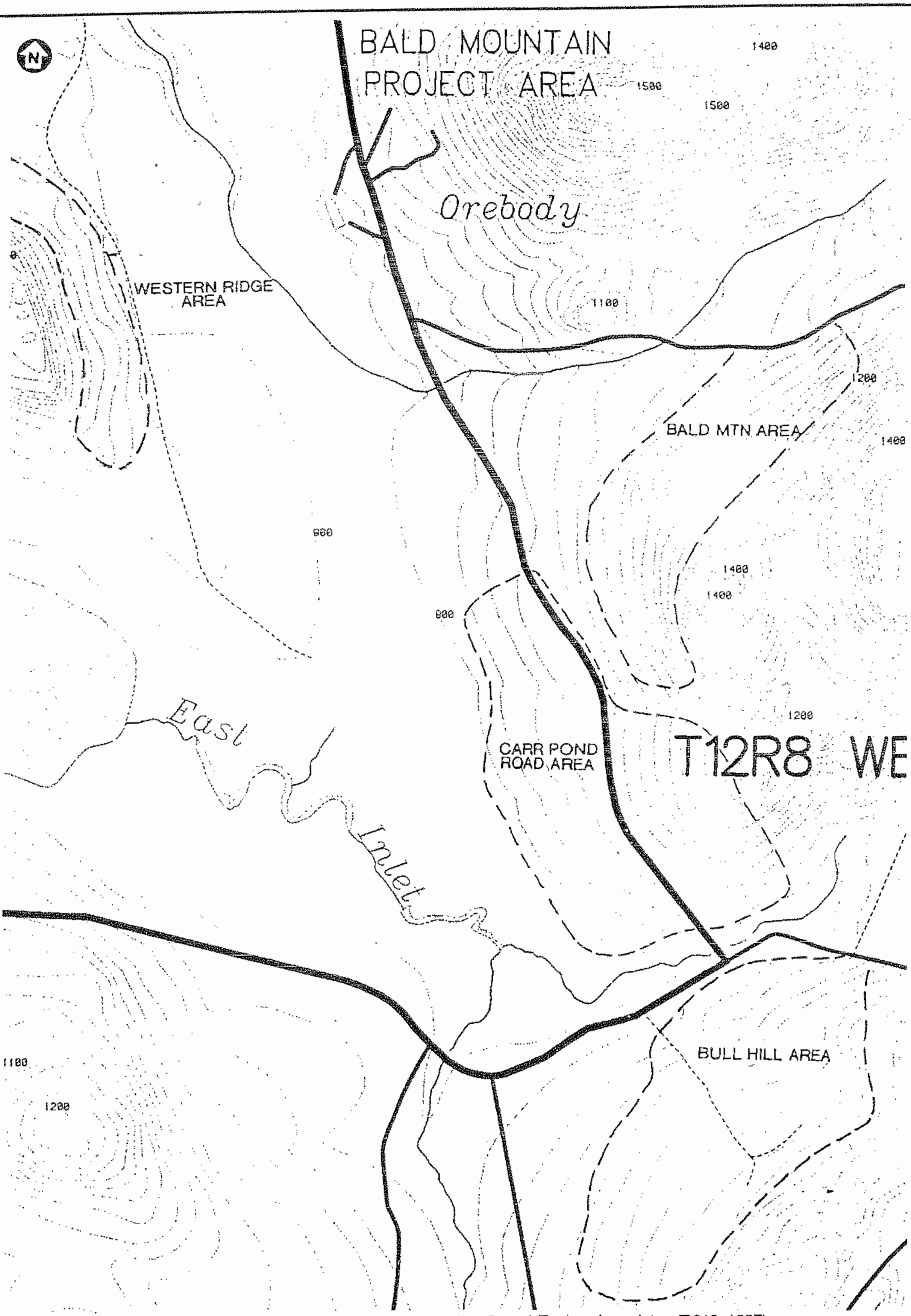
Excess water is limited to groundwater and surface water collected in the mine pit and runoff from the process area. The water quality is expected to be reflective of existing groundwater conditions (WA.040, 1997). The water is expected to be acidic and contain elevated metals. To mitigate this, excess water will be detained in storage ponds located to the south of the facility on the opposite side of Bald Mountain Brook. As a contingency, the ability to raise the pH of the excess water will be built into the collection system prior to pumping the water to the storage ponds (EE.010, 1997). Potential land application areas are shown on Figure 7.3. During the growing season, water will be applied to a land application area located along Carr Pond Road with the use of the Bull Hill site as a backup.

Water applied to the land application area should have no impact on water quality or aquatic resources in nearby receiving waters. The design report specifies the application rate, land area, and operation and monitoring requirements (TA.012 1997). These operational parameters have been based on detailed field studies in accordance with the detailed work plan, presented in Appendix C of the EIR Scoping Document (BH.010 1997). These conditions are designed to prohibit direct runoff into nearby water bodies.

Once operational, attempts to control groundwater into the mine pit will be considered. If dominant seeps are encountered in isolated defined fractured areas or fault zones during operations, investigations will be made to evaluate the potential of intercepting this water prior to encountering the exposed footwall rock. Water collected upgradient of the pit will be discharged into the perimeter ditches as clean water and routed to the detention basins located downgradient of the mine.

7.4 ENGINEERING REPORT

The engineering report is presented in the Companion Reports. In accordance with the guidance document submitted for LURC and MDEP review and comment (REW 1/31/97), details on some of the plans will be finalized as part of final design to be performed after license approval. A narrative discussing the contents of these plans and Black Hawk's commitment to the conceptual obligations associated with each plan is discussed in Section 15.



Ref: *Land Application Design Evaluation Report*, Tewhey Associates (T.012, 1997)

Scale: as shown

Date: Dec. 1997

Figure 7.3
Location of Land Application Areas
Bald Mountain Project

NNM Resources, Inc.
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BHK

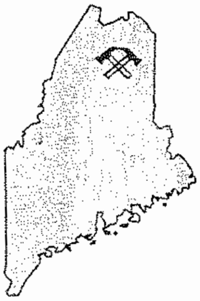
Black Hawk Mining Inc.

Volume 3

ENVIRONMENTAL IMPACT REPORT

Bald Mountain Project

T12R8
Aroostook County, Maine



NNM Resources, Inc.
wholly owned subsidiary of
Black Hawk Mining Inc.
Toronto, Ontario

ENVIRONMENTAL IMPACT REPORT

Bald Mountain Project
T12R8, Aroostook County, Maine

NNM Resources, Inc.
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prepared for:

Land Use Regulation Commission
(coordinating agency)
and
Maine Department of Environmental Protection
Augusta, Maine

coordinated by:
Richard E. Wardwell, P.E., Ph.D.
Orono, Maine

DECEMBER 1997

EXECUTIVE SUMMARY

NNM Resources, Inc., a wholly owned subsidiary of Black Hawk Mining, Inc. (Black Hawk) is proposing to develop a gold/silver deposit in northern Maine known as the Bald Mountain Project. In 1995, Knox Nickel Corporation, a wholly owned subsidiary of Black Hawk, purchased all the issued shares of Boliden Resources, Inc. (the owner of the mining leases) and changed the name of the company to NNM Resources, Inc. Black Hawk's plans are to permit, develop, and process only the gold/silver gossan zone which overlays the sulfide zone of the large deposit. The gossan zone contains 1.2 million tons of 0.132 oz/ton gold and 2.94 oz/ton silver. This zone has been naturally oxidized and leached of its zinc, copper, and iron sulfides leaving the gold and silver in a resultant sand-like gossan. Laboratory testwork confirmed that the gold and silver in the gossan can be leached and recovered by an environmentally friendly vat leach process.

Black Hawk is submitting a formal application for mining the gossan deposit. Development plans call for:

- identification and mitigation, in the most cost effective way, of potential environmental impacts
- removal of top soil and 40 feet of glacial till to expose the gossan zone
- mining of the gossan by standard gravel pit equipment and technology with minimal drilling and blasting,
- crushing and agglomerating the gossan at a production rate of 1000 tons per day
- placing of the agglomerated gossan in a walled (concrete basement) vat
- extraction and beneficiation of the ore by dissolving and recovering of the gold and silver, recycling the leach solution, and washing and draining the agglomerate
- hauling the drained agglomerate to a lined landfill where it is piled, contoured, and covered.

A mining application is being prepared in accordance with Chapter 13 of the Land Use Regulation Commission (LURC) regulations entitled, *Metallic Mineral Exploration, Advance Exploration, and Mining Rules* (Rules). The application is a joint submittal to LURC and the Maine Department of Environmental Protection (MDEP).

As part of the environmental review process, the Environmental Impact Report (EIR) has been prepared to be submitted with the Application. The EIR was prepared in accordance with the EIR Scoping Document (Black Hawk, March 1997). The EIR identifies environmental issues relevant to the proposed project, encompassing environmental, physical, cultural, land use, and socioeconomic impacts of the proposed project. It identifies measures for mitigating significant impacts, and proposes site and processing alternatives.

The major findings indicate that potential site impacts, relating to surface water and groundwater quality downgradient of the mine pit and tailings landfill have been minimized with the current mine plan. Attributes of the plan that help to minimize environmental impacts include the following:

- Location and weathered nature of the gossan layer almost eliminates the acid producing characteristics of the gossan and waste rock.

- Limited depth and granular nature of the deposit allows for routine excavation processes.

- Attributes of the vat leach process (to be used for ore beneficiation) helps minimizes environmental impacts and include the following:

  * small, isolated batch process
  * net consumer of process water
  * in a covered building
  * wet process therefore no dust
  * very quiet operation
  * leach solution recycled
  * no free water in the final agglomerated tailings
  * the final agglomerated tailings have an acid neutralizing potential because of the cement and lime used in the agglomerating step of the process
  * agglomerated tailings will be drained and trucked to the landfill in a dry stable condition.

- Overall land disturbance is small; no streams are altered and less than 1 acre of wetlands are disturbed.

- Abandonment of the site, including the tailings landfill, will result in a revegetated site contoured to blend with natural conditions.

- Mine site is an isolated area away from towns and lakefront cottages.

The EIR demonstrates that potential impacts from the proposed mining activity have been controlled and mitigated. The potential for unanticipated failures of the engineering controls at the site have been identified and alternatives for corrective measures presented.

6. SOCIOECONOMIC IMPACT ASSESSMENT

Black Hawk retained Dames & Moore (D&M) to perform an updated socioeconomic study for the reduced mining plan and using updated information. The current study was performed in accordance with a work plan approved by LURC and DEP (October 23, 1991) to fulfill requirements of the state's Rules. It builds on the previous study performed by Superior Mining (E.043, 1982). Following completion of supplemental field-related work and data collection, a report was prepared to document results of the socioeconomics study (DM.010, 1997). As presented in the companion reports, data was summarized in table and figure format with supporting appendices. Local and regional literature sources that corroborate results of the investigation were cited.

Socioeconomic analyses typically have a three part sequence leading to the actual impacts. The typical stages are: new employment, in-migration, and population changes which then cause the majority of the social and economic impacts. The proposed Bald Mountain Project is significantly smaller than previous proposals considered by Superior Mining, Chevron, and Boliden Resources. The smaller direct employment leads to significantly smaller effects through the chain of in-migration, change in population, and resulting impacts.

The following sections summarize the potential impact of the mine on the socioeconomic conditions in the region (DM.010, 1997). Baseline socioeconomic conditions are discussed in detail in the report and summarized in the *Baseline Monitoring Studies* being submitted as part of the application.

6.1 SUMMARY OF SOCIOECONOMIC STUDY

The construction and operation of the Bald Mountain mine will provide benefits and impose relatively minor demands on the surrounding communities. The magnitude of the impacts from the current proposal are very different from earlier studies for other possibilities at this mine site. Land use, employment, duration, and indirect impacts are all a fraction of the size of earlier estimated impacts. Nonetheless, the Bald Mountain Project would have been listed in the top 10 additions of new employers for the State of Maine in 1996, so that the job impacts are still meaningful.

The potential socioeconomic impacts associated with the Bald Mountain mine site have changed in important ways since a 1982 socioeconomic study (E.086, 1982). The change is primarily due to a significantly smaller scale of operation with about 75 employees during the operation phase of the proposed project instead of about 200 employees in the previous study. The construction phase is even more dramatically shortened from 2.5 years to 6 months with the current project and a corresponding reduction from 385 to about 60 construction workers.

The Bald Mountain project is not likely to create the kind of problems associated with intense activity associated with construction and the reduced impact of operations at closure. The construction period is relatively short, 6 months, the construction crew relatively small, and the construction work force is the approximate size of the operations work force. All these factors suggest that there will not be large new demands for local services nor will there be a large decline with the transition to the operations phase.

At the time of the mine closure, if the mine operates and closes as scheduled, there will be additional expenditures to remove buildings and close the site. At closure, workers would lose their jobs although the potential exists for the Black Hawk to demonstrate the profitability and local desirability of other development in the region. As the initial positive impacts from the mine opening were not believed to create large demands on public services, nor would the closure be expected to significantly change demands for public services. The employment and income impacts associated with closing the mine will be greatly alleviated if the mining industry locates and develops additional developments. The nature of this project allows community leaders to anticipate these changes much better than with the closing of other area businesses. The operating life of the mine also allows time for other economic opportunities to expand in the region.

It is estimated that up to 70 employees will be hired locally out of the total number of 75 direct employees. The potential employment at the mine site is less than five percent of those unemployed in the study area. While the match between jobs and workers is uncertain, it is likely that heavy machinery operation and other tasks could be filled by some of the unemployed. Alternatively, some lower paid or part-time employed individuals may move up the job ladder and open the way for those currently unemployed. This study assumed that no in-migration would result from the secondary jobs as a result of scattered job openings in an area of relatively high unemployment or the addition of new workers as part of the newly in-migrant households.

The result of the smaller initial size of the current project and the resulting smaller in-migrate worker population is that the total population impact of the current proposal, estimated to be about 30 people and less than 10 children (DM.010, 1997). Population related social and economic impacts of the current proposal are much smaller than previous conceptions of the project and compares in size to the maintenance only option studied for Loring AFB. Consistent with the analysis performed for the maintenance option at Loring Air Force Base (USA1994), no impact from the Bald Mountain Project is expected for the following:

- Population
- Housing
- Public Services
- General government
- Police and fire
- Education
- Health Care

- Transportation
- Utilities

Evidence about the size of impacts from operation can secondly be assessed by looking more closely at a multiplier impact on public services and variations in population in the less populous central part of the County. The multiplier analysis relates a percentage change in population into an equivalent percentage change in public service, housing and other similar demands. If population changes by 5 percent, then all public service and housing demands change by 5 percent.

The range of a 0 to 30 person change in population estimated to result from the mine is a small percent of the study area and of the county in general. The individuals may be a larger percentage of an individual town if they all chose to locate in one town. This is highly unlikely because the existing facilities and personal preferences would discourage this potential. The long term gradual decline in population of the area and the closing of Loring AFB lead to a decline in county population of over 11 percent. In that context, the estimated in-migration appears to be small percentage of recent population changes in the study area and within the normal variation expected in an area over any given period.

6.2 PUBLIC HEALTH AND SAFETY

As discussed in the summary above, the small population impact will result in no impact to public health and safety.

6.3 SCHOOLS

Increased costs may be incurred by the state for education subsidies for the limited increased school enrollment. However, the limited population growth is within the normal variation expected in a given year, assuming that all the new workers located in several of the communities in the region.

6.4 ROADS AND TRAFFIC ENGINEERING

A separate report on the transportation impacts of the project has been prepared for this project. This analysis was performed by Eaton Traffic Engineering (ETE) of Brunswick, Maine in accordance with requirements of the traffic-movement rules pursuant to the Maine Site Location of Development Act (06-096 CMR 374). A copy of the ETE report (ET.010, 1997) is included in the *Baseline Monitoring Studies*. As part of this, a traffic study for the Bald Mountain Project was conducted to evaluate the impact of new traffic generated by the proposed facility on roadway in the vicinity of the site. Based on the reduced mining plan and limited additional traffic, Black Hawk currently proposes to upgrade the existing Fish River Road/Carr Pond Road system and use it as access to the project site.

7. MITIGATION MEASURES

Various mitigation measures have been incorporated into the mine plan to minimize environmental impacts. The mine plan has been reduced in scope with limiting extraction to only the shallow gossan ore. With the reduced mining plan, the socioeconomic impacts are negligible (DM.010, 1997). These impacts and mitigation alternatives are discussed in detail in the following sections.

7.1 ENVIRONMENTAL IMPACTS

Several mitigative measures have been incorporated into the project design to reduce the environmental impacts associated with mining and processing the ore deposit at the Bald Mountain Project. These measures are discussed in the following sections.

7.1.1 Reduced Excavation Depth

The current mine plan limits mining to only the upper gossan layer which overlies the massive sulfide deposit. The decision to limit mining to the gossan layer was based on economic factors. The cost to mitigate the environmental impacts associated with the deeper excavation was a contributing component in the selection of the final mine plan.

Limiting mining to the gossan layer reduces the depth of excavation from over 700 feet to an average depth of 150 feet below bedrock surface. This shallower depth helps to mitigate environmental impacts at the site by:

- reducing the total amount of land disturbance
- eliminating the need to alter streams
- limiting the development to one watershed
- minimizing excess water during operation
- reducing operational life which limits potential impacts prior to closure
- reducing wetland impacts to less than one acre
- reducing the total amount of waste rock
- improving water quality in the pit by limiting the area of exposed footwall rock subject to acid generation

The shallow mine pit reduces the total amount of acid producing waste rock from the eastern slope of the excavation. The smaller pit also reduces the amount and severity of acid producing footwall rock left exposed on the eastern pit slope against Bald Mountain. Based on the ABA and humidity cell testing, the footwall rock next to the gossan has less acid producing potential than the same rock abutting the massive sulfide deposit (S.241, 1990; S.246, 1992; LX.010, 1997). Only the footwall rock next to the gossan will be exposed during operations with the current plan.

The shallow excavation also reduces the amount of excess water which will need to be handled at the site. The smaller footprint of the mine pit will reduce the total excess water from 124 gpm to about 76 gpm with the gossan excavation at an average elevation of 850' msl. This reduced depth is instrumental in reducing the flow of excess water to manageable rates which can be handled.

7.1.2 Mitigate Acid Generation

Exposure of materials at the site (e.g. agglomerated tailings, waste rock, footwall rock) containing sulfide minerals can result in the oxidation of the sulfides and the production of acidity, resulting in elevated concentrations of sulfate and metals in the groundwater. The essential components for sulfide oxidation are 1) the presence of reactive sulfide minerals and their exposed surface area, 2) water and/or atmospheric humidity, and 3) the presence of oxygen.

The amount of oxygen available to react with the sulfides is often the limiting factor in these reactions. Since these kinetics are relatively rapid, exposure of sulfide minerals to the atmosphere, even for a matter of days or months, can result in oxidation of sulfide minerals. The extent of acid generation and metal dissolution will depend on the surface area of the rock fragments and the nature and distribution of iron/sulfide minerals in the exposed wall rock. If acidity is generated as the result of oxidation of the sulfide minerals, it can either be flushed by precipitation or fluctuating groundwater moving through the rock, or it can accumulate in the rock and remain available for flushing in the future. The formation of low pH groundwater enhances the solubility of many metallic minerals in the rock (SM.040, 1997).

Several steps have been taken with the proposed design and operation of the Bald Mountain Project to mitigate acid generation from the mill tailings, waste rock, and exposed footwall. As the first step, waste characterization testing has been performed to help quantify the potential for acid generation of materials at the site. Acid Base Accounting (ABA) and kinetic humidity cell testing were used to evaluate the potential for acid drainage and metals dissolution resulting from metallic mining activities at the Bald Mountain projects. These tests were run on gossan ore, residual gossan ore tailings, massive sulfide, footwall rocks, and hangingwall rocks as summarize in Table 7-1.

ABA tests are used to determine if a rock has the potential to be acid generating by evaluating the presence of reactive sulfur and the potential neutralization capacity of the rock. Laboratory humidity cell tests attempt to simulate the accelerated natural weathering and oxidation of rocks and the subsequent release of metals and acidity.

Table 7.1
Geochemical Testing Summary
Acid Generation Potential
Bald Mountain Project, Black Hawk Mining Inc.

Material	Sample	Boring		Tests		
		Number	Depth	TCLP	ABA	Humidity Cell
1. Waste Materials - Gossan Mine						
Tailings[a]	Comp 2	(note 1)			x	
	Comp 3				x	
	Comp 4			x	x	x
Tailings w/ waste rock	10-90	(note 2)			x	x
(M21, M29, M87, M88,	15-85	(note 2)			x	x
M90, M97)[a]	20-80	(note 2)			x	x
Waste Rock						
Gossan Ore[b]	SRK-1A/B	B7	116-131'		x	
		B7	141-156'			
	SRK-2	B7	131-141'		x	
	SRK-3A/B	B6	76-85'		x	
		B6	90-94'			
footwall waste rock[a]	Comp 1	(note 2)			x	
	Comp 5	(note 3)			x	x
	Comp 6	(note 4)			x	x
2. Pit Water Quality						
Gossan Footwall[a]	Comp 5	(note 3)			x	x
	Comp 6	(note 4)			x	x
Gossan Ore[b]	SRK-1A/B	B7	116-131'		x	
		B7	141-156'			
	SRK-2	B7	131-141'		x	
	SRK-3A/B	B6	76-85'		x	
		B6	90-94'			
Gossan Waste Rock[b]	SRK-4	B7	101-116'	x	x	
(beneath gossan layer)	SRK-5	B7	166-176'		x	
	SRK-6	B7	156-166'		x	
	SRK-7	B5	163-173'		x	
Supergene[b]	SRK-8	B2	295-320'	x	x	
Massive Sulfide - Wall Rock[b]						
Zn	SRK-9	B6	104-149'		x	

Material	Sample	Boring Number	Boring Depth	Tests TCLP	Tests ABA	Tests Humidity Cell
3. Other Tests						
Massive Sulfide Footwall[b]	SRK-13A/C	B2	615-666'	x	x	x
		B7	358-395'			
		B8	127-167'			
	SRK-14A/D	B5	353-390'	x	x	x
		B7	323-390'			
		B8	43-127'			
		B8	167-229'			
Massive Sulfide - Wall Rock[b]						
Zn	SRK-10	B6	377-417'	x	x	x
Cu	SRK-11A/C	B5	205-271'	x	x	x
		B5	256-311'			
		B5	349-404'			
		B7	218-251'			
		C29	598-673'			
Massive Sulfide Waste Rock[c]		(Table 2, SRK 1990)				
pyrite	2 samples				x	
pyrrhotite	1 sample				x	
sphalerite	2 samples				x	
Hanging Wall Rocks[c]		(Table 2, SRK 1990)				
chert	3 samples				x	
tuff	2 samples				x	
andesite	3 samples				x	
Footwall Rocks[c]		(Table 2, SRK 1990)				
siliceaous volcanics	9 samples				x	
stringer sulfides	3 samples				x	
andesite	4 samples				x	

References

a. Lorax (1997), *Assessment of ARD and Metal Leaching Potential of Vat Leaching Residues and Waste Rock*, Bald Mountain Project, Black Hawk Mining, Inc.

b. SRK (1992), *Report on Mine Rock Acid Generation Potential*, Proposed Bald Mountain Project, Boliden Resources Inc.

c. SRK (1990), *Report on the Acid Generation Characteristics of Mine Wastes for the Proposed Bald Mountain Project*, Boliden Resources Inc., August.

Notes: Lorax (1997) samples-

1) tailings: Comp 2-goethite tailings; Comp 3-limonite tailings; Comp 4-composite from 55% goethite and 45% limonite tailings from bench scale tests
2) gossan waste rock composite: M21(32-218'), M29 (31-123'), M87 (32-355'), M88 (48-200'), M90 (28-189'), M97 (25-380')
3) Comp 5: M87 (57-110'), M88 (50-110'), M90 (75-105')
4) Comp 6: M87 (110-189'), M88 (110-190'), M90 (105-177')

These tests are designed to provide a measure of the rate of oxidation, metal dissolution, and acid generation, as might occur in mine wall rock. The results of these tests are summarized in other reports (S.241, 1990; S.246, 1992; LX.010, 1997; WA.031, 1997)

Agglomerated Gossan Tailings - As part of the vat leach process, the crushed ore is agglomerated with cement to form uniform sand-like balls (< ¾" diameter). The agglomerated ore is then leached, washed, and drained for several days to remove the precious metal. The addition of cement helps to neutralize the potential low pH of the agglomerated tailings. The leaching process appears to remove much of the reactive sulfur from the samples. The agglomeration process greatly reduces the surface area of the waste material.

Based on ABA testing, samples of the agglomerated tailings do not have acid producing potential (LX.010, 1997). As a result, gossan tailings are classified as Group B wastes. The agglomeration process reduces the environmental impact of the residual tailings by eliminating the acid generation potential of the material.

Waste Rock - During mining, overburden will be removed and groundwater levels surrounding the mine will be lowered, exposing previously saturated rock to the atmosphere. Testing indicates that the footwall rock abutting the gossan deposit to the east is acid producing (LX.010, 1997) and classified as a Group A waste (WA.031, 1997).

To mitigate this situation, waste rock during excavation of the footwall will be kept in the mined out pit area at all times during operations. As a result, any runoff will be collected with the other precipitation and groundwater flow into the pit, and become part of the excess water to be controlled at the site. This process provides for direct control of acid runoff from the waste rock during operations. Likewise, rain water and groundwater which contacts the footwall rock will be directed into the excavation by the inward gradients provided by dewatering the pit. These processes will prevent any direct discharge of acid water to the surrounding environment during operations.

It is difficult to predict the water quality of the collected water due to the complex interactions and mixing of various water sources (SM.040, 1997; WA.040, 1997). The best prediction indicates that the water will not be significantly different than the existing groundwater quality in the deposit, except for a lowered pH. To mitigate any impacts to adjacent water resources, all excess site water will be collected and buffered if needed. The water quality will be detained and land applied (EE.010, 1997; T.012, 1997).

Operational Pit Water Quality - The current mining plan proposes to excavate from the northwestern portion of the mine in an easterly direction where the footwall rocks will be exposed as shown on Figure 7.1. This proposed mining plan will help minimize the exposure of the majority of the footwall rocks until the last phase of mining. This plan will help to limit the exposure of the footwall rocks to atmospheric oxygen and help to minimize oxidation of the sulfide minerals in the footwall rocks during mining operations.

Closure Pit Water Quality - The oxidation of reactive rocks exposed as the result of mine dewatering will influence the quality of the pit water upon mine closure. When mining operations cease and groundwater levels are allowed to return to static conditions, water moving through the oxidized rock surfaces will transport metals and acidity into the water that flows into the pit lake. The changes in the groundwater geochemistry as the result of mining operations will depend on the ambient groundwater geochemistry, the surface area of reactive wall rock that is oxidized and the groundwater flux into the pit.

Based on the test data to date, it is doubtful that the water quality will be much different than the existing groundwater quality in the gossan. Additional models and analyses could be run to provide other estimates of the pit water quality (SM.040, 1997). Due to the noted environmental complexities, the accuracy of the results will not be known until actual field measurements are made at closure.

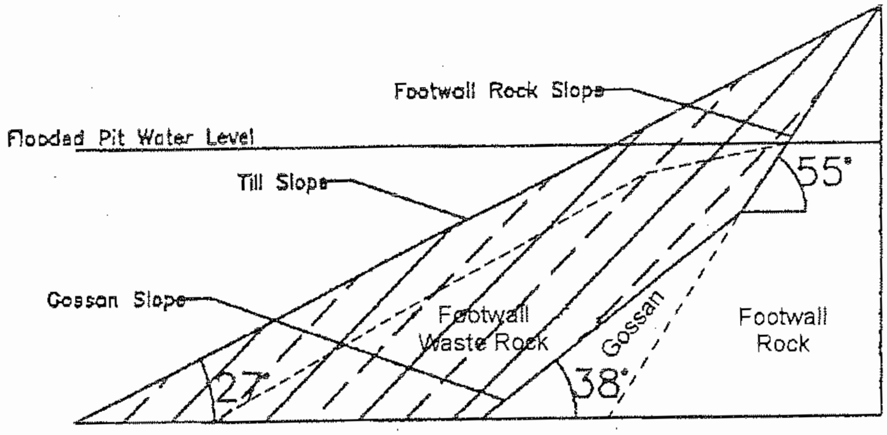
Rather than conducting additional analyses within unknown assurances to their accuracy, Black Hawk has elected to incorporate measures into the mine plan to mitigate adverse water quality in the mine pit at closure. These measures will be implemented to reduce the levels of oxygen needed for the generation of acid from sulfide materials.

To limit the exposure of the footwall to oxygen, till and waste rock will be placed against the footwall as illustrated in Figure 7.2 and buried in the pit. The reclamation cross-sections are shown in Figure 5.2. Column testing conducted by SRK suggests that submerging the waste rocks will help to limit the oxidation of the sulfide minerals. The flattened footwall slope and the bottom of the mine pit will be covered with 5-feet of till. This veneer of material will limit the amount of oxygen available for acid generation.

Once this is completed, the pumps in the pit will be shut off and the pit allowed to fill with groundwater. It is estimated that it will take approximately six to eight years for the water level to reach steady state conditions (G.020, 1997). To accelerate this process and further eliminate the potential for acid production, water will be pumped into the pit from nearby surface water bodies, reducing the filling time to less than 12 months. It is estimated that the steady state water level in the pit will be close to the till/gossan contact elevation of approximately 910 to 925 feet MSL.(GJW 1997). This will effectively submerge the footwall and acid producing waste rock and eliminating future acid production.

7.1.3 Leachate Generation from Tailings Landfill

Agglomerated tailings emanating from the ore processing area are classified as a Group B waste. Only material passing through the ore processing facility and inert demolition debris at closure will be allowed in the landfill. By doing this, only Group B wastes will be placed in the landfill.



Backfill Volume = 300,000 cu.yds.
Exposed Backfill Volume = 36,000 cu.yds.
(Post Flooding)

Scale: as shown Date: Dec. 1997	Figure 7.2 Pit Wall Backfill Detail Bald Mountain Project	**NNM Resources, Inc.** a subsidiary of **Black Hawk Mining, Inc.**

While acid production will be minimal, the agglomerated tailings still leach elevated concentrations of metals and inorganic elements. To minimize environmental impacts, the tailings landfill has been design with a leachate collection system to collect drainage, infiltration, and runoff from the active landfill cell. All of the leachate will be returned to the mill for use as make up water in the agglomeration process. In this manner, all of the cyanide containing water will remain within the ore processing system. Excess water at the site will be limited to groundwater and surface water collected in the mine pit and runoff from the process area.

The leachate collection system reduces the potential for groundwater impacts compared to traditional tailings impoundment where the tailings are kept water submerged to prevent oxidation. To further limit the impact and assure that all leachate can be used as makeup water, the open landfill area will be kept to 4 acres or less, limiting the flows to an average of about 4 gpm.

Clean runoff will be diverted around the active cell. Runoff and infiltration on the open cells will be collected and returned to the processing facility. Total impacts from the landfill are further reduced by the limited operating period. The gossan will be removed in less than 4 years. At closure, the landfill will be capped with a composite barrier, drainage layer, and topsoil. The barrier exceeds the requirements of the Rules, but has been selected to assure that virtually no infiltration occurs through the landfill during the post-closure period.

7.1.4 Excess Water Control

As discussed in Section 5, excess water will occur at the site due to groundwater and surface water flow into the mine pit and from site runoff from the ore processing facility. Various mitigation measures have been incorporated in the design to minimize the excess water at the site.

Surface water runoff from the processing plant, haul roads, and ancillary facilities will be minimized by constructing separation berms as close to the facilities as possible. These berms will be used to intercept clean runoff before it encounters the mine area. In this manner, water collected within the mine area will be kept to a minimum. The mine pit will be built in two phases which limits the exposed area during the early phases of ore excavation.

For the tailings landfill, volume reduction methods include the following:

- constructing and operating small cell areas of 4 acres to reduce the open area exposed to infiltration
- separating unused portions of the landfill footprint to further divert clean runoff

- developing the landfill in a manner that attempts to reach final grade as soon as possible and then capping those portions of the landfill at final grade

- placing an interim cover on cell areas that will be inactive for more than six months to further limit infiltration through these intermediate grades

- limiting open landfill cell development to small cells of 4 acres or less

The vat leach process needs make up water for the hydration of the cement to agglomerate the ore. Flow from the landfill leachate collection system will be the primary source of make up water. At all times, the plant can use all the flow from the landfill as currently design. However, the less flow from the landfill will allow the plant to use more of the water from the other sources. Therefore, one of the first mitigation measures is to reduce the open area of the operating cell at the landfill. The other mitigative measures diverts clean water around the site and limits the open area of the pit for the longest possible time.

7.1.5 Excess Water Collection and Treatment

Excess water is limited to groundwater and surface water collected in the mine pit and runoff from the process area. The water quality is expected to reflect existing groundwater conditions with a slightly lowered pH (WA.040, 1997). To mitigate this, excess water will be detained in storage ponds located to the south of the facility on the opposite side of Bald Mountain Brook as shown in Figure 3.2. Facilities to raise the pH of the excess water before it is pumped to the storage ponds will be built into the pump station located adjacent to the ore processing facility (EE.010, 1997). From the storage ponds, water will be applied to a land application area located along Carr Pond Road (T.012, 1997). The design of the collection and treatment facility is discussed in more detail in the application and referenced reports. These reports specify the application rate, land area, and operation and monitoring requirements to assure that this system does not have an impact on water quality or aquatic resources in nearby receiving waters (T.012, 1997).

Extreme flows due to unanticipated weather events, exceeding the design capacity of the storage ponds and land application area, can still be handled at the site. On a temporary basis, alternatives for handling the excess water include:

- storing in the freeboard capacity of the leachate pond and storage ponds

- routing to the pit for temporary storage

- trucking to an off-site treatment plant

Water will continue to be collected and treated for an indefinite period following reclamation of the open pit, tailings landfill, and plant site. After water has drained from the tailings landfill and water quality in the pit has stabilized, treatment will be curtailed. The small trickle of flow from the capped tailings landfill will flow passively into a small wetland that will be developed in the reclaimed leachate pond.

Collection and treatment is disused in more detail below.

Water Storage - Excess water will be stored in storage ponds for detention and to store during the dormant season for land application during the growing season. These ponds will be built south of Bald Mountain Stream and the tailings landfill as shown in Figure 3.2. For planning purposes, excess water will be stored from the beginning of October until the end of May. A maximum of 85 acre feet of storage will be required during the last year of operation.

To enhance operational flexibility and provide emergency storage, the pond will be divided into two cells, separated by the berm of compacted till. During normal operations, one cell will be lowered to provide emergency storage capacity in the event of extended plant shut-downs. Excess water will be pumped from one cell to the land application area while the other cell is being filled. This will maximize the retention time for excess water prior to land application. During the winter months, both cells will be used to store excess water. The pond level will drop during the early summer as water is pumped to the land application area. The pond will be emptied at the end of the summer to provide storage capacity for the following fall, winter, and spring seasons.

The combined capacity of the water storage ponds is approximately 115 acre-feet, not including 2 feet of freeboard. The water storage ponds are designed to store the following:

- an average of approximately 60-gpm continuous flow of surface runoff and collected groundwater from the ore processing area and mine pit over an 8-month period
- winter precipitation of 23-inches falling directly on the pond surface
- the 24-hour/100-year storm event

The water storage ponds will be temporary structures. At the end of mining, the water storage ponds will be closed by pumping the remaining water to the land application area. Sediments collected in the pond bottoms will be removed, characterized, and placed in an appropriate disposal facility. The dikes forming the ponds will be regraded to preclude any future impoundment of surface water. The interior pond slopes and any recently disturbed earth will be seeded to establish a perennial grass cover resistant to erosion and assist in the establishment of native vegetation.

Land Application - A land application system is proposed to dispose of excess water generated during operations at the Bald Mountain Project (T.012, 1997). This system was designed to match the hydrologic capacity of the shallow soils.

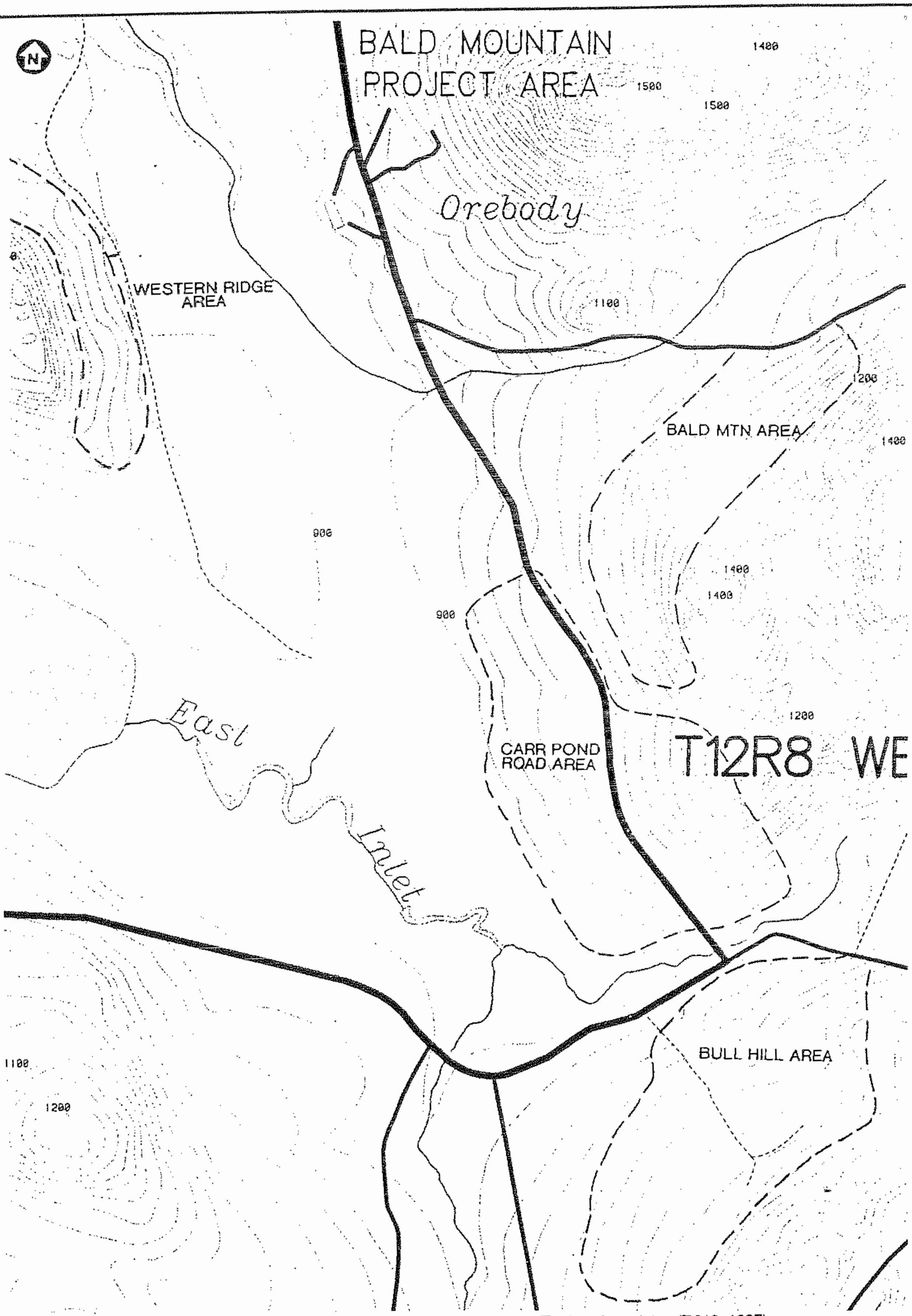
The project quality of excess water is similar and, in many aspects, generally superior to the quality of water applied at other land application systems in Maine (T.012, 1997). Two areas, consisting predominantly of Chesuncook silt loam, were identified near the mine site. Of the four areas shown in Figure 7.3, the primary area for land application is south of the mine site, straddling Carr Pond Road. The secondary, backup area, is located further to the south on the northern slope of Bull Hill.

Design of a spray irrigation system for the Bald Mountain Project is based primarily on the ability of the land application areas to accommodate the conservative estimate of 100 gpm of additional water, through a combination of evapotranspiration and interflow through the shallow soil matrix. Water will be land applied through a spray irrigation system at a rate of 1.0 to 2.0 in/ac/wk during a 130 day period. The rate of irrigation will be kept low, so that water remains in the shallow soil, above the dense basal till, with limited infiltration to the deeper water table. During the winter months, water will be stored in a pond for land application the next growing season.

Irrigation will occur on 5 to 6 acre plots on a 7-day rotation schedule. One plot will be irrigated each day during the growing period. As with other land application sites in Maine, irrigation will be postponed following 8-hour periods of more the ½ inch of rainfall. As described in detail in the waste discharge license application, the water storage ponds will be used to permit smooth operation during rainy periods in the irrigation season. Each irrigation plot will be inspected weekly to ensure that water is not flowing across the land surface in a channeled manner. Channels and small rivulets will be repaired to disperse flow.

The suitability of land application for excess water at Bald Mountain was based on a comparison with existing systems in the State of Maine and geochemical characteristics of site specific soils (T.012, 1997). The estimated water quality of the collected groundwater and surface water runoff is sufficiently clean so that land application of this excess water will not represent an excessive loading. As discussed, excess water from the mining operation will be neutralized, if necessary. Water chemistry is expected to be consistent with or better than the quality from other land application systems before discharge in the spray irrigation areas.

Potential for the spray irrigation system to influence surface water and groundwater quality is expected to be minimal because of the design of the irrigation system, the short duration of application (i.e. less than five years), and geologic conditions in the irrigation areas. Actual performance of the land application areas will be monitored by the following: measurements of soil moisture, inspections for vegetative stress, groundwater



Ref: *Land Application Design Evaluation Report*, Tewhey Associates (T.012, 1997)

Scale: as shown

Date: Dec. 1997

Figure 7.3
Location of Land Application Areas
Bald Mountain Project

NNM Resources, Inc.
a subsidiary of
Black Hawk Mining, Inc.

quality, and surface water quality in the East Inlet to Clayton Lake and Bald Mountain Brook.

7.2 SOCIOECONOMIC IMPACTS

As demonstrated in the recent socioeconomic study performed by Dames and Moore (DM.010, 1997), the proposed mine will have only a small impact on the population of the area and virtually no impact on the social services of the region. In part, the proposed mine will barely compensate for the gradual population reduction in the area and the recent closure of Loring AFB. The project expects that over 90% of the work force will come from the local region, which will help to reduce the current unemployment and add a large ratio of multiplied expenditures compared to the minimal additional demands on the current services required of the local communities. For these reasons, no other mitigation efforts were required to compensate for the minimal socioeconomic impacts.

8. ASSESSMENT OF ALTERNATIVES

Several design and process alternatives were evaluated in the selection of the final mine proposal. In each case, the environmental benefits for each alternative was considered along with the economic impacts to developed the plan described in the previous sections. This section discusses some of the alternative evaluated during conceptual design.

8.1 DESIGN ALTERNATIVES

Design alternatives were considered for the ore processing unit and mine waste units as described in the following sections.

8.1.1 Ore Processing Unit

In the gossan ore at the Bald Mountain site, the gold (principle value mineral) occurs as free and minute particles in a naturally oxidized rock. The gold particles are readily soluble in a dilute sodium cyanide solution.

The alternative processes consider are as follows:

1. Do not develop the resource: This alternative was rejected because there are proven methods of recovering the gold which are environmentally sound. The project economics are positive so the resource is available for investor interest and for job creation in the region.

2. Conventional Milling: The gold in the gossan can be readily extracted so a simple, conventional gold mill would be a practical ore processing method. However, if the gossan ore was conventionally processed (grinding, leaching, and gold recovery), then a conventional mill tailings pond would be required. The tailings pond will have to retain a water cover to prevent acid formation of the impounded tailings. The use of a fluid retention pond would increase the environmental risks associated with operations and post closure reclamation. The economics for such a small deposit would not be positive so the project would not have materialized. For these reasons, conventional grinding and leaching process was rejected.

3. Heap Leaching: The gold in the gossan ore is readily extractable even with limited crushing to -½ inch particles, agglomerated and heap leached. This alternative was also rejected. Although a heap leach processing approach could be done successfully, there are several negative affects to be considered. The operation would only be seasonal (i.e. spring, summer, and fall) thereby affecting job creation. The amount of excess water to be handled at the site would increase significantly. Likewise, process water would be included in the water that would need to be handled at the site. Limiting excess water at the site would be more difficult because the entire heap leach pile would be exposed to the weather until

the gossan ore reserve has been leached and cover placed at closure. There would be the necessity for a more intense and expensive water treatment plant. The economics would be less favorable and environmental approval more difficult.

4. The gold in the gossan ore could be recovered in a custom smelter operation. This alternative was rejected because the economics would not be positive and the environmental risks increased. The value of the gold content of the gossan would not cover the cost of mining, transportation, and processing at a custom smelter. Regional job creation would be very limited.

Based on this analysis, the vat leach process was chosen as the alternative with the less potential risk to the environmental and still be economically feasible. This process produces a dry stable agglomerated tailings that can be disposed of in a tradition waste landfill. All leachate encountering the waste pile can be used as make up water in the agglomeration the crushed ore. Therefore, no process water will be included in the excess water to be handled at the site.

8.1.2 Mine Waste Unit

Various options were considered for the design of the landfill for the site. Initially, footwall waste rock was to be placed in the landfill. As demonstrated in the Waste Characterization Report (W.031, 1997), footwall waste rock is acid producing. The landfill had to be designed to handle Group A wastes and included a composite liner consisting of a geomembrane and soil layer.

Vat leached agglomerated tailings are not acid producing due to the buffering provided by the cement and lime used in the agglomeration process. The placement of some waste rock in the landfill increased the overall potential environmental impacts associated with the tailings landfill by:

- making all the waste a sensitive Group A waste
- increasing the landfill footprint by almost double

To reduce the amount of wastes in the landfill, the footwall waste rock will remain in the mine pit. By doing so, the landfill was redesigned to accept only Group B waste associated with the sand-like agglomerated tailings from the vat leaching process. This redesign also uses more of the excess till at the site. This, in turn, reduces the size of the final till stockpile at closure. Likewise, keeping the acid producing waste in the pit eliminates the potential impacts from acid production.

As noted above, the initial design included a layer to increase the travel time to bedrock beneath the liner system. With the new design, it is estimated that it will take more than 5 years for the wetting front to pass through the till liner. Prior to this, the landfill will be closed and capped to virtually eliminate additional infiltration. Therefore, the travel time layer at this site is not necessary. It would be useful to retard unanticipated breaches in the till barrier. The potential for this is very remote considering the thickness of the layer and the stability of the till foundation material. Likewise, it could be argued that it would be better to observe any unanticipated seepage during the operation of the landfill when remedial steps can be taken to isolate the problem and mitigate the problem. In accordance with the Rules, the travel time layer was eliminated on the basis of the additional protection provide by the site and landfill design by the following:

- limited time of landfill operations (3.5 years)
- reduced hydraulic heads within landfill created by the installation of a leachate collection layer
- enhanced closure with installation of composite cap
- underlying fractured bedrock is not a significant receptor since the existing groundwater is already impacted by the ore body and the groundwater is not used as a water resources nor will it in the future

8.2 WASTE MINIMIZATION ALTERNATIVES

In development of the proposed mining plan presented in the application, procedures and techniques to minimize waste were evaluated in detail to reduce the potential environmental impacts of the project and to reduce the overall development and closure costs. This section described the options considered and incorporated to minimize waste.

8.2.1 Alternative Extraction Techniques

The biggest reduction in waste volume, compared to other mining plans discussed for the Bald Mountain Project, relates to limiting extraction to gossan layer. This greatly reduces the waste rock generation, thereby vastly reducing the overall environmental impact of the project. The shallow depth does not warrant the expense of underground mining techniques. In-situ mining is not feasible for hard rock applications and would have a high risk of impacting regional groundwater resources. As such, the proposed shallow open pit mine to extract the gossan ore has the least environmental impact.

8.2.2 Alternative Beneficiation Techniques

As mentioned above, other options were considered for beneficiation of the ore. Conventional milling would require a large water impoundment for tailings disposal. Heap leach process would produce more wastes, increase the volume of excess water, include cyanide containing fluids within the excess water, and create a larger waste area at closure. For these reasons, vat leaching process was selected, in part, for having minimal
environmental impacts.

Cyanide will be destroyed at the end of the mining operations using an SO_2 oxidation process as discussed in detail in the application. Other cyanide destruction processes were considered including natural degradation, alkaline chlorination, and hydrogen peroxide oxidation. Other processes not considered in detail include biological, acidification/regeneration, UV/ozone, and ion exchange. Natural degradation was eliminated from consideration due to the uncontrolled nature and unknown timing for this process. The other processes were much more involved, too complicated, and/or economically less favorable than the selected method for the Bald Mountain Project.

The vat leach process for the agglomerated ore is a net water user. Therefore, all cyanide process water can be recycled during operations. There is only a need to destroy cyanide at closure and only for the small volume of process water that remains at that time. The INCO process was selected based on its simplicity, ease of operation and construction, and economics.

8.2.3 Opportunities

Options for reusing waste materials at the site were evaluated in detail. The opportunities for this were limited due to the sulfur content of many of the materials. The following has been done to reduce the amount of waste material at the site:

- to reduce the size of the till/hangingwall waste rock pile
    - tailings landfill liner design has incorporated a thick layer of till
    - till will be used as a cover for the footwall and pit floor to reduce exposure of acid generating surfaces
    - inert waste rock from the hangingwall will be used to armor drainage ditches and further protect surfaces at closure
- to reduce the amount of exposed footwall rock
    - expending the operational effort to keep the footwall waste rock within the pit
    - placing the footwall waste rock against the exposed footwall and covering will till
    - flooding the pit at closure

Aside for these considerations, there were no other opportunities for reuse, in-mine disposal, sale, recovery, treatment/processing of mine wastes considering the small size of the mining operation and the types of waste materials produced by the mining operations.

8.3 WASTE HANDLING AND TREATMENT ALTERNATIVES

Various waste handling and treatment alternatives were evaluated as discussed in this section.

8.3.1 Tailings Deposition

The vat leaching process produces a dry, sand-like agglomerated tailings that will be trucked to the landfill, deposited, and spread in lifts. The most common disposal technique is the use of hydraulically placed slurried tailings. While the operational costs are less with this technique than with trucking the dry agglomerated tailings, the environmental impacts are significantly higher for several reasons. The volume of waste material (i.e. solids and fluid) is much larger. The space occupied by the agglomerated tailings is further increased due to the flat surface of the hydraulically placed material. The hydraulic tailings would require at least two to three times the footprint than proposed design. Likewise, there is very little opportunity to manage the size of the exposed tailings to reduce excess water balance and to closed portions while the processing plant is still in operation.

Seepage from the slurried tailings impoundment would be much higher that the dry agglomerated tailings due to the large hydraulic head on the liner system. The potential environmental risks are much higher due to the impoundment of fluid. Post closure maintenance would be more involved due to need to keep the impoundment flooded to help assure no acid generation of the reconstituted tailings. Future environmental risks would also be higher with the impoundment of a slurried, compressible tailings.

Based on the environmental benefits, the agglomerated tailings from the ore processing plant will be truck to the landfill and placed in individual cells of 4 acres or less and capping. The higher operational costs are compensated by the improvement in environmental protection provided by this alternative.

8.3.2 Waste Rock

The amount of waste rock generated during the mining operation is kept to a minimum by limiting excavation depth to the bottom of the gossan and by maximizing the pit wall slopes as allowed by the slope stability considerations. In addition, the access road has been relocated to the hangingwall on west side of the pit. This minimizes the amount of exposed footwall during the first two years of pit development.

For ease of pit operations, the waste rock was going to be removed and placed in either the till stockpile if it is hangingwall rock or the tailings landfill if it is footwall rock. This would required handling the rock only once. It would also assure that the rock is not in the way of the mining operations. With the proposed mining plan, the hangingwall rock will still be removed to the till stockpile, but the footwall rock will be stockpiled within the pit footprint. This requires that the footwall rock be re-handled several times during mining operations. However, this procedure will assure that any acid producing runoff during operations will be collected and handled with the other pit water. At closure, the rock will then be flooded to reduce post closure exposure. This procedure greatly reduces the exposure of footwall waste rock that creates the potential for acid generation.

8.3.3 Potential for Acid Generation

The current mining plan proposes to excavate from the northwestern portion of the mine in an easterly direction where the footwall rocks will be exposed. This proposed mining plan will help minimize the exposure of the majority of the footwall rocks until the last phase of mining. This plan will help to limit the exposure of the footwall rocks to atmospheric oxygen and help to minimize oxidation of the sulfide minerals in the footwall rocks.

During operations, acid generating footwall waste rock will be left in the mine pit area. At closure, this material will be placed against the footwall and covered with a layer of till to reduce oxygen exchange and the pit flooded.

8.3.4 Control of Excess Water

The water balance described in Section 5.2.4 indicates that an average of 58 gpm of excess water will develop at the site. This rate varies from 25 to 69 gpm. Various alternatives were evaluated to minimize the excess water at the site. These include:

- limiting open landfill cell development to small cells of 4 acres or less
- separating and handling upstream surface water by diversion ditches around the operation site
- keeping the operating site as small as possible
- staging mine development to limit the initial pit area to a minimal value
- reducing groundwater inflow into the mine pit by intercepting with upgradient dewatering wells or diverting around the pit area by grouting bedrock fractures

With the exception of the groundwater flow into the mine pit, all of these alternatives were adopted in the proposed design. Methods to reduce and control groundwater inflow into the pit that were considered include:

- upgradient groundwater intercepting ditch in till overburden

- upgradient bedrock relief
    - fracturing the bedrock trench
    - intercepting groundwater with collection wells
- drainage gallery in the upgradient bedrock discharging to local faults
- upgradient grouting of bedrock fractures

Based on this evaluation, it did not appear that these techniques were economically feasible nor technically reliable to reduce excess groundwater at the site. While the technology is available and well known, the effectiveness of these techniques is difficult to predict with any degree of reliability. As such, the effectiveness of these alternatives would not be known until they had been implemented at great expense. A review of the water balance indicated that excess water would still have to be handled in some fashion even if the groundwater flow could be eliminated. Considering this and the economic and technical challenges of these alternatives, attempts to intercept or divert groundwater around the mine is not proposed as part of the mining plan.

The potential for controlling groundwater can only realistically be evaluated during operations. As discussed in the application, if dominant seeps are encountered in isolated defined fractured areas or fault zones during operations, investigations will be made to evaluate the potential of intercepting this water prior to encountering the exposed footwall rock. Water collected upgradient of the pit will be discharged into the perimeter ditches as clean water and routed to the detention basins located downgradient of the mine. Alternatively, it may be possible to segregate seeps in the mine pit to separate acid from non-acid water quality. These alternatives will be evaluated during operations to further reduce excess water and reduce the loadings to the storage ponds and land application areas.

8.3.5 Treatment of Excess Water

Excess water is limited to groundwater and surface water collected in the mine pit and runoff from the process area. The water quality is expected to be reflective of existing groundwater conditions (WA.040, 1997). The excess water is expected to be somewhat acidic and contain elevated metals. To mitigate this, various treatment alternatives were evaluated and include but are not limited to:

- pretreatment using filtration and precipitation techniques
- full treatment alternatives including filtration, precipitation, ion exchange, and various polishing alternatives

- land application using:
    - * area north of the pit
    - * constructed wetlands
- use of manufactured and natural wetlands and/or peat for additional treatment

The water quality is already close to background conditions. Based on this analysis, there is no need for extensive treatment beyond buffering the pH, storing for a period, and discharging to a land application area (EE.010, 1997). Excess water will be detained in storage ponds located to the south of the facility on the opposite side of Bald Mountain Brook. During the growing season, water will be applied to a land application area located along Carr Pond Road. All other treatments were eliminated from consideration due to the unnecessary expense.

8.4 RECLAMATION ALTERNATIVES

At closure, the ore processing facility will be completely dismantle and placed in the landfill. The till stockpile will be graded to a uniform slope, topsoil placed on the surface, and mulched and seeded to promote vegetation. To limit exposure of acid generating rock, a layer of till will be placed on the bottom and against the footwall rock in the mine pit and the excavation flooded with water to limit exposure.

Backfilling the entire pit with till was considered. The environmental gain was determined to be marginal and prohibitively expensive. For this reason, this alternative was discarded.

When facility removal and site revegetation is completed, the area will revert back to natural appearance. Other alternatives would be less involved, less expensive, and more intrusive on the appearance of the site after the mine has shut down. To help minimize the long term impacts of the project on the environmental, complete removal of the mill facilities and enhanced capping of the landfill has been incorporated into the design.

8.5 SITING ALTERNATIVES

The mine pit are dictated by the location of the ore body. However, the siting of the processing facility, tailings landfill, and storage ponds have been done to limit wetland impacts to less than one acre. Likewise, the proposed layout of the site has been designed to avoid and minimize impacts to the greatest extent practicable by limiting site runoff from the area.

The tailings landfill has been sited to keep activities within the Bald Mountain Brook watershed, thus restricting any theoretical impacts to surface and ground water to a single watershed. An in depth search for landfill sites had been conducted by Superior Mining and Boliden Resources (S.017, 1982; S.242, 1990). These extensive reports are available for review upon request. With the exception of the selected site, other areas encroach upon the watersheds of other surface water bodies. The landfill area has reduced in size drastically with limiting ore extraction to the gossan and producing a sand-like dry agglomerated tailings. The smaller landfill size greatly reduces wetlands impacts and eliminates the need to impact surface water bodies as proposed with the large mine design.

The site has been selected to keep mine disposal, ore processing and waste disposal within one watershed. This focuses the concentration of operational and closure monitoring to one area. The landfill's location near the mine and processing facility assures that any unanticipated behavior which does not conform to the intended plan will be readily visible. As a result, remedial actions, if necessary, can be developed and implemented in a timely manner before variations from the plan impact the environment. Likewise, placing the landfill next to the other facilities allows for a unified reclamation plan concentrated in one area.

8.6 ASSESSMENT SUMMARY

Exclusive of the no-action alternative, Black Hawk has selected development processes and management techniques which have the lowest environmental risk during operations and especially during the closure and post-closure period. While a cyanide leach process is used to extract the metal from the ore, steps (described in this report and summarize here) have been incorporated into the mine plan to assure no release to the environment. All beneficiation takes place within a closed building. As a net water user, all process water can and must be recycled during the operations. Cyanide is drained and washed from the agglomerated ore prior to removal from the processing plant. At closure, the remaining cyanide will be destroyed with the INCO SO_2 process.

The ore is crushed and then agglomerated with lime and cement. This neutralizes acid producing potential of the tailings. As such, the agglomerated tailings are classified as a Group B waste. The material is a sand like material that will be trucked to the landfill and placed in a stable, relatively incompressible deposit. Any residual cyanide that may be present in the pore space of the tailings will be collected in the landfill leachate collection facility and recycled back to the plant for use as make up water. At closure, the landfill will be capped with a composite barrier which exceeds the minimum requirements in the Rules. This is done to assure no infiltration will occur during the post-closure period. At closure, the residual moisture in the tailings deposit will be collected, tested, and, if needed, recycled back to the process plant to destroy any residual cyanide.

Acid producing waste rock will remain in the mine pit at all times. During operations, runoff will be collected with the other groundwater inflow and routed to storage ponds and land application area for treatment and discharge. To minimize the potential for acid production, the acid producing waste rock will be placed against the footwall rock slope of the mine pit, buried in a layer of till, and submerged at closure.

Based on the ore processing system and waste management techniques, there is virtually no risk for process water to escape to the environment. The tailings will be encapsulated in a stable, incompressible deposit which has been capped with a composite barrier to eliminate infiltration. Acid producing waste rock remains in the mine pit during operations and is buried and submerged under water at closure.

With these steps, the risks to public health and the environment have been minimized by selecting the ore processing method, reagent alternatives, and waste management techniques which have the lowest possible impact, if any, on these receptors.

STATE OF MAINE
DEPARTMENT OF ENVIRONMENTAL PROTECTION

ANGUS S. KING, JR.
GOVERNOR

EDWARD O. SULLIVAN
COMMISSIONER

June 23, 1998

James Hendry
Vice President, Mining
Black Hawk Mining Inc.
95 Wellington Street West, Suite 2000
Toronto, Ontario M5J 2N7

Re: NNM Resources, Inc., Bald Mountain Gold Project

Dear Mr. Hendry:

This letter follows up on our conversation at the May 20, 1998 meeting regarding potential "fatal flaw issues" for the Bald Mountain Gold Project. During the meeting you requested a list from the Department that details the issues that may present significant obstacles for your company to overcome in the permitting process. None of these should come as a surprise as they have been noted to Black Hawk and its consultants in the past.

First, we are concerned about the elevated levels of arsenic associated with the ore deposit. According to your waste characterization report, "The tailings from the vat leach operation, when deposited in the landfill, are predicted to release large quantities of arsenic during periods of active infiltration and seepage." "Reductions in arsenic concentrations overtime has not been observed." We are aware of the fact that the quality of groundwater directly below the ore deposit indicates high levels of arsenic. Since no treatment mechanisms for arsenic is proposed in your application, we are concerned that the existing groundwater quality in the vicinity of the mine site will be further degraded by the concentrations of arsenic in the tailings landfill.

Second, we have reservations regarding the post-closure water quality of the mine pit. In your application you state that the final pit water quality will be similar to the existing groundwater quality in the ore deposit. Since a majority of the water entering the mine pit during the final phases of operation will be through the reactive footwall rocks, it seems reasonable to expect that the pit water quality will be lower than initially predicted. We are in agreement that the post-closure water quality of the mine pit will not be that of pristine surface water. Pursuant to the Metallic Mining Rules, the Department and LURC can set performance requirements based on naturally occurring background concentrations. However, if the water quality in the mine pit deteriorates substantially below background levels, this impact would negate our ability to make a positive finding of no adverse environmental impact in the permitting process.

Third, is our concern regarding the drawdown of water levels in the cedar swamp located below the mine site. In your failure analysis, you indicate that a water level drop of 8 feet may occur in the wetland due to the dewatering activities at the mine pit. Although your dewatering activities

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at the mine pit are temporary in nature (less than 3.5 years), it may substantially affect the wetland characteristics of the cedar swamp. It is imperative that the dewatering operation be further evaluated to determine the magnitude and duration of any potential impacts to the wetland.

As I stated to you during our meeting, we do not consider our engineering review comments to be fatal flaw issues. I am confident that Black Hawk can readily address these issues by submitting the additional design information requested in our March 31, 1998 letter.

We strongly recommend that we discuss the above referenced key concerns, as well as any other outstanding issues, of Black Hawk's proposed gold project as soon as possible. If you have any questions, please feel free to contact me.

Sincerely,

Mark Stebbins

Mark Stebbins
Mining Coordinator
Bureau of Land & Water Quality

cc. J. Madore, MDEP
Brooke Barnes, MDEP
M. Kirkpatrick, MDEP
J. Williams, LURC
C. Varney, LURC
R. Wardwell
D. Martin, Aroostook County Commissioners

J.S. Cummings
7043 Surfside Lane
Grand Prairie, TX 75054

September 7, 2012

Open letter to: Representative John L. Martin
STATE of MAINE, HOUSE of REPRESENTATIVES
Augusta, ME 04333

Re: The Bald Mountain matter

Dear John:

Since your submittal of LD 1853 in March of this year I have tried, without success, to communicate with the current owners of mineral-rights at Bald Mountain (i.e. J.D. Irving Ltd of Canada and Prentiss & Carlisle of Bangor). As you are a public servant and also have played a role on behalf of the Irving group in Maine, I am addressing this letter to you with copies to interested parties.

SECTION 1 - Executive Summary

(A) During the ballyhoo following your submittal of LD 1853, the failure of you and the Irving group to even mention my name during comments to the general public and/or the press, is inexcusable. After introducing LD 1853, you and the Irving group played-up the great benefits that the Bald Mountain Deposit could bring to Aroostook County. It is evident that without invoking the Bald Mountain Deposit, LD 1853 would have been on life-support. The complete blackout of my name in comments and statements by you and Irving personnel with regard to the Bald Mountain matter has caused me emotional distress and diminished my hard-won reputation in the field of metallic resources.

(B) In a pre-production, color brochure (circa 1981) titled: MAINE'S BALD MOUNTAIN PROJECT, the corporations funding my exploration (The Superior Oil Company and The Louisiana Land & Exploration Company) stated on page 4 that a thirteen year search by the Maine firm J.S. Cummings, Inc. has resulted in the discovery of the Bald Mountain Deposit. On January 7, 1980, you signed, as Speaker of the House, a declaration by the MAINE SENATE and HOUSE of REPRESENTATIVES recognizing me for the Bald Mountain discovery.

(C) From what I read in the press it appears that the Irving group's mining plan for the hard-rock deposit at Bald Mountain follows the prior mind-set: mine it by open-pit.

(D) The Bald Mountain hard-rock deposit SHOULD NOT be mined by open-pit.

(E) Mining the hard-rock Bald Mountain deposit by open-pit would result in extracting millions of tons of rock containing paltry amounts of copper and zinc and millions of tons of barren waste rock.

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(F) Mining the hard-rock deposit by open-pit greatly increases the likelihood of serious environmental problems, particularly those related to the tailings-pond.

(G) It appears that on the order of 60 to 90 percent of the copper available in the envisioned hard-rock open-pit, might be obtained from compact, high-grade, underground operations.

(H) The porphyry system of ore-deposit delineation, employing dominantly vertical-holes, was engendered shortly after discovery and approved by later parties. Such has resulted in a failure to specially define the grade, tonnage and configuration of the high-grade, eastern copper zone, the western copper zone, and the central, high-grade zinc zone.

(I) Numerous drill holes in the eastern copper zone belie the notion that Bald Mountain contains only low-grade copper. Three parallel angle-holes that were designed by me, before the porphyry experts took over, show numerous intercepts in excess of 6% copper, and one hole (BM 29) showed numerous intercepts varying from 11 to 15% copper.

(J) Analysis of total footage of vertical-holes versus total footage of angle-holes within the eastern copper zone reveals that for a defined minimum footage and a defined minimum percent copper, approximately 30 percent more high-grade zones would be evident if the footage employed in the vertical-holes had been employed as angle-holes.

(K) A vertical shaft or incline with underground crosscuts or drifts would be required to delineate the tonnage, grade and configuration of the eastern copper zone. If successful the same thing should be done in the western copper zone and the central zinc zone. with the objective being to mine such zones by underground methods.

(L) The text within SECTION 3 lays out minimum technical data to support the foregoing.

(M) The soft-rock gold-silver gossan, with a gross dollar value of at least $200 million (allowing for a 20% decrease in Au-Ag prices) should yield a very high 'net', probably in the range of 40 percent in consideration of low-cost mining and treatment. Proper mining would allow the natural overburden (excepting gossan) to be redistributed over the exposed bedrock if the hard-rock open-pit scenario is not employed.

SECTION 2 - Significance of J.S. Cummings metallic resource efforts in Maine

There was much posturing by both corporate and government officials in the late 1980's and early 90's with regard to the Bald Mountain matter. However, the only written documentation as to the ineptness, of both government and corporate entities, which led to the descent of Bald Mountain and the demise of tens of millions in exploration expenditures, is contained in my brief book: *Metals in the Maine Earth,* Cummings, J.S., 2008 - URSUS), a copy of which I mailed to you in 2008. The last sentence on the last page of text (p.44) states:

> *The historical evidence (1991-2008) establishes that Maine's metallic mining regulations represent a 'de facto' ban on metal mining in the state and thus such regulations should be expunged.*

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To say the 1991 regulations needed to be 'expunged' is not to say that metallic mining regulations were not needed. To my knowledge I am the only person that ever stated in writing that the 1991 rules were a 'de facto' ban on mining. If you had previously put forth such a judgment in writing, I am unaware of such. Such entities as the Maine Geological Survey and the UMO geology department have been 'blind' to the eradication of metal-exploration that followed the passage of the 1991rules. Then, 'out of the blue' in March of 2012 you shocked many in the state with your apparently original proposal as submitted to the legislature. The old rules were not 'just' amended by LD 1853, but in line with my words 'expunged' (your words "...to replace current mining law ...").

Bald Mountain was just one of numerous potential treasures that I discovered. Although the Bald Mountain Deposit has received the bulk of attention, my discovery of the Ledge Ridge Deposit in the early 1970's (Cummings, J.S., 1988, pgs. 234-256 – URSUS) in the western interior is as notable from the standpoint of successful exploration strategy as is Bald Mountain. The same can be said of my post-Bald Mountain discovery of the CL Deposit, located close by the Bald Mountain Deposit. Such discoveries resulted from an innovative geochemical and geologic system, as standard prospecting procedures could never have discovered these concealed deposits.

Any thinking, that had I not found the Bald Mountain Deposit in1977, another entity would have discovered such in the last few decades, reveals a lack of knowledge on the subject. During the 1960's the Maine wildlands were a 'hotbed' for metal exploration, but by 1972 all had given-up on northern Maine (e.g. Exxon, Texaco, Kennecott, Anaconda, American Metals, ASARCO, etc., etc.) without so much as finding even a 'poor' metal prospect. Prior to my explorations in northern Maine, Exxon (a.k.a. Humble) held a mineral lease on the ground where I eventually found the Bald Mountain and other metal deposits.

At the Maine Geological Survey (MGS) one may find a so-called history of metal activity in the state, but that rendition is clearly tainted. From the early1960's until the discovery of the Bald Mountain Deposit in the late 1970's, the MGS treated me as a 'pariah' as I was a vehement critic of their metal investigations and policies. This adversarial relationship brought me close to the 'brink' only months before the Bald Mountain discovery. If you doubt the foregoing you should contact former Commissioner of Conservation, Richard Barringer.

During the early 1970's, at which time all metal exploration corporations (large and small) had abandoned northern Maine, two of my three remaining 'backers' pulled-the-plug. Superior Oil, was adamant that they would not support my program on a 'solo' basis. J.S. Cummings, Inc. was one step from bankruptcy when I secured the Louisiana Land & Exploration company (LL&E) to go partners with Superior

In 1974, as a result of my recommendations. Superior and LL&E obtained mineral-rights leases on extensive acreage in northern Maine, including the as yet undiscovered Bald Mountain Deposit. At that time the woodlands in the Bald Mountain area (T 12 R 8) were owned by Great Northern Paper Co. and Prentiss & Carlisle of Bangor. My royalty rights, for discovery of valuable minerals in the areas where Superior and LL&E obtained leases on mineral-rights are contained in an agreement with Superior and LL&E dated January 1, 1974. These royalty rights passed to and were accepted by Chevron, Boliden and Black Hawk. (Black Hawk was never a 'player'. See page 42, Cummings, J.S., 2008. *The Boliden – Black Hawk Charade).*

About six months after discovery, Superior (SMC), by prior agreement, assumed control of mine development, and in conjunction with prior JSC drilling, completed plus 200 holes. I continued exploration beyond the perimeters of the potential mining zone and served on the pre-mining committee. The groups that followed SMC - LL&E (i.e. Chevron Minerals and Boliden Mining) did

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minimal orebody delineation by physical means, instead, concentrating on such things as metallurgy, tonnage-grade calculations, plant design and state mining regulations. These post-discovery efforts did not enhance or diminish the basic Bald Mountain model developed in the period 1978 to 1982.

At the time that the 1991 rules were passed you must have been aware, as Speaker of the House, that such were the rules-to-nowhere. These rules not only eviscerated metal exploration, but signaled to the mining companies that you will never be able to 'mine metal' in the State of Maine. My 'technical' loss of 'royalty' rights is tied to the passage of the 1991 rules and the fall-out resulting from such.

As I did not receive advance notice from the last Lessee that the Bald Mountain mineral - rights were being relinquished to the landowners (clearly as a result of the 1991 rules), I did not have the opportunity to solicit funding to establish a new group which could have maintained the Lease until the 1991 rules were expunged. This would have prevented the mineral-rights from reverting to the landowners. Thus my royalty rights were abrogated both as a result of legislative action and unethical actions by the last two Bald Mountain Lessees.

The foregoing is pertinent and belies the notion that a series of groups acquired and then periodically released the Bald Mountain mineral-rights back to the landowners. I held royalty rights on Bald Mountain and other sites for approximately 26 years. Because of the 1991 rules, the mineral rights lease at Bald Mountain and other areas were eventually surrendered to the landowners, as it was perceived (correctly) that no company would ever be able to mine metals in Maine as a result of those rules.

Had it not been for the 1991 rules, at this time the Irving group, which acquired the Bald Mountain mineral-rights as a result purchasing GNP lands in northern Maine, would be subject to the original Lease executed by Superior and LL&E and subsequently passed on to Chevron, Boliden and Black Hawk. Such would have put the Irving group in the position of Lessor.

Had you sought to do in 1991 what you have recently done for the Irving group, my royalty rights would be intact.

As a Maine native I spent most of my adult life trying to bring Maine's potential metallic resources out of the dark ages, only to find that those who seek to profit from my struggle and sacrifices, have shunned me. However, such persons cannot 'undo' my numerous discoveries nor the fact that I wrote the book on 'how to' successfully explore for metal deposits in the state, (*Geochemical detection of volcanogenic massive sulphides in humid-temperate terrain* - Cummings, J.S., 1988, 298 pgs. - URSUS). It is pertinent to my story to note that during the 'long haul', neither I nor my company ever received a 'penny' in the form of grants, contracts, etc, from either the State of Maine or federal agencies.

Your role as a longtime prominent public servant in the State of Maine and one who is familiar with the Bald Mountain past, causes the omission of my name during the LD 1853 scenario, to be doubly disturbing. Following submittal of LD 1853, you invoked the Bald Mountain Deposit, citing the potentially great economic benefits to Aroostook County if the rules were changed. Without invoking the Bald Mountain Deposit, it is certain that LD 1853 would have met a rapid demise.

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SECTION 3 - Conceptual and empirical failure of the mining-model for Bald Mountain

It appears that if the Irving group proceeds and acquires the necessary permits, they intend to mine the hard-rock copper-zinc concentrations at Bald Mountain by means of a large open-pit. This scenario is a prescription for a debacle, meaning either that the permits may never be granted, or if such are granted then undoubtedly there will be unwanted environmental problems down-the-road. If the Bald Mountain mass were viewed within its genetic - empirical constraints and developed within those constraints, some of the most harsh environmental criticisms would be partially or completely ameliorated.

During the discovery period (through drill hole 43), Superior had been a constant critic of my angle-hole pattern. As a result, at the time SMC took over the development program a vertical-hole regimen was instituted. That mind-set has persisted over the decades. The vertical-hole regimen did not signal that angle-holes were never drilled, rather such meant that vertical-holes were the norm. SMC's president had come from a porphyry copper background in the southwestern U.S. where the vertical system was a foregone conclusion.

There is no problem with a vertical-hole regimen as long as one is dealing with porphyries or gently dipping or flat-lying systems. However, genetically the Bald Mountain Deposit, which is classed as a volcanogenic massive sulphide (VMS), is far removed from a porphyry copper system. In VMS types of deposits, layers, bands, or masses of metals of variable configuration may have a wide variety of attitudes, from gently dipping to vertical. It is easy to visualize the problem if one tried to determine the configuration and tonnage of a series of narrow, vertical or near-vertical ore masses by using vertical holes.

Prior investigations have indicated that approximately 33 million tons of the sulphide mass contains approximately 1.1 -1.3% copper and approximately 1.0 % zinc. If the copper-zinc minerals were spread more or less uniformly throughout the sulphide mass, one might make a case for a hard-rock open-pit mine at Bald Mountain. However, there is at least one zone of very high-grade copper and another of modest grade, in addition to a high-grade zinc zone. Such means that millions of tons of rock that were included in the calculated average-grade for the projected hard-rock open-pit, (i.e. pre Irving) contain paltry amounts of copper and zinc.

The sulphide mass that would be extracted by hard-rock open-pit mining is made up of iron-sulphide minerals that contain approximately 40 to 53% sulphur, exclusive of copper and zinc sulphide minerals. Tonnage showing copper &/or zinc levels above the cut-off grade would be subject to grinding and milling, with tonnage below the cut-off grade going to the waste-rock storage area. In addition to the above, another 10 to 15 million tons of perimeter hard-rock would be mined to enable the pit to expand with depth. Such would also go to waste rock storage.

If the deposit were subjected to hard-rock open-pit mining similar to the scenario noted above, then approximately 94% of the sulphide mass that was subject to grinding and milling, (i.e. 31 million tons of high-sulphide slurry) would go to the tailings-pond, with the remaining 5- 6% (plus or minus) going into the concentrate for sale to a smelter.

Recovery rates, that is the percentage of copper &/or zinc that ends up in the concentrates (i.e. for sale to a smelter), are highly variable. Regardless of the average recovery rates determined by prior investigators, there is little doubt that recovery rates for low-end grades would be poor.

de

As a result, undertaking to mine the large, low-grade sulphide mass by means of a hard-rock open-pit at Bald Mountain would require a vastly larger tailings-pond than would be required if a few restricted zones, showing much higher copper-zinc values, were subjected to underground mining.

The Bald Mountain sulphide mass has been considered by prior investigators to have a shallow dip or plunge to the southwest. However, this simplistic picture is refuted by drilling and my research as summarized in Figure 7-7, page 230, Cummings, J.S., 1988 – URSUS).

My pre-drilling analysis suggested that the sulphide layers in the eastern copper zone had a northerly strike and very steep (possible vertical) dips to the east. Hence the locations, bearings, and dip of holes BM 21, 27 and 29.

Figure 7-7 reveals the absurdity of employing a regimen of vertical-holes within a clearly zoned, often steeply dipping copper-zinc VMS deposit. The sinuous lines shown on the drawing represent points of equal zinc/copper ratios for the entire thickness of the sulphide mass. It is clear from my research, as shown on Figure 7-7, that the sulphide is banded or layered, and complexly folded, probably as a result of soft sediment deformation. Figure 7-7 eliminates any thought that the large, thick sulphide mass dipped uniformly and gently to the southwest.

Bands or layers that were horizontal or gently dipping would not show definitive zinc-copper pathways which represent the strike of these layered units. Such is emphasized by the large double fold portrayed in the drawing on page 230. The distinctive banding shown in the central portion of the drawing results from the rapid change in Zn/Cu ratios, such revealing the steep dips of these bands or layers. In the eastern part of the drawing, where the zinc/copper lines are widely spaced, there is virtually no 'change' in Zn/Cu ratios, such resulting from the fact the zinc content in the eastern copper zone is 'nil. Thus holes in this area show uniformly, extremely low zinc/copper ratios throughout the thickness of the mass.

On page 223 (Cummings, J.S., 1988) I noted :

> *It is considered (herein) that most of the high-grade Cu zones have steep or vertical dips (Sec. 72.6), as a result, pre-mining investigations, employing only vertical holes, did not result in effective delineation of the high-grade zones.*

As noted, three of the better copper holes drilled at Bald Mountain were early-stage, parallel angle-holes 21, 27. & 29) which I designed. Of those three holes, BM 29 is the best copper hole drilled at bald Mountain, showing 325 ft. of 5.0% copper. Angle hole BM 5, which I also designed is the best zinc hole drilled at Bald Mountain.

The foregoing confirmed my suspicions (and evidenced by Figure 7-7 and holes 21,27 &29) that in many portions of the sulphide mass we were dealing with zoned or layered metal horizons often having very steep dips (i.e. 75 to 90 degrees). Using total footage of vertical and angle holes in the eastern copper zone, and calculating the footage x % copper for minimum 5 ft intercepts showing a minimum 5% copper, my calculations show that if all of the vertical footage had been employed as angle-holes in the eastern copper zone, then there would be approximately 30 percent more high-grade copper intercepts (i.e. plus 5% Cu, plus 5ft) than presently known in the eastern copper zone.

Within this type of VMS deposit, uniformity or continuity of ore intercepts is not the norm. Rather it is expected that metal-bearing zones in the eastern copper zone would show numerous high-grade copper intercepts dispersed through tens or hundreds of feet. If subjected to proper exploration the eastern copper zone might be found to contain millions of tons of 5 to7% copper, plus possible gold and silver values. My analysis of the nature of the western copper zone, which may contain a significant tonnage of 3% copper, also suggests the need for underground exploration due to the nebulous copper pattern.

de

Clearly, the eastern copper zone should be the focus of underground exploration (e.g. shaft, incline, drifts, etc) prior to considering a hard-rock open-pit plan for the entire deposit, particularly in view of the vastly larger, high-sulphide tailings pond that would result from the hard-rock open-pit. An additional environmental 'positive' that could result if it was found that underground mining could be economically undertaken, would be the likelihood of recycling some of the waste rock to underground storage.

As noted, the hard-rock open-pit scenario that has been espoused for the Bald Mountain Deposit would result in approximately 94% of the mined sulphide mass going to the tailings-pond in the form of a high-sulphide slurry. Experts from the western U.S. will undoubtedly state that tailings-ponds associated with open-pit porphyry deposits are much larger than the tailings-pond that would result from open-pit mining at Bald Mountain. However, what those experts won't tell you is that the tailings from most porphyry deposits contain only a tiny fraction of the sulphides that would enter the Bald Mountain tailings-pond. Often, porphyry tailings consist of simply finely pulverized rock.

Calculated mining costs per ton would be 'higher' for an underground operation than for an open-pit. However, the potential problems (dams, landslides, berms, floods, subsurface fractures, faults) that might affect a large high-sulphide tailings-pond in a region of significant rain and snowfall and irregular topography, do not preclude the possibility that ultimate underground mining costs might be lower per ton than for a large hard-rock open-pit operation.

SECTION 4 - Soft-rock gold-silver open-pit

As noted the soft-rock gold-silver gossan should yield a very high 'net' (dollars) even accounting for a significant drop in Au-Ag prices. This would result from low-cost mining of unconsolidated overburden and gossan. This open-pit would be similar to a large gravel pit and would not entail mining of hard-rock. Proper mining of the gossan should allow the natural overburden (excepting gossan) to be redistributed over the exposed bedrock, assuming that the plan for a huge, hard-rock open-pit had been dispensed with.

Yours truly,

c: Interested parties

de

J.S. Cummings
7043 Surfside Lane
Grand Prairie, TX 75054

May 10. 2013

Representative Jeff McCabe
State of Maine House of Representatives
Augusta, ME 04333

Dear Representative McCabe:

I read with interest a BDN summary (5/13)/pertaining to a hearing on L.D. 1302.

I'm sure you will be interested in the attached copy of a seven page certified letter which I sent to John Martin on September 7, 2012. Martin refused to sign for the letter so the post-office returned such to me. Nevertheless, I received 'positive' comments from dozens of persons to whom I sent copies.

The BDN article noted that you mentioned the Callahan open-pit and ensuing super-fund matters. The Callahan zinc-copper deposit was miniscule in size compared to the Bald Mountain copper-zinc deposit. For example total tons mined at the Callahan site were approximately 800,000 *(Cummings, J..S., 1988, p.49 – Geochemical Detection of Volcanogenic Massive Sulphides in Humid-Temperate Terrain – URSUS).* On the other hand, tonnage available for open-pitting at Bald Mountain would vary from 34,000,000 to 40,000,000 tons, or 42 to 50 times the tonnage mined at the Callahan deposit.

Simply from the standpoint of extractable tonnage, an open-pit at Bald Mountain presents potentially greater risks to the environment than the Callahan deposit. However, as noted in my letter to Martin, such risks are compounded by the fact that approximately 94% of the high-sulphide tonnage (i.e. 32 to 36,000,000 tons) would be relegated to the tailing-pond as high-sulphide slurry.

As if the foregoing were not enough to cause concern as to an open-pit at Bald Mountain, there is the arsenic problem. Some articles in the press have mentioned high levels of arsenic in some waters at the Bald Mountain site. However, to my knowledge no one has informed the public or the legislature that the arsenic content of the sulphide mass is extremely anomalous. The following reference to Bald Mountain drill core is quoted from page 139 *(Cummings, J.S., 1988 – URSUS):*

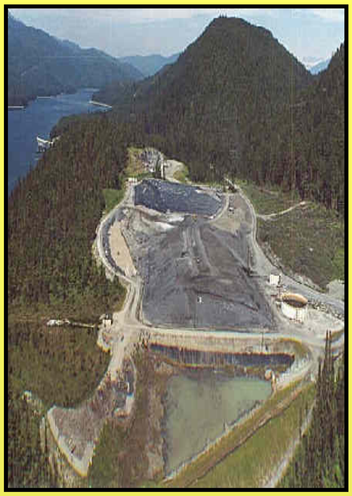
> *Assay data on a suite of ten massive sulphide intercepts showed arsenic (As) contents varying from 1258 ppm to 29,155 ppm (2.91%).*

Thus, the tens of millions of tons of high-sulphide slurry relegated to the tailings-pond would contain very high levels of arsenic. These extremely high arsenic contents are representative of the Bald Mountain mass and are far higher than massive sulphides in general, as my Ledge Ridge discovery (approx 160 miles southwest) showed arsenic levels of only 10 to 15 ppm.

Yours truly

c: Interested Parties

de



Comparison of Predicted and Actual Water Quality at Hardrock Mines

The reliability of predictions in Environmental Impact Statements

Buka
Environmental

Kuipers &
Associates

Comparison of Predicted and Actual Water Quality at Hardrock Mines

The reliability of predictions in Environmental Impact Statements

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Photo credits
Front Cover: Left- Tailings impoundment at the Greens Creek Mine in Alaska USA (Courtesy of David Chambers). Center – Heap leach pad at Marigold Mine in Nevada (Ann Maest). Right – Waste rock dump and open pit at Beal Mountain Mine in Montana (Jim Kuipers). Back cover: Open pit at the Golden Sunlight Mine, Montana (Courtesy of Jeff Barber).

This publication was made possible by EARTHWORKS in Washington, DC, USA with the support of the Wilburforce Foundation of Seattle, Washington, USA. EARTHWORKS is a non-profit organization dedicated to protecting communities and the environment from the destructive impacts of mineral development in the U.S. and worldwide. The organization's mission is to work with communities and grassroots groups to reform government policies, improve corporate practices, influence investment decisions and encourage responsible materials sourcing and consumption.

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PREFACE

The overall purpose of this study is to examine the reliability of pre-mining water quality predictions at hard rock mining operations in the United States. To our knowledge, no effort has previously been made to systematically compare predicted and actual water quality for mines in the U.S. or elsewhere. Environmental Impact Statements (EISs) and similar documents under federal and state law are the single publicly available source of water quality predictions for hard rock mines, and thus they were chosen as the information foundation for conducting the research. In designing the project, we decided to look broadly at as many mines as possible rather than concentrate on an in-depth analysis of a few mines. This approach – which shows general trends and can more easily be extrapolated to the larger set of hard rock mines – will provide the most useful results for mine regulators, which are the principal intended audience for the study. More in-depth studies of individual mines would be a natural next step for continuing investigations.

As part of the study, requests were made to federal and state agencies to provide National Environmental Policy Act (NEPA) documents and information on operational water quality. The effort required to obtain the documents and information, although initially expected to be onerous, was more arduous and protracted than we imagined. We were surprised to find that no single repository exists for NEPA documents, although the Environmental Protection Agency does have most EISs on microfiche. Technical reports associated with EISs were extremely difficult to obtain. Similarly, the availability of operational water quality information was uneven, ranging from disorganized paper-only copies in some states to user-friendly electronic information in others. The authors are grateful to the many agencies that did provide documents and water quality data. One of the most important recommendations in the report is that operational water quality data should be made available to the public in a transparent and easily accessible manner.

The report finds that adverse impacts to water quality are common at mine sites, and they are most often caused by failed mitigation. We recommend that a more in-depth study of the effectiveness of common mitigation measures be undertaken. Another important cause of water quality impacts is errors in geochemical and hydrologic characterization of the mined materials and the mine site area. The companion report (*Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State- of-the-Art)* makes a number of concrete suggestions for improving characterization and predictions.

This report also identifies inherent risk factors that may lead to water quality impacts. Although all mines require carefully executed mitigation measures, mines close to water resources with high acid drainage or contaminant leaching potential need special attention in terms of mitigation and characterization. Adopting protective mitigation and characterization approaches, as recommended here and in the companion report, will help prevent unacceptable water quality impacts, decrease long-term costs, and help instill public trust in the industry. This report is ultimately intended to advance the practice of science, engineering and regulation related to water quality prediction, the recognition of risk, and the application of effective mitigation to hardrock mines. The authors encourage ongoing cooperative efforts with regulators, scientists and engineers, non-governmental organizations, and industry to further the work begun in this study.

Jim Kuipers
Butte, Montana
and
Ann Maest
Boulder, Colorado
September 2006

AUTHORS

Jim (James R.) Kuipers, P.E., of Kuipers & Associates, is a mining engineer with over 20 years of experience in mine permitting, design, construction, operations, reclamation, water treatment and cost estimation. He has extensive experience in the gold and copper mining industries and has worked in the U.S., Canada, Latin America and former USSR. Since 1996 he has focused his work on providing expertise in mine permitting and reclamation and closure issues in addition to publishing articles and giving presentations on financial assurance. Over the course of his career he has had gained extensive knowledge in the various methods and models used to predict water quality at both existing and proposed mine sites as well as their regulatory applications. Mr. Kuipers holds a BS degree in mineral process engineering from Montana College of Mineral Science and Technology and is a registered professional engineer in Colorado and Montana.

Ann S. Maest, PhD, of Buka Environmental, is an aqueous geochemist specializing in the fate and transport of contaminants in natural waters. As a consultant, she has designed, conducted, and managed hydrogeochemistry and modeling studies and worked on independent monitoring and community capacity building projects at numerous mining sites in the U.S. and Latin America. At the U.S. Geological Survey, she conducted research on metal and metalloid speciation in surface water and groundwater. Dr. Maest has published articles on the fate and transport of metals in natural waters and served on national and international committees related to hardrock mining and sustainable development. She holds a PhD in geochemistry and water resources from Princeton University and an undergraduate degree in geology from Boston University.

Kimberley A. MacHardy, Associate Geoscientist with Kuipers & Associates, has a Master's Degree in Geosciences from Montana Tech of The University of Montana. Ms. MacHardy has worked on mine sites in Montana, and mine impacted sites in Nevada, prepared sampling and analysis plans, and coordinated, conducted, and directed field sampling programs. She has worked for two years on the Good Neighbor Agreement for the Stillwater Mine in Montana, where she conducted monthly sampling for water quality parameters and river flows on the Stillwater River, as well as periodic macroinvertebrate and nutrient sampling on both the Stillwater and East Boulder Rivers in Montana.

Gregory Lawson, Associate Geologist with Buka Environmental, has an undergraduate degree in geology from Oberlin College. Mr. Lawson has conducted field work in Japan and the Dominican Republic and has taken course work in chemistry, mineralogy, hydrology, and environmental geology. Mr. Lawson is currently pursuing a PhD in geology at the University of California at Riverside.

ACKNOWLEDGMENTS

Project advice, input and internal peer review were provided by Tom Myers, PhD, hydrogeologist, Dave Chambers, PhD, Center for Science in Public Participation and Glenn Miller, PhD, biochemist, of the University of Nevada-Reno. Technical review and editing was performed by Peggy Utesch and Sarah Zuzulock.

Various versions of the database, report and sections of the report were sent to state and federal regulators and industry consultants for review and comment. Because of the nature of this report, with many site specific examples, it was difficult to obtain peer review for every example and for the report as a whole. Reviewers included regulators from EPA, BLM and the Forest Service as well as industry consultants, and included Stephen Hoffman and Patricia McGrath of the EPA; and Jack Mozingo (Black & Veatch) and Andrew Robertson (Robertson Geoconsultants). The authors take sole responsibility for the contents of the report and will consider additional review comments for future publication or additional efforts derived from this report.

The involvement of all the reviewers lead to substantial improvements to this report and are greatly appreciated

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LIST OF ACRONYMS

ABA	Acid Base Accounting
ACE	Army Corp of Engineers
ADEQ	Arizona Department of Environmental Quality
Ag	Silver
AGP	Acid Generating Potential
Al	Aluminum
ANP	Acid Neutralizing Potential
APP	Arizona Aquifer Protection Permit
As	Arsenic
B	Boron
BADCT	Best Available Demonstrated Control Technology
Be	Beryllium
bgs	below ground surface
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BMP	Best Management Practices
Ca	Calcium
CA WET	California Waste Extraction Test
Cd	Cadmium
CEQ	Council on Environmental Quality
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Cl	Chloride
CN	Cyanide
COE	Army Corp of Engineers
Cr	Chromium
Cu	Copper
DI	Deionized Water
DL-SX	Dump Leach Solvent Extraction
EA	Environmental Assessment
EA/EIR	Environmental Assessment /Environmental Impact Report
ECHO	EPA’s Enforcement History and Online Database
EECA	Engineering Evaluation /Cost Analysis
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EIS/EIR	Environmental Impact Statement /Environmental Impact Report
EPA	Environmental Protection Agency
EP Toxicity	Extraction Procedure Toxicity Test
F	Flotation
F	Fluoride
Fe	Iron
FG	Flotation and Gravity
FOIA	Freedom of Information Act
FONSI	Finding of No Significant Impact
Ft	Feet
gpm	gallons per minute
g/l	grams per liter
Hg	Mercury

HL	Heap Leach
HCT	Humidity Cell Tests
LAD	Land Application Discharge
MAS/MILS	Mineral Availability System /Mineral Industry Locater System
MCL/SMCL	Maximum Contaminant Level/Secondary Maximum Contaminant Level
MDEQ	Montana Department of Environmental Quality
mg/l	milligrams per liter
µg/l	micrograms per liter
msl	mean sea level
MEP	Multiple Extraction Procedure
MEPA	Montana Environmental Protection Act
Mg	Magnesium
Mn	Manganese
MWMP	Metric Water Mobility Procedure
N	Nitrogen
NAG	Net Acid Generating
NCV	Net Carbonate Value
NDEP	Nevada Department of Environmental Protection
NEPA	National Environmental Policy Act
NGOs	Non-Governmental Organizations
NH_4	Ammonia
Ni	Nickel
NNP	Net Neutralizing Potential
NO_3	Nitrate
NP	Neutralizing Potential
NP/AP	Neutralizing Potential/Acid Potential
NPDES	National Pollution Discharge Elimination System
OP	Open Pit
P	Phosphorous
PAG	Potentially Acid-Generating
Pb	Lead
PER	Preliminary Environmental Review
PLS	Pregnant Leach Solution
PGM	Platinum Group Minerals
ppm	parts per million
ROD	Record of Decision
RWD	Report of Waste Discharge
RWQCB	Regional Water Quality Control Board
S	Smelter
Sb	Antimony
SDWA	Safe Drinking Water Act
Se	Selenium
SEIS	Supplemental Environmental Impact Statement
SO_4	Sulfate
SPLP	Synthetic Precipitation Leaching Procedure
SSRE	Sequential Saturated Rolling Extraction
STLC	Soluble Threshold Limit Concentration
SWCB	State Water Control Board
SX/EW	Solvent Extraction Electrowinning
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
Tl	Thallium

t/kt	tons per kiloton
TTLC	Total Threshold Limit Concentrations
UG	Underground
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
VL	Vat Leach
WAD	Weak Acid Dissociable
WQ	Water Quality
Zn	Zinc

EXECUTIVE SUMMARY

INTRODUCTION AND APPROACH

This study reviews the history and accuracy of water quality predictions in Environmental Impact Statements (EISs) for major hardrock mines in the United States. It does so by:

- identifying major hardrock metals mines in the United States and determining which major mines had EISs
- gathering and evaluating water quality prediction information from EISs
- selecting a representative subset of mines with EISs for in-depth study
- examining actual water quality information for the case study mines, and
- comparing actual water quality to the predictions made in EISs.

Based on the results of the evaluations conducted, an analysis was performed to identify the most common causes of water quality impact and prediction failures. In addition, an analysis was conducted to determine if there were inherent risk factors at mines that may predispose an operation to having water quality problems. Conclusions are provided about the effectiveness of the underlying scientific and engineering principles used to make water quality predictions in EISs. Finally, recommendations are made for regulatory, scientific and engineering approaches that would improve the reliability of water quality predictions at hardrock mine sites.

The National Environmental Policy Act (NEPA), enacted in 1969, was the first environmental statute in the United States and forms the foundation of a comprehensive national policy for environmental decision making. NEPA requires federal agencies to take a "hard look" at the environmental impacts of each proposed project to ensure the necessary mitigation or other measures are employed to meet federal and state regulations and other applicable requirements. Under NEPA, when a new mine is permitted, agencies have a duty to disclose underlying scientific data and rationale supporting the conclusions and assumptions in an EIS.

NEPA requires federal agencies proposing major actions that may substantially affect the quality of the human environment to prepare a detailed Environmental Impact Statement (EIS). A "major action" includes actions approved by permit or other regulatory action. If the agency finds that the project *may* have a significant impact on the environment, then it must prepare an EIS. As part of the EIS process, hardrock mines operating on federal lands or otherwise subject to NEPA are required to estimate impacts to the environment, including direct impacts to water quality and indirect impacts that occur later in time but are still reasonably foreseeable. The NEPA analysis process calls for performing original research, if necessary, and reasonable scientifically supported forecasting and speculation. A wide array of scientific approaches has been used to predict water quality that could result at mine sites, and many different engineering techniques were applied to mitigate these potential impacts. The primary subject of this report is the effectiveness of water quality predictions and mitigation that were applied over the past 30 years as a part of the EIS process at hardrock mines in the United States.

IDENTIFICATION OF MAJOR AND NEPA-ELIGIBLE HARD ROCK MINES

Major Hardrock Metal Mines in the United States

Hardrock metal mines in the United States produce gold, silver, copper, molybdenum, lead, zinc and platinum group metals from open pit and underground mining operations. For the purpose of this study, "major" mines were defined as: those that have a disturbance area of over 100 acres and a financial assurance amount of over $250,000; have a financial assurance of $1,000,000 alone (regardless of acreage); or have a production history (since 1975) of greater than 100,000 ounces of gold, 100,000,000 pounds of copper or the monetary value equivalent in another metal. Using those criteria, 183 major hardrock metal mines were identified as having operated since 1975.
The major hardrock mines are located in fourteen states (Alaska, Arizona, California, Colorado, Idaho, Michigan, Montana, Nevada, New Mexico, South Carolina, South Dakota, Utah, Washington and Wisconsin), with the vast

majority (178 of 183) located in western states. Nevada has the greatest number of major mines of any state, with 74 (40%) of the total major mines. Sixty-three percent (63%) of the mines produce gold and/or silver, 16% produce copper, 4% produce copper and molybdenum, 2% produce molybdenum only, 4% produce lead and zinc, and 1% produce platinum group metals (percentages add to greater than 100 because some mines produce multiple commodities).

Seventy-two percent (72%) of the major hardrock mines in the U.S. that have operated since 1975 are open pit mines, while 15% are underground. Sixty-six percent (66%) of the major hardrock mines use cyanide heap or vat leaching, 24% use flotation or gravity processing and 12% process ore by acid dump leaching and solvent extraction/ electrowinning.

Forty-five percent (45%) of the 183 major hardrock mines in operation since 1975 are still operating, and 49% have closed. Only one new major hardrock mine is currently (as of 2005) in construction, and seven others are in various stages of permitting. After the NEPA processes were completed, development proposals were withdrawn for four of the major hardrock mines identified in this study.

Major Hardrock Metal Mines Subject to NEPA

Mines located on federal land administered by the Bureau of Land Management or the Forest Service are subject to the requirements of NEPA. Also subject to NEPA regulations are certain National Pollution Discharge Elimination System (NPDES) permits issued by the Environmental Protection Agency, certain 404 Wetlands permits from the Army Corp of Engineers, and mines located on Native American trust lands administered by the Bureau of Indian Affairs (BIA). In addition, some states (California, Montana, Washington and Wisconsin) have a state-mandated process that is equivalent to NEPA.

NEPA requires environmental analysis of federal actions. As it has evolved, an EIS is required for any “major federal action significantly affecting the quality of the human environment,” and an Environmental Assessment (EA) is required for lesser actions. EAs do not require public comment; the results of an EA can determine whether the action is significant, which will trigger an EIS, but usually the EA is performed in lieu of an EIS.

Of the 183 major modern-era hardrock mines identified, 137 (75%) had federal actions that triggered NEPA analysis. Ninety-three (68%) were located on BLM land, thirty-four (25%) on Forest Service land, and nine (7%) on both BLM and Forest Service land. Disturbance of wetlands triggered NEPA analysis at five (4%) of the mines, requiring a 404 wetlands permits from the Corp of Engineers (COE); a discharge into a water of the United States was the only NEPA trigger at three (2%) mines; and NEPA analysis was triggered at two (1%) mines because they were located on Indian Lands. Twenty-three (19%) mines were located in states that have their own NEPA-equivalent statutes. In many cases, more than one federal agency may be involved in the NEPA process (e.g., Forest Service and BLM, based on location, or Forest Service and EPA, based on location and a NPDES discharge); in addition, state agencies may be responsible for carrying out their own NEPA-equivalent or alternative processes. When this occurs, a Memorandum of Understanding (MOU) is usually written among the various agencies describing their shared responsibilities in order to avoid duplication of efforts. When two or more federal and/or state agencies are involved, the agencies establish a formal agreement delineating which will act in the lead and cooperating roles. In some cases an EIS (or EA) may be developed that will satisfy both NEPA and a NEPA-equivalent state law.

The general makeup of the mines where NEPA is applicable is roughly similar to that of major mines. The NEPA-applicable mines are located in 11 states with all but one located in the western states. Nevada had the most NEPA-applicable major mines with 50% (69) of the total. Eighty-five percent (116) of the NEPA-applicable mines produced gold and/or silver, while 15% (21) produced copper. Seventy-six percent (104) of the NEPA-applicable major mines were open-pit, while 14% (19) were underground mines. Sixty-nine percent (95) used cyanide heap or vat leach, 20% (28) used flotation/gravity and 11% (15) used acid dump leach processing. Forty-seven percent (64) of the major mines subject to NEPA were still operating, 45% (61) have closed, one was in construction, six were in permitting, and five were withdrawn from consideration after undergoing the NEPA process.

EISs were performed at 82 (60%) of the 137 major mines subject to NEPA, either as part of new permitting actions or later expansions or other actions. EAs were performed at the remainder of the mines subject to NEPA. EISs and EAs were obtained by writing, e-mailing, and/or calling state and federal agencies, including the BLM, Forest Service, tribal agencies and by conducting library searches. The process of obtaining NEPA documents took approximately 16 months and involved numerous follow-up calls, and written and email contact. Of the 137 major mines subject to NEPA, 71 mines had documents that were obtained and reviewed. A total of 104 NEPA documents, either EISs or EAs, were reviewed for the 71 mines. The general characteristics of mines with reviewed EISs are similar to those of all major hard rock mines and all NEPA-eligible mines, as shown in Table ES-1.

EVALUATION OF WATER QUALITY PREDICTION INFORMATION IN NEPA DOCUMENTS

Information on the following elements related to water quantity and quality predictions was collected from the 104 NEPA documents: geology/mineralization; climate; hydrology; field and laboratory tests performed; constituents of concern identified; predictive models used; water quality impact potential; mitigation; potential water quality impacts; predicted water quality impacts; and discharge information. There are two types of water quality predictions made in EISs: "potential" water quality, which leans toward worst-case water quality that does not take mitigation into account; and "predicted" water quality, which does consider the beneficial effects of mitigation. Both types of water quality predictions were recorded and used for subsequent comparisons to actual water quality. For each type of information collected from the NEPA documents, a score was derived to characterize the element (e.g., geology/ mineralization used six scores, including one for no information provided). The scoring allowed numeric summaries (percentages) to be calculated based on the information collected from the NEPA documents. The results for the EIS information collected for each mine reviewed in detail (71 mines, 104 EISs) are contained in Section 5 of the report. Limited information on certain water quality elements is contained in Table ES-4.

A preliminary evaluation of the availability of operational water quality information was performed before selection of the case study mines. Operational and post-operational water quality information was available from EISs conducted after the new project EIS, especially for the states of Alaska, Montana and Idaho, where multiple EISs were often available. In other states, such as Arizona, California, Nevada and Wisconsin, technical reports and water quality data were available from state agencies that regulate mining activities.

SELECTION OF CASE STUDY MINES

The case study mines were selected based on:

- the ease of access to information on operational water quality
- the variability in general categories such as geographic location, commodity type, extraction and processing methods, and
- the variability in EIS elements related to water quality, such as climate, proximity to groundwater and surface water resources, acid drainage potential and contaminant leaching potential.

Case studies were developed for the twenty-five mines listed in Table ES-2.

Table ES-1. Comparison of General Categories for All Hard Rock Mines, NEPA-eligible Mines and Mines with Reviewed EISs (% of mines in sub-category)

Category	Sub-category	Major Mines (%)	NEPA-eligible Mines (%)	Mines with Reviewed EISs (%)
Location	Alaska	4.4%	5.1%	9.9%
	Arizona	10.9%	9.5%	11.3%
	California	8.2%	9.5%	11.3%
	Colorado	4.9%	0.0%	0.0%
	Idaho	7.7%	4.4%	8.5%
	Michigan	0.5%	0.0%	0.0%
	Montana	8.2%	10.9%	18.3%
	Nevada	40.4%	50.4%	32.4%
	New Mexico	3.8%	2.2%	2.8%
	South Carolina	1.6%	0.0%	0.0%
	South Dakota	2.7%	0.7%	1.4%
	Utah	3.8%	2.9%	1.4%
	Washington	2.2%	2.9%	0.0%
	Wisconsin	0.5%	0.7%	1.4%
Commodity	Primary Gold	12.6%	12.4%	19.7%
	Primary Silver	7.1%	6.6%	7.0%
	Gold and Silver	62.8%	65.7%	54.9%
	Copper	16.4%	15.3%	19.7%
	Copper and Molybdenum	4.4%	2.9%	1.4%
	Molybdenum	2.2%	0.7%	1.4%
	Lead and Zinc	3.8%	3.6%	5.6%
	Platinum Group	1.1%	1.5%	2.8%
Extraction Methods	Underground	14.8%	13.9%	18.3%
	Open Pit	72.1%	75.9%	71.8%
	Underground + Open Pit	12.0%	10.2%	9.9%
Processing Methods	Heap or Vat Leach	65.6%	69.3%	62.0%
	Flotation and Gravity	24.0%	20.4%	26.8%
	Dump Leach (SX/EW)	12.0%	10.9%	11.3%
	Heap Leach	39.3%	38.7%	25.4%
	Vat Leach	9.3%	10.2%	14.1%
	Heap Leach and Vat Leach	16.9%	20.4%	22.5%
	Smelter	3.3%	1.5%	1.4%
Operational Status	Operating	44.8%	46.7%	49.3%
	Closed	48.6%	44.5%	36.6%
	In Construction	0.5%	0.7%	1.4%
	Permitting	3.8%	4.4%	7.0%
	Withdrawn	2.2%	3.6%	5.6%
Total number of mines in category		183	137	71

Table ES-2. Case Study Mines

Mine	State	Mine	State
Greens Creek	AK	Golden Sunlight	MT
Bagdad	AZ	Mineral Hill	MT
Ray	AZ	Stillwater	MT
American Girl	CA	Zortman and Landusky	MT
Castle Mountain	CA	Florida Canyon	NV
Jamestown	CA	Jerritt Canyon	NV
McLaughlin	CA	Lone Tree	NV
Mesquite	CA	Rochester	NV
Royal Mountain King	CA	Round Mountain	NV
Grouse Creek	ID	Ruby Hill	NV
Thompson Creek	ID	Twin Creeks	NV
Beal Mountain	MT	Flambeau	WI
Black Pine	MT		

The major characteristics of the case study mines were similar to those of all mines with reviewed EISs, as shown in Table ES-3. The availability of information on operational water quality was also a major factor in the selection of case-study mines. The highest percentage of case study mines was from Nevada, and this state had the highest percentage of mines for all major mines, NEPA-eligible mines, and mines with reviewed EISs. Somewhat higher percentages of mines from California and Montana were selected for case studies because of the ease of obtaining operational water quality information from these states. Similar percentages of gold and/or silver mines were selected for the case studies as were present in all mines with reviewed EISs. However, a lower percentage of primary copper mines was selected for case study because of the difficulty in obtaining operational water quality information on these facilities. Case study mines had very similar percentages as all mines with reviewed EISs in terms of extraction and processing methods. In terms of operational status, no case study mines were in construction, in permitting, or withdrawn because operational water quality information would not be available for mines in these types of operational status.

Case study mines were also similar to all mines with reviewed EISs in terms of EIS elements related to water quality, as shown in Table ES-4. The elements listed in Table ES-4 are considered “inherent” factors that may affect water quality conditions. That is, these elements are related to conditions that either relate to climatic and hydrologic conditions at and near the mine site (in the case of climate, and proximity to water resources) or to qualities of the mined materials that may affect water quality (in the case of acid drainage and contaminant leaching potential). For a number of mines, little or no information on these elements was available in initial EISs, but subsequent NEPA documents either contained the first information or contained improved information after water quality conditions developed at the mine site during and after operation. Therefore, for acid drainage and contaminant leaching potential, the highest documented potential in any of the EISs was recorded.

Case study mines were similar to all mines with reviewed EISs in terms of climate and proximity to surface water resources. When compared to all mines with reviewed EISs, a higher percentage of case study mines had shallower depths to groundwater. However, six of the case study mines had groundwater depths greater than 50 feet below the ground surface. In terms of acid drainage potential, lower percentages of case study mines had low and high acid drainage potential, but higher percentages had moderate acid drainage potential. Therefore, the case study mines provide a somewhat more evenly distributed range of acid drainage potentials than all mines with reviewed EISs. Case study mines had nearly identical percentages of mines with low and high contaminant leaching potential, but more case study mines had moderate acid drainage potential, reflecting fewer mines in the “no information” category for case study mines.

Table ES-3. Comparison of General Categories for All Mines with Reviewed EISs and Case Study Mines (% of mines in subcategory)

Category	Subcategory	All Mines with Reviewed EISs	Case Study Mines
Location	Alaska	10%	4%
	Arizona	11%	8%
	California	11%	24%
	Colorado	0%	0%
	Idaho	9%	8%
	Michigan	0%	0%
	Montana	18%	24%
	Nevada	32%	28%
	New Mexico	3%	0%
	South Carolina	0%	0%
	South Dakota	1%	0%
	Utah	1%	0%
	Washington	0%	0%
	Wisconsin	1%	4%
Commodity	Primary Gold	20%	12%
	Primary Silver	7%	4%
	Gold and Silver	55%	64%
	Copper	20%	4%
	Copper and Molybdenum	1%	4%
	Molybdenum	1%	4%
	Lead and Zinc	6%	4%
	Platinum Group	3%	4%
Extraction Methods	Underground	18%	16%
	Open Pit	72%	76%
	Underground + Open Pit	10%	8%
Processing Methods	Heap and/or Vat Leach	62%	72%
	Flotation and Gravity	27%	28%
	Dump Leach (SX/EW)	11%	8%
	Heap Leach	25%	20%
	Vat Leach	14%	16%
	Heap Leach and Vat Leach	23%	32%
	Smelter	1%	0%
Operational Status	Operating	49%	52%
	Closed	37%	48%
	In Construction	1%	0%
	Permitting	7%	0%
	Withdrawn	6%	0%
Total number of mines		71	25

Table ES-4. Comparison of EIS Elements for All Mines with Reviewed EISs and Case Study Mines (% of mines with sub-element)

Element	Sub-element	All Mines with Reviewed EISs	Case Study Mines
Climate	Dry/Arid	20%	20%
	Dry/Semi-Arid	35%	28%
	Humid Subtropical	4%	12%
	Marine West Coast	4%	4%
	Boreal Forest	28%	32%
	Continental	3%	4%
	Sub-Arctic	4%	0%
Surface Water Proximity	No information	7%	4%
	Perennial Streams >1 mile	26%	24%
	Perennial streams <1 mile	25%	28%
	Perennial streams on site	44%	44%
Groundwater Proximity	No information	12%	4%
	Groundwater >200 ft deep	16%	8%
	Groundwater 50-200 ft deep	13%	16%
	Groundwater 0-50 ft deep/springs on site	59%	72%
Acid Drainage Potential (highest)	No information	9%	8%
	Low	58%	48%
	Moderate	6%	32%
	High	27%	12%
Contaminant Leaching Potential (highest)	No information	22%	12%
	Low	32%	32%
	Moderate	30%	40%
	High	17%	16%
Total number of mines		71	25

Overall, the case study mines display a variability in geographic location, commodity type, extraction and processing methods and in EIS elements related to water quality. Considering the additional limitation of having readily accessible operational water quality information, the case study mines reflect well the distribution of general categories and water quality-related elements that are present in the larger subsets of hard rock mines in the United States.

Case studies for each mine contain information collected from EISs and other documents, information on actual water quality, a comparison of predicted and actual water quality, and an analysis of the causes of water quality impacts and prediction errors.

COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Operational and post-operational water quality information was collected from EISs conducted after the new project EIS for mines in Alaska, Montana and Idaho. Interviews of state agency personnel were conducted in California, Montana, Nevada and Wisconsin. Technical reports and water quality data from state agencies that regulate mining were collected for mines in Arizona, California, Nevada and Wisconsin. In some cases, the water quality data showed pre-mining and operational water quality, but baseline data were generally difficult to obtain. The information collected on actual water quality conditions was held in databases or in electronic and paper files for comparison to predicted water quality.

For this evaluation, a water quality impact is defined as increases in water quality parameters as a result of mining operations, whether or not an exceedence of water quality standards or permit levels has occurred. Information on whether groundwater, seep, or surface water concentrations exceeded standards as a result of mining activity is also included. Nearly all the EISs reviewed reported that they expected acceptable water quality (concentrations lower than relevant standards) after mitigation were taken into account. Indeed, if this prediction was not made in the EIS, the regulatory agency would not be able to approve the mine (with certain exceptions, such as pit water quality, in states where pit water is not considered a water of the state).

A comparison between potential (pre-mitigation), predicted, and actual surface water quality for the case study mines is presented in Table ES-5. Sixty percent of the case study mines (15/25) had mining-related exceedences in surface water. Of the mines with surface water quality exceedences, four (17%) noted a low potential, seven (47%) a moderate potential, two a high potential, and three had no information in their EISs for surface water quality impacts in the absence of mitigation measures. For the mines with surface water quality exceedences, only one mine, the McLaughlin Mine in California, was correct in predicting a moderate potential for surface water quality impacts with mitigation in place. However, this mine predicted low acid drainage potential, yet acid drainage has developed on site. Of the mines without surface water quality exceedences (7 or 28%), all were correct thus far in predicting no impacts to surface water with mitigation in place. Three of the seven are desert mines in California, one (Stillwater in Montana) has had increases in contaminant concentrations but no exceedences, and the other three have had no exceedences or increases in mining-related contaminant concentrations in surface water to date. Therefore, most case study mines predicted no impacts to surface water quality after mitigation are in place, but at the majority of these mines, impacts have already occurred.

A comparison between potential (pre-mitigation), predicted, and actual groundwater quality for the case study mines is presented in Table ES-6. The majority (64% or 16/25) of the case study mines had exceedences of drinking water standards in groundwater. However, exceedences at three of the mines, all in Nevada, may be related to baseline conditions; therefore, 52% of the case study mines clearly had mining-related exceedences of standards in surface water. Of the 13 mines with mining-related exceedences in groundwater, only two noted a low potential for groundwater quality impacts in the original EIS. The majority (9 or 69%) stated that there would be a moderate potential, and two stated there was a high potential for groundwater impacts in the absence of mitigation. In terms of predicted (post-mitigation) groundwater quality impacts, 77% (10/13) of the mines with exceedences predicted low groundwater quality impacts in their EISs, including mines predicting low impacts in the original EIS.

Of the mines with mining-related groundwater quality exceedences (13), only one mine – the same mine that correctly predicted that there would be surface water exceedences (McLaughlin, CA), was correct in predicting a high potential for groundwater quality impacts with mitigation in place; the others predicted a low potential (not exceeding standards) in at least one EIS. Of the mines without groundwater quality exceedences (5 or 25%), all were correct in predicting no impacts to surface water with mitigation in place. Again, three of the five are desert mines in California, one (Stillwater, MT) has had increases in contaminant concentrations but no exceedences, and the other (Greens Creek, AK) has had mining-related exceedences in seeps. Therefore, most mines predict no impacts to groundwater quality after mitigation were in place, but in the majority of case study mines, impacts have occurred.

Therefore, as with surface water, the predictions made about groundwater quality impacts without considering the effects of mitigation were somewhat more accurate than those made taking the effects of mitigation into account. Again, the ameliorating effect of mitigation on groundwater quality was overestimated in the majority of the case study mines.

A comparison between acid drainage and development for the case study mines is presented in Table ES-7a. Of the 25 case study mines, nine (36%) have developed acid drainage on site to date. Nearly all the mines (8/9) that developed acid drainage either underestimated or ignored the potential for acid drainage in their EISs.

Table ES-5. Summary of Predicted and Actual Impacts to Surface Water Resources at Case Study Mines

Element	Number/Total	Percentage
Mines with mining-related surface water exceedences	15/25	60%
Mines with surface water exceedences that predicted low impacts without mitigation	4/15	27%
Mines with surface water exceedences that predicted low impacts with mitigation	11/15	73%

Table ES-6. Summary of Predicted and Actual Impacts to Groundwater Resources at Case Study Mines

Element	Number/Total	Percentage
Mines with mining-related groundwater exceedences	13/25	52%
Mines with groundwater exceedences predicting low impacts without mitigation	2/13	15%
Mines with groundwater exceedences predicting low impacts with mitigation	10/13	77%

Table ES-7a. Summary of Acid Drainage Potential Predictions and Results for Case Study Mines

Element	Number/Total	Percentage
Mines predicting low acid drainage potential	18/25	72%
Mines that have developed acid drainage	9/25	36%
Mines with acid drainage that predicted low acid drainage potential	8/9	89%

The majority of the case study mines (18/25 or 72%) predicted low potential for acid drainage in one or more EISs. Of the 25 case study mines, 36% have developed acid drainage on site to date. Of these 9 mines, 8 (89%) predicted low acid drainage potential initially or had no information on acid drainage potential. The Greens Creek Mine in Alaska initially predicted moderate acid drainage potential but later predicted low potential for acid drainage for an additional waste rock disposal facility. Therefore, nearly all the mines that developed acid drainage either underestimated or ignored the potential for acid drainage in their EISs.

Of the 25 case study mines, 19 (76%) had mining-related exceedences in surface water or groundwater. However, nearly half of the mines with exceedences (8/19 or 42%) predicted low contaminant leaching potential in their EISs. The constituents that most often exceeded standards or that had increasing concentrations in groundwater or surface water included toxic heavy metals such as copper, cadmium, lead, mercury, nickel, or zinc (12/19 or 63% of mines), arsenic and sulfate (11/19 or 58% of mines for each) and cyanide (10/19 or 53% of mines).

Eight case study mines predicted low contaminant leaching potential (Table ES-7b). Of these eight mines, five (63%) had exceedences of standards in either surface water or groundwater or both after mining began. The three mines that predicted low contaminant leaching potential and had no exceedences of water quality standards were the three California desert mines: American Girl, Castle Mountain, and Mesquite.

Table ES-7b. Summary of Contaminant Leaching Potential Predictions and Results for Case Study Mines (percentages)

Element	Number/Total	Percentage
Mines predicting low contaminant leaching potential	8/25	32%
Mines with mining-related exceedences in surface water or groundwater	19/25	76%
Mines with exceedences that predicted low contaminant leaching potential	8/19	42%
Mines with exceedences that predicted moderate contaminant leaching potential	8/19	42%
Mines with exceedences that predicted high contaminant leaching potential	3/19	16%

Stated another way, 21 of the 25 case study mines (84%) had exceedences of water quality standards in either surface water or groundwater or both. The exceedences at two of these mines may be related to baseline conditions. Therefore, 76% of the case study mines had mining related exceedences in surface water or groundwater (Table ES-7b). Of the remaining 19 mines, 42% (eight) predicted low contaminant leaching potential (or had no information), 42% (eight) predicted moderate contaminant leaching potential, and only three (16%) predicted high contaminant leaching potential. Therefore, nearly half of the mines that had exceedences of water quality standards underestimated or ignored the potential for contaminant leaching potential in EISs. The constituents that most often exceeded standards or that had increasing concentrations in groundwater or surface water included toxic heavy metals such as copper, cadmium, lead, mercury, nickel, or zinc (12/19 or 63% of mines), arsenic and sulfate (11/19 or 58% of mines for each), and cyanide (10/19 or 53% of mines).

CAUSES OF WATER QUALITY IMPACTS AND PREDICTION ERRORS

Inherent Factors Affecting Water Quality at Mine Sites

This study attempts to determine if there are certain factors that make a mine more or less likely to cause water quality problems and more or less likely to accurately predict future water quality. Such factors could include inherent characteristics of the mined materials and the mine, management approaches to handling mined materials and water, and the type and number of geochemical tests that are performed on mined materials. The inherent factors evaluated include: geology and mineralization; proximity to water resources and climatic conditions; and geochemical characteristics of mined materials, such as acid drainage and contaminant leaching potential.

The relationship between inherent hydrologic and geochemical characteristics and water quality impacts shows that mines with close proximity to surface water or groundwater resources and with a moderate to high acid drainage or contaminant leaching potential have an increased risk of impacting water quality.

Surface water impacts for the mines with close proximity to surface water and high acid drainage or contaminant leaching potential are compared to surface water impacts for all the case study mines in Table ES-8. Overall, for the 13 mines with close proximity to surface water and high acid drainage or contaminant leaching potential, 12 (92%) have had some impact to surface water as a result of mining activity. For all case study mines, only 64% had some surface water quality impact. Eleven of the 13 (85%) have had exceedences of standards or permit limits in surface water as a result of mining activity.

Table ES-8. Surface Water Quality Impacts for Mines with Close Proximity to Surface Water and Elevated Acid Drainage Potential Compared to Surface Water Impacts for All Case Study Mines

	# Mines	Percent (%) with Impact to Surface Water	Percent (%) with Exceedences of Standards in Surface Water	Percent (%) with Exceedences that Predicted No Exceedences
Mines with close proximity to surface water and elevated acid drainage and contaminant leaching potential	13	92 (12/13)	85 (11/13)	91 10/11)
All case study mines	25	64 (16/25)	60 (15/25)	73 (11/15)

Of the 11 mines with surface water exceedences, ten (91%) predicted that surface water standards would not be exceeded. Considering the two mines that accurately predicted no surface water exceedences (Stillwater and Flambeau) and the one that accurately predicted exceedences (McLaughlin), 77% of mines with close proximity to surface water or direct discharges to surface water and moderate to high acid drainage or contaminant leaching potential underestimated actual impacts to surface water. For all case study mines, 73% of the mines with surface water quality exceedences predicted that there would be no exceedences. Compared to all case study mines, higher percentages of mines with close proximity to surface water and elevated acid drainage or contaminant leaching potential had surface water quality impacts and exceedences. EIS water quality predictions made before the ameliorating effects of mitigation were considered (“potential” water quality impacts) were more accurate at predicting operational water quality than predictions based on assumed improvements from mitigation.

Groundwater impacts for the mines with close proximity to groundwater and high acid drainage or contaminant leaching potential are compared to groundwater impacts for all the case study mines in Table ES-9. Of the 15 mines with close proximity to groundwater and high acid drainage or contaminant leaching potential, all but one (93%) have had mining-related impacts to groundwater, seeps, springs or admit water. For all case study mines, only 56% had mining-related impacts to groundwater. For the 15 mines with close proximity to groundwater and elevated acid drainage or contaminant leaching potential, 13 or 87% had mining-related exceedences in groundwater. For all case study mines, only 52% had exceedences in groundwater.

Table ES-9. Groundwater Quality Impacts for Mines with Close Proximity to Groundwater and Elevated Acid Drainage Potential Compared to Groundwater Impacts for All Case Study Mines

	# Mines	Percent (%) with Impact to Groundwater or Seeps	Percent (%) with Exceedences of Standards in Groundwater or Seeps	Percent (%) with Exceedences that Predicted No Exceedences
Mines with close proximity to groundwater and elevated acid drainage and contaminant leaching potential	15	93 (14/15)	93 (14/15)	86 (12/14)
All case study mines	25	68 (17/25)	68 (17/25)	52 (13/25)

These results, although not comprehensive, suggest that the combination of proximity to water resources (including discharges) and moderate to high acid drainage or contaminant leaching potential does increase the risk of water quality impacts and is a good indicator of future adverse water quality impacts. Although this finding makes intuitive sense from a risk perspective, a comprehensive study of cause and effect has never been conducted. Mines with these inherent factors are the most likely to require perpetual treatment to reduce or eliminate the long-term adverse impacts to surface water resources. Although all mines must rely on well executed mitigation measures to ensure the integrity of water resources during and after mining, mines with the inherent factors identified in this study must have mitigation measures that are even more carefully designed to avoid water quality impacts.

FAILURE MODES AND ROOT CAUSES OF WATER QUALITY IMPACTS

This section identifies the underlying causes of water quality impacts at the case study mines. It uses information gathered from the case studies and conducts a "failure modes" and "root cause" analysis. A failure is an outcome that is different than intended or predicted. A failure mode is the general type of failure that occurred or is predicted to occur (e.g., prediction failure, mitigation failure), while a root cause is the underlying, more specific, reason for the failure. The objective of the analysis presented in this section is to identify the most common types and causes of failures in protecting water quality at existing mines so that the failures can be prevented in the future. Results from this analysis can be used to make recommendations for improving both the policy and the scientific and engineering underpinnings of EISs.

Methodology and Approach

The approach uses existing ("historical") information from the 25 case study mines with EISs to identify the causes of water quality impacts that occurred during mining operations. In contrast, most similar risk analyses are conducted before operations begin and focus on generating predictions from engineering design information (e.g., likelihood of failure based on factor of safety calculations). Because our approach is retrospective rather than prospective, we know unequivocally whether a prediction has failed or a water quality failure has occurred. Therefore, the focus of this analysis is to determine what caused the failure to occur. The information used to determine how failure occurred is contained in the case studies, which summarize and compare water quality predictions in EISs with actual water quality conditions during mining operations.

Types of Characterization Failures

There are two types of characterization failures identified in the case studies: hydrologic and geochemical. Inaccuracies in hydrologic and geochemical characterization can lead to a failure to recognize or predict water quality impacts. The primary root causes of hydrologic characterization failures identified in this study are:

- dilution overestimated
- lack of hydrological characterization
- amount of discharge overestimated
- size of storms underestimated.

The primary root causes of geochemical characterization failures identified are:

- lack of adequate geochemical characterization
- sample size and/or representativeness.

The other failure mode identified in the case studies is mitigation failure in which the primary root causes are:

- mitigation not identified, inadequate or not installed
- waste rock mixing and segregation not effective
- liner leak, embankment failure or tailings spill
- land application discharge not effective.

Table ES-10 shows the various failures modes, root causes and identifies various mines that serve as examples of the failure modes. The results are summarized in Table ES-11 and are as described below.

Six of 25 mines exhibited inadequacies in hydrologic characterization.

- At two of the mines, dilution was overestimated.
- At two of the mines, a lack of hydrologic characterization was noted.
- At one of the mines, the amount of discharge generated was underestimated.
- At one of the mines, the size of storms was underestimated.

Eleven of 25 mines exhibited inadequacies in geochemical characterization. Geochemical failures resulted from:

- assumptions made about the geochemical nature of ore deposits and surrounding areas (e.g., mining will only be done in oxidized area)
- site analogs inappropriately applied to a new proposal (e.g., historic underground mine workings do not produce water or did not indicate acid generation)
- inadequate sampling (e.g., geochemical characterization did not indicate potential due to composite samples or samples not being representative of actual mining)
- failure to conduct and have results for long-term contaminant leaching and acid drainage testing procedures before mining begins
- failure to conduct the proper tests, or to improperly interpret test results, or to apply the proper models.

Sixteen of 25 mines exhibited failures in mitigation measures.

- At three of the mines mitigation was not identified, inadequate, or not installed.
- At four of the mines waste rock mixing and segregation was not effective.
- At nine of the mines liner leaks, embankment failures or tailings spills caused impacts to water resources.
- At one mine, land application disposal resulted in impacts to water resources.

Table ES-10. Water Quality Predictions Failure Modes, Root Causes and Examples from Case Study Mines

Failure Mode	Root Cause	Examples
Hydrologic Characterization	Lack of hydrologic characterization	Royal Mountain King, CA; Black Pine, MT
	Dilution overestimated	Greens Creek, AK; Jerritt Canyon, NV
	Amount of discharge underestimated	Mineral Hill, MT
	Size of storms underestimated	Zortman and Landusky, MT
Geochemical Characterization	Lack of adequate geochemical characterization	Jamestown, CA; Royal Mountain King, CA; Grouse Creek, ID; Black Pine, MT
	Sample size and/or representation	Greens Creek, AK; McLaughlin, CA; Thompson Creek, ID; Golden Sunlight, MT; Mineral Hill, MT; Zortman and Landusky, MT; Jerritt Canyon, NV
Mitigation	Mitigation not identified, inadequate, or not installed	Bagdad, AZ; Royal Mountain King, CA; Grouse Creek, ID
	Waste rock mixing and segregation not effective	Greens Creek, AK; McLaughlin, CA; Thompson Creek, ID; Jerritt Canyon, NV
	Liner leak, embankment failure or tailings spill	Jamestown, CA; Golden Sunlight, MT; Mineral Hill, MT; Stillwater, MT; Florida Canyon, NV; Jerritt Canyon, NV; Lone Tree, NV; Rochester, NV; Twin Creeks, NV
	Land application discharge not effective	Beal Mountain, MT

Table ES-11. Summary of Failure Modes for Case Study Mines

Failure Mode	Number of Case Study Mines Showing Failure Mode	Percent of Case Study Mines Showing Failure Mode
Hydrologic Characterization	6	24%
Geochemical Characterization	11	44%
Mitigation	16	64%

CONCLUSIONS AND RECOMMENDATIONS

Identification of Risk and Prevention of Impacts

- Actual water quality impacts are closer to potential (pre-mitigation) rather than predicted (post-mitigation) impacts in EISs; therefore, the threshold for significance determinations, and thus EIS (rather than EA) analysis, should be potential rather than predicted impacts.

- Cyanide is not specifically identified as a contaminant of concern often enough; whenever cyanide is being used in heap or vat leaching or flotation, it should be listed as a potential contaminant of concern.

- A minimum and relatively consistent set of geochemical tests should be required by federal and state mining agencies. See the companion report (*Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State- of-the-Art*) for recommendations for minimum required geochemical testing.

- Mines with close proximity or discharges to water resources, moderate to high acid drainage and/or contaminant leaching potential should undergo more scrutiny by agencies in the permitting process than mines with low inherent water quality impact factors.

- Hydrologic characterization failures are most often caused by over-estimation of dilution, failure to recognize hydrologic features and underestimation of water production quantities. They can be addressed by requiring adequate hydrologic characterizations and making environmentally conservative assumptions about water quality and quantity.

- Lack of adequate geochemical characterization is the single-most identifiable root cause of water quality prediction failures. Improvements in geochemical characterization can provide the greatest contribution to ensuring accurate water quality predictions at hardrock mine sites. As noted in the companion report, the same geochemical test units should be used for testing of all sources and parameters used to predict water quality impacts. In addition, more extensive information on mineralogy and mineralization should be included in EISs, and more attention should be paid to uncertainties in geochemical and hydrologic characterization.

- Mixing and segregation mitigation failures occur at a moderate frequency and are typically caused by using too little neutralizing material and not effectively isolating acid generating material from nearby water resources. This can be addressed by requiring adequate geochemical and hydrologic characterization and minimizing transport along hydrologic pathways.

- Mitigation frequently fails to perform according to plan. It is important to consider the likelihood and consequences of mitigation failure in EISs and identify additional mitigation measures that can be installed if failure occurs. Multiple mitigation measures (e.g., installation of liner and leachate collection system or pump-back system) should be required in most cases and planned for in the design phase.

- Improvements are needed in the prediction of appropriate mitigation measures. Preventive mitigation measures are more cost effective and environmentally protective than remediation after impacts have occurred.

- EISs for new mines should include comprehensive baseline water quality, hydrologic, and geochemical evaluations and careful and supportable identification of mitigation measures, including an evaluation of potential mitigation failures.

Data and Data Quality Issues

- Operational and post-operational water quality information for hard rock mine sites should be readily accessible to the public in a user-friendly web-based format.

- Information provided to the public should include: maps clearly showing the location of mine units, streams, and surface water and groundwater sampling locations; identification of facilities/source areas associated (upgradient) with wells and other sampling points; pre-mining and baseline/background water quality and quantity information; well depths; groundwater elevations in monitoring wells; and water quality data for all monitoring locations.

- In many cases existing conditions were explained by baseline water quality conditions with limited baseline water quality information. An independent review of baseline water quality data for hard rock mines should be conducted to verify those claims.

- With the cooperation of industry and regulators, a more systematic and complete effort should be undertaken to compare water quality predictions against actual water quality impacts as a follow-up to this study.

1. INTRODUCTION

When a mine is permitted in the United States, the project proponent (i.e., mining company) must ensure the regulatory agency or agencies that groundwater and surface water quality will not be adversely affected by the proposed mining operations. Based on laboratory and field characterization tests, and in some cases water quality modeling, qualitative or quantitative predictions of operational and post-closure water quality are presented. However, the validity of these predictions is rarely checked after mining begins. During the course of this investigation no single document was discovered comparing National Environmental Policy Act (NEPA) document predictions to actual water quality. This study is the first such effort to evaluate the reliability of water quality predictions for large hardrock mines.

This study is the second in a two-part series on prediction of water quality at hardrock mines. The first report, titled *Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art* (Maest et al., 2005) provides an overview and critique of the mine characterization and modeling techniques that are being used for prediction of water quality at mines in the U.S. and internationally. The objective of the second study, reported in this document, is to review the history and reliability of water quality predictions for major hardrock mines in the United States. In addition, factors contributing to the reliability of the water quality forecasts are identified, and recommendations are presented for improving water-quality predictions.

1.1. METHODOLOGY AND APPROACH

This project utilized water quality predictions made in Environmental Impact Statements (EISs) because EISs require water quality predictions to be made as part of the regulatory review process in NEPA. This report is not intended to address the regulatory process itself but rather the underlying scientific and technical processes, which are employed in EISs to predict water quality impacts.

The overall project methodology/approach consisted of the following phases:

- define and identify all major hardrock mines in the U.S
- identify NEPA/EIS eligibility of major hardrock mines
- identify and gather EISs and related documentation for major mines
- review, compile and analyze relevant EIS documents and related information on water quality predictions
- gather, review and document in case study format EISs and water quality history information for selected mine sites
- compare EIS predictions with actual water quality information for the selected mines
- identify failure modes and root causes of failures to predict water quality impacts
- develop conclusions and recommendations about the effectiveness and regulatory application of the science underlying water quality predictions at hardrock mines

A database (Excel spreadsheet) was created to catalogue general operational and environmental information from NEPA documents and other sources as well as information on discharges to groundwater and surface water for major and mines subject to NEPA. The data collected include the following:

- location (state and county if available)
- ownership
- commodity (gold, silver, copper, molybdenum, lead, zinc, platinum group metals)
- mining (underground, open pit) and processing methods (heap leach, vat leach, flotation, gravity, dump leach (sx/ew), smelter)
- operational status (year production initiated, present status, year closed, projected year closed)
- disturbance and financial assurance (permitted and/or actual disturbance on BLM, Forest Service, private, state, and Native American Indian Lands; current financial assurance amount, bankruptcy status)
- NEPA applicability by BLM, Forest Service, Corps of Engineers, EPA, Indian Lands, state required
- NEPA documentation including year of document, proposed action, document type (EA, EIS, SEIS)

- record of NEPA document requests and retention
- EIS information (summary of information on geology/mineralization; climate; hydrology; field and lab tests performed; constituents of concern identified; predictive models used; water quality impact potential; mitigation; predicted water quality impacts; discharge information)
- National Pollutant Discharge Elimination System (NPDES) permit information (permit number, major or minor permit, whether reported on EPA ECHO database)

The major challenge for this study was obtaining reliable operational water quality data against which predictions can be measured or evaluated. The ease of obtaining such information varies dramatically from state to state. In some states, NEPA or its equivalent that requires water quality predictions, is applied to all mines in the state, while in other states, NEPA derived water quality predictions are applicable only to mines on public lands. In some states, water quality data are available in electronic forms while in others, only paper copies of water quality data are available. In this study we limit our in-depth case study analysis to mines subject to the NEPA process requiring water quality predictions. Therefore, the focus is predominantly on mines on public lands. The mines selected for case study reflect the general population of large hardrock mines in terms of their geographic distribution, commodity types, and other factors. Generally, mines that have exhibited water quality impacts have more water quality data and analysis than mines without notable environmental impacts. In order to balance the analysis, an effort was made to include not only mines with notable impacts in the case studies, but also mines without notable impacts.

For the case study mines, water quality conditions after mining began are compared to water quality predictions and baseline water quality data. If water quality impacts did occur but were not predicted, the causes of the impacts are provided to the extent practicable. Based on this analysis, recommendations for improvements in the scientific underpinnings of the predictions used in the regulatory process are made.

The study is broken into the following sections after the introduction:

- Section 2 provides background information in NEPA and EISs related to water quality predictions at mine sites.
- Section 3 provides a primer on water quality prediction methods and models that have historically been and are presently in use.
- Section 4 provides the basis for defining major and hardrock mines subject of NEPA and summarizes the information describing the major and NEPA applicable mines on state and federal agency basis.
- Section 5 contains information on water quality predictions for each of the 71 major mines where complete information was available. The information collected includes geology and mineralization, climate hydrology, field and lab tests performed, constituents of concern identified, predictive models used, water quality impact potential, mitigation, predicted water quality impacts and discharge information.
- Section 6 consists of case study summaries for selected mines, focusing on predicted and actual water quality impacts.
- Section 7 contains the general results of the study, including a discussion of inherent factors that may predispose a mine to water quality impacts.
- Section 8 identifies the causes for failed predictions and contains recommendations for improving predictions and the regulatory process related to predictions.
- Appendix A provides major mine statistical information by state and federal agency including location (state and where available, county information), commodity produced, extraction and processing methods, and operational status.
- Appendix B provides more complete information on NEPA documents and water quality data.

2. NEPA AND WATER QUALITY PREDICTIONS

The following sections contain a general description of the National Environmental Policy Act (NEPA) and information in the Act related to scientific analysis and water quality predictions.

2.1. NATIONAL ENVIRONMENTAL PROTECTION ACT

When Congress passed the National Environmental Policy Act (NEPA) in 1969 it was heralded as the foundation of modern American environmental protection by providing a comprehensive national policy for focusing on environmental concerns (CEQ 1997). NEPA does not work by mandating that federal agencies achieve particular substantive environmental results. Rather, NEPA requires federal agencies to take a "hard look" at the environmental impacts of certain proposed projects to ensure the necessary mitigation or other measures are employed to meet federal regulations and other applicable (such as state) requirements.

NEPA requires the consideration of the important potential environmental impacts of a proposed action through express statutory mandates, Council on Environmental Quality (CEQ) regulations, and individual federal agency-specific regulations. Further, the broad dissemination of information mandated by NEPA allows the public and other government agencies to participate in the environmental review process and to react to the effects of a proposed action as part of the permitting process.

To those ends, NEPA requires federal agencies proposing major actions that may substantially affect the quality of the human environment to prepare a detailed Environmental Impact Statement (EIS). A "major action" includes actions approved by permit or other regulatory action. EISs are required to describe different alternatives to the proposed action, including the "no action" alternative, in which the proposed action would not be implemented.

In order to determine whether or not a project will have a significant impact on the environment, the federal agency may prepare an Environmental Assessment (EA). If the agency determines, after preparation of the EA, that the project will not significantly impact the environment, then it may issue a Finding of No Significant Impact (FONSI). Otherwise, if the agency finds that the project *may* have a significant impact on the environment, then it must prepare an EIS. In many cases the agency will prepare an EIS from the outset, particularly where the project is likely to be more controversial. EISs are required to describe different alternatives to the proposed action, including the "no action" alternative, in which the proposed action would not be implemented.

The federal agency must consider three types of impacts – direct, indirect, and cumulative. Direct effects are those that are caused by the action and occur at the same time and place. Indirect effects are those that are caused by the action and occur later in time or farther removed in distance but are still reasonably foreseeable. Indirect effects may include effects on air and water and other natural systems, including ecosystems. A project's "cumulative impact" is the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

2.2. SCIENTIFIC ANALYSIS IN THE NEPA PROCESS

The federal agencies are required to describe the environment of the areas to be affected or created by the alternatives under consideration. In order to do so, a baseline against which to compare predictions of the effects of the proposed action is considered to be critical to the NEPA EIS process.

NEPA and its implementing regulations require all federal agencies to:

> [I]nsure the professional integrity, including scientific integrity of the discussions and analysis in environmental impact statements. [Agencies] shall identify any methodologies used and shall make explicit reference by footnote to the scientific and other sources relied upon for conclusions in the statement (40 CFR 1502.24).

Further, the regulations mandate that all NEPA documents be "supported by evidence that the agency has made the necessary environmental analysis" (40 CFR § 1502.1). Consequently, federal agencies have a duty to disclose the underlying scientific data and rationale supporting the conclusions and assumptions in an EIS. Unsupported conclusions and assumptions violate NEPA. The federal courts pay particular attention to this requirement and have found that federal agencies are required to provide the underlying environmental data that are relied upon in the NEPA process. The scientific data and rationale are typically contained in appendices to an EIS.

The importance of scientific integrity and use of high-quality data in the NEPA analysis process cannot be overstated. To satisfy NEPA, the federal agencies "must explicate fully its course of inquiry, its analysis, and its reasoning." (Dubois V. U.S. Department of Agriculture, 102 F.3d 1273, 1287 (1st Cir. 1996)). NEPA provides specific requirements in the case where data or scientific analyses are unavailable to the federal agency. The existence of incomplete or unavailable scientific information concerning significant adverse environmental impacts essential to a reasoned choice among alternatives triggers the requirements of 40 CFR § 1502.22. This provision requires the disclosure and analysis of the costs of uncertainty and the costs of proceeding without more and better information.

40 CFR § 1502.22 imposes three mandatory obligations in the face of scientific uncertainty: (1) a duty to disclose the scientific uncertainty; (2) a duty to complete independent research and gather information if no adequate information exists (unless the costs are exorbitant or the means of obtaining the information are not known); and (3) a duty to evaluate the potential, reasonably foreseeable impacts in the absence of relevant information, using a four-step process. The four step process involves:

1. a statement that such information is incomplete or unavailable;
2. a statement of the relevance of the incomplete or unavailable information to evaluating reasonably foreseeable significant adverse impacts on the human environment;
3. a summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment, and;
4. the agency's evaluation of such impacts based upon theoretical approaches or research methods generally accepted in the scientific community. For the purposes of this section, "reasonably foreseeable" includes impacts which have catastrophic consequences, even if their probability of occurrence is low, provided that the analysis of the impacts is supported by credible scientific evidence, is not based on pure conjecture, and is within the rule of reason.

The requirement to conduct independent research when faced with incomplete or unavailable information insures agencies comply with NEPA's central purpose "to obviate the need for speculation by insuring that available data is gathered and analyzed prior to the implementation of the proposed action." "The federal courts have held that original research should be performed if necessary together with reasonable scientific supported forecasting and speculation." (Save our Ecosystems at 1248-49 and at 1246 note 9)

3. THE SCIENCE OF WATER QUALITY PREDICTION AND MITIGATION

The science of predicting water quality at hardrock mine sites has been practiced for at least the past 30 years as part of the regulatory review process. Under NEPA, hardrock mines in the United States on federal land are required to estimate impacts to the environment, including direct impacts to water quality and indirect impacts that are later in time but still reasonably foreseeable (Kempton and Atkins, 2000; Bolen, 2002). Mines on private land in the United States may also be subject to state or federal processes that may or may not require prediction of potential impacts to water resources. A wide array of scientific approaches ha been used to predict water quality that could result from proposed construction, expansion, or other actions as described in the following sections.

3.1. SITE CONCEPTUAL MODEL

An accurate conceptual model is a necessary first step in successfully predicting water quality at a mine site (Mayer et al., 2002). A conceptual model is a qualitative description of the hydrology and chemistry of the site and their known and potential effect on mined and natural materials. It includes baseline conditions, sources (mining-related and natural), pathways, biophysicochemical processes, mitigation measures, and receptors. Information about sources and mitigation measures will generally come from the mine plan. Site conceptual models should include mitigation measures, and the effectiveness of mitigation measures on water quality should be evaluated.

A mine is an ever-evolving entity, and the site conceptual model must change as the mine evolves. Changes in the mine plan can appreciably affect future water quality. Short of a significant change, however, the accumulation of many small changes in the mine plan can make it difficult to accurately predict water quality. Therefore, predictions themselves must be continually updated as new environmental information from the mine site becomes available.

3.2. GEOCHEMICAL CHARACTERIZATION

The next step in predicting water quality at mines is the characterization of mined materials and the environment. For the purposes of this study, which focuses on water quality at hardrock mine sites, characterization is defined as field and/or laboratory tests or measurements that help define the physicochemical and biological environment that will be or has been mined and the potential for water quality impacts.

Different phases of mining present different opportunities for characterization. During the exploration phase, whole rock analysis, mineralogy, and acid-base accounting should be conducted as part of the delineation of the ore body, and long-term kinetic testing should be initiated. Information on baseline water quality and quantity (including information on similar areas that have already been mined, if relevant) and hydraulic properties should be gathered, and hydrogeochemical modeling for water quality prediction should be initiated.

During the development phase, information on geology, mineralogy, acid-base accounting, kinetic testing, and hydraulic properties should be continued, and more detailed hydrogeochemical modeling should be conducted. During this phase, bench and field scale testing should be conducted, and the effects of mining (e.g., dewatering) on groundwater potentiometric surfaces should be evaluated.

When active mining is underway, geochemical and hydrologic characterization of mined materials should be conducted (including sampling of leachate and testing of hydraulic properties of mined materials and changes in groundwater elevations in response to mining). Up gradient and downgradient water quality in receptors should be sampled, and the first comparisons of predicted and actual water quality can be conducted.

During the closure, reclamation, and post-closure phases of mining, receptor sampling and measurement of changes in groundwater levels should be continued, and improved comparisons of predicted and actual water quality will be possible. During any phase of mining, the extent of a geochemical characterization program should be dictated by site conditions and the nature of the deposit, with complex geology, hydrology, and mineralogy requiring a greater effort.

3.3. WATER QUALITY MODELING

The stages in developing a predictive hydrogeochemical model of water quality for a mine site include:

- developing a site-wide conceptual model
- selecting an appropriate computational code
- gathering site-specific geologic, geochemical, and hydrologic data and fundamental (e.g., thermodynamic) information as inputs for the model
- calibration of the model (for hydrologic models)
- predictive modeling using the model.

Information needed for a site-wide conceptual model includes:

- baseline conditions (hydrogeologic units, existing waste, water quantity/quality, climate)
- sources (location, volume, chemistry)
- pathways (location, connectivity)
- processes (hydrologic, air flow, geochemical, biological)
- receptors (location, water quality/quantity)
- mitigation measures (type, purpose, natural mitigation, effectiveness).

Selection of a computer code to develop a prediction of water quality should be based on factors such as: 1) modeling objectives; 2) capability of the code to simulate important processes affecting water quality at the mine site, as described by the site conceptual model(s); 3) ability of the code to simulate spatial and temporal distribution of key input parameters and boundary conditions; 4) availability of the code and its documentation to the public; and 5) ease of use of the code, including availability of pre- or post-processors and graphical interfaces.

Site-specific inputs to computer codes are needed to make a model that will have relevance to a given mine site. The quality and representativeness of input data will affect the results of the models. Site-specific inputs to hydrogeochemical codes used to predict water quality are similar to certain information needed for conceptual models and can include geologic, hydraulic/hydrologic, chemical, mineralogic, and climatic data.

Model calibration is the process of comparing site-specific observations (e.g., stream flows, groundwater elevations, or pit lake concentrations) with model simulations. Calibration includes adjusting model parameters (e.g., hydraulic conductivity or porosity) so that the output from the model reproduces observed field conditions. The calibrated model is then used to make predictions of future conditions.

At mine sites, much of the modeling performed is “forward” modeling, or modeling of conditions that do not yet exist. In the case of pit lakes, steady-state water quality and quantity conditions may not exist for hundreds of years, yet predictions about the quality of pit water are often required for regulatory purposes. Even though “final” water quality in pit lakes and other receptors may not develop for decades to centuries, water quality at other similar mines can be used to estimate the degree of uncertainty in the prediction.

Figure 3.1 depicts a mine site, pathways, and receptors and shows where hydrologic and geochemical models can be used at mine sites. More information on the methods and models used to predict water quality at hardrock mine sites can be found in the companion study to this report Predicting *Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art* (Maest et al., 2005).

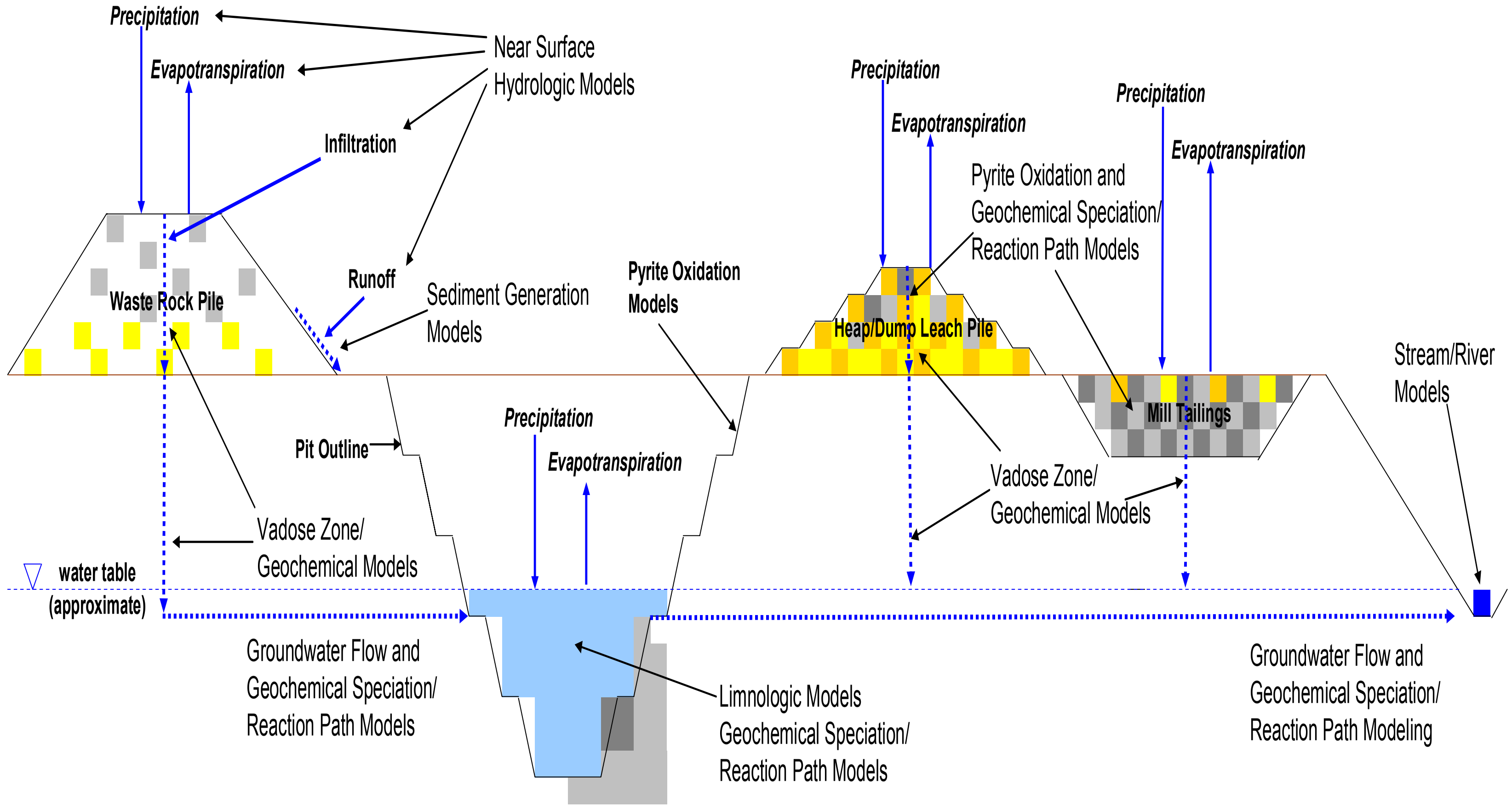

Figure 3.1. A mine site conceptual model with pathways and opportunities for hydrologic and geochemical modeling.

4. IDENTIFICATION OF MAJOR MINES SUBJECT TO NEPA

This section identifies the major hardrock mines in the United States and describes their location, commodity, extraction and processing methods (e.g., underground, open pit), operational status (e.g., operating, closed), extent of physical disturbance, financial assurance amounts, water discharge information under the Clean Water Act, and whether they are subject to the requirements of NEPA. The subset of the mines that is subject to NEPA is described separately, and it is these mines that form the basis of the main analysis in this report. A statistical breakdown is also provided for mines subject to NEPA in terms of NEPA authority (federal agency lead or state agency) and new and subsequent project permitting information. Information on the larger set of major mines and the mines subject to NEPA is contained in a database and Appendix A (database and appendices available at www/kuipersassoc.com or http://www.mineralpolicy.org/publications_welcome.cfm).

4.1. MAJOR MINES

This section describes the method and approach for identifying major mines subject to NEPA and discusses information described above for all mines, mines subject to NEPA, and mines for which EISs were obtained and reviewed in detail.

4.1.1. METHOD AND APPROACH

In order to identify a manageable data set and because they inherently receive the most interest, this study is focused on major hardrock mines. Major mines are defined as those meeting the following criteria:

- disturbance area of over 100 acres and financial assurance amount of over $250,000
- or, financial assurance amount over $1,000,000 alone
- or, cumulative production (1975 to current) of greater than 100,000 ounces of gold, 100,000,000 pounds of copper or the equivalent economic value for other metals

Kuipers (2000) identifies the disturbed area and financial assurance amounts for major mines with financial assurance amounts of over $250,000. In addition, production and other data from Randol (1991, 1995, 1999) and Infomine (2004) were used in establishing the list of major mines for this study.

Information from Kuipers (2000) was initially updated with current disturbance and financial assurance information readily available from regulatory sources (agency websites and publications). Most available information was unchanged from 2000 with the exception of significant updated information from Montana and New Mexico.

Production information was difficult to obtain, although some limited information was available from Randol and Infomine as well as from individual mine sources. The U.S. Geological Survey's Mineral Availability System/ Mineral Industry Locater System (MAS/MILS) is in the process of being overhauled and was unavailable to this study, although the use of coding to protect proprietary data makes the database of limited value to this study. Some mines that could be considered "major" may not meet the above criteria or may not have been included in this list due to the lack of available information.

One hundred eighty three (183) mines in the U.S. were identified as meeting the "major mine" criteria - in terms of meeting minimum disturbance areas and financial assurance or production criteria - and compiled in the Major Mine database. Table 4.1 identifies the major hardrock mines operating from 1975 to present and shows their location, commodity and operational status. Even though the mines subject to NEPA are not discussed until Section 4.2, the mines subject to NEPA and mines reviewed in detail (mines for which EISs were obtained and reviewed) are also identified in Table 4.1. As indicated in the table, for the purposes of this study some mines were combined and are counted as one mine (e.g., Zortman and Landusky, Paradise Peak/Ketchup Flat).

Table 4.1. General Information for Major Hardrock Metals Mines in U.S. Operating from 1975 to Present

Name	State	Commodity	Status	NEPA or State Equivalent Eligibility	Federal Agency and/or State	NEPA Documents Obtained
AJ Project	AK	Au	Withdrawn	Yes	EPA	Yes
Fort Knox	AK	Au	Operating	Yes	COE	Yes
Greens Creek	AK	Au, Ag, Pb, Zn	Operating	Yes	FS	Yes
Illinois Creek	AK	Au, Ag	Operating			
Kensington Project	AK	Au	In construction	Yes	FS	Yes
Pogo Project	AK	Au	Operating	Yes	COE, EPA	Yes
Red Dog	AK	Ag, Pb, Zn	Operating	Yes	COE, EPA	Yes
True North	AK	Au	Operating	Yes	COE	Yes
Ajo	AZ	Cu, Mo	Closed			
Bagdad	AZ	Cu, Mo	Operating	Yes	BLM	Yes
Carlotta	AZ	Cu	Permitting	Yes	FS	Yes
Cyprus Tohono	AZ	Cu	Closed	Yes	Indian Lands	Yes
Hayden	AZ	Ag, Cu	Operating			
Miami - PD	AZ	Ag, Cu	Operating	Yes	BLM, FS	Yes
Miami - BHP	AZ	Cu	Operating			
Mineral Park	AZ	Cu	Operating	Yes	BLM	
Mission	AZ	Ag, Cu	Operating	Yes	Indian Lands	Yes
Morenci	AZ	Cu	Operating	Yes	BLM	Yes
Pinto Valley	AZ	Cu, Mo	Closed			
Ray	AZ	Ag, Cu	Operating	Yes	BLM	Yes
Safford (Dos Pobres/San Juan)	AZ	Cu	Permitting	Yes	BLM	Yes
Sanchez	AZ	Cu	Withdrawn	Yes	BLM	Yes
San Manuel	AZ	Au, Ag, Cu, Mo	Closed			
Sierrita	AZ	Cu, Mo	Operating	Yes	BLM	
Silver Bell	AZ	Cu	Operating			
Superior	AZ	Cu	Closed			
Twin Buttes	AZ	Cu, Mo	Closed	Yes	BLM	
Yarnell	AZ	Au	Withdrawn	Yes	BLM	Yes
American Girl (Cargo Muchaco, Oro Cruz)	CA	Au, Ag	Closed	Yes	BLM	Yes
Briggs	CA	Au	Operating	Yes	BLM	Yes
Cactus Gold (Shumake)	CA	Au, Ag	Closed	Yes		
Castle Mountain	CA	Au, Ag	Closed	Yes	BLM	Yes
Carson Hill	CA	Au, Ag	Closed			
Gray Eagle	CA	Au, Ag, Cu, Zn	Closed			
Hayden Hill	CA	Au, Ag	Closed	Yes	BLM, FS	
Imperial	CA	Au	Permitting	Yes	BLM	
Jamestown (California Gold)	CA	Au	Closed	Yes		Yes
McLaughlin	CA	Au	Closed	Yes	BLM	Yes

Table 4.1. General Information for Major Hardrock Metals Mines in U.S. Operating from 1975 to Present (continued)

Name	State	Commodity	Status	NEPA or State Equivalent Eligibility	Federal Agency and/or State	NEPA Documents Obtained
Mesquite	CA	Au, Ag	Operating	Yes	BLM	Yes
Picacho	CA	Au	Closed	Yes		
Rand	CA	Au, Ag	Operating	Yes		Yes
Royal Mountain King	CA	Au, Ag	Closed	Yes		Yes
Soledad Mountain	CA	Au, Ag	Closed	Yes	BLM	
Climax	CO	Mo	Closed			
Cresson	CO	Au	Operating			
Empire	CO	Au, Ag	Closed			
Henderson	CO	Mo	Operating			
Pride of the West	CO	Au, Ag	Closed			
San Luis	CO	Au, Ag	Closed			
Summitville	CO	Au, Ag	Closed			
Sunnyside	CO	Au, Ag, Pb, Zn	Closed			
Victor	CO	Au	Operating			
Beartrack	ID	Au, Ag	Closed	Yes	FS	Yes
Black Pine	ID	Au, Ag	Closed	Yes	BLM, FS	Yes
Champagne	ID	Au, Ag	Closed			
Coeur	ID	Ag, Cu	Closed			
Galena	ID	Ag, Cu	Operating			
DeLamar	ID	Au, Ag	Closed			
Sunbeam	ID	Au	Closed	Yes	FS	Yes
Grouse Creek	ID	Au, Ag	Closed	Yes	FS	Yes
Lucky Friday	ID	Ag, Pb, Zn	Operating			
Stibnite	ID	Au, Ag	Closed	Yes	FS	Yes
Stone Cabin	ID	Au, Ag	Closed	Yes	BLM	Yes
Thompson Creek	ID	Mo	Operating	Yes	BLM, FS	Yes
Thunder Mountain	ID	Au	Closed			
Yellow Pine	ID	Au, Ag	Closed		FS	
White Pine	MI	Cu	Closed			
Basin Creek	MT	Au, Ag	Closed	Yes	FS	Yes
Beal Mountain	MT	Au, Ag	Closed	Yes	FS	Yes
Black Pine	MT	Au, Ag, Cu	Closed	Yes	FS	Yes
Continental	MT	Au, Ag, Cu, Mo	Operating	Yes		
Diamond Hill	MT	Au	Closed	Yes		
East Boulder	MT	PGM	Operating	Yes	FS	Yes
Golden Sunlight	MT	Au	Operating	Yes	BLM	Yes
Kendall	MT	Au, Ag	Closed	Yes	BLM	Yes
Mineral Hill	MT	Au, Ag	Closed	Yes	FS	Yes
Montana Tunnels	MT	Au, Ag, Pb, Zn	Operating	Yes		Yes
Montanore	MT	Ag, Cu	Withdrawn	Yes	FS	Yes
Rock Creek	MT	Ag, Cu	Permitting	Yes	FS	Yes
Stillwater	MT	PGM	Operating	Yes	FS	Yes

Table 4.1. General Information for Major Hardrock Metals Mines in U.S. Operating from 1975 to Present (continued)

Name	State	Commodity	Status	NEPA or State Equivalent Eligibility	Federal Agency and/or State	NEPA Documents Obtained
Troy	MT	Ag, Cu	Closed	Yes	FS	Yes
Zortman and Landusky	MT	Au, Ag	Closed	Yes	BLM	Yes
Alligator Ridge	NV	Au, Ag	Closed	Yes	BLM	
Aurora Partnership (Mine)	NV	Au, Ag	Closed	Yes	FS	Yes
Austin Gold Venture	NV	Au, Ag	Closed	Yes	FS	Yes
Bald Mountain	NV	Au, Ag	Operating	Yes	BLM	Yes
Horseshoe/Galaxy	NV	Au	Closed			
Battle Mountain Complex (Reona, Copper Basin, Copper Canyon, Iron Canyon, Shoshone-Eureka Phoenix)	NV	Au, Ag	Operating	Yes	BLM	Yes
Big Springs	NV	Au, Ag	Operating	Yes	FS	Yes
Blue Star (Genesis)	NV	Au, Ag	Operating	Yes	BLM	
Bootstrap/Capstone/Tara	NV	Au, Ag	Operating	Yes	BLM	
Borealis	NV	Au, Ag	Closed	Yes	FS	
Buckhorn	NV	Au, Ag	Closed	Yes	BLM	
Bullfrog	NV	Au, Ag	Closed	Yes	BLM	
Candelaria	NV	Au, Ag	Closed	Yes	BLM	
Carlin Mine/Mill # 1	NV	Au, Ag	Operating	Yes	BLM	
Casino/Winrock	NV	Au, Ag	Closed	Yes	BLM	
Rochester	NV	Au, Ag	Operating	Yes	BLM	Yes
Copper Leach Project (Equitorial Tonopah)	NV	Cu	Closed	Yes	BLM	
Cortez	NV	Au, Ag	Operating	Yes	BLM	Yes
Cortez Pipeline (South Pipeline)	NV	Au, Ag	Operating	Yes	BLM	Yes
County Line	NV	Au, Ag	Closed	Yes	BLM	
Crescent Pit	NV	Au, Ag	Operating	Yes	BLM	
Crowfoot/Lewis	NV	Au, Ag	Operating			
Daisy	NV	Au, Ag	Closed	Yes	BLM	
Dee	NV	Au, Ag	Closed	Yes	BLM	Yes
Denton Rawhide	NV	Au, Ag	Operating	Yes	BLM	
Easy Junior	NV	Au, Ag	Closed	Yes	BLM	
Elder Creek	NV	Au, Ag	Closed	Yes	BLM	
Florida Canyon	NV	Au, Ag	Operating	Yes	BLM	Yes
Fondaway Canyon	NV	Au, Ag	Closed	Yes	BLM	
Getchell	NV	Au, Ag	Operating			
Gold Acres	NV	Au, Ag	Operating	Yes	BLM	
Gold Bar	NV	Au, Ag	Closed	Yes	BLM	
Gold Quarry/Maggie Creek	NV	Au, Ag	Operating	Yes	BLM	Yes
Golden Eagle	NV	Au, Ag	Closed	Yes	BLM	

Table 4.1. General Information for Major Hardrock Metals Mines in U.S. Operating from 1975 to Present (continued)

Name	State	Commodity	Status	NEPA or State Equivalent Eligibility	Federal Agency and/or State	NEPA Documents Obtained
Goldfield	NV	Au, Ag	Operating	Yes	BLM	
Goldstrike (Betze)	NV	Au, Ag	Operating	Yes	BLM	Yes
Griffon	NV	Au, Ag	Closed	Yes	FS	Yes
Ivanhoe/Hollister	NV	Au, Ag	Operating	Yes	BLM	
Jerritt Canyon	NV	Au, Ag	Operating	Yes	FS	Yes
Dash	NV	Au, Ag	Operating	Yes	FS	Yes
Kinsley Mountain	NV	Au, Ag	Closed	Yes	BLM	
Leeville	NV	Au, Ag	Operating	Yes	BLM	Yes
Lone Tree	NV	Au, Ag	Operating	Yes	BLM	Yes
Manhattan	NV	Au, Ag	Closed	Yes	BLM, FS	
Marigold	NV	Au, Ag	Closed	Yes	BLM	Yes
McCoy/Cove	NV	Au, Ag	Closed	Yes	BLM	
Meikle	NV	Au, Ag	Operating	Yes	BLM	
Mineral Ridge	NV	Au, Ag	Operating	Yes	BLM	
Mount Hamilton	NV	Au, Ag	Closed	Yes	FS	
Mule Canyon	NV	Au, Ag	Operating	Yes	BLM	Yes
North Area Leach	NV	Au, Ag	Operating			
Northumberland	NV	Au, Ag	Closed	Yes	BLM, FS	
Olinghouse	NV	Au, Ag	Closed	Yes	BLM	Yes
Paradise Peak/Ketchup Flat	NV	Au, Ag	Closed	Yes	BLM	
Pete	NV	Au	Operating	Yes	BLM	Yes
Pinson	NV	Au, Ag	Closed	Yes	BLM	
Preble	NV	Au, Ag	Closed	Yes	BLM	
Post/Mill # 4	NV	Au, Ag	Operating			
Rain	NV	Au, Ag	Operating	Yes	BLM	Yes
Robinson (Ruth)	NV	Au, Cu	Operating	Yes	BLM	Yes
Rosebud	NV	Au, Ag	Closed	Yes	BLM	
Round Mountain	NV	Au, Ag	Operating	Yes	BLM, FS	Yes
Ruby Hill	NV	Au, Ag	Operating	Yes	BLM	Yes
Santa Fe/Calvada	NV	Au, Ag	Closed	Yes	BLM	
Sleeper	NV	Au, Ag	Closed	Yes	BLM	
Sterling JV	NV	Au, Ag	Operating	Yes	BLM	
Talapoosa	NV	Au, Ag	Withdrawn	Yes	BLM	
Tonkin Springs	NV	Au, Ag	Closed	Yes	BLM	
Trenton Canyon	NV	Au, Ag	Operating	Yes	BLM	Yes
Triplet Gulch/Robertson	NV	Au, Ag	Closed	Yes	BLM	
Twin Creeks	NV	Au, Ag	Operating	Yes	BLM	Yes
Wind Mountain	NV	Au, Ag	Closed	Yes	BLM	
Yankee	NV	Au, Ag	Closed	Yes	BLM	
Yerington	NV	Cu	Closed	Yes	BLM	
Chino	NM	Cu	Operating		BLM	
Cobre (Continental Pit)	NM	Cu	Closed	Yes	BLM	
Copper Flat	NM	Cu	Closed	Yes	BLM	Yes

Table 4.1. General Information for Major Hardrock Metals Mines in U.S. Operating from 1975 to Present (continued)

Name	State	Commodity	Status	NEPA or State Equivalent Eligibility	Federal Agency and/or State	NEPA Documents Obtained
Cunningham Hill	NM	Au, Ag	Closed			
Questa	NM	Mo	Operating			
Tyrone	NM	Cu	Operating			
Tyrone - Little Rock pit	NM	Cu	Closed	Yes	BLM, FS	Yes
Ridgeway	SC	Au, Ag	Closed			
Brewer	SC	Au	Closed			
Barite Hill	SC	Au	Closed			
Gilt Edge (Anchor Hill)	SD	Au, Ag	Closed	Yes	FS	Yes
Golden Reward	SD	Au, Ag	Closed			
Homestake	SD	Au, Ag	Closed			
Richmond Hill	SD	Au, Ag	Closed			
Wharf	SD	Au, Ag	Operating			
Barneys Canyon	UT	Au, Ag	Operating			
Bingham Canyon - Bingham Pit Fourth Line Expansion Modernization Project Tailing Modernization	UT	Au, Ag, Cu, Mo	Operating			
Drum Mine	UT	Au, Ag	Closed	Yes	BLM	Yes
Escalante Silver	UT	Ag	Closed	Yes	BLM	Yes
Goldstrike Project	UT	Au, Ag	Closed			
Lisbon Valley Copper	UT	Cu	Operating	Yes	BLM	Yes
Mercur Mine	UT	Au, Ag	Closed	Yes	BLM	Yes
Cannon	WA	Au, Ag	Closed	Yes		
Crown Jewel (Buckhorn Mountain)	WA	Au	Permitting	Yes	BLM, FS	
Kettle River/Lamefoot/K2	WA	Au, Ag	Closed	Yes	FS	
Pend Oreille	WA	Pb, Zn	Operating	Yes		
Flambeau (Ladysmith)	WI	Pb, Zn	Closed	Yes		Yes

Table 4.2 contains summary statistics on the information collected for the modern-era (i.e., in operation since 1975) major hardrock mines including location, commodity produced, extraction and processing methods, and operational status. Ownership information was also collected but was not analyzed in this report. The gross statistical data for the major hardrock metals mines in the U.S. was compiled and is summarized and discussed in the following sections. In addition, Appendix A provides a detailed breakdown of the statistical data by state and federal agency.

4.1.2. LOCATION

The 183 modern-era major hardrock metals mines identified are located in 14 states (five major mines were identified in three eastern states, and the remainder were in the western U.S.).

Table 4.2. General Information for Major Hardrock Mines

Feature		All Major Mines	
		Number	%
States	Alaska	8	4.4%
	Arizona	20	10.9%
	California	15	8.2%
	Colorado	9	4.9%
	Idaho	14	7.7%
	Michigan	1	0.5%
	Montana	15	8.2%
	Nevada	74	40.4%
	New Mexico	7	3.8%
	South Carolina	3	1.6%
	South Dakota	5	2.7%
	Utah	7	3.8%
	Washington	4	2.2%
	Wisconsin	1	0.5%
Commodity	Primary Gold	23	12.6%
	Primary Silver	13	7.1%
	Gold and Silver	115	62.8%
	Copper	30	16.4%
	Copper and Molybdenum	8	4.4%
	Molybdenum	4	2.2%
	Lead and Zinc	7	3.8%
	Platinum Group	2	1.1%
Operation Type	Underground	27	14.8%
	Open Pit	132	72.1%
	Underground + Open Pit	22	12.0%
	Heap or Vat Leach	120	65.6%
	Flotation and Gravity	44	24.0%
	Dump Leach (SX/EW)	22	12.0%
	Heap Leach	72	39.3%
	Vat Leach	17	9.3%
	Heap Leach and Vat Leach	31	16.9%
	Smelter	6	3.3%
Status	Operating	82	44.8%
	Closed	89	48.6%
	In Construction	1	0.5%
	Permitting	7	3.8%
	Withdrawn	4	2.2%

As indicated in Table 4.2, 74 (40%) of the major mines are located in Nevada. Nevada's modern-era mines are almost all primary gold and silver mines developed and operated since 1975, although a few notable historic gold and copper mining operations are present in the state.

Arizona, California and Montana are also significant mining states with 20 (11%), 15 (8%) and 15 (8%) respectively located in those states. Arizona's modern-era mines, on the other hand, are nearly all copper mines that were developed and operated from the early 1900s to the 1960s with many still operating. Despite California's illustrious mining history, nearly all its modern-era major mines were developed and operated since 1975. In the same manner, Montana's modern-era major mines were developed and operated since 1975 with the exception of the ongoing copper operations at Butte.

The states of Idaho, Colorado, New Mexico, Utah, Alaska and South Dakota respectively have 13 (8%), nine (5%), seven (4%), seven (4%), eight (4%) and five (3%) of the major mines. Idaho, Colorado, New Mexico and Utah have both historic and new mines. Alaska's and South Dakota's modern-era mines have all been developed and operated since 1975, with the exception of the Homestake Mine located in South Dakota.

Three (2%) of the major mines are located in South Carolina, four (2%) in Washington and one (1%) each in Michigan and Wisconsin. The modern-era major mines in South Carolina, Washington and Wisconsin were all developed and operated since 1975, while the Michigan mine was an historic operation.

No major mines were located in other states. However, some mining was still being conducted in Missouri and Tennessee in 1975, but production at these mines since 1975 has been less than the production criteria identified for major mines included in this study**.**

4.1.3. COMMODITY

The 183 modern-era major hardrock mines produce gold, silver, copper, molybdenum, lead, zinc and platinum group minerals (platinum and palladium).

As indicated in Table 4.2, two-thirds or 115 (63%) of the mines were identified as gold and silver mines. When combined with the 23 (13%) mines identified as primary gold mines and 13 (7%) mines identified as primary silver mines, 151 (83%) of the modern-era major hardrock mines extract precious metals.

There are 30 (16%) modern-era mines that are primary copper mines, while eight (4%) produce both copper and molybdenum. Four (2%) mines are primary molybdenum mines. Seven (4%) modern-era mines produce lead and zinc, while two (1%) produce platinum group minerals. Some of the mines produce multiple commodities (e.g., gold, silver, lead, zinc); therefore, the number of mines identified in this section is greater than the 183 total mines.

4.1.4. EXTRACTION AND PROCESSING METHODS

The 183 modern-era major hardrock mines are operated by both open pit and underground extraction methods, and employ heap or vat leaching, flotation/gravity, and dump leaching processing methods.

As shown in Table 4.2, the majority of mines (132 or 72%) are operated by open pit methods only. Twenty-seven (15%) of the mines are operated solely by underground mining methods, and 22 (12%) of the mines are operated by combined underground and open pit methods. Following a boom in open pit mining, the trend for gold in particular has been toward underground mining as shallower resources are exploited.

As indicated in Table 4.2, cyanide leaching is the predominant method used for gold ore processing and is used at 120 (66%) of the major mines identified. Seventy-two (38%) of the operations rely on heap leaching processes, while 17 (9%) rely on vat leaching. Thirty-one (17%) use both heap leaching and vat leaching processing methods.

Dump leaching is used exclusively at copper mines, and is the process used at 22 (12%) of the major mines identified. Flotation and gravity processing were the primary process methods used at 44 (24%) of the mines identified.

Six (3%) of the major mines had smelters associated with their operations. These mines were all copper mines.

4.1.5. OPERATIONAL STATUS

As this study takes into account a nearly 30-year time span (1975 to present), many of the 183 mines identified will have operated and subsequently closed. As shown in Table 4.2, 82 (45%) of the mines operated during that period are still currently operating. Eighty-nine (49%) of the major mines that operated have closed during that period. Currently, only one (less than 1%) of the major mines is a new mine (Pogo, Alaska) and is in construction, while seven (4%) are in permitting. A significant number of the mines identified are expanding, but they are not specifically identified in this study.

4.1.6. DISTURBANCE AND FINANCIAL ASSURANCE

Reliable disturbance and financial assurance information is not readily available outside of the Kuipers (2000) study, which identified the disturbed areas and reclamation amounts for most modern-era major mines in this study. Updated information is not readily available, except for a limited number of mines in certain states. Information on actual or projected disturbed acres and financial assurance amounts was available for only 138 of the 183 major mines in this study.

The 138 mines have actually or are projected to disturb 262,308 acres in total and have an aggregate financial assurance amount of $1.8 billion. The average major mine disturbance area is 1,901 acres, and the average financial assurance amount is $13.2 million.

4.1.7. NPDES INFORMATION

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or other conveyances that discharge to surface waters. In most cases, the NPDES permit program is administered by authorized states, although it may also be administered by the EPA. Since its introduction in 1972, the NPDES permit program is responsible for significant improvements to our nation's water quality.

Of the 183 major modern-era mines identified in this study, 41 (23%) have NPDES permits according to the EPA's Enforcement History and Online (ECHO) database.[1] EPA classifies larger, more regulated facilities as *major* facilities and smaller facilities as *minor* facilities.[2] On that basis, EPA has classified 27 of the 41 NPDES permitted major mines as major facilities and 14 as minor facilities.

At least four other facilities were identified as having permitted discharges to surface water that were not identified in the search of the ECHO database.

4.2. MAJOR MINES WITH NEPA EIS ANALYSIS

A subset of the 183 identified major modern-era mines is subject to NEPA regulation. For a hardrock mine to be subject to the NEPA process, the six independent requirements are:

- location on federal land administered by the USDA Forest Service
- location on federal land administered by the USDI Bureau of Land Management;
- requirement for new source NPDES permit from EPA
- requirement for 404 wetlands permit from the Army Corp of Engineers (ACE)
- location on Indian Lands administered by the BIA
- state mandated requirement for NEPA equivalent process

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[1] http://www.epa.gov/echo/

[2] **"Minor discharge"** means a discharge of wastewater which has a total volume of less than 50,000 gallons on every day of the year, does not closely affect the waters of another state and is not identified by the Department, the Regional Administrator or by the Administrator of EPA in regulations issued by him pursuant to Section 307(a) of the Federal Act, as a discharge which is not a minor discharge, except that in the case of a discharge of less than 50,000 gallons on any day of the year which represents one or two or more discharges from a single person, which in total exceeds 50,000 gallons on any day of the year, then no discharge from the facility is a minor discharge.

Of the 183 major modern-era mines identified, 137 (77%). meet the above requirements and are subject to the NEPA process. Of the 137 modern-era hardrock mines subject to NEPA analysis, the following criteria were the requirements used to determine their eligibility for NEPA:

- 93 (68%) are located on BLM administered lands
- 34 (25%) are located on Forest Service administered lands
- nine (7%) are located on both BLM and Forest Service administered lands
- five (4%) required 404 wetlands permits from the COE invoking NEPA
- three (2%) required NPDES permits from EPA invoking NEPA
- two (1%) are located on Indian Lands invoking NEPA
- 23 (19%) are located in states (California, Montana, Wisconsin) that have NEPA requirements
- 17 (14%) require both NEPA for federal purposes and are located in states that have NEPA requirements
- six (5%) require NEPA to meet state requirements only

Table 4.3 summarizes the general information collected for the 137 major hardrock mines subject to NEPA, including location, commodity produced, extraction and processing methods, and operational status. Statistical information for the major hardrock mines subject to NEPA in the U.S. was compiled and is summarized and discussed in the following sections with more detailed information by state and federal agency available in Appendix A.

4.2.1. LOCATION

The 137 modern-era major hardrock mines identified as subject to NEPA are located in 11 states (one major mine subject to NEPA was located in Wisconsin, and the remaining mines are in the western U.S.). States that have major mines but do not have mines subject to NEPA include: Colorado, Michigan and South Carolina.

As indicated in Table 4.3, 69 (50%) of the major mines subject to NEPA are located in Nevada. California, Montana and Arizona are also significant with 13 (10%), 15 (11%) and 13 (10%) of the major mines subject to NEPA respectively located in those states. The states of Idaho, Alaska and Utah respectively have six (4%), seven (5%), and four (3%) of the major mines subject to NEPA. Four (3%) are located in New Mexico, while one (1%) each is located in South Dakota and Wisconsin. In many cases, historically operated mines have succeeded in patenting or otherwise removing land from the public domain and result in no required NEPA analysis, except in states that require NEPA analysis separately. Colorado is notable in this regard, as it historically and presently hosts a significant mining industry, but although nine modern-era major hardrock mines were identified in the state, none were subject to NEPA.

4.2.2. COMMODITY

The 137 major hardrock mines subject to NEPA produce gold, silver, copper, molybdenum, lead, zinc and platinum group minerals (platinum and palladium).

As indicated in Table 4.3, over two-thirds or 90 (66%) of the mines were identified as gold and silver mines. When combined with the 17 (13%) mines identified as primary gold mines and nine (7%) mines identified as primary silver mines, 116 (85%) of the modern-era major hardrock mines subject to NEPA extract precious metals.

There are 21 (15%) modern-era mines subject to NEPA that are primary copper mines, while four (3%) mines produce both copper and molybdenum. Only one (1%) mine is a primary molybdenum mine. Five (4%) modern-era mines subject to NEPA produce lead and zinc, while two (2%) of the mines produce platinum group minerals. Some of the mines produce multiple commodities (e.g., gold, silver, lead, zinc) so the numbers of mines identified in this section total greater than the 137 total mines subject to NEPA.

4.2.3. EXTRACTION AND PROCESSING METHODS

The 137 major hardrock mines subject to NEPA are operated by both open pit and underground mining methods, and employ heap or vat leaching, flotation/gravity, and dump leaching processing methods.

Table 4.3. General Information for Major Mines Subject to NEPA

Feature		All Major Mines	
		Number	%
States	Alaska	7	5.1%
	Arizona	13	9.5%
	California	13	9.5%
	Idaho	6	4.4%
	Montana	15	10.9%
	Nevada	69	50.4%
	New Mexico	4	2.9%
	South Dakota	1	0.7%
	Utah	4	2.9%
	Washington	4	2.9%
	Wisconsin	1	0.7%
Commodity	Primary Gold	17	12.4%
	Primary Silver	9	6.6%
	Gold and Silver	90	65.7%
	Copper	21	15.3%
	Copper and Molybdenum	4	2.9%
	Molybdenum	1	0.7%
	Lead and Zinc	5	3.6%
	Platinum Group	2	1.5%
Operation Type	Underground	19	13.9%
	Open Pit	104	75.9%
	Underground + Open Pit	14	10.2%
	Heap or Vat Leach	95	69.3%
	Flotation and Gravity	28	20.4%
	Dump Leach (SX/EW)	15	10.9%
	Heap Leach	53	38.7%
	Vat Leach	14	10.2%
	Heap Leach and Vat Leach	28	20.4%
	Smelter	2	1.5%
Status	Operating	64	46.7%
	Closed	61	44.5%
	In Construction	1	0.7%
	Permitting	6	4.4%
	Withdrawn	5	3.6%

As shown in Table 4.3, the majority of mines 104 (76%) are operated by open pit methods only. Nineteen (14%) of the mines are operated solely by underground mining methods. Fourteen (10%) of the mines are operated by combined underground and open pit methods.

As indicated in Table 4.3, cyanide leaching is the predominant method used for gold ore processing and is used at 95 (69%) of the major mines subject to NEPA identified. Fifty-three (39%) of the operations rely on heap leaching processes, while 14 (10%) rely on vat leaching. Twenty-eight (20%) of these mines use both heap leaching and vat leaching processing methods.

Dump leaching is used exclusively at copper mines, and is the process used at 15 (11%) of the major mines subject to NEPA identified. Flotation and gravity processing were the primary process methods used at 28 (20%) of the mines subject to NEPA identified.

Two (2%) of the major mines subject to NEPA had smelters associated with their operations. These mines were both copper mines.

4.2.4. OPERATIONAL STATUS

As this study takes into account a time span of approximately 30 years (1975 to present), many of the 137 major mines subject to NEPA identified will have operated and closed. As shown in Table 4.3, 64 (47%) of the mines subject to NEPA operated during that period are still currently operating. Sixty-one (45%) of the major mines subject to NEPA that operated have closed during that period. Currently, only one (less than 1%) new mine subject to NEPA (Pogo, Alaska) is in construction, while six (4%) are in permitting, and five (4%) were withdrawn from the permitting process.

4.3. COLLECTION OF EISS FOR MINES SUBJECT TO NEPA

EISs were performed at 82 (60%) of the 137 major mines subject to NEPA, either as part of new permitting actions or as part of later expansion or other subsequent actions. EAs only, based on agency regulatory findings of no significant impact, were performed at the remainder of the mines subject to NEPA. The EISs resulted from the following conditions or mine site actions:

- ten (7%) of the mines with EISs were in operation prior to NEPA enactment but had later EISs for expansion or other (e.g., land swap) purposes
- twenty (15%) out of 71 (51%) mines originally permitted as new operations with EAs had subsequent EISs related primarily to expansion proposals
- fifty-two (38%) of the mines subject to NEPA were originally permitted as new projects with EISs

EISs and EAs were obtained by writing, emailing, and/or calling state and federal agencies, including the BLM, USDA Forest Service, and tribal agencies, as well as conducting library searches. Some agencies were quick to respond to our requests and provided information promptly. Most agencies required a written Freedom of Information Act (FOIA) request letter, and most were honored within 30 days of receipt, while others took months to respond. There were several agencies that denied our FOIA request for a fee waiver and charged copying fees for documents. Due to the cost of copying, some documents were not acquired. There were occasions for older mines where the agencies no longer had copies of the NEPA documents because they had been “loaned out” and never returned or older documents were “thrown out” to make room for new projects. The process of obtaining NEPA documents took approximately 16 months and involved numerous follow-up calls, written, and email contact.

Of the 137 major mines subject to NEPA, 71 mines had documents that were obtained and reviewed. A total of 104 NEPA documents, either EISs or EAs, were reviewed for the 71 mines. Table 4.4 identifies the 71 NEPA mines that were reviewed for this study and summarizes information on the location, commodity, extraction, processing methods and operational status for the 71 mines reviewed. The general statistical data for the major hardrock metals mines subject to NEPA reviewed in the U.S. are summarized and discussed in the following sections.

4.3.1. LOCATION

The 71 modern-era major hardrock mines with EISs that were reviewed are located in 10 different states. One major mine is located in the mid-west (Wisconsin), seven are in Alaska, and the remaining mines are in the western contiguous U.S.

As indicated in Table 4.4, 24 (34%) of the major mines with EISs that were reviewed are located in Nevada. Arizona, California and Montana are also significant with eight (11%), eight (11%) and 13 (18%) respectively located in those states. The states of Idaho, New Mexico and Alaska respectively have six (9%), two (3%) and seven (10%). South Dakota, Utah and Wisconsin each have one (1%) of the major mines with reviewed EISs.

Table 4.4. General Information for Mines with Reviewed EISs

Feature		All Major Mines	
		Number	%
	Alaska	7	9.9%
	Arizona	8	11.3%
	California	8	11.3%
	Idaho	6	8.5%
	Montana	13	18.3%
	Nevada	24	33.8%
	New Mexico	2	2.8%
	South Dakota	1	1.4%
	Utah	1	1.4%
	Wisconsin	1	1.4%
Commodity	Primary Gold	14	19.7%
	Primary Silver	5	7.0%
	Gold and Silver	39	54.9%
	Copper	14	19.7%
	Copper and Molybdenum	1	1.4%
	Molybdenum	1	1.4%
	Lead and Zinc	4	5.6%
	Platinum Group	2	2.8%
Operation Type	Underground	13	18.3%
	Open Pit	51	71.8%
	Underground + Open Pit	7	9.9%
	Heap or Vat Leach	44	62.0%
	Flotation and Gravity	19	26.8%
	Dump Leach (SX/EW)	8	11.3%
	Heap Leach	18	25.4%
	Vat Leach	10	14.1%
	Heap Leach and Vat Leach	16	22.5%
	Smelter	1	1.4%
Status	Operating	35	49.3%
	Closed	26	36.6%
	In Construction	1	1.4%
	Permitting	5	7.0%
	Withdrawn	4	5.6%

4.3.2. COMMODITY

The 71 modern-era major hardrock mines with EISs that were reviewed produce gold, silver, copper, molybdenum, lead, zinc and platinum group minerals (platinum and palladium).

As indicated in Table 4.4, 39 (55%) of the mines were identified as gold and silver mines. When combined with the 14 (20%) mines identified as primary gold mines and five (7%) mines identified as primary silver mines, 58 (82%) of the modern-era major hardrock mines with reviewed EISs extract precious metals.

There are 14 (20%) modern-era mines with reviewed EISs that are primary copper mines, while one (1%) produces both copper and molybdenum. Only one (1%) is a primary molybdenum mine. Four (6%) of the mines produce lead and zinc, and two (3%) produce platinum group minerals. Some of the mines produce multiple commodities (e.g., gold, silver, lead, zinc); therefore, the numbers of mines identified in this section have a total greater than the 137 mines subject to NEPA.

4.3.3. EXTRACTION AND PROCESSING METHODS

The 71 modern-era major hardrock mines with EISs reviewed are operated by both open pit and underground mining methods, and employ heap or vat leaching, flotation/gravity, and dump leaching process methods.

As shown in Table 4.4, the majority of mines (51 or 72%) are operated by open pit methods only. Thirteen (18%) of the mines are operated solely by underground mining methods. Seven (10%) of the mines are operated by combined underground and open pit methods.

As indicated in Table 4.4, cyanide leaching is the predominant method used for gold ore processing and is used at 44 (62%) of the major mines with reviewed EISs. Eighteen (25%) of the operations rely on heap leaching processes, while 10 (14%) rely on vat leaching. Sixteen (23%) use both heap leaching and vat leaching processing methods.

4.3.4. OPERATIONAL STATUS

Many of the 71 mines with reviewed EISs have operated and subsequently closed during the 30-year time span (1975 to present) of this study. As shown in Table 4.4, 35 (49%) of the mines operated during that period are currently operating. Twenty-six (37%) of the major mines that operated have closed during that period. Currently, one (less than 1%) new mine (Pogo, Alaska) is in construction, while 5 (7%) are in permitting.

4.3.5. NPDES INFORMATION

According to the EPA's Enforcement History and Online (ECHO) database, 19 (27%) of the 71 major modern-era mines subject to NEPA reviewed in detail have NPDES permits. EPA classifies larger, more regulated facilities as *major* facilities and smaller ones as *minor* facilities. On that basis, EPA has classified nine of the 19 NPDES permitted major mines as major facilities and 10 as minor facilities.

At least one other major mine subject to NEPA was identified as having permitted discharges to surface water that were not identified in the search of the ECHO database.

4.4. COMPARISON OF MINE INFORMATION

A comparison of the statistical results for major mines, major mines subject to NEPA, and major mines subject to NEPA with EISs reviewed are provided in Table 4.5. The table shows that the various categories of mines are comparable and that the NEPA subject mines with EISs reviewed in detail are reasonably comparable to the major hardrock metals mines and NEPA subject mines based on general statistical information.

The hardrock mines in the United States are spread over 14 states, most of them in the western United States. The mines with reviewed EISs cover 10 states, excluding Colorado, Michigan, South Carolina, and Washington. Colorado, Michigan, and South Carolina have no mines subject to NEPA, so mines from these states were excluded from review based on the constraints of the study. The mines subject to NEPA with EISs reviewed in detail are similar to all major mines and all major mines subject to NEPA in terms of commodity type. The mines reviewed in detail have a somewhat larger representation of primary gold mines and copper mines, but a somewhat smaller percentage of combined gold and silver mines. In terms of extraction methods, the mines subject to NEPA with reviewed EISs have a somewhat higher proportion of underground mines compared to all major mines and all major mines subject to NEPA but are otherwise quite similar to the larger dataset. For processing methods, the mines subject to NEPA with reviewed EISs have a somewhat lower percentage of heap leach operations and a somewhat higher proportion of vat leach operations but are otherwise quite similar to the larger dataset. In terms of operational status, the mines subject to NEPA with EISs reviewed have a somewhat higher proportion of operating mines and a lower percentage of closed mines but are otherwise similar to the larger dataset. These differences will favor examination of the more modern mines in the United States.

Table 4.5. Comparison of Major Mines, Major Mines Subject to NEPA and Major Mines Subject to NEPA with EISs Reviewed in Detail

Feature		Major Mines	Major Mines Subject to NEPA	Major Mines Subject to NEPA with EISs Reviewed in Detail
		% of total mines in category		
States	Alaska	4.40%	5.10%	9.90%
	Arizona	10.90%	9.50%	11.30%
	California	8.20%	9.50%	11.30%
	Colorado	4.90%		
	Idaho	7.70%	4.40%	8.50%
	Michigan	0.50%		
	Montana	8.20%	10.90%	18.30%
	Nevada	40.40%	50.40%	32.40%
	New Mexico	3.80%	2.20%	2.80%
	South Carolina	1.60%		
	South Dakota	2.70%	0.70%	1.40%
	Utah	3.80%	2.90%	1.40%
	Washington	2.20%	2.90%	
	Wisconsin	0.50%	0.70%	1.40%
Commodity	Primary Gold	12.60%	12.40%	19.70%
	Primary Silver	7.10%	6.60%	7.00%
	Gold and Silver	62.80%	65.70%	54.90%
	Copper	16.40%	15.30%	19.70%
	Copper and Molybdenum	4.40%	2.90%	1.40%
	Molybdenum	2.20%	0.70%	1.40%
	Lead and Zinc	3.80%	3.60%	5.60%
	Platinum Group	1.10%	1.50%	2.80%
Operation Type	Underground	14.80%	13.90%	18.30%
	Open Pit	72.10%	75.90%	71.80%
	Underground + Open Pit	12.00%	10.20%	9.90%
	Heap or Vat Leach	65.60%	69.30%	62.00%
	Flotation and Gravity	24.00%	20.40%	26.80%
	Dump Leach (SX/EW)	12.00%	10.90%	11.30%
	Heap Leach	39.30%	38.70%	25.40%
	Vat Leach	9.30%	10.20%	14.10%
	Heap Leach and Vat Leach	16.90%	20.40%	22.50%
	Smelter	3.30%	1.50%	1.40%
Operational	Operating	44.80%	46.70%	49.30%
	Closed	48.60%	44.50%	36.60%
	In Construction	0.50%	0.70%	1.40%
	Permitting	3.80%	4.40%	7.00%
	Withdrawn	2.20%	3.60%	5.60%

5. WATER QUALITY PREDICTIONS INFORMATION

Information relevant to water quality predictions was collected by reviewing the available scientific and technical documentation for each of the 71 major mines where complete information in the form of EISs or EAs was available. The information collected consisted of the following elements:

- geology/mineralization
- climate
- hydrology
- field and lab tests performed
- constituents of concern identified
- predictive models used
- water quality impact potential
- mitigation
- predicted water quality impacts
- discharge information

Some of the elements contain sub-elements. For example, hydrology includes the sub-elements of surface water hydrology (proximity to surface water) and groundwater hydrology (depth to groundwater). For each type of information, a score was derived to characterize the element (e.g., geology/mineralization used six scores, including one for no information provided). The scoring allowed statistics to be performed on the information in the NEPA documents. All of the elements except for constituents of concern and mitigation have percentages that add to 100 percent. Because a given mine could have more than one type of constituent of concern (e.g., metals and metalloids and cyanide), scores will sum to greater than 100 percent. Similarly, a given mine could have more than one type of groundwater mitigation or surface water mitigation (e.g., source controls and monitoring and perpetual treatment), and scores will also sum to greater than 100 percent. Although a given mine could have conducted more than one type of field or laboratory geochemical characterization test, the scores were so that each mine had a unique score (e.g., one category is static testing only, and another is static, short-term leach, and kinetic testing).

In a number of instances, multiple EISs or EAs were reviewed for a given mine. For those mines, different approaches were used to concatenate the scores into one score per mine site. In general, the most environmentally conservative score was used as the bulk score for the mine. For example, for surface water proximity (a sub-element of hydrology), the score from the EIS that noted the closest proximity to surface water was used. The approach for concatenating scores from multiple EISs is described, where relevant, for each element and sub-element.

With the exception of the climate classifications, all scoring was based on information available in the EISs or EAs. If information or a subset of the information was not described in the EIS or EA, other additional sources of information to describe the element were not used. In this way, the scores reflect only the information that was considered by the regulators in the environmental review process.

5.1. SUMMARY OF RESULTS

The information summarized in this section was derived from the 71 mines reviewed for this study that were subject to the regulatory requirements of NEPA that resulted in water quality predictions. All information in this section was collected from the reviewed EISs or EAs and is a summary of or an exact replica or that information as it appeared in the document. In most cases, the information was scored to allow for statistical analysis. For mines with multiple EISs and/or EAs, only one final score was used in the tables and statistical analysis. In most cases, this was the most environmentally conservative score. For example, for groundwater depth, the score denoting the shallowest depth to groundwater was used, and for acid drainage potential, the score indicating the highest acid drainage potential was used.

Geology and mineralization information focused primarily on the geologic and mineralogical characteristics of the ore and the surrounding rock that would make mined materials more or less susceptible to acid drainage generation. The synopsis is only a generalized overview of all the rock types and mineralization present at the site, especially for rocks in the area of the ore deposit that will be mined. The major categories scored varied from low potential to create acid drainage to high potential to generate acidity with the following results:

- No/insufficient information available (23%)
- Low sulfide content, carbonate present or hosted in carbonate (10%)
- Low sulfide content, low carbonate content/carbonate not mentioned (7%)
- Sulfides present, carbonate or moderate to high NP rock present (33%)
- Sulfides present, no carbonates/carbonates not mentioned or associated with ore body (23%)
- High sulfide content, carbonates low/not present (3%)

Climate information gathered included general descriptions of climate type (i.e., arid, semi arid, coastal marine, northern, etc), precipitation data, and evaporation data. The climate - type descriptions in the NEPA documents varied substantially in detail and scope of coverage. The modified Köppen system was used to denote the major climate regions and their sub-classifications, and the results for the NEPA mines were with the following results:

- Dry/Arid Low and Middle Latitude Deserts (20%)
- Dry/Semi-Arid Middle Latitude Climates (35%)
- Humid Subtropical (4%)
- Marine West Coast (4%)
- Boreal Forest (28%)
- Continental (3%)
- Sub-Arctic (4%)

Hydrology information gathered included information on surface water proximity and depth to groundwater depth. Information on surface water proximity was classified as:

- No information provided (7%)
- Intermittent/ephemeral streams on site - perennial streams >1 mile away (26%)
- Intermittent/ephemeral streams on site - perennial streams <1 mile away (25%)
- Perennial streams on site (44%)

Depth to Groundwater information was classified as:

- No information provided (12%)
- Depth to groundwater > 200 feet (16%)
- Depth to groundwater < 200 but >50 feet (13%)
- Depth to groundwater 0 to 50 feet and/or springs on site (59%)

Laboratory and field geochemical testing methods information gathered focused on the main types of geochemical characterization tests used: static, short-term leach and kinetic testing, and fell into the following categories:

- No information (10%)
- Static testing only (13%)
- Short-term leach testing only (6%)
- Kinetic testing only (2%)
- Static and short-term leach testing (17%)
- Static and kinetic testing (16%)
- Short-term leach and kinetic testing (2%)
- Static, short-term leach, and kinetic testing (35%)

Constituents of concern (COC's) were identified in the EISs and included:

- None/insufficient information (16%)
- Metals (74%)
- Radionuclides (1%)
- Cyanide (23%)
- Metalloids, oxyanions (55%)
- Conventional pollutants (49%)

Predictive models were used in the EISs with the following frequency:

- No predictive models used (44%)
- Only water quantity predictive models used (26%)
- Only water quality predictive models used (2%)
- Both water quantity and water quality predictive models used (29%)

This report distinguishes between potential and predicted water quality impacts. A potential water quality impact is one that could occur if mitigation are not in place, and predicted water quality impacts are those that threaten water quality even after mitigation are in place. Potential water quality impacts are related to the inherent characteristics of the mine location or of the mined materials, such as acid drainage and contaminant leaching, climate, and proximity to water resources. Potential water quality impacts are described in the NEPA documents. The elements of water quality impact potential included acid drainage potential, contaminant leaching potential, and potential groundwater, surface water, and pit water impacts.

Acid drainage potential was summarized and scored as follows:

- No information available (9%)
- Low acid drainage potential (58%)
- Moderate acid drainage potential (6%)
- High acid drainage potential (27%)

Contaminant leaching potential was summarized and scored as follows:

- No information available (22%)
- Low contaminant leaching potential (leachate does not exceed water quality standards) (32%)
- Moderate potential for elevated contaminant concentrations (leachate exceeds water quality standards by 1-10 times) (30%)
- High potential for elevated contaminant concentrations (leachate exceeds water quality standards by over 10 times) (17%)

Groundwater impact potential was summarized and scored as follows:

- No information available (20%)
- Low groundwater quality impacts (< relevant standards) (25%)
- Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) (48%)
- High groundwater quality impacts (>10 times relevant standards) (7%)

Surface water impact potential was summarized and scored as follows:

- No information available (23%)
- Low surface water quality impacts (< relevant standards) (33%)
- Moderate surface water quality impacts (≥ and up to 10 times relevant standards) (41%)
- High surface water quality impacts (>10 times relevant standards) (3%)

Pit water impact potential was summarized and scored as follows:

- No information available (22%)
- Low pit water quality impacts (water quality similar to surrounding groundwater or < relevant standards) (12%)
- Moderate pit water quality impacts (≥ and up to 10 times relevant standards) (17%)
- High pit water quality impacts (>10 times water quality standards) (14%)
- No pit lake or water expected (pit above water table or no pit) (35%)

EISs analyze and may require mitigation to address potential water quality impacts that are identified. Mitigation measures are commonly designed for the protection of groundwater and surface water resources, and may address pit water quality (depending on state requirements). Water-quality mitigation identified in the EISs fell into groundwater, surface water, and pit water measures. For mines that proposed treatment as part of the mitigation measures, the type of treatment was also categorized and scored.

Proposed groundwater mitigation were summarized and scored as follows (total exceeds 100% as some mines employ multiple mitigation):

- No information available or no mitigation identified (17%);
- Groundwater monitoring or characterization of mined materials (48%);
- Source controls without treatment (liners, leak detection systems, run on/off controls, caps/covers, adit plugging) (71%);
- Groundwater/leachate capture with treatment (38%);
- In-perpetuity groundwater capture and/or treatment; long-term mitigation fund (4%);
- Liming, blending, segregation, etc. of potentially acid-generating (PAG) material (19%).

Proposed surface water mitigation were summarized and scored as follows:

- No information available or no mitigation identified (15%);
- Surface water monitoring (14%);
- Stormwater, sediment, or erosion controls (68%);
- Source controls not involving capture of water (including liners, adit plugging, caps/covers, leak detection systems, spill prevention measures, and liming/blending/segregating of PAG materials) (30%);
- Surface water/leachate capture and/or treatment (including settling, land application, routing of water, seepage collection) (30%);
- Perpetual surface water capture and/or treatment (3%);
- Surface water augmentation or replacement (3%).

Proposed pit water mitigation were summarized and scored as follows:

- No information provided or none identified (25%);
- Pit lake monitoring (9%);
- Pit lake prevention (backfill, pumping, stormwater diversion, use in mine operation) (41%);
- Treatment of pit water or backfill amendment (e.g., lime addition) (9%);
- Not applicable: no pit lake will form (underground mine or pit above water table) (33%);
- Contingency or research fund for pit lake, adaptive management (3%).

Proposed water treatment measures were summarized and scored as follows:

- No information provided or no water treatment measures identified (70%);
- Solids or sediment settling ponds (9%);
- Water treatment for cyanide (9%);
- Water treatment for metals and/or acid drainage (22%);
- Water treatment using non-conventional approaches (15%);
- Perpetual water treatment (6%).

A predicted water quality impact is one that could occur after mitigation is in place. It is these predicted, or post-mitigation, impacts that are considered by regulators when evaluating whether a proposed mine will meet applicable water quality standards.

Predicted groundwater quality impacts were summarized and scored as follows:
- No information available (9%)
- Low groundwater quality impacts (< relevant standards) (80%)
- Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) (6%)
- High groundwater quality impacts (>10 times relevant standards) (6%)

Predicted surface water quality impacts were summarized and scored as follows:
- No information available (9%)
- Low surface water quality impacts (< relevant standards) (83%)
- Moderate surface water quality impacts (≥ and up to 10 times relevant standards) (7%)
- High surface water quality impacts (>10 times standards) (1%)

Predicted pit water quality impacts were summarized and scored as follows:
- No information available (16%)
- Low pit water quality impacts (concentrations less than relevant standards or water quality similar to surrounding groundwater) (17%)
- Moderate pit water quality impacts (≥ and up to 10 times relevant standards) (19%)
- High pit water quality impacts (>10 time relevant standards) (13%)
- No pit lake or water expected (underground mine or pit above the water table (35%)

In many cases, EISs identified mines or certain facilities at mines (e.g., heap leach pads or tailings impoundments) as “zero discharge” facilities. Many mines also had discharges to surface water that are regulated by either federal National Pollution Discharge Elimination System (NPDES) permits or similar permits issued by individual states under EPA authority.

Discharges were summarized and scored as follows:
- Zero Discharge Facilities (39%)
- Surface Water Discharge Permit (41%)
- Groundwater Discharge Permit (6%)

Each of the following sections describes the approach to categorizing the relevant NEPA information and summarizes and discusses the information collected from the 71 major mines for which we reviewed NEPA documentation. In Tables 5.5 through 5.22, the 25 mines subsequently chosen as case study mines are indicated by an asterisk (*). Identifying them in this section allows for a visual review of the variability in elements that may affect operational water quality.

5.2. GEOLOGY AND MINERALIZATION

Geology and mineralization information collected from the NEPA documents included rock type (e.g., general categories such as igneous, sedimentary, and metamorphic, and more detailed categories such as granite, dolomite, and greenstone), and information on mineralogy/ mineralization, alteration and ore associations. Plumlee and others have suggested that knowledge about mineralization type can help to predict the environmental behavior of ore deposits (e.g., Seal and Hammarstrom, 2003, for massive sulfide and gold deposits). Table 5.1 lists these mineralization types, examples, and associated rock types.

Table 5.1. Mineralization Types, Examples and Associated Rock Types

Mineralization Types	Examples	Associated Rock Types
Volcanogenic massive sulfide (VMS) deposits	Iron Mountain CA, Blackbird mine, ID	Volcanic: basaltic (Cyprus type), rhyolitic-andesitic (Kuroko-type); sedimentary rock such as turbidites and black shales (Besshi-type)
High sulfidation epithermal (quartz alunite epithermal) deposits	Summitville, CO, Red Mountain Pass, CO, Goldfield and Paradise Peak, NV, Mt. Macintosh, BC, Julcani, Peru	Silicic volcanic or intrusive rocks (e.g., quartz latite)
Porphyry Cu and Cu-Mo deposits	Globe, AZ, Mt.Washington, BC, Alamosa CO	Altered, intermediate-composition intrusive rocks
Cordilleran lode deposits	Butte, MT; Magma, AZ, Quiruvilca, Peru	Altered, intermediate-composition intrusive rocks
Climax-type porphyry Mo deposits	Climax, Henderson, Mt. Emmons, CO	Silica- and uranium-rich granitic or rhyolitic intrusions
Polymetallic vein deposits and adularia-sericite epithermal vein deposits	Central City, CO (polymetallic vein); Creede and Bonanza, CO; Comstock NV; Sado, Japan (adularia-sericite)	igneous intrusions
Hot-spring Au-Ag and Hg deposits	Leviathan, Sulphur Bank, and McLaughlin, CA; Round Mountain, NV	Epithermal and vein deposits; volcanic rocks
Skarn and polymetallic replacement deposits	Leadville, Gilman, and Rico, CO; New World, MT; Park City and Tintic, UT. Skarn deposits associated with porphyry-Mo, -Cu- Mo and -Cu deposits - Yerington, NV; Chino, NM	Outermost portions of intrusions or in sediments adjacent to the intrusions
Stratiform shale-hosted (SEDEX) deposits	Red Dog, Lik, and Drenchwater, Alaska; Sullivan, BC; Mt. Isa and Broken Hill, Australia	Black shale and chert-bearing host rocks
Mississippi-Valley-Type (MVT) deposits	Old Lead Belt, Viburnum Trend in Missouri, Tri-State (Missouri, Kansas, and Oklahoma), Northern Arkansas, Upper Mississippi (Wisconsin), and Central Tennessee districts	Dolostones, limestones, sandstones in sedimentary basins
Magmatic sulfide deposits	Sudbury Complex, Ontario; Duluth Complex, Minnesota; Stillwater Complex, MT; Bushveld Complex, South Africa	Layered mafic intrusions, ultramafic volcanic rocks or ultramafic accumulations
Banded-iron formation (BIF) deposits	Superior-type deposits -- Mesabi Iron Range, Minnesota; Marquette Iron Range, Michigan	Chemical sediments in which iron oxides, carbonates, silicates or sulfides are finely interlaminated or interbedded with chert or jasper.
Low-sulfide, gold-quartz vein deposits	Juneau Gold Belt and Fairbanks, Alaska; Mother Lode, CA	In quartz veins in medium-grade greenstone metamorphic rocks
Alkalic Au-Ag-Te vein deposits	Cripple Creek, CO; Boulder County, CO; Ortiz, NM; Zortman and Landusky, MT.	Diatremes or breccia pipes in alkalic igneous intrusive complexes

Source: Plumlee et al., 1999.

A synopsis of the geology and mineralization information for each mine with NEPA documentation was developed, focusing primarily on the geologic and mineralogical characteristics of the ore and the surrounding rock that would make mined materials more or less susceptible to acid drainage generation. The synopsis is only a generalized overview of all the rock types and mineralization present at the site, especially for rocks in the area of the ore deposit that will be mined. Based on the synopsis, a score was developed for each mine that focused on sulfide content and the presence of carbonates or other type of neutralizing rock or minerals. The score represents the overall reported mineralization, but rocks of one type could dominate environmental behavior at a given mine site. The major categories scored varied from low potential to create acid drainage to high potential to generate acidity and were:

- No/insufficient information available (0)
- Low sulfide content, carbonate present or hosted in carbonate (1)
- Low sulfide content, low carbonate content/carbonate not mentioned (2)
- Sulfides present, carbonate or moderate - high NP rock present (3)
- Sulfides present, no carbonates/carbonates not mentioned or associated with ore body (4)
- High sulfide content, carbonates low/not present (5)

A list of rock types and names and their associated relative neutralizing and acid-generating potential is taken from Plumlee (1999) and is contained in Table 5.2. In some cases, the geology of the deposit provided neutralizing ability, even if the rock type was other than carbonate. For example, the layered mafic intrusions of the Stillwater and East Boulder mines in Montana have inherent neutralizing ability even though they do not have carbonates. In addition, skarn deposits (which are not listed in Table 5.1), such as at the Battle Mountain Complex in Nevada and certain kinds of volcanic tuffs, such as at the Florida Canyon Mine in Nevada, can also provide moderate to high neutralizing ability.

Table 5.2. Rock Types and Names and Associated Relative Neutralizing and Acid-Generating Potential.

Rock Type	Subcategory	Rock Name	Relative Neutralizing and Acid-Generating Potential
Sedimentary	Chemical/ Biological	Limestone	High NP
		Dolomite	Mod – high NP
		Chert	Mod NP
	Detrital	Black Shale	Low - mod NP, low - mod AP
		Redbed shales	Mod NP
		Arkose	Low NP
		Calcareous sandstone	Low NP
		Quartzose sandstone	Low NP
Igneous	Intrusive	Carbonatite	High NP, Mod AP
		Ultramafic	Mod – high NP, mod AP
		Granite	Low NP
	Volcanic	Komatiite	Mod – high NP, some AP
		Basalt	Low – mod NP
		Andesite	Low – mod NP
		Poorly welded volcanic tuff	Mod – high NP
		Highly welded volcanic tuff	Low – mod NP
		Rhyolite flows	Low – mod NP
Metamorphic		Marble	High NP
		Gneiss	Low NP
		Quartzite	Very low NP
		Sulfidic schists	Low NP, high AP

Source: Plumlee, 1999.

Table 5.3 presents the mineralization/ore classifications for the 71 NEPA mines in the study. For mines with multiple EISs or EAs, the highest individual score was used.

Table 5.3. Mineral/Ore Associations

0		1		2		3		4		5	
No/insufficient information available		Low sulfide content, carbonate present or hosted in carbonate		Low sulfide content, low carbonate content/carbonate not mentioned		Sulfides present, carbonate or mod-high NP rock present		Sulfides present, no carbonates/carbonates not mentioned or associated with ore body.		High sulfide content, carbonates low/not present	
Fort Knox	AK	Cortez Pipeline	NV	Kensington Project	AK	AJ Project	AK	Bagdad	AZ	Montana Tunnels	MT
Pogo Project	AK	Dash	NV	Sanchez	AZ	Greens Creek	AK	Safford (Dos Pobres)	AZ	Golden Sunlight	MT
True North	AK	Griffon	NV	Yarnell	AZ	Red Dog	AK	Hayden Hill	CA		
Cyprus Tohono	AZ	Jerritt Canyon	NV	American Girl	CA	Carlotta	AZ	Beartrack	ID		
Morenci	AZ	Marigold	NV	Imperial	CA	Black Pine	ID	Grouse Creek	ID		
Ray	AZ	Olinghouse	NV			Stibnite	ID	Basin Creek	MT		
Castle Mountain	CA	Rochester	NV			Thompson Creek	ID	Beal Mountain	MT		
Jamestown	CA					Diamond Hill	MT	Black Pine	MT		
McLaughlin	CA					East Boulder	MT	Mineral Hill	MT		
Mesquite	CA					Rock Creek	MT	Montanore	MT		
Royal Mountain King	CA					Stillwater	MT	Troy	MT		
Stone Cabin	ID					Battle Mountain Phoenix	NV	Zortman Landusky	MT		
Austin Gold Venture	NV					Cortez	NV	Copper Flat	NM		
Bald Mountain	NV					Florida Canyon	NV	Tyrone Little Rock	NM		
Rain	NV					Gold Quarry	NV	Mule Canyon	NV		
Gilt Edge	SD					Goldstrike	NV	Lisbon Valley	UT		
						Leeville	NV	Flambeau	WI		
						Lone Tree	NV				
						Pete	NV				
						Robinson (Ruth)	NV				
						Round Mountain	NV				
						Ruby Hill	NV				
						Trenton Canyon	NV				
						Twin Creeks	NV				
	16		7		5		24		17		2

No/Insufficient Information Available

Almost one-quarter of the mines (23% or 16 mines) did not contain sufficient information to evaluate the mineralization or ore associations. Four of the mines, Fort Knox, True North, Austin Gold Venture, and Rain, had only EAs, while two of the mines, Morenci and Ray, had EISs conducted for land exchange purposes. The McLaughlin Mine is a shallow, low-sulfidation epithermal hot-spring deposit, but insufficient information was provided in the McLaughlin EIS to categorize it.

Low Sulfide Content, Carbonate Present or Hosted in Carbonate

Ten percent (7 mines) of the NEPA mines analyzed, all located in Nevada, had rocks with low sulfide content and carbonate present or hosted in carbonate. These mines would be expected to have a relatively low impact on the environment in terms of acid-generation potential.

Low Sulfide Content, Low Carbonate Content/Carbonate Not Mentioned

Five mines (7%) also had low sulfide content but had low carbonate content, or the presence of carbonates was not mentioned. The absence of carbonate would give these mines a somewhat higher potential to generate acid than those in the previous category. Jerritt Canyon is a sediment-hosted Carlin-type deposit, but the presence of sulfides was not mentioned in the Jerritt Canyon EISs, so it was placed in the low sulfide content, carbonate present or hosted in carbonate category.

Sulfides Present, Carbonate or Moderately High Neutralizing-Potential Rock Present

The highest number of mines (24 or 34%) had both sulfides and carbonate or moderately high neutralizing potential rock present. The sulfide content at these mines was not described as “low,” so the potential for acid generation is higher than the first two categories. The majority of mines in this category are in Nevada, and four of these are sediment-hosted Carlin-Type deposits (Seal and Hammarstrom, 2003). Two of the Montana mines (East Boulder and Stillwater) were placed in this category because of the presence of moderately high neutralizing potential rock (ultramafic rocks), rather than because of their carbonate content. Mines in this category have higher sulfide content than those in the previous categories but also have neutralizing rock present. The potential acid drainage potential at mines in this category will depend on the relative amounts of sulfide and neutralizing material and the proximity to one another, the availability of these minerals to weathering, the rates at which they weather, and other factors, such as climatic conditions.

Sulfides Present, No Carbonates/Carbonates Not Mentioned or Associated with Ore Body

The next category, sulfides present with no carbonate, or carbonates not mentioned or associated with the ore body, contained 17 mines (24%), and most of these mines are in Montana. The mines in this group have a relatively high potential to generate acid because of the lack of neutralizing material and the presence of sulfides.

High Sulfide Content, Carbonates Low/Not Present

Mines in the last category (2 or 3%) have the highest potential to generate acid because of the high sulfide content and the lack of or low carbonate content. Of these two mines, Golden Sunlight has had extensive problems with acid drainage (see Section 6 and Appendix B).

5.3. CLIMATE

Climate information gathered from each EIS (and/or preceding EA) included general descriptions of climate type (i.e., arid, semi arid, coastal marine, northern, etc.) and information on the amount of precipitation and evaporation.

The climate descriptions in the NEPA documents varied substantially in detail and scope of coverage (e.g., most reported the amount of precipitation, but few reported the amount of evaporation). Descriptions in the documents included "arid" (14 mines), "semi-arid" (25 mines) and "long winter" (three mines). Other descriptions particular to individual mines included "coastal marine," "continental highlands," "high desert," "modified continental," "mountain," "pacific maritime," "southern," and "temperate."

Precipitation in terms of annual moisture was reported relatively consistently in every EIS analyzed. It was generally provided in terms of a range of average annual precipitation calculated as rainfall. As noted above, evaporation data were provided sporadically, with some EISs providing an annual figure or range and with others only saying "evaporation exceeds precipitation."

In addition to recording the climate descriptions noted in the EISs, the Köppen system was used to characterize climate at each mine site. The Köppen system, developed by German climatologist and amateur botanist Wladimir Köppen in 1928, is a universally used system that allows for comprehensive and comprehensible climate classification. Köppen's system has been widely modified, with Trewartha's modified Köppen system being the most widely used version today.

The modified Köppen system uses letters to denote the six major climate regions and their sub-classifications. The sub-classifications are based on average monthly temperature and precipitation values. The regions and subclassifications are as follows:

Major Climate Regions

A for tropical humid climates
B for hot dry climates
C for mild mid-latitude climates
D for cold mid-latitude climates
E for polar climates
H for highland climates

Subtypes for Precipitation

s – dry season in summer, where: when 70% or more of annual precipitation falls in winter (for C climates)
w – dry season in winter, where: when 70% or more of annual precipitation falls in summer (for A, C, or D climates)
f – constantly moist, or: rainfall consistent throughout year (for A, C, or D climates)
m – monsoon rain, short dry season

Subtypes for Temperature

a - warmest month above or equal to 22°C
b – warmest month below 22°C (for C or D climates)
c – less than four months over 10°C (for C or D climates)
d – same as 'c' but coldest month below -37°C (for D climates)
h – hot and dry: all months above 0°C (for B climates)
k – cool and dry; at least one month below 0°C (for B climates)

Köppen classification maps were obtained for the states in which the 71 major NEPA mines analyzed were located, and mine locations were matched with climate classifications. Based on that information, the following climate classifications shown in Table 5.4 were derived for the 71 NEPA mines analyzed. It was possible to locate all 71 mines on the classification maps, so Köppen classifications are available for all the NEPA mines, even if details of the climatic conditions were not described in the EISs. Because the Köppen classification is characterized by its location on the maps and the same Köppen score was used for each EIS, concatenating scores from multiple EISs were not necessary.

Dry/Arid Low and Middle Latitude Deserts (B/C,w,h/k)

Regions classified as *B* with precipitation subtype w and temperature subtypes *h/k* are typified by the low latitude Sonoran desert of New Mexico and Arizona and the Mohave Desert of Arizona and California. Fourteen mines in those states fell into this classification, including all the mines reviewed in New Mexico, Arizona and southern California.

Dry/Semi-Arid Middle Latitude Climates (B/D,s,a)

Regions classified as *B/D* with precipitation subtype *s* and temperature subtype *a* are typified by the higher elevation mid-latitude valley and range deserts of Nevada and Utah. Twenty-four mines in those states fell into this classification, including all the mines reviewed in Nevada and Utah. Depending on elevation, the amount of precipitation and evaporation can vary significantly from site to site in this region.

Humid Subtropical (C,s,a)

Regions classified as *C* with precipitation subtype s and temperature subtype *a* are humid subtropical regions ("Mediterranean" climates) typified by the central and coastal areas of California. Three mines located in central California were reviewed in this classification.

Marine West Coast (C,f,b)

Regions classified as *C* with precipitation subtype *f* and temperature subtype *b* are marine west coast climates typified by mild but wet weather typified by the southern Alaska coast. Three of the six mines located in Alaska fell into this classification.

Boreal Forest (D,s,a)

Although some ecologists or foresters do not consider any forests in the United States to be "boreal," the Köppen classification recognizes this as a region in the United States. Regions classified as *D* with precipitation subtype *s* and temperature subtype *a* have moist, severe (cold) winter climates and cool summers typified by inland Boreal Forests. Nineteen mines in the states of Idaho and Montana and one in Northern California (20 total) fell into this classification (including all the mines reviewed in Idaho and Montana).

Continental (D,f,a)

Regions classified as *D* with precipitation subtype *f* and temperature subtype *a* have temperate climates with humid hot summers and year-round precipitation typified by the mid-western United States. Two mines located in South Dakota and Wisconsin fell into this classification.

Sub-Arctic (D,f,c)

Regions classified as *D* with precipitation subtype *f* and temperature subtype *c* have year-round precipitation and cool summers typified by the mainland of Alaska. Three mines located in Alaska were reviewed from this classification.

Table 5.4. Koppen Climate Classification

B/C,w,h/k)		B/D,s,a		C,s,a		C,f,b		D,s,a		D,f,a		D,f,c	
Dry/Arid Low and Middle Latitude Deserts		Dry/Semi-Arid Middle Latitude Climates		Humid Tropical		Marine West Coast		Boreal Forest		Continental		Sub Arctic	
Bagdad	AZ	Austin Gold Venture	NV	Royal Mountain King	CA	AJ Project	AK	East Boulder	MT	Gilt Edge	SD	Fort Knox	AK
Carlotta	AZ	Bald Mountain	NV	Jamestown	CA	Greens Creek	AK	Montana Tunnels	MT	Flambeau	WI	Pogo Project	AK
Cyprus Tohono	AZ	Battle Mountain Phoenix	NV	McLaughlin	CA	Kensington Project	AK	Beartrack	ID			True North	AK
Morenci	AZ	Cortez	NV			Red Dog	AK	Troy	MT				
Ray	AZ	Cortez Pipeline	NV					Montanore	MT				
Safford (Dos Pobres)	AZ	Dash	NV					Diamond Hill	MT				
Sanchez	AZ	Florida Canyon	NV					Basin Creek	MT				
Yarnell	AZ	Gold Quarry	NV					Hayden Hill	CA				
American Girl	CA	Goldstrike	NV					Black Pine	ID				
Castle Mountain	CA	Griffon	NV					Grouse Creek	ID				
Imperial	CA	Jerritt Canyon	NV					Stibnite	ID				
Mesquite	CA	Leeville	NV					Stone Cabin	ID				
Copper Flat	NM	Lone Tree	NV					Thompson Creek	ID				
Tyrone Little Rock	NM	Marigold	NV					Beal Mountain	MT				
		Mule Canyon	NV					Black Pine	MT				
		Olinghouse	NV					Golden Sunlight	MT				
		Pete	NV					Mineral Hill	MT				
		Rain	NV					Rock Creek	MT				
		Robinson (Ruth)	NV					Stillwater	MT				
		Rochester	NV					Zortman Landusky	MT				
		Round Mountain	NV										
		Ruby Hill	NV										
		Trenton Canyon	NV										
		Twin Creeks	NV										
		Lisbon Valley	UT										
	14		25		3		4		20		2		3

5.4. HYDROLOGY

Hydrology information gathered from each EIS (and/or preceding EA) included information on surface water proximity and groundwater depth. Descriptions varied widely from document to document, although most contained some information on both surface water proximity and groundwater depth.

5.4.1. SURFACE WATER PROXIMITY

Information on surface water proximity was entered into the database and classified according to one of four categories:

- No information provided (0)
- Intermittent/ephemeral streams on site - perennial streams >1 mile away (1)
- Intermittent/ephemeral streams on site - perennial streams <1 mile away (2)
- Perennial streams on site (3)

An intermittent stream is one that flows only during wet periods that are not tied to short-term storm events, for example, when it receives water from springs or melting snow. Ephemeral streams are those that flow only in response to precipitation and whose channel is always above the water table. Most desert drainages are ephemeral. In most cases, the streams were not identified as one or the other in the NEPA documents, so no distinction was made between these two types of non-perennial streams. Generally, mines with perennial streams on site are more susceptible to surface water quality impacts from mining than those with only intermittent or ephemeral streams on site.

For mines with multiple EISs or EAs, the highest individual score was used. If there are only intermittent or ephemeral streams on site but no distance to perennial surface water is noted, it was scored as a 2 (perennial streams <1 mile away). Direct discharges to surface water, including NPDES permits, are discussed in Section 5.1. Results for the surface water hydrology classifications are presented in Table 5.5.

No Information Provided

Five mines (7%) reviewed did not provide information on the proximity to surface water resources. In some cases, maps may have been included in the EIS, but insufficient information was provided on the maps (e.g., whether or not streams were perennial) to make a supportable classification. Of these five mines, one (Rain) had only an EA.

Intermittent/Ephemeral Streams on Site - Perennial Streams >1 Mile Away

Nineteen mines (27%) were classified as having intermittent and/or ephemeral streams on site and perennial streams greater than one mile away. This classification could also be summarized as “far from surface water.” The mines in this category were located in the southwestern states of New Mexico and Arizona and in California, Idaho, Nevada, and Utah.

Intermittent/Ephemeral Streams on Site - Perennial Streams <1 Mile Away

Sixteen mines (23%) were classified as having intermittent and/or ephemeral streams on site and perennial streams less than one mile away. This classification could also be summarized as “moderately far from surface water.” The mines in this category were located in Alaska, California, Montana, Nevada, and Wisconsin.

Perennial Streams on Site

The highest number of mines (31 or 44%) was classified as having perennial streams on site. This classification could also be summarized as "close to surface water." The mines in this category are located in Alaska, Arizona, California, Idaho, Montana, New Mexico, Nevada and South Dakota.

Table 5.5. Surface Water Proximity

0		1		2		3	
No information		Intermittent/ ephemeral streams on site - perennial streams >1 mile away		Intermittent/ ephemeral streams on site - perennial streams <1 mile away		Perennial streams on site	
Yarnell	AZ	Bagdad*	AZ	True North	AK	AJ Project	AK
Imperial	CA	Cyprus Tohono	AZ	McLaughlin*	CA	Fort Knox	AK
Royal Mountain King*	CA	Safford (Dos Pobres)	AZ	Golden Sunlight*	MT	Greens Creek *	AK
Diamond Hill	MT	Sanchez	AZ	Montana Tunnels	MT	Kensington Project	AK
Rain	NV	American Girl*	CA	Stillwater*	MT	Pogo Project	AK
		Castle Mountain*	CA	Austin Gold Venture	NV	Red Dog	AK
		Mesquite*	CA	Battle Mountain Phoenix	NV	Carlotta	AZ
		Black Pine	ID	Goldstrike	NV	Morenci	AZ
		Copper Flat	NM	Leeville	NV	Ray*	AZ
		Bald Mountain	NV	Marigold	NV	Hayden Hill	CA
		Cortez	NV	Pete	NV	Jamestown*	CA
		Cortez Pipeline	NV	Robinson (Ruth)	NV	Beartrack	ID
		Florida Canyon*	NV	Rochester*	NV	Grouse Creek*	ID
		Gold Quarry	NV	Round Mountain*	NV	Stibnite	ID
		Griffon	NV	Ruby Hill*	NV	Stone Cabin	ID
		Lone Tree*	NV	Flambeau*	WI	Thompson Creek*	ID
		Mule Canyon	NV			Basin Creek	MT
		Olinghouse	NV			Beal Mountain*	MT
		Lisbon Valley	UT			Black Pine*	MT
						East Boulder	MT
						Mineral Hill*	MT
						Montanore	MT
						Rock Creek	MT
						Troy	MT
						Zortman and Landusky*	MT
						Tyrone Little Rock	NM
						Dash	NV
						Jerritt Canyon*	NV
						Trenton Canyon	NV
						Twin Creeks*	NV
						Gilt Edge	SD
	5		19		16		31

Note: In Tables 5.5 through 5.22, the 25 mines chosen as case study mines are indicated by an asterisk (*).

5.4.2. DEPTH TO GROUNDWATER

Information on the depth to groundwater was entered into the database and classified according to one of four categories:

- No information provided (0)
- Depth to groundwater > 200 feet (1)
- Depth to groundwater < 200 but >50 feet (2)
- Depth to groundwater 0 to 50 feet and/or springs on site (3)

Table 5.6 contains the results of the scoring of the 71 NEPA mines for depth to groundwater. For mines with multiple EISs or EAs, the individual highest score was used. The shallowest depth to groundwater was used, even if the groundwater was described as being "perched," or if the groundwater was alluvial. If springs were noted on the site but there was no other information about the depth to groundwater, it was scored as a 3. Therefore, springs were considered an expression of groundwater rather than as surface water. In general, mines with shallower depths to groundwater are more susceptible to groundwater quality impacts than those with greater depths to groundwater.

No Information Provided

NEPA documentation from eight mines (11%) did not provide any information on the depth to groundwater. Two of these mines (True North, AK; Austin Gold Venture, NV) had only EAs.

Depth to Groundwater > 200 feet

Twelve mines (17%) were classified as having a depth to groundwater of greater than 200 feet. The mines in this category are considered to be far from groundwater resources and are located in Arizona, California, Montana and Nevada.

Depth to Groundwater < 200 but > than 50 feet

Nine mines (13%) were classified as having a depth to groundwater of less than 200 but greater than 50 feet. The mines with this classification are located in Arizona, California, Idaho, Montana and Nevada and Utah.

Depth to Groundwater Less Than 50 feet and/or Springs on Site

The largest number of mines (42 or 59%) was classified as having a depth to groundwater of less than 50 feet and/or having springs on site. The mines with this classification are located in Alaska, Arizona, California, Idaho, Montana, Nevada, South Dakota and Wisconsin.

Table 5.6. Depth to Groundwater.

0		1		2		3	
No information		Depth to groundwater >200 feet		Depth to groundwater <200 but >50 feet		Depth to groundwater 0 to 50 ft or springs on site with no other info	
AJ Project	AK	Ray*	AZ	Cyprus Tohono	AZ	Fort Knox	AK
True North	AK	Castle Mountain*	CA	Mesquite*	CA	Greens Creek*	AK
Carlotta	AZ	Montanore	MT	Black Pine	ID	Kensington Project	AK
Imperial	CA	Bald Mountain	NV	Mineral Hill*	MT	Pogo Project	AK
Royal Mountain King*	CA	Cortez Pipeline	NV	Marigold	NV	Red Dog	AK
Copper Flat	NM	Griffon	NV	Pete	NV	Bagdad*	AZ
Tyrone Little Rock	NM	Leeville	NV	Round Mountain*	NV	Morenci	AZ
Austin Gold Venture	NV	Mule Canyon	NV	Twin Creeks*	NV	Safford (Dos Pobres)	AZ
		Olinghouse	NV	Lisbon Valley	UT	Sanchez	AZ
		Rain	NV			Yarnell	AZ
		Ruby Hill*	NV			American Girl*	CA
		Trenton Canyon	NV			Hayden Hill	CA
						Jamestown*	CA
						McLaughlin*	CA
						Beartrack	ID
						Grouse Creek*	ID
						Stibnite	ID
						Stone Cabin	ID
						Thompson Creek*	ID
						Basin Creek	MT
						Beal Mountain*	MT
						Black Pine*	MT
						Diamond Hill	MT
						East Boulder	MT
						Golden Sunlight*	MT
						Montana Tunnels	MT
						Rock Creek	MT
						Stillwater*	MT
						Troy	MT
						Zortman and Landusky*	MT
						Battle Mountain Phoenix	NV
						Cortez	NV
						Dash	NV
						Florida Canyon*	NV
						Gold Quarry	NV
						Goldstrike	NV
						Jerritt Canyon*	NV
						Lone Tree*	NV
						Robinson (Ruth)	NV
						Rochester*	NV
						Gilt Edge	SD
						Flambeau*	WI
	8		12		9		42

5.5. GEOCHEMICAL CHARACTERIZATION AND MODELING

5.5.1. TESTING METHODS

Information was gathered from each EIS (and/or preceding EA) on the types of laboratory and field geochemical testing methods used to characterize the potential of the project to generate acid and leach contaminants of concern. The general methods listed included:

- whole rock analysis
- mineralogy
- paste pH
- sulfur analysis
- static testing
- short-term leach testing
- kinetic testing
- other additional tests

A number of the methods have sub-categories; for example, types of short-term leach testing methods include the Nevada Meteoric Water Mobility Procedure (MWMP), U.S. EPA's Synthetic Precipitation Leaching Procedure (SPLP), and the California Waste Extraction Test (CA WET). A review of the different types of geochemical characterization methods is contained in the companion report to this document (Maest et al., 2005). It is possible that additional geochemical characterization methods were performed but not mentioned in the NEPA documents. For example, although sulfur analysis was not specifically mentioned, it may have been conducted as part of the acid-base accounting evaluation. Similarly, mineralogical analysis may have been conducted as part of evaluating the ore body, but the results may not have been presented in the NEPA documents.

The scoring for this category focused on the main types of geochemical characterization tests used: static, short-term leach, and kinetic testing, and were scored at follows:

- No information (0)
- Static testing only (1)
- Short-term leach testing only (2)
- Kinetic testing only (3)
- Static and short-term leach testing (4)
- Static and kinetic testing (5)
- Short-term leach and kinetic testing (6)
- Static, short-term leach, and kinetic testing (7)

Tests identified as "weather" or "weathering" were assumed to be kinetic tests, and column or barrel testing for heap detoxification was also considered to be kinetic testing. For mines with multiple EISs, the EIS with the most types of testing (highest score) was recorded. Table 5.7 lists the types and combinations of types of geochemical characterization tests that were mentioned for the 71 NEPA mines with EISs and EAs that were reviewed.

Table 5.7. Geochemical Characterization

0		1		2		3		4		5		6		7	
No lab/field predictive testing conducted/type unknown		Static testing only		Short-term leach testing only		Kinetic testing only		Static and short-term leach testing conducted		Static and kinetic testing conducted		Short-term leach and kinetic testing		Static, short-term leach, and kinetic testing conducted	
AJ Project	AK	True North	AK	Carlotta	AZ	Basin Creek	MT	Safford (Dos Pobres)	AZ	Fort Knox	AK	Mineral Hill*	MT	Greens Creek*	AK
Red Dog	AK	Bagdad*	AZ	Imperial*	CA			Sanchez	AZ	Pogo Project	AK			Kensington Project	AK
Morenci	AZ	Cyprus Tohono	AZ	Jamestown*	CA			American Girl*	CA	Mesquite*	CA			Yarnell	AZ
Ray*	AZ	Royal Mountain King*	CA	Austin Gold Venture	NV			Castle Mountain*	CA	Stibnite	ID			Hayden Hill	CA
Black Pine	MT	Montana Tunnels	MT					McLaughlin*	CA	Stone Cabin	ID			Beartrack	ID
East Boulder	MT	Montanore	MT					Black Pine	ID	Diamond Hill	MT			Thompson Creek*	ID
Troy	MT	Tyrone Little Rock	NM					Grouse Creek*	ID	Rock Creek	MT			Beal Mountain*	MT
Rain	NV	Cortez	NV					Bald Mountain	NV	Copper Flat	NM			Golden Sunlight*	MT
		Mule Canyon	NV					Griffon	NV	Dash	NV			Stillwater*	MT
		Pete	NV					Leeville	NV	Gold Quarry	NV			Zortman Landusky*	MT
								Trenton Canyon	NV	Goldstrike	NV			Battle Mountain Phoenix	NV
								Lisbon Valley	UT					Cortez Pipeline	NV
														Florida Canyon*	NV
														Jerritt Canyon*	NV
														Lone Tree*	NV
														Marigold	NV
														Mule Canyon	NV
														Olinghouse	NV
														Robinson (Ruth)	NV
														Rochester*	NV
														Round Mountain*	NV
														Ruby Hill*	NV
														Twin Creeks*	NV
														Gilt Edge	SD
														Flambeau*	WI
	8		9		4		1		12		11		1		25

No Information Provided

Eleven percent of the mines (8) either did not perform geochemical characterization, did not mention that they performed testing, or did not mention the type of testing performed. Of these, two had land-exchange EISs (Morenci and Ray, AZ), and one had an EA (Rain, NV).

Static Acid-Base Accounting (ABA) Testing Only

Nine mines (13%) performed static testing only. Three of these mines (True North, AK; Royal Mountain King, CA; Pete, NV) had EAs. (The 1987 document for Royal Mountain King was an EIR/EA). The remaining six mines had EISs, and two of these were in Arizona, two in Montana, one in New Mexico, and one in Nevada. Eight of the mines mentioned acid-base accounting testing with no mention of the type of ABA testing performed, and one, (Pete, NV), owned by Newmont, used net carbonate value testing (NCV), a method developed by Newmont.

Short-term Leach Testing Only

Four mines (6%) conducted only short-term leach testing. One (Austin Gold Venture, NV), was permitted with a 1986 EA; no mention of the type of short-term leach testing was made for this mine. Of the other three mines, two were in California and one was in Arizona. The Carlotta Mine in Arizona used the meteoric water mobility procedure (MWMP) test devised by the State of Nevada; the Jamestown Mine in California used the California waste extraction test (WET); and the Imperial Mine in southern California used three EPA short-term leach methods, the Extraction Procedure (EP) Toxicity test (Method 1310), the Synthetic Precipitation Leaching Procedure (SPLP – Method 1312), and the Multiple Extraction Procedure (MEP – Method 1320). Information on the details of these methods is contained in Maest et al. (2005).

Kinetic Testing Only

One mine (1%)(Basin Creek Mine, MT) conducted only kinetic testing. The kinetic method used was column testing of the spent ore for heap cyanide detoxification (rinsing with the heap with hydrogen peroxide to break down cyanide). This method is not traditionally considered to be kinetic testing (as humidity cell testing is), but it does test behavior of mined material over a longer time period and is therefore categorized as kinetic testing for the purposes of this study.

Static and Short-term Leach Testing

Twelve mines (17%) performed both static testing and short-term leach testing. All of these mines had EISs rather than EAs. Ten of the mines identified the static testing only as acid-base accounting testing. The McLaughlin Mine in California employed a static acid-base accounting test that used hydrogen peroxide, similar to the net acid generating (NAG) test used more commonly in Australia and Southeast Asia. The Leeville Mine in Nevada, owned by Newmont, used the net carbonate value (NCV) acid-base accounting test.

Five of the mines that used both static and short-term leach testing used the synthetic precipitation leaching procedure (SPLP, EPA Method 1312), two of the mines (American Girl and McLaughlin) used the California waste extraction procedure (CA WET), four of the mines (all in Nevada) used the meteoric water mobility procedure (MWMP), one used the extraction procedure (EP) toxicity test, and one had no information on the type of short-term leach testing employed. See Maest et al. (2005) for a review of the testing procedures and their advantages and disadvantages. Two mines (American Girl and McLaughlin) performed two types of short-term leach testing, CA WET and SPLP and deionized water extraction and CA WET, respectively.

Static and Kinetic Testing

Eleven mines (16%) performed both static testing and kinetic testing. Only one of these mines, (Fort Knox, AK) had an EA; all others had EISs. For the static testing, nine of the mines mentioned only acid-base accounting testing, one did not mention the type of static testing used, and one (Gold Quarry/Maggie Creek, NV), owned by Newmont, used the NCV method.

For the kinetic testing, five mines used humidity cell tests (HCT), five used column tests, one used “weathering tests,” and three did not provide any information on the type of kinetic testing used (two mines used two types of kinetic testing).

Short-term Leach and Kinetic Testing

One mine (1%), (Mineral Hill Mine, MT) conducted both short-term leach and kinetic testing. Batch extraction and column tests were used at this mine.

Static, Short-term Leach, and Kinetic Testing

Twenty-five mines (35%) conducted static, short-term leach and kinetic testing. All these mines had EISs rather than EAs. Thirteen of the mines were in Nevada, four in Montana, two in Alaska, two in Idaho, and one each in California, South Dakota and Wisconsin. For static testing, the Greens Creek Mine in Alaska used the BC Research (modified) test; the Beal Mountain Mine in Montana mentioned using the modified Sobek method; and the Golden Sunlight Mine in Montana and the Marigold and Robinson (Ruth) mines in Nevada mentioned using the NAG test. None of the other mines specified which type of ABA testing was used.

For the short-term leach testing, ten of the mines (all in Nevada) used the MWMP test; seven of the mines used the SPLP test; two used the TCLP test; two used the EP Toxicity test, one used the soluble/total threshold limit test; one used the shake flask test; one used sequential saturated rolling extractions; and two had no information on the type of short-term leach test used. Some of the mines used multiple types of short-term leach methods.

For the kinetic testing, 18 mines used humidity cell tests, six used column tests, and four provided no information on the type of kinetic testing used. Some mines used multiple types of kinetic testing, all including HCT and “weathering,” field extractions or column tests.

Static Testing – Overall Summary

Eighty percent of the mines (56) reported conducting some kind of static testing. A wide variety of static test methods were identified. Forty-eight of the mines (69%) did not specify the type of static testing or listed acid-base accounting (ABA) without listing the type of ABA method used (e.g., Sobek, modified Sobek – see Maest, et al., 2005). One mine (Beal Mountain, MT) mentioned using the modified Sobek method, and one mine (Greens Creek, AK) mentioned using the modified BC Research technique. Four of the mines that conducted static testing mentioned using the net acid generating (NAG) technique or a technique similar to the NAG method. Three of the mines (Gold Quarry, Leeville, Pete, NV), all owned by Newmont, mentioned using the net carbonate value (NCV) approach.

Short-term Leach Tests – Overall Summary

Short-term leach test methods were identified at 41 (59%) of the 71 mines. Five of the mines (7%) did not specify which type of short-term leaching method they used. Two of the mines (Jamestown and McLaughlin, CA) used the California waste extraction test; four of the mines used the older EP Toxicity test (EPA Method 1310); two of the mines used the Toxicity Characteristic Leaching Procedure (TCLP, EPA Method 1311), and 12 of the mines (17%) used the Synthetic Precipitation Leaching Procedure (SPLP, EPA Method 1312). Fifteen of the mines (21%) (14 in Nevada; Carlotta, AZ) used the Nevada MWMP.

Kinetic Testing – Overall Summary

Kinetic testing was identified at 38 (54%) of the 71 NEPA mines. Of the mines that reported conducting kinetic testing, the most common method was humidity cell testing (23 or 33%). Eight of the mines (11%) did not specify the type of kinetic testing conducted, and thirteen (19%) of the mines reported conducting column tests. Descriptions of the kinetic tests varied and included 10- week, 15- week and 21- to -39- week humidity cell tests;, column leach tests;, laboratory weathering testes, and long-term field leaching extract tests.

Slightly fewer than half (31) of the mines (44%) therefore, did not conduct any long-term testing of mined materials, and 38 mines (54%) did conduct kinetic testing to estimate the long-term environmental behavior of mined materials. A number of the mines that conducted kinetic testing only reported pH and/or pH and sulfate measurements for their kinetic testing results. Therefore, very few mines reported on the long-term potential for contaminant leaching, other than for acidity and sulfate generation.

Other Types of Geochemical Characterization

Sulfur Analysis

Of the mines that did report conducting sulfur analyses (16 or 23%), two did not mention the type of sulfur analysis performed, five (31%) conducted only total sulfur analysis, six (38%) reported total and sulfide or pyritic sulfur analysis, and three (19%) conducted the most thorough possible analysis: total sulfur and sulfur fractions (potentially including total, sulfate, organic, pyritic and sulfide sulfur forms).

Additional Tests

Additional types of geochemical characterization tests that were identified in the EISs included barrel or other types of tests to simulate heap rinsing, trace element analysis, petrographic analysis, infiltration tests conducted on waste rock piles, and studies on mixing acid leachate with groundwater.

5.5.2. CONSTITUENTS OF CONCERN IDENTIFIED

Constituents of concern (COCs) were identified in the EISs directly (specifically called constituents of concern or contaminants of concern) or indirectly (e.g., as constituents that were present at elevated levels in leachate or as analytes in required monitoring programs). Table 5.8 lists the identified constituents of concern for the 71 mines. The general categories of constituents of concern and specific examples cited in the EISs were:

- metals (aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, silver, thallium, tin, zinc)
- radionuclides (radium, uranium)
- anions and nitrogen compounds (sulfate, nitrate/nitrite/ammonia (from blasting), fluoride)
- cyanide (cyanide and compounds)
- metalloids, oxyanions (antimony, arsenic, molybdenum, selenium, tungsten, vanadium)
- conventional pollutants (total dissolved solids, total suspended solids, pH, organics, nutrients (e.g., phosphate or nitrogen compounds not resulting from blasting), sediment, salts (e.g., chloride, sodium), turbidity, oil and grease)

Because a given mine often had more than one constituent of concern (e.g., metals and anions and cyanide), the percentage of mines with COCs in all the above categories sums to more than 100%. For mines with multiple EISs or EAs, if a COC was mentioned in any of the EISs, it was included as a COC for the mine as a whole.

Table 5.8 shows that 11 of the 71 mines (16%) had no information or insufficient information on constituents of concern. The largest number of mines, 51 (74%) identified metals as COCs, while nearly equal numbers of mines identified anions and nitrogen compounds, metalloids and oxyanions, and conventional pollutants as COCs (ranging from 49% to 58%). Only 16 of the mines (23%) identified cyanide as a constituent of concern; this number does not include all heap leach and vat leach precious metals operations – only the ones that specifically identified cyanide as a constituent of concern. Only one mine (Lisbon Valley Copper, UT) identified radionuclides (uranium and radium) as a constituent of concern.

Table 5.8. Identified Constituents of Concern

Score	Category	Number in category	Percent
0	None/insufficient information	11	15.9%
1	Metals	51	73.9%
2	Radionuclides	1	1.4%
3	Anions and nitrogen compounds	40	58.0%
4	Cyanide	16	23.2%
5	Metalloids, oxyanions	38	55.1%
6	Conventional pollutants	34	49.3%

The most commonly identified metals of concern were cadmium (24 mines), copper (29 mines), lead (20 mines), iron and manganese (22 mines each) and zinc (28 mines). Mercury was identified as a COC in sixteen mines. The most commonly identified metalloid of concern was arsenic (28 mines). Selenium (15 mines) and antimony (11 mines) were also mentioned as metalloid COCs at a number of mines. The most commonly identified anions of concern were sulfate (26 mines) and nitrate (16 mines). The most commonly mentioned conventional pollutants were total dissolved solids (19 mines) and pH (15 mines). Four mines mentioned elevated or high pH as a potential concern (Bear Track, ID; Copper Flat, NM; Marigold, NV; Lisbon Valley Copper, UT).

5.5.3. PREDICTIVE MODELS USED

The EISs and EAs from the 71 NEPA mines were reviewed to determine whether water quantity or water quality predictive models were used, and if so, what types of predictive model or models were used. The information on general types of predictive models used was classified and scored according to one of four categories:

- No predictive models used (0)
- Only water quantity predictive models used (1)
- Only water quality predictive models used (2)
- Both water quantity and water quality predictive models used (3).

For mines with multiple EISs, if a predictive model was used in any of the EISs, it was included for the mine as a whole. Table 5.9 lists the general types of predictive models used at the 71 NEPA mines.

No Predictive Models Used

No predictive models were used at 31 (44%) of the 71 NEPA mines. Eight of these mines were in Montana, seven in Nevada, five in Arizona, four in California, four in Alaska, one in Idaho, and one in New Mexico. Of these, seven had EAs, and the remainder had EISs.

Only Water Quantity Predictive Models Used

Of the mines that did report using predictive models, water quantity only (not combined with water quality models) predictive models were identified as being used at 18 (25%) of the mines. The water quantity models included surface transport models (SEDCAD), groundwater modeling (FLOWPATH) and infiltration modeling (HELP). The

Table 5.9. Predictive Models Used

0		1		2		3	
No predictive models used		Water quantity predictive model only		Water quality predictive model only		Water quality and quantity predictive models used	
AJ Project	AK	Sanchez	AZ	Flambeau*	WI	Greens Creek *	AK
Fort Knox	AK	Yarnell	AZ			Pogo Project	AK
Kensington Project	AK	American Girl*	CA			Safford (Dos Pobres)	AZ
Red Dog	AK	Hayden Hill	CA			Mesquite*	CA
True North	AK	Imperial	CA			Thompson Creek*	ID
Bagdad*	AZ	Beartrack	ID			Golden Sunlight*	MT
Carlotta	AZ	Grouse Creek*	ID			Montanore	MT
Cyprus Tohono	AZ	Stibnite	ID			Tyrone Little Rock	NM
Morenci	AZ	Stone Cabin	ID			Battle Mountain Phoenix	NV
Ray*	AZ	Mineral Hill*	MT			Cortez Pipeline	NV
Castle Mountain*	CA	Stillwater*	MT			Gold Quarry	NV
Jamestown*	CA	Zortman and Landusky*	MT			Goldstrike	NV
McLaughlin*	CA	Bald Mountain	NV			Lone Tree*	NV
Royal Mountain King*	CA	Dash	NV			Marigold	NV
Black Pine	ID	Florida Canyon*	NV			Mule Canyon	NV
Basin Creek	MT	Griffon	NV			Olinghouse	NV
Beal Mountain*	MT	Leeville	NV			Robinson (Ruth)	NV
Black Pine*	MT	Lisbon Valley	UT			Round Mountain*	NV
Diamond Hill	MT					Ruby Hill*	NV
East Boulder	MT					Twin Creeks*	NV
Montana Tunnels	MT					Gilt Edge	SD
Rock Creek	MT						
Troy	MT						
Copper Flat	NM						
Austin Gold Venture	NV						
Cortez	NV						
Jerritt Canyon*	NV						
Pete	NV						
Rain	NV						
Rochester*	NV						
Trenton Canyon	NV						
	31		18		1		21

types of water quantity codes used included: the near-surface-process hydrologic process codes HEC-1 and HELP (used at four of the mines) for infiltration, evaporation, and runoff; the codes SEDCAD (used at three of the mines), MUSLE, RUSTLE, and R1/R4SED for predicting sediment movement or effects of sedimentation on streams; a code for developing storm hydrographs (WASHMO); groundwater flow models (MODFLOW - reported being used at two of the sites); vadose zone models (HYDRUS) and drawdown models (at two mines). One mine, (Lone Tree, NV) used the propriety code MINEDW to predict 3-dimensional groundwater flow. See Maest et al. (2005) for a review of these models.

Only Water Quality Predictive Models Used

One mine (Flambeau Mine, WI) used a geochemical model only (not in combination with a water quantity model) to predict the concentration of contaminants in leachate in the backfilled pit.

Both Water Quantity and Water Quality Predictive Models Used

Twenty-one (30%) of the mines used a combination of water quantity and water quality models to predict water quality impacts after mining began. Of these, some mines used a water quantity code in combination with the geochemical codes PHREEQE (3 mines), WATEQ (1 mine), or MINTEQ (five mines), or PYROX or other type of pyrite oxidation code (3 mines). One mine used the code LEACHM to simulate water balance and contaminant transport. Three mines in Nevada used the CE-QUAL-W2 to simulate pit water flow and limited water quality characteristics and one mine used CE-Qual-R1. Four mines used unspecified mass balance or mass loading modeling (and the Tyrone/Little Rock Mine in New Mexico specifically mentioned using FLOWPATH), and five mines used proprietary models to predict pit water concentrations or groundwater concentrations downgradient of a waste rock facility.

5.6. WATER QUALITY IMPACT POTENTIAL

In this report we distinguish between potential and predicted water quality impacts. A potential water quality impact is one that could occur if mitigation are not in place, and predicted water quality impacts are those that threaten water quality even after mitigation are in place. Potential water quality impacts are related to the inherent characteristics of the mined materials. For example, tailings could have a potential to impact downgradient water quality if they have elevated acid drainage potential or contaminant leaching potential. However, if the tailings are in a properly lined facility with a backup capture system or are backfilled as a paste in underground workings or a tailings impoundment, their predicted water quality impacts could be low.

The elements of water quality impact potential include acid drainage potential, contaminant leaching potential, and potential groundwater, surface water and pit water impacts.

5.6.1. ACID DRAINAGE POTENTIAL

Information on acid drainage potential was based on static testing results, sulfur or pyrite contents or simply on statements in the EIS or EA that described the acid drainage potential as “low,” “moderate,” or “high” or that the material does or does not have the potential to produce acid. Identification of existing acid drainage was reported in some cases, but more importance was placed on the potential for acid drainage for the proposed project that was the subject of the EIS or EA.

The information on acid drainage potential contained in the EISs was summarized and scored as follows:

- No information available (0)
- Low acid drainage potential (1)
- Moderate acid drainage potential (2)
- High acid drainage potential (3)

Table 5.10 contains the names of the mines in the four categories for acid drainage potential. The recorded potential for acid drainage is for unit/material with the greatest potential to produce acid. If the EIS statement was somewhat negative (e.g., the potential for acid drainage exists), the entry was scored as a 2 (moderate potential to generate acid).

For mines with multiple EISs, the EIS with the highest potential to generate acid was used as the score for the mine. Mines with low acid drainage potential also include mines with material that has the potential to generate high-pH waters.

Table 5.10. Acid Drainage Potential

0		1		2		3	
No information available		Low		Moderate		High	
AJ Project	AK	Fort Knox	AK	Greens Creek*	AK	Red Dog	AK
Morenci	AZ	Kensington Project	AK	Carlotta	AZ	Black Pine*	MT
Ray*	AZ	Pogo Project	AK	Hayden Hill	CA	Golden Sunlight*	MT
Austin Gold Venture	NV	True North	AK	Grouse Creek*	ID	Zortman and Landusky*	MT
Rain	NV	Bagdad*	AZ	Stone Cabin	ID	Battle Mountain Phoenix	NV
Flambeau*	WI	Cyprus Tohono	AZ	Thompson Creek*	ID		
		Safford (Dos Pobres)	AZ	Beal Mountain*	MT		
		Sanchez	AZ	Diamond Hill	MT		
		Yarnell	AZ	Montana Tunnels	MT		
		American Girl*	CA	Montanore	MT		
		Castle Mountain*	CA	Gold Quarry	NV		
		Imperial	CA	Goldstrike	NV		
		Jamestown*	CA	Jerritt Canyon*	NV		
		McLaughlin*	CA	Leeville	NV		
		Mesquite*	CA	Lone Tree*	NV		
		Royal Mountain King*	CA	Mule Canyon	NV		
		Beartrack	ID	Pete	NV		
		Black Pine	ID	Robinson (Ruth)	NV		
		Stibnite	ID	Rochester*	NV		
		Basin Creek	MT	Twin Creeks*	NV		
		East Boulder	MT				
		Mineral Hill*	MT				
		Rock Creek	MT				
		Stillwater*	MT				
		Troy	MT				
		Copper Flat	NM				
		Tyrone Little Rock	NM				
		Bald Mountain	NV				
		Cortez	NV				
		Cortez Pipeline	NV				
		Dash	NV				
		Florida Canyon*	NV				
		Griffon	NV				
		Marigold	NV				
		Olinghouse	NV				
		Round Mountain*	NV				
		Ruby Hill*	NV				
		Trenton Canyon	NV				
		Gilt Edge	SD				
		Lisbon Valley	UT				
	6		40		20		5

Some of the conditions thought to limit the potential for acid drainage (as stated in the EISs) were: a limited amount of water or oxygen; removal of sulfide ore from the open pit; silica buffering, encapsulating of sulfides in silica; and lack of acid drainage from past mining activity at the same site. Some EISs predicted low to moderate acid drainage potential based on the results of kinetic testing even though static testing results suggested that acid drainage could form. Finally, several mines acknowledged that acid drainage could not be accurately predicted.

No Information Available

Six mines (8%) had EISs or EAs that made no mention of acid drainage potential. Of these, two were land-exchange EISs (Morenci, Ray, AZ), and two were evaluated with EAs rather than EISs (Austin Gold Venture, Rain, NV). The EIS for the AJ Project in Alaska had no direct mention of acid drainage potential. The EIS for the Flambeau Mine in Wisconsin mentioned that tests indicated that waste rock with sulfur content of 2% or less would not be expected to produce acid, but there was no indication of the amount of high (or low) sulfur material present.

Low Acid Drainage Potential

The acid drainage potential for the majority of mines (40 or 56%) was described as being low or nonexistent. Eleven of these mines were in Nevada; seven were in California; six were in Montana; five were in Arizona; four were in Alaska; three were in Idaho; two were in New Mexico; one was in South Dakota (Gilt Edge); and one was in Utah (Lisbon Valley Copper).

EISs for four of these mines provided no information on or did not perform static or kinetic testing of mined materials. The Imperial Mine, California, EIR stated that the waste rock and leached ore had high acid neutralization potential, but no information was provided in the EIR on static or kinetic test methods or results. Similarly, the Jamestown Mine, California, EIR stated that chemical analysis of the overburden material indicated that it is non-hazardous, non-toxic, and non-acid generating, but no information was provided in the EIR on the type or results of the chemical tests. The East Boulder Mine in Montana performed no static or kinetic testing, but appears to base the low acid drainage potential on the low sulfur content. The EIS for the Troy Mine in Montana also had no information on static or kinetic tests in the EIS. This EIS is over 20 years old, and it stated that the mineralogy of the host rocks and the type of minerals being mined apparently do not produce acid mine water.

The remainder of the mines did perform some kind of static or kinetic testing, but in a number of cases, the statements about low acid drainage potential did not appear to be based on test results. For example, unsupported statements such as "not expected to generate acid" were found in EISs for True North in Alaska, Stillwater Mine in Montana (1992 EIS), and Basin Creek in Montana, and the low acid generation potential was based on the low sulfur content in the East Boulder, Montana and Fort Knox, Alaska EISs. Some mines appeared to base the prediction of low acid drainage potential at least in part on existing conditions (i.e. no observed acid drainage related to past mining activities) at the mine (e.g., Bagdad, AZ; Troy, MT; Copper Flat, NM; Kensington, AK (1992 EIS); Rock Creek, MT (1998 EIS)).

Some mines predicted that there would be moderate or high acid drainage potential based on static tests but downgraded the potential to low based on kinetic tests. For example, at the Florida Canyon Mine in Nevada, unoxidized sulfide rock was considered to have the potential to generate acid based on static testing. However, results from "reanalyzed" samples and kinetic testing indicted that the rock was not acid generating because no samples with ANP:AGP <1 had kinetic test pH values <5.75 (note that pH standards for natural waters are always >6).

The Copper Flat, New Mexico, EIS stated that ABA tests indicated that the waste rock may have the potential to generate acid, but column kinetic tests of the unoxidized rock showed little oxidation after 20 weeks. Similarly, the 2001 Marigold, Nevada, EIS stated that not all waste rock was non-acid-generating, but column kinetic testing did not generate acid in 20 weeks. In the 1997 EIS for the Kensington, Alaska, mine, static testing results on ore were in an area of uncertainty for acid generation potential (NP:AP = 1-3), but results from kinetic testing produced no acid within 20 weeks of testing. As noted in Maest et al. (2005), a number of workers consider that 20 weeks is too short of a time period for kinetic testing.

EISs for two mines in this category stated that low amounts of water would limit acid drainage (Mineral Hill, Montana (1986 EIS) and Cortez Pipeline, Nevada (2000 EIS). The 2001 Rock Creek EIS also noted that the lack of exposure of sulfides to oxygen in the underground mine would limit acid drainage.

Three mines in this category acknowledged that acid drainage could not be accurately predicted. The 1978 EIS for the Troy Mine in Montana stated that no predictive tests were available to determine whether or not the mined material would generate acid. The Lisbon Valley, Utah, Mine EIS stated that impacts to groundwater or the pit could not be predicted based on the level of testing to date. The 1995 EIS for the Rock Creek Mine in Montana EIS stated that the long-term potential for acid drainage was unknown, as static tests would not predict this with certainty, and that kinetic tests would be useful. Kinetic tests were performed on material from the nearby Troy Mine, and based on these results, subsequent EISs also predicted that acid generation potential would be low. Although uncertainty about acid generation potential is acknowledged in the 1998 Rock Creek EIS, the potential for acid drainage from the tailings was predicted to be low.

Moderate Acid Drainage Potential

The EISs for 20 mines (28%) indicated moderate acid drainage potential. The mines in this category included two in Alaska (Greens Creek and Red Dog), one in Arizona (Carlotta), one in California (Hayden Hill), three in Idaho, four in Montana, and 10 in Nevada. The Lone Tree, Nevada mine EIS identified the moderate acid drainage potential based on to static testing results but also noted that kinetic tests did not produce acid, that the sulfides are encapsulated in silica and that silica buffering is important. The Mule Canyon, NV mine EIS acknowledged the potential generation of acid if the excavated mine materials were to come in contact with water.

Two of the mines in this category (Carlotta, AZ and Thompson Creek, ID) acknowledged some potential to generate acid but also noted that removal of sulfide ore from the open pit would leave little source of acid generation in the open pits. The 1984 EIS for the Grouse Creek, Idaho, Mine stated that even though an historic mine on the property had acid drainage from a portal, conditions would be different for the proposed mine. The EIS for the Montanore Mine in Montana stated that post-mining water quality could be acidic, but that acid drainage could not be accurately predicted. The EIS for the Diamond Hill Mine in Montana stated, as did some of those mines in the low acid drainage potential category, that the dry climate, low permeability transmissivity of the country rock, the total lack of discharge from an existing adit, and the lack of seeps or springs in the area, would limit the amount of acid drainage forming at the site. Some samples from the Robinson (Ruth) Mine in Nevada had large negative net carbonate values (NCV – indicative of acid drainage potential), but the EIS stated that 20-week kinetic results had near-neutral pH values (6-7), and that the high percentage of carbonate rocks in the pit area after mining would result in neutral drainage.

High Acid Drainage Potential

Only five mines were identified as having high acid drainage potential. It is notable that none of the original EISs (Golden Sunlight and Zortman and Landusky, MT) or EAs (Black Pine, MT; Battle Mountain Phoenix, NV) for these mines indicated high acid drainage potential, and it was only recognized in all cases by EISs or EAs that were written following actual evidence of acid drainage occurring.

5.6.2. CONTAMINANT LEACHING POTENTIAL

Information on contaminant leaching potential was typically based on constituents identified in short-term leach test results, although some limited information was also available from longer-term kinetics testing results. If quantitative information on contaminant leaching potential was available (i.e., concentrations in short-term or kinetic test leachate), these results were compared to water quality standards (drinking water or other standards or criteria, as identified in the EISs). In other cases, the contaminant leaching potential was identified qualitatively. The contaminants identified were most often metals/metalloids, although other contaminants such as cyanide, sulfate, and/or nitrates were also listed.

The information on contaminant leaching potential was summarized and scored according to the following four categories:

- No information available (0)
- Low contaminant leaching potential (leachate does not exceed water quality standards) (1)
- Moderate potential for elevated contaminant concentrations (leachate exceeds water quality standards by 1-10 times) (2)
- High potential for elevated contaminant concentrations (leachate exceeds water quality standards by over 10 times) (3)

The categories and factors chosen to score and describe contaminant leaching potential are not absolute in terms of potential environmental impact because different mines used different types of leaching procedures with different solid:liquid ratios (see Maest, et al., 2005) and different approaches to qualitatively describing the contaminant leaching potential. In addition, the potential for contaminant leaching is predicted without considering mitigation measures. The Environmental Protection Agency Potential uses TCLP leachate standards for hazardous waste that are based on 100 times the drinking water standards. However, we are using the four categories listed above as a conservative approach (environmentally protective) to gain a rough understanding of the potential for contaminant leaching from mining waste.

In the scoring, contaminant leaching potential was categorized according to the unit or material with the greatest potential to produce contaminants. For the entries with qualitative descriptions of the potential for contaminant leaching, if the EIS statement was somewhat negative (e.g., the potential for contaminant leaching exists), the entry was scored as a 2. If metals concentrations expected from mining operations were described as “low” or as not having significant increases over background/baseline concentrations, the entry was scored as a 1. For mines with multiple EISs, the EIS with the highest potential to generate contaminants was used as the score for the mine.

Table 5.11 shows the distribution and identity of mines in the four categories.

No Information Available

The EISs for 15 mines (21%) contained no information on contaminant leaching potential. These mines included two in Alaska, five (of eight) in Arizona, two fin California, one each in Idaho, Montana and New Mexico, and three in Nevada. Three of these mines (True North, AK; Royal Mountain King, CA (EIR-EA); Rain, NV) had EAs rather than EISs.

Low Contaminant Leaching Potential

An approximately equal number of mines had low (22 or 31%) and moderate (21 or 30%) contaminant leaching potential. Two of the mines in the low contaminant leaching potential category (East Boulder, Montana and Tyrone, New Mexico) did not perform short-term leach or kinetic tests (the East Boulder Mine also performed no static testing). In both cases, the low contaminant leaching potential was based on the low sulfur/sulfide content.

In fact, many of the mines in this category based the low contaminant leaching potential on predicted low acid generation potential. For those mines that did conduct contaminant leaching tests (e.g., short-term leach tests), results were variably compared to drinking water standards and standards for leach tests (e.g., soluble threshold levels for California; TCLP levels). In addition to the East Boulder, Montana, and Tyrone, New Mexico mines, five other mines in this category did not perform short-term leach tests (Fort Knox, AK : Mesquite, CA; Stibnite, ID; Basin Creek and Diamond Hill, MT). These five mines did perform kinetic tests, but metals were not always determined to have been analyzed in the leachate.

Table 5.11. Contaminant Leaching Potential

0		1		2		3	
No information available		Low		Moderate		High	
AJ Project	AK	Fort Knox	AK	Pogo Project	AK	Kensington Project	AK
True North	AK	Greens Creek*	AK	Carlotta	AZ	Red Dog	AK
Bagdad*	AZ	Safford (Dos Pobres)	AZ	McLaughlin*	CA	Beartrack	ID
Cyprus Tohono	AZ	Sanchez	AZ	Black Pine*	MT	Golden Sunlight*	MT
Morenci	AZ	American Girl*	CA	Mineral Hill*	MT	Rock Creek	MT
Ray*	AZ	Castle Mountain*	CA	Montanore	MT	Bald Mountain	NV
Yarnell	AZ	Hayden Hill	CA	Stillwater*	MT	Battle Mountain Phoenix	NV
Imperial	CA	Jamestown*	CA	Troy	MT	Cortez Pipeline	NV
Royal Mountain King*	CA	Mesquite*	CA	Zortman and Landusky*	MT	Gold Quarry	NV
Stone Cabin	ID	Black Pine	ID	Florida Canyon*	NV	Leeville	NV
Montana Tunnels	MT	Grouse Creek*	ID	Goldstrike	NV	Lone Tree*	NV
Copper Flat	NM	Stibnite	ID	Griffon	NV	Round Mountain*	NV
Cortez	NV	Thompson Creek*	ID	Jerritt Canyon*	NV	Twin Creeks*	NV
Dash	NV	Basin Creek	MT	Marigold	NV		
Rain	NV	Beal Mountain*	MT	Mule Canyon	NV		
		Diamond Hill	MT	Olinghouse	NV		
		East Boulder	MT	Pete	NV		
		Tyrone Little Rock	NM	Rochester*	NV		
		Austin Gold Venture	NV	Ruby Hill*	NV		
		Robinson (Ruth)	NV	Gilt Edge	SD		
		Trenton Canyon	NV	Flambeau*	WI		
		Lisbon Valley	UT				
	15		22		21		13

Low = leachate concentrations < water quality standards; Moderate = leachate exceeds water quality standards by 1 - 10 times; High = leachate exceeds water quality standards by > 10 times.

Moderate Contaminant Leaching Potential

Twenty-one mines (30%) identified had moderate contaminant leaching potential. Four of the mines in this category did not perform short-term leach or kinetic testing (Black Pine, Montanore, Troy, MT; Pete, NV). Two of the Montana mines based the moderate contaminant leaching potential on tailings water quality. The Goldstrike Mine in Nevada also did not perform short-term leach tests but did conduct kinetic testing.

High Contaminant Leaching Potential

Thirteen (18%) of the mines identified had high contaminant leaching potential (Kensington Project, AK; Beartrack, ID; Golden Sunlight and Rock Creek mines, MT; Bald Mountain, Battle Mountain Complex, Cortez Pipeline, Gold Quarry/Maggie Creek, Leeville, Lone Tree, Round Mountain and Twin Creeks, NV). Two of the mines in this category conducted no short-term leach tests (Rock Creek, MT; Gold Quarry/Maggie Creek, NV), but they did conduct kinetic testing.

Nevada had the highest percentage (75%) of mines with either moderate or high contaminant leaching potential (18/24 mines), followed by Montana with 62% (8/13 mines). Nevada also had a high percentage (75%) of mines conducting short-term leach tests (18/24 mines). California had the highest percentage (63%) of mines with low contaminant leaching potential (5/8 mines) and only one (McLaughlin) with moderate contaminant leaching potential. California also had a high percentage (75%) of mines conducting short-term leach tests (6/8 mines). Both states have short-term leach tests that were developed specifically for use in those states – the meteoric water mobility procedure (MWMP) for Nevada and the waste extraction test (CAL WET) test for California.

Of the 12 mines with high contaminant leaching potential, only three (Red Dog, AK; Golden Sunlight, MT; Battle Mountain Complex, NV) also identified high acid generation potential. Five mines (Kensington Project, AK; Beartrack, ID; Rock Creek, MT; Bald Mountain and Cortez Pipeline, NV) identified high contaminant leaching potential and low acid drainage potential.

5.6.3. POTENTIAL GROUNDWATER QUALITY IMPACTS

Groundwater impact potential refers to the proposed project's potential to adversely affect groundwater quality in the absence of mitigation measures. Section 5.7.1 describes the projects' predicted impact on groundwater after proposed mitigation measures were put in place. The information on groundwater quality impact potential was summarized and scored according to the following four categories:

- No information available (0)
- Low groundwater quality impacts (< relevant standards) (1)
- Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) (2)
- High groundwater quality impacts (>10 times relevant standards) (3)

For mines with multiple EISs, the EIS with the highest individual score for potential groundwater impacts was used as the score for the mine. Scores for potential groundwater impacts were often based on qualitative information or descriptions (e.g., "moderate" effects expected on groundwater quality). If an EIS entry noted anything regarding potential groundwater quality that was negative, it was scored as a 2 (moderate impacts). The EISs were also reviewed for any information on the potential for long-term groundwater quality impacts.

Table 5.12 lists the mines in the four categories for groundwater impact potential.

No Information Available

Fourteen (20%) of the 71 reviewed mines with EISs did not provide any information on groundwater quality impact potential. Four of these mines had EAs rather than EISs (Fort Knox and True North, AK; Basin Creek, MT; Pete, NV). Of the remaining 10 mines in this category, four were in Arizona, two in New Mexico, and one each was in Alaska, Idaho, Montana, and Nevada.

Low Groundwater Quality Impact Potential

At 19 mines (27%), the EISs identified low groundwater impact potential. Of these mines, one had high acid drainage potential, and four had high contaminant leaching potential. Nine of these 19 mines had shallow depths to groundwater or springs on site.

Moderate Groundwater Quality Impact Potential

The majority of the mines (33 or 47%) had moderate groundwater impact potential. Two of these mines had high acid drainage potential (Zortman and Landusky, MT; Battle Mountain Complex, NV), and five had high contaminant leaching potential (Rock Creek, MT; Battle Mountain Complex, Cortez Pipeline, Leeville, Twin Creeks, NV). Twenty-one of these 33 mines had close proximity to groundwater or springs on site.

Table 5.12. Groundwater Quality Impact Potential

0		1		2		3	
No information available		Low		Moderate		High	
AJ Project	AK	Kensington Project	AK	Greens Creek*	AK	Pogo Project	AK
Fort Knox	AK	Red Dog	AK	Carlotta	AZ	McLaughlin*	CA
True North	AK	Bagdad*	AZ	American Girl*	CA	Golden Sunlight*	MT
Morenci	AZ	Cyprus Tohono	AZ	Hayden Hill	CA	Florida Canyon*	NV
Ray*	AZ	Sanchez	AZ	Jamestown*	CA	Round Mountain*	NV
Safford (Dos Pobres)	AZ	Castle Mountain*	CA	Mesquite*	CA		
Yarnell	AZ	Imperial	CA	Royal Mountain King*	CA		
Beartrack	ID	Black Pine	ID	Grouse Creek*	ID		
Basin Creek	MT	Stone Cabin	ID	Stibnite	ID		
Black Pine*	MT	Diamond Hill	MT	Thompson Creek*	ID		
Copper Flat	NM	Stillwater*	MT	Beal Mountain*	MT		
Tyrone Little Rock	NM	Bald Mountain	NV	East Boulder	MT		
Griffon	NV	Cortez	NV	Mineral Hill*	MT		
Pete	NV	Gold Quarry	NV	Montana Tunnels	MT		
		Lone Tree*	NV	Montanore	MT		
		Mule Canyon	NV	Rock Creek	MT		
		Rain	NV	Troy	MT		
		Ruby Hill*	NV	Zortman and Landusky*	MT		
		Lisbon Valley	UT	Austin Gold Venture	NV		
				Battle Mountain Phoenix	NV		
				Cortez Pipeline	NV		
				Dash	NV		
				Goldstrike	NV		
				Jerritt Canyon*	NV		
				Leeville	NV		
				Marigold	NV		
				Olinghouse	NV		
				Robinson (Ruth)	NV		
				Rochester*	NV		
				Trenton Canyon	NV		
				Twin Creeks*	NV		
				Gilt Edge	SD		
				Flambeau*	WI		
	14		19		33		5

For potential impacts (without considering effect of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

High Groundwater Quality Impact Potential

Only five of the reviewed mines (7%) were identified as having a high potential for groundwater impact (Pogo Project, AK; McLaughlin, CA; Golden Sunlight, MT; Florida Canyon and Round Mountain, NV). Of these, only the Golden Sunlight Mine had high acid drainage and contaminant leaching potential. The Round Mountain Mine had high contaminant leaching potential but low acid drainage potential. The other mines in this category had low to moderate acid drainage and contaminant leaching potential.

Long-term Groundwater Quality Impacts

A number of mines mentioned that groundwater quality impacts would not occur until years in the future or that groundwater impacts would worsen with time. These delayed impacts often result from rising water levels in underground mines, cessation of groundwater pumping in open pit mines or movement of the wetting front through waste rock dumps or other unsaturated mine materials over time. At the Montana Tunnels mine, poor water quality was not expected to seep out of the pit and affect downgradient groundwater and surface water resources until 480 years after mining.

A number of other mine EISs mention long-term groundwater quality impacts. The 2003 EIS for the Pogo Project in Alaska stated that there is some potential for increased concentrations of contaminants downgradient of the mine over the long term (thousands of years) in excess of 10 times water quality standards.

The 2004 Draft EIS for the Golden Sunlight Mine in Montana noted that after mining, if the groundwater table rebounds to a static condition, fracture-controlled flow to surface seeps could increase and acid springs could develop again. They suggest that maintaining the pit as a hydrologic sink could minimize the risk of seep development. At the Montana Tunnels mine, poor water quality is not expected to seep out of the pit and affect downgradient groundwater and surface water resources until 480 years after mining. The EIS for the Montanore Mine in Montana noted that after water levels rise in the mine, discharge could occur from the adits or “along natural pathways.”

Although the water is expected to be of relatively good quality, the EIS stated that the potential for acid drainage exists. The new project EIS for the Rock Creek Project in Montana noted that seepage from the proposed tailings impoundment to groundwater could approach several hundred gallons per minute by the end of the 30-year mine life, and that the long-term potential for acid drainage was unknown at this point. The EIS proposed a tailings seepage pumpback system to prevent changes in groundwater quality.

Modeling performed for the Battle Mountain Phoenix project in Nevada predicted that waste rock infiltration could degrade downgradient groundwater, and the potential for long-term impacts to groundwater quality existed during the post-closure period. They proposed a contingent long-term groundwater management plan to address these potential impacts. The 1991 EIS for the Goldstrike Project in Nevada stated that groundwater could be impacted by outflow from the pit once the pit reaches steady state conditions. The subsequent 2003 EIS stated that a pit lake was not expected to discharge to groundwater, but that water quality impacts were possible in areas affected by mine water management activities, including reinfiltration of dewatering water. Groundwater at the Rochester Mine in Nevada, which had two EAs, was predicted to be of good quality. The 2003 expansion EA for the Rochester Mine in Nevada stated that the Coeur operations or Relief Canyon operations near the Rochester Mine could generate long-term impacts to groundwater.

5.6.4. POTENTIAL SURFACE WATER QUALITY IMPACTS

Surface water impact potential refers to the proposed project’s potential to adversely affect surface water quality in the absence of mitigation measures. Section 5.7.2 describes the project’s predicted impact on surface water resources after proposed mitigation measures were put in place. The information on surface water quality impact potential was summarized and scored according to the following four categories:

- No information available (0)
- Low surface water quality impacts (< relevant standards) (1)
- Moderate surface water quality impacts (≥ and up to 10 times relevant standards) (2)
- High surface water quality impacts (>10 times relevant standards) (3)

For mines with multiple EISs, the EIS with the highest individual score for potential surface water impacts was used as the score for the mine. Scores for potential surface water impacts were often based on qualitative information or descriptions (e.g., no impacts expected on surface water quality). If an EIS entry noted anything regarding potential surface water quality that was negative, including a potential for sedimentation or erosion effects to surface water, it was scored as a 2 (moderate impacts). The EISs were also reviewed for any information on the potential for long-term surface water quality impacts and the effect of water quantity (e.g., groundwater pumping) on surface water resources.

Table 5.13 lists the mines that fall into the four categories for surface water impact potential.

Table 5.13. Surface Water Quality Impact Potential

0		1		2		3	
No information available		Low		Moderate		High	
AJ Project	AK	Kensington Project	AK	Greens Creek*	AK	Zortman and Landusky*	MT
Fort Knox	AK	Pogo Project	AK	Carlotta	AZ	Twin Creeks*	NV
Red Dog	AK	Bagdad*	AZ	Hayden Hill	CA		
True North	AK	Cyprus Tohono	AZ	Jamestown*	CA		
Morenci	AZ	Sanchez	AZ	McLaughlin*	CA		
Ray*	AZ	American Girl*	CA	Mesquite*	CA		
Safford (Dos Pobres)	AZ	Castle Mountain*	CA	Grouse Creek*	ID		
Yarnell	AZ	Imperial	CA	Stibnite	ID		
Royal Mountain King*	CA	Black Pine	ID	Thompson Creek*	ID		
Beartrack	ID	Stone Cabin	ID	Beal Mountain*	MT		
Basin Creek	MT	Diamond Hill	MT	Montana Tunnels	MT		
Black Pine*	MT	East Boulder	MT	Rock Creek	MT		
Montanore	MT	Golden Sunlight*	MT	Battle Mountain Phoenix	NV		
Copper Flat	NM	Mineral Hill*	MT	Dash	NV		
Tyrone Little Rock	NM	Stillwater*	MT	Goldstrike	NV		
Florida Canyon*	NV	Troy	MT	Griffon	NV		
Rain	NV	Austin Gold Venture	NV	Jerritt Canyon*	NV		
		Bald Mountain	NV	Leeville	NV		
		Cortez	NV	Lone Tree*	NV		
		Cortez Pipeline	NV	Marigold	NV		
		Gold Quarry	NV	Olinghouse	NV		
		Mule Canyon	NV	Pete	NV		
		Ruby Hill*	NV	Robinson (Ruth)	NV		
		Lisbon Valley	UT	Rochester*	NV		
				Round Mountain*	NV		
				Trenton Canyon	NV		
				Gilt Edge	SD		
				Flambeau*	WI		
	17		24		28		2

For potential impacts (without considering effect of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

No Information Available

Approximately one-quarter (17 or 24%) of the mines did not provide any information on the potential for surface water quality impacts. Mines in this category included two in Alaska, four in Arizona, one each in California and Idaho, three in Montana, two in New Mexico, and two in Nevada. Of these 18 mines, five had EAs rather than EISs (Fort Knox and True North, AK; Royal Mountain King, CA (EIR-EA); Basin Creek, MT; Rain, NV).

Low Surface Water Quality Impact Potential

Nearly equal numbers of mines were identified as having low (24 or 34%) and moderate (28 or 40%) potential for surface water quality impacts. Of the 24 mines with low potential for surface water quality impacts, one had high acid drainage and contaminant leaching potential (Golden Sunlight, Montana), and four others had high contaminant leaching potential (Kensington, AK; Bald Mountain, Cortez Pipeline, Gold Quarry/Maggie Creek, NV). For the two Golden Sunlight EISs with information on surface water quality impact potential, the low potential was attributed to: the lack of any perennial surface waters in close proximity of the proposed facilities (if clean-up efforts are prompt); the slow movement of the wetting front through the waste rock dumps; and run-on controls.

Six of the 24 mines with low surface water quality impact potential had perennial streams on site (Kensington and Pogo, AK; Stone Cabin, ID; East Boulder, Mineral Hill, and Troy, MT), and 11 were far from surface water resources (> one mile). Those mines with close proximity to surface water but low potential for impacts generally ascribed the low potential to dilution. In most cases, surface water quality was expected to have some impact from mining operations but was not predicted or expected to exceed relevant water quality standards in surface water. The Kensington Project in Alaska was expected to have low surface water quality impacts, even though it is close to surface water and has high contaminant leaching potential. The low potential at the Kensington Project was attributed to the low acid drainage potential and the observation that waste rock and tailings infiltration water quality is expected to be similar to background groundwater quality.

Moderate Surface Water Quality Impact Potential

Twenty-eight mines (40%) were identified as having moderate potential for surface water quality impacts. Of these 28 mines, one mine (Battle Mountain Phoenix, NV) had high potential for acid drainage and contaminant leaching. However, the closest perennial surface water is one mile from the facilities, and no offsite impacts to surface water were expected. Four other mines in this category had high contaminant leaching potential (Rock Creek, MT; Leeville, Lone Tree, Round Mountain, NV). The Rock Creek Project is also located close to surface water resources. The Rock Creek Project EIS acknowledged the potential impact to surface water quality of the mine facilities, but noted that water treatment, dilution, and groundwater pumping would help mitigate these impacts. The Lone Tree Mine is located two miles from the Humboldt River but discharges dewatering water to the Humboldt River. Water pumped from the ground and discharged into the Humboldt River was considered to generally be of good quality; however, the 1996 EIS did note recent increased concentrations of arsenic, iron, and sulfate in mine discharge water and aquatic life exceedences of iron, copper and lead in the discharge water. The Leeville Mine proposed to discharge dewatering water to reinfiltration basins and also to the Humboldt River if that does not provide sufficient volume, and discharge water did not meet the arsenic drinking water standard. Round Mountain has no perennial streams on site.

High Surface Water Quality Impact Potential

Only two of the reviewed mines were identified as having a high potential for surface water impacts (Zortman and Landusky, MT; Twin Creeks, NV). The 1993 Supplemental EA for the Zortman and Landusky Mine noted that existing water quality in Mill Gulch and upper Sullivan Creek has already become acidic as a result of waste rock and leach pad leachate. Similarly, surface water at the Twin Creeks Mine had already shown occasional exceedences of total dissolved solids and arsenic (arsenic by over 10 times the 10-µg/l drinking water standard) as a result of discharge of dewatering water in Rabbit Creek.

Long-term Surface Water Quality Impact Potential

A number of EIS mentioned the effect of time on potential impacts to surface water resources as a result of mining operations. The 1997 EIS for the Golden Sunlight Mine in Montana noted that slow movement of the wetting front through waste rock and run-on controls could limit potential migration of acid drainage to surface water. This same mechanism could delay impacts of acid drainage to surface water. The Montana Tunnels Mine EIS, as noted earlier, stated that poor-quality water was not expected to seep out of the pit until hydrologic equilibrium was reached in

480 years. At this time, no more than 15 gpm was expected to flow out of the pit toward Spring Creek. Contaminants in the pit seepage water were expected to be diluted and retarded in groundwater, and the impact on Spring Creek water quality was stated as unknown. The 1995 EIS for the Rock Creek Mine in Montana noted that the long-term potential for acid drainage was unknown, and the 2001 EIS noted that if there is outflow of mine adit water, perpetual treatment might be required prior to discharge to the Clark Fork River.

The 1984 Grouse Creek, Idaho, EIS mentioned that water quality changes in surface streams were predicted to be of short duration. Modeling conducted (PYROX modeling of tailings) for the 1999 Thompson Creek, Idaho, EIS concluded that potential impacts to water quality in Squaw Creek should be reduced as a result of excess neutralization capacity at the end of the 100-year period.

Water Quantity Effects

Several EISs mentioned potential water quantity effects on surface water resources. Most of these potential impacts were related to groundwater pumping for dewatering operations and excavation of underground workings. The 2001 EIS for the Rock Creek Project in Montana concluded that water levels in and groundwater inflow to several wilderness lakes overlying the mined-out portions of the underground mine could potentially be reduced if faults or fractures acted as groundwater conduits and grouting programs were ineffective. The 1995 Bald Mountain, Nevada, EIS acknowledged the potential for reduced flow in the Cherry Creek Spring as a result of dewatering operations. Similarly, the Battle Mountain, Nevada, EIS noted that dewatering operations could reduce flow in perennial streams and springs. The 2003 Goldstrike, Nevada, EIS concluded that the primary issue related to the quality of surface water was degraded stream water quality resulting from dewatering operations. Based on hydrologic modeling results, there was some recognized potential for additional flow reductions to perennial water sources in localized areas from future mine-induced drawdown. Finally, the Marigold, Nevada, 2001 EIS stated that groundwater pumping or drainage modification could cause reduction in surface water flows and impacts to riparian or wetland areas.

5.6.5. POTENTIAL PIT WATER IMPACTS

Pit water impact potential refers to the proposed project’s potential to adversely affect water quality in the pit in the absence of mitigation measures. Water in the pit refers to either pit lake water or water associated in the interstices of pit backfill material. Section 5.7.3 describes the projects’ predicted impact on pit water quality after proposed mitigation measures were put in place. The information on pit water quality impact potential was summarized and scored according to the following five categories:

- No information available (0)
- Low pit water quality impacts (water quality similar to surrounding groundwater or < relevant standards) (1)
- Moderate pit water quality impacts (≥ and up to 10 times relevant standards) (2)
- High pit water quality impacts (>10 times water quality standards) (3)
- No pit lake or long-term standing water expected (pit above water table or no pit) (4)

For mines with multiple EISs, the EIS with the highest individual score for potential pit water impacts was used as the score for the mine. Scores for potential pit water impacts were often based on qualitative information or descriptions (e.g., pit water quality expected to be poor). If an EIS entry noted anything regarding potential pit water quality that was negative, it was scored as a 2 (moderate impacts). If the pit was proposed to be backfilled but the EIS did not address backfill water quality, it was scored as a 0. For mines with multiple proposed pits above the water table, the pit with the highest score (1, 2, or 3) was used to score the mine as a whole. Information on long-term pit water quality impacts is also discussed.

Table 5.14 lists the mines that fall into the five categories for potential pit water quality impacts.

Table 5.14. Pit Water Quality Impact Potential

0		1		2		3		4	
No information available		Low		Moderate		High		No pit lake expected to form (pit above water table or no pit)	
Fort Knox	AK	Bagdad*	AZ	Sanchez	AZ	Safford (Dos Pobres)	AZ	AJ Project	AK
Red Dog	AK	Castle Mountain*	CA	Jamestown*	CA	McLaughlin*	CA	Greens Creek*	AK
True North	AK	Imperial	CA	Mesquite*	CA	Golden Sunlight*	MT	Kensington Project	AK
Carlotta	AZ	Black Pine	ID	Beartrack	ID	Montana Tunnels	MT	Pogo Project	AK
Morenci	AZ	Stone Cabin	ID	Grouse Creek*	ID	Gold Quarry	NV	Cyprus Tohono	AZ
Ray*	AZ	Basin Creek	MT	Thompson Creek*	ID	Goldstrike	NV	Hayden Hill	CA
Yarnell	AZ	Tyrone Little Rock	NM	Cortez Pipeline	NV	Lone Tree*	NV	Diamond Hill	MT
American Girl*	CA			Marigold	NV	Twin Creeks*	NV	East Boulder	MT
Royal Mountain King*	CA			Mule Canyon	NV	Lisbon Valley	UT	Mineral Hill*	MT
Stibnite	ID			Olinghouse	NV	Flambeau*	WI	Montanore	MT
Beal Mountain*	MT			Robinson (Ruth)	NV			Rock Creek	MT
Black Pine*	MT			Round Mountain*	NV			Stillwater*	MT
Zortman and Landusky*	MT			Gilt Edge	SD			Troy	MT
Copper Flat	NM							Bald Mountain	NV
Austin Gold Venture	NV							Cortez	NV
Battle Mountain Phoenix	NV							Griffon	NV
Dash	NV							Jerritt Canyon*	NV
Florida Canyon*	NV							Leeville	NV
Pete	NV							Rain	NV
								Rochester*	NV
								Ruby Hill*	NV
								Trenton Canyon	NV
	19		7		13		10		22

For potential impacts (without considering effect of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

No Information Available

A high proportion of the mines with proposed open pits that were expected to contain water (19 or 27%) did not provide information on potential pit water quality impacts. Of these, four had EAs rather than EISs (Fort Knox and True North, AK; Royal Mountain King, CA (EIR-EA); Austin Gold Venture, NV), and two were land-exchange EISs (Morenci and Ray, AZ). Of the remaining 13 mines, two were in Arizona, one each was in Alaska, California, Idaho and New Mexico, three were in Montana and four were in Nevada.

Low Pit Water Quality Impact Potential

Seven (10%) of the mines identified low potential for pit water quality impacts. The majority of these mines ascribed the low impact potential for impact to low acid drainage and/or contaminant leaching potential of rocks within the pit. None of these mines identified a high potential for either acid drainage or contaminant leaching.

Moderate Pit Water Quality Impact Potential

Moderate pit water quality impacts were identified for 13 (18%) of the 71 NEPA mines. Of these, the EIS for the Beartrack, Idaho mine had high contaminant leaching potential. The EIS for the Round Mountain Mine and the Cortez Pipeline mines in Nevada identified moderate acid drainage potential. The potential for moderate pit water quality impacts was generally ascribed to increased concentrations from evapoconcentration and the presence of materials with elevated acid-generating and/or contaminant leaching potential within the pit. In some cases, future water quality in the pits was based on observed water quality in existing pits at the site.

High Pit Water Quality Impact Potential

Ten (14%) of the mines were identified as having a high potential for pit water quality impacts, including the McLaughlin Mine in California, the Golden Sunlight and Montana Tunnels mines in Montana, and the Flambeau Mine (with a backfilled pit) in Wisconsin. The Golden Sunlight Mine identified high acid drainage and contaminant leaching potential, and the Gold Quarry/Maggie Creek, Lone Tree, Cortez Pipeline and Twin Creeks mines in Nevada identified high contaminant leaching potential. The majority (seven) of these 10 mines conducted both water quantity and quality modeling to predict pit water quality. The Flambeau Mine conducted only water quality modeling of the pit backfill leachate and predicted that manganese concentrations would be over 10 times drinking water standards.

No Pit Lake or Water Expected

Twenty-two (31%) of the mines were not expecting water in the pit either because the pit was above the water table or it was a proposed underground mine. Even when the bottom of a pit may be above the water table, seasonal water can still collect in the pit. In a number of these instances, remedial measures were proposed to avoid accumulation of pit water (see Section 5.6.3). Of the 22 mines, all the mines in Alaska and Montana and the Leeville Mine in Nevada are underground mines; all the other listed mines in this category are open pit mines with pit bottoms expected to be above the water table.

Long-term Pit Water Quality Impacts

EISs for several mines discussed the potential impact of time on pit water quality. The pit water at the Montana Tunnels Mine in Montana (as noted earlier in the section on potential groundwater quality impacts) was expected to become acidic and discharge to groundwater after 480 years. Pit water in the Cortez Pipeline Mine in Nevada was expected to exceed Nevada drinking water standards for pH (elevated pH), fluoride, sulfate, cadmium, manganese, mercury silver, and total dissolved solids at 250 years post closure. The Lone Tree, Nevada, open pit water quality was expected to be acidic initially, become neutral after 10 years and exceed drinking water standards for arsenic (until 10 years post-closure, then not exceed), cadmium (for one year only), nickel, fluoride, antimony (after 25 years) and sulfate (until 10 years). Nickel and fluoride concentrations were expected to exceed water quality standards by less than 10 times, but antimony concentrations are expected to be over 10 times higher than standards. The EIS for the Robinson (Ruth) Mine in Nevada stated that some improvement in pit (Liberty and Ruth pits) water quality could be expected as mineralization is removed by mining. The EIS also noted that pit dewatering and subsequent refilling would result in improved pit water quality because acidic solutions were discharged into the pit during historic leaching activities.

5.7. PROPOSED MITIGATION

EISs may analyze and subsequent Records of Decision (ROD) may require mitigation to address potential water quality impacts that are identified in the EISs. Mitigation are commonly designed for the protection of groundwater and surface water resources and may address pit water quality (depending on state requirements).

Mitigation include pollution prevention measures and abatement measures. Pollution prevention measures aim to control pollution at its source and include liners, special handling of potentially acid-generating (PAG) waste, adit plugging, leak-detection systems, and caps and covers. Abatement measures are designed to mitigate pollution after it has been created and include capture, treatment and discharge of contaminated water, or in some cases may require replacement measures (such as for water quantity). They may also be short-term (e.g., during the operational life of the project) or long-term (e.g., perpetual water treatment and/or site maintenance).

In many cases, the EISs reviewed described mitigation that would be included in the mine plan “if necessary.” Many EISs described measures to prevent or mitigate the impacts of acid drainage, including: isolation, segregation, or amendment of acid-generating wastes; and capture and treatment of acid drainage. The mitigation identified in EISs were for proposed projects or expansions of existing projects and are therefore proposed rather than actual mitigation. The mitigation that are actually implemented will depend on a number of factors and are often contained as requirements in the ROD after the mine is permitted. However, the proposed mitigation discussed in this section are an important part of the NEPA process because they respond to the identified potential impacts. In many cases they determine, or are depended upon to bring about, the predicted or post-mitigation, impacts (e.g., liners used for potential cyanide contamination leading to prediction of no or acceptable contamination).

Water-quality mitigation identified in the EISs fell into groundwater, surface water, and pit water measures. For mines that proposed treatment as part of the mitigation measures, the type of treatment was also categorized and scored.

5.7.1. PROPOSED GROUNDWATER MITIGATION

The information on groundwater mitigation contained in the EISs was summarized and scored according to one or more of the following categories:

- No information available or no mitigation identified (0)
- Groundwater monitoring or characterization of mined materials (1)
- Source controls without treatment (liners, leak detection systems, run on/off controls, caps/covers, adit plugging) (2)
- Groundwater/leachate capture with treatment (3)
- Perpetual groundwater capture and/or treatment; long-term mitigation fund (4)
- Liming, blending, segregation, etc. of potentially acid-generating (PAG) material (5)

Table 5.15 lists the mines with proposed groundwater mitigation that fell into the six categories.

No Information Available or No Mitigation Identified

Twelve (17%) of the 71 NEPA mines did not identify any type of groundwater mitigation.

Groundwater Monitoring or Characterization of Mined Materials

Nearly half of the mines (33, or 46%) proposed groundwater monitoring or materials characterization as a type of groundwater mitigation. Monitoring and characterization do not directly mitigate impacts to groundwater, but results of these tests can be used to identify the need for mitigation after the facility is in operation.

Table 5.15. Proposed Groundwater Mitigation

0		1		2		3		4		5	
No information available		Monitoring or characterization		Source controls without treatment		Groundwater/leachate capture		In-perpetuity capture and/or treatment; long-term fund		Liming, blending, segregation, etc. of PAG material	
AJ Project	AK	Carlotta	AZ	Kensington Project	AK	Greens Creek*	AK	Golden Sunlight*	MT	Greens Creek*	AK
Fort Knox	AK	Morenci	AZ	Pogo Project	AK	Kensington Project	AK	Rock Creek	MT	Pogo Project	AK
True North	AK	Safford	AZ	Red Dog	AK	Pogo Project	AK	Goldstrike	NV	Grouse Creek*	ID
Bagdad*	AZ	Hayden Hill	CA	Carlotta	AZ	Red Dog	AK			Stone Cabin	ID
Ray*	AZ	Jamestown*	CA	Cyprus Tohono	AZ	Castle Mountain*	CA			Beal Mountain*	MT
Royal Mountain King*	CA	McLaughlin*	CA	Morenci	AZ	Hayden Hill	CA			Diamond Hill	MT
Stone Cabin	ID	Mesquite*	CA	Safford	AZ	Jamestown*	CA			Montanore	MT
Basin Creek	MT	Beartrack	ID	Sanchez	AZ	Mesquite*	CA			Zortman Landusky*	MT
Troy	MT	Black Pine	ID	Yarnell	AZ	Thompson Creek*	ID			Florida Canyon*	NV
Rochester*	NV	Grouse Creek*	ID	American Girl*	CA	Golden Sunlight*	MT			Jerritt Canyon*	NV
Trenton Canyon	NV	Stibnite	ID	Castle Mountain*	CA	Mineral Hill*	MT			Leeville	NV
Copper Flat	NM	Thompson Creek*	ID	Hayden Hill	CA	Montana Tunnels	MT			Marigold	NV
		Beal Mountain*	MT	Imperial	CA	Rock Creek	MT			Twin Creeks*	NV
		Golden Sunlight*	MT	Jamestown*	CA	Stillwater*	MT				
		Montanore	MT	Mesquite*	CA	Zortman Landusky*	MT				
		Rock Creek	MT	Beartrack	ID	Austin Gold Venture	NV				
		Stillwater*	MT	Black Pine	ID	Phoenix	NV				
		Zortman Landusky*	MT	Grouse Creek*	ID	Cortez	NV				
		Austin Gold Venture	NV	Stibnite	ID	Cortez Pipeline	NV				
		Bald Mountain	NV	Thompson Creek*	ID	Gold Quarry	NV				
		Phoenix	NV	Beal Mountain*	MT	Goldstrike	NV				
		Cortez	NV	Black Pine*	MT	Leeville	NV				
		Cortez Pipeline	NV	East Boulder	MT	Lone Tree*	NV				
		Dash	NV	Golden Sunlight*	MT	Pete	NV				
		Gold Quarry	NV	Montana Tunnels	MT	Rain	NV				
		Goldstrike	NV	Montanore	MT	Robinson (Ruth)	NV				
		Lone Tree*	NV	Stillwater*	MT	Flambeau*	WI				
		Marigold	NV	Zortman Landusky*	MT						
		Mule Canyon	NV	Venture	NV						
		Pete	NV	Bald Mountain	NV						
		Rain	NV	Battle Mountain Phoenix	NV						
		Robinson (Ruth)	NV	Cortez	NV						
		Twin Creeks	NV	Cortez Pipeline	NV						
		Lisbon Valley Copper	UT	Florida Canyon*	NV						
				Gold Quarry	NV						
				Griffon	NV						
				Jerritt Canyon*	NV						
				Leeville	NV						
				Marigold	NV						
				Olinghouse	NV						
				Pete	NV						
				Rain	NV						
				Robinson (Ruth)	NV						
				Round Mountain*	NV						
				Ruby Hill*	NV						
				Twin Creeks*	NV						
				Tyrone - Little Rock	NM						
				Gilt Edge	SD						
				Copper	UT						
				Flambeau*	WI						
	12		33		50		27		3		13

Source Controls Without Treatment (liners, leak detection systems, run on/off controls, caps/covers, adit plugging)

The majority of the mines (50, or 70%) proposed source controls without treatment to protect groundwater. The majority of these measures consisted of liners for tailings impoundments and heap leach operations to prevent groundwater contamination ("zero discharge" facilities).

Groundwater/Leachate Capture with Treatment

Approximately one-third (27 or 38%) of the mines proposed groundwater or leachate capture, either with or without treatment.

Perpetual Groundwater Capture and/or Treatment; Long-term Mitigation Fund

Only three of the mines (4%) (Rock Creek and Golden Sunlight, MT; Goldstrike (Betze), NV) mentioned in perpetuity capture and/or treatment or other type of long-term groundwater mitigation. For Rock Creek and Goldstrike, perpetual treatment or maintenance was identified as a possible long-term option if necessary, and the Goldstrike Mine proposed a $250,000 fund to cover monitoring costs beyond the year 2030 (in a 1991 EIS), and a $1,000,000 fund for the review, monitoring, and mitigation of impacts directly associated with the project, but not specifically identified in the EIS. Seepage from tailings and waste rock at the Golden Sunlight Mine in Montana, however, was expected in the 1997 EIS to require perpetual treatment.

The three mines, where EISs identified groundwater capture and treatment mitigation requirements, collected and treated acid drainage from beneath waste dumps, dewatered tailings or tailings leachate.

Liming, Blending, Segregation, etc. of Potentially Acid-Generating (PAG) Material

Thirteen (18%) of the mines identified special handling of PAG waste as a groundwater mitigation measure.

5.7.2. PROPOSED SURFACE WATER MITIGATION

The information on surface water mitigation contained in the EISs was summarized and scored according to the following categories:

- No information available or no mitigation identified (0)
- Surface water monitoring (1)
- Stormwater, sediment, or erosion controls (2)
- Source controls not involving capture of water (including liners, adit plugging, caps/covers, leak detection systems, spill prevention measures and liming/blending/segregating of PAG materials) (3);
- Surface water/leachate capture and/or treatment (including settling, land application, routing of water, seepage collection) (4)
- Perpetual surface water capture and/or treatment (5)
- Surface water augmentation or replacement (6)

Table 5.16 lists the mines with mitigation that fell into the seven categories.

No Information Available or No Mitigation Identified

The EISs for eleven mines (15%) contained no information on surface water mitigation.

Table 5.16. Proposed Surface Water Mitigation

0		1		2		3		4		5		6	
No information available		Monitoring or characterization		Stormwater/sediment/erosion controls		Source controls without water capture		Surface water/leachate capture/treatment		In-perpetuity capture/treatment		Surface water augmentation/ replacement	
AJ Project	AK	Castle Mountain*	CA	Greens Creek*	AK	Kensington	AK	Greens Creek *	AK	Rock Creek	MT	Golden Sunlight*	MT
Fort Knox	AK	Hayden Hill	CA	Kensington Project	AK	Bagdad*	AZ	Kensington Project	AK	Zortman Landusky*	MT	Goldstrike	NV
Red Dog	AK	Jamestown*	CA	Pogo Project	AK	Morenci	AZ	Pogo Project	AK				
True North	AK	Mesquite*	CA	Red Dog-	AK	Sanchez	AZ	Yarnell	AZ				
Ray*	AZ	Grouse Creek*	ID	Bagdad*	AZ	American Girl*	CA	Jamestown*	CA				
Basin Creek	MT	Thompson	ID	Carlotta	AZ	Castle Mountain*	CA	McLaughlin*	CA				
East Boulder	MT	Black Pine*	MT	Cyprus Tohono	AZ	Imperial	CA	Stibnite	ID				
Mineral Hill*	MT	Rock Creek	MT	Morenci	AZ	Jamestown*	CA	Stone Cabin	ID				
Troy	MT	Stillwater*	MT	Safford (Dos	AZ	McLaughlin*	CA	Thompson Creek*	ID				
Copper Flat	NM	Zortman Landusky*	MT	Sanchez	AZ	Mesquite*	CA	Diamond Hill	MT				
Gilt Edge	SD	Dash	NV	Yarnell	AZ	Beartrack	ID	Golden Sunlight*	MT				
		Gold Quarry	NV	American Girl*	CA	Grouse Creek*	ID	Rock Creek	MT				
		Goldstrike	NV	Castle Mountain*	CA	Stibnite	ID	Zortman Landusky*	MT				
		Twin Creeks*	NV	Imperial	CA	Beal Mountain*	MT	Bald Mountain	NV				
				Jamestown*	CA	Black Pine*	MT	Gold Quarry	NV				
				McLaughlin*	CA	Rock Creek	MT	Jerritt Canyon*	NV				
				Mesquite*	CA	Stillwater*	MT	Marigold	NV				
				Royal Mountain King*	CA	Zortman Landusky*	MT	Rain	NV				
				Beartrack	ID	Bald Mountain	NV	Robinson (Ruth)	NV				
				Black Pine	ID	Battle Mountain	NV	Tyrone - Little	NM				
				Grouse Creek*	ID	Cortez	NV	Flambeau*	WI				
				Stibnite	ID	Cortez Pipeline	NV						
				Beal Mountain*	MT	Dash	NV						
				Black Pine*	MT	Florida Canyon*	NV						
				Montana Tunnels	MT	Jerritt Canyon*	NV						
				Montanore	MT	Lone Tree*	NV						
				Stillwater*	MT	Marigold	NV						
				Zortman Landusky*	MT	Pete	NV						
				Austin Gold	NV	Round Mountain*	NV						
				Bald Mountain	NV	Tyrone - Little	NM						
				Battle Mountain	NV	Lisbon Valley	UT						
				Cortez	NV	Flambeau*	WI						
				Dash	NV								
				Goldstrike	NV								
				Griffon	NV								
				Jerritt Canyon*	NV								
				Leeville	NV								
				Lone Tree*	NV								
				Marigold	NV								
				Mule Canyon	NV								
				Olinghouse	NV								
				Rain	NV								
				Robinson (Ruth)	NV								
				Rochester*	NV								
				Round Mountain*	NV								
				Ruby Hill*	NV								
				Trenton Canyon	NV								
				Twin Creeks*	NV								
				Lisbon Valley Copper	UT								
	11		14		49		32		21		2		0

Surface Water Monitoring

Fourteen (20%) of the mines identified monitoring as one of the proposed surface water mitigation.

Stormwater, Sediment or Erosion Controls

The largest number of mines (49 or 69%) proposed stormwater, sediment or erosion controls.

Source Controls Not Involving Capture of Water (including liners, adit plugging, caps/covers, leak detection systems, spill prevention measures and liming/blending/segregating of PAG materials)

Thirty two (45%) of the mines proposed source controls to protect surface water that included capping of dumps and tailings, stabilization measures, spill prevention measures and removal actions.

Surface Water/Leachate Capture and/or Treatment (including settling, land application, routing of water, seepage collection)

Nearly one-third of the mines (21 or 30%) proposed surface water or leachate capture and/or treatment as a surface water mitigation measure.

In Perpetuity Surface Water Capture and/or Treatment

Only two mines, (Rock Creek and Zortman and Landusky, MT) mentioned the possibility of perpetual treatment of surface water. In the case of Rock Creek it applies to the treatment of water discharging to the surface from the underground mine after plugging, if necessary, before the water is discharged to the Clark Fork River.

Surface Water Augmentation or Replacement

Only two mines mentioned the possibility of replacing or augmenting surface water: the Golden Sunlight Mine in Montana proposed supplying water sources for wildlife if the supply and quality of springs deteriorated; and the Goldstrike (Betze) Mine in Nevada proposed replacing or augmenting perennial surface flows if they were lost or decrease as a result of dewatering activities.

5.7.3. PROPOSED PIT WATER MITIGATION

The information on pit water mitigation contained in the EISs was summarized and scored according to one or more of the following categories:

- No information provided or none identified (0)
- Pit lake monitoring (1)
- Pit lake prevention (backfill, pumping, stormwater diversion, use in mine operation) (2)
- Treatment of pit water or backfill amendment (e.g., lime addition) (3)
- Not applicable: no pit lake will form (underground mine or pit above water table) (4)
- Contingency or research fund for pit lake, adaptive management (5)

Table 5.17 lists the mines with pit water mitigation that fell into the six categories.

No Information Provided or None Identified

Approximately one-quarter (19 or 27%) of the mines had no information on pit water quality mitigation; all of these mines had proposed open pits.

Table 5.17. Proposed Pit Water Mitigation

0		1		2		3		4		5	
No information available		Pit lake monitoring		Pit lake prevention (backfill, pumping, stormwater diversion, use in mine operation)		Treatment of pit water or backfill amendment (e.g. lime addition)		Not Applicable: no pit lake will form (underground mine or pit above water table)		Contingency or research fund for pit lake; adaptive management	
Fort Knox	AK	Castle Mountain*	CA	Bagdad*	AZ	Hayden Hill	CA	AJ Project	AK	Pipeline	NV
True North	AK	Grouse Creek*	ID	Carlotta	AZ	Stibnite	ID	Greens Creek*	AK	Goldstrike	NV
Red Dog	AK	Goldstrike	NV	Cyprus Tohono	AZ	Golden Sunlight*	MT	Kensington Project	AK		
Morenci	AZ	Round Mountain*	NV	Safford (Dos Pobres/San	AZ	Battle Mountain Phoenix	NV	Pogo Project	AK		
Ray*	AZ	Twin Creeks*	NV	Sanchez	AZ	Marigold	NV	American Girl*	CA		
Jamestown*	CA	Lisbon Valley Copper	UT	Yarnell	AZ	Flambeau*	WI	Black Pine*	MT		
McLaughlin*	CA			Castle Mountain*	CA			Diamond Hill	MT		
Mesquite*	CA			Hayden Hill	CA			East Boulder	MT		
Royal Mountain King*	CA			Imperial	CA			Mineral Hill*	MT		
Beartrack	ID			Black Pine	ID			Montanore	MT		
Thompson	ID			Grouse Creek*	ID			Rock Creek	MT		
Montana Tunnels	MT			Stibnite	ID			Stillwater*	MT		
Venture	NV			Stone Cabin	ID			Troy	MT		
Cortez	NV			Basin Creek	MT			Bald Mountain	NV		
Gold Quarry/ Maggie Creek	NV			Beal Mountain*	MT			Griffon	NV		
Mule Canyon	NV			Golden Sunlight*	MT			Jerritt Canyon*	NV		
Olinghouse	NV			Zortman	MT			Leeville	NV		
Robinson (Ruth)	NV			Bald Mountain	NV			Marigold	NV		
Copper Flat	NM			Phoenix	NV			Pete	NV		
				Dash	NV			Rain	NV		
				Florida Canyon*	NV			Rochester*	NV		
				Jerritt Canyon*	NV			Ruby Hill*	NV		
				Lone Tree*	NV			Trenton Canyon	NV		
				Marigold	NV						
				Pete	NV						
				Tyrone - Little	NM						
				Gilt Edge	SD						
				Flambeau*	WI						
	19		6		28		6		23		2

Pit Lake Monitoring

Monitoring of pit water quality was proposed at six (8%) of the mines. At two of these mines (Round Mountain and Twin Creeks) no other type of pit water quality mitigation was proposed.

Pit Lake Prevention (backfill, pumping, stormwater diversion, use in mine operation)

Pit lake prevention was identified at 28 (39%) of the mines; pit lake prevention measures included backfilling, pumping to prevent pit lake formation, stormwater diversion and use of pit water elsewhere in the mining operation.

Treatment of Pit Water or Backfill Amendment (e.g., lime addition)

Treatment of pit water or backfill amendment (e.g., lime addition) was identified at six (8%) of the mines.

Not Applicable: No Pit Lake Will Form (underground mine or pit above water table)

At approximately one-third (23 or 32%) of the 71 mines, no pit lake was expected to form, either because the mine was an underground mine or the bottom of the pit was above the water table.

Contingency or Research Fund for Pit Lake, Adaptive Management

At two of the mines, a contingency fund or research fund was proposed to address potential issues related to pit water quality. The Cortez Pipeline Mine in Nevada proposed adaptive management, because no mitigation measures appeared to be feasible for long-term potential environmental impacts and a contingency fund for monitoring and corrective action, should any be necessary. At the Goldstrike (Betze) Mine in Nevada, Barrick proposed to contribute $50,000 yearly, for a maximum of 10 years, to a college or university for conducting research related to water quality at inactive open pit mines.

5.7.4. PROPOSED WATER TREATMENT

The information on water treatment measures contained in the EISs was summarized and scored according to the following categories:

- No information provided or no water treatment measures identified (0)
- Solids or sediment settling ponds (1)
- Water treatment for cyanide (2)
- Water treatment for metals and/or acid drainage (3)
- Water treatment using non-conventional approaches (4)
- Perpetual water treatment (5)

Table 5.18 lists the mines with water treatment that fell into the six categories.

No Information Provided or No Water Treatment Measures Identified

Forty-eight (68%) of the mines provided no information on water treatment or no water treatment was proposed.

Solids or Sediment Settling Ponds

Six (8%) of the mines proposed settling of solids or sediment as a treatment method.

Water Treatment for Cyanide

Six (8%) of the mines proposed treatment for cyanide.

Water Treatment for Metals and/or Acid Drainage

Treatment for metals and/or acid drainage was proposed at 16 (23%) of the 71 NEPA mines.

Water Treatment Using Non-Conventional Approaches

Other types of treatment, including biological, land application, and passive approaches were proposed at 11 (15%) of the mines.

Water Treatment in Perpetuity

Perpetual treatment was specifically proposed, if necessary, at only four mines (Grouse Creek, ID; Golden Sunlight, Rock Creek and Zortman Landusky, MT).

Table 5.18. Proposed Water Treatment

0		1		2		3		4		5	
No information available/No treatment measures identified		Solids or sediment settling ponds		Water treatment for cyanide		Water treatment for metals and/or acid drainage		Water treatment using non-conventional approaches		Perpetual water treatment	
AJ Project	AK	Kensington Project	AK	Kensington Project	AK	Greens Creek*	AK	Beartrack	ID	Grouse Creek*	ID
Fort Knox	AK	Mineral Hill*	MT	Jamestown*	CA	Kensington Project	AK	Stibnite	ID	Golden Sunlight*	MT
True North	AK	Rock Creek	MT	Grouse Creek*	ID	Pogo Project	AK	Stone Cabin	ID	Rock Creek	MT
Bagdad*	AZ	Stillwater*	MT	Beal Mountain*	MT	Red Dog	AK	East Boulder	MT	Zortman and Landusky*	MT
Carlotta	AZ	Cortez Pipeline	NV	Lone Tree*	NV	Grouse Creek*	ID	Golden Sunlight*	MT		
Cyprus Tohono	AZ	Goldstrike	NV	Zortman and Landusky*	MT	Stone Cabin	ID	Mineral Hill*	MT		
Morenci	AZ					Golden Sunlight*	MT	Montanore	MT		
Ray*	AZ					Mineral Hill*	MT	Rock Creek	MT		
Safford	AZ					Montanore	MT	Stillwater*	MT		
Sanchez	AZ					Rock Creek	MT	Zortman and Landusky*	MT		
Yarnell	AZ					Zortman and Landusky*	MT	Lone Tree*	NV		
American Girl*	CA					Battle Mountain Phoenix	NV				
Castle Mountain*	CA					Goldstrike	NV				
Hayden Hill	CA					Lone Tree*	NV				
Imperial	CA					Twin Creeks*	NV				
McLaughlin*	CA					Flambeau*	WI				
Mesquite*	CA										
Royal Mountain King*	CA										
Black Pine	ID										
Thompson Creek*	ID										
Basin Creek	MT										
Black Pine*	MT										
Diamond Hill	MT										

Table 5.18. Proposed Water Treatment (Cont.).

0		1		2		3		4		5	
No information available/No treatment measures identified		Solids or sediment settling ponds		Water treatment for cyanide		Water treatment for metals and/or acid drainage		Water treatment using non-conventional approaches		Perpetual water treatment	
Montana Tunnels	MT										
Troy	MT										
Austin Gold Venture	NV										
Bald Mountain	NV										
Cortez	NV										
Dash	NV										
Florida Canyon*	NV										
Gold Quarry	NV										
Griffon	NV										
Jerritt Canyon*	NV										
Leeville	NV										
Marigold	NV										
Mule Canyon	NV										
Olinghouse	NV										
Pete	NV										
Rain	NV										
Robinson (Ruth)	NV										
Rochester*	NV										
Round Mountain*	NV										
Ruby Hill*	NV										
Trenton Canyon	NV										
Copper Flat	NM										
Tyrone-Little Rock	NM										
Gilt Edge	SD										
Lisbon Valley Copper	UT										
	48		6		6		16		11		4

5.8. PREDICTED WATER QUALITY IMPACTS

As noted in Section 5.5, this study distinguishes between potential and predicted water quality impacts. A predicted water quality impact is one that could occur after mitigation are in place. Predicted, or post-mitigation, impacts are considered by regulators when evaluating whether a proposed mine will meet applicable water quality standards. If a project predicts that waters of the state will not meet relevant standards as a result of the proposed activities, it is unlikely that the project will be approved. In general, very few EISs predicted that surface water and groundwater quality standards would not be met after mitigation were in place. Pit waters, on the other hand, are often not considered a water of the state, and under those conditions they are not necessarily required to meet Clean Water Act or Safe Drinking Water Act standards or criteria.

The elements of predicted water quality impacts reviewed in the 71 NEPA mine EISs include groundwater, surface water and pit water quality impacts.

5.8.1. PREDICTED GROUNDWATER QUALITY IMPACTS

The information on predicted groundwater quality impacts contained in the EISs was summarized and scored according to the following four categories:

- No information available (0)
- Low groundwater quality impacts (< relevant standards) (1)
- Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) (2)
- High groundwater quality impacts (>10 times relevant standards) (3)

For mines with multiple EISs, the EIS with the highest individual score for predicted groundwater impacts was used as the score for the mine. Scores for predicted groundwater impacts were often based on qualitative information or descriptions (e.g., “moderate” effects expected on groundwater quality). If an EIS entry noted anything regarding predicted groundwater quality that was negative, it was scored as a 2 (moderate impacts). Information on long-term groundwater quality impacts was also noted.

Table 5.19 lists the mines with predicted groundwater quality impacts that fell into in the four categories for predicted groundwater quality impacts.

No Information Available

No information was available on predicted groundwater quality impacts for 7 (10%) of the 71 NEPA mines. Two of the six mines had EAs rather than EISs (Royal Mountain King, CA (EIR-EA); Pete, NV). The Ray Mine in Arizona, which had a land-exchange EIS, acknowledged that mining will likely affect groundwater, but stated that a description of impacts was not possible because a detailed mine plan had not been developed. The East Boulder Mine in Montana predicted that nitrates from blasting agents and seepage from tailings impoundments could enter groundwater, but no estimates were made about potential impacts on groundwater. As noted in section 5.5, the Montana Tunnels Mine in Montana predicted that poor quality water would seep from the pit to groundwater in 480 years, but no estimates were made of the impact on groundwater.

Low Groundwater Quality Impacts

The majority of the mines (56 or 79%) predicted that groundwater quality impacts would be low and below relevant standards. A number of mines mentioned that there would be no impacts to groundwater outside of the mine area or of mixing zones, implying that groundwater on site would be impacted by the proposed actions. A number of the other mines stated that some combination of large depths to groundwater, the presence of neutralizing rock, and proposed mitigation measures would ensure that groundwater quality would not be impacted.

Moderate Groundwater Quality Impacts

Four mines (6%) predicted moderate groundwater quality impacts, exceeding water quality standards by up to 10 times, after mitigation were in place. Thompson Creek Mine in Idaho mentioned the potential for seepage from tailings impoundments and waste rock dumps to groundwater escaping the seepage control system, resulting in moderate groundwater impacts. The Tyrone Mine mentioned an existing groundwater plume from the stockpile and exceedence of the fluoride standard. The Cortez Pipeline Mine in Nevada predicted low groundwater quality impacts from proposed facilities but stated that the quality of reinfiltration of dewatering water may be degraded by soluble constituents in previously unsaturated alluvium. The Marigold Mine in Nevada predicted that escape of constituents from the heap leach pad could degrade groundwater quality.

Table 5.19. Predicted Groundwater Quality Impacts

0		1		2		3	
No information available		Low		Moderate		High	
AJ Project	AK	Fort Knox	AK	Thompson Creek*	ID	Pogo Project	AK
Red Dog	AK	Greens Creek*	AK	Tyrone Little Rock	NM	McLaughlin*	CA
Ray*	AZ	Kensington Project	AK	Cortez Pipeline	NV	Zortman and Landusky*	MT
Royal Mountain King*	CA	True North	AK	Marigold	NV	Golden Sunlight*	MT
East Boulder	MT	Bagdad*	AZ				
Montana Tunnels	MT	Carlotta	AZ				
Pete	NV	Cyprus Tohono	AZ				
		Morenci	AZ				
		Safford (Dos Pobres)	AZ				
		Sanchez	AZ				
		Yarnell	AZ				
		American Girl*	CA				
		Castle Mountain*	CA				
		Hayden Hill	CA				
		Imperial	CA				
		Jamestown*	CA				
		Mesquite	CA				
		Beartrack	ID				
		Black Pine	ID				
		Grouse Creek*	ID				
		Stibnite	ID				
		Stone Cabin	ID				
		Basin Creek	MT				
		Beal Mountain*	MT				
		Black Pine*	MT				
		Diamond Hill	MT				
		Mineral Hill*	MT				
		Montanore	MT				
		Rock Creek	MT				
		Stillwater*	MT				
		Troy	MT				
		Copper Flat	NM				
		Austin Gold Venture	NV				
		Bald Mountain	NV				
		Battle Mountain Phoenix	NV				
		Cortez	NV				
		Dash	NV				
		Florida Canyon	NV				

For predicted impacts (considering effects of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

Table 5.19. Predicted Groundwater Quality Impacts (continued)

0		1		2		3	
No information available		Low		Moderate		High	
		Gold Quarry	NV				
		Goldstrike	NV				
		Griffon	NV				
		Jerritt Canyon	NV				
		Leeville	NV				
		Lone Tree	NV				
		Mule Canyon	NV				
		Olinghouse	NV				
		Rain	NV				
		Robinson (Ruth)	NV				
		Rochester	NV				
		Round Mountain	NV				
		Ruby Hill	NV				
		Trenton Canyon	NV				
		Twin Creeks	NV				
		Gilt Edge	SD				
		Lisbon Valley	UT				
		Flambeau	WI				
	7		56		4		4

For predicted impacts (considering effects of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

High Groundwater Quality Impacts

Four of the 71 NEPA mines predicted high groundwater quality impacts after mitigation were considered. The Pogo Mine in Alaska predicted increases in arsenic (of up to 500 µg/l) and cyanide concentrations in alluvial groundwater from the underground mine, even after plugging and backfilling. The McLaughlin Mine in California predicted that seepage from the tailings facility would result in permanent degradation of local groundwater and noted the potential for shallow groundwater to flowing toward Hunting Creek. The McLaughlin EIS stated that the local groundwater was not connected to the regional system, so water supplies would not be impacted. A cyanide plume (from tailings seepage) already existed at the Golden Sunlight Mine in Montana when the 1997 EIS was written. The EIS stated that seepage from the tailings impoundment and one of the waste rock complexes would require perpetual treatment. The 2001 Zortman and Landusky Mines EIS predicted that concentrations of most contaminants from the Zortman and Landusky Mines would increase over time, and pit backfill would increase contaminant loads in the short term. The 1996 EIS predicted that acid and metal concentrations in toe seeps could increase or, at best, remain roughly unchanged for the first few years after capping.

Long-term Groundwater Quality Impacts

Several mines predicted groundwater impacts that would be long-term or that would not occur for years into the future. The Pogo Mine in Alaska predicted that increases in arsenic and total dissolved solids would occur from the underground mine over the long-term (hundreds to thousands of years), after plugging and backfilling after mine closure. The McLaughlin Mine in California predicted that the proposed tailings facility would allow 40 gpm of seepage into local groundwater, and this impact would be long term, resulting in permanent degradation of the local groundwater. The 1997 Golden Sunlight EIS predicted that seepage from Tailings Impoundment No.2 and West Waste Rock Complex would require perpetual treatment. At the Montana Tunnels Mine, as noted in Section 5.5, poor quality water was not expected to seep out of the pit and discharge to groundwater (at 15 gpm) until 480 years later when water levels in the pit reached equilibrium.

The 2001 Zortman and Landusky EIS predicted that backfilling would increase loads of contaminants in the short term, but that in the long term, removing waste rock would have a positive impact on groundwater quality. The Battle

Mountain Complex EIS noted that there was a potential for long-term impacts to groundwater quality during the post-closure period, but that with the contingent long-term groundwater management plan, significant impacts to groundwater were not expected.

5.8.2. PREDICTED SURFACE WATER IMPACTS

The EIS information on predicted surface water quality impacts was summarized and scored according to the following four categories:

- No information available (0)
- Low surface water quality impacts (< relevant standards) (1)
- Moderate surface water quality impacts (≥ and up to 10 times relevant standards) (2)
- High surface water quality impacts (>10 times standards) (3)

For mines with multiple EISs, the EIS with the highest individual score for predicted surface water impacts was used as the score for the mine. Scores for predicted surface water impacts were often based on qualitative information or descriptions (e.g., no impacts expected on surface water quality). If an EIS entry noted anything regarding predicted surface water quality that was negative, including sedimentation or erosion effects on surface water, it was scored as a 2 (moderate impacts). Information on long-term surface water quality impacts was also discussed.

Table 5.20 lists the mines with predicted surface water impacts in each of the four categories.

No Information Available

No information was available on predicted surface water quality impacts for six (8%) of the mines. Two of these mines (Royal Mountain King, CA; True North, AK) had EAs rather than EISs, and the Ray Mine in Arizona had a land-exchange EIS. The Diamond Hill Mine in Montana mentioned weathering of sulfides and the Dash Mine in Nevada mentioned soil loss, but neither contained specifics on surface water quality predictions. The Montana Tunnels Mine in Montana mentioned destruction of springs and decreased flows in streams, and as discussed in the surface water quality potential section. Poor-quality water was expected to seep out of the pit in 480 years, but the impact on surface water quality was not mentioned.

Low Surface Water Quality Impacts (water quality standards not exceeded)

The vast majority (57 or 80%) of the mines predicted that surface water quality impacts would be low or non-existent. As for predicted groundwater quality impacts, mines that predicted low surface water quality impacts mentioned the effects of mixing zones, implying that surface water would be impacted by the proposed actions but dilution would reduce concentrations to below standards. Other mines stated that some combination of distance to or low amount of surface water, low potential for acid drainage or contaminant leaching, and proposed mitigation or management measures would ensure that surface water quality would not be impacted.

Moderate Surface Water Quality Impacts (≥ and up to 10 times relevant standards)

Seven (10%) of the mines predicted that surface water quality impacts would be moderate, exceeding relevant standards by up to 10 times, where specific water quality conditions were mentioned. The Pogo Project EIS predicted moderate impacts to Liese Creek from tailings during mining operations. Modeling conducted for the McLaughlin Mine EIS in California predicted that arsenic, nickel, zinc, silver, iron and copper concentrations would not exceed drinking water standards in Hunting Creek but that manganese would slightly exceed its standard. The EIS for the Beartrack Mine in Idaho predicted exceedence of zinc standards in one reach of Napias Creek, and the Thompson Creek Mine in Idaho predicted exceedence of aquatic life criteria in Bruno Creek during low-flow conditions from tailings infiltration. The Olinghouse Mine in Nevada predicted reduction in discharge and sedimentation impacts to surface water.

Table 5.20. Predicted Surface Water Quality Impacts

0		1		2		3	
No information available		Low		Moderate		High	
True North	AK	AJ Project	AK	Pogo Project	AK	Zortman and Landusky*	MT
Ray*	AZ	Fort Knox	AK	McLaughlin*	CA		
Royal Mountain King*	CA	Greens Creek *	AK	Beartrack	ID		
Diamond Hill	MT	Kensington Project	AK	Thompson Creek*	ID		
Montana Tunnels	MT	Red Dog	AK	Tyrone Little Rock	NM		
Dash	NV	Bagdad*	AZ	Marigold	NV		
		Carlotta	AZ	Olinghouse	NV		
		Cyprus Tohono	AZ				
		Morenci	AZ				
		Safford (Dos Pobres)	AZ				
		Sanchez	AZ				
		Yarnell	AZ				
		American Girl*	CA				
		Castle Mountain*	CA				
		Hayden Hill	CA				
		Imperial	CA				
		Jamestown*	CA				
		Mesquite*	CA				
		Black Pine	ID				
		Grouse Creek*	ID				
		Stibnite	ID				
		Stone Cabin	ID				
		Basin Creek	MT				
		Beal Mountain*	MT				
		Black Pine*	MT				
		East Boulder	MT				
		Golden Sunlight*	MT				
		Mineral Hill*	MT				
		Montanore	MT				
		Rock Creek	MT				
		Stillwater*	MT				
		Troy	MT				
		Copper Flat	NM				
		Austin Gold Venture	NV				
		Bald Mountain	NV				
		Battle Mountain Phoenix	NV				
		Cortez	NV				
		Cortez Pipeline	NV				
		Florida Canyon*	NV				

For predicted impacts (considering effects of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

Table 5.20. Predicted Surface Water Quality Impacts (continued)

0		1		2		3	
No information available		Low		Moderate		High	
		Gold Quarry	NV				
		Goldstrike	NV				
		Griffon	NV				
		Jerritt Canyon*	NV				
		Leeville	NV				
		Lone Tree*	NV				
		Mule Canyon	NV				
		Pete	NV				
		Rain	NV				
		Robinson (Ruth)	NV				
		Rochester*	NV				
		Round Mountain*	NV				
		Ruby Hill*	NV				
		Trenton Canyon	NV				
		Twin Creeks*	NV				
		Gilt Edge	SD				
		Lisbon Valley	UT				
		Flambeau*	WI				
	6		57		7		1

For predicted impacts (considering effects of mitigation): Low = < water quality standards; Moderate = predicted to exceed water quality standards by 1 - 10 times; High = predicted to exceed water quality standards by > 10 times.

High Surface Water Quality Impacts

One mine (Zortman and Landusky, MT) predicted high surface water quality impacts as a result of mining, even after mitigation were considered. Some irreversible impacts to the surface water quality were expected from the leach pad and from other mine features such as waste rock and open pits even though current water quality was already poor.

Long-term Surface Water Quality Impacts

A number of mines mentioned the effect of time on predicted surface water quality impacts. The EIS for the Greens Creek Mine in Alaska predicted a lag time for acid generation in tailings of 20 to 50 years. The EIS for the Pogo Mine in Alaska predicted that after closure of the dry stack tailings, water quality would improve. Although surface water quality impacts were predicted to be low at the Grouse Creek Mine in Idaho, the EIS mentioned that if acid drainage occurs, the effects could be long-term. The Beal Mine in Montana was predicted to have both long and short-term environmental effects in German Gulch, but the effects were not predicted to be significant in terms of either areal extent or severity.

As mentioned above, poor-quality water was not expected to seep out of the pit at the Montana Tunnels Mine in Montana until pit water levels equilibrate in 480 years, but the impact on water quality in Spring Creek was unknown. Long-term surface water quality impacts were not expected at the Zortman and Landusky Mine in Montana because pad water at the bottom of one of the Landusky leach pads, although predicted to become acid over time, would be contained on a liner. Water quality impacts in the northern drainages were predicted to increase if acid-generating material was placed as pit backfill in the headwaters of these drainages. For a mine expansion proposal initially approved in 1996 at the Zortman Mine, improved water quality was predicted over time as a result of reduced constituent loads in Ruby and Carter Gulch due to removal of the Alder Gulch waste rock dump, the Ruby Gulch tailings, the proposed sorting of backfill, and effective reclamation of the Zortman pit complex. This Zortman mine expansion never occurred and was withdrawn by the operator subsequent to bankruptcy. Water quality impacts to surface water from sulfate were predicted to occur at the Golden Sunlight Mine in Montana but not for 500 years or more.

A number of mines mentioned the effect of time on predicted surface water quality impacts. The EIS for the Greens Creek Mine in Alaska predicted a lag time for acid generation in tailings of 20 to 50 years. The EIS for the Pogo, Alaska, Mine predicted that after closure of the dry stack tailings, water quality would improve. Although surface water quality impacts were predicted to be low at the Grouse Creek Mine in Idaho, the EIS mentioned that if acid drainage occurs, the effects could be long-term. The Beal Mine in Montana was predicted to have both long and short-term environmental effects in German Gulch, but the effects were not predicted to be significant in terms of either areal extent or severity. As mentioned above, poor-quality water was not expected to seep out of the pit at the Montana Tunnels Mine until pit water levels equilibrate in 480 years, but the impact on water quality in Spring Creek was unknown.

5.8.3. PREDICTED PIT WATER IMPACTS

The information on predicted pit water quality impacts was summarized and scored according to the following five categories:

- No information available (0)
- Low pit water quality impacts (concentrations less than relevant standards or water quality similar to surrounding groundwater) (1)
- Moderate pit water quality impacts (≥ and up to 10 times relevant standards) (2)
- High pit water quality impacts (>10 time relevant standards) (3)
- No pit lake or long-term standing water expected (underground mine or pit above the water table) (4)

For mines with multiple EISs, the EIS with the highest individual score (1, 2, or 3) for predicted pit water impacts were used as the score for the mine. Scores for predicted pit water impacts were often based on qualitative information or descriptions (e.g., pit water quality expected to be poor). If an EIS entry noted anything regarding predicted pit water quality that was negative, it was scored as a 2 (moderate impacts). If the pit was proposed to be backfilled but the EIS did not address backfill water quality, it was scored as a 0. For mines with multiple proposed pits, the pit with the highest score (1, 2, 3, or 4) was used to score the mine as a whole. Information on long-term pit water quality impacts and the need for perpetual treatment are also discussed.

Table 5.21 lists the mines with predicted pit water quality impacts in each of the five categories.

No Information Available

Twelve (17%) of the mines provided no information on predicted pit water quality. Four of the mines (True North, AK; Royal Mountain King, CA (EIR-EA); Black Pine, ID; Austin Gold Venture, NV) had EAs rather than EISs, and the Morenci and Ray mines in Arizona had land-exchange EISs.

Low Pit Water Quality Impacts

EISs for 12 (17%) of the mines predicted pit water quality would be acceptable for all potential uses, either by being below water quality standards or having a composition similar to surrounding groundwater. Of these, only one (Safford, AZ) conducted pit lake water quality modeling. The Safford Project had high potential (pre-mitigation) pit water quality impacts. The designation as high related predominantly to poor water quality in an existing pit lake.

Two other mines (Grouse Creek and Thompson Creek, ID) had moderate potential pit water quality impacts, and the others in this category all had low potential pit water quality impacts. The main reason given for predicting low pit water quality impacts was the presence of low acid drainage and/or contaminant leaching potential in the pit rather than improvements from any mitigation measures. However, the Lisbon Valley Mine in Utah predicted high potential (pre-mitigation) pit water quality impacts, but dilution from diverted surface runoff was predicted to improve water quality to better than existing groundwater conditions.

Table 5.21. Predicted Pit Water Quality

0		1		2		3		4	
No information available		Low		Moderate		High		No pit lake expected to form (pit above water table or no pit)	
True North	AK	Fort Knox	AK	Sanchez	AZ	McLaughlin*	CA	AJ Project	AK
Red Dog	AK	Safford (Dos Pobres)	AZ	Jamestown*	CA	Golden Sunlight	MT	Greens Creek *	AK
Bagdad*	AZ	Yarnell	AZ	Mesquite*	CA	Montana Tunnels	MT	Kensington Project	AK
Carlotta	AZ	Castle Mountain*	CA	Beartrack	ID	Zortman Landusky*	MT	Pogo Project	AK
Morenci	AZ	Imperial	CA	Copper Flat	NM	Gold Quarry	NV	Cyprus Tohono	AZ
Ray*	AZ	Grouse Creek*	ID	Tyrone Little Rock	NM	Lone Tree*	NV	American Girl*	CA
Royal Mountain King*	CA	Stibnite	ID	Bald Mountain	NV	Twin Creeks*	NV	Hayden Hill	CA
Black Pine	ID	Thompson Creek*	ID	Battle Mountain Phoenix	NV	Gilt Edge	SD	Black Pine*	MT
Stone Cabin	ID	Basin Creek	MT	Cortez Pipeline	NV	Flambeau*	WI	Diamond Hill	MT
Austin Gold Venture	NV	Beal Mountain*	MT	Goldstrike	NV			East Boulder	MT
Dash	NV	Pete	NV	Marigold	NV			Mineral Hill*	MT
Florida Canyon*	NV	Lisbon Valley	UT	Olinghouse	NV			Montanore	MT
				Mule Canyon	NV			Rock Creek	MT
				Robinson (Ruth)	NV			Stillwater*	MT
				Round Mountain*	NV			Troy	MT
								Cortez	NV
								Griffon	NV
								Jerritt Canyon*	NV
								Leeville	NV
								Rain	NV
								Rochester*	NV
								Ruby Hill*	NV
								Trenton Canyon	NV
	12		12		15		9		23

Moderate Pit Water Quality Impacts

Moderate pit water quality impacts were predicted for 15 (21%) of the mines. A number of the mines in this category mentioned the effect of evapoconcentration on pit water quality. Six of the mines in this category conducted pit lake modeling to estimate pit water quality (Mesquite, CA; Cortez Pipeline, Goldstrike, Olinghouse, Robinson (Ruth) and Round Mountain, NV). The Robinson (Ruth), Nevada, EIS mentioned some improvements in water quality resulting from removal of mineralization from mining of the pit.

High Pit Water Quality Impacts

High pit water quality impacts were predicted at nine (13%) of the mines. Five mines in this category modeled pit lake or pit backfill leachate water quality (Gold Quarry, Lone Tree and Twin Creeks, NV; Gilt Edge, SD; Flambeau, WI). The McLaughlin Mine in California expected pit water with high concentrations of metals, even though neutralizing material was present in the pit. The Golden Sunlight Mine in Montana noted the need for perpetual treatment of pit water. The Zortman and Landusky Mine in Montana predicted that backfilling the pit would increase concentrations, at least initially, but that sulfide oxidation could be slowed by backfilling. Pit water quality at the Gold Quarry Mine in Nevada was predicted to exceed concentrations of metals by over 10 times but ultimately to be similar to surrounding groundwater quality. As discussed below, a number of the mines that used modeling to predict pit water quality predicted changing water quality over time in the pit lake or backfill. At the Twin Creeks Mine in Nevada, hydrogeochemical pit lake modeling predicted that antimony, arsenic and thallium would exceed drinking water standards (antimony and arsenic by over 10 times) for the life of the pit but that aluminum concentrations would only be exceeded for the first 27 years until the lobes of the pit lakes merged. The model also predicted that there would be no net outflow to groundwater or surface water.

No Pit Lake or Long-Term Standing Water Expected

Almost one-third (23 or 32%) of the mines predicted that pit water (either in a pit lake or in backfill) would not be present, either because it was an underground mine or because the bottom of the pit would be above the water table. The following mines in this category are all expected to have open pits or backfilled open pits, but the bottom of the pits are predicted to be above the water table: Cyprus Tohono, Arizona; American Girl and Hayden Hill, California; and all the Nevada mines except Leeville, which is an underground mine. The remainder of the mines listed in this category in Table 5.21, including the Leeville Mine in Nevada, are underground mines.

Long-term Pit Water Quality Impacts in Long-Term

A number of mines predicted that pit water quality impacts would occur in the long-term or change over time. A number of the mines that used hydrogeochemical models to predict pit water quality reported predicted changes in water quality over time. For example, in Nevada, the Cortez Pipeline Mine predicted good pit water quality initially, with drinking water standards not exceeded until ~190 years after the end of mining and migration of pit waters into adjacent aquifers more than 250 years after end of mining. Also in Nevada, the Goldstrike Mine pit water was predicted to exceed, in the long term, the drinking water standard for arsenic, cadmium, fluoride, iron, lead, and TDS. Similarly, at the Lone Tree Mine in Nevada, pit lake water quality was predicted to be acidic initially but become neutral after 10 years, exceeding drinking water standards for arsenic and sulfate before it becomes neutral. Cadmium would exceed drinking water standards for only one year, and for nickel, fluoride and antimony exceedence would happen only after 25 years. At the Twin Creeks Mine in Nevada, hydrogeochemical pit lake modeling predicted that antimony, arsenic, and thallium would exceed drinking water standards (antimony and arsenic by over ten times) for the life of the pit but that aluminum concentrations would only be exceeded for the first 27 years until the lobes of the pit lakes merged. The model also predicted that there would be no net outflow to groundwater or surface water. Long-term pit water quality was predicted by modeling to be poor at the Gilt Edge Mine in South Dakota. Zinc and arsenic concentrations were predicted to increase to 8.5 and 1.05 mg/l respectively, by year five after pit closure, and copper concentrations were expected to increase to 0.4 by year 34.

Perpetual Treatment Required

Mines in Montana made long-term pit water quality predictions without modeling, with the Golden Sunlight Mine predicting that water entering or in the pit would require perpetual treatment. The Montana Tunnels, Montana, Mine pit water was predicted to be initially acidic with elevated concentrations of heavy metals, but as the pit continued to fill with water, pyrite oxidation rates were expected to diminish with burial of the diatreme. Finally, at the Zortman and Landusky Mine, pit backfilling was expected to increase loads of contaminants in the short term due to the disturbance of acid generating material, the re-establishment of flowpaths and mobilization of soluble oxidation products.

Proposed Action Would Improve Pit Water Quality

The Lisbon Valley Mine in Utah predicted high potential (pre-mitigation) pit water quality impacts, but dilution from diverted surface runoff was predicted to improve water quality to better than the existing groundwater conditions.

One mine, (Robinson (Ruth), NV) predicted improvement of pit water quality as a result of the proposed actions. Some improvement in pit (Liberty and Ruth pits) water was expected as mineralization is removed by mining. Further, to the extent that acidic solutions were discharged into the pit during historic leaching activities, pit dewatering and subsequent refilling will also result in improved water quality.

5.9. DISCHARGE INFORMATION

In many cases, EISs identified mines or certain facilities at mines (e.g., heap leach pads or tailings impoundments) as “zero discharge” facilities. There is some debate about the meaning of “zero discharge,” because discharges can occur as spills or leaks from liners, despite design requirements. For the purposes of this analysis, a “zero discharge” facility is defined by the design goal rather than the actual performance.

Many mines also have discharges to surface water that are regulated by either federal National Pollution Discharge Elimination System (NPDES) permits or similar permits issued by individual states under EPA authority. EPA classifies larger, more regulated facilities as “major” facilities and smaller facilities as “minor” facilities. These discharges can be treated or untreated, depending on the concentrations in the discharge water.

A smaller number of mines discharge to groundwater, typically through re-infiltration basins, which is a form of land application. Often the water discharged to groundwater is mine or pit dewatering water. Land application or infiltration basins are considered a form of treatment, so technically, all water discharged to groundwater using these methods is treated. It is also possible to re-inject mine water to groundwater through deep wells. However, no mines reviewed used this type of groundwater discharge.

Table 5.22 lists the mines described in EISs as zero discharge facilities and those that propose to discharge to surface water and groundwater. Note that the total number of mines does not add to 71 because a number of the mines do not have surface water or groundwater discharges and are also not zero-discharge facilities.

Zero Discharge Facilities

Twenty-eight (39%) of the mines had proposed zero-discharge designs for at least some of their facilities. Tailings, heap leach, open pits, mills and dams were described as being zero-discharge facilities. Open pits were described as being “zero discharge” facilities if they did not discharge to groundwater and instead acted as a groundwater sink. Using these definitions, mines with individual “zero discharge” facilities could still require a NPDES permit.

Table 5.22. Discharge Information

1		2		3	
Zero Discharge Facility		Discharge to Surface Water		Discharge to Groundwater	
AJ Project	AK	AJ Project	AK	Stillwater*	MT
Fort Knox	AK	Greens Creek*	AK	Cortez Pipeline	NV
Cyprus Tohono	AZ	Kensington Project	AK	Leeville	NV
Morenci	AZ	Pogo Project	AK	Twin Creeks*	NV
Safford (Dos Pobres)	AZ	Red Dog	AK		
American Girl*	CA	Bagdad*	AZ		
Castle Mountain*	CA	Carlotta	AZ		
Hayden Hill	CA	Morenci	AZ		
Jamestown*	CA	Ray*	AZ		
Grouse Creek*	ID	Safford (Dos Pobres)	AZ		
Stibnite	ID	McLaughlin*	CA		
Thompson Creek*	ID	Beartrack	ID		
Beal Mountain*	MT	Thompson Creek*	ID		
Black Pine*	MT	Basin Creek	MT		
Mineral Hill*	MT	Beal Mountain*	MT		
Stillwater*	MT	East Boulder	MT		
Austin Gold Venture	NV	Mineral Hill*	MT		
Battle Mountain Phoenix	NV	Montana Tunnels	MT		
Cortez	NV	Montanore	MT		
Cortez Pipeline	NV	Rock Creek	MT		
Florida Canyon*	NV	Stillwater*	MT		
Griffon	NV	Zortman and Landusky*	MT		
Marigold	NV	Gold Quarry	NV		
Mule Canyon	NV	Goldstrike	NV		
Robinson (Ruth)	NV	Lone Tree*	NV		
Round Mountain*	NV	Twin Creeks*	NV		
Ruby Hill*	NV	Gilt Edge	SD		
Twin Creeks*	NV	Flambeau*	WI		
	28		28		4

Surface Water Discharges

Twenty-eight (39%) of the mines proposed discharging to surface water, and all but one of these (Leeville, NV) had NPDES permits. Of the 28 mines with NPDES permits, ten are major and 13 are minor facilities. For the Leeville Mine, dewatering water was proposed to be disposed of in re-infiltration basins, but if that does not provide sufficient volume, the EIS stated that the dewatering water could be discharged to the Humboldt River. It is notable that eight mines described as zero discharge facilities (AJ, AK; Morenci and Stafford, AZ; Thompson Creek, ID; Beal Mountain, Mineral Hill, and Stillwater, MT; Twin Creeks, NV) also have NPDES permits. In those cases, particular facilities may be identified as "zero discharge" (e.g., heap leach or tailings facility), and/or the NPDES permits are for stormwater and pit dewatering and are not related to the discharge of pollutants.

Groundwater Discharges

Four mines (Stillwater, MT; Cortez Pipeline, Leeville, and Twin Creeks, NV) proposed to discharge to groundwater. At the Stillwater Mine, adit water was proposed to be land applied. At the three Nevada mines, dewatering water was proposed to be discharged to groundwater through re-infiltration basins.

5.10. GENERAL RELATIONSHIPS AMONG ENVIRONMENTAL CHARACTERISTICS IN THE NEPA DOCUMENTS

Sections 5.2 to 5.9 presented the general findings on information in the EISs for the 71 NEPA mines reviewed in detail. In this Section, the relationships among environmental characteristics identified in the NEPA documents for these mines are examined. These characteristics include:

- geology and mineralization
- acid drainage potential
- contaminant leaching potential
- climate
- proximity to water resources

This section examines, for example, if there is a relationship between geology and mineralization and identified acid drainage potential, or between climate and identified proximity to water resources. The study also examines whether there is a relationship between factors such as acid drainage potential and the identified potential for water quality impacts. In theory, there should be a relationship between mineralogy and acid drainage potential, between climate and depth to groundwater, and among these factors and the likelihood that water resources will be impacted.

5.10.1. GEOCHEMICAL CHARACTERISTICS: GEOLOGY/MINERALIZATION, ACID DRAINAGE POTENTIAL, AND CONTAMINANT LEACHING POTENTIAL

In a number of cases, little information was available in the EISs on rock type or mineralization. Geologic and mineralogic information available in the EISs was generally insufficient to make even general predictions about contaminant leaching potential based on mineralogy (e.g., identification of arsenic-containing minerals).

Some of the more notable mines, for which no or insufficient information was available in the NEPA documents, are listed below.

- The Pogo Project in Alaska, which EIS otherwise might be considered one of the more complete and comprehensive from a water quality predictions standpoint.
- Jamestown, McLaughlin and Royal Mountain King mines in California, had EISs that were conducted as part of California's EIR process and have subsequently resulted in contaminant leaching that could have been identified mineralogically.
- The Austin Gold Venture and Rain mines in Nevada where new project permitting was conducted using EAs and contaminant leaching has occurred that could have been predicted from knowing the mineralogy.

In many cases, mines identified with low-sulfide content may be based on insufficient characterization applied to the EIS. For example, Jerritt Canyon's EIS indicates low sulfide content, but the fact that the ore requires roasting before leaching indicates that relatively high sulfide and/or carbon content is present in the ore. Six mines had no information on acid drainage potential, and 15 mines had no information on contaminant leaching potential.

The identification of geology and mineralization, as currently conducted in EISs, is generally a blunt tool for predicting water quality impacts. Geologic and mineralogic information is usually focused on the ore body rather than on all mined materials that could potentially impact water resources. There were relatively weak relationships between geology, mineralization or ore association and acid drainage potential. Mineralization scores that favored acid drainage development (three to five: moderate to high sulfide contents with or without neutralizing material) generally had higher scores for acid drainage potential. However, 50% (nine of 18) of mines that had mineralization/ore associations of four (sulfides present, no associated carbonates) and five (high sulfide content, carbonates low/not present) reported low acid drainage potential. The reasons for the low acid drainage potential scores may be related to different rocks being evaluated for mineralization and acid drainage potential or to other factors that were considered by the mine in determining the potential for acid drainage. However, the discrepancy or lack of good agreement between identified mineralization and acid drainage potential highlights the importance of coordinating mineralogic and acid drainage potential evaluations in the NEPA process. As noted in the companion report (Maest et al., 2005), the same geochemical test units should be used for testing of all parameters used to predict water quality impacts. In addition, more extensive information on mineralogy and mineralization should be included in EISs. Similarly, there was a weak relationship between mineralization and contaminant leaching potential. Of the 18 mines that identified moderate to high sulfides present and little neutralization potential, seven (39%) identified low contaminant leaching potential. In general, rocks with higher sulfide content are expected to leach higher concentrations of contaminants, especially heavy metals.

Although the relationship between acid drainage potential and contaminant leaching potential is not necessarily good, wastes that develop acid drainage usually have high concentrations of other contaminants as well, especially heavy metals. Only four mines identified a high acid drainage potential (Black Pine, Golden Sunlight, and Zortman and Landusky, MT; Battle Mountain Complex, NV). None of these four mines identified a low contaminant leaching potential. However, of the 19 mines that identified a moderate acid drainage potential, seven (37%) identified a low contaminant leaching potential. Twelve mines identified a high contaminant leaching potential. It is possible to have a high contaminant leaching potential and a low acid drainage potential, because acidic conditions are not a requirement for contaminant leaching. Only two mines identified high acid drainage and contaminant leaching potential: Golden Sunlight in Montana, and the Battle Mountain Complex in Nevada. Zortman and Landusky identified both high acid drainage and contaminant leaching potential, but not until the fourth EIS/EA in 2001.

Fourteen mines identified both moderate to high acid drainage and contaminant leaching potential. In theory, these mines should also identify a higher potential for water quality impacts (recall that "potential" refers to pre-mitigation conditions). Ten of these 14 mines (71%) also identified a moderate to high potential for surface water and groundwater quality impacts. However, only one of the 14 mines predicted moderate or high surface water quality impacts post-mitigation (Zortman and Landusky, MT). Only two of the 14 identified moderate or high groundwater quality impacts (Zortman and Landusky and Golden Sunlight, MT). Therefore, even though a high proportion of the mines link geochemical characteristics to water quality, the vast majority declare in EISs that mitigation measures will prevent water quality impacts.

5.10.2. HYDROLOGIC AND CLIMATIC CHARACTERISTICS

Relationship between Proximity to Surface Water and Depth to Groundwater

Based on the data in Section 5.4, hydrology, the surface water and groundwater classifications are compared in Table 5.23. The data indicate that extreme differences in proximity to groundwater and surface water rarely exist. Mines with deep groundwater generally also are located far from surface water resources, and mines with shallow groundwater also are located close to surface water resources. However, some variability within the various classifications does exist (e.g., springs may exist in desert areas with no perennial streams, and deep groundwater may still result in discharges directly to surface water – typically from mine dewatering).

Table 5.23. Comparison of Surface Water and Groundwater Hydrology Classifications for the 71 NEPA Mines Reviewed in Detail

		Groundwater Hydrology Classification							
		No information provided		Depth to groundwater > 200 ft		Depth to groundwater < 200 ft but > 50 ft		Depth to groundwater 0-50 ft and/or springs on site	
Surface Water Hydrology Classification	No information provided	Imperial	CA	Rain	NV			Yarnell	AZ
		Royal Mountain King	CA					Diamond Hill	MT
	Intermittent/ephemeral streams on site-perennial streams > 1 mile away	Copper Flat	NM	Castle Mountain	CA	Cyprus Tohono	AZ	Bagdad	AZ
				Bald Mountain	NV	Mesquite	CA	Safford (Dos Pobres)	AZ
				Cortez Pipeline	NV	Black Pine	ID	Sanchez	AZ
				Griffon	NV	Lisbon Valley	UT	American Girl	CA
				Olinghouse	NV			Cortez	NV
								Florida Canyon	NV
								Gold Quarry	NV
								Lone Tree	NV
	Intermittent/ ephemeral streams on site - perennial streams <1 mile away	True North	AK	Leeville	NV	Marigold	NV	McLaughlin	CA
		Austin Gold Venture	NV	Ruby Hill	NV	Pete	NV	Golden Sunlight	MT
						Round Mountain	NV	Montana Tunnels	MT
								Stillwater	MT
								Battle Mountain Phoenix	NV
								Goldstrike	NV
								Robinson (Ruth)	NV
								Rochester	NV
								Flambeau	WI
	Perennial streams on site	AJ Project	AK	Ray	AZ	Mineral Hill	MT	Fort Knox	AK
		Carlotta	AZ	Montanore	MT	Twin Creeks	NV	Greens Creek	AK
		Tyrone Little Rock	NM	Trenton Canyon	NV			Kensington Project	AK
								Pogo Project	AK
								Morenci	AZ
								Hayden Hill	CA
								Jamestown	CA
								Beartrack	ID
								Grouse Creek	ID
								Stibnite	ID
								Stone Cabin	ID
								Thompson Creek	ID
								Basin Creek	MT
								Beal Mountain	MT
								Black Pine	MT
								East Boulder	MT
								Rock Creek	MT
								Troy	MT
								Zortman and Landusky	MT
								Dash	NV
								Jerritt Canyon	NV
								Gilt Edge	SD

5.10.3. COMBINATIONS OF GEOCHEMICAL AND HYDROLOGIC CHARACTERISTICS AND RELATIONSHIP TO POTENTIAL AND PREDICTED WATER QUALITY IMPACTS

Seventeen of the 71 NEPA mines reviewed identified moderate to high acid drainage potential and close proximity to surface water (perennial streams on site and/or direct discharges to surface water). Of these, 13 (77%) identified a moderate to high potential for surface water quality impacts. However, only two (12%) of these (Thompson Creek, ID and Zortman Landusky, MT) identified a high post-mitigation potential for surface water quality impacts (Table 5.24).

Table 5.24. Potential and Predicted Surface Water Quality Impacts for Mines with Moderate to High Acid Generation Potential and Close Proximity to Surface Water.

Name	State	Surface Water Impact Potential	Predicted Surface Water Quality Impacts
Greens Creek	AK	2	1
Carlotta	AZ	2	1
Hayden Hill	CA	2	1
Grouse Creek	ID	2	1
Stone Cabin	ID	1	1
Thompson Creek	ID	2	2
Beal Mountain	MT	2	1
Black Pine	MT	0	1
Montana Tunnels	MT	2	0
Montanore	MT	0	1
Zortman and Landusky	MT	3	3
Gold Quarry/Maggie Creek	NV	1	1
Goldstrike	NV	2	1
Jerritt Canyon	NV	2	1
Leeville	NV	2	1
Lone Tree	NV	2	1
Twin Creeks	NV	3	1

0 = no information; 1 = low; 2 = moderate; 3 = high.

Twenty of the 71 NEPA mines identified moderate to high acid drainage potential and close proximity to groundwater resources (0 – 50 ft depth to groundwater, springs on site, or discharges to groundwater). Of these, 15 (75%) identified a moderate to high potential for groundwater quality impacts. However, only three (15%) of these (Thompson Creek, ID; Golden Sunlight and Zortman and Landusky, MT) identified a high post-mitigation potential for groundwater quality impacts as shown in Table 5.25.

Similar results were found for the combination of contaminant leaching potential and proximity to water resources. Of the 17 mines with moderate to high contaminant leaching potential and close proximity to surface water resources, nine identified a moderate to high potential (pre-mitigation) for surface water quality impacts, but only two predicted moderate (Bear Track, ID) or high (Zortman and Landusky, MT) impacts to surface water after mitigation were in place, as shown in Table 5.26. Table 5.27 shows that 21 mines identified a moderate to high contaminant leaching potential and close proximity to groundwater resources. Of these 21 mines, 15 identified a moderate to high potential for groundwater quality impacts based on inherent characteristics. However, only four mines predicted that there would be moderate to high groundwater quality impacts after mitigation were in place.

Table 5.25. Potential and Predicted Groundwater Quality Impacts for Mines with Moderate to High Acid Drainage Potential and Close Proximity to Groundwater Resources

Name	State	Groundwater Impact Potential	Predicted Groundwater Impact
Greens Creek	AK	Low	Low
Hayden Hill	CA	Low	Low
Grouse Creek	ID	Low	Low
Stone Cabin	ID	No Info	Low
Thompson Creek	ID	Low	Moderate
Beal Mountain	MT	Low	Low
Black Pine	MT	Moderate	Low
Diamond Hill	MT	Low	Low
Golden Sunlight	MT	High	High
Montana Tunnels	MT	No Info	No Info
Zortman and Landusky	MT	Moderate	High
Battle Mountain Complex	NV	High	Low
Gold Quarry/ Maggie Creek	NV	High	Low
Goldstrike	NV	Moderate	Low
Jerritt Canyon	NV	Moderate	Low
Leeville	NV	High	Low
Lone Tree	NV	High	Low
Robinson (Ruth)	NV	Low	Low
Rochester	NV	Moderate	Low
Twin Creeks	NV	High	Low

These results suggest that even though a high proportion of the mines link a higher acid drainage or contaminant potential and close proximity to water with potential adverse impacts to water quality, the vast majority declare in EISs that mitigation measures will prevent these potential water quality impacts. Predictions of water quality not only do not assume “worst-case” conditions, they consistently assume “best-case” conditions, with all mitigation measures working effectively. Generally, post-mitigation predictions are more qualitative than pre-mitigation predictions (e.g., liners will not leak). As noted in Section 5, for mines with multiple EISs, the score represents the highest acid drainage potential, contaminant leaching potential and highest potential and predicted water quality. If individual EISs were examined, even fewer mines declared that inherent geochemical and hydrologic characteristics could adversely impact water quality.

Table 5.26. Potential and Predicted Surface Water Quality Impacts for Mines with Moderate to High Contaminant Leaching Potential and Close Proximity to Surface Water Resources

Name	State	Surface Water Impact Potential	Predicted Surface Water Impact Potential
Kensington Project	AK	Low	Low
Pogo Project	AK	Low	Moderate
Carlotta	AZ	Moderate	Low
Beartrack	ID	No Info	Moderate
Black Pine	MT	No Info	Low
Mineral Hill	MT	Low	Low
Montanore	MT	No Info	Low
Rock Creek	MT	Moderate	Low
Troy	MT	Low	Low
Zortman and Landusky	MT	High	High
Gold Quarry/ Maggie Creek	NV	Low	Low
Goldstrike	NV	Moderate	Low
Jerritt Canyon	NV	Moderate	Low
Leeville	NV	Moderate	Low
Lone Tree	NV	Moderate	Low
Twin Creeks	NV	High	Low
Gilt Edge	SD	Moderate	Low

5.10.4. CONCLUSIONS

The identification of geology and mineralization, as currently conducted in EISs, is generally a blunt tool for predicting water quality impacts. Geologic and mineralogic information is usually focused on the ore body rather than on all mined materials that could potentially impact water resources. Relatively weak relationships existed between geology and mineralization or ore association. Similarly, a relatively weak relationship existed between geology and mineralization and the potential for water quality impacts. The discrepancy or lack of good agreement between identified mineralization and acid drainage potential highlights the importance of coordinating mineralogic and acid drainage potential evaluations in the NEPA process. As noted in the companion report (Maest et al., 2005), the same geochemical test units should be used for testing of all parameters used to predict water quality impacts. In addition, more extensive information on mineralogy and mineralization should be included in EISs.

The EISs reviewed in detail spanned a period from 1978 to 2004. The availability of geochemical characterization data affects the ability to determine the potential for mines to release contaminants to water resources. Starting in 1980, regulatory agencies began to require or collect basic information on geochemical characterization, such as static and short-term leach testing. After 1990, many of the mines were conducting combinations of kinetic testing and static or short-term leach testing. EISs performed after about 1990 should have more reliable information on water quality impact potential than those with EISs completed before this time.

Table 5.27. Potential and Predicted Groundwater Quality Impacts for Mines with Moderate to High Contaminant Leaching Potential and Close Proximity to Groundwater Resources

Name	State	Groundwater Impact Potential	Predicted Groundwater Impact Potential
Kensington Project	AK	1	1
Pogo Project	AK	3	3
McLaughlin	CA	3	3
Beartrack	ID	0	1
Black Pine	MT	0	1
Golden Sunlight	MT	3	3
Rock Creek	MT	2	1
Stillwater	MT	1	1
Troy	MT	2	1
Zortman and Landusky	MT	2	3
Battle Mountain Complex	NV	2	1
Florida Canyon	NV	3	1
Gold Quarry/ Maggie Creek	NV	1	1
Goldstrike	NV	2	1
Jerritt Canyon	NV	2	1
Leeville	NV	2	1
Lone Tree	NV	1	1
Rochester	NV	2	1
Twin Creeks	NV	2	1
Gilt Edge	SD	2	1
Flambeau	WI	2	1

0 = no information; 1 = low; 2 = moderate; 3 = high.

6. WATER QUALITY PREDICTIONS AND IMPACTS AT NEPA MINES

This section contains a comparison of NEPA document identified potentials, mitigation, and predictions with actual water quality information contained either in subsequent NEPA documents or in other verifiable sources for selected mines.

Each case study includes a brief description of the information contained in the NEPA documents for each mine, along with information on water quality impacts either included in the NEPA documents, or contained in other documents as referenced. A summary of information on the water quality impacts and their causes is then provided for each mine. Additional information including the actual information from the NEPA document or other sources of information is contained in Appendix B Case Study Detailed Information (available at www/kuipersassoc.com or http://www.mineralpolicy.org/publications_welcome.cfm)

6.1. METHODS AND APPROACH

Two levels of study were undertaken for this project. The first level consisted of reviewing all available EISs for information relevant to water quality predictions in Section 5. The second level of study contained in this section, consisted of selecting a more limited number of mines for an in-depth study of predicted and actual water quality. The primary goal of the in-depth studies is to gain insights into the methods and approaches used to predict water quality and to determine whether these tools were successful.

The availability of water quality information after mining began was the primary factor in selecting a mine for in-depth study. For example, a number of operating or recently closed open-pit mines in Nevada and other states have no or very limited information on pit water quality because the mines have not stopped dewatering operations. These mines may have water quality information on groundwater or leachates, but no information is currently available that can be used to compare water quality predicted in the EIS to actual water quality. In addition to the availability of water quality information, the selected mines are also intended to represent a cross-section of commodities, mining types and climates.

In making the final selection of mines for in-depth study, the following priorities were identified:

- mines with long histories and NEPA documentation from new project to reclamation and closure;
- mines with different proximities to water resources but indicating water quality impacts
- mines that conducted some geochemical testing, and if possible, some water quality modeling;
- mines with different potentials to generate acid and leach contaminants to water resources

The list of mines that actually meet these criteria, particularly with respect to adequate reliable evaluations that have addressed water quality predictions and impacts, and are publicly available, is limited. NEPA histories at mines where subsequent EISs have been performed sometimes perform an evaluation of, current conditions and pre-mining predictions. These cases provide the most readily accessible, although not singular, opportunities for insight into the accuracy of water quality predictions as based on the information contained in NEPA documents.

A preliminary evaluation of the availability of operational water quality information was performed before selection of the case study mines. Operational and post-operational water quality information was available from EISs conducted after the new project EIS, especially for the states of Alaska, Montana, and Idaho, where multiple EISs were often available. In other states, such as Arizona, California, Nevada and Wisconsin, technical reports and water quality data were available from state agencies that regulate mining activities.

In addition to NEPA documents, which also include post-mining Engineering Evaluation/Cost Analysis (EE/CA), documents containing additional water quality information from some mines (e.g., Beal Mountain, MT; Grouse Creek, ID), water quality data were obtained for mines in Arizona, Nevada, California, and Wisconsin where situations with multiple EISs did not exist or those EISs did not address water quality impacts. The data for mines was obtained from files at the state regulatory agencies or from reports written by agency personnel or mining company consultants. In many cases the information obtained is useful for pointing out what information was not contained in original NEPA documents relevant to eventual water quality impacts. The authors recognize that additional insights might have been gained by analyzing additional water quality data for the various mine sites, however the focus was on obtaining data that was verifiable and/or otherwise contained in prepared reports as a matter of efficiency.

The information gathered is presented in the form of case studies, which consist of three sections: summary of water quality predictions from NEPA documents; actual water quality data from NEPA documents, state water quality databases and other sources; and a comparison of predicted and actual water quality.

6.2. GENERAL AND ENVIRONMENTAL CHARACTERISTICS OF CASE STUDY MINES

In all, 25 different mines with complete NEPA documents and additional information obtained are presented and examined in detail with respect to water quality predictions and impacts in this section. Table 6.1 shows the complete list of 25 mines selected for case studies.

Table 6.1 Case Study Mines

Name	State
Greens Creek	AK
Bagdad	AZ
Ray	AZ
American Girl	CA
Castle Mountain	CA
Jamestown	CA
McLaughlin	CA
Mesquite	CA
Royal Mountain King	CA
Grouse Creek	ID
Thompson Creek	ID
Beal Mountain	MT
Black Pine	MT
Golden Sunlight	MT
Mineral Hill	MT
Stillwater	MT
Zortman and Landusky	MT
Florida Canyon	NV
Jerritt Canyon	NV
Lone Tree	NV
Rochester	NV
Round Mountain	NV
Ruby Hill	NV
Twin Creeks	NV
Flambeau	WI

6.2.1. GENERAL CHARACTERISTICS OF CASE STUDY MINES

Table 6.2 shows the 25 mines selected for in-depth study and the variability in their locations, commodities, mine operation types, climatic characteristics and proximity to water resources.

Table 6.2 Mines Selected for In-Depth Study: General Mine Site Characteristics

Mine	State	Commodity	Mine Type	Climate	Proximity to Groundwater	Proximity to Surface Water
Greens Creek	AK	Au, Ag, Pb, Zn	UG, FG	Marine West Coast	0-50 ft. or springs	Perennial streams on site
Bagdad	AZ	Cu, Mo	OP, FG, DL-SX	Dry/Arid	0-50 ft. or springs	Perennial streams >1 mi. away
Ray	AZ	Ag, Cu	OP, FG, DL-SX	Dry/Arid	>200 ft.	Perennial streams on site
American Girl	CA	Au, Ag	OP, HL, VL	Dry/Arid	0-50 ft. or springs	Perennial streams >1 mi. away
Castle Mountain	CA	Au, Ag	OP, HL, VL	Dry/Arid	>200 ft.	Perennial streams >1 mi. away
Jamestown	CA	Au	OP, VL	Humid Tropical	0-50 ft. or springs	Perennial streams on site
McLaughlin	CA	Au	OP, VL	Humid Tropical	0-50 ft. or springs	Perennial streams >1 mi. away
Mesquite	CA	Au, Ag	OP, HL, VL	Dry/Arid	<200 ft. but >50 ft	Perennial streams >1 mi. away
Royal Mountain King	CA	Au, Ag	OP, FG, VL	Humid Tropical	No info	No info
Grouse Creek	ID	Au, Ag	OP, HL, VL	Boreal Forest	0-50 ft. or springs	Perennial streams on site
Thompson Creek	ID	Mo	OP, FG	Boreal Forest	0-50 ft. or springs	Perennial streams on site
Beal Mountain	MT	Au, Ag	OP, HL	Boreal Forest	0-50 ft. or springs	Perennial streams on site
Black Pine	MT	Au, Ag, Cu	UG, FG	Boreal Forest	0-50 ft. or springs	Perennial streams on site
Golden Sunlight	MT	Au	UG, OP, VL	Boreal Forest	0-50 ft. or springs	Perennial streams <1 mi. away
Mineral Hill	MT	Au, Ag	UG, VL	Boreal Forest	<200 ft. but >50 ft	Perennial streams on site
Stillwater	MT	PGM	UG, FG, S	Boreal Forest	0-50 ft. or springs	Perennial streams <1 mi. away
Zortman and Landusky	MT	Au, Ag	OP, HL	Boreal Forest	0-50 ft. or springs	Perennial streams on site
Florida Canyon	NV	Au, Ag	OP, HL	Dry/Semi-Arid	0-50 ft. or springs	Perennial streams <1 mi. away
Jerritt Canyon	NV	Au, Ag	UG, OP, HL, VL	Dry/Semi-Arid	0-50 ft. or springs	Perennial streams on site
Lone Tree	NV	Au, Ag	OP, HL, VL	Dry/Semi-Arid	0-50 ft. or springs	Perennial streams >1 mi. away
Rochester	NV	Ag	OP, HL	Dry/Semi-Arid	0-50 ft. or springs	Perennial streams <1 mi. away
Round Mountain	NV	Au, Ag	OP, HL, VL	Dry/Semi-Arid	<200 ft. but >50 ft.	Perennial streams <1 mi. away
Ruby Hill	NV	Au, Ag	OP, HL	Dry/Semi-Arid	0-50 ft. or springs	Perennial streams <1 mi. away
Twin Creeks	NV	Au, Ag	OP, HL, VL	Dry/Semi-Arid	<200 ft. but >50 ft.	Perennial streams on site
Flambeau	WI	Pb, Zn	OP, F	Continental	0-50 ft. or springs	Perennial streams <1 mi. away

The mines studied in detail include one from Alaska, two from Arizona, six from California, two from Idaho, six from Montana, seven from Nevada, and one from Wisconsin. Eighteen mines were primarily gold and/or silver, two were primarily copper or copper molybdenum and one each were platinum group, primary molybdenum, and lead/zinc mines.

Four of the mines selected for study were underground mining operations, while 19 were open pit mining operations. Two were combined open pit and underground mining operations. Five of the mines used flotation (and in some cases gravity) processes exclusively for beneficiation (production of concentrates), two used both flotation and dump leach solvent extraction/electrowinning (SX/EW), and one used dump leach SX/EW processing exclusively. One used flotation with vat leaching processing; while 14 used either heap leaching, vat leaching, or a combination of both processes.

Five mines were located in dry/arid climates, seven in dry/semi-arid climates, eight in boreal forest climates, three in humid subtropical climates and one each in continental and marine west coast climates. Eighteen of the mines selected for study had a depth to groundwater of 0-50 feet or springs on site; four had groundwater depths of between 50 and 200 feet, two had a depth to groundwater of greater than 200 feet, and one had no information on the depth to groundwater. Eleven case study mines had perennial surface water streams on site, seven had perennial streams less than one mile away, six had perennial streams greater than one mile away, and one had no information on the proximity to surface water resources.

The major characteristics of the case study mines were similar to those of all mines with reviewed EISs, as shown in Table 6.3, considering that the availability of information on operational water quality was also a major factor in the selection of case-study mines. The highest percentage of case study mines was from Nevada, and this state had the highest percentage of mines for all major mines, NEPA-eligible mines, and mines with reviewed EISs. Somewhat higher percentages of mines from California and Montana were selected for case studies because of the ease of obtaining operational water quality information from these states.

Similar percentages of gold and/or silver mines were selected for case study as were present in all mines with reviewed EISs. However, a lower percentage of primary copper mines was selected for case study because of the difficulty in obtaining operational water quality information for these facilities. Case study mines and all mines with reviewed EISs had similar distributions of extraction and processing methods. In terms of operational status, no case study mines were in construction, in permitting, or withdrawn because operational water quality information would not be available for mines in these types of operational status.

Case study mines were also similar to all mines with reviewed EISs in terms of EIS elements related to water quality, as shown in Table 6.4. The elements listed in Table 6.3 are considered “inherent” factors that may affect water quality conditions. That is, these elements are related to conditions that are either related to climatic and hydrologic conditions at and near the mine site (in the case of climate, and proximity to water resources) or to qualities of the mined materials that may affect water quality (in the case of acid drainage and contaminant leaching potential). For a number of mines, little or no information on these elements was available in initial EISs, but subsequent NEPA documents either contained the first information or contained improved information after water quality conditions developed at the mine site during and after operation. Therefore, for acid drainage and contaminant leaching potential, the highest documented potential in any of the EISs was recorded.

Case study mines were similar to all mines with reviewed EISs in terms of climate and proximity to surface water resources. When compared to all mines with reviewed EISs, a higher percentage of case study mines had shallower depths to groundwater. However, six of the case study mines had groundwater depths greater than 50 feet below the ground surface. In terms of acid drainage potential, lower percentages of case study mines had low and high acid drainage potential, but higher percentages had moderate acid drainage potential. Therefore, the case study mines provide a somewhat more evenly distributed range of acid drainage potentials than all mines with reviewed EISs. Case study mines had nearly identical percentages of mines with low and high contaminant leaching potential, but more case study mines had moderate acid drainage potential, reflecting fewer mines in the "no information" category for case study mines.

Table 6.3. Comparison of General Categories for All Mines with Reviewed EISs and Case Study Mines (% of mines in subcategory)

Category	Subcategory	All Mines with Reviewed EISs	Case Study Mines
Location	Alaska	10%	4%
	Arizona	11%	8%
	California	11%	24%
	Colorado	0%	0%
	Idaho	9%	8%
	Michigan	0%	0%
	Montana	18%	24%
	Nevada	32%	28%
	New Mexico	3%	0%
	South Carolina	0%	0%
	South Dakota	1%	0%
	Utah	1%	0%
	Washington	0%	0%
	Wisconsin	1%	4%
Commodity	Primary Gold	20%	12%
	Primary Silver	7%	4%
	Gold and Silver	55%	64%
	Copper	20%	4%
	Copper and Molybdenum	1%	4%
	Molybdenum	1%	4%
	Lead and Zinc	6%	4%
	Platinum Group	3%	4%
Extraction Methods	Underground	18%	16%
	Open Pit	72%	76%
	Underground + Open Pit	10%	8%
Processing Methods	Heap and/or Vat Leach	62%	72%
	Flotation and Gravity	27%	28%
	Dump Leach (SX/EW)	11%	8%
	Heap Leach	25%	20%
	Vat Leach	14%	16%
	Heap Leach and Vat Leach	23%	32%
	Smelter	1%	0%
Operational Status	Operating	49%	52%
	Closed	37%	48%
	In Construction	1%	0%
	Permitting	7%	0%
	Withdrawn	6%	0%
Total number of mines		71	25

Table 6.4. Comparison of EIS Elements for All Mines with Reviewed EISs and Case Study Mines (% of mines with sub-element)

Element	Sub-element	All Mines with Reviewed EISs	Case Study Mines
Climate	Dry/Arid	20%	20%
	Dry/Semi-Arid	35%	28%
	Humid Subtropical	4%	12%
	Marine West Coast	4%	4%
	Boreal Forest	28%	32%
	Continental	3%	4%
	Sub-Arctic	4%	0%
Surface Water Proximity	No information	7%	4%
	Perennial Streams >1 mile	26%	24%
	Perennial streams <1 mile	25%	28%
	Perennial streams on site	44%	44%
Groundwater Proximity	No information	12%	4%
	Groundwater >200 ft deep	16%	8%
	Groundwater 50-200 ft deep	13%	16%
	Groundwater 0-50 ft deep/springs on site	59%	72%
Acid Drainage Potential (highest)	No information	9%	8%
	Low	58%	48%
	Moderate	6%	32%
	High	27%	12%
Contaminant Leaching Potential (highest)	No information	22%	12%
	Low	32%	32%
	Moderate	30%	40%
	High	17%	16%
Total number of mines		71	25

Overall, the criteria of having variability in general categories such as geographic location, commodity type, extraction and processing methods and variability in EIS elements related to water quality were met for the selected case study mines. Considering the additional limitation of having readily accessible operational water quality information, the case study mines reflect well the distribution of general categories and water quality-related elements that are present in the larger subsets of hard rock mines in the United States.

6.2.2. ENVIRONMENTAL INFORMATION RELATED TO WATER QUALITY

Table 6.5 shows the mines selected for in-depth study and the variability in their environmental characteristics that may affect water quality. The NEPA information, which was also contained in Section 5, includes geology and mineralization, water quality potential, mitigation, and predicted water quality impacts.

Geology and Mineralization

In terms of geology and mineralization categorizations for the 25 case study mines selected, no or insufficient information was available in the NEPA documents for five mines. Two mines were categorized as having low sulfide content with carbonate present or hosted in carbonate. Eight mines were categorized as having sulfides present with carbonate or moderately high neutralizing-potential rock present and eight were categorized as having sulfides present with no carbonates or carbonates not mentioned or associated with the ore body. One mine was categorized as having high sulfide content with carbonates low or not present.

Table 6.5. Water Quality Characterizations for Case Study Mines.

NEPA EIS Water Quality Category		Greens Creek	Bagdad	Ray	American Girl	Castle Mountain	Jamestown	McLaughlin	Mesquite	Royal Mountain King	Grouse Creek	Thompson Creek	Beal Mountain	Black Pine
		AK	AZ	AZ	CA	CA	CA	CA	CA	CA	ID	ID	MT	MT
Geology and Mineralization		Sulfides present, carbonate or mod-high NP rock present	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body	No/insufficient information available	Gold ore in quartz/magnetite stringers or disseminated. No mention of carbonates	No mention of carbonates; no information on ore mineralogy	No/insufficient information available	No/insufficient information available	Ore in gneiss and granite. No mention of carbonates or sulfides	No/insufficient information available	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body	Sulfides present, carbonate or mod-high NP rock present	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body
Geochemical Characterization and Modeling	Testing Methods	Static, short-term leach, and kinetic tests	Static testing only	No lab/field predictive testing conducted/type unknown	Static ABA and short-term leach tests (WET, SPLP)	Static ABA and short-term leach tests (SPLP)	Short-term leach testing only	Static and short-term leach tests	Static and kinetic tests, whole rock analysis	Static testing only	Static and short-term leach testing conducted	Static, short-term leach, and kinetic testing conducted	Static, short-term leach, and kinetic testing conducted	No information
	Constitutents of Concern	Zinc	Arsenic, fluoride, lead, metals, sulfate	Copper, beryllium, zinc, turbidity, pH	No information	Total dissolved solids	Tailings leachate: barium, arsenic, chromium	Copper	Arsenic, selenium, silver, bismuth, thallium	No information	Lead, arsenic, cyanide, ammonia, nitrate	Cadmium, copper, iron, lead, zinc, selenium, sulfate	Arsenic, cadmium, lead, nitrate, sulfate, cyanide, TDS	Sulfate, copper, zinc, iron, cadmium, low pH
	Predictive Models	Water quality and quantity	None	None	Water quantity	None	None	None	Water quantity and quality	None	Water quantity only	Water quality and quantity	None	None
Water Quality Impact Potential	Acid Drainage	Moderate	Low	No information	Low	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate	High
	Contaminant Leaching	Low	No information	No information	Low	Low	Low	Moderate	Low	No information	Low	Low	Low	Moderate
	Groundwater	Moderate	Low	No information	Moderate	Low	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	No information
	Surface Water	Moderate	Low	No information available	Low	Low	Moderate	Moderate	Moderate	No information	Moderate	Moderate	Moderate	No information
	Pit Water	No pit lake expected to form	Low/similar to surrounding groundwater	No information	No pit lake expected to form	Low	Moderate	High	Moderate	No information	Moderate	Moderate	No information	No pit lake expected to form
Proposed Mitigations	Groundwater	Groundwater/ leachate capture; Liming, blending, segregation, etc. of PAG material	No information	No information	Source controls without treatment	Groundwater/ leachate capture	Groundwater/ leachate capture; Monitoring or characterization	Monitoring or characterization	Groundwater/ leachate capture; Monitoring or characterization	No information	Monitoring or characterization; Source controls without treatment; Liming, blending, segregation, etc. of PAG material	Monitoring or characterization; Groundwater/ leachate capture	Monitoring or characterization; source controls without treatment; Liming, blending, segregation, etc. of PAG material	Source controls without treatment
	Surface Water	Stormwater/ sediment/ erosion controls; Surface water leachate capture/treatment	Stormwater/ sediment/ erosion controls; Source controls without water capture	No information	Source controls without water capture	Monitoring or characterization; Stormwater/ sediment/ erosion controls; Source controls without water capture	Monitoring or characterization; Stormwater/ sediment/ erosion controls; Source controls without water capture; Surface water/leachate capture/ treatment	Stormwater/sediment /erosion controls; Source controls without water capture; Surface water/ leachate capture/ treatment	Monitoring or characterization; Stormwater/ sediment/ erosion controls; Source controls without water capture	Stormwater/ sediment/ erosion controls	Monitoring or characterization; stormwater/sediment /erosion controls; source controls without water capture	Monitoring or characterization; surface water/ leachate capture/ treatment	Stormwater/ sediment/ erosion controls; source controls without water capture	Monitoring or characterization; stormwater/ sediment/ erosion controls; source controls without water capture
	Pit Water	No pit lake will form	Pit lake prevention	No information	No pit lake will form	Pit lake monitoring; Pit lake prevention	No information	No information	No information	No information	Pit lake prevention	No information	Pit lake prevention	No pit lake will form
	Water Treatment	Treatment for metals and/or acid drainage	No information or none identified	No information or none identified	No information or none identified	No information or none identified	Water treatment for cyanide	No information or none identified	No information or none identified	No information or none identified	Treatment for cyanide, metals and/or acid drainage; treatment in perpetuity	No information or none identified	Water treatment for cyanide	No information or none identified
Predicted Water Quality Impacts	Groundwater	Low	Low	No information	Low	Low	Low	High	Low	No information	Low	Moderate	Low	Low
	Surface Water	Low	Low	No information	Low	Low	Low	Moderate	Low	No information	Low	Moderate	Low	Low
	Pit Water	No pit lake expected to form	No information	No information	No pit lake expected to form	Low	Moderate	High	Moderate	No information	Low/similar to surrounding groundwater	Low/similar to surrounding groundwater	Low/similar to surrounding groundwater	No pit lake expected to form
Discharges	Zero Discharge	No information	No information	No information	Yes	Yes	Yes	No information	No information	No information	Yes	No information	Yes	Yes
	Surface Discharge	Yes	Yes	Yes	No information	No information	No information	Yes	No information	No information	No information	Yes	No information	No information
	Groundwater Discharge	No information	No information	No information	No information	No information	No information	No information	No information	No information	No information	No information	No information	No information

Table 6.5. Water Quality Characterizations for Case Study Mines (continued)

NEPA EIS Water Quality Category		Golden Sunlight	Mineral Hill	Stillwater	Zortman and Landusky	Florida Canyon	Jerritt Canyon	Lone Tree	Rochester	Round Mountain	Ruby Hill	Twin Creeks	Flambeau
		MT	**MT**	**MT**	**MT**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**WI**
Geology and Mineralization		High sulfide content, carbonates low/not present	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body	Sulfides present, carbonate or mod-high NP rock present	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body	Sulfides present, carbonate or mod- high NP rock present	Low sulfide content, carbonate present or hosted in carbonate	Sulfides present, carbonate or mod- high NP rock present	Low sulfide content, carbonate present or hosted in carbonate	Sulfides present, carbonate or mod- high NP rock present	Sulfides present, carbonate or mod- high NP rock present	Sulfides present, carbonate or mod- high NP rock present	Sulfides present, no carbonates/ carbonates not mentioned or associated with ore body
Geochemical Characterization and Modeling	Testing Methods	Static, short-term leach, and kinetic tests	Short-term leach and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests	Static, short-term leach, and kinetic tests
	Constituents of Concern	Aluminum, arsenic, cadmium, copper, zinc, pH, sulfate, calcium, magnesium, chromium, iron, lead, manganese, nickel, selenium, nitrate	Arsenic, cyanide, manganese, nitrate	Nitrate	Aluminum, cadmium, iron, copper, fluoride, zinc, cyanide, metallocyanide complexes, low pH, sulfate, nitrate, arsenic	Aluminum, antimony, arsenic, cadmium, iron, lead, mercury, thallium, TDS, cyanide	Arsenic, selenium, nitrate, sulfate	Arsenic, iron, cyanide, antimony, cadmium, nickel, fluoride, sulfate, TDS	Iron, aluminum, copper, lead, cadmium, zinc, pH	Aluminum, arsenic, fluoride, magnesium, nickel, zinc, antimony, selenium, iron, mercury, lead, manganese, nitrate, sulfate, TDS	Arsenic, aluminum, antimony, TDS, pH	TDS, pH, beryllium, cadmium, selenium, zinc, aluminum, antimony, arsenic, iron, manganese, mercury, nickel, thallium, sulfate	Iron, manganese, sulfate
	Predictive Models	Water quality and quantity	Water quantity only	Water quality and quantity	Water quantity only	Water quantity only	None	Water quality and quantity	None	Water quality and quantity	Water quality and quantity	Water quality and quantity	Water quality only
Water Quality Impact Potential	Acid Drainage	High	Low	Low	High	Low	Moderate	Moderate	Moderate	Low	Low	Moderate	No information
	Contaminant Leaching	High	Moderate	Moderate	Moderate	High	Moderate	High	Moderate	High	Moderate	High	Moderate
	Groundwater	High	Moderate	Low	Moderate	High	Moderate	Low	Moderate	High	Low	Moderate	Moderate
	Surface Water	Low	Low	Low	High	No information	Moderate	Moderate	Moderate	Moderate	Low	High	Moderate
	Pit Water	High	No pit lake expected to form	No pit lake expected to form	No information	No information	No pit lake expected to form	High	No pit lake expected to form	Moderate	No pit lake expected to form	High	High
Proposed Mitigations	Groundwater	Monitoring or characterization; Source controls without treatment; Ground-water/ leachate capture with treatment; In-perpetuity capture and/or treatment; Long-term fund	Groundwater/ leachate capture with treatment	Monitoring or characterization; Source controls without treatment; Groundwater/ leachate capture with treatment	Monitoring or characterization; Source controls without treatment; Groundwater/ leachate capture with treatment; Liming, blending, segregation, etc. of PAG material	Source controls without treatment; Liming, blending, segregation, etc. of PAG material	Source controls without treatment; Liming, blending, segregation, etc. of PAG material	Monitoring or characterization; Groundwater/ leachate capture with treatment	No information	Source controls without treatment	Source controls without treatment	Monitoring or characterization; Source controls without treatment; Liming, blending, segregation, etc. of PAG material	Source controls without treatment; groundwater/ leachate capture with treatment
	Surface Water	Surface water/ leachate capture/ treatment; Surface water augmentation/ replacement	No information	Monitoring or characterization; Stormwater/ sediment/ erosion controls; Source controls without water capture	Monitoring or characterization; Stormwater/ sediment/erosion controls; Source controls without water capture; Surface water/ leachate capture/ treatment; In-perpetuity capture/ treatment	Source controls without water capture	Stormwater/ sediment/ erosion controls; Source controls without water capture; Surface water/ leachate capture/ treatment	Stormwater/ sediment/ erosion controls; Source controls without water capture	Stormwater/ sediment/ erosion controls	Stormwater/ sediment/ erosion controls	Stormwater/ sediment/ erosion controls	Monitoring or characterization; Stormwater/ sediment/ erosion controls	Source controls without water capture; Surface water/ leachate capture/ treatment
	Pit Water	Treatment of pit water or backfill amendment	No pit lake will form	No pit lake will form	Pit lake prevention	Pit lake prevention	Pit lake prevention	Pit lake prevention	No pit lake will form	Pit lake monitoring	No pit lake will form	Pit lake monitoring	Pit lake prevention
	Water Treatment	Water treatment in perpetuity	Water treatment using non-conventional approaches	Water treatment using non-conventional approaches	Treatment for cyanide, metals and/or acid drainage; Non-conventional approaches; Treatment in perpetuity	No information available or no water treatment measures identified	No information available or no water treatment measures identified	Treatment for cyanide, metals and/or acid drainage; Treatment using non-conventional approaches	No information available or no water treatment measures identified	No information available or no water treatment measures identified	No information available or no water treatment measures identified	Water treatment for metals and/or acid drainage	Water treatment for metals and/or acid drainage
Predicted Water Quality Impacts	Groundwater	High	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low
	Surface Water	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low
	Pit Water	High	No pit lake expected to form	No pit lake expected to form	High	No pit lake expected to form	No pit lake expected to form	High	No pit lake expected to form	Moderate	No pit lake expected to form	High	High
Discharges	Zero Discharge	No information	No information	No information	No information	Yes	No information	No information	No information	Yes	Yes	No information	No information
	Surface Discharge	No information	Yes	Yes	Yes	No information	No information	Yes	No information	No information	No information	Yes	Yes
	Groundwater Discharge	No information	No information	Yes	No information	No information	No information	No information	No information	No information	No information	Yes	No information

Geochemical Characterization and Modeling

In terms of geochemical characterization and modeling categorizations for the 25 case study mines selected, no or insufficient information was available in the NEPA documents for two mines. Static testing only was performed at two mines and short-term leach testing only at one mine. Static and short-term leach testing were performed at three mines. Static and kinetic testing was conducted at one mine and short-term leach and kinetic testing conducted at one mine also. Static, short-term leach and kinetic testing were conducted at 14 mines.

No information was available on constituents of concern in the NEPA documents for two of the case study mines. The other mines identified a variety of constituents that can be categorized as metals (19 mines), metalloids (14 mines), sulfate (10 mines), nitrogen compounds (eight mines), cyanide (six mines) and other conventional pollutants (11 mines).

No predictive models were used according to the NEPA documents for nine of the 25 case study mines. Only water quantity predictive models were used at four mines while only water quality predictive models were used at one mine. Both water quantity and water quality predictive models were used as a part of the NEPA process at ten mines.

Water Quality Impact Potential

No information on acid drainage potential was contained in the NEPA documents for two of the case study mines. Low acid drainage potential was identified at eleven mines, moderate acid drainage potential at eight mines and high acid drainage potential at three mines.

No information on contaminant leachate potential was contained in the NEPA documents for three of the case study mines. Low contaminant leaching potential (leachate does not exceed water quality standards) was identified at six mines. Moderate potential for elevated contaminant concentrations (leachate exceeds water quality standards by 1-10 times) was identified at 11 mines. High potential for elevated contaminant concentrations (leachate exceeds water quality standards by over 10 times) was identified at four mines.

Groundwater impact information was not available in the NEPA documents for three of the case study mines. Low groundwater quality impacts (< relevant standards) were identified at four of the mines. Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) were identified at 12 of the mines. High groundwater quality impacts (>10 times relevant standards) were identified at five of the mines,

Surface water impact information was not available in the NEPA documents for five of the case study mines. Low surface water quality impacts (< relevant standards) were identified at six of the mines. Moderate surface water quality impacts (≥ and up to 10 times relevant standards) were identified at 11 of the mines. High surface water quality impacts (>10 times relevant standards) were identified at two of the mines.

Pit water impact information was not available in the NEPA documents for five of the case study mines. Low pit water quality impacts (water quality similar to surrounding groundwater or < relevant standards) was identified at one mine. Moderate pit water quality impacts (≥ and up to 10 times relevant standards) were identified at four mines. High pit water quality impacts (>10 times water quality standards) were identified at six mines. No pit lake was expected to form (pit above water table or no pit) at eight mines.

Proposed Mitigation

Groundwater mitigation information was not available or no mitigation were identified in the NEPA documents for four of the case study mines. Groundwater monitoring or characterization of mined materials was identified as a mitigation at 11 mines. Source controls without treatment (liners, leak detection systems, run on/off controls, caps/covers, adit plugging) was identified as a mitigation at 13 mines. Groundwater/leachate capture with treatment was identified as a mitigation at nine mines. Perpetual groundwater capture and/or treatment and/or a long-term mitigation fund were identified as mitigation measures at one mine. Liming, blending, segregation, etc. of potentially acid-generating (PAG) material was identified as mitigation at seven mines.

Surface water mitigation information was not available or no mitigation were identified in the NEPA documents for two of the case study mines. Surface water monitoring was identified as a mitigation measure at seven mines. Stormwater, sediment or erosion controls were identified as mitigation measures at eighteen mines. Source controls not involving capture of water (including liners, adit plugging, caps/covers, leak detection systems, spill prevention measures, and liming/blending/segregating of PAG materials) were identified as mitigation at twelve mines. Surface water/leachate capture and/or treatment (including settling, land application, routing of water, seepage collection) was identified as a mitigation at 10 mines. Perpetual surface water capture and/or treatment were identified mitigation measures at one mine.

Pit water mitigation information was not available or no mitigation were identified in the NEPA documents for five of the case study mines. Pit lake monitoring was identified as a mitigation measure at two mines. Pit lake prevention (backfill, pumping, stormwater diversion, use in mine operation) was identified as a mitigation at nine mines. Treatment of pit water or backfill amendment (e.g., lime addition) was identified as a mitigation at one mine. No pit lake was expected to form (underground mine or pit above water table) at seven mines.

Water treatment information was not available or water treatment was not identified in the NEPA documents for twelve of the case study mines. Water treatment for cyanide was identified as a mitigation approach at five mines. Water treatment for metals and/or acid drainage was identified as a mitigation measure at seven mines. Water treatment using non-conventional approaches was identified as a mitigation method at four mines. Perpetual water treatment to meet discharge standards was identified as a mitigation at three mines.

Predicted Water Quality Impacts

Predicted groundwater quality impact information was not available in the NEPA documents for two of the case study mines. Low groundwater quality impacts (< relevant standards) were predicted at 17 of the mines. Moderate groundwater quality impacts (≥ and up to 10 times relevant standards) were predicted at one mine. High groundwater quality impacts (>10 times relevant standards) were predicted at four mines.

Predicted surface water quality impact information was not available in the NEPA documents for two of the case study mines. Low surface water quality impacts (< relevant standards) were predicted at 18 of the mines. Moderate surface water quality impacts (≥ and up to 10 times relevant standards) were predicted at three of the mines. High surface water quality impacts (>10 times standards) were predicted at one mine.

Pit water quality impact information was not available in the NEPA documents for four of the case study mines. Low pit water quality impacts (concentrations less than relevant standards), or water quality similar to surrounding groundwater were predicted at four mines. Moderate pit water quality impacts (≥ and up to 10 times relevant standards) were predicted at two mines. High pit water quality impacts (>10 time relevant standards) were predicted at six mines. No pit lake (underground mine or pit bottom above water table) was expected to form in eight of the mines.

Discharges

Two case study mines had groundwater discharges, suggesting that 20 of the mines were not expected to have groundwater discharges. Thirteen case study mines had surface water discharges with various forms of NPDES permits, while 12 were not expected to have surface water discharges. Seven mines were identified as “zero discharge” facilities.

6.3. PREDICTED AND ACTUAL WATER QUALITY AT THE CASE STUDY MINES

Summaries for the 25 case study mines are contained in Section 6.3. Ownership, commodities, extraction and processing types, years of operation, acres disturbed, and financial assurance amounts are summarized for each case study mine. Information related to water quality predictions and conditions is summarized in three sections: water quality predictions summary, which contains information from the NEPA documents reviewed; actual water quality conditions; and comparison of predicted and actual water quality conditions. More detailed information on the case study mines is contained in Appendix B Case Study Detailed Information, especially on environmental quality information from the NEPA documents and actual water quality conditions.

6.3.1. GREENS CREEK, ALASKA

The Greens Creek mine, owned by Kennecott Minerals Corporation (70%) and Hecla (30%), has been in operation since 1984. The primary commodities mined are gold, silver, lead and zinc from underground mining and flotation and gravity processing operations. It disturbs 170 acres on Tongass National Forest lands in Forest Service Region 10 (actually within a National Monument). It has a current financial assurance amount of $26.2 million.

6.3.1.1. WATER QUALITY PREDICTIONS SUMMARY

The Tongass National Forest was the lead agency for all NEPA actions at the Greens Creek Mine. NEPA was required for the new project to be permitted, and an EIS was completed in 1983. NEPA was not required by the EPA for the NPDES discharge permit. Subsequent EAs for general operation and waste rock expansion were conducted in 1988 and 1992, respectively. In 2003, an EIS was conducted for tailings disposal. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1983 EIS

The 1983 EIS contains no specific mention of any specific geochemistry field or lab tests performed, however the EIS did identify the potential for the project to degrade surface and/or groundwater as a result of acid drainage. Increased concentrations of total dissolved solids and sulfate were predicted for groundwater in general (no specific mention was made about the basis of this prediction or the actual increased concentrations), but surface water concentrations were predicted to meet regulatory standards due to high dilution (greater than 68:1). Excess tailings liquids and other mine-related discharges were to be released from sediment basins and ponds without further treatment to the marine environment.

1988 EA

The 1988 EA specifically cited the results of "preliminary" lab tests, including sulfur determinations, biological tests and column leach tests performed in 1982 and 1985, as an indication that the tailings would not produce acid drainage. Only one tailings sample was analyzed for acid drainage potential.

1992 EA

The 1992 EA described geochemical tests, including metals analysis, acid-base accounting, synthetic precipitation leach tests and leachate modeling. The results indicated that some waste rock had the potential to be acid-producing, but a greater portion was shown to be acid-neutralizing; Overall, no net acid drainage production was expected from waste rock. Zinc concentrations in waste rock leachate (using existing waste rock material) were predicted to be high (0.5 – 1.3 mg/l), based on the synthetic precipitation leach tests, while other metals concentrations were predicted to be low.

2003 EIS

The 2003 EIS did not address waste rock issues. The 2003 EIS included a hydrology and geochemistry evaluation of the tailings facility in the Appendix. The evaluation included both static and long-term testing. According to the text, static test results indicated that the tailings were potentially acid generating (all static test results indicated an AGP:ANP ratio of greater than 1.0). However, based on humidity cell tests it was concluded that the tailings would not produce acid drainage, although the evaluation acknowledged some inconsistencies in the results. Predictions based largely on oxidation rates projected lag times for acid drainage generation of 10 to 33 years. According to the EIS, reclamation and closure methods would slow or stop the weathering process (e.g., oxidation rates) so that acidification would not occur.

The prediction of no significant acid drainage in the evaluation relied upon the use of a mass loading model (Excel© spreadsheet with Palisade@Risk©) to simulate water quality downgradient from the tailings facility. Modeling results predicted the tailings would remain alkaline for at least 500 years while acknowledging that the prediction of rates of oxidation and acidification are complex and acidic conditions could exist in the tailings. The primary mitigation employed was an engineered soil cover to reduce acidification risk by through reduction of oxygen infiltration.

6.3.1.2. ACTUAL WATER QUALITY CONDITIONS

According to the 1992 EA, actual runoff from the waste rock piles was reported to have an average zinc concentration of 1.65 mg/l.

The hydrology and geochemistry evaluation in the 2003 EIS contained some site water chemistry information that can be used to verify the previous and existing water quality predictions. Tailings facility water had relatively neutral pH values (7.8 to 8.0), increased sulfate concentrations (1,800 to 2,000 mg/l) and low metals concentrations (0.01 mg/l zinc) in the tailings saturated zone. However, underdrain water quality showed some moderate acidity (pH 6.5 to 6.7), generally lower sulfate concentrations (800 to 2,000 mg/l) and higher zinc concentrations (1-2 mg/l) and in the tailings unsaturated zone, new tailings showed lowered pH (5.8 to 6.6) and increased sulfate (2,300 to 2,400 mg/l) with higher zinc concentrations (0.1 – 3.6 mg/l) and additionally significantly increased copper, lead and selenium. Old unsaturated tailings showed a neutral pH (7.5) but high concentrations of sulfate (17,000 mg/l) along with increased concentrations of metals (zinc and magnesium).

According to the 2003 EIS, groundwater quality monitoring wells monitored from 1988 to 2000 have not indicated increasing metal and sulfate levels or acidity so far, although anomalously high sulfate concentrations are noted. Surface water quality monitoring similarly indicates no impacts to surface water quality although some evidence of increased cadmium, copper, mercury and zinc greater than Alaska Water Quality Standards were noted in the late 1980's and 1990. However, the EIS contradicts itself by acknowledging that lower pH, higher sulfate and increased zinc concentrations are evident in some smaller streams. The EIS speculated that the increased concentrations were due to sulfide material (tailings or waste rock) lying outside the tailings pile capture area. The potential for long-term acid drainage from the tailings was mentioned in the 2003 EIS, but impacts occurred in less than 20 years rather than in greater than 500 years.

No reports or notices of violations related to water quality were noted.

6.3.1.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.6 provides a summary and comparison of potential, predicted and actual water quality information for the Greens Creek mine. The accuracy of the predictions is discussed in this section.

Table 6.6. Greens Creek, AK, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings	• 1983 EIS: Increased concentrations of sulfate and TDS in groundwater but no impact to surface water and marine waters due to mitigation • 1988 EA: Testing indicates no potential for acid drainage • 2003 EIS: Tailings have long-term potential for acid drainage	• 1983 EIS: Surface water and marine water dilution adequate to meet standards • 2003 EIS: acid drainage to be mitigated by short-term capture of tailings solution and long-term by reclamation and closure • grade and cap tailings	• 1983 EIS: No impacts to surface water or marine water predicted • 2003 EIS: No impacts from acid drainage for at least 500 years	• 2003 EIS: Old unsaturated tailings leachate, new tailings leachate, and underdrain water quality all show evidence of acidity and increased sulfate and zinc and in some cases copper, lead, magnesium and selenium • 2003 EIS: Surface water quality monitoring indicates some evidence of lower pH and increased cadmium, copper, mercury, sulfate and zinc due to high sulfide material (tailings or waste rock) lying outside the tailings pile capture area
	Waste Rock	• 1992 EA: Some waste rock has the potential to be acid drainage producing but a greater portion is acid drainage neutralizing, with a prediction of no net acid drainage generation from waste rock. • 1992 EA: Zinc concentrations for waste rock leachate predicted to be high (0.5 – 1.3 mg/l) and other metals concentrations low.	• 1983 EIS: Surface water and marine water dilution adequate to meet standards. • 1992 EA: Mixing of waste rock to neutralize acid drainage potential 2003 EIS: Backfilling of waste rock into underground mine	• 1983 EIS: No impacts to surface water or marine water predicted • 1992 EA: No impacts to surface water or marine water predicted	• 1992 EA: Actual runoff from the waste rock piles was reported to have an average zinc concentration of 1.65 mg/l. • 2003 EIS: lower pH, higher sulfate, and increased zinc concentrations are evident in some smaller streams possibly due to high sulfide material (tailings or waste rock) lying outside the tailings pile capture area

<u>Tailings Seepage and Waste Rock Runoff</u>: The observed acidic and metal-rich drainage seeping from the tailings impoundment and the observed high zinc concentrations in waste rock runoff were not predicted in the 1988 EA. In this EA, geochemical testing indicated no potential for acid drainage. The 2003 EIS predicted long-term potential for acid drainage in tailings (10 to 33 years, based on ABA tests), but the post- mitigation (following installation of reclamation covers) prediction, using modeling, indicated that this would not occur for at least 500 years. The long-term potential for acid drainage from tailings occurred in less than 20 years. Therefore, the observed acidic, metal-rich seepage from tailings entering smaller streams mentioned in the 2003 EIS was not accurately predicted in the 1988 EA. The 1992 EA estimated, based most likely on existing leachate concentrations, that zinc concentrations in the expanded waste rock leachate material would be high (0.5 – 1.3 mg/l) but that net drainage from the waste rock would not be acidic. No subsequent information on waste rock leachate concentrations has been obtained to determine if values from the expanded facility are within the predicted range.

Surface water quality impacts: The observed lower pH and increased metal and sulfate concentrations in surface water were not predicted by the EISs. The 1983 EIS predicted that dilution would prevent impacts to surface water. Therefore, the observed surface water quality impacts were not accurately predicted.

6.3.2. BAGDAD, ARIZONA

The Bagdad mine, wholly owned by Phelps Dodge Corporation, is an historic mine that has been in operation since before 1960. The primary commodities mined are copper and molybdenum from open pit mining and flotation and dump leach processing operations. It disturbs approximately 4,424 acres on private land and BLM lands. It has a current financial assurance amount of $12.7 million.

6.3.2.1. WATER QUALITY PREDICTIONS SUMMARY

The BLM has been the lead agency for all NEPA actions at the Bagdad mine. NEPA was not required for the historic mining project to be permitted and was not required by the EPA for the NPDES discharge permit. An EIS was completed in 1996 for only impacts related to the expansion of the mill tailings and waste rock storage areas. The following sections summarize the water quality predictions made in the NEPA document reviewed as well as information on actual water quality.

1996 EIS

The 1996 EIS included information on total sulfur, pyritic sulfur and NP/AP (ABA) testing. Increased (greater than background) concentrations of arsenic, fluoride and lead were noted along with elevated levels of other metals and sulfate. No predictive modeling was performed. According to the EIS, potential adverse groundwater impacts from tailings water would be minimal, and impacts to surface water were predicted to be low, due to construction design of the tailings facilities. The low potential for acid mine drainage was illustrated by the overall quality of the pit water, which had relatively low concentrations of metals and sulfate in a highly mineralized area. The overall quality of the water was described as good with only a few measurements of metals and fluoride that exceeded Aquifer Water Quality Standards. Exceedences were also found in groundwater samples from non-disturbed areas of the mine, suggesting that elevated background concentrations of arsenic, fluoride and lead exist in the groundwater in the Bagdad region.

According to the EIS, mitigation would consist of the majority of the tailings water evaporating off the surface of the facility. Toe channels and underdrains around the South waste rock dump would be used to prevent the percolation of surface water through the facility to minimize infiltration into the aquifer. Surface runoff would be promoted by using grading and a cap. Stormwater diversions would be implemented. Horizontal dewatering wells were proposed to limit water entering the pit and lower the potential for sulfide ore oxidation. The proposed South waste rock disposal facility was not expected to adversely impact groundwater quality, and no impacts to water quality of Francis Creek, Burro Creek, or Big Sandy River were predicted.

6.3.2.2. ACTUAL WATER QUALITY CONDITIONS

Surface water quality monitoring data from the Arizona Department of Environmental Quality (ADEQ) for 1991 to 2004 was obtained and reviewed. In addition, information from an EPA report on damage cases (U.S. EPA, 1997) provided information on releases from the Cyprus Bagdad Mine. The records show that prior to and following the 1996 EIS, water quality impacts had been noted at the site including the following:

- In May-June of 1991, a tailings impoundment failed and discharged to Copper Creek. Elevated concentrations of mercury, phenols, ammonia, copper and acidity occurred in Boulder and Copper creeks, resulting in a fish kill. Boulder Creek was diverted around the spill, and the contamination was reportedly cleaned up.

- In 1991 and 1992 samples were taken from various surface water resources (Boulder Creek, Wilder-Burro Creek, Copper Creek), which showed periodic exceedences of water quality standards for arsenic, beryllium copper, lead, mercury, pH and turbidity. Contaminant sources were not identified.
- From 1998-2002, samples were taken from similar surface water resources (Boulder Creek, Burro Creek, Butte Creek) with periodic exceedences of water quality standards for arsenic, copper, lead, mercury, selenium and turbidity. Contaminant sources were not identified, but exceedences occurred at Phelps Dodge monitoring points.
- In May 1991, seepage of pregnant leach solution from the Copper Creek Leaching System was discovered in a receiving pool in Boulder Creek Studies indicated that instead of being contained by the Copper Creek Flood Basin, the heavily contaminated solution seeped under the dam The concentration of total copper in samples collected in the pool in Boulder Creek was as high as 76.4 mg/l. Out of 18 samples collected from the pool during the month that the seepage was discovered, every sample exceeded background copper levels by more than 0.5 mg/l, the state's Agricultural Livestock Watering Standard for total recoverable copper. No information was available in the files reviewed that clearly documented the source of the infiltration; however, several documents referred to "repairs" to various HDPE liners. It was not clear from information in the files precisely which units were lined, when they were lined, or the capacity or dimensions of the units.
- On March 29, 1993, U.S. EPA issued a Finding of Violation and Order against Cyprus. On September 13, 1996, the U.S. Department of Justice brought civil action against Cyprus for discharging contaminated water in violation of the Clean Water Act and Arizona law. The civil action cited discharges from tailings ponds, pipelines, leach dumps, other facilities and a sewage treatment plant. The largest discharges cited, however, came from the mine's Copper Creek Leaching Basin. In a Consent Decree, Cyprus agreed to pay a civil penalty totaling $760,000.
- Of 143 samples of water collected from January 1992 until October 1993, all of which were collected from sumps installed in the alluvial gravels of Boulder Creek downgradient from the facility, not one sample showed any elevation above background concentrations of copper. The cutoff wall was credited with reducing total copper concentrations in shallow ground water 400 feet downgradient of the wall from 7.2 mg/l before the wall was constructed to 0.8 mg/l afterwards. ADEQ personnel concluded in an internal 1995 memorandum that the overall effectiveness of the remedial measures undertaken by Cyprus was amply demonstrated by the consistently low concentrations of copper measured in sumps downgradient of the wall and the consistently within-standard copper values achieved in the receiving pool. As of November 1996, the available water quality enforcement files did not contain any more information regarding how Cyprus is managing it's PLS pond and other structures.

6.3.2.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.7 provides a summary and comparison of potential, predicted and actual water quality information for the Bagdad mine. The accuracy of the predictions is discussed in this section.

The 1996 EIS identified the potential for acid drainage and other impacts, and suggested that existing water quality did not demonstrate impacts because background water quality had exceedences. The EIS specifically predicted that there would be no impacts to the water quality of Francis Creek, Burro Creek or Big Sand River. However, exceedences of water quality standards were observed in Burro Creek between Francis Creek and Boulder Creek after the 1996 EIS. Therefore, assuming that the source of the exceedences is the mine, the observed water quality was not accurately predicted in the EIS.

Table 6.7. Bagdad, AZ. Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Surface Water	Tailings	1996 EIS: • Potential for acid drainage and other impacts indicated in testing. • Existing water quality does not indicate impacts. • Background water quality indicates natural exceedences.	1996 EIS: • Facility design to prevent groundwater and surface water impacts. o Stormwater diversions o Grade and cap surface o Leachate collection	1996 EIS: • No impacts to water quality of Francis Creek, Burro Creek or Big Sandy River are predicted.	WQ Monitoring (1998-2002): • Boulder Creek: exceedences for arsenic, lead, mercury, and selenium • Burro Creek: exceedences for copper and mercury Butte Creek: exceedences for mercury and selenium

6.3.3. RAY MINE,ARIZONA

The Ray mine owned by ASARCO has been in operation since 1948. It is projected to continue operations until 2044. The primary commodities mined are copper and silver from open pit mining and flotation and gravity and dump leach processing operations. It disturbs 6,231 acres on private land. It has a financial assurance amount of $784,826.

6.3.3.1. WATER QUALITY PREDICTIONS SUMMARY

The BLM has been the lead agency for all NEPA actions at the Ray mine. NEPA was not required for the historic mining project to be permitted and was not required by the EPA for the NPDES discharge permit. An EIS was completed in 1999 only for the impacts related to a proposed land exchange that would enable the mining company to eliminate public lands from within and adjacent to areas of ongoing mine development. The following sections summarize the water quality predictions made in the NEPA document reviewed. Information on actual water quality is discussed in the following section.

1999 EIS

The EIS was completed for a land exchange. No geochemical tests or models were mentioned in the EIS, and as a result, no information on acid drainage potential or contaminant leaching potential was provided. The mine is a porphyry copper deposit.

According to the EIS, the foreseeable mining uses on the selected lands will likely affect groundwater. Similarly, the foreseeable mining uses on the selected lands would result in impacts to surface water sources and features. Impacts to surface water sources and features are not currently known. However, the EIS stated that it is not possible to describe specific details concerning groundwater or surface or water quality impacts because a detailed mine plan has not been developed and because specific designs and measures that may minimize impacts to surface water and groundwater sources and features are not currently known .

6.3.3.2. ACTUAL WATER QUALITY CONDITIONS

Groundwater monitoring data from 1990 to 1994 were obtained from the Arizona Department of Environmental Quality (ADEQ), and information on violations and water quality exceedences from 1990 through 1996 were obtained from U.S. EPA (1997: Damage Cases). Information from both sources indicates the following:

- Due to a spill or spills in 1990, TDS, ammonia, arsenic and copper concentrations exceeded standards along a 14 to 50 mile stretch of the Gila River. Exceedences of up to eight times the standard were noted.
- Tributary headwater streams (Mineral Creek) showed exceedences of arsenic, beryllium, copper and turbidity during the period 1990-1994, and elevated concentrations of copper and zinc in sediment were also noted.
- An ADEQ complaint investigation conducted from 1991-1994 in Mineral Creek from the headwaters to the Gila River, revealed that at multiple sites sampled around the Ray Mine and Gibson Mine, uses were impaired by arsenic, beryllium, copper, low pH, and zinc.
- An EPA copper mine study in 1992 showed that two sites in Mineral Creek had uses impaired by copper and low pH.
- From August 1990 through November 1993, at least 19 spills of hazardous materials were reported at the ASARCO Ray Mine. The majority of spills were from dams, pipelines and ponds. The discharges typically resulted from either accidental releases associated with heavy rain or from chronic seepage from leach facilities to groundwater, which then entered the creek. As a result, surface water quality has been significantly affected. A total of 41 violations of total copper, dissolved copper, and beryllium numeric surface water quality standards was documented by the Arizona Department of Environmental Quality (ADEQ), EPA, and ASARCO in Mineral Creek below the Ray Mine.
- On March 30, 1995, ASARCO noted a low pH reading in Mineral Creek. Upon investigation, ASARCO discovered that a 30-inch gravity flow transit pipeline was leaking. The next day, an HPDE line to the Ray concentrator came apart at the flanged end and released approximately 150,000 gallons of fresh water.
- Unauthorized discharges of Ray Unit process waters to Mineral Creek and Elder Gulch have occurred many times in recent years, including numerous violations of permit effluent limits. During one eight-month period from January to August 1993, nine spills occurred at the mine that resulted in unauthorized discharges to Mineral Creek. The specific causes included overflows, equipment failures and damage caused by heavy machinery. Ambient water quality sampling data have documented non-compliance with water quality standards in Mineral Creek for a variety of metals. Copper concentrations as high as 2.7 mg/l were reported in creek waters below the mine. In 1993, copper concentrations in the creek above 1 mg/l were recorded in May, June, July, August and September. Water quality violations were documented in the same stretch of the creek for beryllium. In March 1993, discharges from a tributary of Mineral Creek that also drains the Ray Unit, Elder Gulch, exceeded standards for hexavalent chromium, sulfide, and total arsenic.
- In December 1992 and January 1993, heavy rains caused the Gila River to breach the AB-BC tailings impoundment containment dike 13 times in January 1993, eroding through the dike and into the toe of the tailings pile. The total discharge was approximately 292,000 tons (216,000 cu yd) of tailings. Sampling of the river showed that elevated concentrations of pollutants occurred at least 11 miles downstream of the spill. The tailings formed bank and bottom deposits in the river, impairing both recreational uses and the quality of habitat for plants and animals. The discharge also had an adverse effect on the sediment loading of the river and stream morphology.

In July 1996, the Arizona Department of Environmental Quality (ADEQ) reported that approximately one-half mile of the Mineral Creek stream bed below the Ray Mine was visibly affected by mining activities. The cobble and gravel substrate was coated with a blue-green layer of copper oxides. According to ADEQ, visible environmental damage to Mineral Creek constitutes a violation of narrative surface water quality standards. quality standards for beryllium, cadmium and copper were also violated in Mineral Creek in April 1996. ADEQ termed the violations a dramatic degradation of water quality by mining activities. In addition, groundwater standards for arsenic, cadmium, pH and beryllium were exceeded in three wells. In April 1995, EPA reported that six groundwater wells downgradient of the electrowinning plant and the electrowinning dam were continuously pumping pregnant leach solution. EPA concluded that it is likely that contaminants are escaping from the Ray Unit and entering Mineral Creek via groundwater.

6.3.3.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.8 provides a summary and comparison of potential, predicted and actual water quality information for the Ray mine. The accuracy of the predictions is discussed in this section.

The 1999 EIS did not provide any information on potential impacts to water quality, with the only mitigation being that all affected water would be captured in the open pit. It did not address the numerous and serious past or existing surface water, groundwater and stream habitat impacts from mine operations. Prior to the 1999 EIS, Ray mine operations did result in degradation of surface water in Mineral Creek and the Gila River with ammonia, arsenic, beryllium, copper, low pH, total dissolved solids, turbidity and zinc.

Table 6.8. Ray, AZ, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings	1999 EIS: • No information provided	1999 EIS: • All affected water to flow towards the open pit capture zone	1999 EIS: • Impacts to groundwater and surface water predicted, but details cannot be described because a detailed mine plan has not been developed.	WQ Monitoring: • Prior to the 1999 EIS significant impacts to surface water and groundwater were identified as a result of tailings spills, leaking pregnant leach solution and other sources

6.3.4. AMERICAN GIRL, CALIFORNIA

The American Girl Mine is owned by MK Gold Company (50%) and Hecla Mining Company (50%). Operations were started in 1995, and the mine closed in 1996. Gold and silver were produced from both underground and open pit operations and were processed using vat leach (for gold) and cyanide heap leach (for silver) methods. It disturbs 155 acres of BLM land in Imperial County and has a current financial assurance amount of $278,750.

6.3.4.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA and CEQA were required for the project to be permitted. An older EA was completed in 1988, and EIS/EIR was completed in 1994. No subsequent NEPA or state equivalent environmental assessments were performed for the project. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1988 EA

Annual precipitation is 3 to 4 inches per year, and evaporation in nearby cities is 100 to 119 inches annually. All the surface drainages in the area are ephemeral, with flows occurring only during and following major precipitation events. Groundwater in the vicinity of the proposed heap leach pad occurs from 80-240 feet bgs.

Gold ore is in quartz/magnetite stringers in metasedimentary and igneous rock. No field or laboratory tests were performed. A water quantity model was performed to predict the amount of drawdown in the groundwater table. No information was provided on acid drainage potential, contaminant leaching potential, or constituents of concern.

A background groundwater quality evaluation showed that TDS, chloride and fluoride concentrations exceeded drinking water standards. Two potential groundwater impacts were identified: drawdown of groundwater in the alluvial deposits due to withdrawal for operations, which could influence surrounding groundwater users, and groundwater quality influences resulting from the heap leach operations. The proposed mine was determined to have no identifiable impact on surface water resources, because surface waters flows only during major precipitation events.

The heap leach pad was proposed to be lined. Ore processing (mill and heap leach) operations were planned to be operated as zero discharge facilities. Inflow of groundwater to mine pits/underground areas was expected to be consumed in zero-discharge project operations (dust control, process water, etc.), which would avoid seepage of contaminated water into groundwater. Diversion ditches above the mining areas were proposed to channel water around active mining and waste rock disposal areas. Sediment traps would be installed, if required, during construction.

No impact to groundwater was predicted with proper installation and operation of the lined pad facility. Even if leachate from the pad bypasses the liner, groundwater impacts were predicted to be minimal, as the leachate would reach the saturated zone after a long travel time, allowing the leachate to be naturally attenuated. The American Girl Canyon Project was predicted to have no identifiable impact on groundwater quality, and other alternatives were expected to have no impact as well. The proposed alternative was also predicted to have no identifiable impact on surface water resources, as surface waters flow only during major precipitation events. In the underground test adit, the first inflows were encountered at an elevation of about 510 above msl, just above the base of the proposed open pits. Therefore, the pit is not expected to contain permanent water after mining.

No information was provided on discharges to groundwater or surface water.

1994 EIS

The mine area is arid, has low amounts of precipitation, arid winds, high temperatures, and a high percentage of sunshine in a desert environment. Average on-site precipitation is 2.14 inches, and at Yuma station, annual evaporation is 97.66. No evaporation data were collected on site. All surface drainages in the area are ephemeral. Flash flooding and sediment-laden flow are common and result in shifting of drainage channel positions. Groundwater in the vicinity of the proposed project occurs in the alluvium of Tumco and American Girl Washes, and in the unconsolidated deposits underlying Pilot Knob Mesa. The depth to groundwater was variable. The bedrock groundwater table was generally 100 ft deep in the American Girl Wash. Exploration holes drilled to depths of 500-600 ft bgs have significantly lower water levels. Groundwater in the vicinity of the existing leach pad and open-pit occurs at a depth ranging from 35-240 ft bgs. The Padre Madre Wash had drill holes completed to depths of at least 200 ft below the base of the canyon floor, and they were dry. The Tumco Wash exploration holes were dry to the 500 ft elevation with some seeps and inflows below this elevation. Water has been encountered in exploration holes at depths of 700 ft Depths to groundwater in the Pilot Knob Mesa range from 200-400 ft.

Mineralization has a strong quartz-magnetite association and is characterized by irregular stringer zones containing the two minerals. High grade zones may occur as semi-massive lenses up to several feet thick. Gold occurs within the magnetite-quartz stringers or is disseminated in the surrounding wall rock. Geochemical testing of waste materials from the Padre Madre and American Girl Canyon mine operations have shown little potential to generate acid or leach metals or other constituents at concentrations of concern for waste characterization or water quality. Waste Extraction Test (WET) results for the Oro Cruz tailings would be classed as a Class C (inert) waste. The Oro Cruz tailings and spent ore would not be acid generating (total sulfur less than 0.01%). EPA Method 1312 (SPLP) tests showed that the Oro Cruz tailings would not leach metals or other constituents of concern to surface water or groundwater. Due to the degree of oxidation of the ore and waste rock, acid generation would not be significant.

The Proposed Oro Cruz operations may impact groundwater by accidental leakage of solutions from the American Girl Canyon heap leach facility. A potential impact of mine waste material and exposed mineralized areas would be the leaching of constituents from these materials into surface water. The depths of open-pit mining in the proposed

Cross and Queen pits would generally be above the levels of groundwater encountered in Oro Cruz exploration holes. Groundwater inflows into the mine pits would be non-existent or limited to minor seeps.

For mitigation, processing facilities would continue to be regulated as a zero discharge site by the RWQCB requirements.

Oro Cruz tailings and spent ore were not predicted to leach metals or other constituents of concern for contamination of groundwater. The impact to groundwater quality from the leach pad was not predicted to be significant. Surface water quality data are unavailable due to the ephemeral nature of the streams. The impact of Oro Cruz operations on surface water quality was not predicted to be significant. The depths of open-pit mining in the proposed Cross and Queen pits would generally be above the levels of groundwater encountered in Oro Cruz exploration holes. Groundwater inflows into the mine pits were expected to be non-existent or limited to minor seeps.

No information was provided on discharges to groundwater or surface water.

6.3.4.2. ACTUAL WATER QUALITY CONDITIONS

The information on actual water quality conditions was based on a phone call with staff from the Regional Water Quality Control Board (RWQCB) in Palm Desert, California in September 2004. The American Girl Mine has completed mining operations, and the RWQCB rescinded their permit in 2004. The groundwater wells were abandoned and completely reclaimed after five years of post-closure monitoring (every six months). No water quality problems were encountered, but after shut down, one sampling had elevated copper concentrations in the groundwater. The RWQCB required monitoring for an additional five years, and no problems were encountered during this period. Groundwater monitoring was required for TDS, pH, copper, total cyanide, sulfate, arsenic, gold, silver, mercury, iron, nitrate and selenium.

6.3.4.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.9 provides a summary and comparison of potential, predicted and actual water quality information for the American Girl Mine. The accuracy of the predictions is discussed in this section.

To date, no groundwater, surface water or pit water quality impacts were observed.

Table 6.9. American Girl, CA, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings and Spent Ore	• Accidental leakage of solutions from the American Girl Canyon heap leach facility to groundwater	• Zero-discharge processing facilities	• No leaching of contaminants from spent ore to groundwater. Impact to groundwater from leach pad not significant	• None
Surface Water	Mine waste/ ore/exposed mineralized areas	•Leaching of constituents from mine waste/ exposed mineralized areas to surface water	• Zero-discharge processing facilities	• Impact to surface water quality not significant	• None
Pit Water	Open pit walls	• Groundwater inflows into the mine pits would be non-existent or limited to minor seeps.	• Zero-discharge processing facilities	• Groundwater table below bottom of pits	• None

6.3.5. CASTLE MOUNTAIN, CALIFORNIA

The Castle Mountain Mine, also known as the Viceroy Mine, is located in San Bernardino County and is owned by Viceroy Gold Corporation (75%) and MK Gold Company (25%). The mine operated from 1992 to 2001. Gold and silver ore are extracted from an open pit, and heap and vat leach processing were used. The mine is located on 3,645 acres of BLM land in the Needles District and 265 acres of private land; the number of disturbed acres is unknown. The bond amount is $1,605,000.

6.3.5.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA and CEQA were required for the new project to be permitted. A new project EIS/EIR was completed in 1990 (document not obtained after numerous attempts), and an expansion EIS was completed in 1997. The expansion included increasing the area of open pit, creating an overburden storage site and expanding the heap leach pad. There are no NPDES permits for the mine. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1998 EIS/EIR

The mine is in an arid desert setting. Precipitation in the New York Mountains in the northwest boundary of the valley exceeds 10 inches, while the valley floor receives ~8 inches. Streams within the basin are ephemeral, with the exception of Piute Spring, which flows perennially and is several miles from the mine site. Depth to groundwater is shallowest in the western recharge portion of the basin and becomes deeper toward the east. The general groundwater flow direction is toward the east-southeast. Depths in monitoring wells in the vicinity of the project area in 1990 ranged from ~360 - 750 feet.

Volcanic, metamorphic and igneous (granitic) rocks are in the project area. Recent alluvium has filled Lanfair Valley with 550-1000 ft of clay-rich Pleistocene age lacustrine deposits that are interbedded with Pleistocene lava flows. Static (ABA) and short-term leach tests (EPA Method 1312 - EP Toxicity test) were performed. Both the raw ore and leached ore show little to no potential to generate acid. Existing data indicate little potential for acid-producing conditions. Total sulfur was below detection in the overburden. In raw and leached ore, the NP/AP was 2.7 and 8.0 respectively. Soluble metals in the ore and overburden are non detectable for most metals. None of the results exceed California Soluble Threshold Limit Concentrations.

Due to low metal concentrations, the extremely dry site environment, and the net neutralizing potential of the ore and waste rock, the geochemistry of materials that would be mined was not expected to pose a threat to surface or groundwater quality. Because of the low soluble metals concentrations and the high NP:AP ratio of ore and overburden that would remain in the mine pit walls, it is expected that the quality of any water that could collect in the mine pits would be good. This water would be suitable for wildlife use.

The heap leach pads were planned to be lined, and sealed drainage/collection facilities would transport and contain the leaching solution. Leach pads dikes were proposed for confining and controlling drainage from the leach piles. At project completion, heap leach piles will be neutralized and rinsed and solution will be removed from storage facilities. Leakage detection/ monitoring system will be employed for the leach pads, emergency solution storage and storm water storage basins. If a pit lake forms, it will be monitored monthly for conformation to state and federal water quality standards. Should any pit lake constituent exceed a federal or state MCL, the pit will be backfilled above the high water level. Storage basins will be constructed with adequate freeboard to preclude entry of storm water into the system. No water quality impacts were expected after mitigation are in place.

No information was provided on discharges to groundwater or surface water.

6.3.5.2. ACTUAL WATER QUALITY CONDITIONS

Based on a phone call with staff of the Palm Desert Regional Water Quality Control Board in September 2004, the Castle Mountain, or Viceroy, Mine is in the process of closure and is still monitoring groundwater for TDS, total and free cyanide and arsenic. Groundwater at the site is approximately 600 ft deep, and there is no surface water near the mine. The Regional Board tests for heap leach impacts to groundwater from the pads and the ponds, with an emphasis on cyanide.

6.3.5.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.10 provides a summary and comparison of potential, predicted and actual water quality information for the Castle Mountain Mine.

Mitigation were used even though the potential for water quality impacts was low. There were no impacts to date.

Table 6.10. Castle Mountain, CA, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and surface water	Heap leach facility	• No threat to surface water or groundwater quality due to dry site environment and low potential to generate acid and metals	• Lined heap leach pad, leachate collection systems, leach pad dikes; rinsing and neutralization upon closure	• Same as potential	• None to date
Pit Water	Open Pit	• Good pit water quality due to low potential for acid generation and metals leaching; suitable for wildlife use.	• Monitoring; backfilling if standards exceeded	• Same as potential	• None to date

6.3.6. JAMESTOWN, CALIFORNIA

The Jamestown mine, owned by Sonora Mining Corporation, began operation in 1987 and closed in 1994. The primary commodity mined was gold from open pit mining and flotation processing, with vat leach processing operations conducted off-site. The mine is located on private lands. There is no current financial assurance for the mine.

6.3.6.1. WATER QUALITY SUMMARY

The County of Tuolumne has been the lead agency under the California Environmental Quality Act (CEQA) for the new project to be permitted, and an EIS/EIR was completed in 1983. Supplemental EIS/EIRs were conducted in 1986 and 1989 (not obtained), and an EIS/EIR was conducted in 1991 for mine expansion. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1983 EIS/EIR

According to the 1983 EIS/EIR, the Mother Lode ore zone is a quartz-rich and separated by a slate (phyllite) and serpentenite assemblages. A short-term leach test (WET or CAMWET test) was the only field or laboratory test mentioned in the EIS/EIR. Barium, arsenic and chromium were noted in the tailings leachate. Acid drainage potential was not specifically addressed. According to the EIS/EIR, the most important potential groundwater impact is the long-term migration of leachate generated from the tailings site. Dissolved constituents derived from the stockpiles may pass through the sedimentation ponds and eventually discharge to surface water. Accidental damage to the tailings pipeline could release chemical constituents (e.g., barium, arsenic, chromium) to surface water. Surface mine pits will be allowed to fill with water. The precise water quality of these ponds was not determined for the EIS/EIR but would presumably be of poorer quality than the pre-mining groundwater due to the effects of oxidation and evaporation.

According to the EIS/EIR, mitigation consisted of the tailings embankment being designed as a zero discharge system, but the potential for tailings water to seep from the pond into surface water was acknowledged. Surface water or groundwater quality impacts were not expected after mitigation are in place. The only impact that could not be mitigated would be lowered groundwater levels in the drawdown area near the pit.

1991 EIS/EIR

The proposed expansion included utilization of cyanide for leaching on site (not previously proposed or used). Short-term leach testing (CAMWET test) was performed on flotation tailings, thiourea tailings and representative rock and soil samples. Results indicated that the mine tailings will not contain contaminants that need to be controlled, and the overburden material was non-hazardous, non-toxic, and non-acid generating. According to the EIS/EIR, overall groundwater quality may be impacted to some degree by the quality of water in the abandoned pits. The impoundment water may contain concentrations of total dissolved solids higher than is currently present in the bedrock groundwater systems. Overburden storage areas could potentially impact the quality of surface waters, and the solution could potentially seep from the tailings facility into surface water.

According to the EIS/EIR, mitigation consisted of the zero discharge tailings embankment, the use of cyanide destruction processes, dilution of cyanide tailings with flotation tailings and monitoring. Erosion control structures for the tailings management facility were also mentioned. Potential impacts to groundwater and surface water were expected to be insignificant.

1985 Report of Waste Discharge

A 1985 Report of Waste Discharge (RWD) was obtained from the RWQCB. According to the report, hydrothermal solutions have mineralized ultrabasic intrusive rocks, sediments and volcanics, but the percentages of sulfides were low.

Waste Extraction Tests were performed on four samples: Composite head sample = ore from diamond drill core; Sample C = tailings and process water produced by thiourea leaching of the flotation concentrate; Sample D = tailings and process water produced by cyanide leaching; and Test #20 Tail = tailings from froth flotation testing without residue from treatment of the concentrate. A Potential Acidity with Peroxide test, described in EPA 670/274-070, pg 48-49, was also performed. Neutralization potential was tested using the procedure by Grube (pg 50-51 of the Report of Waste Discharge).

Each of the four samples was divided into two samples (A and B). For the composite head sample (ore), there were no exceedences of standards in the extract. For sample C (thiourea tailings), there were exceedences of arsenic (18 and 19 µg/l). Sample D (cyanide tailings) had exceedences of arsenic (15, 16 µg/l) and TDS (551, 550 mg/l). Sample Test #20 (froth flotation tailings) had one exceedence of arsenic (15µg/l). Generally all concentrations were low.

Acid base accounting tests were performed. The NP/AP ratios were 6.8 for the ore tailings, 2.8 for the thiourea tailings, and 3.1 for the cyanide tailings. The froth tailings generated no acid. Additional ore and waste rock samples (one ore and 5 waste rock) all had NP/AP values of between 3.5:1 and 47:1.

The Jamestown Mine (Harvard and Crystalline pits) was proposed to be operated as a closed system, with the exception of some seasonal surface runoff from the east side of the property that will be closely monitored.

6.3.6.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring data from 1988 to 2003 were obtained from the RWQCB and reviewed. No information was obtained on the number of surface water and groundwater monitoring locations, and no information was available on baseline water quality conditions or water quality violations.

The records show the following information on operational water quality:

- Exceedences of sulfate, nitrate and arsenic drinking water standards occurred in some groundwater monitoring wells. Downgradient of the waste rock and tailings management facilities, sulfate, nitrate, TDS and arsenic concentrations increased over time. Sulfate concentrations steadily increased (up to ~2,000 mg/l) since ~ 1990; nitrate concentrations increased (up to ~600 mg/l) from ~1990 to ~1997 and then decreased); total dissolved solids concentrations were as high as ~3,200 mg/l and are continuing to increase; and arsenic concentrations (up to 20 μg/l), may have peaked in the mid-1990s. For example, sulfate concentrations downgradient of the waste rock dump increased from 50 mg/l in January 1990 to 2,600 mg/l in May 2003, and increased in groundwater downgradient of the tailings facility from 63 mg/l in January 1988 to 2,000 mg/l in October 2003. TDS concentrations in a tailings area monitoring well increased from 310 mg/l in February 1988 to 3,200 mg/l in October 2003.
- Sulfate and nitrate concentrations exceeded drinking water standards in the Harvard Pit. Sulfate concentrations were continually increasing (up to ~1,200 mg/l), arsenic concentrations may have peaked in late 1990's (max. conc. = 1,600 μg/l l), and pH values decreased from ~8.5 (1987) to ~6.8 (2000). Sulfate concentrations were 10 mg/l in April 1988 (and then less than 200 mg/l for the remainder of 1988) and increased steadily to 1,200 mg/l in May 1999 and May 2003. Arsenic concentrations were ~10 μg/l in 1988 but increased to 1,600 μg/l in July 1991 and, with two exceptions, were >400 μg/l since 1995.

Before closure, Sonora Mining Company sold much of the land at the mine to Tuolumne County, and the county indemnified the mine, at the same time canceling a $3 million insurance policy for mine remediation. Since then, the RWQCB has sued the county for water quality violations related to the tailings impoundment and waste rock piles. The pit water at the site is considered groundwater, but there has been no official ruling yet on whether it is groundwater or surface water. The water level in the pit will be rising for the next 40 to 50 years. There were no notices of violation for pit water quality (RWQCB, October 2004 conversation).

6.3.6.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.11 provides a summary and comparison of potential, predicted and actual water quality information for the Jamestown mine. The accuracy of the predictions is discussed in this section.

Observed Groundwater Quality Impacts from Tailings and Waste Rock: The 1983 EIS/EIR indicated the potential for migration of tailings leachate to groundwater. However, no impacts to groundwater quality were predicted after mitigation were in place. The RWD noted that acid drainage potential was low but that there was potential for generation of contaminated leachate from the tailings. However, this information was not noted in the EIR/EIS.

The 1991 EIS/EIR also indicated no potential for acid drainage or other contaminants, although it does indicate that tailings and waste rock seepage with high TDS could impact groundwater and/or surface water. Laboratory test results indicated that the mine tailings will not contain contaminants that need to be controlled, and that the overburden material was non-hazardous, non-toxic and non-acid generating. Arsenic and TDS drinking water standards were slightly exceeded in the short-term leach tests performed on the tailings, but actual concentrations of arsenic, TDS, sulfate, and nitrate were substantially higher in groundwater.

Table 6.11. Jamestown, CA. Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings	• 1983 EIS/EIR: Migration of tailings leachate to groundwater and surface water 1991 EIS/EIR: No potential for acid drainage or other contaminant leaching. Seepage with high TDS could impact groundwater and/or surface water. Exceedences of As and TDS drinking water standards in short-term leach tests; NP:AP ratios 2.8 and 3.1.	• 1983 EIS/EIR and 1991 EIS/EIR: Facility design to prevent groundwater and surface water impacts. • Embankment design (zero discharge) • Compact tailings subsurface (no liner) • Grade and cap surfaces	• 1983 EIS/EIR: No impacts to surface water or groundwater quality after mitigation are in place • 1991 EIS/EIR: Potential impacts to groundwater and surface water are expected to be insignificant	WQ Monitoring: Groundwater affected by tailings and waste rock. Sulfate, nitrate, TDS and arsenic concentrations have increased significantly and exceed drinking water standards
	Waste Rock	• 1983 EIS/EIR: Migration of leachate to groundwater and surface water. Water quality from stockpiles would be of similar or lower quality than the pre-mining groundwater 1991 EIS/EIR: No potential for acid drainage or other contaminants. NP:AP ratios 3.5 to 47; no short-term leach testing on waste rock. Waste rock could affect surface water quality	• 1983 EIS/EIR: No mitigation identified • 1990 EIS/EIR: No mitigation identified		
Pit Water	Open Pit	• 1983 EIS/EIR: Similar or lower quality than premising groundwater due to oxidation and evaporation. Potential impacts to groundwater from water in pits. • 1991 EIS/EIR: Groundwater quality may be impacted by water in the abandoned pits	• 1983 EIS/EIR: No mitigation identified • 1990 EIS/EIR: No mitigation identified	• 1983 EIS/EIR: No impacts to surface water or groundwater quality after mitigation are in place • 1991 EIS/EIR: Potential impacts to groundwater and surface water are expected to be insignificant. No estimates of pit water quality.	Pit water sulfate concentrations have been continually increasing (up to ~1,200 mg/l), arsenic concentrations may have peaked in late 1990's (max. conc. = 1,600 μg/l), pH decreased from ~8.5 (1987) to ~6.8 (2000).

The EIS predicted that impacts to groundwater and surface water after mitigation are in place are expected to be insignificant. Therefore, the potential (pre-mitigation) water quality was a better measure of actual water quality than the predicted (post-mitigation) water quality impacts. Additionally, the 1991 EIS/EIR did not note the exceedences of sulfate, nitrate, TDS and arsenic in groundwater that were already evident in groundwater monitoring data by 1990. The test results were inaccurate, because contaminants have leaked from the tailings impoundment and the waste rock and impacted groundwater.

Observed Pit Water Quality Impacts: The 1983 EIS/EIR did indicate that pit lake water quality would be poorer than pre-mining groundwater quality. However, no details on the types of impacts (chemically) were presented. Therefore, predictions of pit water quality were correct generally, but neither the contaminants of concern nor the concentrations were estimated in the EIRs.

6.3.7. MCLAUGHLIN, CALIFORNIA

The McLaughlin Mine was owned by Homestake Mining Company and operated from 1985-2002. The primary commodity mined was gold from open pit mining and pressure oxidation of sulfide/refractory ore followed by vat leach cyanide processing operations. It disturbs 803 acres in the Ukiah District on BLM land. It has a current financial assurance amount of $12.2 million.

6.3.7.1. WATER QUALITY PREDICTIONS SUMMARY

The counties of Yolo, Napa and Sonoma were the lead agency under the CEQA for the new project to be permitted, and an EIS/EIR was completed in 1983. NEPA/CEQA was not required for the NPDES discharge permit. No subsequent NEPA or state equivalent environmental assessments were performed for the project. The following sections summarize the water quality predictions made in the NEPA document reviewed as well as information on actual water quality.

1983 EIS/EIR

Static and short term leach testing, paste pH, and an unidentified water quality model were presented as characterization and modeling approaches in the EIS/EIR. Copper, manganese and TDS were identified as the constituents of concern. They identified the potential for permanent degradation of groundwater quality; however, surface water quality impacts were predicted to be minimized with the implementation of mitigation measures. The pit water was predicted to be of poor quality.

According to the EIS/EIR, geochemical testing consisted of static (similar to NAG – using hydrogen peroxide), short-term leach (deionized water extraction test; California Waste Extraction Procedure), and paste pH tests. Modeling (type of model not specified) of impacts to surface water (Hunting Creek) quality was conducted. Constituents of concern identified included copper, manganese and total dissolved solids.

Ninety-two percent of the waste rock was determined to be either neutral or neutralizing. Comparison of the (tailings) extract analysis concentrations (from the WET test) with the health-based Soluble Threshold Limit Concentrations (STLCs) showed that the concentrations of copper exceeded the STLC; therefore, the tailings were considered hazardous. In addition to high copper values, the tailings extract also had lead, arsenic, silver and cyanide concentrations in excess of water quality standards.

According to the EIS, permanent degradation of groundwater quality was expected, due to tailings seepage. Potential impacts from waste rock to surface water included: (1) increased sedimentation from runoff, (2) increased total dissolved solids from leachate, and (3) increased heavy metal concentrations from acidic leachate. Water accumulated in the pit was expected to be of poor quality, with high concentrations of heavy metals and major ions including arsenic, cadmium, iron, lead, manganese, mercury, nickel, boron, sodium, chloride and sulfate.

Mitigation identified in the EIS included groundwater monitoring and underdrains for waste rock piles. Erosion/sedimentation controls would be used to protect surface water from waste rock impacts. Lime will be added to sediment ponds if acidic conditions are encountered during mining. Potentially acid generating rock will be surrounded by alkaline material during waste rock disposal. No mitigation for pit water or the tailings facility were identified.

The proposed tailings facility would allow 40 gpm of seepage to local groundwater underlying the reservoir. This impact would be long term, resulting in permanent degradation of the local groundwater and potentially of the shallow groundwater flowing toward surface water. Existing groundwater data in the tailings area showed poor quality water with long residence times and very low permeability. Therefore, although the proposed action and alternatives would lead to permanent degradation of localized groundwater, local water supplies would not be impacted, because the groundwater regime in the valley in which the tailings impoundment is located has not been found to be connected to a regional aquifer system, and the dam foundation would penetrate to less permeable material. There was predicted to be no impact to surface water quality under normal operation of the mill facilities.

Possible releases of TDS could occur from the waste rock dump but were planned to be collected in the underdrains, the diversion ditches, or in the sediment impoundment. Modeling indicated that arsenic, nickel, zinc, silver, iron, and copper concentrations would be lower than drinking water standards in surface water. Manganese was predicted to slightly exceed its standard.

The quality of water accumulated in the pit was expected to be of poor quality, with high concentrations of metalloids, heavy metals and major ions, including arsenic, cadmium, iron, lead, manganese, mercury, nickel, boron, sodium, chloride and sulfate. Alkaline-producing materials in the rocks would likely produce alkaline pH conditions in the mine pit water and would tend to reduce metals leached from the rocks. Pit water would not reach surface streams, and no impacts on the quality of surface water were anticipated.

6.3.7.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring data were obtained from the RWQCB in Sacramento for 1982 to 2004 and included the following:

- Baseline water quality data from 1982 – 1986 indicate that groundwater hydraulic conductivity is low and existing water quality poor and groundwater is considered to be unusable. The mine obtained an exclusion for meeting groundwater standards at the site, with groundwater standards set at no increase over background.
- Groundwater monitoring wells downgradient of the tailings impoundment showed increases and exceedences of TDS, chloride, nitrate, and sulfate from ~1984 to ~1992, with increases of copper and other metals during the same period.
- Groundwater monitoring wells downgradient of the waste rock dumps show increasing concentrations of sulfate (in excess of SDWA standards), boron, TDS, calcium, iron, manganese and other constituents from ~1985 to ~1998. Zinc concentrations increased after 1998.
- Surface monitoring locations downstream of the mine show exceedences of sulfate and occasionally large exceedences of arsenic, chromium, copper, lead, manganese mercury, lead, iron and zinc.
- The open pit also receives pump-back water from the waste rock dumps, so water chemistry may also reflect waste rock drainage/leachate. Pit water exceeds secondary drinking water standards for pH (low), TDS, chloride, sulfate, iron and manganese. If pit water discharges to surface water, the elevated concentrations of copper, nickel, and zinc could cause exceedences of standards for the protection of aquatic life.
- No violations were noted. According to the RWQCB, if concentrations chronically exceed standards, enforcement actions are issued. However, apparently due to the regulatory exclusion for groundwater at the site no enforcement actions were taken by the RWQCB despite evidence that groundwater has been chronically degraded below the tailings impoundment and waste rock storage areas. Similarly, no enforcement actions were taken by the RWQCB, despite apparent evidence of chronic degradation of surface water.

6.3.7.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.12 provides a summary and comparison of potential, predicted and actual water quality information for the McLaughlin mine. The accuracy of the predictions is discussed in this section.

Table 6.12. McLaughlin, CA, Potential, Predicted and Actual Impacts
(all information from 1983 EIR/EIS unless otherwise noted; actual impacts from water quality monitoring data)

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings	• Permanent degradation of groundwater is expected, due to tailings seepage	• Monitoring only	• Permanent degradation of local groundwater from tailings, but no impact outside the existing poor quality confined aquifer	• Downgradient wells show increases and exceedences of TDS, chloride, nitrate, and sulfate from ~1984 to ~1992, with increases of copper, and other metals
	Waste Rock	• Possible release of TDS could occur from waste rock dump	• Leachate will be collected in the underdrains, the diversion ditches, or in the sediment impoundment. • Segregation and blending of PAG waste rock.	• Groundwater will not be impacted outside the existing poor quality confined aquifer	• Downgradient wells show increasing concentrations of sulfate (in excess of SDWA standards), boron, TDS, calcium, iron, manganese, and other constituents from ~1985 to ~1998. Zinc concentrations increased after 1998
Surface Water	Tailings	• No impact to surface water quality	• No mitigation identified	• No impact to surface water quality	• Downstream surface monitoring locations show exceedences of sulfate, and occasionally large exceedences of arsenic, chromium, copper, lead, manganese, mercury, iron and zinc
	Waste Rock	• Surface water quality impacts may potentially occur from waste rock o increased sediment o increased total dissolved solids o increased heavy metal concentration	• Lime will be added to sediment ponds if acidic conditions develop • Segregation and blending of PAG waste rock	• Manganese was predicted to slightly exceed its standard	
Pit Water	Open Pit	• Pit water is expected to be of poor quality	• Alkaline pH conditions in the mine pit would tend to reduce metals leached	• Pit water not expected to reach surface streams	Pit water exceeds secondary drinking water standards for pH (low), TDS, chloride, sulfate, iron and manganese

<u>Degradation of Local Groundwater from Tailings and Waste Rock Seepage</u>: The 1983 EIS/EIR identified the potential for permanent degradation of local groundwater from tailings seepage. Release of TDS from waste rock was predicted, but mitigation measures (underdrains, diversion ditches, segregation of PAG rock, lime addition to waste rock runoff) were expected to avoid impacts to groundwater. However, wells downgradient of waste rock show elevated sulfate (up to 5,000 mg/l), boron, TDS, iron, manganese and zinc (up to 1.7 mg/l) concentrations. Therefore, groundwater impacts from tailings were accurately predicted, but predictions for groundwater impacts from waste rock were inaccurate.

Surface Water Impacts: Potential surface water quality impacts from tailings were not expected; however, potential impacts from waste rock were recognized and modeled. Modeled arsenic, nickel, zinc, silver, iron and copper concentrations were predicted to be lower and manganese higher than drinking water standards in Hunting Creek. The modeling results were correct for zinc, silver, manganese and copper, which did not exceed standards but were incorrect for arsenic, nickel and iron, which did exceed standards.

Pit Water Quality: Pit water quality was expected to be poor (with high concentrations of arsenic, cadmium, iron, lead, manganese, mercury, nickel, boron, and sulfate, but alkaline conditions were expected to reduce metal concentrations. The pit water is of poor quality, as predicted. There are elevated concentrations of iron, manganese, nickel, boron, sodium, chloride and sulfate, as predicted, but there are not high concentrations of arsenic, cadmium or lead at this time. The pH of the pit water is 5.08, which is acidic rather than alkaline, so the prediction that the pit water will have an alkaline pH is inaccurate. Pit water quality exceeds drinking water drinking water standards for pH (low), TDS, sulfate, manganese, nickel and boron.

6.3.8. MESQUITE, CALIFORNIA

The Mesquite Mine is owned by Newmont Mining Company and is an open pit, heap leach gold and silver operation. Production started in 1985, and the mine is still in operation. The mine disturbs 3,655 acres of BLM land in the El Centro District, and has a financial assurance amount (last updated in 1998) of $3,048,081.

6.3.8.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA and CEQA were required for the new project to be permitted. A new project EIS was completed in 1984, and two expansion EISs were conducted in 1987 and 2000. The new project EIS (1984) and the 2000/2002 (draft/final) expansion EIS were obtained for this report. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1984 EIS

From a rain gauge 14 miles away, annual precipitation ranged from 1.17 to7.42 inches. Annual rainfall in the Amos basin probably ranges from 3 inches on the valley floor to 5.5 inches in the higher mountains. Mean annual pan evaporation is 137 inches, mean annual lake evaporation is 96 inches. The Coachella Canal, approximately 15 miles southwest of the project area, is the closest perennial surface water feature. Drainages on the site flow only during infrequent thunderstorms. Groundwater occurs in alluvial deposits, and, to a limited extent, in fractures and joint systems in bedrock in the Chocolate Mountains. Average depth to groundwater near the proposed Mesquite mine is 200 feet below ground surface. Depth to groundwater becomes as shallow as 145 feet just south of highway 78.

Alluvium covers a majority of the site. Older rocks include Miocene/Oligocene non-marine silts, sand, angular gravel, with a considerable amount of gypsum, and Mesozoic and Precambrian igneous and metamorphic rocks in the northern part of the site. Static acid-base potential tests were performed on overburden and leached ore. Both overburden and leached ore residue have sufficient neutralizing capacity to prevent any formation of acidic leachate.

Water quality impact potential: Background groundwater quality in the region had exceedences of fluoride in most wells and chloride, sulfate, iron, manganese and arsenic in alluvial wells. Bedrock wells exceeded for iron, manganese, arsenic and mercury. The only potential significant environmental impact to groundwater would be from percolated surface waters containing chemicals used in ore processing, accidental fuel spillage, spillage of reagents or chemicals, breakage of solution pipelines or leachate from waste dumps. Low soil moisture and depth to groundwater present a secondary defense against contamination. Surface water in the Imperial Valley typically has high TDS values, around 990 mg/l. Surface water quality in the project area could be affected by the presence of suspended solids in runoff, hazardous materials accumulated in the processing plant area or by any accidental escape of leach solution from the processing system. There will most likely be pit lakes because pit bottoms will be 400-500 ft deep.

Proposed mitigation include: impermeable liners for leach pads; immediate application of calcium hypochlorite to any spilled/released cyanide on exposed soil; containment area around reagent building; sumps in process building to collect spilled materials; collection and storage for runoff from the heap leach facility; rinsing of heap leach pads upon completion of the leaching; and impervious barriers under areas exposed to toxic chemicals.

Predicted water quality impacts: As a result of implementing the proposed project design and all solution containment measures, no significant adverse impact on groundwater quality is expected. The proposed project design includes measures to prevent any adverse impacts on surface water quality, including the prevention of contamination from the use of dilute cyanide leach solution. No information was provided on discharges to groundwater or surface water.

2000/2002 EIS

Annual precipitation is three inches/ear, and evaporation is ~80 inches/year. The closest perennial surface water feature is the Coachella Canal, located approximately 15 miles southwest of the site. The groundwater flow direction is generally from northeast to southwest, following the surface contours. Prior to mining, groundwater depths ranged from about 200 to 300 feet deep.

Gold ore occurs in gneiss and granitic basement rock in essentially free or native forms. It is concentrated in microfractures in minute sizes and amounts. Minor amounts of silver ore are found disseminated in microfractures of gneiss and granitic basement rock. Static acid-base accounting, whole rock analysis for metals, and 20-week kinetic tests were performed. From whole rock analysis, arsenic, selenium, silver, bismuth and thallium were identified as potential constituents of concern. Rock types encountered in the Rainbow and north half sections were typically net neutralizing. The kinetic tests were inoculated with *Thiobacillus ferrooxidans* and showed no acid generation or any indication that acid would form. The kinetic tests indicated that even the most sulfidic members of the hornblende biotite gneiss and mafic gneiss rock units are not likely to generate acid. Soluble metals concentrations in the overburden/interburden were generally low. A hydrologic/hydraulic evaluation of runoff was conducted using the runoff model HEC-1. Pit water quantity and quality modeling was conducted by Baker Consultants.

Ore processing operations could leak or spill processing fluids if they are not properly designed, constructed and operated. Petroleum products could impact groundwater if a substantial leak were to occur. Infiltrating precipitation could carry soluble constituents from the overburden/interburden to groundwater. Increased runoff could occur from road surfaces during infrequent large storms, but roads cover only a small fraction of the site. The potential exists for minor hydrocarbon leaks/spills from equipment. Water quality in the existing pit lake is generally alkaline (pH 8.3 - 8.9), slightly to moderately saline (total alkalinity 258 - 334 mg/l of $CaCO_3$, TDS 1,400 - 3,600 mg/l) and low in dissolved trace metals. Initially, the pit water chemistry will be similar to the existing pit water, with TDS in the 1,500-400 mg/l range. At equilibrium, TDS is expected to reach 5,000-10,000 mg/l. Long term pit chemistry will be the same as the existing pits.

Proposed mitigation for the expansion include: heap leach pad liner and leak detection system; monitoring; storage of bulk petroleum products above ground in designated areas with secondary containment and leak detection. Best Management Practices will minimize stormwater-related pollution and include monitoring and inspection protocols to gauge their effectiveness. Ore processing facilities will have run-on controls and will be operated in a manner that protects against release of process fluids or other constituents that may adversely affect surface water quality.

Groundwater quality was evaluated over five years for pH, specific conductance, temperature, total dissolved solids, arsenic, copper, iron, sulfate and nitrate/nitrite. None of the parameters showed trends of adverse change in water quality. There are no known groundwater quality impacts from the 15 years of activity that have occurred at the Mesquite Mine to date. Modeling indicates that for the out-of-pit configuration, groundwater would not flow through any of the mine pits, so the build up of dissolved constituents in the pit lakes will not affect water quality away from the mine pits. With petroleum containment and monitoring in place, fuels and oil use at the site are not expected to impact groundwater quality. Because soluble metals concentrations in waste rock are generally low and the material is not acid generating, and because of the low annual precipitation, waste rock would not have a significant impact on groundwater quality. With heap leach pad operation requirements in place, significant effects to surface water quality are not expected. The likelihood of spills is small, and they would be easily removed. Long term pit chemistry is expected to be the same as the existing pits. No information was provided on discharges to groundwater or surface water.

6.3.8.2. ACTUAL WATER QUALITY CONDITIONS

The information on actual water quality conditions is based on a phone call with the RWQCB in Palm Desert, California, in September 2004. The Mesquite Mine is still conducting leaching operations but is otherwise shut down. There was one unreported spill in early 2003/late 2002, and a violation was written by the RWQCB. However, this was a very minor spill. Quarterly reporting is required for TDS, total and free cyanide, pH, sulfate, arsenic, gold, silver, copper iron, and nitrate. No major problems, for example with cyanide, have occurred.

6.3.8.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.13 summarizes potential, predicted and actual impacts for the Mesquite Mine. A spill did occur in 2002/2003. The potential for spills was recognized in both the 1984 and 2002 EISs, but because of mitigation measures, they were expected to be cleaned up rapidly and not affect groundwater or surface water. To date, this prediction has been true.

Table 6.13. Mesquite, CA, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	• Heap leach facility • Waste rock	• Ore processing fluids, fuel or chemical spills, pipeline breaks, waste rock leachate (1984) • Leaks or spills of ore solution, petroleum leaks, leachate from waste rock (2002)	• Leach pad liners, calcium hypochlorite applied to cyanide spills, rinse pads after mining (1984) • Heap leach pad liner/leak detection, monitoring, storage of petroleum products in areas with secondary containment, leak monitoring (2002)	• No impact to groundwater (1984) • No impacted predicted because existing groundwater quality unchanged and fuels/oil containment/monitoring. Waste rock would no have significant impact. (2002)	• Spill occurred, but no impacts to groundwater occurred.
Surface Water	• Heap leach facility	• Erosion of soils, processing plant materials, ore solution leachate (1984) • Runoff from roads, fuel spills	• Reagent containment and sumps, heap leach runoff controls (1984) • Stormwater BMPs, monitoring, heap leach run-on controls (2002)	• No impact to surface water quality (1984) • No significant surface water quality effects expected from heap leach pad or spills (2002	• Spill occurred, but no impacts to surface water occurred.
Pit Water	• Open pit	• Pit lakes will exist (1984) • Long-term pit chemistry same as existing pits (2002)	• None	• No information (1984) • Long-term pit chemistry expected to be same as existing pits.	• None

6.3.9. ROYAL MOUNTAIN KING, CALIFORNIA

The Royal Mountain King Mine is owned by Meridian Gold, Inc. and was in operation from 1990 to 1995. The primary commodity mined was gold from open pit mining and vat leach processing operations. It disturbed 650 acres on private land. It has a current financial assurance amount of $3.3 million.

6.3.9.1. WATER QUALITY PREDICTIONS SUMMARY

El Dorado County was the lead agency under CEQA for the new project to be permitted, and an EIS/EIR was completed in 1987. NEPA/CEQA was not required for the NPDES discharge permit. The following sections summarize the water quality predictions made in the documents reviewed.

1987 EIS/EIR

The EIS/EIR contained very little information on geochemical characterization tests (only static acid-base accounting tests were performed) and did not identify any particular constituents of concern. Based on static acid-base accounting test results, the EIS/EIR concluded that there was no net acid forming potential associated with the overburden materials. No information was provided on contaminant leaching potential. The EIS/EIR stated that the waste management units will contain chemicals and reagents that have the potential to contaminate the groundwater system. No information was provided on mitigation, with the exception of stormwater management approaches.

Additional Information

1988 Geochemical Characterization Testing by Donald R. Baker

Geochemical characterization testing consisted of total digestions of tailings and waste rock samples (results were compared to Total Threshold Limit Concentrations (TTLC)), WET tests on waste rock (results were compared to Soluble Threshold Limit Concentrations (STLC)), and a Deionized Water Extraction test on waste rock. Total digestion leachate values for tailings were elevated for antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, silver, vanadium and zinc (>10 to 100 times MCL/SMCL values). Total digestion and WET test values for waste rock leachate were elevated for antimony, arsenic, beryllium (total digestion only), cadmium (total digestion only), chromium, cobalt, copper, lead, mercury (total digestion only), nickel, silver (total digestion only), vanadium (total digestion only) and zinc. Deionized water extract concentrations for waste rock were elevated for arsenic.

1987 Report of Waste Discharge

According to the report, three different types of ore will be mined in the project. The Skyrocket ore body, which comprises roughly 59% of the total reserves, is a refractory (unoxidized) carbonaceous deposit. Mountain King, which comprises 30% of ore reserves, is predominantly unoxidized. Gold Knoll, the remaining 11% of reserves, is a mix of oxidized and unoxidized ore.

There will be three sources of solid waste generated on the property: overburden; flotation tailings; and heap leach concentrate residues. Each type of waste was subjected to: acid-base accounting (hot hydrogen peroxide oxidation); total metal content; short-term leach (WET, DI water extract); sulfuric-acid extractable metal concentration for samples with acid-forming potential; and bioassay studies on all wastes except overburden. The testing results showed the contaminant potential to be high for all materials.

Overburden. Deionized water extractions on waste rock material showed several exceedences of drinking water standards. Arsenic concentrations in the extract exceeded drinking water standards (10 µg/l) by over 10 times, and selenium concentrations in leachate from one sample were elevated but did not exceed the drinking water standard. Total chromium concentrations exceeded the drinking water standard by almost two times. For the WET test results, leachate concentrations in samples from all four types of overburden exceeded the drinking water standard for arsenic by factors of 2 to 26, and chromium concentrations also exceeded drinking water standards in all four waste rock types ranging from a factor of 1.5 to 3. Nickel concentrations also exceeded drinking water standards in all four samples, with concentrations ranging between 4 to 7 times the remanded standard of 100 µg/l.

Flotation Tailings. WET test leachates for all four tailings lithologies (one from each pit, as well as a composite) showed drinking water exceedences for arsenic, barium, total chromium, lead, and nickel; the detection limit for mercury in the WET leachate was too high to conduct comparisons to standards. There was also a single exceedence (from the Mountain King pit) for selenium. In the deionized water extraction, there was one drinking water exceedence for selenium in a leachate sample from the Mountain King pit, and one exceedence of arsenic, also from the Mountain King pit. Arsenic levels in the DI extraction leachate were equal to the drinking water standard in the Gold Knoll pit sample. Arsenic concentrations in the DI extraction leachate exceeded the drinking water standard in all four floatation tailings samples by a factor of 2 to 3. Lead concentrations in the DI leachate were elevated but did not exceed the drinking water standard. Nickel concentrations exceeded the remanded drinking water standards in DI leachate from the Mountain King pit sample.

Leached Concentrates (Heap Leach Ore). Arsenic concentrations in the heap leach concentrates were high enough to classify this material as hazardous waste, according to the TTLC. In the deionized water extraction of the leached concentrates, antimony concentrations exceeded the drinking water standard by a factor of more than 10 in all four samples (each pit, as well as a composite sample). Arsenic concentrations exceeded the new standard in all four samples by factors of fewer than 2 to almost 3. The detection limit for lead exceeded current standards. Mercury concentrations exceeded the standard in the Gold Knoll pit sample. Nickel concentrations exceeded the remanded drinking water standard by a factor of almost two in the Sky Rocket sample and was at the standard in the composite sample. In addition, results from the extraction procedure utilizing citric acid (WET test) showed elevated concentrations of antimony, arsenic, lead and nickel from all samples. The lead levels in the Mountain King pit samples were high enough compared to the STLC to merit classifying the heap leach concentrates as a hazardous waste. Extractions using H_2SO_4 produced results similar to the DI water extraction. The leached transport solution exceeded, by a factor of over one hundred, the drinking water standards for arsenic, copper, cyanide and mercury, TDS, and nickel concentrations exceeded drinking water standards in the transport solution by 10 times or more. Lead, silver, sulfate and zinc concentrations in the leach transport solution exceeded drinking water standards by one to 10 times. Detection limits for cadmium, chromium, silver and thallium for leach transport solutions were higher than their respective water quality standards.

Acid Drainage Potential. All overburden lithologies and flotation tailings samples had excess neutralization potential. NP:AP ratios were approximately 40:1 or higher, indicating that acid generation was unlikely. However, acid generation potential was high in the concentrates from the heap leaching circuit, with NP:AP ratios ranging from 1:3 to 1:12.

According to the report, the tailings impoundment will not require an engineered lining. Both the solids and the liquid in the slurry were tested extensively and do not present any potential for having an adverse impact on the environment. In addition, the rocks underlying the tailings impoundment have low permeabilities.

6.3.9.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring data were obtained from the RWQCB in Sacramento for 1987 to 2004 and included the following:

- Tailings wells showed exceedences of drinking water standards for chloride, nitrate, nickel, selenium, sulfate, TDS and manganese. Heap leach concentrate area wells had exceedences of drinking water standards for antimony, arsenic, chromium, manganese, copper, nickel, nitrate, selenium, sulfate, TDS, and total and WAD cyanide. Waste rock wells showed exceedences of drinking water standards for nitrate, TDS, sulfate, arsenic, chloride and selenium.

- Surface water monitoring showed exceedences of drinking water standards for nitrate, sulfate, TDS and arsenic.
- Pit water monitoring shows exceedences of sulfate and TDS SMCL values in North Pit; exceedences of arsenic, sulfate, TDS, and chloride drinking water standards in Skyrocket Pit.
- The mine area has been subject to historic mining, so background water quality (pre-historic mining) is difficult to determine. There are some artesian salt springs in the marine deposits, but not all groundwater is salty. Skyrocket Pit outlet flows to Littlejohns Creek. The mine claims that elevated groundwater concentrations are background levels. Some of the groundwater is very salty, but the chemical signature from the waste rock piles is still apparent. The RWQCB proved, using Piper diagrams, that the groundwater had changed over time as a result of mining activity (RWQCB interview, 10/15/04).
- There were 29 violations issued to the mine from the RWQCB from January 1993 to August 2004; between nine and 12 of them were related to water quality or quantity problems, and the remainder were related to inadequacies in reporting and other non-water quality issues. The State Water Control Board, not the RWQCB, vacated the 2003 cease and desist order, agreeing with the mine that it was too complex, and the State Board was not sure the mine could comply with the order. If the order had been kept, the mine would be in violation all the time. The RWQCB feels that the financial assurance is too low because it does not include foreseeable future releases.
- Local public interest groups have sued Royal Mountain King for discharges to Littlejohns Creek (from Skyrocket Pit) and for the presence of elevated arsenic, ammonia and cyanide in groundwater. The lawsuit requests a cease and desist order and containment.
- Meridian Gold received the California Mining Association Reclamation Award in 1994.

6.3.9.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.14 provides a summary and comparison of potential, predicted and actual water quality information for the Royal Mountain King mine. The accuracy of the predictions is discussed in this section.

Groundwater Impacts from Tailings: The 1987 EIS/EIR did not address potential impacts from tailings but did state generally that waste management units will contain chemicals and reagents that have the potential to contaminate the groundwater system. The 1987 Report of Waste Discharge (RWD) found that tailings do not have the potential for impacts, that low permeability material below the impoundment was sufficient mitigation, and therefore no engineered lining was required. However, water quality monitoring results from wells downgradient of the tailings impoundment showed exceedences of drinking water standards for sulfate, chloride, nitrate, nickel, selenium, TDS and manganese. Therefore, the potential impact information for tailings presented in the EIR was accurate, but the predictions based on the low permeability material were inaccurate and resulted in inadequate mitigation measures being taken at the site.

Groundwater Impacts from Waste Rock: The 1987 EIS/EIR determined, based on the results of static testing, that there was no net acid forming potential associated with waste rock. The RWD found that the waste rock was not considered hazardous. Short-term leach test leachate exceeded drinking water standards for arsenic, selenium, chromium and nickel. Water quality monitoring results from wells downgradient of waste rock showed exceedences of drinking water standards for nitrate, total dissolved solids, sulfate, arsenic (up to 1,400 µg/l), chloride and selenium. Therefore, predictions for groundwater impacts from waste rock were accurate for arsenic and selenium, but not for chromium and nickel. In addition, short-term leach testing results did not predict the observed exceedences of nitrate, TDS, sulfate and chloride.

Arsenic concentrations were increasing steadily from 1987 to 2004. Nitrate, TDS, sulfate, chloride and selenium concentrations were not predicted to be elevated but were (if they were monitored). The other constituents that were predicted to be elevated in waste rock leachate are not elevated in groundwater downgradient of the waste rock storage areas at this time. Pit water (Skyrocket Pit) has elevated concentrations of antimony, arsenic, nickel, sulfate and TDS. All of these except sulfate and TDS were predicted based on short-term leach results for waste rock.

Groundwater Impacts from Heap Leach Facility: The 1987 EIS/EIR stated generally that waste management units will contain chemicals and reagents that have the potential to contaminate the groundwater system. The RWD found

Table 6.14. Royal Mountain King, CA, Potential, Predicted and Actual Impacts (all information from the 1987 EIR/EIS unless otherwise stated; actual impacts information from water quality monitoring data)

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings	• Waste management units will contain chemicals and reagents that have the potential to contaminate the groundwater system.1987 RWD: Tailings do not present any potential for adverse impact to the environment, underlying rocks have low permeability.	• RWD: Tailings impoundment will not require an engineered liner	• No information.	Tailings wells show exceedences of drinking water standards for chloride, nitrate, nickel, selenium, sulfate, TDS, manganese.
	Waste Rock	• No net acid forming potential associated with the overburden materials	• Only stormwater controls		• Waste rock wells show exceedences of drinking water standards for nitrate, TDS, sulfate, arsenic, chloride, selenium.
	Heap Leach Concentrate	• Waste management units will contain chemicals and reagents that have the potential to contaminate the groundwater system. RWD: Short-term leach tests solution would be elevated in Sb, As, Cu, CN, Pb, Hg, SO4, TDS, Zn.	• None identified. RWD: liner required.		• Heap leach area wells show exceedences of drinking water standards for antimony, arsenic, chromium, manganese, copper, nickel, nitrate, selenium, sulfate, TDS, total and WAD cyanide.

that arsenic and lead concentrations in the heap leach concentrates were high enough to classify them as hazardous waste; therefore, a liner was required. Short-term leach tests predicted that heap leach concentrate solution would be elevated in antimony, arsenic, copper, cyanide, lead, mercury, nickel, sulfate, TDS and zinc. Groundwater downgradient of the leach pad facility showed exceedences of drinking water standards for antimony, arsenic, chromium, manganese, copper, nickel, nitrate, selenium, sulfate, TDS, total and WAD cyanide. Of these, antimony, arsenic, copper, nickel, sulfate, TDS and cyanide were predicted to be elevated. Chromium, manganese, nitrate and selenium concentrations were not predicted to be elevated or were not evaluated, but they were elevated in wells downgradient of the heap leach facility. Therefore, the potential water quality concerns were accurate (in particular, arsenic was released from the lead pad materials), but the designated mitigation (liner) did not prevent the contamination of downgradient groundwater.

6.3.10. GROUSE CREEK, IDAHO

The Sunbeam Mine, owned by Sunbeam Mining Company, began operations in 1984. The Hecla Mining Company began mining the Grouse Creek and Sunbeam deposits in 1994 and operated until its closure in 1997. The primary commodities mined were gold with some silver from open pit mining, with heap leach and vat leach processing. It disturbs 524 acres on private land and Challis National Forest lands in Forest Service Region 4. It has a financial assurance amount of $7,038,945.

6.3.10.1. WATER QUALITY PREDICTIONS SUMMARY

The Challis National Forest has been the lead agency for all NEPA actions at the Ground Creek Mine. NEPA was required for the new project to be permitted, and an EIS was completed in 1984. The EIS was also utilized by the EPA in issuing the NPDES discharge permit. A subsequent EIS for mine expansion was completed in 1992. The following sections summarize the water quality information and predictions made in the NEPA documents reviewed.

1984 EIS

The 1984 EIS describes the deposit as a gold and silver ore containing pyrite and iron oxides. Acid drainage was observed from the Sunnyside Mine adit (pH range of 3.3 to 3.9) on the study site, indicating the presence of acid drainage. However, the EIS stated that the potential for generating significant acid drainage from mine or waste dumps is minimal, based on the fact that very little sulfide material is available within the ore body and that “weather tests” indicated that the pH of the drainage of mine-run samples is stable. The acid drainage that has been reported from the abandoned Sunbeam Mine portal (pH 3.2) may be a result of an isolated sulfide-bearing stratum within the mine area itself that is exposed to localized oxidation conditions due to variation in the water table within the mine area. The EIS stated that the proposed Grouse Creek open pit will not be subject to the same conditions that can cause the formation of acid drainage. Mitigation identified included surface water controls and surface water and groundwater monitoring. Cyanide was identified as a constituent of concern.

1992 SEIS

The 1992 Supplemental EIS identified the gold and silver ore deposit as containing gold, native silver, electrum, metal sulfides, including pyrite, and iron oxides. Results of geochemical testing (including sulfur analysis, static ABA and short term leach tests) indicated that moderate acid drainage was expected. Metals, metalloids, and other contaminants (nitrate and cyanide) were identified as constituents of concern; however, EP toxicity analysis of waste rock samples indicated the potential for heavy metal concentrations in leachate to be “relatively low,” with lead being the only metal expected to exceed drinking water MCLs, as long as the water maintained a low to moderate acidity. The potential for significant groundwater degradation was determined to be minimal, and the potential for cyanide entering groundwater in sufficient quantities to do real harm was described as very minimal, but the potential does exist.

Source controls for groundwater capture and treatment and storm water controls were required during operations. There is a potential for some drainage from the Grouse Creek pit to occur post-reclamation, but the water is not expected to be acidic because of the buffering capacity of the carbonate-rich rocks.

6.3.10.2. ACTUAL WATER QUALITY CONDITIONS

Hecla experienced financial difficulties at the same time that water quality issues became noticeable. In 2000 the Grouse Creek Mine was declared a Forest Service Superfund site, and in 2002 an Engineering Evaluation/Cost

Analysis (EECA) for Non-time Critical Removal Action was performed at the Grouse Creek Mine Site. The following information was taken from the EECA.

Hecla Mining Company has been monitoring water quality since 1987. In 1995 cyanide was detected in both surface water and groundwater monitoring stations. Cyanide detection in wells below the South Embankment indicated that contaminated water was moving through the underlying materials below the tailings impoundment. Cyanide was periodically detected in Jordan Creek below the constructed wetlands. Since 1999, cyanide (total and WAD) concentrations have decreased in Jordan Creek. Since 2001, cyanide (WAD) concentrations have mostly been below detection limits (0.002 mg/l).

Chemicals of Potential Concern identified in tailings pore water included aluminum, copper, arsenic, selenium, silver, zinc, cyanide, ammonia and mercury. Constituents that exceeded acute water quality criteria for protection of aquatic life included aluminum, copper, arsenic, selenium, silver, zinc and cyanide. Sampling data showed trends toward generally improving tailings impoundment water quality when the EE/CA was written. WAD cyanide concentrations were decreasing and were predicted to decline to less than 0.0025 mg/l by April 2002. Ammonia concentrations were declining steadily in tailings impoundment water and were predicted to be below 25 mg/l in 2003 and below 20 mg/l in 2004. Silver concentrations were declining, and concentrations at most sampling sites currently are below the detection limit (0.0005 mg/l). Copper concentrations have declined to an average of 0.04 mg/l since Fall 2000, and mercury concentrations were below the detection limit of 0.0002 mg/l. Total nitrate concentrations were increasing steadily, possibly due to metabolism of ammonia by microbial biomass.

Some contamination of groundwater is still evident at the site. However, since 2001, all contaminants of concern entering the Yankee Fork receiving water were below detection limits. Detectable cyanide (WAD and total) concentrations were last measured in Jordan Creek in June 2000.

6.3.10.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.15 provides a summary and comparison of potential, predicted and actual water quality information for the Grouse Creek Mine. The accuracy of the EIS water quality predictions is discussed in this section.

Table 6.15 Grouse Creek, ID, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings and Waste Rock	• 1984 EIS: acid drainage observed but geochemical tests indicated minimal acid drainage potential • 1992 SEIS: Moderate acid drainage potential; low risk of significant groundwater contamination but potential impact to surface water from tailings	• 1984 EIS: stormwater controls and water monitoring • 1992 SEIS: stormwater controls and groundwater capture and treatment during operations; reclamation with buffering rock; composite liner system for tailings impoundment; French drains under waste rock dumps	• 1984 EIS: no impacts to water quality • 1992 SEIS: no impacts to water quality; adverse water quality effects from impoundment leakage unlikely due to underdrain and collection system	• EE/CA: tailings impoundment leakage into groundwater resulted in CN in groundwater and surface water. Tailings pore water exceeds standards for aluminum, copper, arsenic, selenium, silver, zinc and cyanide.

Cyanide in Groundwater and Surface Water. Cyanide was identified as a constituent of concern in both the 1984 and the 1992 EISs. The potential for contamination of groundwater by cyanide was recognized in the 1992 SEIS, but the actual potential was described as very minimal. Short-term leach tests performed for the 1992 SEIS indicated metal concentrations in leachate would be low with only lead predicted to exceed drinking water MCL's as long as the water maintained a low to moderate acidity. The EE/CA showed that the tailings liner failed to contain the tailings solutions and the underlying French drain system did not capture all tailings leakage, resulting in contamination of groundwater and surface water with cyanide and other contaminants. Although the potential for cyanide contamination of groundwater and surface water was noted in the 1992 SEIS, adverse water quality effects from impoundment leakage was wrongly thought to be unlikely due to mitigation such as the underdrain and collection system. Therefore, the observed impact to groundwater and surface water from tailings leakage was not predicted.

6.3.11. THOMPSON CREEK, IDAHO

The Thompson Creek Mine, owned by Thompson Creek Mining Company, has been in operation since 1983. The primary commodity mined is molybdenum from open pit mining and flotation processing operations. It disturbs 2,100 acres on Salmon-Challis National Forest lands in U.S. Forest Service Region 4, BLM administered land, and private land. It has a current financial assurance amount of $11.3 million.

6.3.11.1. WATER QUALITY PREDICTIONS SUMMARY

The Salmon-Challis National Forest has been the lead agency for all NEPA actions at the Thompson Creek Mine. NEPA was required for the new project to be permitted, and an EIS was completed in 1980. NEPA was not required for the NPDES discharge permit. In 1999 a Supplemental EIS was conducted for a plan of operation change dealing with tailings disposal. The following sections summarize the water quality information and predictions made in the NEPA documents reviewed.

1980 EIS

The 1980 EIS cites laboratory tests to characterize leachate, determine weathering effects over 20 years, and determine the quantity of acid the waste rock would consume. The specific nature of the tests and test results were not provided. The tests indicated that there was sufficient buffering capacity to neutralize acid drainage and that leachate would not contain significant concentrations of contaminants. The EIS stated that such conditions would continue for 20 years, but no basis is provided for the prediction.

The 1980 EIS did note a concern that water infiltrating waste dumps will leach materials in toxic concentrations from waste rock and that these will reach surface water. The EIS also noted that infiltration from the tailings impoundment could exceed EPA drinking water standards for iron, manganese, nitrate TDS, and zinc, which could cause Bruno Creek to exceed water quality criteria during low flow.

No acid drainage characterization tests were conducted for tailings, and according to the EIS, the tailings would be similar to low-grade ore, which did not indicate potential for acid drainage. However, tailings leachate tests showed potential for elevated levels of iron and manganese in excess of drinking water standards, and iron and zinc concentrations in excess of EPA criteria for protection of aquatic life. According to the EIS, the areal extent of potential groundwater contamination was unknown, and potential increases of metal concentrations in surface water could occur but would be similar to background levels due to dilution and biological activity. The general prediction of the 1980 EIS was that acid drainage would not occur at the Thompson Creek mine.

1999 EIS

According to the 1999 EIS, in 1988 visual signs of acid drainage were observed in the mine pit and the face of the tailings impoundment. The presence of acid drainage was subsequently confirmed in the mine pit and tailings impoundment, and in 1990 a geochemical characterization program was initiated.

Tailings Impoundment

Tailings and tailings embankment samples were collected and subjected to total sulfur, pyrite sulfur and neutralization potential analyses. In addition, selected samples were subjected to kinetic testing. Static testing results showed an average sulfur content of 0.8%, average acid neutralization potential (ANP) of 6 tons/kiloton (t/kt), acid generation potential (AGP) of 24 t/kt , net neutralizing potential (NNP) of 19 t/kt, and the average ANP/AGP ratio was 0.3 in embankment samples. Slimes (interior tailings) samples had an average ANP of 8 t/kt, NNP of 0.4 t/kt and an ANP/AGP ratio of 1.0. The EIS concluded that the static tests indicated the potential for acid drainage in embankment tailings and less potential in slimes tailings due to saturated conditions in the tailings impoundment. The acid drainage potential was confirmed by kinetic testing, with several samples producing acid drainage during the initial test cycles.

The Draft EIS contained predictions of tailings effluent water quality based on various mitigation for periods of up to 1,500 years. The potential for impacts to Squaw Creek were noted. The final EIS predictions were limited to a 100-year period and were based on results from the PYROX model. The predictions were based on assumptions that the interior slimes tailings would remain saturated (immersed in water) and the tailings would therefore not be reactive and produce acid drainage. The exterior (sand) embankment materials were expected to have excess neutralization capacity at the end of the 100-year simulation, although they could produce acid drainage beyond the 100-year period. The model results are based on the assumption that 140 feet of pyrite-depleted flotation tailings would be placed over the entire embankment surface (with pyrite enriched tailings located in the interior of the embankment). The Draft EIS predictions showed potential for acid drainage generation in 300 to 1500 years, but no impact on surface water quality was predicted, based on PHREEQE surface water quality modeling results.

Waste Rock

Waste rock samples representing various geologic units were collected and subjected to static and kinetic testing. Static testing indicated that volcanic waste rock was not acid generating, with average ANP/AGP ratio of 30:1 and an NNP of 20.6 t/kt. Static and kinetic testing on metasedimentary and intrusive rocks indicated the potential for acid drainage generation.

Long-term water quality of waste rock leachate was predicted based on geochemical testing, seepage rate predictions and existing water chemistry. HELP model simulations were used to predict the rate of seepage from the waste rock dumps. No significant acid drainage, metals leaching or impacts to surface water were expected. According to the EIS, based on existing water quality of dump effluent, the “excess” neutralization potential (from calculations on a “tonnage weighted basis,” the NP:AP ratio of the waste rock is 1.5 to 3.1) and assuming mixing in surface waters.

According to the EIS, any acid-producing rock would be mitigated by special handling (segregation) and isolation techniques that are “demonstrated by their use throughout the mining industry.” Potentially acid-generating waste material will be identified, placed in zones within the waste dumps and covered with compacted covers, with a final graded cap placed over the dump to reduce infiltration. Based on the mitigation employed, water quality impacts are not anticipated for either groundwater or surface water at the Thompson Creek Mine, according to the EIS.

Pit Lake

The EIS acknowledged that pit water quality may be characteristic of acid drainage and have high concentrations of molybdenum, iron and manganese. No studies had been conducted at the time of the EIS to quantitatively predict pit lake water quality. The EIS suggests that the pit will act as a terminal groundwater sink, thereby resulting in no impacts to local groundwater or surface water.

6.3.11.2. ACTUAL WATER QUALITY CONDITIONS

According to the 1999 EIS, water quality sampling errors from 1981 to 1990 prevented a reliable baseline water quality evaluation. More recent data (1991 to 1995), the interpretation of which is highly qualified in the EIS, indicated elevated levels of cadmium, copper, lead, sulfate and zinc in surface water, possibly at levels exceeding acute or chronic aquatic life standards. Tailings seepage water quality showed increases in iron, zinc and alkalinity, which, according to the 1999 EIS, were predicted in the 1980 EIS.

According to the 1999 EIS, from 1989 to 1995, sulfate concentrations in creeks downgradient of the waste rock dumps increased from 100 mg/l to 500 mg/l in one case and from 300 mg/l to 1,000 mg/l in another case. No significant changes in other parameters were so far indicated.

Monitoring of seepage from the Buckskin and Pat Hughes waste dumps indicated sulfate and selenium levels were rising since 1991. Selenium concentrations exceeded water quality standards in the seepage from both waste dumps. Thompson Creek has been ordered to meet water quality standards for selenium by the expiration date of its present NPDES permit (Dave Chambers, Center for Science in Public Participation, personal communication, 2005).

6.3.11.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.16 provides a summary and comparison of potential, predicted and actual water quality information for the Thompson Creek Mine. The accuracy of the predictions is discussed in this section.

<u>Acid Drainage and Metal Leaching from Tailings and Waste Rock, Including the Open Pit:</u> The 1980 EIS did not indicate acid drainage potential for either tailings or waste rock but did indicate metals leaching potential in tailings and waste rock. Pit lake water quality was predicted to be typical of oligotrophic mountain lakes. The 1999 EIS indicated acid drainage potential in tailings and waste rock, but acid drainage from tailings was not predicted for at least 100 years. The pit lake was predicted to be contaminated by acid drainage but was expected to act as a terminal sink and create no impacts on local water resources. Therefore, the potential for acid drainage was initially underestimated and subsequently predicted to take longer to develop than it did. However, the potential for metal leaching was noted in both EISs.

<u>Elevated Concentrations of Metals and Sulfate in Surface Water:</u> The 1980 EIS stated that water infiltrating the waste dumps could potentially leach materials in toxic concentrations that would reach surface water, and infiltration from the tailings impoundment could cause Bruno Creek to exceed water quality criteria during low flow. This EIS predicted moderate surface water quality impacts after mitigation were in place. The 1999 EIS noted potential impacts to water quality in Squaw Creek, but predicted no impacts to surface water after mitigation were in place. Therefore, potential (pre-mitigation) impacts were closer to actual impacts, and the degree of success of mitigation measures was overestimated, especially in the 1999 EIS.

Table 6.16. Thompson Creek, ID, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings	• 1980 EIS: No acid drainage potential but metals leaching potential • 1999 EIS: acid drainage potential in tailings	• 1980 EIS: dilution and biological activity • 1999 EIS: saturated conditions in the tailings impoundment to result in less acid drainage potential in slimes tailings	• 1980 EIS: water quality will be similar to background levels • 1999 EIS: acid drainage not predicted for at least 100 years	• Acid drainage observed in 1988 and confirmed in the tailings embankment Tailings seepage water had increases in Fe, Zn and alkalinity
	Waste Rock	• 1980 EIS: No acid drainage or contaminant potential • 1999 EIS: acid drainage potential in waste rock	• 1980 EIS: No mitigation identified • 1999 EIS: segregation and blending of PAG waste rock	• 1980 EIS: No impacts predicted • 1999 EIS: No impacts to groundwater predicted	• Buckskin and Pat Hughes waste dump seepage - rising SO_4 and Se levels since 1991
Surface Water	Tailings	• 1980 EIS: No potential for surface water impacts identified	• 1980 EIS: No mitigation identified	• 1980 EIS: No impacts predicted	• Elevated levels of Cd, Cu, Pb, SO_4 and Zn in surface water (1991-1995) • Increasing downstream SO_4 concentrations (100 to 500 and 300 to 1,000 mg/l), 1989 to 1995
	Waste Rock	• 1980 EIS: No potential for surface water impacts identified • 1999 EIS: acid drainage potential in waste rock	• 1980 EIS: No mitigation identified • 1999 EIS: segregation and blending of PAG waste rock	• 1980 EIS: No impacts predicted • 1999 EIS: No significant acid drainage or metals leaching or impacts to surface water are predicted	
Pit Water	Open Pit	• 1980 EIS: No potential for pit water impacts identified • 1999 EIS: pit water quality may be characteristic of acid drainage and have high concentrations of contaminants	• 1980 EIS: No mitigation identified • 1999 EIS: Pit will be terminal sink	• 1980 EIS: No impacts predicted • 1999 EIS: no impacts on local groundwater or surface water	• Visual signs of acid drainage observed/confirmed in mine pit (1988)

6.3.12. BEAL MOUNTAIN, MONTANA

The Beal Mountain Mine, owned by Pegasus Gold Mining Company, was in operation from 1989 to1998. The primary commodities mined were gold and silver from open pit mining, and heap leach processing was used. It disturbs 429 acres on Deerlodge National Forest in U.S. Forest Service Region 1. Due to ongoing water discharge issues and lawsuits from local public interest groups, the site was declared a Forest Service CERCLA site in 2003 and has been the subject of on-going remediation efforts since that time. The bond in 1998, when Pegasus Gold Mining Company went bankrupt, was $6.3 million. To date, the State of Montana and Forest Service have spent in excess of an additional $6 million in remediation costs.

6.3.12.1. WATER QUALITY PREDICTIONS SUMMARY

The Deerlodge National Forest and Montana Department of Environmental Quality (formerly Department of State Lands) were the lead agencies for NEPA and Montana Environmental Policy Act (MEPA) actions at the Beal Mountain Mine. NEPA was required for the new project to be permitted, and an EA was completed in 1988. In 1993 an EIS was conducted for mine expansion. The NPDES permit was not required or part of the NEPA/MEPA action for the original operations, which were supposed to be zero discharge. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1988 EA

According to the EA, the sulfide content of the ore ranged from 3 to 8% (pyrrhotite, pyrite, chalcopyrite, with traces of molybdenite and arsenopyrite), but a rind of clay and /or iron oxides enclosing fresh sulfides in a cherty matrix account for low acid production. Geochemical characterization tests conducted included whole rock analysis, ABA and EP Toxicity tests. Constituents of concern identified included arsenic, cadmium and lead. Results of the acid-base testing indicated the waste rock would not generate acidic waters and would not be a significant source of metals due to the low sulfide content of the waste material and the large acid-buffering capacity of the majority of the waste rock. Tests on waste rock indicated that a leachate developed under acidic conditions would be innocuous. Impact from residual cyanide from the leaching process was predicted to be minor.

Mitigation identified in the EA included diversion of stormwater and collection of pit water for process use. The leach pad and solution ponds would be lined and have either a blanket drain or leak detection system that would be monitored. The pit would be backfilled, underlain by a layer of limestone and gravel and be free-draining, resulting in no pit lake. The leach pad would be rinsed to address residual cyanide followed by natural degradation, dilution and “mobilization.” Water quality impacts from the leach pad were expected to be minor and probably unpredictable.

1993 EIS

The 1993 mine expansion EIS included geochemical characterization testing, including static ABA, short term leach tests (EPA Method 1310), kinetic tests (15 week humidity cell tests) and trace element analysis. Constituents of concern identified include nitrate, sulfate, cyanide, increased sediment and TDS. Due to the presence of pyrite, pyrrhotite and iron disulfides associated with the deposit, the potential for acid production exists. Geochemical material characterization tests for the main Beal and South Beal deposits indicate a low potential for acid formation. However, the release of sulfates and metals into surface waters is still considered to be a possibility, and these substances could become mobile regardless of acid production. Kinetic testing (humidity cell tests) was conducted for 15 weeks, and the results indicated that the South Beal quartzite waste would not be acid producing. Samples of main Beal waste with higher sulfide content were chosen to test a worst-case scenario, and static tests showed that the potential for acid generation exists for these samples. Leachate extraction tests resulted in no metals concentrations exceeding regulatory limits, and metals mobility was predicted to be minimal. Results from static tests on heap leach material suggested an uncertainty as to whether sulfate release and metals leaching would eventually become a concern. Results from kinetic tests on the heap leach material showed sulfate release for all samples, indicating a possibility for oxidation of pyrite. A chemical analysis of humidity cell leachate after week nine indicated the possibility of arsenic mobility.

According to the EIS, successful reclamation would minimize any potential for impacts to groundwater from the release of sulfate and would reduce infiltration. Addition of main Beal waste rock as backfill material into South Beal pits could provide a new source of potentially acid generating material, but testing of backfill material before placement, segregating acid producing material and keeping the pit floor above the water table were expected to prevent negative impacts to water. The leach pad has a liner and effluent is controlled, resulting in only minor expected impacts from arsenic and metals. If pyrite oxidation occurs, waste would be segregated in order to isolate reactive waste and cap it. Addition of South Beal waste rock to the waste rock dump is not expected to produce acid or release contaminated leachate, but could provide neutral material for capping to help isolate potential leachable contaminants.

The LAD (land application discharge) system for disposal of excess leach solution demonstrated that all contaminant levels, including arsenic, are successfully attenuated prior to discharge. A cyanide destruction water treatment plan is used prior to LAD disposal. Addition of lime to waste rock will occur if necessary. Pit bottoms will be above the water table. Backfilling and capping were expected to prevent water accumulation in the pits. Pit floors composed of marble bedrock were expected to reduce the potential for contaminant leaching. Any water that may accumulate in pits prior to backfilling would be used for irrigation on reclaimed portions of the waste rock facilities or other areas. The South Beal heap and waste rock area will be monitored to determine whether it will produce acid drainage.

Predicted impacts to groundwater from mining the South Beal Pits are expected to be minimal because the pits would be open for only one to two years. The water table under the pits is 25 to 50 ft below the estimated levels of the pit floors, so groundwater would not come in contact with backfilled waste from main Beal pit. If water infiltrates backfilled pits, sulfate could be produced and enter groundwater. Sulfate is expected to be released from South Beal ore, but the pH of the water is expected to remain neutral. Concentration of nitrate and sulfate released from the waste rock facilities may continue to increase with the addition of the South Beal waste. The potential that nitrate will discharge to groundwater downgradient of the pits into German Gulch was expected to be minimal due to the distance between the pits and the stream. Beal Mine was predicted to have both long- and short-term environmental effects in German Gulch; however, these effects were not predicted to be significant in terms of either areal extent or severity of impact. Results of leach tests (EPA Method 1310) indicated that metals mobility should be minimal. Open pit, waste rock dump and heap materials are not expected to cause acid drainage, either during operations or after mining. The heap is part of a zero discharge circuit and is not expected to release any water to the surface.

6.3.12.2. ACTUAL WATER QUALITY CONDITIONS

According to the 1993 EIS, elevated levels of sulfate were detected at the monitoring stations near the main Beal waste rock facility. Although the source has not been verified, it could be a precursor to acid drainage. Currently, sulfate concentrations in seeps emanating from below the main Beal waste rock dump are increasing. This could either be due to dissolution of gypsum incorporated in the rock, dissolution of soil amendments, application of a sulfate used for chemical dust abatement, or the oxidation of iron disulfides in mined material. Water quality in German Gulch has changed since baseline data were collected, showing that TDS, sulfate and nitrate concentrations have increased considerably. Currently, State Water Quality Standards (SWQS) are exceeded at some monitoring stations, demonstrating that existing Best Management Practices or mitigation measures are not effective. Nitrate concentrations have increased in groundwater in the vicinity of the main Beal project relative to background baseline conditions.

Existing Conditions Report

According to the February 2004 Existing Conditions Report (ECR), developed as part of the Engineering Evaluation /Cost Analysis (EE/CA) for this CERCLA site, surface water sampling results from German Gulch showed that concentrations of nitrate (MCL = 10 mg/l) and sulfate were less than 10 mg/l. Total recoverable concentrations of most metals and metalloids (including arsenic and copper) were below chronic aquatic life standards, while total recoverable iron concentrations in German Gulch did exceed secondary MCL values near the mine site. Selenium concentrations were well below the chronic aquatic life standard of 0.005 mg/l. The total concentration of cyanide in German Gulch was 0.008 mg/l, slightly higher than the chronic standard of 0.0052 mg/l. Total recoverable concentrations of copper were below the chronic aquatic standard at all stations in German Gulch in 2003. Selenium concentrations measured in December 2003 were 0.011 mg/l.

Groundwater quality monitoring well data indicated that groundwater in the LAD area exceeded standards for nitrate, iron and cyanide and had elevated total dissolved solids concentrations. Cyanide was not detected in the LAD area groundwater prior to 2001 when the LAD was initiated. Springs below the LAD area also showed appreciable increases in cyanide and selenium concentrations. Concentrations of selenium, sulfate, nitrate and total dissolved solids were elevated in seeps sampled at the toe of the waste rock dump.

Geochemical data from both static and kinetic tests indicated that roughly one-third of the waste rock and ore mined from the Beal Pit is potentially acid generating, one third is not and the remaining one-third has uncertain potential to generate acid. Geochemical characterization test results from South Beal pit ore and waste rock suggested a low potential for acid drainage from the pit highwalls and waste rock, and a high potential from residual ore. However, the relatively small amount of residual ore is not expected to generate enough acidity to overwhelm the neutralization potential of the surrounding rock.

Static testing of spent ore indicated a high potential for acid generation; however, kinetic tests indicated a low potential for acid generation. Alkalinity and pH values have decreased somewhat following cessation of leaching operations, indicating that the neutralizing capability of the heap is slowly being depleted. Selenium and copper concentrations in the pad appear to be declining.

Water emanating from the toe drain collection system is pumped to a storage pond and has elevated selenium, sulfate and nitrate concentrations and cannot be discharged directly to surface water or groundwater without treatment.

Current leach pad water quality has elevated concentrations of sulfate (2,600 mg/l), selenium (0.38 mg/l), arsenic (0.16 mg/l), iron (4.0 mg/l, copper (0.42 mg/l), total cyanide (9.5 mg/l) and WAD cyanide (0.061 mg/l) Alkalinity values have decreased to about 100 mg/l ($CaCO_3$ equivalent).

6.3.12.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.17 provides a summary and comparison of potential, predicted and actual water quality information for the Beal Mountain Mine. The accuracy of the predictions is discussed in this section.

Increases in/Exceedences of Cyanide, TDS, Sulfate and Nitrate Concentrations in Surface Water: The 1988 EA predicted that the low sulfide content, high buffering capability and low metals concentrations would prevent degradation of water from the waste rock dump. The 1988 EA also indicated that there was only a minor potential for acid drainage from leach pad and waste rock material, and water quality was not predicted to be impacted. However, the increased sulfate concentrations may be a precursor to acid drainage. The 1988 EA predicted only a minor impact from residual cyanide from the leaching process. The leach pad liner system was expected to mitigate the potential for cyanide contamination, but it did not. The 1993 EIS indicated some potential for acid drainage from leach pad material and waste rock, but results of short-term leach tests indicated that metals mobility would be minimal. Therefore, predictions made in the new project EA and the 1993 EIS noted some potential for acid drainage and increased sulfate concentrations and underestimated the potential for contamination of surface water from the leach pad and waste rock.

Exceedences of Nitrate, Cyanide, and Iron Concentrations in Groundwater: As noted above, the leach pad liner system was expected to mitigate the potential for cyanide contamination. The open pit, waste rock dump, and heap were not predicted to cause acid drainage during operations or after mining, but the 1993 EIS did indicate some potential for acid drainage from leach pad and waste rock material. Therefore, predictions made in the new project EA and the 1993 EIS noted some potential for acid drainage, underestimated the potential for metals leaching and underestimated the potential for contamination of groundwater from the leach pad and waste rock.

Table 6.17. Beal Mountain, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Leached Ore	• 1988 EA: Impact from residual cyanide from the leaching process was predicted to be minor and probably undetectable • 1993 EIS: South Beal ore in leach pad could be acid generating but expected to remain neutral	• 1988 EA: solution ponds equipped with sump, leak detection • 1988 EA: leach pad rinsed to address residual cyanide followed by natural degradation, dilution and "mobilization." • 1993 EIS: effluent treated for cyanide and disposed by LAD	• 1988 EA: Water quality impacts from the leach pad would be minor and probably unpredictable • 1993 EIS: only minor impacts from As via LAD 1993 EIS: Heap is part of a zero discharge circuit and would not release any water to the surface.	• 2004 ECR: LAD of leach pad leachate following water treatment resulted in contamination of groundwater exceeding standards for nitrate, iron, cyanide. Accidence of cyanide concentrations in surface water
	Waste Rock	• 1988 EA: Low acid drainage and metals potential suggests that degradation of water will not occur from the waste rock dump • 1993 EIS: some potential for acid drainage and release of sulfates and metals to water resources	• 1988 EA: No mitigation identified • 1993 EIS: reclamation would minimize any potential for impacts to groundwater from the release of sulfates and reduce infiltration • 1993 EIS: segregation and blending of PAG waste rock with lime added if necessary	• 1988 EA: No impacts predicted • 1993 EIS: Concentration of NO_3 and SO_4 releases from waste rock facilities may continue to increase	• 1993 EIS: Increased SO_4 concentrations in waste rock toe seeps - possible precursor to acid drainage. Increases in TDS, SO_4, NO_3 in German Gulch relative to baseline data. • 2004 ECR: elevated Se, sulfate, nitrate and TDS in seeps below waste rock
Pit Water	Open Pit	• 1988 EA: Mine pit water expected to contain elevated ammonia and nitrate/ nitrite from blasting.	• 1988 EA: Diversion of stormwater and pit water for process use • 1988 EA: pit backfilled, lined with limestone and gravels, free-draining; rock in pit would neutralize contaminants	• 1988 EA: No pit water predicted • 1993 EIS: Predicted impacts would have little if any effect on groundwater.	2004 ECR: water from the open pit toe drains has elevated selenium, sulfate and nitrate and requires capture and treatment

6.3.13. BLACK PINE, MONTANA

The Black Pine Mine, owned by ASARCO, was in operation from 1974 to 1989 but was closed at various points during this period. The primary commodities mined were gold, silver and copper from underground mining, using flotation and gravity processing methods. The ore has also been mined as a silica flux for ASARCO's East Helena Smelter. It disturbs 429 acres on the Deerlodge National Forest in U.S. Forest Service Region 1 and has a current financial assurance amount of $8.07 million.

6.3.13.1. WATER QUALITY PREDICTIONS SUMMARY

The Deerlodge National Forest and Montana Department of Environmental Quality (formerly Department of State Lands) were the lead agencies for NEPA and MEPA actions at the Black Pine Mine. NEPA was required for mine re-opening after an extended closure period, and an EA in the form of a Preliminary Environmental Review (PER) was completed in 1981. In 2003 an EA was conducted for short-term reclamation due to the existence of water quality issues. In 2004 another EA was conducted to address long-term reclamation. The NPDES permit was not required or part of the NEPA/MEPA action for the original operations, which were supposed to be zero discharge. The following sections summarize pertinent information in the NEPA documents reviewed.

1981 Preliminary Environmental Review

The primary minerals identified were sulfides and sulfosalts including hubnerite, tetrahedrite, pyrite and galena. Secondary mineral association consists of malachite, pyromorphite, oxidized lead, antimony and native silver. No geochemical characterization testing was performed, so the potential for acid drainage or leaching of contaminants was not identified in the PER. The amount of seepage from the tailings impoundment to groundwater was predicted to be low (14.6 gpm), and constituents reporting to the tailings impoundment were considered to be of low concentrations and degradable. Impacts to groundwater from tailings were predicted to be minimal. According to the PER, impacts to surface water systems in the project area will be minimal. No planned discharge to surface waters will occur. The tailings impoundment was designed as a closed cycle system.

2003 EA

According to the 2003 EA, the waste rock dump contains primarily quartzites and argillites of the Spokane Formation and ore vein material. Pyrite, iron staining and copper-bearing minerals can be seen on the surface of the dump, and copper staining from mobilization of copper minerals can be seen on rocks, bones and other debris on the surface of the dump. No sampling of the waste rock dump for geochemical characterization was performed. However, constituents of concern identified from existing waste rock dump seepage included sulfate, copper, zinc, iron, cadmium and low pH.

Mitigation identified in the EA included relocation and improvements to the seepage collection systems below the waste rock dump, consolidation/placement of contaminated materials on top of the waste rock dump and regrading the waste rock dump from angle of repose to a 3:1 slope.

2004 EA

No additional geochemical characterization information or water quality predictions were performed for this EA. The EA addressed final reclamation by requiring reclamation of the waste rock dump with a composite engineered cover consisting of a six 12-inch, low-permeability layer overlain by a drainage layer (sandy gravel) and then a soil cover (six inches of topsoil underlain by 18 inches of subsoil). Additional areas of contaminated soil would also be addressed.

The EA included a contingency to require more permanent long-term water management measures if the proposed reclamation measures are not effective, and the current bond assumes those measures will be necessary. The water treatment would most likely involve capture, pumpback, treatment and disposal.

6.3.13.2. ACTUAL WATER QUALITY CONDITIONS

The 2003 EA was initiated to reduce on-going water quality impacts caused by leachate from the waste rock dump, and it discusses these impacts. In 2000 MDEQ identified acid drainage and metals in springs on site with elevated levels of sulfate, metals and low pH. The 2003 EA showed waste rock was discharging acid drainage and metals to underlying groundwater and springs. Seepage collection and reclamation of the waste rock dump was performed to mitigate acid drainage. The leachate runs overland and off site and has killed vegetation in the area of the flows. Several ephemeral springs and one perennial spring issuing from the waste rock dump are contaminated by the dumps and are acidic (2.6 to 4.7) and high in sulfate, copper, zinc, iron and cadmium. The springs drain into groundwater and ephemeral drainages that flow into Smart Creek.

6.3.13.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.18 provides a summary and comparison of potential, predicted and actual water quality information for the Black Pine Mine. The accuracy of the predictions is discussed in this section.

Impact of Acid Drainage from Waste Rock Dump on Springs, Groundwater, and Ephemeral Drainages: No geochemical testing was performed on waste rock in any of the environmental reports. Information on geology and mineralization gave some hint of the potential for acid drainage (sulfides in quartzites with carbonates on site, but not in ore body), but this information was not evaluated or used as a basis for ordering geochemical testing. The only identified source of potential water contamination in the 1981 PER was the tailings impoundment. The 1981 PER indicated no potential for acid drainage or contaminants with no planned discharge to surface water and predicted minimal impacts to water resources. The 2004 EA indicated long-term potential for acid drainage and metals from the waste rock dump and underground workings. Therefore, the observed water quality impacts to springs, groundwater and surface drainages were not predicted. No geochemical testing on waste rock was performed, and the mineralization, although suggestive of potential acid generation, was not further investigated. The only identified potential source of water contamination, the tailings impoundment, has not yet been shown to be impacting groundwater.

Table 6.18. Black Pine, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Waste Rock	• 1981 EA: no potential for acid drainage or leaching of contaminants was identified • 2003 EA: existing leachate from the waste rock dump contaminating groundwater and springs on site with acid drainage and metals. • 2004 EA: long-term leachate from the waste rock dump and potential water quality problems from underground mine workings	• 1981 EA: No planned discharge to surface waters will occur • 2003 EA: relocation and improvements to the seepage collection systems below the waste rock dump; consolidation /placement of contaminated materials on top of the waste rock dump; and regrading the waste rock dump from angle of repose to a 3:1 slope. • 2004 EA: reclamation of the waste rock dump with a composite engineered cover; contingency to require more permanent long-term water management measures if the proposed reclamation measures are not effective ○ capture, pumpback, treatment and disposal.	• 1981 EA: impacts to surface water systems in the project area will be minimal • 2003 EA: reduction of existing water quality impacts is expected • 2004EA: long-term reduction and prevention of future water quality impacts is expected	2000 DEQ: identified existing leachate from the waste rock dump contaminating springs on site showed elevated levels of sulfates, copper, zinc, iron, cadmium, and low pH (2.6 - 4.7).

6.3.14. GOLDEN SUNLIGHT, MONTANA

The Golden Sunlight Mine, owned by Placer Dome, Inc., has been in operation since 1983. The primary commodities mined are gold and silver from open pit and some limited underground mining, using cyanide vat leach and gravity processing methods. It disturbs 2,967 acres on private, state and BLM lands. It has a current financial assurance amount of $64.1 million.

6.3.14.1. WATER QUALITY PREDICTIONS SUMMARY

The Bureau of Land Management and Montana Department of Environmental Quality (formerly Department of State Lands) were the lead agencies for NEPA and MEPA actions at the Golden Sunlight mine. NEPA and MEPA were required for the new project to be permitted, and an EIS was completed in 1981. A subsequent EA for expansion was conducted in 1990, followed by an additional EIS for mine expansion in 1997. Currently an additional EIS is being developed for consideration of open pit backfilling. The following section summarizes the pertinent information in the NEPA documents reviewed.

1981 EIS

Only ABA tests were performed. No constituents of concern were identified. Results of testing confirmed the potential for the ore to produce acid. According to the EIS, the potential for acid mine drainage from the proposed project was considered to be minimal, based on the previous, historic mining activity and waste dump development on the project site that had not resulted in acid mine drainage. There was also a general lack of a water discharge from existing underground workings at the mine.

The EIS addressed the potential for groundwater contamination from tailings leachate, which contained cyanide. Mitigation identified in the EIS included the use of finger drains, a clay liner, cutoff trench and the impervious nature of the underlying sediments. Seepage would be collected in ditches and pumped back to the impoundment. Normal operation of the proposed facilities would not result in a significant adverse impact to the areas existing subsurface and surface water resources. The risk to groundwater after mitigation was predicted to be low. The design approach was projected to achieve a zero discharge facility. The infiltration of mining-impacted water to the groundwater system was predicted to be very localized and not cause any measurable change in groundwater quality.

1990 EA

The EA identified sulfide mineralization, with waste rock containing 1 to 5 % sulfides, of which 99 % was pyrite with minor amounts of chalcocite, chalcopyrite, bornite, galena, sphalerite and barite. Oxidation of waste rock was expected to be generally limited to within 100 ft of the surface. ABA, EP Toxicity, total sulfur and sulfur fractionation, and “laboratory weathering” geochemical characterization tests were performed. Constituents of concern identified included low pH, elevated levels of metals, nitrate and high salt concentrations.

According to the EA, the pH value for waste rock averaged 4.2 (acid generating). All laboratory weathering samples of waste rock produced acid. All samples of unoxidized mudrock near the breccia ore body produced acid in the laboratory weathering tests. All samples of oxidized mudrock also produced acid in the laboratory weathering tests. If reclamation does not eliminate available oxygen and water, the tailings are predicted to eventually acidify. Waste rock piles are also predicted to eventually acidify from oxygen convection due to the high sulfide content and lack of a waste rock cap. Ultimate water quality in the mine pit is uncertain, but leachate analysis suggests the water would have low pH and elevated levels of metals, nitrate and salts in excess of the natural groundwater conditions. The EA suggested that water seeping from the pit would be modified by “a variety of unidentifiable geochemical processes,” and this flow would reduce the quality of the receiving water and exceed water quality standards.

According to the EA, engineered mitigation would consist of an impoundment designed with an amended soil liner and a piping system above the liner to carry tailing seepage through the embankment face to a collection system and the mill circuit. The slurry wall would intercept the majority of seepage from the impoundment. It is anticipated that seepage to the east and south of the impoundment may occur. In time, a decrease in the effectiveness of the plumbing system for the impoundment is expected. This decrease in efficiency may result in a rise of phreatic levels within the impoundment and drainage through the impoundment bottom or through the embankment face.

To meet the requirements of the Montana Metal Mine Reclamation Act (MMRA), GSM committed to treat any discharge from the mine pit, waste rock dumps and tailings impoundments. The 1990 EA states that "Treatment in perpetuity has never been addressed by the regulatory agencies."[3] In addition, a mass balance model was used to justify the recommendation for a two-ft waste rock and two-ft soil cap cover to minimize infiltration and leachate quantities.

1998 EIS

The 1998 EIS resulted from citizen lawsuits that appealed the 1990 EA decision. This EA found that there would be no significant impacts, even though the high potential for acid drainage and substantial reclamation and water treatment requirements were identified..

The EIS identified high potential for acid drainage and contaminant leaching. The potential contaminants list was increased in the 1998 EIS to include aluminum, arsenic, cadmium, copper, zinc, pH, sulfate, chromium, iron, lead, manganese, nickel and selenium. Contaminants typically exceeded drinking water standards by 10 times or more in waste rock pore water extracts. Groundwater contamination was predicted to occur in tens to hundreds of years. Pit water, if allowed to form, was similarly expected to be characteristic of acid drainage. The tailings impoundments were also expected to become acid generating over the long-term.

The 1998 EIS acknowledged the presence of acid drainage-like solutions from springs in the project area, containing elevated concentrations of sulfate and trace metals. These springs were considered natural because of the abundant ferricrete associated with them, suggesting that acid drainage has been produced by Bull Mountain for some time. However, it is possible that mining activity caused the elevated concentrations, and no baseline water quality data are available to determine the cause or causes of the elevated concentrations.

An acid drainage transport model was used to estimate the potential for contamination from the waste rock dumps to affect surface water in the Jefferson River. HELP modeling was used to estimate precipitation inflow rates into the waste rock dumps. A mixing cell model was used to predict interaction of leachate with the groundwater flow system and eventual transport to surface water. Dump seepage was predicted to reach the water table within 30 to100 years, followed by a period of approximately 2,000 years where seepage was primarily characterized by high sulfate levels, followed by a steep increase in acidity and metals contamination beginning in approximately 3,000 years and extending for up to 10,000 years in the future. Best case results suggested the most significant impacts would not occur for up to 5,000 years in the future, while worst case results suggested the same impacts would occur approximately 600 years in the future.

In addition to an engineered cover (2 ft non acid-generating material and 2 ft soil) and perpetual waste rock seepage water treatment, mitigation included installation of drains and other seepage capture devices to reduce the amount of acid drainage that reaches groundwater.

The tailings impoundments were expected, over the short-term, to continue to leak cyanide-containing solutions into groundwater and to require pumpback systems to mitigate the groundwater plume and prevent it from reaching surface water. The No. 1 tailings impoundment was expected to continue leaking until it is effectively reclaimed, and localized leaks were expected to occur from the No. 2 tailings impoundment over the long-term. After closure the leachate was expected to become acidic. However, the EIS predicted that an engineered cover (2 ft NAG and 2 ft

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[3] It appears that this may be the first regulatory reference in the U.S. dealing with hardrock mine sites that acknowledges the possibility of perpetual treatment as a potential scenario.

soil) would decrease leachate infiltration to groundwater and little or no impact to groundwater would occur. Present day tailings impoundment plume mitigation included groundwater pumpback systems, slurry walls and landowner buyouts as well as replacement water provisions.

No pit pond would be allowed to form if it exceeds Montana surface water quality standards. Pit water treatment would be required if necessary for discharge.

2005 EIS

In 2002 another citizens' lawsuit resulted in a requirement for the Golden Sunlight Mine to prepare an EIS to address pit backfilling, which the court ruled the mine was required to do in order to meet the State's constitutional requirements. The Draft EIS was issued in 2005. It contains an analysis of the potential for backfilling of the open pit to impact groundwater and surface water quality and will most likely include predictions for both backfilling and non-backfilling as well as pit lake scenarios.

6.3.14.2. ACTUAL WATER QUALITY CONDITIONS

According to the 1998 EIS, monitoring of existing waste rock dumps showed sulfide oxidation and potential for acid drainage, with some piles already producing acid drainage. Evidence shows some springs on the project site were impacted, but larger impacts to groundwater or surface water from the waste rock dumps have not been evident to date.

The primary source of existing groundwater contamination at Golden Sunlight is the tailings impoundment. The groundwater contains cyanide and copper concentrations above standards and has required numerous mitigation, as described in the previous section.

6.3.14.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.19 provides a summary and comparison of potential, predicted and actual water quality information for the Golden Sunlight Mine. The accuracy of the predictions is discussed in this section.

Groundwater Contamination from Tailings Impoundment: Potential groundwater contamination with cyanide and metals from the tailings impoundment was identified in the 1983 EIS, but mitigation (clay liner, finger drains, leachate collection) were predicted to prevent any impacts to groundwater. The 1990 EA stated that capture of the tailings plume would prevent more extensive groundwater contamination, but capture was not entirely effective. Therefore, the estimated potential (pre-mitigation) impacts of cyanide and metals from the tailings impoundment were accurate. The predictions that the tailings impoundment mitigation would prevent groundwater contamination and that plume capture would limit further groundwater impact were not accurate.

Acid Drainage in Waste Rock Pore Fluids, Pit Water, and Springs Downgradient of Waste Rock Dumps: Geochemical characterization conducted for the 1981 EIS identified the potential for acid drainage, but because historic operations had not resulted in acid drainage, the potential was considered to be low. In addition, the acid-base accounting results were accompanied by a statement from the laboratory that laboratory results were not representative of field conditions (due to grinding of sample), and that acid drainage generation could be less important than indicated by the test results. Therefore, acid-base accounting tests did predict the acid drainage that ultimately developed at the site, but the prediction that acid drainage would not develop based on information from historic operations was not accurate.

Table 6.19. Golden Sunlight, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings	• 1981 EIS: Geochemical tests indicate acid drainage potential but site indications used to suggest low actual potential. • 1981 EIS: Potential for contamination of groundwater from tailings solution containing cyanide. • 1990 EA: Potential for acid drainage and metals in leachate • 1998 EIS: Short-term tailings leak containing cyanide and other contaminants expected to continue • 1998 EIS: Long-term potential for tailings to go acid	• 1981 EIS: Facility design to prevent groundwater and surface water impacts. o use of finger drains o clay liner o cutoff trench o impervious nature of the underlying sediments • 1990 EA: Capture of contaminated groundwater o Slurry walls and downgradient wells • 1998 EIS: Capture of contaminated groundwater o Slurry walls and downgradient wells o landowner buyouts o replacement water provisions o perpetual treatment of tailings seepage • 1998 EIS: Reclamation cover to decrease long-term potential for impacts from acid drainage	• 1981 EIS: Risk to groundwater "slight" • 1990 EA: Prevent contamination from becoming more extensive in groundwater and will protect surface water • 1998 EIS: Little or no long-term impact to groundwater from acid drainage. No impacts to groundwater outside of existing cyanide plume.	• 1990 EA: Contamination of cyanide and copper in downgradient wells • 1998 EIS: Continued contamination of cyanide and copper in dowgradient wells • Water Quality Monitoring: Capture not 100% efficient due to operational problems

Table 6.19. Golden Sunlight, MT, Potential, Predicted and Actual Impacts (continued).

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Waste Rock	• 1981 EIS: Geochemical tests indicate acid drainage potential but site indications used to suggest low actual potential • 1990 EA: Significant potential for acid drainage and metals in waste rock leachate • 1998 EIS: Significant potential for impacts from acid drainage and metals over long-term	• 1981 EIS: No mitigation identified as needed • 1990 EA: Capture of contaminated groundwater ○ Slurry walls and downgradient wells • 1990 EA: Engineered covers to reduce leachate production • 1998 EIS: Capture of contaminated groundwater ○ Slurry walls and downgradient wells ○ installation of drains and other seepage capture devices • 1998 EIS: Reclamation cover to decrease long-term potential for impacts from acid drainage	• 1981 EIS: Risk from acid drainage "minimal" • 1990 EA: Mitigation to prevent significant long-term impacts from acid drainage • 1998 EIS: Mitigation to prevent significant long-term impacts from acid drainage in surface water. No impacts to groundwater outside of proposed mixing zone.	Water Quality Monitoring: No actual impacts noted to date although springs near east waste rock dump and pore water in all waste rock dumps indicate long-term acid drainage and metals leaching impacts
Groundwater, Surface Water and Pit Water	Open Pit	• 1983 EIS: Pit not expected to go below groundwater level • 1990 EA: Significant potential for acid drainage and metals in leachate from open pit • 1998 EIS: Pit water expected to be characteristic of acid drainage	• 1983 EIS: No mitigation identified as needed • 1990 EA: Capture of contaminated pit water • 1998 EIS: Capture and treatment – no pit lake allowed to form	• 1983 EIS: no impacts to water quality • 1990 EA: Mitigation to prevent significant long-term impacts from acid drainage • 1998 EIS: Mitigation to prevent significant off-site impacts from acid drainage	Water Quality Monitoring: Monitoring of pit water indicates acid drainage characteristics

6.3.15. MINERAL HILL, MONTANA

The Mineral Hill Mine (also known as the Jardine Joint Venture), owned by TVX Gold Inc., was in operation from 1989 to1996. The primary commodities mined were gold and silver from an underground mine that used cyanide vat leach processing methods. It disturbs 106 acres on private and Gallatin National Forest lands in U.S. Forest Service Region 1. It has a current financial assurance amount of $8.5 million.

6.3.15.1. WATER QUALITY PREDICTIONS SUMMARY

The Gallatin National Forest and Montana Department of Environmental Quality (formerly Department of State Lands) were the lead agencies for NEPA and MEPA actions at the Mineral Hill Mine. NEPA and the Montana Environmental Policy Act (MEPA), which closely mirrors the federal law, were required for the new project to be permitted, and an EIS was completed in 1986. A subsequent EIS for reclamation and closure was conducted in 2001. The following sections summarize the pertinent information on water quality from the NEPA documents reviewed.

1986 EIS

According to the 1986 EIS, minerals in the gold-bearing zone included arsenopyrite, pyrrhotite, pyrite, chlorite, quartz and amorphous carbon. Metamorphosed marine sediments host the gold ore. Geochemical characterization testing consisted of a batch extraction leach test on the tailings material. The leachate the from batch extraction contained elevated cyanide as free cyanide, arsenic and manganese. Arsenic and cyanide contamination from old tailings on the site was also mentioned as affecting background water quality. Identified potential groundwater impacts (to Bear Creek alluvium) included direct seepage from the tailings dump and production of leachate in mine workings and backfill.

The lack of water in the workings (location above the water table) were expected to limit the potential for acid drainage. Removal and reprocessing of old, existing tailings piles was proposed to address historic tailings impacts on water quality at the site. Tailings from current mining would not be dewatered before backfilling; however, slurry would be controlled by ditches in the mine, collected in underground sumps and pumped back to the mill circuit. Tailings disposed on surface would be dewatered and placed in a lined repository.

2001 EIS

According to the EIS, mining operations ceased before the originally anticipated life-of-mine. Changes in proposed reclamation techniques and water management practices prompted the EIS.

The tailings facility design resulted in unanticipated lateral flow that escaped the liner system, resulting in contamination of alluvial groundwater and surface water. The seepage contains cyanide, nitrate, manganese, sulfate, arsenic and TDS. The proposed mitigation for the discharge would involve capture and treatment of the leachate with discharge to the vadose zone for evapotranspiration and the use of a 48-inch thick water balance cover to reduce seepage.

Modern mining operations impacted the historic flow from the mine, which was less than a few gallons per minute (gpm), resulting in an increased flow of approximately 15 gpm with arsenic concentrations in excess of standards. The proposed mitigation for the impacts would involve treating the 15 gpm flow to reduce arsenic to acceptable levels and discharging to groundwater (versus present discharge to surface water).

Proposed long-term mitigation included replacement of the water treatment system and long-term monitoring and maintenance for 100 years; financial assurance insured those operations.

6.3.15.2. ACTUAL WATER QUALITY CONDITIONS

Groundwater and surface water was contaminated by tailings leachate, which contained cyanide, nitrate, sulfate, TDS, manganese and arsenic. Increased flow from the mine adit contains arsenic in excess of the mine's NPDES discharge standards.

6.3.15.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.20 provides a summary and comparison of potential, predicted and actual water quality information for the Mineral Hill mine. The accuracy of the predictions is discussed in this section.

Table 6.20. Mineral Hill, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings	• 1986 EIS: potential for elevated cyanide, arsenic and manganese in tailings leachate to contaminate groundwater • 2001 EIS: potential for cyanide, arsenic, manganese, sulfate, nitrates and TDS in tailings leachate to contaminate alluvial aquifer and surface water	• 1986 EIS: Tailings dewatered and placed in a lined repository • 2001 EIS: capture and treatment of the leachate with discharge to the vadose zone; water balance cover to reduce seepage	• 1986 EIS: no surface water impacts predicted • 2001 EIS: no impacts predicted as long as mitigation is maintained (100 years)	2001 EIS: tailings leachate containing cyanide, nitrate, manganese, sulfate, arsenic and TDS escaped the liner system and caused exceedences in alluvial groundwater and surface water
	Underground Workings	• 1986 EIS: potential for acid drainage from mine workings or backfill to contaminate alluvial aquifer • 2001 EIS: no information	• 1986 EIS: none • 2001 EIS: water treatment to reduce arsenic to acceptable levels and discharge to groundwater	• 1986: no impacts predicted • 2001 EIS: no impacts predicted as long as mitigation is maintained (100 years)	• 2001 EIS: flow from mine workings of approximately 15 gpm that contained arsenic in excess of standards

<u>Contamination of Alluvial Groundwater and Surface Water by Tailings Seepage:</u> Geochemical characterization (batch leach test) conducted for the 1986 EIS identified the potential for elevated concentrations of cyanide, arsenic and manganese in tailings leachate. Tailings were dewatered and placed in a lined repository, and no impacts to water resources were predicted in the 1986 EIS after mitigation were in place. The potential for seepage of tailings leachate to groundwater was identified in the 1986 EIS. The 2001 EIS identified the potential for alluvial groundwater and surface water contamination with cyanide, arsenic and manganese (as identified in 1986), as well as sulfate, nitrate and TDS (not predicted as contaminants of concern in the 1986 EIS). The liner system in the tailings impoundment failed to prevent lateral flow of leachate. Therefore, geochemical characterization did predict the observed increases in three of six constituents in tailings leachate, but post-mitigation predictions were inaccurate because the mitigation were not able to prevent impacts to groundwater and surface water resources.

<u>Increased Volume and Exceedence of Arsenic Standard in Adit Drainage:</u> The potential for leakage from mine workings to Bear Creek alluvium was identified in the 1986 EIS, but the mine was not expected to produce appreciable amounts of water, so no impacts were predicted. Increased flow (compared to historic mining flows) from the underground mine (15 gpm) contained enough arsenic that treatment is required prior to discharge. Arsenic was noted in tailings leachate from the batch extraction tests, but no tests were conducted on mine workings walls. Acid

drainage, which was predicted as being a potential issue in 1986, has not been an issue so far. Therefore, the hydrologic prediction that there would not be much water in the underground workings was not accurate. Arsenic was not identified as a constituent of concern in mine drainage, in part because no geochemical characterization tests were conducted on waste rock or ore.

6.3.16. STILLWATER, MONTANA

The Stillwater Mine, owned by Stillwater Mining Company, has been in operation since 1986. The primary commodities mined are platinum group minerals from underground mining, using flotation processing methods. It disturbs 255 acres on private and Custer National Forest lands in U.S. Forest Service Region 1. It has a current financial assurance amount of $7.8 million.

6.3.16.1. WATER QUALITY PREDICTIONS SUMMARY

The Custer National Forest and Montana Department of Environmental Quality (formerly Department of State Lands) were the lead agencies for NEPA and MEPA actions at the Stillwater Mine. NEPA was required for the new project to be permitted, and an EIS was completed in 1985. In 1992 an EIS was conducted for a mine expansion and in 1998 an EIS was conducted for a new tailings disposal facility and revised waste management. The following sections summarize the pertinent water quality information in the NEPA documents reviewed.

1985 EIS

According to the 1985 EIS, the original intrusion contained iron, nickel, chromium, copper and platinum-group (sulfide) minerals. Other nickel-copper-chromium deposits are located in the local area. No information is contained in the EIS on geochemical characterization testing or water quality impact potential. The only constituent of concern identified was nitrogen. Mitigation would include lining of the tailings impoundment with 36-mil hypalon synthetic liner to prevent seepage from reaching the Stillwater River. Only nitrogen compounds were expected to affect groundwater quality. Even under most severe conditions (high flow and high nitrate concentrations in pond seepage and low flow and high nitrate concentrations in river) excess algal growth in the river was not expected to occur. Additional nitrogen compounds would not influence algae growth because of the low phosphorous concentrations in the river. Stillwater River was not predicted to be influenced by seepage from dewatering of the underground workings.

1992 EIS

Geochemical characterization consisted of static testing of ore and waste materials. The EIS proposed to do static and if necessary kinetic testing to identify potential for acid production and metals leaching. Constituents of concern identified in ore included lead, cadmium, mercury and zinc, iron, copper, nickel, TDS, sulfate, nitrate, chromium, ammonia and nitrate. Mitigation included lining of the tailings impoundment, reclamation to include a structural cap of waste rock, and reduction in the use of nitrogen-containing explosives. The operation is a zero-discharge facility except for underground workings dewatering discharges, which are percolated to groundwater (land application discharge or LAD).

1998 EIS

According to the 1998 EIS, acid-base accounting, Toxicity Characteristic Leaching Procedure (TCLP), Sequential Saturated Rolling Extraction, and column leach extraction tests were performed, and the HELP model was used to estimate infiltration into waste rock and tailings. ABA test results showed low potential for the waste rock to generate acid.

According to the EIS, the primary mitigation for the new tailings impoundment were an HDPE and clay liner with an seepage collection system and treatment of water from underground workings for nitrogen using denitrification with an anoxic biotreatment cell.

Seepage from the unlined storage pond was predicted to have no significant impact on groundwater quality because of the low permeability of underlying glacial material (project less than 2 gpm seepage). Groundwater in the area is not expected to be impacted. Modeling predicted nitrate concentrations in the Stillwater River from Hertzler LAD water to be 0.70 mg/l, but concentrations are expected to be much lower due to uptake by vegetation, evaporation and high flow in the Stillwater River. Alluvial waters along the Stillwater River are not predicted to be affected, as the Hertzler Tailings Impoundment and LAD are more than one mile from the river.

6.3.16.2. ACTUAL WATER QUALITY CONDITIONS

The 1992 EIS stated that chromium, zinc and to a lesser extent, cadmium, were elevated in well downgradient of the LAD relative to upgradient wells. Increased TDS, sulfate, nitrate and to a lesser extent, chromium and zinc, were thought to reflect the disposal of excess adit water through land application and percolation. According to the 1998 EIS, water discharged from the West Side Adit and East Side Adit between March 1990 and June 1997 exceeded standards (either Montana human life or aquatic standards) for dissolved cadmium, copper, manganese, zinc and total recoverable cadmium, copper and lead. Nitrogen in adit discharge water was much higher than baseline levels. Dissolved chromium regularly exceeded human health standards at all groundwater monitoring sites in the LAD area, and there were slight elevations of sulfate, chloride, phosphorous, cadmium, iron, and zinc observed downgradient of the LAD area**.**

The Stillwater Mine has been collecting surface water and groundwater quality data since 1980 to document the water quality to prior the development of the mine and during on-going mine operations. In 2003, a comprehensive Baseline Water Quality Study (CSP2, 2003) was completed examining the baseline water quality from before mining to present. The results of the study showed that over the approximately 18 years of mine life no noticeable impacts (compliance with Montana non-degradation water quality standards) to water quality in the Stillwater River have occurred due to the operation of the Stillwater Mine. There were no discernable impacts with the exception of increased nitrogen concentrations, which are from mining operations. The increase in concentration averages approximately 0.2 mg/l over the life of the mine with seasonal fluctuations ranging from less than 0.1 mg/l to as high as 0.7 mg/l (the regulatory limit in SMC's MPDES permit is 1.0 mg/l). Stillwater Mining, as part of to Good Neighbor Agreement with local conservation organizations, has agreed to optimize its water treatment and land application discharge operations and remove 90% more nitrogen than is required by its NPDES permit and reduce maximum concentration increases in groundwater to 2.0 mg/l and in the Stillwater River to 0.2 mg/l.

6.3.16.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.21 provides a summary and comparison of potential, predicted and actual water quality information for the Stillwater Mine. The accuracy of the predictions is discussed in this section.

Elevated Concentrations of Nitrate, Metals and Anions in Adit Discharge and Groundwater in the LAD Area:. The 1985 EIS did not include geochemical characterization but did indicate the potential for increased nitrogen concentrations. The 1992 EIS identified lead, cadmium, mercury, zinc, iron, copper, nickel, chromium, TDS, sulfate and nitrogen in ore and waste materials as constituents of concern. The 1992 EIS also noted that increased concentrations of chromium, zinc, cadmium and other constituents were present in groundwater in the LAD area. The 1998 EIS indicated no potential for groundwater impact from land application of adit discharge water, even though increased concentrations had been noted in the 1992 EIS. The 1998 EIS indicated that groundwater being discharged from the underground mine to percolation and LAD exceeded surface water standards for metals and nitrogen, and groundwater at the site had elevated levels of metals and sulfate. However, the 1998 EIS failed to identify that the most likely source for the metals and sulfate was historic tailings, and not current mine operations other than for nitrate. Therefore, many of the constituents with increased concentrations in groundwater in the LAD area had been identified as constituents of concern, but the potential for impacts to groundwater from the LAD system was underestimated.

Table 6.21. Stillwater, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings and Waste Rock	• 1985 EIS; no potential for acid drainage or other contaminants except nitrogen • 1992 EIS; potential for Pb, Cd, Hg, Zn, Fe, Cu, Ni, Cr, TDS, Sulfate, nitrogen compounds • 1998 EIS: no potential for acid drainage or metals identified: potential for nitrogen identified	• 1985 EIS; line tailings impoundment • 1992 EIS; line tailings, cap waste rock, reduce explosives usage • 1998 EIS: line tailings impoundment	• 1985 EIS; nitrogen will increase in groundwater but no impacts to surface water quality • 1992 EIS; no impacts to water quality predicted 1998 EIS: no impacts to water quality predicted	1985 – 2004: No discernible impacts to surface water or groundwater other than nitrogen (below standards)
	Discharge Water from Underground Workings	1998 EIS: Water discharged from underground workings exceeds standards for Cd, Cu, Mn, Zn, Pb with high levels of nitrogen. LAD discharge contains elevated levels of Cr, SO_4, Cl, P, Cd, Fe, Zn	• 1998 EIS: water treatment to reduce nitrogen and land application discharge at agronomic rates for nitrogen uptake	• 1998 EIS: Groundwater quality not expected to be diminished and surface water would not be affected	• Adit water (1990 - 1997) exceeded Montana standards for Cd, Cu, Pb, Mn, Zn; N concentrations higher than baseline. Groundwater downgradient of LAD had regular exceedences of Cr and slight elevations of SO_4, Cl, P, Cd, Fe, Zn. • Increases in the Stillwater River of N, up to 0.7 mg/l (std = 1.0 mg/l).

<u>Increases in Nitrate Concentrations Above Baseline Values in Stillwater River:</u> A Baseline Water Quality Review which examined the groundwater and surface water quality at the mine found that no detectable impacts to surface water quality have occurred during the 20+ year mine life other than increases in nitrogen typically 80% below (90% below from 2000-2005) the narrative standard of 1.0 mg/l. The increased concentrations are related to mining activity. The potential for movement of nitrate toward the river was acknowledged, but, nitrate and ammonia concentrations from the LAD were not expected to affect the Stillwater River. Modeling predicted nitrate nitrogen concentrations from the LAD to be 0.70 mg/l or lower in the river, due to uptake by vegetation, evaporation and high flow in the Stillwater River. Therefore, the impacts of nitrate (above baseline values but below standards) to the Stillwater River were accurately predicted.

6.3.17. ZORTMAN AND LANDUSKY, MONTANA

The Zortman and Landusky mines (initially two separate mines), owned by Pegasus Gold Co., started operation in 1979. The operations were suspended in 1997, followed by company bankruptcy and mine closure in 1998. The primary commodities mined were gold and silver from numerous open pits using cyanide heap leach processing methods. It disturbs 1,215 acres on private and BLM lands. It had a financial assurance amount of $70.5 million when Pegasus went bankrupt.

6.3.17.1. WATER QUALITY PREDICTIONS SUMMARY

The Bureau of Land Management and the Montana Department of Environmental quality (formerly Department of State Lands) were the lead agencies for NEPA and MEPA actions at the Zortman and Landusky mines. NEPA and MEPA were required for the new project to be permitted, and an EIS was completed for both mines in 1979. In 1993 an EA for modified operating and reclamation was performed, and in 1996 an EIS for a major expansion of the Zortman Mine, along with modified reclamation plans for both mines, was performed. Subsequent to Pegasus's bankruptcy, a SEIS was conducted in 2001 to address reclamation and closure issues. The following sections summarize the water quality information in the NEPA documents reviewed.

1979 EIS

According to the EIS, oxidation (on both properties) generally persists to the levels of the deepest workings on the property, which are 500 ft bgs. No geochemical characterization tests were conducted, and the only constituents of concern identified were cyanide and cyanide complexes. The potential for a lining failure was acknowledged, in either the heap or process water pads, which would release an unknown amount of solution to the groundwater. In this case, the presence of significant amounts of heavy metal ions in the seepage would be of a potentially great concern. For surface water, the major concerns were identified as sedimentation and chemical contamination from potential leaks or overflows of leach pad or pregnant and barren ponds. However, no measurable cumulative impact was expected to surface water from either project after mitigation (berms, ditches and impermeable barriers) are in place. The potential for acid drainage development was expected to be low because only oxide ore would be mined.

Mitigation were directed towards potential cyanide leach solution leakage and stormwater management. A groundwater monitoring program was proposed, where any contaminated groundwater would be pumped and piped for containment and neutralization in either the barren pond or and emergency storage pond until the source of the leak is detected and repaired. However, because of the utilization of both membrane and clay liners, it was not anticipated that either operation would have a significant effect on groundwater quality during normal operations. The utilization of berms, ditches and impermeable barriers was expected to prevent deterioration of surface water from the waste ponds. A cumulative effect on the groundwater was predicted from infiltration from both pits. The impact, however, was expected to be small due to the small area proposed for mining. No water was expected to accumulate in pits because the pit floors were proposed to be sloped and graded to prevent the formation of ponds.

1990/91 EA

Static tests were conducted as part of the 1990 EA to assess the potential for acid rock drainage. The sample results showed some rock units had net acid generating potential and some units had net neutralizing potential. The study used the composite of all rock samples to conclude that widespread development of ARD was not likely. As mitigation, the operator's plan stated that any high sulfide waste rock would be placed on the leach pad instead of the waste rock dump. In 1993 BLM issued a noncompliance with ZMI for not following this mitigation and ordered waste rock disposal in the Mill Gulch waste rock dump to cease.

The main water quality issue in this EA was the post-closure retention of high cyanide concentrations in the spent ore. A cyanide degradation study was required as part of the EA. The study concluded that cyanide concentrations would rapidly degrade after leaching and that only minimal rinsing would be necessary. This study turned out to be correct regarding cyanide levels, but did not address the high nitrate concentrations left in the heap effluent from the degradation of cyanide.

1993 EA

According to the EA, iron sulfides including pyrite, pyrrhotite and marcasite were identified in the ore. Geochemical characterization tests performed include paste pH, total sulfur, ABA, leachate extraction tests and long-term field-based leachate extractions. Constituents of concern identified included cadmium, fluoride, sulfate, zinc, low pH, nitrate and arsenic. Major ores being mined contained both oxide and sulfide rock.

The EA identified mitigation including properly engineered caps over reclaimed dumps and heap leach pads. Pump-back systems were proposed to reduce impacts to groundwater by collecting acidified water below Sullivan Park dike and routing it into the pump-back system. A water treatment plant was required to be constructed at the Zortman Mine to treat mine drainage from both mines. The treatment plant was brought online in 1994. Slurry cutoff walls below the dike were proposed to reduce the volume of acidic water bypassing the contingency pond. Perforation of the leach pad liners would be delayed until leach pad seepage meets water quality standards. Diversion structures were designed to withstand 6-inch, 100-year, 24-hour storm events. Leach pad underdrains will capture water that is pumped to the contingency pond and not discharged to surface waters but directed to the processing circuit.

1996 EIS

Geochemical characterization tests performed include total sulfur, paste pH, ABA, kinetic testing (both long term and short term) and humidity cell tests for ore and waste rock, and cyanide speciation analysis. The HELP model was used to predict infiltration rates. Constituents of concern identified included cyanides, sulfate, TDS, nitrate and metals. Static tests performed on Zortman and Landusky ores showed a strong potential to generate acid. For both mine sites, waste samples having negative NNP's were considered potentially acid generating. At Landusky, short-term increases in TDS, sulfate and metals concentrations were predicted to occur at Sullivan Creek, Mill Gulch and Montana Gulch due to the lack of diluting water, but the loads were expected to be reduced rapidly.

Mitigation identified included segregating acid-generating waste from non-acid generating waste and using a combination of "water barrier" and "water balance" reclamation covers. Most of the historic mine workings would be removed by extended mining of Zortman pits. Old adits would be bulkheaded where exposed in the pits to minimize oxygen flow and discharge of transient water. A water quality improvement plan would be implemented. Capture systems, cutoff walls and recovery wells would be used to intercept poor quality surface water. Existing waste rock dumps would be removed and used as backfill material for pits. The Zortman pit complex was proposed to be backfilled with waste rock to an elevation necessary to drain freely into Ruby Gulch and Alder Spur, thereby reducing the potential for groundwater discharge to the north. Water treatment of collected groundwater and surface water for cyanide, nitrate, acid drainage, metals and other constituents would be implemented as required. The EIS predicted that the volume of acid drainage that would need water treatment over the next 20 years would be between 211 and 419 gpm. In 2005 the Zortman and Landusky water treatment plants treated at an annualized average of 490 gpm.

2001 EIS

According to the 2001 supplemental EIS, iron and iron/arsenic sulfides are present in the igneous intrusion responsible for the orebody. Carbonates exist in the area, but not in the ore deposit itself. Additional geochemical characterization tests were performed including paste pH, paste TDS, and ABA. Constituents of concern identified included sulfate, low pH, iron, aluminum, zinc, arsenic, copper, cadmium, cyanide and nitrate. It is expected that eventually most sources at the site (leach pads, waste rock, pits) have significant potential to generate acid drainage and to leach metals and other contaminants, although some units are not presently generating acid drainage. Water quality was generally expected to become acidic and have increased sulfate concentrations. The potential for infiltration of contaminated water to impact deeper groundwater was considered low due to surface water/groundwater interaction (groundwater losing to surface water in all cases) at higher elevations.

Mitigation included consolidation and backfilling of acid-generating waste, water barrier liners, water balance reclamation covers and revegetation to significantly reduce impacts to groundwater and surface water quality in the various drainages. Water treatment plants (lime precipitation with additional arsenic treatment) at the Zortman and Landusky mines would be used to treat water in perpetuity. Short-term biological treatment was also proposed to reduce cyanide, selenium and nitrate levels for leach pad waters being discharged.

According to the EIS, downgradient water quality predictions showed a wide range of possible concentrations. Therefore, continued monitoring and provisions for supplemental capture and treatment were proposed to prevent significant impacts to water quality. Spent ore on the L87/91 pad is expected to be a significant source of acid generation in the future. Water quality impacts in the northern drainages were predicted to increase if the acid generating material from the L87/91 pad was placed as pit backfill in the headwaters of these drainages. Concentrations of most contaminants from the Landusky Mine were predicted to increase over time. Pit backfilling was expected to increase loads of contaminants in the short term due to the disturbance of acid-generating material, the re-establishment of flowpaths and mobilization of soluble oxidation products (metal-sulfate salts).

6.3.17.2. ACTUAL WATER QUALITY CONDITIONS

1993 EA

Acid has developed from waste rock dumps and ore heap retaining dikes. The flow of acidic water from the toe of the dump and observed venting of sulfurous steam from portions of the dump are manifestations of the sulfide oxidation reactions occurring within the dump. Mill Gulch waste dump has generated acid drainage with pH periodically dropping as low as 3.9. Based on field inspections, BLM and DSL found that approved operating and reclamation plans were not preventing acid drainage. Mill Gulch and upper Sullivan Creek have become acidic as a result of pyrite oxidation in waste rock placed in Mill Gulch Waste Dump, the Sullivan Park dike, and possibly places within the excavated foundation of the 1991 leach pad. Surface water monitoring sites in Sullivan Creek were impacted by acid drainage from the 1991 leach pad, with pH between values between 2.6 and 2.8. Groundwater samples downstream of the Sullivan Park dike indicate that sulfate concentrations in the alluvial groundwater near the facility have increased.

1996 EIS

Acid drainage is currently being generated from pit walls and floors, leach pads and pad foundations, and waste rock piles.

2001 EIS

Acid drainage with metals, metalloids, nitrate and cyanide is common in groundwater at the site and is impacting surface water quality. Capture and treatment of discharges is effective at reducing discharges to below regulatory standards except for arsenic (treatment method is effective but was not always employed by Pegasus).

Recent Water Quality Monitoring Data

Recent (through 2005) surface water quality monitoring data from Montana DEQ indicates the 2001 EIS was correct in identifying mitigation and improving groundwater quality and protecting surface water quality. The notable exception has been in Swift Gulch where surface water quality has worsened, with higher sulfate and metals concentrations. Characterization of the source of Swift Gulch contamination has been difficult and has made identification of potential mitigation measures problematic.

6.3.17.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.22 provides a summary and comparison of potential, predicted and actual water quality information for the Zortman and Landusky mines. The accuracy of the predictions is discussed in this section.

Table 6.22. Zortman and Landusky, MT, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Heap Leach Piles, Open Pit, and Waste Rock Dumps	• 1979 EIS: only oxide ore and no potential identified other than cyanide • 1993 EA: potential for impacts from acid drainage including pH, sulfate, Cd, F, Zn, As, and nitrate. • 1996 EIS: strong potential to generate acid drainage and high TDS, sulfate and metals values • 2001 EIS: high potential to generate acid drainage with pH, sulfate, metals, metalloids, cyanide and nitrate.	• 1979 EIS: only oxide ore to be mined; stormwater controls and liners to prevent cyanide seepage • 1993 EA: reclamation caps (water barrier); groundwater capture and treatment for acid drainage and cyanide, stormwater controls. • 1996 EIS: waste segregation; water balance and water barrier reclamation covers; groundwater and surface water capture and treatment for cyanide, nitrate, acid drainage, metals and other contaminants • 2001 EIS: waste consolidation; reclamation covers, water capture and perpetual treatment	• 1979 EIS: no water quality impacts predicted • 1993 EA: no additional water quality impacts predicted • 1996 EIS: reduced water quality impacts predicted • 2001 EIS: Contaminants to increase over time but surface water quality expected to meet standards. Concentrations of most contaminants from the Landusky Mine are going to increase over time. Pit backfill expected to increase loads of contaminants in the short term due to the disturbance of acid generating material, the re-establishment of flowpaths and mobilization of 'soluble oxidation products'	1993 EA: acid drainage from waste rock dumps and heap leach retaining dikes. Surface water impacted by acid drainage with pH 2.6-2.8. Increased sulfate in groundwater • 1996 EIS: multiple 100+-yr storm events; extensive groundwater and surface water contamination with acid drainage and metals/metalloids, nitrate, cyanides • 2001 EIS: acid drainage with metals, metalloids, nitrate, cyanide common throughout groundwater and in surface water

<u>Low pH and elevated sulfate concentrations in surface water and groundwater</u>: The 1979 EIS indicated no potential for contaminants other than cyanide, based only on oxide ore being mined. The potential for development of acid drainage and groundwater and surface water impacts from acid drainage was not acknowledged in the 1997 EIS. The 1993 EA identified the potential for impacts from acid drainage, sulfate, metals, arsenic and nitrate. Acid drainage from waste rock dumps and heap leach retaining dikes was already impacting groundwater and surface water, but no additional water quality impacts were predicted as a result of capture and treatment. The 1996 EIS indicated strong potential for acid drainage from waste rock and high TDS, sulfate and metals values. Multiple 100+-year storm events led to impacts to surface water and groundwater from acid drainage associated with both waste rock both in dumps and used as leach pad base material. Reduced impacts on water quality were predicted. The 2001 EIS

indicated a high potential to generate acid drainage from waste rock with pH, sulfate, metals and metalloids along with cyanide and nitrate. Metals and metalloids, nitrate and cyanide are common in groundwater and surface water, and contaminants were expected to increase over time; however, surface water quality was expected to be protected.

6.3.18. FLORIDA CANYON, NEVADA

The Florida Canyon Mine, owned by Florida Canyon Mining Company (parent company was formerly Pegasus Gold and now Apollo Gold), has been in operation since 1986. The primary commodities mined are gold and silver from open pit mining and heap leach processing operations. It disturbs 2,149 acres on BLM land. It has a current financial assurance amount of $16.9 million.

6.3.18.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EA was completed in 1986 (not reviewed). In 1995 an EA was conducted for a mine expansion (not reviewed), in 1997 an EIS was conducted for a mine expansion and reclamation, and another expansion EIS was completed in 1999 (not reviewed). The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1997 EIS

According to the 1997 EIS, old mineralization is associated with quartz-veining as auriferous pyrite and free gold. Static testing (ABA), whole rock analysis, short term leach testing (MWMP), kinetic testing (humidity cell and column leach testing) and petrographic analyses were performed. Constituents of concern identified in whole rock and MWMP tests included aluminum, arsenic, cadmium, iron, lead, mercury, antimony, thallium and total dissolved solids (TDS). Static tests showed that 41.5% of the rock had the potential to produce acid and an additional 36.2% of the whole rock had uncertain potential to produce acid. According to the EIS, the modified Sobek method was used to fine-tune the estimate. The result was that only 0.2% of mined rock was identified as having potential to generate acid drainage. Kinetic tests were inconclusive but tended to show a low acid generation potential. However, two of the 14 samples showed acid generating potential. MWMP tests also showed the potential for leaching aluminum, arsenic and iron. HELP, OPUS and UNSAT2 were used to model waste rock seepage.

The EIS characterized baseline groundwater quality; in some wells the EIS claims that concentrations already exceeded drinking water standards for arsenic, aluminum, chloride, manganese, sulfate, TDS, fluoride, and nickel. According to the EIS, even though these samples were taken just downgradient of the heap and pit eight years after the mine commenced construction, the results were attributed to different water quality in different aquifers rather than mining activities. However, the EIS also mentions that groundwater may be impacted by seepage from the heap leach facility, waste rock dumps and by the release of constituents from the pit backfill material. The potential was recognized for dissolution of constituents from the backfill to degrade groundwater quality. No information was presented on surface water quality impact potential or pit water impact potential.

According to the EIS, mitigation consisted of segregating and disposing of potentially acid generating materials within the waste rock dumps. The heap leach facility will be designed as a zero discharge facility and employ a leak detection system. Partial backfilling of the open pit above the water table will eliminate the formation of a pit lake. No impacts to ground water quality were expected as a result of backfilling of the pit with waste rock. Water quality impacts from waste rock dumps were not expected due to low seepage rate, low acid generation potential, natural attenuation properties of alluvium, depth to groundwater, and the waste rock management plan. Contamination of groundwater by leach solution was not expected.

6.3.18.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring data were obtained from the Nevada Department of Environmental Protection (NDEP) for the period 1999 to 2003. Twenty-four groundwater monitoring locations are noted, although not all are in use. No surface water monitoring locations were noted. Information was available on baseline water quality conditions and water quality violations.

Following the 1997 EIS, there were numerous water quality impacts. One monitoring well had elevated concentrations of cyanide (WAD CN = 0.225 mg/l) and other constituents (chloride, mercury, nitrate, and TDS) in groundwater beginning in 2000, suggesting contamination of groundwater with cyanide leach solutions. Following actions taken to address deficiencies in the heap leach pad leak detection pump back system, lower elevations of constituents were noted, although mercury concentrations still exceeds standards. A Notice of Violation was issued for using higher pumping rates than those for which the system had been designed.

Other groundwater monitoring wells on the site showed exceedences of drinking water standards for aluminum, arsenic, cadmium, chloride, iron, manganese, nickel and TDS.

6.3.18.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.23 provides a summary and comparison of potential, predicted and actual water quality information for the Florida Canyon Mine. The accuracy of the predictions is discussed in this section.

Table 6.23. Florida Canyon, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Leach Pads	1997 EIS: • Seepage from the heap leach facility. • Background water quality indicates natural exceedences.	1997 EIS: Facility design to prevent groundwater impacts (zero discharge with leak detection with pumpback of leaks if detected	1997 EIS: No impacts to groundwater predicted	WQ Monitoring: Contamination of groundwater with cyanide and other constituents noted and partially mitigated with leak pumpback system
	Waste Rock, Open Pit, or baseline conditions	1997 EIS: Water quality would be same as pre-mining (background water quality indicates natural exceedences).	1997 EIS: • Backfill pit to prevent formation of pit lake. • Segregation/disposal of PAG rock in the waste rock dumps	1997 EIS: No impacts to groundwater predicted.	WQ Monitoring: Exceedences of drinking water standards noted in various monitoring wells, which could be attributed to waste rock and open pit leachate or baseline conditions.

<u>Contamination of Groundwater by Seepage from the Leach Pad:</u> Groundwater in at least one well has been impacted by cyanide, mercury, chloride, nitrate and TDS from heap pad leachate. Short-term leach tests results were elevated (above drinking water standards) for aluminum, arsenic, iron, lead, mercury, thallium, and TDS, so this test was predictive for mercury and TDS. The EIS noted that there was the potential for groundwater quality impacts by seepage from the heap leach facility, waste rock dumps, and by release of constituents from the pit backfill material.

The heap leach facility was designed as a zero-discharge operation with a leak-detection system, and contamination of groundwater by leach solution was not expected. Therefore, the potential groundwater quality forecast was correct, and the post-mitigation (predicted) groundwater quality impacts were incorrect. The assumption/prediction that leach pad mitigation (liner and leak detection system) would be effective in preventing groundwater contamination was inaccurate.

Elevated Concentrations of Metals and Sulfate in Groundwater: The possible causes of the observed exceedences are currently not known but include elevated background concentrations, seepage from the waste rock dumps, and infiltration from the open pit. The constituents that exceed concentrations in groundwater (aluminum, arsenic, cadmium, chloride, iron, manganese, nickel, TDS) are very similar to those exceeding standards in the MWMP (short-term leach) test (aluminum, arsenic, iron, lead, mercury, thallium, TDS). Therefore, the short-term leach tests were predictive in identifying constituents that would be elevated in groundwater, regardless of the cause.

6.3.19. JERRITT CANYON, NEVADA

The Jerritt Canyon Mine, owned currently by Queenstake Resources, has been in operation since 1980. The primary commodities mined are gold and silver from underground and open pit mining and heap and vat leach processing operations. It disturbs 3,411 acres on Humboldt-Toiyabe National Forest in U.S. Forest Service Region 4. It has a current financial assurance amount of $7.1 million.

6.3.19.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EIS was completed in 1980. In 1991, an EA was completed in support of an increase in the height and an expansion of the seepage collection system of the tailings impoundment. In 1994 another EIS was conducted for a mine expansion. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1980 EIS

According to the 1980 EIS, results from short-term leach tests conducted on waste rock samples showed only minimal potential for leaching of heavy metals and other toxic substances to surface and groundwater. However, suspended solids from erosion were expected to increase. No other information was provided on tailings testing or potential for water quality impacts in the 1980 EIS.

According to the EIS, mitigation will consist of locating the mill and tailings impoundment in the headwaters of a small watershed, and this was expected to have negligible effects on water quality. The tailings impoundment will be lined to provide an impervious barrier to vertical movement. Horizontal seepage of liquids will be controlled by the dam embankment design. Diversion ditches will direct flow around the mine pit and back into natural drainages (run on controls). Groundwater flowing into the pits will be used for dust control, and at times, excess water may be discharged to Jerritt Canyon.

The EIS included information on background surface water sampling stations that showed elevated nitrate concentrations, anomalous values for zinc, and exceedences of the drinking water standard for mercury and chromium.

1991 EA

This EA was written to analyze a 50-foot height increase to the tailings impoundment and to install a seepage remediation system. There were no geochemical tests performed on tailings material.

Even though the EA analyzed the new seepage remediation system, it did not provide details of the ongoing contamination (see Section 6.3.19.2), other than to indicate that pre-mining background water quality was within standards and that a plume of salt extended up to 1000 feet from the tailings impoundment. The EA indicated that concentrations of constituents seeping from the tails were relatively low. It indicated the six pumpback wells previously installed were not sufficient to prevent migration away from the impoundment.

1994 EIS

According to the EIS, geochemical testing on waste rock included static acid-base accounting, humidity cell, column leaching and short-term leach (MWMP) tests. Constituents of concern identified from waste rock leach tests included arsenic, selenium, nitrate and sulfate. Waste rock from the Roberts Mountain and Hanson Creek formations had low acid-generation potential. Waste rock from the Snow Canyon formation had moderate potential to generate acid. Waste rock from the unoxidized, strongly altered intrusive rock was acid-forming but would make up less than 2% of the waste rock in the proposed waste rock dumps. Groundwater quality would be potentially affected if waste rock and pits generate acid and mobilize metals and other compounds. Spring and seep water quality may be affected by contact with waste rock dumps, or by contact with pit walls. There is potential for acid drainage from waste rock, ore stockpiles or pits to affect waterways, and a potential increase in sedimentation resulting from roads, pits and waste rock dumps.

According to the EIS, mitigation would consist of the Saval, Steer, Burns Basin pits (proposed) lying above the regional groundwater table and not accumulating water. The New Deep deposit will be mined using underground techniques, so no pit lake will form. No existing pit has encountered the regional groundwater table. Acid mine drainage will be mitigated with selective handling and isolation of acid forming waste rock and capping, contouring, or drainage control to reduce infiltration. No impacts to surface or ground water were predicted due to the implementation of the waste rock characterization and handling program and plugging of the underground workings.

6.3.19.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring data was obtained from the Nevada Department of Environmental Protection (NDEP) for 1997-1998 and 2000- 2003. Twenty-one surface water monitoring locations and seven groundwater monitoring locations were identified. In addition, one Notice of Violation (NOV) was identified.

The records showed that following the 1980 EIS and 1994 EIS, water quality impacts occurred at the site including the following:

- A Finding of Alleged Violation (FOAV) was issued in 1991 due to a cyanide plume in the groundwater, caused by seepage from the tailings impoundment. A seepage collection system was installed to pump tailings seepage back to the tailings facility.
- Groundwater monitoring wells downgradient of the tailings impoundment showed exceedences for chloride (chloride and total dissolved solids (TDS), with values peaking at 30,000 mg/l (TDS) and 12,000 mg/l chloride in well GW-9. Exceedences of over times federal drinking water standards were common for these constituents, with exceedences of over 10 times standards occurring constantly between 1993 and 2004. Exceedences of federal arsenic and sulfate drinking water standards were also occasionally noted. The tailings impoundment is being gradually evaporated to eliminate seepage.
- Surface monitoring points in drainages below waste rock dumps on Burns Creek, Mill Creek, Jerritt Creek, Snow Creek and Sheep Creek showed exceedences of secondary federal drinking water standards for TDS and sulfate. One surface monitoring site showed a steady increase in TDS and sulfate concentrations from 2001-2004, with exceedences of over 10 times standards for both by early 2004. The exceedences were most likely related to the waste rock disposal pile.

6.3.19.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.24 provides a summary and comparison of potential, predicted and actual water quality information for the Jerritt Canyon mine. The accuracy of the predictions is discussed in this section.

Table 6.24. Jerritt Canyon, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater and Surface Water	Tailings	• 1980 EIS: No information provided for groundwater. Possibility of release of toxic materials to streams due to breakage of the tailings pipeline.	• 1980 EIS: Tailings located in headwaters of small water shed will protect water quality • 1980 EIS: Facility design to prevent groundwater impacts ○ Tailings disposal pond will be lined ○ Horizontal seepage controlled by embankment design.	• 1980 EIS: No impacts predicted • 1991 EA: Six pumpback wells are not effective at preventing migration of plume from impoundment	Water Quality Monitoring • 1991: Cyanide plume detected from tailings pond and seepage collection installed • 1993-2004: Groundwater monitoring wells downgradient of the tailing impoundment show exceedences for Cl and TDS consistently from 1993 –2004
	Waste Rock	• 1980 EIS: Minimum potential for some leaching of some heavy metals and other toxic substances in the waste rock into surface and ground water • 1994 EIS: Groundwater and surface water quality may be affected by acid drainage and other constituents in waste rock	• 1980 EIS: No information provided • 1994 EIS: Waste rock mitigation include: ○ Segregation and blending of PAG waste rock. ○ 1994 EIS: Capping, contouring and drainage controls ○ 1994 EIS: Waste rock characterization and handling (segregation, cap, contour, drainage) program	• 1980 EIS: Minimum impacts predicted • 1994 EIS: No impacts to groundwater or surface water predicted	Water Quality Monitoring • 2001-2004: Surface monitoring shows a steady increase in TDS and SO_4 concentrations downstream from waste rock piles from 2001-2004 with most recent data indicating exceedences of standards by 10 times
	Open Pit	• 1980 EIS: No information • 1994 EIS: Groundwater and surface water quality may be affected by acid drainage and other constituents in pit walls	1980 EIS: Divert surface water flow around pit and groundwater from pit used for dust control or discharged	• 1980 EIS: No impacts predicted • 1994 EIS: No pit lakes predicted to form	

<u>Cyanide Plume and Exceedences of Chloride, TDS, Sulfate and Arsenic in Groundwater from Tailings Impoundment Leakage</u>: The tailings generated from the vat leach operation were responsible for creation of a cyanide plume in groundwater. Exceedences of chloride, TDS, arsenic and sulfate were also observed in wells downgradient of the tailings impoundment. Geochemical characterization in the 1994 EIS focused on the waste rock and noted the potential for leaching of arsenic, selenium, nitrate and sulfate. However, no geochemical testing was performed on tailings material. No information on potential (pre-mitigation) groundwater impacts from tailings was noted, but post-mitigation (related to waste rock and underground mine backfilling and sealing) groundwater quality was predicted to

be good. The only potential impact from tailings was the possibility of release of toxic materials to streams due to breakage of the tailings pipeline. The tailings impoundment was lined and had seepage control features, but these were not adequate to prevent groundwater contamination. Therefore, predictions about the impact of tailings on groundwater were non-existent, and the mitigation for the tailings system failed.

Impact of Waste Rock on Surface Water Quality: Exceedences of sulfate and TDS (by over 10 times the standard) were observed in surface water downstream/gradient of the waste rock piles. Acid-base accounting and short-term leach testing performed on waste rock showed moderate potential for acid drainage and minimal potential for leaching of arsenic, selenium, nitrate, and sulfate. Potential surface water impacts from waste rock were noted in the EISs. However, no impacts to surface water or groundwater were predicted post-mitigation due to the implementation of the waste rock characterization and handling program. Therefore, the potential (pre-mitigation) forecasts were more accurate than the post-mitigation predictions, and the mitigation and management approaches were not successful in preventing surface water impacts from waste rock. Geochemical characterization was able to predict the leaching of sulfate from waste rock, but the impact was larger (>10 times standards) than the "minimal" leaching predicted.

6.3.20. LONE TREE, NEVADA

The Lone Tree Mine, owned by Newmont Mining Company, has been in operation since 1991. The primary commodities mined are gold and silver from open pit mining and heap and vat leach processing operations. It disturbs 2,691 acres and is permitted to disturb 3,547 on both private land and BLM land. It has a current financial assurance amount of $8.4 million.

6.3.20.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was not originally required for the new project in 1991 because it was located on private land. NEPA was required for mine expansion onto public land, and an EIS was completed in 1996. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1996 EIS

Geochemical characterization consisted of static (ABA), kinetic (humidity cell tests), and short-term leach (MWMP) tests and a mixing experiment using acid leachate from Lone Tree rocks and Wayne Zone groundwater. Modeling included water quantity and water quality using MINEDW to predict three-dimensional groundwater flow, and hydrogeochemical modeling of pit lake water by PTI (proprietary). Constituents of concern identified included arsenic, iron, sulfate and total dissolved solids (mine discharge water); antimony, arsenic, cadmium, nickel, fluoride, and sulfate (pit lake); and arsenic, copper, cyanide, iron and sulfate (tailings).

Although static testing indicated that tailings were potentially acid generating, kinetic testing indicated they were not. Sulfides were reported to be encapsulated in silica; humidity cells tests on overburden suggested that silicate buffering would be important. The contaminant leaching potential was predicted to be moderate to high.

Groundwater - Pit lake water was predicted to mix with groundwater after steady state groundwater levels are reached; due to natural attenuation, no groundwater exceedences were expected.

Surface Water - Water pumped from the ground and discharged into the Humboldt River is generally of good quality, except for recently increased concentrations of arsenic, iron and sulfate in mine discharge water (Draft EIS). The Final EIS stated that iron, copper and lead exceeded aquatic life criteria in mine discharge water.

Pit Lake - Pit lake water quality was predicted to be acidic and exceed the arsenic standard initially but become neutral after 10 years and not exceed standards for arsenic after that time; cadmium concentrations were predicted to exceed drinking water standards for one year; nickel, fluoride, and antimony for over 25 years; and sulfate until 10 years. Nickel and fluoride concentrations were predicted to exceed their respective limits by less than 10 times and antimony by over 10 times. In the long term, the pit water was predicted to have exceedences of one to 10 times for aluminum, antimony, arsenic, fluoride, total dissolved solids and pH. The drinking water standard for thallium was predicted to be exceed by over 10 times in long term.

6.3.20.2. ACTUAL WATER QUALITY CONDITIONS

Water monitoring and compliance data for the period 1998-2002 were obtained from the Nevada Department of Environmental Protection (NDEP). There are 16 groundwater monitoring locations (11 monitoring wells and five production wells) at Lone Tree. No information on violations was found.

Possible mine water quality related impacts and exceedences were indicated including the following:

- Mine Water Supply Wells: Production well WW-13 exceeded the secondary standards for fluoride and manganese in 1998 and 2000. Concentrations of both constituents were less than twice the standard.
- Heap leach groundwater monitoring wells: Occasional exceedences of Secondary MCLs were recorded at wells MO15-1A, MO15-2A, MO15-3 3 from 1999-2000 for aluminum, iron, and TDS. Except for an aluminum concentration of 1.05 mg/l (standard is 0.05-0.2 mg/l), all concentrations were less than twice the drinking water standard.
- Tailings monitoring wells: Tailings monitoring wells recorded numerous exceedences of secondary drinking water MCLs from 1999-2002. Constituents of concern included fluoride, iron, manganese and TDS. Frequent fluoride SMCL exceedences were recorded from 1999-2001, but the primary MCL (4.0 mg/l) was not exceeded. Some tailings monitoring wells had arsenic concentrations at the level of the new standard (10 μg/l) in 2000 and 2002.
- The tailings impoundment experienced a major leak in November, 2000, but the leak was not detected below the vadose zone.
- Between 1998 and 2002, dewatering water discharged into the Humboldt River exceeded standards frequently for pH, total dissolved solids, fluoride, boron and un-ionized ammonia.

6.3.20.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.25 provides a summary and comparison of potential, predicted and actual water quality information for the Lone Tree mine. The accuracy of the predictions is discussed in this section.

<u>Exceedence of Arsenic and Secondary Drinking Water Standards in Groundwater:</u> Because information on background groundwater quality was not obtained, it is unknown if the observed exceedences in groundwater relate to seepage from facilities or background conditions. Heap leach monitoring wells had exceedences of arsenic, aluminum, iron and TDS. Tailings monitoring wells had exceedences of arsenic, fluoride, iron, manganese and TDS. Potential water quality impacts noted in the EIS included discharge of acid water from overburden, tailings, leach pads and ore stockpiles. Tailings MWMP extract for tailings exceeded drinking water standards for pH, TDS, sulfate, arsenic, copper, iron (all by <10x) and cyanide (>10x). These results did not predict noted exceedences of fluoride or manganese in tailings wells. No acid drainage has occurred to date.

<u>Exceedence of Permit Limits for Dewatering Discharge:</u> More information is needed on NPDES discharge water quality. The EIS predicted that no significant impacts would occur to the Humboldt River after mitigation were performed, which included cooling and treatment of discharge water to remove arsenic.

Table 6.25. Lone Tree, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	MITIGATION	Predicted Impacts	Actual Impact
Groundwater	Heap Leach	1996 EIS: No estimates of potential impacts to water quality	1996 EIS: No specific mitigation provided	1996 EIS: No estimates of predicted water quality	WQ Monitoring: possible exceedences of As, Al, Fe, and TDS
	Tailings	1996 EIS: No potential for acid drainage. Moderate to high potential for As, Cu, CN, Fe, and sulfate	1996 EIS: No specific mitigation provided	1996 EIS: No estimates of predicted water quality	WQ Monitoring: possible exceedences of secondary drinking water MCLs from 1999-2002 for fluoride, iron, manganese, and TDS
	Waste Rock	1996 EIS: No estimates of potential impacts to water quality	1996 EIS: Overburden mixing and segregation	1996 EIS: No estimates of predicted water quality	WQ Monitoring: No exceedences indicated
	Open Pit	1996 EIS: Pit lake water quality acidic initially, but after 10 yr neutral; would exceed standards for As, Cd, Ni, F, Sb (by >10x), Tl (by >10x), and SO_4 at different times	1996 EIS: Diversions to prevent runoff from entering pits	1996 EIS: Groundwater downgradient from mine pit would approach baseline quality of regional groundwater, not expected to exceed MCLs	
Surface Water	Pit Dewatering	1996 EIS: Fe, Cu, and Pb are the only parameters that exceeded aquatic life criteria in mine discharge water	1996 EIS: Affected springs mitigated by: piping in water, drilling into a deeper aquifer, improving existing springs to enhance yield, or developing/improving nearby springs to offset loss. Monitoring	1996 EIS: No significant impacts would occur, but discharge to Humboldt River would increase total dissolved solids and trace elements	Water pumped from the ground and discharged into the Humboldt River Discharge exceeds permit limits for TDS, B, F, pH and NH_3.

6.3.21. ROCHESTER, NEVADA

The Rochester Mine, owned by Coeur Rochester, Inc., has been in operation since 1986, although the site has been mined since the 1860s. The primary commodities mined are gold and silver from open pit mining and heap leach processing operations. It disturbs 1,447 acres on both private land and BLM land. It has a current financial assurance amount of $8.4 million.

6.3.21.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EA was completed in 2001. In 2003 an EA was conducted for a mine expansion. There has never been an EIS completed for this facility, but beginning in 2004 the BLM began preparing a closure EIS. The following sections summarize the water quality predictions made in the NEPA documents.

2001 EA

The 2001 EA considered the Nevada Packard deposit, which was a satellite deposit from the primary Rochester project. Geochemical characterization consisted of acid-base accounting, short-term leach testing (MWMP) and whole rock analysis. Constituents of concern identified included antimony, arsenic, iron, lead, mercury and silver. No predictive modeling was performed. Acid drainage potential was estimated to be low. Rocks in the project area generally have low sulfur content and low neutralizing potential. Only two of 26 acid-base accounting results showed potential to generate acid. Whole rock (ICP) analyses of non-ore and unmineralized rock samples suggested that antimony, arsenic, lead, mercury and silver could produce leachate with elevated concentrations. Short-term leach test (MWMP) results showed that antimony, arsenic, iron and mercury could occur in elevated concentrations in discharge water from the non-ore material.

There was no information in the 2001 EA on potential impacts to groundwater. Due to historic mining in the area, the current site includes abandoned tailings material, waste dumps and leach pads that are likely to have an impact on surface water quality. The water table is 140 feet below the proposed pit bottom, so no pit lake is expected to form. No information on mitigation was provided.

The proposed action was considered unlikely to degrade groundwater resources or further degrade baseline surface water quality, since a part of the proposed action included reclamation of the abandoned pre-Coeur workings.

2003 EA

This was the most recent EA to consider continuing expansions of projects at the Rochester Mine. Reports of earlier testing showed that some of the lithologies above 6,600 feet were substantially acid generating, but no details were provided. Below 6,600, from 10 to 20 percent of the rock was classified as potentially acid generating (PAG), based on acid-base accounting and humidity cell analysis. MWMP tests showed limited metal mobility from non-PAG rock, but test pH values ranged from 4.0 to 6.4. For PAG rock, lead, cadmium, zinc, copper and aluminum concentrations were occasionally high.

The section on potential impacts claimed that the rock was mostly non-PAG, and the surrounding rock would neutralize any acid that may be generated.

Future developments at the Coeur operations could generate long-term impacts to groundwater. The potential for acid rock drainage from the present actions was identified.

6.3.21.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring and compliance data were collected from the Nevada Department of Environmental Quality (NDEP) for the period 2000- 2003. Three surface water monitoring locations and 17 groundwater monitoring locations were noted for the site. The following information on water quality was noted.

- Groundwater monitoring wells downgradient of the Stage I heap leach pad showed exceedences of arsenic, mercury, cadmium, nitrate and WAD cyanide during the period 2000 to 2003.
- Surface water monitoring sites in a spring downgradient of the Stage I heap leach pad showed exceedences of nitrate, lead, cyanide, arsenic, mercury.
- In 2003 NDEP issued Rochester a Finding of Alleged Violation (FOAV) for cyanide exceedences discovered during quarterly monitoring. The violation was issued in response to the discovery of cyanide exceedences in MW-16, a monitoring well screened in the shallow bedrock below the site. Contamination had been previously confined to the alluvium.
- In 1987 a release of process solution from the East Pregnant Pond occurred, causing pregnant solution to run into American Canyon for 12-18 hours at a rate of 5-10 gpm. The United States EPA issued a Notice of Violation to Coeur-Rochester on June 30^t, 1988, for violating the Clean Water Act by discharging pregnant

solution to American Canyon. On July 20th, 1988, NDEP issued an FOAV to Coeur-Rochester for the December 27th, 1987, pregnant solution release. It does not appear that NDEP pursued a monetary settlement.

- In 1998 a broken pipeline resulted in the displacement of 200 tons of ore off the liner, causing 19,400 gallons of process solution containing 45.3 lbs. of cyanide to be released to the environment. Of this, 5,000 gallons of process solution containing 11.7 lbs. of cyanide were discharged off site to American Canyon, an intermittent drainage. A dike was installed in American Canyon to stop solution flows, and affected soil was treated with hydrogen peroxide to degrade cyanide. Displaced ore was moved back to containment.

6.3.21.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.26 provides a summary and comparison of potential, predicted and actual water quality information for the Rochester Mine. The accuracy of the predictions is discussed in this section.

Table 6.26. Rochester, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impact
Groundwater	Heap Leach, Open Pit, Waste Rock	2001 EA: None identified. 2003 EA: Future developments at the Coeur operations could generate long-term impacts to groundwater.	2001 EA: None identified 2003 EA: None identified	2001 EA: The proposed action is considered unlikely to degrade groundwater resources. 2003 EA: Water recharging the groundwater system from infiltration through Rock Disposal Sites not expected to differ from the current groundwater chemistry.	WQ Monitoring: Leaks from the Stage I heap leach pad and the N. Barren pond have resulted in numerous exceedences in groundwater monitoring wells. Exceeding constituents include WAD Cyanide, mercury, cadmium, nitrate and arsenic.
Surface Water and Springs	Heap Leach, Open Pit, Waste Rock	2001 EA: Due to historic mining, current site includes abandoned tailings, waste dumps, and leach pads that are likely to have an impact on t surface water quality. 2003 EA: There is a potential for increased sedimentation from surface disturbance associated with Proposed Action. There is potential for acid drainage from the present actions (2003)	2001 EA: Diversion ditches, as well as other sediment control measures. 2003 EA: Part of the proposed action includes reclamation of the Project, as well as some of the abandoned pre-Coeur mine workings.	2001 EA: Proposed action unlikely to further degrade surface water quality. 2003 EA: The proposed action is unlikely to further degrade baseline water quality, since part of the proposed action includes reclamation of project as well as some abandoned pre-Coeur mine workings.	Contamination of American Canyon (intermittent drainage) by process solution release of Nov. 29th, 1998. Exceedences of nitrate and arsenic in American Canyon Springs from heap leach pad and process solution ponds.

<u>Exceedences of Arsenic, Mercury, Cadmium, Nitrate and Cyanide in Heap Leach Monitoring Wells and Springs</u>: Short-term leach tests and whole rock analysis identified antimony, arsenic, iron, lead, mercury and silver as constituents of concern. Therefore, the potential for arsenic and mercury exceedences was identified, but the cadmium, nitrate and cyanide exceedences were anticipated. There was no information on potential or predicted

impacts to groundwater in the 2001 or 2003 EAs related to the heap leach pad. Therefore, the potential for some of the observed exceedences was noted in the 2001 EA, but the observed exceedences were not predicted to occur in groundwater.

Contamination of American Canyon by Cyanide from Process Solutions: Cyanide was not specifically identified as a constituent of concern, and no potential or predicted impacts from release of process solution to surface water were identified. Therefore, the observed impact to surface water was not predicted in the EAs.

6.3.22. ROUND MOUNTAIN, NEVADA

The Round Mountain Mine, owned by Round Mountain Gold Corporation, has been in operation since 1977. The primary commodities mined are gold and silver from open pit mining and heap leach and vat leach processing operations. It disturbs 4,431acres on private, BLM and Forest Service lands. It has a current financial assurance amount of $41.7 million.

6.3.22.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EA was completed in 1977. In 1987 and 1992, EAs were conducted for a mine expansions, In 1996 an EIS was conducted for further mine expansion. The following section summarizes the water quality predictions made in the only NEPA document obtained and reviewed, the 1996 EIS.

1996 EIS

The primary host rock for mineralization is the Tertiary Round Mountain tuff, in which gold occurs in quartz-carbonate and quartz-pyrite veins. Geochemical characterization consisted of short-term leach testing, static acid-base accounting, kinetic testing and soil attenuation tests. MWMP tests were performed on leach pad offload materials (spent ore), and TCLP and MWMP tests were performed on tailings materials. Net neutralization potential (NNP) and humidity cell tests were performed on pit wall materials. Soil attenuation tests were conducted on leachate from leach offload piles. The effects of mine dewatering and future inflow of water to the pit were predicted using MODFLOW. The pit lake was modeled with CE-THERM-R1 for thermal stratification and overturn, and MINTEQA2 for geochemistry of the pit lake. The Davis-Ritchie model was used to calculate the thickness of the oxidized zone in the wall rock. Groundwater quality was sampled for four different water types, including geothermal waters since 1986, which provides a baseline to compare this project against. The groundwater near the tailings impoundment was not monitored.

There are two facilities in which spent ore will be deposited: leach offload piles and tailings impoundments. Spent ore was identified as having the potential to generate elevated pH values and to leach antimony, arsenic, selenium, and cyanide, and possibly iron, mercury, nickel, nitrate, and fluoride, as well as generating elevated pH values. Geochemical test results suggested that degradation could occur if water were to seep through the leach offload piles and discharge directly into a protected surface water source or groundwater aquifer. The potential was identified for stormwater runoff to mobilize metals and cyanide from the spent ore materials. However, significant impacts to surface water or groundwater quality from leach offload piles was not anticipated due to attenuation in soils.

The potential was identified for carbon-in-leach tailings to leach iron, lead, manganese, TDS and sulfate in concentrations in excess of MCLs; carbon-in-leach tailings, however, would be only 5-10% of total tailings. MWMP test average concentrations on spent ore showed exceedences of over 10 times for arsenic and less than 10 times for antimony, selenium, and cyanide. The pH was also higher than standards. Based on TCLP tests, tailings did not exhibit hazardous properties. If tailings seepage reaches groundwater, there is potential for degradation.

The EIS proposed a zero-discharge tailings facility with a seepage underdrain system designed to alleviate head. If, after cessation of mine processing operations, seepage of tailings solution is still occurring through the underdrain system, the seepage would create a potential impact to groundwater. Any metals and cyanide mobilized by snowmelt or rainfall that runs off the piles or seeps through the piles and later infiltrates the alluvial soils would be rapidly attenuated in the upper soil column, indicating that significant impacts to groundwater from the leach offload piles were not expected.

Excavation of the pit was predicted to expose sulfide minerals and form acid drainage. A 300-foot deep pit lake is expected to form in the pit after dewatering ceases. Forty percent of pit wall samples had potential to generate acid, but modeling indicated that the pit water will not be acidic. In the long run, pit water was predicted to exceed drinking water standards for aluminum, arsenic, fluoride, manganese, mercury, nickel, pH (high), TDS, sulfate and zinc. Modeling of final groundwater levels and flow rates, as well as predicted precipitation and evaporation rates suggested that the pit lake will have no net outflow to either groundwater or surface waters.

6.3.22.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring and compliance data were collected from the Nevada Department of Environmental Protection (NDEP) for the period 1999-2003. Ten groundwater monitoring locations were noted for the site. The following information on water quality was noted:

- Groundwater monitoring wells recorded a number of exceedences of secondary standards for aluminum, fluoride, iron, manganese and TDS. Aluminum exceedences occurred in the pit dewatering water. The other constituents all had exceedences in alluvial wells downgradient of the tailings, heap offload disposal sites and dewatering water. One of the wells had a substantial increase in fluoride concentration. Arsenic exceedences, of both the old and new standards, were very common and are mentioned as a background condition.
- Wells near the tailings also experienced frequent exceedences for antimony and lead. High pH values were also common.
- As noted, the trend in exceedences is for them to be clustered near the tailings and the heap offload sites. A second trend is for the highest concentrations to occur at the shallowest alluvial reaches, which could suggest a surface source. Most of the constituents, but not fluoride, also occur in dewatering water, which is another potential source.

6.3.22.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.27 provides a summary and comparison of potential, predicted and actual water quality information for the Round Mountain Mine. The accuracy of the predictions is discussed in this section.

<u>Exceedences of Aluminum, Antimony, Fluoride, Iron, Lead, Manganese and TDS in Groundwater</u>: The cause of the exceedences in groundwater is not known, but could be due to background groundwater quality and/or discharge from the tailings or heap leach facilities or dewatering water. Because the waste rock was shown to have a significant potential to leach contaminants, the fact that there is relatively little groundwater contamination indicates the mitigation may be working. However, there are trends that cannot be explained by assuming that all exceedences are background. Fluoride is the biggest issue especially since it is a constituent of concern for leaching from the waste rock. It suggests that the baseline water quality was not adequately determined.

Table 6.27. Round Mountain, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings, heap leach offload, or baseline conditions.	Test results suggest some exceedences could occur if water were to seep through leach offload piles, discharge directly to a protected groundwater aquifer. MWMP tests show exceedences of over 10 times for arsenic, and less than 10 times for antimony, selenium and cyanide. pH is also higher than allowed. If, after cessation of mine operations, seepage of tailings is still occurring through underdrain, seepage would create potential impact to groundwater.	Tailings facility designed for zero discharge. Backfill and reclaim the tailings seepage collection pond after underdrain seepage has ceased.	No discharge from pit, so no impact to GW. Significant impacts to ground water quality from leach offload piles not anticipated due to attenuation in soils. Minimal impact to ground water quality from tailings facilities due to management, design. Any metals or cyanide mobilized by snowmelt or rainfall that runs off piles/seeps through piles and infiltrates alluvial soils would be attenuated in upper soil column.	Exceedences of secondary standards for aluminum, fluoride, iron, manganese, pH (high) and TDS and primary drinking water standards for arsenic, antimony, and lead all appear to be related to baseline conditions. No mining-related exceedences are evident.

6.3.23. RUBY HILL, NEVADA

The Ruby Hill Mine, owned by Barrick Goldstrike since its acquisition from Homestake, has been in operation since 1997. Mining ceased and reclamation commenced in 2002, although processing of gold and silver from its cyanide heap leaches continues to this day. It disturbs 696 acres on private lands. It has a current financial assurance amount of $7.1 million. The mine issued a DEIS to reopen and expand its operations in 2005.

6.3.23.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EIS was completed in 1997. The following sections summarize the water quality predictions made in the NEPA documents reviewed.

1997 EIS

The ore is oxide and hosted in limestone, with some sulfides present. The following predictive tests were performed: whole rock analysis static ABA, MWMP, humidity cell and synthetic precipitation leach procedure (EPA method 1312). The average ANP:AGP was 813 for alluvial material and 955 for oxidized limestone samples; the potential for acid generation was considered low. Leach tests indicated there was a moderate potential for contaminant/metals leaching; meteoric water mobility procedure (MWMP) results from alluvial material and oxidized limestone showed occasional drinking water exceedences for aluminum, arsenic, antimony and TDS. EPA method 1312 leach tests showed exceedences for aluminum, arsenic and pH (high).

Modeling indicated low potential for groundwater degradation. Increased erosion was the only noted surface water quality concern. No impacts to surface or ground water were predicted, due to the nature of the rocks, as well as the distance to water. The pit bottom will be above the regional water table, so no pit lake was expected.

6.3.23.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring and compliance data were obtained from the Nevada Department of Environmental Protection (NDEP) for the period 1997-2003, and the 2005 DEIS also summarizes water quality at the site. Nine groundwater monitoring locations were noted for the site.

Only two constituents had substantially high concentrations: arsenic and nitrate. Two wells had high arsenic concentrations, often exceeding MCL values by two to four times; concentrations increased by about 20% between 1996 and 2003. However, the highest concentration occurred upgradient of the mine. Elevated pH values were also common in groundwater wells. Nitrate concentrations frequently approached the MCL in several wells. The 2005 EIS suggested these predated the mine and were due to septic systems.

There were lead exceedences (less than twice the drinking water standard) during the fourth quarter of 1997 and the first quarter of 1998 in monitoring well MW-4, although no problems were recorded after this point. Since the exceedences did not recur, it did not result in any action by NDEP.

6.3.23.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.28 provides a summary and comparison of potential, predicted and actual water quality information for the Ruby Hill Mine. The accuracy of the predictions is discussed in this section.

Table 6.28 Ruby Hill, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impact
Groundwater	Baseline conditions.	Low potential for degradation from leaching of Arsenic and Aluminum, according to the Horizontal Plane Source Model. Partial backfilling of pit (preferred alternative) would increase potential chemical impacts.	Zero discharge heap leach with a leakage detection/collection system; rinsing of heap leach during closure followed by a land application of rinse water.	Contamination of groundwater by leach solution not expected. Cumulative impacts from the waste rock and leach residue are not expected to occur.	None. Any exceedences appear to be related to baseline conditions.

Water quality impacts were not expected and did not occur. Therefore, assuming that the exceedences are related to baseline conditions, the water quality predictions were accurate.

6.3.24. TWIN CREEKS, NEVADA

The Twin Creeks Mine, owned by Newmont Mining Corporation since its acquisition from Santa Fe Mining, is the combination of the Rabbit Creek and Chimney Creek mines, which began operating in around 1988. The primary commodities mined are gold and silver from open pit mining and heap leach, vat leach, and oxide milling processing operations. It disturbs 4,549 acres on private land and 8,898 acres on BLM lands for a total disturbance of 13,447 acres. The current financial assurance amount is not known.

6.3.24.1. WATER QUALITY PREDICTIONS SUMMARY

Initially, the two mines, Chimney Creek and Rabbit Creek, were permitted with EAs. In 1996 an EIS was conducted for a mine expansion, which included combining the two existing mines. The following section summarizes the geochemical characterization, hydrologic analysis and predictions and water quality predictions made in the 1996 EIS.

1996 EIS

Arsenic-mercury mineralization occurs mostly in oxidized ore, but there is some sulfide ore in the South Pit deposit. Sulfide minerals associated with gold mineralization include pyrite, stibnite, realgar and orpiment. Sulfide ore from the Mule Canyon Mine will also be processed at the Twin Creeks Mine.

Waste rock and pit wall rock were analyzed with static (ABA), kinetic (20-wk humidity cell; 46 pit wall rock samples), mineralogy, and short-term leach tests (MWMP). Hydrologic modeling included MINEDW (proprietary) for groundwater dewatering. Mass balance modeling was used to predict the final pit lake elevation. CE-THERM-R1 was used to predict pit evaporation. DE-QUAL-W2 was used for modeling limnologic processes. Geochemical modeling included MINTEQA2 for predicting pit water chemistry and the Davis-Ritchie model for predicting the thickness of the oxidized zone in the pit walls over time.

Based on MWMP leachate results for waste rock, pit wall rock and tailings, and on humidity cell tests for pit wall rock, total dissolved solids, aluminum, antimony, arsenic, beryllium, cadmium, chloride, chromium, copper, iron, lead, manganese, mercury, nickel, nitrate, selenium, silver, sulfate, thallium and zinc were the constituents of concern. Waste rock (based on MWMP tests) leachate could exceed drinking water standards for total dissolved solids, beryllium, cadmium, selenium, zinc (all by 1 – 10 times), and for aluminum, antimony, arsenic, iron, manganese, mercury, nickel, sulfate and thallium (all by >10 times).

The acid generating potential of pit wall rock ranged from a net neutralizing potential (NNP) of -350 to +671t/kt, with an average of +162 t/kt (average is non acid generating). The majority (91%) of rocks in the proposed final pit surface were predicted to not be acid generating. Of the waste rock, approximately 9% was predicted to be potentially acid generating. Heap leach ore was apparently not tested, but sulfide ore had a NNP weighted average of -67 t/kt (acid generating). Juniper and Sage mill tailings were net acid neutralizing; Mule Canyon Mine ore, which is milled at Twin Creeks, was potentially acid generating. Tailings MWMP leachate concentrations exceeded drinking water standards for arsenic, antimony, cadmium, chromium, copper, iron, lead, mercury, silver, and selenium; tailings filtrate had elevated concentrations of zinc and chloride.

Infiltrating dewatering water was identified as having the potential to flush soluble salts, including chloride and nitrate, from the shallow alluvium to groundwater. The water also contained elevated concentrations of antimony, but observations prior to the DEIS indicate the alluvium could attenuate it. No significant impacts to groundwater quality were expected from the sulfide ore stockpiles or tailings due to low precipitation, groundwater depth and natural attenuation. The surface water in Rabbit Creek could be affected by the discharge of dewatering water, which has shown occasional exceedences of total dissolved solids (by 1-10 times) and arsenic (by >10 times). Testing showed that the pit lake could have water quality problems in both the short term and long term.

The DEIS proposed numerous mitigation; some were presented as design criteria and others were actual plans for monitoring and mitigation. Some waste rock would be placed over tailings, and thus seepage would be collected and discharged to process facilities, evaporated, or treated prior to discharge. Most waste rock dumps would be constructed on top of alluvium with net neutralizing potential and more than 100 feet to the groundwater after the dewatering drawdown recovers. A basal layer of acid neutralizing material would be placed underneath acid generating waste rock. Tailings facilities would be designed with liners, subdrains, collection ponds and pumpback systems to prevent migration of tailings waters into groundwater. Groundwater would be monitored to detect infiltration of mine water, with mitigation measures to follow if infiltration is detected. Heap leach pads would be designed with synthetic liner and leak detection system and operated as a zero-discharge facility; solution ponds were planned to be double-lined with leak detection systems. A bioremediation facility was proposed to treat hydrocarbon-contaminated soil.

For surface water discharge and discharge to the infiltration basin, treatment was proposed for dewatering water to remove arsenic. The connection between Jake Creek and the regional groundwater system will be evaluated, followed by monitoring for water quantity and quality. Diversion structures will be inspected to ensure proper function and combat soil loss. Drainage structures will be stabilized after completion of mining. The pit lake water quality will be monitored, but there was no plan identified to mitigate problems.

Mine dewatering would lower the regional groundwater elevation, but re-infiltration would increase water levels in the reinfiltration pond area by up to 70 feet, even though stream flow increase was not expected. Drawdown would potentially reduce baseflow in perennial streams and springs, including Little Humboldt River and Jake Creek. Pit water was not expected to discharge to groundwater, so no impacts to downgradient groundwater were expected.

Tailings facilities would be designed to be zero discharge to prevent migration of tailings waters into groundwater systems. Potential for adverse effects to water quality from sludge disposal was considered minimal. Limited or no impact was expected to occur from bioremediation facilities. Modeling showed that drinking water standards were predicted to be exceeded for antimony and arsenic (>10 times) and thallium (1 – 10 times) for the life of the pit. Aluminum concentrations were predicted to exceed standards in the north lobe of the pit for the first 27 years, but after the pit lakes merged, no exceedences were predicted. Steady state pit water quality would exceed TDS standards by 1-10 times. No net outflow from the pit to groundwater or surface water was expected.

Dewatering water discharged to Rabbit Creek has shown occasional exceedences of total dissolved solids and arsenic. However, the receiving water, Rabbit Creek, is dry and the flow will rarely reach Jake Creek, so downstream surface water quality impacts were predicted to be minimal. Discharge to infiltration basins was also expected to leach some salts into the underlying groundwater from the alluvium.

6.3.24.2. ACTUAL WATER QUALITY CONDITIONS

Water quality monitoring and compliance data were collected from the Nevada Department of Environmental Protection (NDEP) for the period 2000-2003. Seven groundwater monitoring locations were noted for the site. The following information on water quality was noted:

- Monitoring reports submitted show high arsenic concentrations in many wells. These reports refer to arsenic levels as background. However, the concentrations fluctuated by as much as two-fold, and the wells are screened in shallow alluvium. Some wells are located near the tailings impoundments. Therefore, the claim that arsenic concentrations are baseline requires further analysis.
- Cyanide was detected in monitoring well MW-2 in October 1995, from seepage in the Pinon tailings impoundment. Seepage is believed to have occurred when the supernatant pool was filled too deeply, which may have resulted in seepage through the tailings embankment in excess of the collection pipe's capacity. Due to ongoing exceedences, there may be an ongoing leak. NDEP evaluated and characterized seepage fluids in the vadose zone below the facility and plugged well MW-2 because they believed it was acting as a conduit. The well was replaced with monitoring well MW-2R-1. Vadose zone wells (VW wells) were added to monitor seepage from the tailings impoundment. Vadose zone monitoring wells were added during 2003 to monitor seepage from the tailings impoundment (VW-1 through VW-26), and water quality in these wells is of poorer quality with multiple exceedences of TDS, sulfate, chloride, cyanide, aluminum, antimony, arsenic, manganese, iron and mercury. With possible exception of arsenic, it does not appear that tailings water regularly reaches the pre-existing alluvial groundwater.

6.3.24.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.29 provides a summary and comparison of potential, predicted and actual water quality information for the Twin Creeks Mine. The accuracy of the predictions is discussed in this section.

Table 6.29. Twin Creeks, NV, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impacts	Mitigation	Predicted Impacts	Actual Impacts
Groundwater	Tailings impoundment	Infiltrating dewatering water could flush soluble salts, including chloride and nitrate, from shallow alluvium to groundwater. Low potential for impacts from heap leach. No significant impacts from sulfide ore stockpiles or tailings.	Layer of acid-neutralizing material underneath overburden storage. Overburden placed over tailings, seepage collected and discharged to process facilities, evaporated, or treated prior to discharge. Tailings facilities have liners, subdrains, collection ponds, and pumpback systems. Heap leach pads have liner and leak detection, as well as double lined solution ponds with leak detection. Monitoring.	Dewatering would lower groundwater elevation, infiltration would increase levels in reinfiltration pond area up to 70 feet; stream flow increase not expected. Pit water not expected to discharge to GW, so no impacts. Tailings facilities have liners, subdrains, collection ponds, and pumpback systems.	The Pinon tailings impoundment formed a leak which caused a perched zone with poor water quality including high concentrations of WAD cyanide, arsenic, TDS and other constituents.
Surface Water	Dewatering water	Drawdown would potentially reduce baseflow in perennial streams and springs, including Little Humboldt River and Jake Creek.	Evaluation of connection between Jake Creek and groundwater system, followed by monitoring. Inspection of diversion structures to ensure function and combat soil loss. Stabilization of drainage structures after mining.	Potential for impacts from sludge disposal is considered minimal. Limited/no impact expected from bioremediation facilities.	Water discharged to Rabbit Creek has shown occasional exceedences (by 1-10 times) of total dissolved solids and arsenic (over 10 times).

Leakage of Cyanide from Tailings Impoundment to Groundwater: Geochemical testing showed that seepage from the tailings impoundment could degrade groundwater if the mitigation failed. The high concentrations of the vadose zone wells show that failure did occur. Therefore, the predictions that groundwater would not be degraded due to the zero discharge design were incorrect.

Elevated Arsenic Concentrations in Groundwater: There are questions about the baseline occurrence of arsenic in some of the wells. Because of their location and the variability of the concentrations, it cannot be determined whether the baseline condition, assumed by regulators, is correct. For this reason, it appears the characterization of the baseline water quality was insufficient.

6.3.25. FLAMBEAU, WISCONSIN

The Flambeau Mine, owned by Kennecott, was in operation from 1991 to 1995. The primary commodities mined were lead and zinc from open pit mining and flotation processing operations.

6.3.25.1. WATER QUALITY PREDICTIONS SUMMARY

NEPA was required for the new project to be permitted, and an EIS was completed in 1990. The following sections summarize the water quality predictions made in the NEPA document reviewed.

1990 EIS

Dominant rock types within the mineralized horizon are quartz-rich sediments and volcanic ash, massive sulfide, semi-massive sulfide, and chert. Economically valuable minerals are chalcocite, bornite and chalcopyrite, with trace amounts of gold and silver. The upper gossan cap is 30 feet thick. High-grade supergene copper (chalcocite, bornite in pyrite/chert) extends from below the gossan cap to a maximum depth of 225 feet. Lower grade copper sulfide minerals are present below the supergene-enriched zone.

Geochemical testing and modeling were conducted as part of the EIS. Wet/dry leach test (possibly humidity cell tests) and a second leach test of continued saturation of materials were conducted. Whole rock analysis and sulfur analysis were performed on waste rock (5 samples), topsoil, till, sandstone and saprolite samples. Acid production tests were performed on waste rock. Based on the results from leach tests and geochemical modeling, iron, manganese and sulfate were identified as constituents of concern. A geochemical model was used to predict the composition of leachate in the open pit backfill.

Acid drainage potential tests indicated that waste rock with a sulfur content of 2% or less would not be expected to produce acid. The matrix of the enriched horizon was made up of pyrite and chert. There was no indication of the amount of high sulfur material. Leach tests identified the potential for elevated concentrations of copper, iron, manganese and sulfate in interstitial waters in the backfilled pit. Waste rock from the mining operation would have the potential to leach contaminants to groundwater and surface water.

The EIS identified a number of proposed mitigation. High sulfur waste stockpiles and ore crushing/loading areas would be lined to prevent seepage. In the worst case scenario, leakage would leak into mine pit, where water would be treated before discharge. Settling ponds will collect runoff from low sulfur waste stockpiles for treatment prior to discharge to the Flambeau River. The ponds are proposed to be unlined, but seepage to groundwater would flow mostly to the open pit. Backfilling will eliminate the possibility of a pit lake, and the backfill will be limed. Water from the open pit, and the high sulfur waste rock pile would be routed through the wastewater treatment plant before being discharged to the Flambeau River.

The EIS identified a number of predicted impacts to groundwater, surface water and pit water. Slightly increased levels of TDS, hardness, sulfate, iron and manganese might be expected from leachate infiltration to groundwater. Contaminants would flow into the adjacent mine pit, where water would be treated prior to discharge to the Flambeau River. High sulfur waste stockpile, ore crushing and loading areas would be lined using a geomembrane; therefore, no impacts to groundwater quality were expected. Settling ponds would collect runoff from low sulfur waste stockpiles and seep into groundwater at a rate of at least 5,000-6,000 gallons/day; this could cause an increase in contaminant concentrations in the groundwater near the ponds. Most groundwater under the ponds would flow into the pit, limiting the potential zone of contamination. Surface water impacts could include increased soil erosion and discharge of sediment (increased turbidity) to the river. Discharge into the Flambeau River will not cause the concentration of any substances in the river to exceed the most stringent applicable water quality standards. The groundwater drawdown may affect additional acreage. A small amount of contaminants from the settling ponds may be transported in the groundwater to the Flambeau River but would not measurably affect the river water quality. After closure, discharge of contaminants would not likely be measurable in the Flambeau River due to dilution by the large river flow. Pit backfilling will eliminate pit waters. Modeled leachate concentrations in pit backfill were predicted to be 0.014 mg/l copper, 0.32 mg/l iron, 0.725 mg/l manganese, and 1,360 mg/l sulfate.

6.3.25.2. ACTUAL WATER QUALITY CONDITIONS

Monitoring and compliance data for the period 2000-2003 were obtained from the 2003 Annual Report, Groundwater and Surface Water Trends (Flambeau Mining Company, January 1, 2004). One surface water monitoring location and four groundwater monitoring locations were noted. The following water quality data was noted.

Four monitoring wells in the backfilled pit showed exceedences of drinking water MCLs or secondary standards for iron (up to 12 mg/l), manganese (up to 37 mg/l), pH (as low as 6.1), sulfate (up to 1,700 mg/l) and total dissolved solids (up to 3,400 mg/l). One in-pit well showed continued increasing or elevated concentrations of iron, sulfate, TDS and manganese; other wells showed decreasing concentrations. Groundwater elevations were higher in the backfilled pit than they were between the pit and the river, so water potentially flows from the pit to the river. After groundwater elevations returned to pre-mining levels, concentrations of iron, manganese, sulfate and TDS increased and pH decreased. Values for pH before pumping began were quite variable (5.8 - ~8.3). Concentrations appeared to peak in 2000 and were slowly decreasing for manganese (from a high of over 5,000 µg/l), sulfate (from a high of almost 700 mg/l) and TDS (from a high of ~1,300 mg/l), but are continuing to increase for iron (up to ~6 mg/l). Zinc concentrations were variable and still (as of 2003) ~700 µg/l (Lehrke, 2004).

Although concentrations in surface water up and downgradient of the mine showed no temporal water quality trends, a report from the Great Lakes Indian Fish and Wildlife Commission stated that water parameters measured have changed from those measured during mine operation, and that the change makes it impossible to compare during- and post-mining water quality (Coleman, 2004). In addition, the report states that the downstream sample site SW-2 is above the discharge point for surface water coming from the southeast portion of the mine site and therefore may not capture all releases from the mine.

6.3.25.3. COMPARISON OF PREDICTED AND ACTUAL WATER QUALITY

Table 6.31 provides a summary and comparison of potential, predicted and actual water quality information for the Flambeau Mine. The accuracy of the predictions is discussed in this section.

<u>Elevated Concentrations of Iron, Manganese, Sulfate, TDS and Acidity in Pit Backfill Leachate:</u> The concentrations of copper, iron, manganese and sulfate in the backfilled pit were predicted using geochemical modeling in the 1900 EIS. The modeling apparently used concentrations from short-term leach tests, but the details of modeling were not provided in the EIS. Predictions were also made in 1996 and 1997 as part of the mine's backfill plan. Concentrations predicted in 1997 for copper, manganese, and iron were substantially higher than those predicted in the EIS. For example, copper concentrations predicted in 1997 were 0.18 to 0.56 mg/l, and concentrations in the EIS were 0.014 mg/l. Compared to EIS-predicted post-mining concentrations in the pit backfill, post-mining concentrations in the backfill were higher by up to 45 times for copper, 70 times for manganese, 30 times for iron, and 1.25 times for sulfate. Therefore, modeling underestimated actual concentrations of metals and other contaminants in the pit backfill leachate.

Table 6.31. Flambeau, WI, Potential, Predicted and Actual Impacts

Resource	Source	Potential Impact	Mitigation	Predicted Impact	Actual Impact
Pit Backfill Leachate	Pit backfill	Pit backfill will eliminate pit waters.	Backfilling to eliminate possibility of a pit lake. Liming of backfill.	Pit backfill will eliminate pit waters. Predicted leachate concentration in pit backfill was 0.014 mg/l copper, 0.32 mg/l iron, 0.725 mg/l manganese and 1,360 mg/l sulfate.	Four monitoring wells in the backfilled pit show exceedences of drinking water standards for iron, manganese, pH, sulfate and TDS. One in-pit well shows continued increasing or elevated concentrations of iron, sulfate, TDS and manganese; other wells show decreasing concentrations.
Groundwater	Pit backfill	Waste rock from the mining operation would have the potential to leach contaminants to ground water.	High sulfur waste stockpiles and ore crushing/ loading areas lined. Treatment of mine water before discharge; Liming of backfill. Settling ponds to collect runoff from low sulfur stockpiles.	Slightly increased TDS, hardness, sulfate, iron and manganese may be expected from leachate infiltration. No impacts from high sulfur stockpile, ore crushing areas. Worst-case leakage would leak into mine pit, where water would be treated before discharge. Groundwater under ponds flows to pit, limiting contamination.	Samples taken from a well between the river and the pit show exceedences of drinking water standards for iron (2.8-7.4 mg/l), manganese (3.1-4.2 mg/l), pH (5.9-6.2), sulfate (250-460 mg/l), and TDS (810-1,100 mg/l).
Surface Water and Springs	Pit backfill and mine operations	Waste rock from the mining operation would have the potential to leach contaminants to surface waters.	Settling ponds collect runoff from low sulfur stockpiles for treatment prior to discharge. Ponds unlined, but seepage to groundwater would flow mostly to pit. Contaminant flow to pit treated prior to discharge to river.	Increased erosion and discharge to river possible. Discharge will not cause concentration of any substance to exceed standards. Contaminants from ponds may be transported to river, wouldn't affect water quality. Post-closure discharge of contaminants not measurable in river due to dilution.	No observable changes in surface water quality, but sample locations may not capture all releases from mine.

7. SUMMARY OF CASE STUDY FINDINGS AND INHERENT FACTORS AFFECTING OPERATIONAL WATER QUALITY

Section 7 presents a general summary of predicted and actual water quality for the 25 case study mines. To determine the accuracy of water quality predictions, statements made in the NEPA documents about potential and predicted water quality impacts were compared with actual operational water quality data, using information from Section 6. Water quality impacts from acid drainage and other contaminants may be delayed, depending on the amount and availability of neutralizing and acid-generating material, the distance to water resources, and other factors (Maest et al., 2005). Because mines that have not had water quality impacts to date may have impacts in the future, a greater emphasis is placed in this report on comparing predictions for mines that have already had water quality impacts.

“Inherent” factors affecting operational water quality at the case study mines are also identified and discussed. The potential inherent factors identified in the EISs that can affect water quality at mine sites include geology and mineralization, acid drainage and contaminant leaching potential, climate and proximity to water resources. If a strong relationship exists between certain of these factors and operational water quality for the case study mines, it may be possible to estimate in advance – knowing only what can be gathered from EISs – which mines may have better and worse environmental performance.

Section 7.1 presents the general findings on the accuracy of water quality predictions in the EISs and EAs. Section 7.2 presents information on the relationship between inherent characteristics (or combinations of characteristics) and actual water quality at the case study mines. Although predictions from all EISs for a given mine were considered, the initial predictions (i.e., in the first EIS or EA) are often the most important, because, with the exception of separate expansions, the major mitigating measures are based on these initial predictions. Although sample sizes are not large enough for statically valid comparisons, general statistical measures (simple percentages for a population with a given characteristic) are presented to indicate the importance of the associations discussed.

7.1. ACCURACY OF WATER QUALITY PREDICTIONS: SUMMARY OF CASE STUDY FINDINGS

Findings for individual case study mines are presented in Section 6. In Section 7.1, predicted and actual water quality data are reviewed for all 25 case study mines to determine if there are patterns in the accuracy of EIS water quality predictions.

7.1.1. ACID DRAINAGE/CONTAMINANT LEACHING POTENTIAL AND DEVELOPMENT

The potential for acid drainage is usually determined using static acid-base accounting tests, while the potential for contaminant leaching is usually determined using the results from short-term leach tests and analysis of the leachate for metal concentrations. Kinetic test results can be used to determine both acid drainage and contaminant leaching potential. It is possible to have neutral or even basic drainage and elevated contaminant concentrations, especially for constituents such as arsenic and other oxyanions, cyanide, and anions such as nitrate and sulfate. Therefore, these two geochemical characteristics (acid drainage and contaminant leaching) are discussed separately.

The results for acid drainage and contaminant leaching potential and development are contained in Tables 7.1, 7.2 and 7.3. The majority of the case study mines (18/25 or 72%) predicted low potential for acid drainage in one or more EIS. Of the 25 case study mines, 36% have developed acid drainage on site to date. Of these nine mines, eight (89%) predicted low acid drainage potential initially or had no information on acid drainage potential. The Greens Creek Mine in Alaska initially predicted moderate acid drainage potential but later predicted low potential for acid drainage for an additional waste rock disposal facility. Therefore, nearly all the mines that developed acid drainage either underestimated or ignored the potential for acid drainage in their EISs.

Table 7.1. EIS and Operational Water Quality Information for Case Study Mines

Site	State	Highest (Lowest) Acid Drainage Potential	Acid Drainage Developed on Site?	Contaminant Leaching Potential	Standards Exceeded in SW?	Constituent Increasing or Exceeding in SW	Standards Exceeded in GW?	Constituents Increasing or Exceeding in GW or Seeps
Greens Creek	AK	Moderate (Low)	Yes	Low	Yes	low pH, Cd, Cu, Hg, Zn, SO_4	No	GW: SO_4; seeps: SO_4, Zn, pH, Cu, Pb, Se
Bagdad	AZ	Low	Yes	No info	Yes	As, Pb, Hg, Se	No info	NA
Ray	AZ	No info	Yes	No info	Yes	TDS, NH_3, As, Be, Cu, turbidity	No info	NA
American Girl	CA	Low (0 initial)	No	Low (No info initial)	No	None	No	None
Castle Mountain	CA	Low	No	Low	No	None	No	None
Jamestown	CA	Low	No	Low	No info	NA	Yes	SO_4, NO_3, As
McLaughlin	CA	Low	Yes	Moderate	Yes	SO_4, As, Cr, Cu, Pb, Mn, Ni, Hg, Fe, Zn	Yes	TDS, Cl, NO_3, SO_4, Cu, Fe, Mn, B, Zn
Mesquite	CA	Low	No	Low (No info initial)	No	None	No	None
Royal Mountain King	CA	Low	No	No info	Yes	NO_3, SO_4, TDS, As	Yes	Cl, NO_3, Ni, Se, SO_4, TDS, Mn, As, Sb, Cr, Cu, Ni, CN
Grouse Creek	ID	Moderate	No	Low	Yes	CN	Yes	GW: CN; Tail pore water: Al, Cu, As, Se, Ag, Zn, CN
Thompson Creek	ID	Moderate (Low initial)	Yes	Low	Yes	Cd, Cu, Pb, Zn, SO_4	No info	Seeps: Fe, Zn, SO_4, Se; GW: NA
Beal Mountain	MT	Moderate (Low initial)	No	Low	Yes	NO_3, TDS, SO_4, CN	Yes	GW: NO_3, Fe, CN; TDS. Seeps: CN, Se, SO_4, NO_3
Black Pine	MT	High (no info initial)	Yes	Moderate	Yes	SO_4, Cu, Zn, Fe, Cd, low pH	No info	Seeps: low pH, SO_4, Cu, Zn, Fe, Cd; GW: NA

Table 7.1. EIS and Operational Water Quality Information for Case Study Mines (continued)

Site	State	Highest (Lowest) Acid Drainage Potential	Acid Drainage Developed on Site?	Contaminant Leaching Potential	Standards Exceeded in SW?	Constituent Increasing or Exceeding in SW	Standards Exceeded in GW?	Constituents Increasing or Exceeding in GW or Seeps
Golden Sunlight	MT	High (Low initial)	Yes	High	No	NA	Yes	CN, Cu, low pH
Mineral Hill	MT	Low	No	Moderate	Yes	CN, NO_3, Mn, SO_4, As, TDS	Yes	CN, NO_3, Mn, SO_4, As, TDS
Stillwater	MT	Low	No	Moderate	No	NO_3	No	Adit: Cd, Cu, Pb, Mn, Zn, NO_3. GW: Cr, Fe, SO_4, Cl, PO_4, Cd, Zn
Zortman and Landusky	MT	High (Low initial)	Yes	Moderate	Yes	metals, metalloids, NO_3, low pH, CN	Yes	low pH, As, metals, NO_3, CN
Florida Canyon	NV	Low	No	Moderate	No	NA	Yes	CN, Hg, NO_3, Cl, TDS
Jerritt Canyon	NV	Moderate	No	Moderate	Yes	TDS, SO_4	Yes	CN, Cl, TDS, SO_4
Lone Tree	NV	Moderate	No	High	Yes	pH, TDS, F, B, NH_3	Yes (baseline?)	F, Fe, Mn, TDS, Al, B, NH_4, pH
Rochester	NV	Moderate (Low initial)	No	Moderate	Yes	NO_3, As	Yes	CN, Hg, Cd, NO_3, As
Round Mountain	NV	Low	No	High	No info	NA	Yes (baseline?)	Al F, Fe, Mn, TDS, Sb, Pb
Ruby Hill	NV	Low	No	Moderate	No info	NA	Yes (baseline?)	As, NO_3, Pb
Twin Creeks	NV	Moderate	No	High	Yes	TDS, As	Yes - perched GW	TDS, SO_4, Cl, CN, Al, Sb, As, Mg, Fe, Hg, Mn
Flambeau	WI	No info	Yes	Moderate	No	SO_4, Mn, low pH, Fe	Yes	Fe, Mn, pH, SO_4, TDS

No info = no information; NA = not applicable; Ag = silver; Al = aluminum; As = arsenic; B = boron; Be = beryllium; Cd = cadmium; Cl = chloride; CN = cyanide; Cr = chromium; Cu = copper; F = fluoride; Fe = iron; Hg = mercury; Mn = manganese; Ni = nickel; NO_3 = nitrate; NH_4 = ammonia; Pb = lead; Sb = antimony; Se = selenium; SO_4 = sulfate; TDS = total dissolved solids; Zn = zinc.

Table 7.2. Acid Drainage Potential Predictions and Results for Case Study Mines (Percentages)

Element	Number/Total	Percentage
Mines predicting low acid drainage potential	18/25	72%
Mines that have developed acid drainage	9/25	36%
Mines with acid drainage that predicted low acid drainage potential	8/9	89%

Table 7.3. Contaminant Leaching Potential Predictions and Results for Case Study Mines (Percentages)

Element	Number/Total	Percentage
Mines predicting low contaminant leaching potential	8/25	32%
Mines with mining-related exceedences in surface water or groundwater	19/25	76%
Mines with exceedences that predicted low contaminant leaching potential	8/19	42%
Mines with exceedences that predicted moderate contaminant leaching potential	8/19	42%
Mines with exceedences that predicted high contaminant leaching potential	3/19	16%

Eight case study mines predicted low contaminant leaching potential (Table 7.3). Of these eight mines, five (63%) had exceedences of standards in either surface water or groundwater or both after mining began. The three mines that predicted low contaminant leaching potential and had no exceedences of water quality standards were the three California desert mines: American Girl, Castle Mountain and Mesquite. Stated another way, 21 of the 25 case study mines (84%) had exceedences of water quality standards in either surface water or groundwater or both (Table 7.1). The exceedences at two of these mines may be related to baseline conditions. Of the remaining 19 mines, eight (42%) predicted low contaminant leaching potential (or had no information), eight (42%) predicted moderate contaminant leaching potential, and only three (16%) predicted high contaminant leaching potential. Therefore, nearly half of the mines that had exceedences of water quality standards underestimated or ignored the potential for contaminant leaching potential in EISs. The constituents that most often exceeded standards or that had increasing concentrations in groundwater or surface water included toxic heavy metals such as copper, cadmium, lead, mercury, nickel, or zinc (at 12/19 or 63% of case study mines), arsenic and sulfate (11/19, or 58% each), and cyanide (10/19, or 53%).

7.1.2. PREDICTED AND ACTUAL IMPACTS TO SURFACE WATER RESOURCES

Table 7.4 lists the case study mines, their potential and predicted surface water quality impacts from the EISs, and whether or not there were mining-related impacts or exceedences in surface water. The results in percentages are presented in Table 7.5. Sixty percent (15/25) of the case study mines had mining-related exceedences in surface water. One mine, (Stillwater Mine, MT) had mining-related increases of nitrate in surface water, but concentrations have not exceeded standards.

Table 7.4. Predicted and Actual Impacts and Proximity to Surface Water Resources at Case Study Mines

Site	State	Highest (Lowest) Potential Impact to SW	Highest Predicted Impact to SW	SW Impact?	Standards Exceeded in SW?	Perennial Streams or Discharge?
Greens Creek	AK	Low	Low	Yes	Yes	Both
Bagdad	AZ	Low	Low	Yes	Yes	Discharge
Ray	AZ	No info	No info	Yes	Yes	Discharge
American Girl	CA	Moderate (Low initial)	Low	No	No	No
Castle Mountain	CA	Low	Low	No	No	No
Jamestown	CA	Moderate	Low	No info	No info	Perennial
McLaughlin	CA	Moderate	Moderate	Yes	Yes	Discharge
Mesquite	CA	Moderate (Low)	Low	No	No	No
Royal Mountain King	CA	No info	No info	Yes	Yes	No info (Perennial); No discharge
Grouse Creek	ID	Moderate (Low initial)	Low (no info initial)	Yes	Yes	Perennial
Thompson Creek	ID	Moderate	Moderate (Low)	Yes	Yes	Both
Beal Mountain	MT	Moderate (no info initial)	Low	Yes	Yes	Both
Black Pine	MT	No info	Low	Yes	Yes	Perennial
Golden Sunlight	MT	Low	Low	No	No	No
Mineral Hill	MT	Low	Low	Yes	Yes	Both
Stillwater	MT	Low (no info initial)	Low	Yes	No	Discharge (unused)
Zortman and Landusky	MT	High (no info initial)	High (Low initial)	Yes	Yes	Both
Florida Canyon	NV	No info	Low	No	No	No
Jerritt Canyon	NV	Moderate	Low	Yes	Yes	Perennial
Lone Tree	NV	Moderate	Low	Yes	Yes	Discharge
Rochester	NV	Moderate	Low	Yes	Yes	No
Round Mountain	NV	Moderate	Low	No info	No info	No
Ruby Hill	NV	Low	Low	No info	No info	No
Twin Creeks	NV	High	Low	Yes	Yes	Both
Flambeau	WI	Moderate	Low	No	No	Discharge

Table 7.5. Predicted and Actual Impacts to Surface Water Resources at Case Study Mines (Percentages)

Element	Number/Total	Percentage
Mines with mining-related surface water exceedences	15/25	60
Mines with surface water exceedences predicting low impacts without mitigation	4/15	27%
Mines with surface water exceedences predicting low impacts with mitigation	11/15	73%

A little over one-third (nine or 36%) of the case study mines noted a low potential for surface water impacts. Ten (40%) of the case study mines noted a moderate potential, and one noted a high potential for surface water quality impacts in the absence of mitigating measures. Of the 15 mines with exceedences of standards in surface water, three (20%) noted a low potential (pre-mitigation), seven (47%) stated that there would be a moderate potential, two stated there would be a high potential, and three had no information in their EISs on surface water quality impact potential in the absence of mitigation (Table 7.4).

In terms of predicted (post-mitigation) surface water quality impacts, 73% (11/15) of the mines with surface water quality impacts predicted low water quality impacts in their initial EISs, two predicted moderate impacts, and two had no information on post-mitigation impacts to surface water resources (Table 7.5). Therefore, the predictions made about surface water quality impacts before the effects of mitigation were considered were more accurate than those made taking the effects of mitigation into account. Stated in another way, the ameliorating effect of mitigation on surface water quality was overestimated in the majority of the case study mines. No mine conducted field or laboratory studies to determine the effects of mitigation on water quality improvement; rather, the predictions for both surface water and groundwater quality appeared to be based on unstated assumptions or best professional judgment.

Of the mines with surface water quality exceedences, only one mine(McLaughlin, CA) was correct in predicting a moderate potential for surface water quality impacts with mitigation in place; the others predicted low potential (not exceeding standards) in at least one EIS. However, the McLaughlin Mine predicted low acid drainage potential, and acid drainage has developed on site. Of the mines without surface water quality exceedences (seven or 28%), all were correct thus far in predicting no impacts to surface water with mitigation in place. Three of the seven are desert mines in California, one (Stillwater, MT) has had increases in contaminant concentrations but no exceedences, and the other three have had no exceedences or increases in mining-related contaminant concentrations in surface water to date. Therefore, most case study mines predicted no impacts to surface water quality after mitigation are in place, but at the majority of these mines, impacts have already occurred.

7.1.3. PREDICTED AND ACTUAL IMPACTS TO GROUNDWATER RESOURCES

Table 7.6 lists the case study mines, their potential and predicted groundwater quality impacts from the EISs ,and whether or not there were mining-related impacts or exceedences in groundwater or seeps. The results in percentages are presented in Table 7.7. The majority (64%,or 16/25) of the case study mines had exceedences of water quality standards in groundwater. However, exceedences at three of the mines, all in Nevada, may be related to baseline conditions; therefore, 52% of the case study mines clearly had mining-related exceedences of standards in surface water. Exceedences at one mine (Twin Creeks, NV) were said to be in "perched" groundwater. One mine (Greens Creek, AK) had mining-related increases of sulfate in groundwater, but concentrations have not exceeded standards. No information on groundwater quality impacts was available for four mines; however, two of these mines had mining-related exceedences in seeps. There were drinking water exceedences in adit water at the Stillwater Mine in Montana.

Table 7.6. Predicted and Actual Impacts and Proximity to Groundwater Resources at Case Study Mines

Site	State	Highest (Lowest) GW Impact Potential	Highest (Lowest) Predicted GW Impact	GW Impacts?	Standards Exceeded in GW?	Mining-related Exceedences in Seeps?	Shallow Groundwater or Discharge?
Greens Creek	AK	Moderate (Low)	Low	Yes	No	Yes	Shallow
Bagdad	AZ	Low	Low	NA	NA	NA	Shallow
Ray	AZ	No info	No info	NA	NA	NA	No
American Girl	CA	Moderate	Low	No	No	No	Shallow
Castle Mountain	CA	Low	Low	No	No	No	No
Jamestown	CA	Moderate	Low	Yes	Yes	NA	Shallow
McLaughlin	CA	High	High	Yes	Yes	NA	Shallow
Mesquite	CA	Moderate (Low initial)	Low	No	No	No	No
Royal Mountain King	CA	Moderate	No info	Yes	Yes	NA	No info
Grouse Creek	ID	Moderate (Low initial)	Low (no info initial)	Yes	Yes	NA	Shallow
Thompson Creek	ID	Moderate	Moderate (Low)	NA	NA	Yes	Shallow
Beal Mountain	MT	Moderate (no info initial)	Low	Yes	Yes	Yes	Shallow
Black Pine	MT	No info	Low	NA	NA	Yes	Shallow
Golden Sunlight	MT	High (Moderate)	High (Low initial)	Yes	Yes	Yes	Shallow
Mineral Hill	MT	Moderate	Low (no info initial)	Yes	Yes	NA	No
Stillwater	MT	Low (no info initial)	Low	No	No	Yes - adit	Both
Zortman and Landusky	MT	Moderate (Low)	High (Low)	Yes	Yes	Yes	Shallow
Florida Canyon	NV	Moderate	Low	Yes	Yes	NA	Shallow
Jerritt Canyon	NV	Moderate (Low initial)	Low (no info initial)	Yes	Yes	NA	Shallow
Lone Tree	NV	Low	Low	No? (baseline?)	Yes (baseline?)	NA	Shallow
Rochester	NV	Moderate (no info initial)	Low	Yes	Yes	NA	Shallow
Round Mountain	NV	High	Low	No? (baseline?)	Yes (baseline?)	NA	No
Ruby Hill	NV	Low	Low	No? (baseline?)	Yes (baseline?)	NA	No
Twin Creeks	NV	Moderate	Low	Yes	Yes - perched GW	NA	Discharge
Flambeau	WI	Moderate	Low	Yes	Yes	NA	Shallow

Table 7.7. Predicted and Actual Impacts to Groundwater Resources at Case Study Mines (Percentages)

Element	Number/Total	Percentage
Mines with mining-related groundwater exceedences	13/25	52%
Mines with groundwater exceedences predicting low impacts without mitigation	2/13	15%
Mines with groundwater exceedences predicting low impacts with mitigation	10/13	77%

About one-third of the case study mines (eight or 32%) noted a low potential for groundwater quality impacts in the absence of mitigating measures (Table 7.7). Of the 13 mines with mining-related exceedences in groundwater, only two noted a low potential for groundwater quality impacts in the original EIS, the majority (nine or 69%) stated that there would be a moderate potential, and two stated there was a high potential for groundwater impacts in the absence of mitigation (Table 7.7). In terms of predicted (post-mitigation) groundwater quality impacts, most of the case study mines (10 or 80%) predicted low groundwater quality impacts (not exceeding standards) after mitigation were in place. And an even higher percentage (10 or 77%) of the mines with exceedences in groundwater predicted low water quality impacts in their EISs (including mines predicting low impacts in the original EIS). Therefore, as with surface water, the predictions made about groundwater quality impacts without considering the effects of mitigation were somewhat more accurate than those made taking the effects of mitigation into account. Again, the ameliorating effect of mitigation on groundwater quality was overestimated in the majority of the case study mines.

Of the mines with mining-related groundwater quality exceedences (13), only one mine – the McLaughlin Mine in California – was correct in predicting a high potential for groundwater quality impacts with mitigation in place. This is the same mine that correctly predicted that there would be surface water exceedences. The others predicted low potential (not exceeding standards) for groundwater quality impacts in at least one EIS. Of the mines without groundwater quality exceedences (five or 25%), all were correct in predicting no impacts to surface water with mitigation in place. Again, three of the five are desert mines in California, one (Stillwater MT) has had increases in contaminant concentrations but no exceedences, and the other (Greens Creek, AK) has had mining-related exceedences in seeps. Therefore, most mines predicted no impacts to groundwater quality after mitigation were in place, but in the majority of case study mines, impacts have occurred.

7.2. INHERENT FACTORS AFFECTING WATER QUALITY AT CASE STUDY MINES

One of the goals of this study was to determine if there are certain factors that make a mine more or less likely to have water quality problems and more or less likely to accurately predict future water quality. Such factors could include: inherent characteristics of the mined materials; inherent characteristics of the mine; management approaches to handling mined materials and water; the type and number of geochemical tests that are performed on mined materials; and the interpretation of test results.

There are two types of water quality predictions in EISs: "potential" water quality (does not take mitigation into account) and "predicted" water quality (does take mitigation into account). As noted in Section 7.1, nearly all the EISs reviewed reported that they expected acceptable water quality (concentrations lower than relevant standards) after mitigation were taken into account. Indeed, if this prediction was not made in the EIS, the regulatory agency would not be able to approve the mine (with certain exceptions, such as pit water quality in states where pit water is not considered a water of the state).

Certain inherent characteristics of the mined materials or mining locations may make the mine more or less susceptible to water quality impacts and more or less likely to have accurate predictions about future water quality. Some of the inherent characteristics that may influence a mine's environmental behavior include:

- ore type and association (e.g., commodity, sulfide vs. oxide ore, vein vs. disseminated)
- climate (e.g., amount and timing of precipitation, evaporation, temperature)
- proximity to water resources (distance to surface water resources, depth to groundwater resources, presence of springs)
- pre-existing water quality (baseline groundwater and surface water quality conditions)
- constituents of concern
- acid generation and neutralization potentials (and timing of their release), and
- contaminant generation potential.

In addition to the inherent characteristics of a mine and its location, the management of the mine and its wastes and waters, the processing chemicals used, and the type of operation (e.g., vat leach and tailings vs. heap leach facility; underground vs. surface mine) will have an important effect on a mine's environmental behavior. The management and mitigation measures used can be one of the root causes of water quality problems, and these issues are addressed in Section 8.

This section examines the inherent factors that can influence environmental behavior at mine sites. Information from the EISs presented in Section 5, was used to evaluate the inherent factors and the mitigation measured used, and information on operational water quality at the case study mines, presented in Section 6 was used to determine if the identified water quality potential was accurate.

For this evaluation, a water quality impact is defined as increases in concentration of water quality parameters as a result of mining operations, whether or not an exceedence of water quality standards or permit levels has occurred. Information on whether groundwater, seep or surface water concentrations exceeded standards as a result of mining activity is also included.

Information gathered from the EISs was used to categorize the inherent characteristics of the mine and its materials. All of the potential inherent factors listed above were listed in the database under NEPA information. The inherent factors evaluated include: geology and mineralization; proximity to water resources and climatic conditions; and geochemical characteristics of mined materials, such as acid drainage and contaminant leaching potential.

Mines with close proximity to water resources and moderate to high acid drainage or contaminant leaching potential are examined together to determine if this combination of inherent factors results in a higher risk of adverse water quality impacts. Results for case study mines with this combination of factors are included in Tables 7.1, 7.4 (surface water) and 7.6 (groundwater and seeps). The tables list: the acid drainage and contaminant leaching potential: the presence of surface water or groundwater impacts: the presence of acid drainage on site; exceedence of standards in surface water, groundwater or seeps; constituents that have increased in concentration over baseline conditions or exceeded standards; the presence of perennial streams or shallow groundwater on site; and the type of discharge to surface water or groundwater. The discharges to surface water are usually permitted National Pollution Discharge Elimination System (NPDES) discharges under the Clean Water Act. The tables also include information from the EISs on water quality predictions, including the potential (pre-mitigation) and predicted (post-mitigation) impact to water resources.

7.2.1. MINES WITH CLOSE PROXIMITY TO SURFACE WATER AND MODERATE TO HIGH ACID DRAINAGE OR CONTAMINANT LEACHING POTENTIAL

EIS and operational water quality information for mines with close proximity to surface water and elevated acid drainage or contaminant leaching potential is listed in Tables 7.1 and 7.4.

Mines with Moderate to High Acid Drainage Potential

The following case study mines have perennial streams on site or discharge directly to surface water and have a moderate to high acid drainage potential (see Table 7.1):

- Greens Creek, Alaska
- Grouse Creek, Idaho
- Thompson Creek, Idaho
- Beal Mountain, Montana
- Black Pine, Montana
- Zortman and Landusky, Montana
- Jerritt Canyon, Nevada
- Lone Tree, Nevada
- Twin Creeks, Nevada

Of these nine mines, all (100%) had mining-related exceedences of water quality standards in surface water. Of the nine mines with identified moderate to high acid drainage potential and close proximity to surface water resources, four (44%) have currently developed acid drainage on site. Impacts to surface water from the other five mines resulted from cyanide, nitrate, sulfate, metalloids, ammonia or other anions (Table 7.1).

At the Greens Creek Mine, elevated concentrations of sulfate and zinc and lower pH values were measured in smaller streams, most likely as a result of leaching of high sulfide material (tailings or waste rock) lying outside of the tailings pile capture area. At the Grouse Creek Mine, tailings impoundment leakage into groundwater resulted in cyanide in surface water. At the Thompson Creek Mine, creeks downgradient of the waste rock dumps had increasing concentrations of sulfate (to values in excess of water quality standards) over a six-year period. At the Beal Mountain Mine, nitrate, total dissolved solids, and sulfate concentrations in streams have increased relative to baseline conditions, and cyanide exceeded aquatic life standards. At the Black Pine Mine, springs impacted by waste rock flow into Smart Creek and have elevated concentrations of sulfate, copper, zinc, iron, and cadmium, and low pH values. At the Zortman and Landusky Mine, streams were impacted by acid drainage from waste rock and the heap leach pad. The Lone Tree Mine has been in general compliance with overall permit requirements for discharge of its dewatering water to the Humboldt River, but there were some exceedences of permit limits, and Newmont has been fined for these exceedences. Although no information was obtained on stream water quality at the Twin Creeks Mine, dewatering water discharged to Rabbit Creek has shown exceedences of total dissolved solids and arsenic standards by up to 10 times.

Each of these nine mines predicted low surface water impacts after mitigation were in place in at least one or all of the EISs (Table 7.4). For the Thompson Creek and Zortman and Landusky mines, later EISs predicted higher potential impact to surface water, but in both cases, the initial EIS predicted low impacts to surface water resources. In a number of cases, the mines expanded before the development of poor water quality conditions. These results suggest that even though mines may identify a moderate to high acid drainage potential, they predict that surface water resources will not be impacted after mitigation are implemented. In all cases where elevated acid drainage potential was identified, the predicted impact to surface water was identified as “low” in at least one EIS, yet impacts have occurred (see Tables 7.1 and 7.4).

Mines with Moderate to High Contaminant Leaching Potential

The following mines have perennial streams on site or discharge directly to surface water and identified a moderate to high potential for contaminant leaching in their EISs (see Table 7.1):

- McLaughlin, California
- Black Pine, Montana
- Mineral Hill, Montana
- Stillwater, Montana

- Zortman and Landusky, Montana
- Jerritt Canyon, Nevada
- Lone Tree, Nevada
- Twin Creeks, Nevada
- Flambeau, Wisconsin

Of these nine mines, five also have moderate to high acid drainage potential and proximity to surface water resources and were discussed above. With the exception of the Flambeau Mine, which has developed acid drainage on site, all nine mines have had some impact to surface water quality from mining operations, as shown in Table 7.1. For nine mines with proximity to surface water resources and moderate to high contaminant leaching potential, eight (89%) have shown some impact to surface water quality, and seven (78%) of the nine mines have had exceedences of standards in surface water.

Of the remaining four mines, the McLaughlin Mine has had exceedences of sulfate (showing steady increases since mining began, and occasionally large exceedences of arsenic, chromium, copper, lead, manganese, mercury, iron and zinc. However, no surface water quality violations were recorded for the McLaughlin Mine because of the way baseline water quality is calculated. At the Mineral Hill Mine, tailings leachate containing cyanide, nitrate, manganese, sulfate, arsenic, and dissolved solids has escaped the liner system and caused exceedences in surface water. The Stillwater Mine does not have perennial streams on site, but it does have a NPDES permit for discharge of mine water to surface water. However, this permit has never been used. Nitrate concentrations in the Stillwater River have increased to as high as 0.7 mg/l (site-specific limit is 1.0 mg/l) as a result of mining activity, but no standards or limits were exceeded. At the Flambeau Mine, there were no observable changes in surface water quality, but there is some concern that surface water sample locations may not capture all releases from mine. The Flambeau Mine has had groundwater impacts from the backfilled pit. More monitoring of additional locations over a longer time period is required to determine if observed poor groundwater quality will adversely affect downgradient surface water.

In terms of EIS predictions, six of the nine mines identified moderate to high potential for surface water impacts without mitigation, but eight of the nine predicted low impacts to surface water after mitigation were in place (as noted above, the Zortman and Landusky Mine initially predicted a low impact to surface water resources). To date, predictions for surface water impacts at the McLaughlin, Stillwater and Flambeau mines were accurate, but the remaining six mines underestimated the actual impact to surface water in their EISs.

Comparison to All Case Study Mines

Surface water impacts for the mines with close proximity to surface water and high acid drainage or contaminant leaching potential are compared to surface water impacts for all the case study mines in Table 7.8. Overall, for the 13 mines with close proximity to surface water and high acid drainage or contaminant leaching potential (see Table 7.1), 12 (92%) have had some impact to surface water as a result of mining activity (see Table 7.5). For all case study mines, only 64% had some surface water quality impact. Eleven of the 13 (85%) have had exceedences of standards or permit limits in surface water as a result of mining activity. These results, although not comprehensive, suggest that the combination of proximity to surface water resources (including direct discharges to surface water) and moderate to high potential for acid drainage does increase the risk of water quality impacts. Although this finding makes intuitive sense from a risk perspective, a comprehensive study of cause and effect has never been conducted.

Of the 11 with exceedences, 10 (91%) predicted that surface water standards would not be exceeded. Considering the two mines that accurately predicted no surface water exceedences (Stillwater and Flambeau) and the one that accurately predicted exceedences (McLaughlin), 77% of mines with close proximity to surface water or direct discharges to surface water and moderate to high acid drainage or contaminant leaching potential underestimated actual impacts to surface water. For all case study mines, 73% of the mines with surface water quality exceedences predicted that there would be no exceedences. Compared to all case study mines, higher percentages of mines with close proximity to surface water and elevated acid drainage or contaminant leaching potential had surface water quality impacts and exceedences. EIS water quality predictions made before the ameliorating effects of mitigation were considered ("potential" water quality impacts) were more accurate at predicting operational water quality than predictions based on assumed improvements from mitigation. Mines with these inherent factors are the most likely to require perpetual treatment to reduce or eliminate the long-term adverse impacts to surface water resources.

Table 7.8. Surface Water Quality Impacts for Mines with Close Proximity to Surface Water and Elevated Acid Drainage Potential Compared to Surface Water Impacts for All Case Study Mines

	# Mines	**Percent (%) with Impact to Surface Water**	**Percent (%) with Exceedences of Standards in Surface Water**	**Percent (%) with Exceedences that Predicted no Exceedences**
Mines with close proximity to surface water and elevated acid drainage and contaminant leaching potential	13	92 (12/13)	85 (11/13)	91 10/11)
All case study mines	25	64 (16/25)	60 (15/25)	73 (11/15)

7.2.2. MINES WITH SHALLOW DEPTH OR DISCHARGES TO GROUNDWATER AND WITH MODERATE TO HIGH ACID DRAINAGE OR CONTAMINANT LEACHING POTENTIAL

The operational water quality of mines with shallow groundwater or discharges to groundwater resources – and with moderate to high acid drainage or contaminant leaching potential – is evaluated in this section. Mines with close proximity to groundwater resources are often close to surface water as well. Therefore, a number of mines evaluated above will also appear in this section. Mines that discharge to groundwater usually do so through infiltration basins or some other kind of land application. Although this is not a direct discharge to groundwater, it does increase the likelihood that the discharge water and any associated contaminants will reach groundwater. EIS and operational water quality information for mines with close proximity to groundwater and elevated acid drainage or contaminant leaching potential is listed in Tables 7.1 and 7.6.

Mines with Moderate to High Acid Drainage Potential

The following mines have a relatively shallow depth to groundwater (0 to 50 feet), have springs on site, or discharge to groundwater – and have a moderate to high acid drainage potential (see Table 7.1):

- Greens Creek, Alaska
- Grouse Creek, Idaho
- Thompson Creek, Idaho
- Beal Mountain, Montana
- Black Pine, Montana
- Golden Sunlight, Montana
- Zortman and Landusky, Montana
- Jerritt Canyon, Nevada
- Lone Tree, Nevada
- Rochester, Nevada
- Twin Creeks, Nevada

Of these 11 mines, some groundwater quality information was obtained for all but two (Thompson Creek, ID; Black Pine, MT). However, there is information about seepage water quality from both of these facilities. Of the 11 mines with shallow depths to groundwater, springs on site or that discharge to groundwater and that have moderate to high acid drainage potential, 10 (91%) have had some impact to groundwater or seeps from mining operations (see Table 7.6). The one exception is the Lone Tree Mine, which has groundwater exceedences that may be related to baseline conditions.

The Greens Creek Mine in Alaska has a depth to groundwater that ranges from the ground surface up to 50 feet deep. Seepage/runoff from the waste rock piles has an average zinc concentration of 1.65 mg/l, and tailings seepage water (including underdrain water) has had pH values as low as 5.8, with elevated sulfate (up to 2,400 mg/l), zinc (up to 3.6 mg/l), copper, lead, and selenium concentrations. Anomalously high sulfate concentrations were observed in groundwater monitoring wells, but metal concentrations have not increased as of 2000.

The Grouse Creek Mine has springs and shallow groundwater (depths ranging from 0.5 ft in alluvial aquifers to 100 ft in upland areas). The tailings liner and French drains installed below the tailings impoundment were not successful in preventing contamination from tailings leachate, and cyanide has been detected in both surface water and groundwater monitoring stations. Some contamination of groundwater is still evident at the site.

No groundwater data were obtained for the Thompson Creek Mine, which has flowing artesian wells, alluvial groundwater that is connected to streams, and some groundwater in bedrock fractures. However, tailings seeps have shown increases in iron and zinc, and sulfate and selenium concentrations in waste rock seeps were increasing since 1991, with selenium concentrations in excess of water quality standards.

At the Beal Mountain Mine in Montana, there is limited information on groundwater depth, but there are springs on site, and groundwater depth below the pit is only 25 to 50 ft Groundwater in the land application area exceeded standards for nitrate, iron and cyanide and had elevated total dissolved solids concentrations. Springs below the land application area also show appreciable increases in cyanide and selenium. Concentrations of selenium, sulfate, nitrate and total dissolved solids were elevated in springs sampled at the toe of the waste rock dump.

At the Black Pine Mine in Montana, groundwater depths are approximately 45 feet in the impoundment area, and there are 30 springs in the project area. Although no direct information on groundwater quality was available, seeps downgradient of waste rock and the soils barren areas are acidic (pH 2.6-4.7) and have elevated concentrations of sulfate, copper, zinc, iron and cadmium.

The Golden Sunlight Mine has alluvial groundwater at 50 to 60 feet deep and numerous springs on site. Tailings effluent has contaminated downgradient wells with cyanide and copper (up to 65 mg/l copper). Acid drainage is being produced from the waste rock dumps, ore stockpiles, tailings and adits.

The Zortman and Landusky Mine in Montana has perched groundwater at 140 to 150 feet, an overall depth to groundwater of <200 feet, and springs and seeps on site. Karst features control groundwater flow in some areas. Acid drainage has been generated from waste rock dumps (as low as pH 3.9), the ore heap retaining dikes, pit walls and floors, and leach pads and pad foundations. Sulfate concentrations have increased in alluvial groundwater downgradient of the heap retaining dikes.

The Jerritt Canyon Mine has perched groundwater at eight to 70 feet deep, and 23 springs and eight seeps on site. The regional groundwater depth is approximately 700 feet. Groundwater has been impacted by seepage from the tailings impoundment, and a cyanide plume exists on site. Groundwater in the vicinity of the tailings area also has exceedences of chloride (up to 12,000 mg/l), TDS (up to 30,000 mg/l) and sulfate.

Groundwater at the Lone Tree Mine ranges from 10 to >200 feet deep. Pre-mining groundwater levels have scored the mine as being close to groundwater resources, but the large dewatering rate for this mine has lowered groundwater levels considerably. The Lone Tree Mine in Nevada has had exceedences of primary and secondary drinking water standards in groundwater, but it is not clear if the cause is baseline conditions or seepage from mine facilities.

Depth to groundwater at the Rochester Mine ranges from <1 to 20 feet in the alluvial aquifer and from the ground surface to approximately 400 feet in the bedrock aquifer. There are springs on site. Leaks from the heap leach pad and the barren solution pond have caused numerous exceedences of WAD cyanide, mercury, cadmium, nitrate and arsenic in groundwater.
The Twin Creeks Mine, which operates a large dewatering system, has a groundwater depth of over 100 feet over most of the mine site; the pit floor is approximately 400 feet below pre-mining groundwater levels. However, the mine discharges to groundwater through infiltration basins. Degradation of groundwater (perched water) with cyanide and other constituents has occurred as a result of seepage from the tailings impoundment. The vadose zone monitoring wells that were added during 2003 to monitor seepage from the tailings impoundment have shown multiple exceedences of total dissolved solids, sulfate, chloride, cyanide, aluminum, antimony, arsenic, iron, mercury and manganese.

Therefore, for the 11 case study mines with close proximity to groundwater resources or that discharge to groundwater and that have moderate to high acid drainage potential, eight (73%) have shown some adverse impact to groundwater quality from mining activity. Of the remaining three mines in this category, two have contaminated seeps flowing from tailings and/or waste rock storage areas (Thompson Creek, ID; Black Pine, MT), but no groundwater quality data were obtained, for a total of 10 mines (91%) with mining-related impacts to groundwater or seeps. One mine in this category (Lone Tree, NV) has had no groundwater impacts. However, the groundwater table at the Lone Tree Mine has been lowered considerably from dewatering operations, and it is unlikely that groundwater impacts would be evident at this time.

For the 11 case study mines with close proximity to groundwater and elevated acid drainage potential, seven (64%) had mining-related exceedences in groundwater. Of the remaining four mines, three had mining-related exceedences in seeps, and one (Lone Tree) has baseline exceedences. All 11 mines (100%) predicted low groundwater impacts in one or more EIS after mitigation were in place (Table 7.6), but three mines (Thompson Creek, ID; Golden Sunlight and Zortman and Landusky, MT) also predicted higher impacts in at least one EIS. Only four mines predicted low groundwater impacts without mitigation. Therefore, the predictions that considered the effects of mitigation on groundwater quality were overly optimistic, and the predictions without mitigation were more accurate.

Mines with Moderate to High Contaminant Leaching Potential

The following mines are have a relatively shallow depth to groundwater (0 to 50 feet), have springs on site, or discharge to groundwater – and have a moderate to high contaminant leaching potential (see Table 7.1):

- McLaughlin, California
- Black Pine, Montana
- Golden Sunlight, Montana
- Stillwater, Montana
- Zortman and Landusky, Montana
- Florida Canyon, Nevada
- Jerritt Canyon, Nevada
- Lone Tree, Nevada
- Rochester, Nevada
- Twin Creeks, Nevada
- Flambeau, Wisconsin

Of these 11 mines, all but four (McLaughlin, CA; Stillwater, MT; Florida Canyon, NV; Flambeau, WI) also have moderate to high acid drainage potential and were discussed above. As noted earlier, all of these seven mines have had some impact to groundwater or springs/seeps as a result of mining activity with the possible exception of the Lone Tree Mine in Nevada, which has exceedences in groundwater that may be related to baseline conditions. In addition, the originally shallow groundwater table at the Lone Tree Mine has been lowered considerably from dewatering operations, and it is unlikely that groundwater impacts would be evident at this time.

The McLaughlin Mine in California has been touted by the mining industry as an example of a mine with laudable environmental behavior and has received numerous environmental awards. When the state of Wisconsin passed a requirement for new mines in sulfide ore bodies to demonstrate that other mines with net acid generation potential have operated and been closed for at least 10 years without polluting groundwater or surface water (Wisconsin Act 171 {Statute §293.50}, passed in 1997), the McLaughlin Mine was one of the three examples used by Nicolet Minerals in their application for a permit for the Crandon Mine (Nicolet Minerals, 1998). The McLaughlin Mine has a regulatory exclusion for groundwater at the site, so no groundwater enforcement actions can be brought by Regional Water Quality Control Board (RWQCB). At the McLaughlin Mine, wells downgradient of the tailings impoundment had exceedences of TDS (up to 12,000 mg/l), chloride, nitrate (up to ~37 mg/l), and sulfate, and increases of copper (up to 280 µg/l) and other metals from 1984 – 1992 (mine began operation in 1985). Wells downgradient of waste rock dumps had increasing concentrations of sulfate (up to 5,000 mg/l), boron, TDS, calcium, iron, manganese and other constituents from 1985 to 1998 and zinc (up to 1.7 mg/l) after this timeframe.

The Stillwater Mine in Montana has also received environmental awards, and acid drainage has not developed on the site to date, likely due in part to the unique ultramafic host rock and associated mineralogy. Depth to groundwater at the mine is 40 to 90 feet, and there are three springs on site; the mine discharges adit water to percolation ponds and a land disposal area on the site. Groundwater at the Stillwater mine in the area of the East land application disposal area has exceeded drinking water standards for chromium, but the cause is tailings from an historic government-operated World War II- era mine. The adit water that percolates to groundwater is unimpacted, except for nitrogen contamination, but contains cadmium, copper, lead, manganese, zinc and nitrogen concentrations in excess of baseline surface water values. Groundwater downgradient of the land application facility has slight elevations of sulfate, chloride, phosphorous, cadmium, iron and zinc, but these appear to be a baseline issue.

The pre-mining regional groundwater table at the Florida Canyon Mine was quite deep (~400 feet), but alluvial groundwater exists at 0 to 250 feet deep. A contaminant plume with elevated concentrations or exceedences of WAD cyanide, mercury, nitrate, chloride, and TDS exists in groundwater downgradient from the leach pad. Other groundwater monitoring wells on the site show exceedences of drinking water standards for aluminum, arsenic, cadmium, chloride, iron, manganese, nickel and TDS.

Depth to groundwater at the Flambeau Mine is Wisconsin before mining began was generally <20 feet and flowed toward the Flambeau River. Samples taken from a well between the river and the backfilled open pit showed elevated levels (compared to baseline values) or exceedences of drinking water standards for iron, manganese, pH, sulfate, and total dissolved solids. Concentrations appeared to peak in 2000 and have been slowly decreasing for manganese, sulfate and TDS, but are continuing to increase for iron. Zinc concentrations are variable and still (as of 2003) ~700 µg/l (Lehrke, 2004).

Of the mines that have close proximity to groundwater, springs on site, or that discharge to groundwater – and have a moderate to high contaminant leaching potential – eight of 11 mines (73%) had groundwater quality impacts, and two of the remaining three had seeps that were adversely impacted from mining activity (91% have mining-related impacts to groundwater, seeps, springs, or adit water). The remaining mine (Lone Tree, NV) has had exceedences of primary and secondary drinking water standards in groundwater, but it is not clear whether the cause is baseline conditions or seepage from mine facilities. All of the 11 mines had exceedences of standards in groundwater (8), or seeps, springs, or adits (4).

Of the 11 mines in this category, all but one (McLaughlin, CA) predicted low groundwater quality impacts after mitigation were installed. The Stillwater Mine in Montana predicted low impacts to groundwater, and no exceedences of standard have thus far resulted from current operations or operators. The Lone Tree Mine in Nevada also predicted low groundwater impacts, and current information suggests that this is true (assuming the exceedences are a baseline issue). However, the lowered water table likely prevents the observation of impacts to groundwater. EIS water quality predictions made before the ameliorating effects of mitigation were considered ("potential" water quality impacts) were more accurate at predicting operational water quality than predictions based on assumed improvements from mitigation. Therefore, of the 11 mines in this category, eight (73%) underestimated actual impacts to groundwater resources from mining activity.

Comparison to All Case Study Mines

Groundwater impacts for the mines with close proximity to groundwater and high acid drainage or contaminant leaching potential are compared to groundwater quality impacts for all the case study mines in Table 7.9. Taken as a whole, there are 15 mines with close proximity to groundwater, springs on site, or discharges to groundwater – and with moderate to high acid drainage or contaminant leaching potential (see Table 7.1 and 7.6). Of these 15 mines, 11 have had mining-related impacts to groundwater, and three have had adverse impacts to seeps, springs, or adit water (with the one possible exception being the Lone Tree Mine in Nevada), for a total of 14 (93%) with impacts to groundwater, seeps, or adit water. For all case study mines, only 14 (56%) had mining-related impacts to groundwater and three had mining-related impacts to seeps, for a total of 17 (68%) with impacts to groundwater, seeps or adit water.

Table 7.9. Groundwater Quality Impacts for Mines with Close Proximity to Groundwater and Elevated Acid Drainage Potential Compared to Groundwater Impacts for All Case Study Mines

	# Mines	Percent (%) with Impact to Groundwater or Seeps	Percent (%) with Exceedences of Standards in Groundwater or Seeps	Percent (%) with Exceedences that Predicted no Exceedences
Mines with close proximity to groundwater and elevated acid drainage and contaminant leaching potential	15	93 (14/15)	93 (14/15)	86 (12/14)
All case study mines	25	68 (17/25)	68 (17/25)	52 (13/25)

For the 15 mines with close proximity to groundwater and elevated acid drainage or contaminant leaching potential, 10 had mining-related exceedences in groundwater and four had mining-related exceedences in seeps or adit water, for a total of 14 (93%) with impacts to groundwater, seeps, or adit water. For all case study mines, 13 had mining-related exceedences in groundwater, and four more had exceedences in seeps or adit water, for a total of 17 (68%) with exceedences in groundwater, seeps, or adit water. Of the mines with groundwater, seep or adit water exceedences, 12 (86%) of those with close proximity to groundwater and high acid drainage or contaminant leaching potential predicted that there would be no exceedences (including those that predicted low potential in their initial EIS). For all case study mines with exceedences, 13 (52%) predicted that there would be no exceedences, including those that predicted low potential in their initial EIS. These results, although not comprehensive, suggest that the combination of proximity to groundwater resources (including discharges to groundwater) and moderate to high acid drainage or contaminant leaching potential does increase the risk of water quality impacts and is a good indicator of future adverse groundwater quality impacts.

7.3. SUMMARY AND CONCLUSIONS

Overall Findings

Of the 25 case study mines, nine (36%) have developed acid drainage on site to date. Nearly all the mines (8/9) that developed acid drainage either underestimated or ignored the potential for acid drainage in their EISs. Of the 25 case study mines, 19 (76%) had mining-related exceedences in surface water or groundwater. However, nearly half of the mines with exceedences (8/19 or 42%) predicted low contaminant leaching potential in their EISs. The constituents that most often exceeded standards or that had increasing concentrations in groundwater or surface water included toxic heavy metals such as copper, cadmium, lead, mercury, nickel, or zinc (12/19 or 63%), arsenic and sulfate (11/19 or 58% each), and cyanide (10/19 or 53%).

Sixty percent of the case study mines (15/25) had mining-related exceedences in surface water. Of the mines with surface water quality exceedences, four (17%) noted a low potential, seven (47%) a moderate potential, two a high potential, and three had no information in their EISs for surface water quality impacts in the absence of mitigation measures. For the mines with surface water quality exceedences, only one mine, the McLaughlin Mine in California, was correct in predicting a moderate potential for surface water quality impacts with mitigation in place. However, this mine predicted low acid drainage potential, yet acid drainage has developed on site. The other mines with surface water exceedences predicted low potential (not exceeding standards) for impacts in at last one EIS. Therefore, most case study mines predicted no impacts to surface water quality after mitigation were in place, but at the majority of these mines, impacts have already occurred.

The majority (64% or 16/25) of the case study mines had exceedences of drinking water standards in groundwater. However, exceedences at three of the mines, all in Nevada, may be related to baseline conditions; therefore, 52% of the case study mines clearly had mining-related exceedences of standards in surface water. Of the 13 mines with mining-related exceedences in groundwater, only two noted a low potential for groundwater quality impacts in the original EIS, the majority (nine or 69%) stated that there would be a moderate potential, and two stated there was a high potential for groundwater impacts in the absence of mitigation. In terms of predicted (post-mitigation) groundwater quality impacts, 77% (10/13) of the mines with exceedences predicted low groundwater quality impacts in their EISs (including mines predicting low impacts in the original EIS). Therefore, as with surface water, the predictions made about groundwater quality impacts without considering the effects of mitigation were somewhat more accurate than those made taking the effects of mitigation into account. Again, the ameliorating effect of mitigation on groundwater quality was overestimated in the majority of the case study mines.

Findings on Relationship Between Inherent Factors and Water Quality

Overall, for the 13 mines with close proximity to surface water and high acid drainage or contaminant leaching potential, 12 (92%) have had some adverse impact to surface water as a result of mining activity. For all case study mines, only 64% had some surface water quality impact. Eleven of the 13 (85%) have had exceedences of standards or permit limits in surface water as a result of mining activity. Of the 15 mines with close proximity to groundwater and high acid drainage or contaminant leaching potential, all but one (93%) have had mining-related impacts to groundwater, seeps, springs, or adit water. For all case study mines, only 56% had mining-related impacts to groundwater.

For the 15 mines with close proximity to groundwater and elevated acid drainage or contaminant leaching potential, 13 (87%) had mining-related exceedences in groundwater. For all case study mines, only 52% had exceedences in groundwater. These results, although not comprehensive, suggest that the combination of proximity to water resources (including discharges) and moderate to high acid drainage or contaminant leaching potential does increase the risk of water quality impacts and is a good indicator of future adverse water quality impacts. Although this finding makes intuitive sense from a risk perspective, a comprehensive study of cause and effect has never been conducted. Mines with these inherent factors are the most likely to require perpetual treatment to reduce or eliminate the long-term adverse impacts to surface water resources.

8. FAILURE MODES AND ROOT CAUSES OF WATER QUALITY IMPACTS

This section identifies the underlying causes of water quality impacts at the case study mines. It uses information gathered from the case studies presented in Section 6 and conducts a "failure modes" and "root cause" analysis. A failure is an outcome that is different than intended or predicted. A failure mode is the general type of failure that occurred or is predicted to occur (e.g., prediction failure, mitigation failure), while a root cause is the underlying, more specific, reason for the failure. The objective of the analysis presented in this section is to identify the most common types and causes of failures in protecting water quality at existing mines so that the failures can be prevented in future. Results from this analysis can be used to make recommendations for improving both the policy and scientific/engineering underpinnings of EISs.

8.1. METHODOLOGY AND APPROACH

The approach presented in this section uses existing ("historical") information from mines with EISs to identify the causes of water quality impacts that occurred during mining operations. In contrast, most failure modes effects analyses (FMEA) are conducted before operations begin and instead focus on generating predictions from engineering design information (e.g.,, likelihood of failure based on factor of safety calculations). Because our approach is retrospective rather than prospective, we know unequivocally whether a prediction has failed or a water quality failure has occurred. Therefore, the focus of this analysis is to determine what caused the failure to occur. The information used to determine how failure occurred is contained in Section 6, which summarizes and compares water quality predictions in EISs with actual water quality conditions during mining operation.

8.1.1. FAILURE MODES AND ROOT CAUSES

According to Robertson (2003), any approach or mitigation measure that does not achieve the intended result (e.g., to prevent water quality impacts) or that results in undesirable consequences is considered a "failure." This study has identified two primary types, or modes, of failures: characterization and mitigation. Root cause refers to the specific reason or reasons for the failure. Table 8.1 summarizes the failure modes and root causes for all water quality or prediction failures that can be identified in the case studies.

There are two types of characterization failures identified in the case studies: hydrologic and geochemical. Inaccuracies in hydrologic and geochemical characterization can lead to failure to recognize or predict water quality impacts. The primary root causes of hydrologic characterization failures identified in this study are:

- dilution overestimated
- lack of hydrological characterization
- amount of discharge overestimated, and
- size of storms underestimated.

The primary root causes of geochemical characterization failures identified are:

- lack of adequate geochemical characterization, and
- sample size and/or representation.

The other failure mode identified in the case studies is mitigation failures. The primary root causes of mitigation failures identified are:

- mitigation not identified, inadequate or not installed
- waste rock mixing and segregation not effective
- liner leak, embankment failure or tailings spill, and
- land application discharge not effective.

Table 8.1. Water Quality Predictions Failure Modes, Root Causes and Examples from Case Study Mines

Failure Mode	Root Cause	Examples
Hydrologic Characterization	Lack of hydrologic characterization	Royal Mountain King, CA; Black Pine, MT
	Dilution overestimated	Greens Creek, AK; Jerritt Canyon, NV
	Amount of discharge underestimated	Mineral Hill, MT
	Size of storms underestimated	Zortman and Landusky, MT
Geochemical Characterization	Lack of adequate geochemical characterization	Jamestown, CA; Royal Mountain King, CA; Grouse Creek, ID; Black Pine, MT
	Sample size and/or representation	Greens Creek, AK; McLaughlin, CA; Thompson Creek, ID; Golden Sunlight, MT; Mineral Hill, MT; Zortman and Landusky, MT; Jerritt Canyon, NV
Mitigation	Mitigation not identified, inadequate, or not installed	Bagdad, AZ; Royal Mountain King, CA; Grouse Creek, ID
	Waste rock mixing and segregation not effective	Greens Creek, AK; McLaughlin, CA; Thompson Creek, ID; Jerritt Canyon, NV
	Liner leak, embankment failure or tailings spill	Jamestown, CA; Golden Sunlight, MT; Mineral Hill, MT; Stillwater, MT; Florida Canyon, NV; Jerritt Canyon, NV; Lone Tree, NV; Rochester, NV; Twin Creeks, NV
	Land application discharge not effective	Beal Mountain, MT

8.2. EXAMPLES OF CHARACTERIZATION FAILURES FROM CASE STUDY MINES

The following sections provide examples of the various types of characterization failures that were identified from the case study mines in Section 6. The information provided is intended as a short summary identifying the failure modes, root causes and subsequent mitigation. More specific information describing the cause and effects in each case is available in Section 6.

8.2.1. HYDROLOGIC CHARACTERIZATION FAILURES

Incorrect or inadequate hydrological characterization was identified as a contributing factor to water quality impacts at six of the 25 mines evaluated. The failure modes and root causes and effects for each case study with hydrologic characterization failures identified in Table 8.1 are summarized in the following sections.

Greens Creek, Alaska

The original Greens Creek 1983 EIS predicted that dilution would prevent impacts to surface water; however, the 2003 EIS shows that surface water impacts were noticeable in the general mine area and in off-site streams. Stream tributaries were impacted by mine wastes, in part ,due to smaller than predicted flows not providing sufficient dilution of contaminants coming from tailings and waste rock piles. The impacts to surface water were subsequently mitigated by relocating waste rock and capturing and treating tailings leachate.

Royal Mountain King, California
Current data for the Royal Mountain King site shows impacts to groundwater in the vicinity of the waste rock dumps due to near surface groundwater that is resulting in lateral flow and spread of contamination originating from waste rock dump seepage. A more adequate hydrological assessment would have indicated the presence of near surface groundwater and could have allowed for relocation of the waste rock dumps in locations that would not result in groundwater and surface water impacts.

Black Pine, Montana
The waste rock dump has impacted groundwater and springs on the site with acid drainage and is discharging to headwater streams. A lack of hydrologic characterization at the site has led to difficulties in identifying the association between the waste rock dump and springs and seeps at the site and in determining cost effective mitigation methods.

Mineral Hill, Montana
According to the original EIS, the initial low discharge rate (approximately 1gpm) from the underground workings would not result in an appreciable amount of leachate from the workings. At the higher discharge rates (approximately 10 gpm) that existed during operation the amount of discharges were significant and resulting arsenic concentrations exceeded non-degradation water quality standards. The hydrologic characterization conducted for the EIS did not predict significantly more groundwater being encountered by underground mining activities. A more accurate hydrologic evaluation could have allowed for planning of water treatment of mine discharge and may have encouraged a more accurate geochemical characterization.

Zortman and Landusky, Montana
Surface water impacts were associated with storm events exceeding the 100-year design criteria. During the past 25 years, at least four storm events have exceeded the predicted 100-year storm event. In addition to improper design criteria for the mine units and the lack of run-on ditches to prevent upgradient additions to storm events, this suggests that the extent of hydrologic characterization in terms of storm frequency and strength (i.e. amount of rainfall) prediction was inadequate to properly design mine units.

Jerritt Canyon, Nevada
The original 1980 EIS predicted that dilution would prevent impacts to surface water from contaminants. However, subsequent water monitoring data shows that surface water impacts have occurred in the headwaters of streams in the project area, most likely due to contamination from waste rock. Streams were impacted by waste rock in part due to smaller than predicted flows not providing sufficient dilution of contaminants. A more adequate hydrological assessment could have indicated that low flows in headwater streams would not provide adequate dilution.

8.2.2. GEOCHEMICAL CHARACTERIZATION FAILURES

Incorrect or inadequate geochemical characterization was identified as a contributing factor to water quality impacts at 11 of the 25 mines evaluated. The causes and effects for each case study with geochemical characterization failures are summarized below and in Table 8.2.

Greens Creek, Alaska
The Greens Creek 1988 EA predicted no potential for acid drainage in tailings. The 2003 EIS predicted that acid drainage from the tailings would occur but would not become evident for 10 to 33 years (based on static testing) or 500 years (based on modeling results). The 1983 EIS did not address water quality impacts from waste rock, whereas the 1992 EA recognized the potential for acid drainage from waste rock to impact water quality. However, acid drainage is already evident at the site in the general mine area in the form of metal-rich seepage from either the tailings, waste rock, or both sources, suggesting that the geochemical characterization for the predictions in the EISs were not accurate. The root cause of the failure to accurately predict acid drainage could be due to a single factor or a combination of factors such as sample representation, geochemical analysis, modeling and/or interpretation.

Jamestown, California

The geochemical characterization testing (short-term leach tests only) performed for the 1983 and 1991 EIS/EIR did not accurately identify the potential for groundwater impacts that were evident by 1990. Test results indicated that the mine tailings would not contain contaminants that needed to be controlled, and that the overburden material was non-hazardous, non-toxic and non-acid generating. Arsenic and TDS drinking water standards were slightly exceeded in tailings leachate from short-term leach tests, but observed concentrations in groundwater were substantially higher. Therefore, the short-term leach tests were not effective at identifying the contaminants of concern (sulfate and nitrate were not identified as contaminants of concern but exceeded drinking water standards in groundwater) and also underestimated the actual concentrations of constituents in groundwater during operations. In addition, no short-term leach testing was performed on waste rock. The most likely reasons the geochemical characterization failed to identify the potential is due to either sample representation or inadequate geochemical analysis (e.g., failure to perform tests or to perform the appropriate tests, e.g., long-term kinetics tests).

McLaughlin, California

Geochemical characterization conducted in the original McLaughlin Mine EIS appears to have been inadequate, possibly due to inadequate sample representation, lack of kinetic testing, or modeling of results. Acid-base accounting results for waste rock removed from the pit showed that 92% of the waste rock was determined to be either neutral or neutralizing. These results were not accurate for longer-term weathering of waste rock as demonstrated by water quality impacts to groundwater, surface water and pit water at the site. Acid drainage has developed and water resources were impacted by multiple constituents (metals, arsenic, and sulfate).

Royal Mountain King, California

The Royal Mountain King 1987 EIS/EIR did not predict contamination associated with waste rock, however groundwater results show evidence of contamination indicating that geochemical characterization was inadequate. No contaminant leaching potential testing was conducted, but groundwater is contaminated with metals, anions and cyanide. The most likely cause of the failure of geochemical characterization to predict the potential for contamination was static testing results not being accurate for long-term weathering of waste rock. The TTLC levels (standards) used in the static tests also may not have been protective enough to prevent groundwater contamination, or the samples selected for testing may not have been representative.

Grouse Creek, Idaho

The Grouse Creek 1984 EIS did not predict that contaminant leaching from tailings would impact water quality. Initial geochemical characterization tests were apparently conducted on non-representative samples or the “weathering’ tests performed were not adequate to infer contaminant potential. Although moderate acid drainage potential was identified in the 1992 EIS, only lead was predicted to exceed drinking water standards in tailings leachate. The 2002 EE/CA showed that prediction to be in error, with actual tailings pore water showing exceedences of standards for aluminum, copper, arsenic, selenium, silver, zinc and cyanide.

Thompson Creek, Idaho

Acid drainage potential tests were not performed on tailings material in the Thompson Creek 1980 EIS. Acid-base accounting tests conducted on waste rock for the 1980 EIS did not predict acid drainage potential, and the tailings were thought to be similar to waste rock in terms of acid drainage potential, although no support for this assumption was provided. The 1999 EIS geochemical characterization tests included kinetic testing and did indicate the potential for acid drainage from waste rock because the NP:AP ratio was 1.5 to 3.1. ABA and kinetic tests performed on tailings material for the 1999 EIS did note that tailings could become acid generating if exposed to air and water. However, the tailings were predicted to not generate acid as long as saturated, oxygen-free conditions were maintained in the impoundment. The characterization predictions failure for the tailings material was in part related to an incorrect assumption that such conditions would exist and be maintained in the impoundment and that they would prevent acid drainage from developing.

Black Pine, Montana
The original Black Pine 1981 EA did not directly test for acid drainage potential but instead used the total sulfide in the ore (<0.2%) as indicative of low potential for acid drainage generation and impacts. The waste rock dump has since impacted groundwater and springs on the site with acid drainage and is discharging to headwater streams.

Golden Sunlight, Montana
The Golden Sunlight 1981 EIS specifically identified the potential for impacts to groundwater, and ABA testing did identify the potential for the ore to be acid producing. However, these results were dismissed because the ore used in the tests was finely ground (400 mesh) rather than being run-of-mine size, and was therefore considered to not be representative of field conditions. The results were also dismissed because previous historic mining activity and waste dump development on the project area did not result in acid drainage, and because there was no discharge from existing underground workings at the site. The ABA test results were qualified based on a statement from the testing laboratory (B.C. Research) that "Experience has shown that generally relatively more gangue than sulphides is exposed at the larger particle size although this may not always be the case." According to the 1990 EA, the analysis was of a single "highwall composite," and the exact location and means of obtaining the sample were unknown. After the 1981 EIS, all subsequent EISs or EAs acknowledged the high potential for acid drainage development.

Mineral Hill, Montana
The potential for elevated arsenic concentrations in groundwater from the mine workings was not specifically recognized in the geochemical characterization of the site conducted in the 1983 EIS or 1988 EA. No geochemical characterization tests were conducted on waste rock, ore or any material representative of the walls of the underground workings. Geochemical characterization on the tailings material did predict the observed increases in three of six constituents found in tailings leachate, and contaminated groundwater and surface water (cyanide, arsenic, and manganese), but not sulfate, nitrate, and TDS, which are not removed by commonly used mine water treatment techniques (e.g., lime precipitation).

Zortman and Landusky, Montana
The Zortman and Landusky 1979 new project EISs were conducted without any geochemical characterization. Acid drainage was not predicted to occur based on the assumption that only oxide ore would be mined. This resulted in heap leach dikes and foundations being constructed in surface water drainages using what later was determined to be a mixed oxide/sulfide waste rock with high acid drainage generating potential, and waste rock with high acid drainage potential to be similarly placed in surface water drainages. The consequences of mine expansion were not addressed until the 1996 EIS. By this time, many unpredicted impacts had occurred, resulting in significant contamination of groundwater and surface water resources.

Jerritt Canyon, Nevada
The initial geochemical characterization in the 1980 EIS did not include acid drainage potential tests and noted only minimal potential for leaching of contaminants from waste rock. The 1994 EIS, based on significant additional testing, did indicate potential for acid drainage and contaminant leaching from at least some materials. The geochemical characterization in the 1980 EIS most likely failed to predict a high enough potential for contamination due to either sample representativeness or the limited geochemical analysis methods employed. Although acid drainage has not developed, the waste rock contamination has since caused off-site impacts to surface water in the mine area for sulfate and TDS.

8.3. MITIGATION FAILURES

Failure of mitigation to perform was identified as a contributing factor to water quality impacts at 16 of the 25 mines evaluated. The cause and effects for each case study are summarized below.

Greens Creek, Alaska
The 1992 EA recognized the potential for acid drainage from waste rock and proposed mixing of acid generating and non-acid generating rock as a mitigation measure. The 2003 EIS water quality information shows that mixing was not

effective to prevent water quality impacts in the general mine area. The 2003 EIS proposed backfilling of all waste rock to prevent acid drainage impacts.

Bagdad, Arizona

The Bagdad 1996 EIS did not predict any potential for impacts. Monitoring showed that impacts to off-site surface water occurred in 1998-2002, likely due to past tailings or pregnant leach solution spills or more recent events. The mitigation intended by the impoundment of tailings and pregnant leach solution failed in the form of a tailings spill or leak resulting in continued off-site impacts to surface water in the mine area.

Jamestown, California

The Jamestown project employed a sub-compacted liner and poorly designed embankment identified in the original EIS as mitigation for the tailings facility. The liner and embankment failed to protect groundwater quality.

McLaughlin, California

The McLaughlin 1983 EIS/EIR predicted that mitigation measures (underdrains, diversion ditches, segregation of PAG rock, lime addition to waste rock runoff) would avoid impacts to groundwater. However, groundwater wells downgradient of waste rock show water quality impacts indicating that the measures, such as mixing and segregation were not effective, resulting in widespread on-site impacts to groundwater and surface water.

Royal Mountain King, California

The Royal Mountain King 1987 EIS/EIR recognized the potential for impacts from tailings but assumed that low permeability material below the tailings would be sufficient as mitigation to protect groundwater. Similarly, the EIS/EIR recognized the potential for impacts from heap leach material, but assumed that a liner (material not specified) would prevent impacts to groundwater. Groundwater contamination downgradient of the tailings impoundment and heap leach area demonstrates that the low permeability material and liner have not prevented groundwater contamination.

Grouse Creek, Idaho

The contingency for groundwater capture and treatment during operations if necessary was mentioned in the Grouse Creek 1992 SEIS, however it was not installed at that time. The existing mitigation employed in the tailings impoundment (French drain designed to allow for capture of tailings leakage) proved to be ineffective at mitigating groundwater and subsequent surface water impacts to off-site water resources that occurred beginning in 1995. Additional mitigation in the form of groundwater capture and treatment has since been employed and has resulted in no detected impacts to surface water since 2001.

Thompson Creek, Idaho

According to the EIS, any acid-producing rock would be mitigated by special handling (segregation) and isolation techniques that are "demonstrated by their use throughout the mining industry." The methods employed at the mine site did not result in mitigation of acid drainage producing rock and instead led to water quality impacts that have required additional mitigation.

Beal Mountain, Montana

The LAD of leach solution, proposed as mitigation in the Beal Mountain 1993 EIS, resulted in damage to vegetation and contamination of groundwater and surface water with cyanide. The LAD system has failed at Beal Mountain because pre-treatment did not adequately reduce contaminants of concern (in particular cyanide compounds, which proved to be toxic to vegetation) and because there was significant groundwater percolation of contaminated solution and relatively rapid (within the same year) transport to surface water.

Golden Sunlight, Montana

The mitigation for the tailings impoundments identified in the Golden Sunlight 1981 EIS and the later 1990 EA failed due to liner design and construction errors and did not prevent migration of leachate from tailings. Contaminated groundwater from the impoundments has sometimes escaped capture systems due to more extensive leakage than anticipated and operational deficiencies (periodic failure to maintain and operate pumpback system). The design approach for the tailings impoundment with respect to cyanide solution leakage was projected to achieve “from the practical engineering standpoint,” a zero discharge facility. The clay liner in the original tailings impoundment and the synthetic liner in the newer tailings impoundment both failed to meet expectations and have resulted in a discharging facility that requires extensive groundwater capture to prevent more extensive groundwater and surface water impacts.

Mineral Hill, Montana

According to the 2001 EIS, the tailings facility design resulted in unanticipated lateral flow that escaped the liner system, resulting in contamination of alluvial groundwater and surface water. The design error occurred due to a lack of consideration of leachate emanating from the tailings impoundment as well as failure to recognize the potential for lateral flow.

Stillwater, Montana

In 2003 it was determined that a tailings underdrain discharge pipe was improperly designed or constructed and was allowing a leak of approximately 10 gpm to groundwater in the vicinity of the dam toe. It was also determined that the LAD solution storage pond liner was not performing as specified ($1x10^{-6}$ cm/sec) and that as much as 150 gpm of solution was seeping into groundwater. In both cases groundwater standards of 2.0 mg/l nitrate were not exceeded in compliance wells, although nitrogen concentrations increased in downgradient wells. The tailings underdrain pipe was repaired and the seepage is no longer detectable. The compacted clay liner in the LAD solution pond was replaced with a synthetic geomembrane liner.

Florida Canyon, Nevada

The exceedences of water quality standards at the Florida Canyon mine from the leach pads is primarily due to failure of mitigation (design, construction and/or operational errors) to adequately prevent leakage of leach solutions.

Jerritt Canyon, Nevada

The mitigation described in the 1980 EIS for the tailings impoundment, a compacted clay liner and embankment constructed to control seepage, failed as shown by the presence of a significant contaminant plume in the groundwater downgradient of the tailings facility. The failure of the liner and embankment seepage control system appears to be due to higher than design permeability most likely indicating either a problem with construction materials or construction practices.

The 1994 EIS proposed mixing and segregation as mitigation for potential acid drainage and contaminant leaching from waste rock. Subsequent monitoring data shows that waste rock continued to contaminate surface water despite implementation of the mitigation.

Lone Tree, Nevada

The tailings impoundment experienced a significant leak that resulted in leachate escaping into the vadose zone. An operational error (tailings were not placed against the embankment) was identified as the cause of the seepage. Newmont commenced remediation activities, which included trenching, and modified operations to promote drying of tails in the area of the embankments.

Rochester, Nevada

The mine has experienced exceedences of groundwater standards in the vicinity of the heap leach pile and ponds due to either spills or leaks in the liner system. Groundwater pump and treat is being used as a mitigation measure and is discussed in the 2003 EA.

Twin Creeks, Nevada

Leachate from the tailings impoundment has degraded groundwater in the vadose zone. An ongoing monitoring program is in place to determine the extent of vadose zone and potential groundwater contamination.

8.4. SUMMARY OF RESULTS

The Failure modes and effects identified in the study are summarized in Table 8.2. The results can be summarized as follows:

Six of 25 mines exhibited inadequacies in hydrologic characterization.

- At two of the mines, dilution was overestimated.
- At two of the mines, a lack of hydrologic characterization was noted.
- At one of the mines, the amount of discharge generated was underestimated.
- At one of the mines, the size of storms was underestimated.

Eleven of 25 mines exhibited inadequacies in geochemical characterization. Geochemical failures resulted from:

- assumptions made about geochemical nature of ore deposits and surrounding areas (e.g., mining will only be done in oxidized area)
- site analogs inappropriately applied to new proposal (e.g., historic underground mine workings do not produce water or did not indicate acid generation)
- inadequate sampling (e.g., geochemical characterization did not indicate potential due to composite samples or samples not being representative of actual mining)
- failure to conduct and have results for long-term contaminant leaching and acid drainage testing procedures before mining begins, and
- failure to conduct the proper tests, or to improperly interpret test results, or to apply the proper models.

Sixteen of 25 mines exhibited failures in mitigation measures.

- At three of the mines, mitigation was not identified, inadequate, or not installed.
- At four of the mines, waste rock mixing and segregation was not effective.
- At nine of the mines, liner leaks, embankment failures or tailings spills resulted in impacts to water resources.
- At one mine, land application disposal resulted in impacts to water resources.

Table 8.2. Summary of Failure Modes for Case Study Mines

Failure Mode	Number of Case Study Mines Showing Failure Mode	Percent of Case Study Mines Showing Failure Mode
Hydrologic Characterization	6	24%
Geochemical Characterization	11	44%
Mitigation	16	64%

8.5. CONCLUSIONS AND RECOMMENDATIONS

This study shows a variety of failure modes and root causes that have led to water quality impacts at hardrock mine sites in the U.S. As a general conclusion and recommendation, it is clear that regulatory review processes, such as EISs, should include an adequate analysis of baseline water quality, hydrological characterization and geochemical characterization and the full identification of appropriate mitigation and potential mitigation failures. The following sections provide conclusions and recommendations specific to the various failure modes identified in this study.

HYDROLOGIC CHARACTERIZATION

The case studies show the indirect cause and effect relationship between inadequacies in hydrologic characterization methods that were employed at mine sites and have resulted in impacts to water resources ranging from on-site contamination and contamination of headwaters streams to more extensive off-site contamination of surface water with the potential need for long-term water treatment in some cases. Hydrological characterization failures are most often caused by over-estimation of dilution effects, failure to recognize hydrological features (e.g., springs and shallow or perched groundwater) and underestimation of water production and stormwater quantities. Requiring adequate hydrological investigations as well as making conservative assumptions about water quality and quantity can address hydrological failures.

GEOCHEMICAL CHARACTERIZATION

The case studies show the indirect cause and effect relationship between inadequacies in geochemical characterization methods that were employed at mine sites and impacts to water resources. The severity of impacts ranged from on-site contamination and contamination of headwater streams to the need for long-term water treatment in some cases. Failure to identify the potential for contaminant leaching and acid drainage development has been a reoccurring theme at mine sites throughout the U.S. The case studies demonstrate the range of impacts to water resources that have occurred as a result of proper or adequate testing. The case studies also demonstrate that inaccurate geochemical predictions often lead to lack of identification of adequate mitigation measures.

Geochemical characterization failures can be addressed by emphasizing fundamental scientific requirements in the regulatory process. Such requirements should include adequate sample representation and testing, and interpretations that recognize the fundamental uncertainties and limitations of characterization testing. Improved geochemical characterization will lead to improved identification and of mitigation measures. As the most common characterization failure mode, the elimination of geochemical characterization failures can provide a large contribution to ensuring accurate water quality predictions and outcomes at hardrock mine sites.

MITIGATION

Waste rock mixing and segregation

At many mines, waste rock containing acid generating materials is managed by mixing and segregation practices. In most cases no data is available to ascertain the effectiveness of those practices, particularly where there is a significant distance from the source to water resources. The cases cited all have nearby water resources that were impacted. The data suggests that distance to water resources is potentially the most significant factor as to the effectiveness of waste rock mixing and segregation. Mitigation may depend more on climate and factors such as distance and geology affecting travel time and attenuation of contaminants. Where acid drainage generating materials are present, particularly in areas of headwater streams, waste rock mixing and segregation may not prevent impacts to water resources. These types of failures can be addressed by requiring adequate geochemical and hydrologic characterization and ensuring that segregated wastes are placed away from potential water pathways.

Liner leak, embankment failure or tailings spill

The case studies show that mitigation intended to capture contaminants such as liners and tailing impoundments may fail and lead to groundwater and surface water quality impacts. While in most cases, impacts are limited to on-site groundwater and nearby surface water, in some cases the impacts can result in more extensive surface water impacts and potentially to long-term water treatment. In all cases, additional mitigation, most often in the form of groundwater capture and treatment (including perpetual treatment in those severe cases), has resulted in effective capture and treatment of contaminants.

Failure of liners and tailing impoundments to perform is typically caused by design, construction and operational mistakes. These features frequently fail to perform, so it is important to consider the likelihood and consequences of those failures and to identify and implement additional mitigation that can be employed in the event of such failures. In many cases where initial mitigation has failed, such as mines where liner leaks have occurred, additional mitigation in the form of groundwater capture and treatment are often necessary. Additional consideration needs to be given to including groundwater capture and treatment systems as original designed mitigation for high risk features such as tailings impoundments containing cyanide in high risk (near surface water or groundwater) areas.

Land application discharge

The case study shows that land application, instead of acting as a disposal mechanism to facilitate zero discharge, can result in impacts to groundwater and surface water. The impacts demonstrated in this case study were recognized at other land application sites. With the exception of land application for the disposal of low-levels of nutrients that can be applied at agronomic rates, land application disposal has demonstrated a high rate of failure and significant impact at hardrock mine sites in the United States.

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Appendix A
Major Mine Statistical Information

(available at www/kuipersassoc.com or http://www.mineralpolicy.org/publications_welcome.cfm)

Appendix B
Case Study Detailed Information

(available at www/kuipersassoc.com or http://www.mineralpolicy.org/publications_welcome.cfm)



Predicting Water Quality at Hardrock Mines

Methods and Models, Uncertainties, and State-of-the-Art

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Predicting Water Quality at Hardrock Mines

Methods and Models, Uncertainties, and State-of-the-Art

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Front cover: Left – Partially filled open pit at the Equity Silver Mine (silver) in British Columbia, Canada. Center – Open pit at the Bingham Canyon Mine (copper) in Utah USA. Right – Two-year kinetic tests at the Montana Tunnels Mine (gold, silver, lead, zinc) in Montana USA. Back cover: Construction of the heap leach pad at the Marigold Mine (gold) in Nevada USA. All Photos by Ann Maest.

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FOREWORD

The prediction of water quality at mine sites, the focus of this report, is a challenging topic because of its technical complication and inherent uncertainties. The quantity and characteristics of mine wastes are among the most important determinants of water quality at a mine site. Mine wastes or mined materials include the extraction area (open pit or underground mine), waste rock, unprocessed lean ore, heap or dump leach piles, tailings, and metallurgical processing wastes, although all of these wastes may not be present at a specific operation. The quantity of material generated can be very large, with mine waste areas covering hundreds of acres and amassing to tens or hundreds of million tons. The quality of mine waste drainage can be environmentally innocuous, circumneutral to basic with elevated concentrations of metals and oxyanions, or highly acidic with very high heavy metal concentrations. In addition to the potentially large physical size of mine waste disposal facilities, these materials remain on the ground long after mining and processing operations cease and can generate problematic drainage for centuries. Thus, in the absence of remediation, mine wastes are potentially sources of contaminants that may be transported from the mine site and adversely impact environmental or human receptors for many years.

Mine waste characterization techniques, in conjunction with geochemical and physical modeling and relevant existing data, have been applied to predict the quality of drainage that will be generated by mine wastes over time. These predictions are intended to contribute substantially to the fundamental information required to design and cost remediation that will allow compliance with water quality standards in a technically and economically efficient manner. Designing remediation measures in advance of mining allows their costs to be factored into the economics of mineral resource recovery, and for environmental mine waste management measures to be integrated effectively into the mine plan. Whereas this concept is fairly simple, the prediction of mine waste drainage quality over time can be a difficult proposition.

Factors that complicate drainage quality prediction range in scale from small to large. First, on a small scale, drainage quality is influenced by the dissolution of minerals present in the mine wastes, as well as secondary reactions among solutes, gas phases, and solid surfaces. The mineral surface areas available for reaction can be difficult to quantify, and the rates of reaction in a complex system are not well known. Second, on the large scale, geology, climate, methods of mining and mineral processing, and mine waste management approaches vary among and within operations. Variability of these large-scale factors means that characterization problems and results can be unique to an operation or operational component, and this limits the degree to which information from one site can be applied to another. Third, extrapolation from laboratory to operational scale must address complicating factors such as differences in particle size, environmental conditions, water and gas transport, and how these variables affect drainage quality over periods of decades or centuries. There is virtually no available information describing the effect of variables such as these on well characterized operational mine wastes over extended periods of time. The lack of this field information introduces uncertainty into predictions, and this uncertainty must be accounted for. Finally, characterization results and subsequent modeling must lead to environmental mine waste management programs that are practical and verifiable in the field. Given the large masses of material often moved in mining operations, this consideration is far from trivial.

Despite these difficulties, geochemical characterization techniques can provide predictive information on mine waste drainage quality that is beneficial to the environmentally sound management of mine wastes. Given the complexity of long-term predictions and the associated uncertainty, mine waste characterization should be viewed in the context of a program, integrating results from a variety of characterization techniques over time, rather than a single test or a one-time series of tests. This program begins with testing in the exploration phase and extends through closure and post-closure in the form of monitoring. Technical expertise from those experienced in the field will most likely be required to develop and apply a well-designed waste characterization program.

This report identifies various techniques for the geochemical characterization of mine wastes, including conventional geochemical and mineralogical analyses, static tests, short-term dissolution tests, and kinetic tests. For each technique, the report addresses advantages and limitations and sources of uncertainty, and makes concise recommendations for improvements. Sources of uncertainty in characterization and modeling identified in this report can be used to evaluate mine characterization and management plans. The characterization flow chart presented in the report provides a strategy that can be used at a wide variety of mine sites and recognizes that the specific characterization techniques can vary among these sites. Collection of an adequate suite of samples for testing is also discussed, and is a cornerstone for a reliable characterization program.

The application of characterization techniques during various phases of mineral resource development (exploration, development, active mining, and reclamation, closure, and post-closure) is discussed in this report. A modeling approach including development of a conceptual model, input data collection (including characterization results), model selection, sensitivity analysis, and evaluation of results is presented. The information presented in this report addresses many of the challenges associated with predicting water quality at mine sites noted above and will be useful to regulators, mine operators, and the public who are involved in mine waste characterization and modeling projects.

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AUTHORS

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REVIEWERS

Mark Logsdon, of Geochimica, Inc., has more than 30 years experience in hydrogeochemistry and environmental chemistry related to mining and waste management, including teaching, mining-exploration geochemistry, government service, research, and consulting. Since 1984, Mr. Logsdon has been in private consulting, focused on issues involving (a) water-quality conditions in natural and mined ground; (b) planning for and executing mining exploration, development, operations and closures; and (c) prediction and control of acid-mine drainage and the associated, leachable metals that may affect ground and surface waters. He has worked on more than 150 mining projects in North and South America, Europe, Africa, and Austral-Asia.

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1D, 2D, 3D	1, 2, 3 dimensional
µg/L	microgram/liter
µm	micrometers
AAS	atomic absorption spectrometer
ABA	acid base accounting
ACMER	Australian Center for Minerals Extension and Research
ADTI	Acid Drainage Technology Initiative
AG	acid generating
AGP	acid generation potential
AMD	acid mine drainage
AP	acid production potential
ARD	acid rock drainage
AVIRIS	Airborne Visual and Infra-Red Imaging Spectrometer
BCRC	British Columbia Research Confirmation test
BCRI	British Columbia Research Initial test
BC SWEP	British Columbia special waste extraction procedure and modification
^{o}C	degrees Celsius
cm	centimeter
DI	deionized water
EP Toxicity	extraction procedure toxicity test
eq/t	equivalents of calcium carbonate per ton
gm	gram
HCT	humidity cell test
hr	hour
ICMM	International Council on Mining and Metals
ICP-MS	Inductively-coupled plasma – mass spectrometer
IGWMC	International Groundwater Modeling Center
INAP	International Network for Acid Prevention
K_d	distribution coefficient
kg	kilogram
L	liter
m	meter
M	molar
MEP	multiple extraction procedure
MEND	Mine Environmental Neutral Drainage
min	minute
mL	milliliter
mm	millimeter
MWMP	meteoric water mobility procedure
N	normal
NAA	neutron activation analysis
NAG	net acid generating test
NCV	net carbonate value test
NEPA	National Environmental Policy Act
NP	neutralization potential
NPL	National Priorities List
NRC	National Research Council
OD	outside diameter
P	pressure
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control

RCRA	Resource Conservation and Recovery Act
SC	specific conductance
SEM/EDS	scanning electron microscopy/energy dispersive system
SME	Society of Mining, Metallurgy, and Exploration
SPLP	synthetic precipitation leaching procedure
T	temperature
TCLP	toxicity characteristic leaching procedure
TIC	total inorganic carbon
UNEP	United Nations Environmental Programme
USACOE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound
WET	California waste extraction test
WWG	World Wide Acid Rock Drainage Guide
XRD	X-ray diffraction
XRF	X-ray fluorescence

OVERVIEW

In order to determine if a given hardrock mine project will be protective of water resources during and after mining, regulators at state and federal agencies review Environmental Impact Statements or other types of environmental assessment documents submitted by mine proponents. In these assessments, the potential of the mined materials to generate acid and contaminants and to affect water resources is evaluated using a number of laboratory and field techniques and a variety of predictive modeling approaches. The regulator's job is to evaluate, sometimes with incomplete information, whether the tests and modeling that were conducted were appropriate for the site-specific conditions at the mine and whether the predictions and the mining approach are reliable enough to guarantee that future environmental liability is adequately addressed.

According to the U.S. EPA's Abandoned Mine Land Team, the cost of remediating mine sites on the National Priorities List (NPL) in the United States is on the order of $20 billion. Recent increases in the prices of precious and base metals on the world market have triggered an increase in the number of new mines being proposed in the United States and around the world. In the United States alone there are on the order of 170 large hardrock mines – in nearly all regions of the country – that are in various stages of being proposed, in permitting, in construction, operating, or recently closed and require oversight and ongoing evaluations by state and federal agencies. In order to reduce liability costs associated with hardrock mining, improvements must be made in mine evaluations before mining begins and also throughout the life of the mine. This report lays out a framework for evaluating the methods and models used to predict water quality at hardrock mine sites and makes recommendations for their improvement. It is intended to be used by regulators, the interested public, and mine operators and managers.

The companion study to this report, *Comparison of Predicted and Actual Water Quality at Hardrock Mines: The reliability of predictions in Environmental Impact Statements* (Kuipers et al., 2005), reviews predictions made in Environmental Impacts Statement for large hardrock mines in the United States – predictions based in part on characterization and modeling approaches – and evaluates their reliability using operational water quality data. Findings from that study highlight the importance of obtaining characterization data through all stages of mining and using this information in forecasts of mine site water quality.

Although predictive modeling is by its nature uncertain, it is valuable for helping to describe and understand the physical, chemical, and biological changes that can occur to natural systems from mining activity. Much of the uncertainty related to predicting water quality at mine sites derives from inadequate or inaccurate conceptual models, hydrologic and geochemical characterization data, and input data to hydrogeochemical models.

The creation of a site conceptual model is an important first step in predicting water quality at mine sites. In order to create a useful conceptual model, baseline hydrogeologic and geochemical data from the proposed mine must be collected and interpreted. The pathways through which contaminants can travel from mine sources to receptors should be identified and characterized, and the effects of any proposed mitigation measures on contaminant transport should be estimated. Conceptual models are not unique and can change over time as mining progresses. Therefore, it is necessary to revisit conceptual models and modify mining plans and predictive models based on new site-specific information.

One of the biggest challenges in predicting water quality is estimating the long-term geochemical behavior of mined materials. Unlike other industrial facilities, contaminant discharges from mine sites can take years, decades, or longer to develop and are subject to climatic and seasonal variability in concentrations and flow. Laboratory and field geochemical testing and careful measurements of hydrologic and meteorologic conditions at the site over time are needed for improved water-quality predictions. Mineralogic characterization is an underutilized tool in the prediction of the geochemical behavior of mined materials. Static tests and short-term leach tests are not designed to simulate long-term behavior of mined materials. Properly conducted static tests can instead provide estimates of the total amount of acid-generating and -neutralizing material present, and short-term leach tests can be used to simulate the short-term interaction of water with weathered, mined materials. Results from static tests can be useful as an initial screening method to determine which materials should be examined further for acid-generation potential but should not be used to predict the long-term ability of mined materials to generate acid. Similarly, results from short-term leach tests may be useful for estimating leachate concentrations in, for example, waste rock runoff after a storm event but should not be used to predict concentrations of leachate in seeps whose waters derive from slower pathways within the pile. Kinetic tests are designed to estimate longer-term geochemical behavior of mined materials. However, there are a number of issues, mostly related to particle size and length of the tests that can cause kinetic tests to be poor predictors of long-term water quality. These issues require that kinetic testing start as early as possible in the development of a proposed mine, and that the results be reported in terms of available surface area of minerals that control acid generation, acid neutralization, and contaminant leaching. Involvement of a person with in-depth understanding and experience in mine waste characterization approaches and interpretation will help prevent misinterpretation of characterization test results and result in a well-designed and applied waste characterization program.

At mine sites, much of the modeling performed is “forward” modeling, or modeling of conditions that do not yet exist. In the case of pit lakes, steady-state water quality and quantity conditions may not exist for hundreds of years, yet predictions about the quality of pit water are often requested for regulatory purposes. The difficulty in checking modeling results against actual water quality results in large uncertainties in the accuracy of predictive water quality modeling. Most of the other uncertainties in predictive modeling at mine sites relate to values used as inputs to the models rather than to the validity of the model itself. The model or models chosen to predict water quality should be representative of the site (as reflected in the site conceptual model) and be applied at a level of complexity that is appropriate for the available data and the regulatory decisions that must be made. In many cases, available data may limit the model application, and it may be more appropriate to develop a less-complex, screening-level model when data are not available to support a more complex model. For mines that are already developed, field sampling will provide the best measure of water quality. Site-specific values used as inputs to models must be as accurate of the range of conditions at a mine site as possible and should consider seasonal and other types of temporal variability.

The inherent uncertainty in model predictions is rarely stated or recognized. Methods used to evaluate or account for model uncertainty include Monte Carlo analysis, other stochastic methods, and evaluating a range of model input values to develop a range of outcomes (e.g., a range of water quality in a given receptor). These methods account for the fact that, rather than being well described by a single value as required in the model, parameters are better described with a probability distribution. However, uncertainty evaluation of parameter input will not address inaccuracies in conceptual models. Presenting potential contaminant concentrations at receptors as ranges rather than absolute values will better reflect the uncertainty inherent in predictive modeling.

Hydrologic and geochemical codes still solve the same basic equations and reactions that were identified 80 or more years ago. Some of the most notable improvements in both hydrologic and geochemical codes are the operating systems and the graphic interfaces, which allow more user-friendly operation of the codes and better visual output of the modeling results. Individual codes have slight advantages and disadvantages, depending on the application, but the experience of the modeler, the choice of input parameters and data, and the interpretation of the modeling output are more important than the choice of the code itself. The ability of today’s codes and advanced computers to predict an outcome far exceeds the ability of hydrogeologists and geochemists to represent the physical and chemical properties of the site. The degree of confidence in the models is severely limited in part because the models are so complex that they cannot be easily reviewed by regulatory staff and the public. Water quality predictions should always be re-evaluated over time at mines sites and compared to site-specific water quality information as it becomes available. The efficacy of the mitigation measures should also be tested using predictive models and later confirmed with active monitoring. For this analysis, possible ranges in effectiveness of the mitigation measures (e.g., ranges in permeability values of liners) should be used in predictive models.

Predictive modeling of water quality at mine sites is an evolving science with inherent uncertainties. However, using the approaches described in this report, predictive water quality modeling and site characterization information can be reliably used to design protective mitigation measures and to estimate the costs of future remediation of hardrock mine sites.

1.0 INTRODUCTION

The art of predicting future water quality at hardrock mine sites has been practiced for at least the past 30 years. As part of the National Environmental Policy Act (NEPA), mines and other industrial facilities in the United States on federal land are required to estimate impacts to the environment, including direct impacts to water quality and indirect impacts that are later in time but still reasonably foreseeable (Kempton and Atkins, 2000; Bolen, 2002). Facilities on private land in the United States are often subject to State processes that may or may not require prediction of potential impacts to water resources. Other countries have followed a similar approach, largely based on the Environmental Impact Statement or Assessment of NEPA. A wide array of approaches has been used to predict water quality that could result from construction, proposed expansion, or other action at an industrial facility.

In this study, we review the methods and models used to predict water quality at hardrock mine sites, with an emphasis on the state of the art and on advantages and limitations of these techniques. Because water quantity and quality are interrelated, methods and models used to predict water quantity will also be discussed, but the emphasis will be on how these methods relate to water quality. This study brings together technical information on water-quality predictions at mine sites in a single report, and attempts to present a straight forward approach to using and evaluating the results of the methods and models used to predict water quality at mine sites. Approaches developed primarily in the United States, Canada, and Australia and applied in these countries and in other parts of the world, especially in the last 10 years, are discussed, and the format of the study is geared toward use by regulators of hardrock mines. The approach and results of this study could also be used by environmental managers at mine sites and community groups, and allows for the creation of a checklist for prediction methodology used at mine sites. Recommendations are made for improvements in water quality prediction methods and models.

2.0 THE NATURE OF PREDICTIONS

Although future predictions are often part of the business of science, most notably in the fields of meteorology and more recently climate change, scientists are generally uncomfortable with forward (future) predictions (Sarewitz, 1996). Forward predictions cannot be checked for accuracy until the future comes to pass. In the mining industry, the most common example of forward modeling is the prediction of pit lake water quality over time. Predictions of pit lake water quality and water-quality predictions in general have been acknowledged as having large uncertainties (Kempton, 2002), yet results from these predictions often form the basis of permit granting to the mining industry.

The principal use of modeling, according to Oreskes et al. (1994), should be to understand discrepancies between observed data and simulated results, test hypotheses, conduct sensitivity analyses, and explore "what-if" scenarios. If detailed site-specific information is available, an adequate conceptual model of the mine site, for example, can be developed to simulate current conditions or conditions in the recent past. If this is successful, an increased level of confidence can be placed in the use of this model to assess future site conditions (Mayer et al., 2003). However, because natural systems are never closed systems, because inputs to hydrologic and geochemical models are incompletely or only approximately known, and because of scaling problems in natural systems, models used to simulate natural processes cannot be verified (Oreskes et al., 1994).

The length of time over which a mine site will deviate from baseline or pre-mining conditions can be on the order of centuries to tens of thousands of years, as a result of potential delays in the generation or appearance of acid drainage (e.g., Morin et al., 1995; Kempton and Atkins, 2000*)* and the long "half-life" of releases from mining wastes. Therefore, the "future" at hardrock mine sites approximates the period of interest for nuclear waste disposal rather than that for more conventional industrial facilities. In addition, changes in the mine plan after permitting can add uncertainty to the predictions made early in the mining process. Inherent uncertainties, lag times, and the duration of contamination have led some practitioners of modeling at mine sites to emphasize ranges rather than precise values for water-quality predictions. At least three Environmental Impact Statements for mines in Nevada (Battle Mountain Phoenix Project, 2001; Round Mountain, 1996; Twin Creeks, 1996) contain general statements about uncertainty, such as, "…there is considerable uncertainty associated with long-term predictions of potential impacts to groundwater quality from infiltration through waste rock...for these reasons, predictions should be viewed as indicators of long-term trends rather than absolute values." While these statements are certainly true, modeling and predictions do have value as management tools and for helping to understand the biological and physicochemical systems at mine sites (Oreskes, 2000). In addition, water-quality predictions are used to make decisions about mitigation approaches at a mine site, and realistic predictions will ensure that the appropriate type of mitigation is chosen.

An optimistic approach to modeling would consider that our understanding of hydrochemical systems and the problem of relating models at different scales (from the atomic to the watershed level) will continue to advance by implementation of field and laboratory experiments that carefully extract one variable at a time to isolate and compare with the coupled numerical models available today, and by conducting post-audits of predictions. The level of complexity chosen for the model must reflect the scale at which the problem is addressed (White and Brantley, 1995), the availability of information, and the level of detail and accuracy/precision that is required (Banwart et al., 2002). In general, for problems of larger scale (e.g., predicting groundwater flow under a 20-km^2 area at a mine site) and with less available information, a less complex the model should be employed.

3.0 PREVIOUS AND ONGOING INVESTIGATIONS

A number of other studies have reviewed and evaluated methods and models used to predict water quality at hardrock mine sites, and a number of studies are currently under way to review prediction methodologies. For example, INAP (International Network for Acid Prevention) and ADTI (Acid Drainage Technology Initiative) an industry-based organization consortium is in the process of developing a World Wide ARD Guide (WWG) that will capture and summarize the best science and a risk-based approach to acid-drainage management. The first scoping meeting for the WWG was held in December, 2004.

ICMM (International Council on Mining and Metals), in partnership with the UK's Department for International Development, the United Nations Conference on Trade and Development, and the United Nations Environment Programme (UNEP), launched an online library of good practice in mining and metals (www.goodpractice-mining.org) in August 2004. The library contains references for guidelines, standards, case studies, legislations, and other related areas.

Other major players in prediction of water quality at hardrock mine sites are MEND (Mine Environmental Neutral Drainage), a program funded by Canadian federal and provincial governments and the mining industry that ended in 1997; InfoMine/EnviroMine, sponsored by Robertson GeoConsultants, Inc. of Canada, with a website (http://technology.infomine.com/enviromine/) devoted to the identification and dissemination of mining environmental technology; ACMER (Australian Centre for Minerals Extension and Research), an industry initiative to address environmental issues relevant to the minerals industry with a focus on sustainable development; the British Columbia Ministry of Employment and Investment, Energy and Minerals Division (BC Ministry) in Canada; the U.S. Environmental Protection Agency; the Minnesota Division of Natural Resources; and the U.S. Geological Survey.

Although the laboratory and field tests and hydrogeochemical models used for prediction are continually undergoing modifications, the basic characterization and modeling approaches remain relatively unchanged over the past 20 years. As reviewed in later sections of this study, the effectiveness of these methods and models has been questioned by a number of workers, and the advantages and disadvantages of using these approaches have also been discussed at length. Among the previous studies of methods and models used to predict water quality at mine sites, MEND and Infomine have conducted the most thorough reviews, and the BC Ministry, the U.S. Environmental Protection Agency, and the Ian Wark Institute in Australia have also conducted reviews. White, Lapakko and Cox (1999) wrote a thorough review of geochemical characterization methods and the issues affecting their validity.

Acid drainage is considered to be one of the most important and long-lasting environmental concerns at hardrock and coal mines. However, the emphasis on acid drainage prediction has eclipsed concern over neutral and basic mine drainage, which can nonetheless contain elevated and potentially injurious concentrations of metals, metalloids, anions, and other contaminants (Scharer et al., 2000a). For example, elements that form oxyanions in natural waters, such as arsenic, antimony, and vanadium, often have elevated concentrations at higher pH values such as those typical of cyanide heap leach facilities (Miller et al., 1999). Heap leach pads and tailings impoundments are examples of mined materials that may produce neutral or basic drainage with potentially elevated concentrations of contaminants.

This study synthesizes existing reviews and other relevant information in one document that can serve as a stand-alone review and provide a gateway to both broader and more in-depth information on the subject of water-quality predictions in hardrock mining.
Methods and models used to predict acid drainage are addressed, but the study takes a more general and simplified approach that allows for the evaluation of any type of contaminant release from mined materials. This study also emphasizes the advantages and limitations of the characterization methods and models used to predict water quality at mine sites, rather than providing an exhaustive review of these techniques themselves. However, an extensive bibliography is provided for readers who would like more detailed information on the specifics of characterization methods and models.

4.0 STUDY APPROACH

The study approach included reviewing available literature on methods and models used to predict water quality at hard rock mine sites; developing a "toolbox" approach for discussing and evaluating these methods and models; and using information from the literature review and toolboxes to evaluate uncertainties associated with methods and models used to predict water quality at hardrock mine sites.

4.1 Bibliography

A review of the available literature was conducted as a first step in the study. Much of the information available on water-quality predictions at hardrock mine sites is contained in the "gray" literature, that is, in conference proceedings, agency handbooks or manuals, and short course summaries rather than more extensively peer-reviewed papers in journals and books. Bibliographic database searches were conducted using GeoRef, AltaVista, WorldCat, IMMAGE, Proceedings First, Google, Biosis, and Yahoo using the following keywords: prediction, characterization, acid mine/rock drainage, modeling, geochemistry, alkaline drainage, alkaline mine drainage, pit lake, pit lakes model, pit lakes modeling, pit lake water quality, and pit lake characterization. Personal files of the authors and other associates were also searched for documents relating to water quality prediction at hardrock mine sites. The documents were reviewed and categorized according to the characterization method or model that they discuss. An Excel file containing the references and information about their content is available electronically at www.kuipersassoc.com as part of this study.

4.2 Toolbox Approach

The current study uses a "toolbox" approach for reviewing and evaluating methods and models used to predict water quality at mine sites. A similar approach was taken by Plumlee and Logsdon (1999) in the much broader context of methods for conducting "environmentally-friendly" mineral development. Two toolboxes cover the gamut of methods and models of interest for this study: geochemical characterization and modeling. The geochemical characterization toolbox contains field and laboratory methods and tests used to evaluate or predict water quality. The geochemical characterization methods rely heavily on methods used for geologic and mineralogical characterization of rocks and sediments and geochemical characterization of weathering and dissolution of geologic materials. The results from the geochemical characterization methods are in some cases used in models and in other cases are used on their own to evaluate the potential of mined materials to release contaminants. The modeling toolbox contains separate hydrologic and geochemical models as well as mass balance or fate and transport models that combine hydrologic and geochemical information and models. Information from the literature was used to identify advantages and limitations of the characterization methods and models in the toolboxes, and to discuss sources of uncertainty and recommendations for improvements for both the characterization methods and the hydrogeologic models used to predict water quality at hardrock mine sites.

5.0 MINE SITE CONCEPTUALIZATION

Creation of a conceptual model is a necessary first step in the process of successfully predicting water quality at a mine site (Mayer et al., 2002, p. 290). Errors in modeling and especially in long-term predictions often derive from errors in conceptualization (Bredehoeft, 2005). A conceptual model is a qualitative description of the hydrology and chemistry of the site and their effects on mined and natural materials. It includes baseline conditions, sources (mining-related and natural), pathways, biological and physicochemical processes, mitigation measures, and receptors. Information about sources and mitigation measures will generally come from the mine plan. A generalized mine site that illustrates the elements of a conceptual model is depicted in Figure 1.

Baseline conditions at a mine site may include existing contamination from historic or pre-existing mining or other human activities, as well as natural mineralization and naturally elevated concentrations of constituents in water, soil, rocks, and plants. Baseline conditions also include examining the effects of seasonal and temporal variability and storm events on pre-project water quality and quantity.

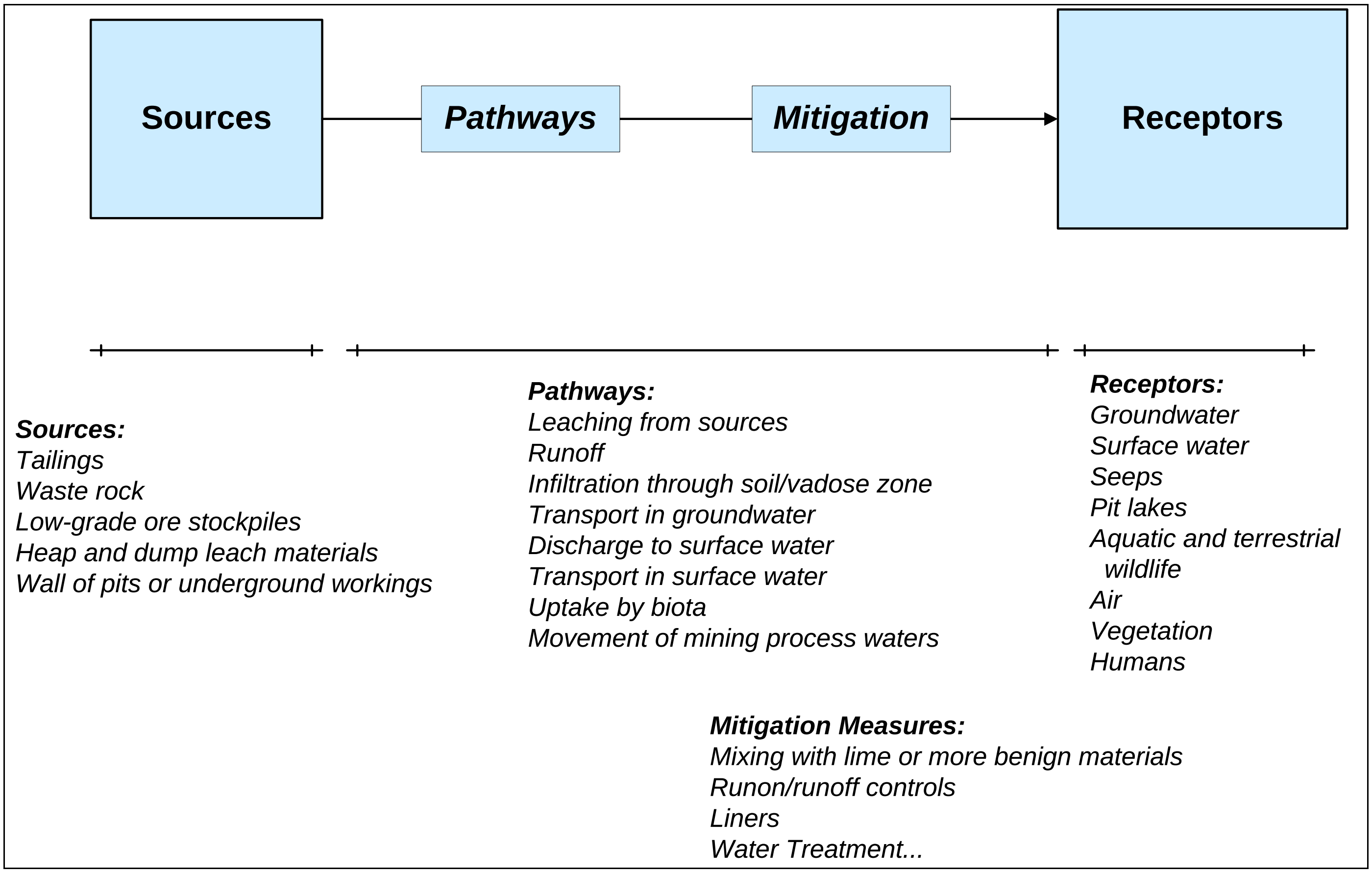

Figure 1. Generalized conceptual model of sources, pathways, mitigations, and receptors at a mine site.

The most common sources of contamination at hardrock mine sites are tailings, waste rock, low-grade ore stockpiles, heap leach piles, dump leach piles, and the walls of open pits and underground workings. A number of these sources are depicted in Figure 2. These sources can leach constituents found in them before they are mined, such as metals and sulfate, and can also leach constituents added by the mining process, such as cyanide in precious metals operations, flotation reagents in tailings, and nitrate from blasting. The mine plan should be used to identify the nature, location, and extent of contamination sources at the mine. Natural sources of metals and other mine-related constituents may also exist and should be identified. In addition to acid-generation potential, sources should be examined for the potential to leach metals and any other constituents of concern identified in the source materials. The location and size/volume of the sources need to be estimated for the conceptual model, and much of this information will be available in the mine plan.

Pathways are physical or biological conduits through which or by which constituents released from mining-related sources can move. Typical pathways at mine sites include transport through air, leaching, infiltration through the soil/vadose zone, movement through alluvial aquifers and fractures in bedrock, transport in groundwater, discharge to surface water, transport in surface water and sediment, and uptake and transfer via biological pathways.

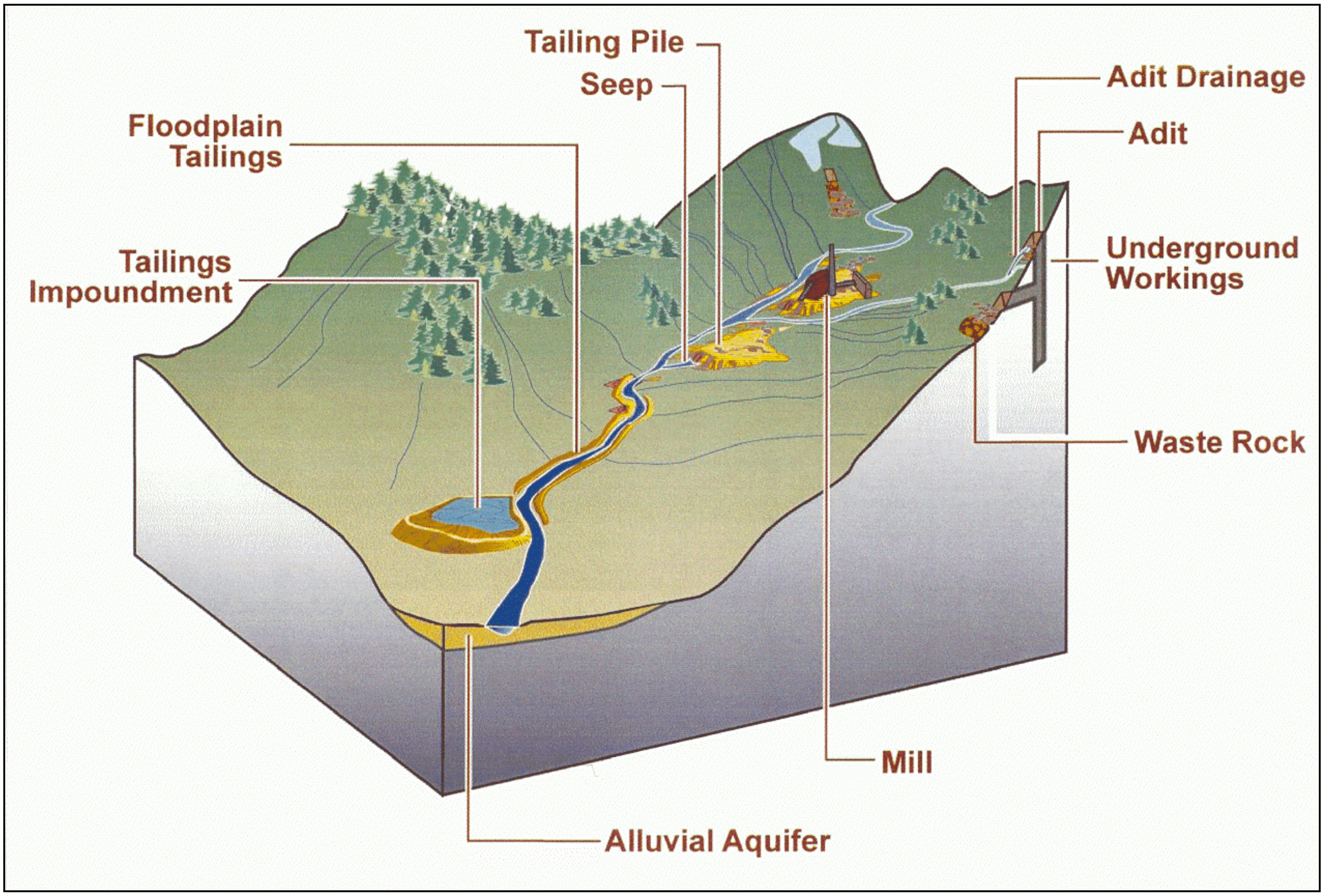

Figure 2. Some typical sources of contamination at hardrock mine sites.

For example, Figure 3 depicts the movement of contaminants from tailings along pathways to a stream. The same pathways would apply to movement of contaminants from a waste rock dump or a heap or dump leach facility. Contaminants from the tailings pile are leached by precipitation, transported along the surface of the tailings pile and the ground in runoff, and transported through the pile and the vadose zone as infiltration to groundwater. Contaminants can also adsorb to material in the vadose zone. Once in groundwater, contaminants can adsorb to aquifer materials and move through groundwater to surface water. Once in surface water, the contaminant can be adsorbed onto stream sediment, dissolved in the water column, resuspended during storms and high-water events, and/or consumed by macroinvertebrates, and then eaten by fish. Another way that constituents can move at mine sites is through the transfer of waters around the site as part of the mining process. For example, groundwater can be pumped to prevent groundwater inflow and allow mining of an open pit, and the water can be used in the mill, discharged to surface water, returned to groundwater via infiltration basins or reinjection wells, or sent to a treatment facility – depending on its quality and the needs of the mining operation. All potential natural pathways and transfer of waters during mining must be known to construct a suitable conceptual model.

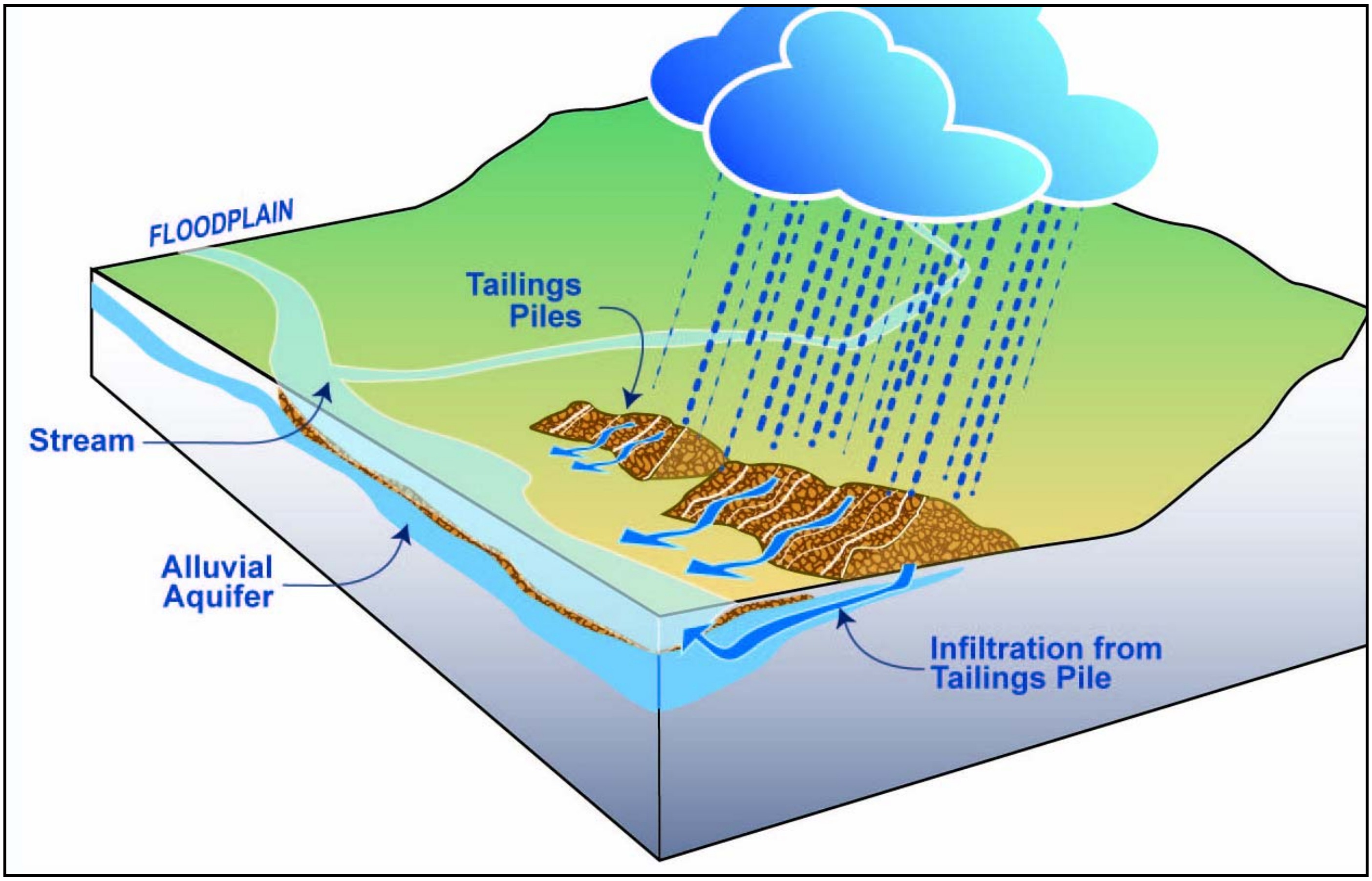

Figure 3. Transport pathways for contaminants in a hypothetical tailings pile.

In the pathways, biological and physicochemical processes control the movement and composition of constituents released from mining sources. Biological and physicochemical processes include: precipitation, evaporation, runoff, infiltration, gas advection (e.g., flow of air into a waste rock pile), erosion, advection/dispersion in groundwater and surface water, geochemical reactions (e.g., dissolution, precipitation, redox reactions, adsorption, acid/base reactions), and reactions involving biota (e.g., uptake of metals and redox transformations). It is these processes that are often the subject of hydrogeochemical modeling predictions at mine sites.

Mitigation measures are used to reduce the likelihood that contaminants will adversely affect receptors. Mitigation and remediation measures can be similar, but mitigation generally refers to up-front measures employed from the start of mining of the site or a unit, while remediation generally refers to measures used after mining of the site or a mining unit occurs. The mine plan should be used to identify the types of mitigations that will be used and which mine units (or mine facilities, such as waste rock dumps, tailings disposal facilities, heap leach facilities) and waters will be affected by the mitigations. Mitigation measures can include: mixing of mined materials with lime or more benign soils/rocks to decrease the acid generation and metal leaching potential, runon/runoff controls, installation of liners, treatment of contaminated waters, and backfilling pits to prevent formation of lakes with poor water quality. Although mitigation measures are not often considered explicitly in prediction models, they can have a profound effect on the concentrations that actually reach receptors. In addition, natural mitigating effects can improve water quality at receptors. Such effects include natural attenuation in soils, the vadose zone, and aquifers; dilution in groundwater and surface water; and biological transformation of substances to more benign forms. Natural processes can also diminish water quality from mine-related discharges at receptors. For example, evaporation can concentrate metals and other ions, and biological transformations can create more toxic species.

Potential receptors include groundwater, surface water (springs, lakes, streams, marine waters), vegetation, air, aquatic biota (e.g., macroinvertebrates, fish), terrestrial wildlife (e.g., birds, mammals), and humans. The location and degree of sensitivity to mine releases must be known for each receptor for development of the conceptual model.

A mine is an ever-evolving entity, and the conceptualization of the mine site must, of necessity, change as the mine evolves. Changes in the mine plan can appreciably affect uncertainty about future water quality, and NEPA, for example, requires that if there is a significant change in the mine plan or operations, a supplemental EIS must be performed. Short of a significant change, however, the accumulation of many small changes in the mine plan can make it difficult to accurately predict water quality. Therefore, predictions themselves must be continually updated as new environmental information from the mine site becomes available.

6.0 GEOCHEMICAL CHARACTERIZATION TOOLBOX

For the purposes of this study, which focuses on prediction of water quality at hardrock mine sites, characterization is defined as field and/or laboratory tests or measurements that help define the biological and physicochemical environment that will be or has been mined and the potential for water quality impacts. A characterization program includes scientific and engineering studies that describe the physical, chemical, and biological characteristics of the site, its rocks and minerals, and its fluids. The program will allow one to describe (a) the nature and extent of potential physical and chemical impacts to ground and surface water, and (b) the engineering or institutional steps to control the potential water-quality impacts. The program put forward to achieve these objectives is called "characterization." The opportunities for characterization (geochemical and hydrogeologic) during different phases of mining are discussed.

A characterization toolbox was assembled that contains methods and approaches used by mine operators currently or in the past. The characterization toolbox mainly focuses on geochemical characterization. The types of hydrogeologic information used as inputs to models are covered under section 6.1 and in the modeling toolbox section (sections 7.1.1, 7.1.2, 7.3, 7.4.2, Table 3, and Table 5). Each geochemical characterization method is briefly described, its advantages and disadvantages are discussed, and the uses of the test for water quality prediction are presented. The major sources of uncertainty associated with the use of geochemical characterization tools and recommendations for improvement are also discussed. Finally, a state-of-the-art approach to geochemical characterization of mined materials is presented.

6.1 Characterization during Different Phases of Mining

The amount of information available and therefore the ability to successfully characterize a mine site in terms of its potential to degrade water resources is directly related to the phase of mine development. During the earliest exploration stages, relatively little site-specific information is available. In contrast, during the post-closure phase potential water quality impacts are better known and the mine site can be characterized with a higher degree of certainty. Characterization cuts across all facilities/sources, pathways, and receptors, but different methods are needed to characterize each.

The extent of a geochemical characterization program should be dictated by site conditions and the nature of the deposit, with complex geology and mineralogy requiring a greater sampling and characterization effort. For example, a complex mixed oxide/sulfide ore body might require a highly rigorous program, while a deposit with distinct oxide/sulfide zoning might require a less rigorous program. Important features of an effective program include adequate sampling to ensure representation of the source materials, sampling of distinct geology or mineralogy types when they are encountered, and a level of environmental characterization that is commensurate with the level of ore characterization. In general, the amount and type of data should also be commensurate with the phase of development, with more detailed evaluations taking place with more advanced phases of the regulatory and economic decision-making processes. The characterization program should be both reactive and proactive so that results are received and evaluated in a timely fashion and the mine plan can change in response to any unexpected findings.

This section describes the site conditions and types of geochemical and hydrogeologic characterization that can occur during different phases of mining, including the exploration, development, active mining, closure/reclamation, and post-closure.

6.1.1 Exploration

The prospecting and exploration stages of mining involve long periods of investment with a high risk of failure (SME, 1992). The primary objective of exploration is to find an economic mineral deposit (NRC, 1999). There are three generally recognized stages of exploration: (1) prospecting, which involves the search for directly observable natural features associated with ore mineralization, or geologic and literature research in geologically favorable areas; (2) detailed surface reconnaissance, which includes geologic mapping, geochemical and/or geophysical coverage and use of other special techniques; and (3) surface drilling and/or underground exploration via adits or shafts (SME, 1992). The exploration phase can last for a few years to more than 10 years.

Geologic and mineralogic information collected from drilling or underground exploration programs is combined with information from geological mapping, and geophysical, stratigraphic, and other studies to delineate the geologic and mineralogic nature of the ore deposit. Borehole data will typically include depth to water, which can be the first step toward a preliminary understanding of the mine-site hydrologic characteristics. As shown in Figure 4, the ore reserve and the location and amounts of associated waste and low-grade ore can be estimated, often by using a geologic model.

The recommended characterization methods to be employed during the exploration phase are:

- Whole rock analysis
- Mineralogy
- Drill core descriptions (petrology and mineralogy)
- Block model or similar model (a computerized estimate of the quantity and characteristics of ore and waste)
- Available literature on the ore deposit
- Mineral occurrences (e.g., on fracture surfaces, in groundmass, using hand specimens and thin section) with an emphasis on sulfides and carbonates
- Acid-base accounting
- Startup of long-term kinetic testing; possible startup of test pads if sufficient material and access to site are available
- Baseline surface and ground water quality and flows (including springs)
- Potentiometric surface for groundwater
- Hydraulic properties (e.g., hydraulic conductivity, porosity, permeability) of soil, vadose zone, and groundwater aquifers, especially under proposed locations of mine facilities
- Examination of characteristics of similar mines in region/area
- Hydrogeochemical models for prediction of water quality.

This information can allow for a gross characterization of potential environmental conditions, including the extent of oxide, mixed oxide/sulfide, and sulfide ore; net acid generation potential (net AGP); and contaminants of concern. However, because long-term characterization has not been conducted, estimates of water quality impact potential made during this stage should be viewed as preliminary and highly uncertain.

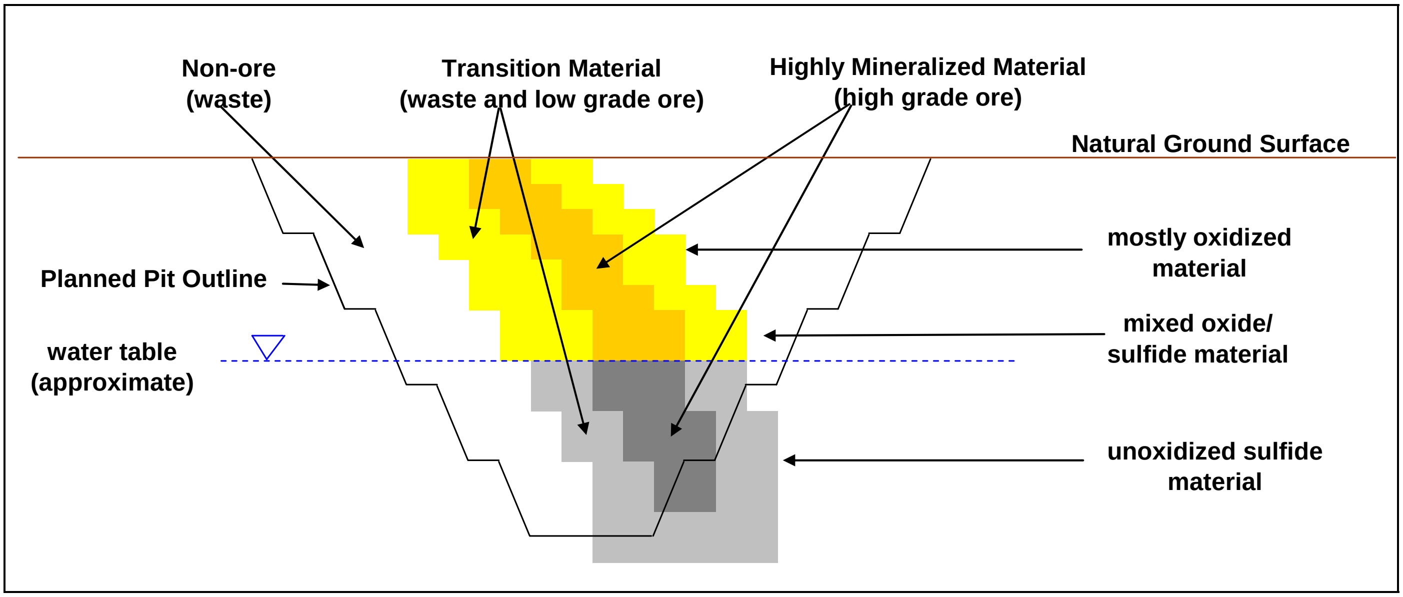

Figure 4. Site conditions and characterization opportunities during the exploration phase of mining.

6.1.2 Development

The development stage of mining projects is intended to take the resource identified by exploration efforts and to determine by what means (e.g., open pit versus underground mining) and at what revenue stream (return on investment) the ore deposit might actually be mined and processed. Before development proceeds, the deposit must be judged to be economic, and the required permits must be obtained. During mine development, infrastructure (power, roads, water, etc.) is put in place, and physical facilities are built, including the mineral processing facility. During the development phase, overburden and waste in open-pit mines are removed and placed in surface waste dumps. For underground mines, the deposits are developed by gaining access to the mineralization through shafts or adits (NRC, 1999).

During the development phase, the following types of characterization should be conducted:

- Continued sampling of geology and mineralogy of ore and waste
- Continued acid-base accounting and kinetic testing of mined materials; startup of field test plots, if waste will be stored at surface. (Note: the design of the test plots must correspond to the conceptual model for how the waste would ultimately be stored.)
- Continued testing of hydraulic properties of soils, vadose zone, and aquifers
- Tailings bench scale testing
- Creation of a mine waste management plan
- Study of changes in groundwater potentiometric surface from dewatering or other mining-related stresses
- More detailed hydrogeochemical models for prediction of water quality.

Figure 5 depicts the site conditions during development and active mining of the deposit. As depicted, due to dilution and inexact characterization methods, some mineralized ore typically reports with the waste material, and some sulfide ore can report to processes typically intended for oxide ores. These errors, which typically originate during the development phase, can result in water quality impacts during later phases of mining.

6.1.3 Active Mining

The active mining phase includes extraction of the in-place mineralized material and associated waste rock by drilling, blasting, mucking (loading), and transporting (hauling). During the active mining phase, the ore is processed, typically by crushing and grinding of the ore and subjecting the ore to various physical or chemical processes to separate and concentrate the valuable minerals from the waste in the ore. Wastes include waste rock, spent leach pad material from heap leach and dump operations (at gold and low-grade base metal mines), and tailings from flotation and vat leach operations (at certain gold and higher grade base metal operations). Heap leach and dump operations also involve the creation of barren and pregnant (containing the valuable metal) solution ponds or conveyances. The potential impacts resulting from release or discharge of tailings, leached rock, or pregnant leach solutions can be substantial (NRC, 1999).

As the mine matures, the amount and degree of useful characterization information increases substantially, allowing for either confidence in the original source characterizations and water-quality predictions, or the realization that errors in previous characterization and prediction work may require changes in the site conceptual model and potentially the mine plan itself. It is almost always more efficient and less expensive to adapt to changes in characterization information by modifying the project than to ignore the information received during the operations phase of mining. The segregation of ore and waste depicted in Figure 5 is realized during the mining operations stage.

During the active mining phase, the following types of characterization are recommended:

- Continued geochemical characterization of mined materials (field test plots and laboratory tests)
- Continued predictive and laboratory verification of the mine waste management plan (e.g., validity of using <0.2% sulfur as cutoff for non acid-generating wastes)
- Collection and sampling of leachate from waste rock, tailings, and other facilities
- Sampling of water quality in streams and groundwater upstream/gradient and downstream/gradient of mine facilities

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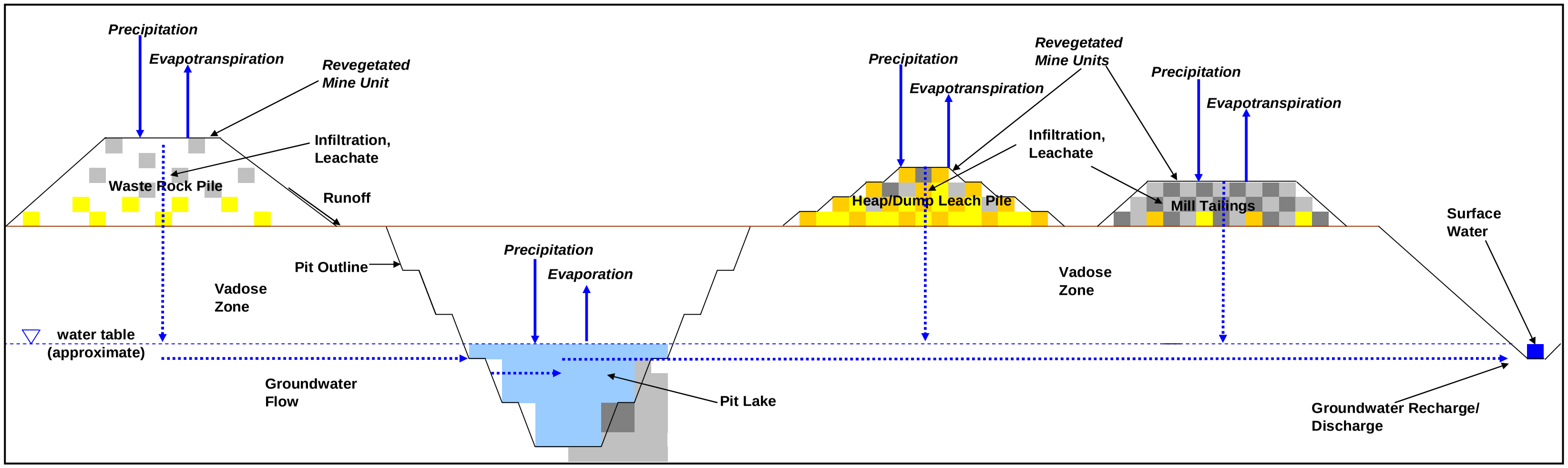

Figure 5. Site conditions and characterization opportunities during development and extraction phases of mining.

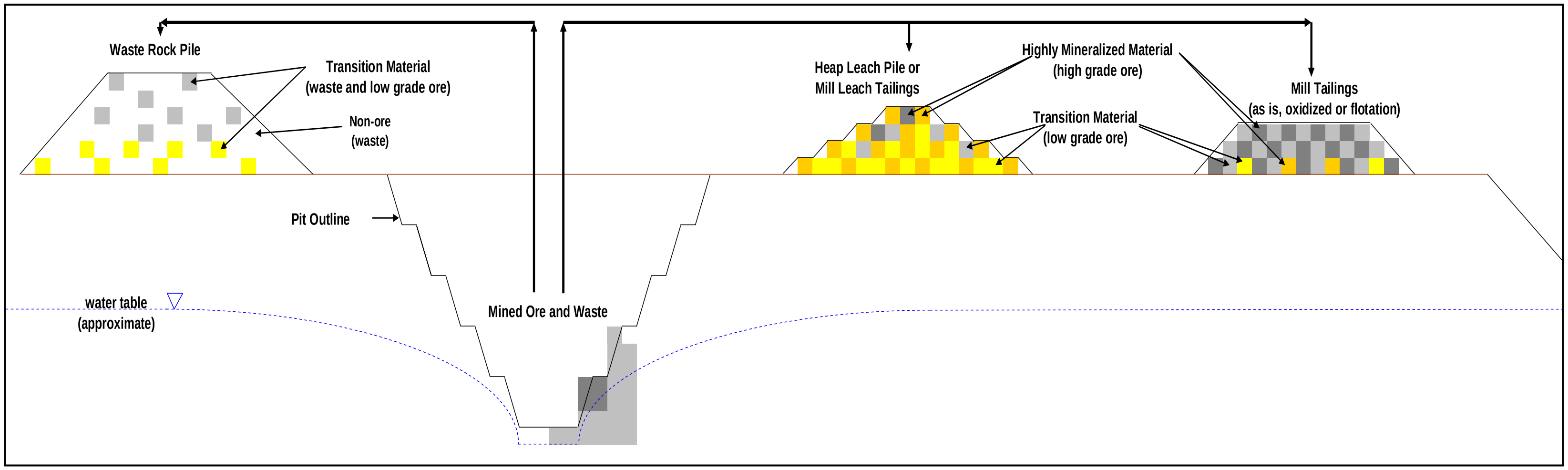

Figure 6. Site conditions and pathways for potential contaminant transport during the closure/post-closure phases of mining. Refer to Figure 5 for definition of shaded areas in waste units and pit areas.

- Testing of hydraulic properties of mined materials (e.g., waste rock, heap leach material, tailings)
- Continued observation of changes in groundwater potentiometric surface resulting from mining-related stresses
- Comparison of predicted (from characterization and modeling efforts) and actual water quality
- Routine evaluation of the results of ongoing characterization for significance to monitoring programs, operational controls, mine planning, and closure planning.

6.1.4 Reclamation, Closure, and Post-Closure

Additional maturation of water quality emanating from the various sources is likely to occur during the closure and post-closure periods. These changes may take place over a period of as little as two years to as many as thousands of years, depending on the nature of the wastes (especially rates of weathering of acid-producing and neutralizing components in mined materials) and the proximity to water resources. At mines in Nevada, for example, that have deep unsaturated zones and great depths to groundwater, acid and sulfate from oxidizing sulfides in waste rock dumps can take tens of thousands of years to reach groundwater resources (Kempton and Atkins, 2000), and pit lakes can take 100 to 300 years to reach hydraulic steady state for large open-pit mines (Bolen, 2002). Figure 6 depicts the site conditions, including potential pathways for transport of contaminants from sources to water resources, during the closure/post-closure period.

Where reactions are occurring and water quality has already been impacted during or shortly after mining, empirical evidence may serve as a good predictor of future water quality. However, in cases where maturation has not occurred, or similarly where leachate has not yet reached water resources, existing data may not adequately predict future impacts even though mine operations may have ceased. In these cases, forward models using existing water quality and mineralogic information can be used to predict potential future water quality years after mining has ceased. Reclamation and closure planning must take into account both existing and future conditions in order to be effective at restoring post-mining utility to the land and at protecting future water quality.

During the closure, reclamation, and post-closure phases of mining, the following characterization methods should be employed:

- Comparison of predicted and actual water quality
- Continued sampling of quality and quantity of water resources, including springs, leachate, surface water, and groundwater at points of compliance and other locations
- Measurement of rate of change in groundwater levels over time after groundwater pumping has ceased
- Monitoring of effectiveness of mitigation measures and comparison to predicted performance.

6.2 Geochemical Characterization Methods Used in Water-Quality Predictions

Table 1 presents a description of geochemical characterization methods used in the prediction of water quality at hardrock mine sites. Included in the table are method descriptions, method references, how the characterization tool is used in water-quality predictions, and the advantages and limitations of the method. The geochemical characterization tools described include geology, whole rock analysis, paste pH, mineralogy, sulfur analysis, static testing (Sobek and modified Sobek methods, and other modifications of neutralizing potential methods, net acid generating test (NAG), and net carbonate value test (NCV)), total inorganic carbon, short-term leach tests, sequential extraction, and modified shake extraction), kinetic tests (humidity cell and column), and field testing of mined materials. A description of the sources of uncertainty associated with their use and recommendations for improvement are contained in the following sections.

A brief overview of each general type of characterization tool is contained in this section, and details are provided in Table 1. Geologic methods are used to identify rock type, mineral occurrences, and alteration types of samples and include geologic mapping, sample logging, petrographic and mineralogic analysis, ore assay, creating a three-

Table 1. Description of Geochemical Characterization Methods used to Estimate Water Quality at Hardrock Mine Sites.

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Geology and geophysics	Geologic mapping, sample logging, petrographic and mineralogic analysis; ore assay; 3D block model of ore body and wastes; structural, fracture density and orientation, and rock competency information; geomorphology; geophysics	See mineralogy; AVIRIS; various.	Downing and Giroux, 2004; SME, 1992; Plumlee, 1999; Lapakko, 2002; Diehl et al., 2004.	Information on rock type, mineralogy, and alteration type used to evaluate acid generation and neutralization capacity of site. Information on structure and fractures used to estimate porosity in competent bedrock. Geomorphology used for effects of landforms on hydrology and geochemistry. AVIRIS used for remote spectral imaging of minerals.	Provides information on ore reserves and potential pathways for transport of contaminants in subsurface.	Representativeness of samples; difficulty in defining structural and fracture information.
Whole rock analysis	Whole rock analysis	Grind sample to ~200 mesh (~50 µm) or finer and digest with aqua regia, HNO_3/perchloric/HF (or make $LiBO_2$ (lithium metaborate) bead by mixing sample with $LiBO_2$ in Pt crucible, heat to 1000°C, dissolve in HNO_3/HF); analyze by ICP-AES, ICP-MS (for trace metals), AAS, neutron activation analysis (NAA), or XRF (for semi-quantitative analysis) for elements of interest.	Johnson and Maxwell, 1981 (as cited in Tremblay and Hogan, 2000); APHA/AWWA/WEF, 1998; Lapakko, 2002.	Determines total potential load of constituents to environment.	Can identify rock types with higher total levels of contaminants; can be used with CIPW normative calculations (e.g., Lawrence and Sheske, 1997) to determine likely mineralogy of sample.	Volatile elements such as As, Sb, Hg may be lost in HNO_3/perchloric/HF acid digestion (use HCl/K chlorate instead); high S^- may precipitate insoluble sulfates and underestimate concentrations of Be, Pb, etc. (Tremblay and Hogan, 2000).
Paste pH	Paste pH	Mix 20 g air-dried test material with 20 mL DI (for 1:1 ratio methods) for 5 sec, let stand 10 min, measure pH.	Sobek et al., 1978; Lapakko, 2002.	Determines potential effect of acid-forming salts in mine waste over short term.	Quick, inexpensive, easy to perform.	Provides no indication of long-term acidity/neutralizing potential of soils/rocks.

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Mineralogy/microscopy/microprobe/petrology	Optical microscopy; XRD; petrographic analysis (reflected and transmitted light); SEM/EDS; electron microprobe; Sulfide Alteration Index; Rietveld analysis	Optical: hand lens, binocular microscope; XRD: grind to powder, place in X-ray goniometer; Petrography: slice solid rock sample into thin section (30-µm thick), polish, examine with reflection/ transmission petrographic microscope; SEM/EDS: use polished section or filter with suspended material from water sample, coat with carbon or gold, expose to electron beam scan, examine composition using back-scattered electrons (if EDS available). Electron Microprobe: like SEM but optimized for chemical analysis; Sulfide Alteration Index: petrographic analysis of alteration of sulfide grains.	Jambor and Blowes, 1994; Blowes and Jambor, 1990 (Sulfide Alteration Index); Raudsepp and Pani, 2003 (Rietveld analysis).	IDs primary/secondary minerals alternation that could affect neutralization potential (NP) and acid generation potential (AGP); degree of alteration of minerals (e.g., Sulfide Alteration Index); type of sulfide minerals and crystal forms (e.g., framboidal) to help evaluate reactivity of minerals; availability of minerals for weathering reactions (liberation) that can affect AGP and contaminant leaching potential.	Provides information about AGP, NP, and availability of minerals for weathering; corroborates rock type information.	Not easy to understand results if not trained in geology; semi-quantitative at best; small sample size/representative-ness; no database for comparison of results; XRD: no information on grain size or condition, not good for identification of secondary minerals (Tremblay and Hogan, 2000, Shaw and Mills, 2004).
Sulfur analysis (different forms of sulfur)	Total S, pyritic S, sulfide S, organic S, sulfate S	Oxidation of ground sample with acid and measurement of S by spectrophotometer (LECO); removal of non-sulfide minerals to determine sulfide S.	ASTM Method 1915-97 (2000, for total sulfur); ASTM method E-1915-99 (2000, for sulfide S).	Potential of samples to generate acid; used in combination with ABA tests.	Distinguishes between forms of S with more (pyritic S, sulfide S) and less (organic S, sulfate S) acid generation potential.	Does not confirm identity of minerals that contain the sulfur; can overestimate (for jarosite, iron sulfates) or underestimate (for chalcopyrite, galena) sulfide content (Lapakko, 2002).

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Static testing	Acid-base accounting (ABA) methods: Sobek Method	Dry pulverized (-60 mesh) samples at ≤ 60°C): AP: total S (by combustion to SO_2 and measurement by infrared detection); subtract sulfate S (by dissolution in HCl) to obtain AP. NP: add 1:3 HCl (pH endpoint usually between 0.8 and 2.5),rate fizz of sample, heat to near boiling, add water and boil, back-titrate to pH 7.0 with 0.1N NaOH.	Sobek et al., 1978.	To evaluate overall amounts of acid-generating and acid-neutralizing materials in a sample; to identify samples that need kinetic testing.	General for Static testing: Gives operationally defined estimate of total neutralizing and acid generating content of samples; well-established technique; relatively fast and inexpensive technique; less labor-intensive than identifying complete mineralogy.	General for Static testing: Provides no information on relative rates, availability, texture, or identity of AG and NP minerals; assumes NP and AG minerals are completely available for weathering; can over- or under-estimate AGP and overestimate NP (see below); testing can be time-consuming. For Sobek Method: Can overestimate AGP (use of Total S); can overestimate NP (boiling, pH endpoint) (Price, 1997; White et al., 1999; Li, 2000; Scharer at al., 2000b).
Static testing	Other ABA and Neutralization Potential Procedures	Lapakko: 1.0N H_2SO_4 to pH 6.0, AP = total S, 4-120 hrs; BC Research Inc. Initial (BCRI): 0.1N H_2SO_4 to pH 3.5, AP = total S, 4+ hrs; BC Research Confirmation (BCRC): 6 or 12N H_2SO_4 to pH 2.5 - 2.8, inoculate with active *T. ferrooxidans* culture, monitor pH (decrease indicates biochemical oxidation of sulfides); Modified Sobek: -200 mesh, uses sulfide rather than total S, 24-hr ambient-T digestion using 0.1-0.5N HCl, with pH 1.5-2.0, for NP, with titration to pH 8.3 rather than 7.0; Sobek - siderite correction: as Sobek, but with H_2O_2.	Mills, 2004b; White et al., 1999.	As above .	Prevents overestimation of NP and AP that can occur using Sobek et al., 1978; confirms presence/absence of bacteria (BCRC).	BC Research Test requires more equipment and takes longer to run than ABA; Variable estimates of NP: NP-Sobek>NP-Modified Sobek>NP-BCRI Initial>NP-Lapakko (Tremblay and Hogan, 2000; Mills, 2004a; White et al., 1999; Plumlee, 1999).

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Static testing	NAG (Net acid-generating)	Add 15% H_2O_2, react until effervescing stops, boil for at least 2 hr (do not let sample dry out), add DI, titrate to pH 4.5 with .1 or .5N NaOH.	Miller et al., 1997.	As above. Widely used in SE Asia and Australia for management and screening tool.	Evaluates net acid-base balance; arrives quickly at estimated net value for AGP; uses simple laboratory equipment and reagents.	Does not distinguish between AP and NP; screening method only; use with caution in carbonaceous rocks (can produce acid in error) or in high-sulfide rocks (elevated temperatures can drop pH) (Tremblay and Hogen, 2000; Stewart et al., 2003b).
Static testing	NCV (Net carbonate value)	Uses combustion-infrared detection for carbon and sulfide analysis. NCV=NP+AGP, where NP=(Total C) - (C after HCl digestion) (=TIC), AGP=(Total S) - (residual S after pyrolysis at 550^o C for 1 hr). XRD, XRF used to confirm NCV results.	Bucknam, 1997. http://www.bucknam.com/ncv.html	As above. Used principally by Newmont.	Procedure can be conducted quickly; includes only carbonate minerals in NP if pyrolysis working as expected; good for screening-level and operational testing tool.	Does not confirm presence of minerals that generate or consume acid; requires sophisticated instrumentation; can overestimate NP when siderite is main carbonate mineral.
Total Inorganic Carbon	TIC	Measure total C by infrared analysis using pulverized sample. Treat split w/ HCl to remove inorganic C and subtract from total for TIC.	Hillebrand et al., 1953.	Measures NP associated with carbonates.	Avoids inclusion of non-carbonate minerals in NP; less expensive than NP.	Only provides carbonate fraction of NP; can overestimate NP when siderite is main carbonate; can only complement total NP results.
Short-term leach tests	SPLP (Synthetic Precipitation Leaching Procedure, Method 1312) and modification by USGS	#1 reagent water to pH 4.2 with 60/40 HNO_3/H_2SO_4; #2 reagent water to pH 5.0 with 60/40 HNO_3/H_2SO_4; 20:1 liquid:solid ratio; 18±2 hours. USGS modification: composite sample of <2-mm fraction; leach 50g in 1L of distilled water, shake for 5 min; settle for 10 min; measure pH and SC; preserve samples for chemical analysis.	US EPA, 1996; http://www.epa.gov/epaoswer/non-hw/industd/guide.htm (for all leach tests); Diehl et al., 2004; Smith et al., 2000.	Measures readily soluble components of mine wastes (all leach tests). SPLP: developed to evaluate metal mobility in an engineered landfill subjected to acid rain. USGS modification used to measure fraction that controls rapid leaching.	Provides indication of extent of leaching of salts and readily dissolvable constituents from dried mine materials (for all short-term leach tests).	Provides no information on long-term leach rates; only simulates short-term interaction with rain/snowmelt; high liquid:solid ratio may underestimate leachability.

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Short-term leach tests	TCLP (Toxicity Characteristic Leaching Procedure, Method 1311)	0.1N acetic acid, pH 2.9, for alkaline wastes; 0.1N sodium acetate buffer solution, pH 5.0 for non-alkaline wastes; 20:1 liquid:solid ratio, 18±2 hours.	US EPA, 1996.	Use to determine if waste is hazardous under RCRA; to evaluate metal mobility in a sanitary landfill.	Applicable standards available.	Use of acetic acid not appropriate for mining applications; only simulates the release of contaminants to groundwater.
Short-term leach tests	MEP (Multiple Extraction Procedure, Method 1320)	Same as EP Toxicity test (see below), but with synthetic acid rain (60/40% H_2SO_4/HNO_3); 20:1 liquid:solid ratio; 9 or more extractions, 24 hr/extraction.	http://www.epa.gov/epaoswer/non-hw/industd/guide.htm	Same as TCLP and SPLP.	Longer procedure than TCLP and SPLP.	Provides no information on long-term leach rates; only simulates short-term interaction with rain/snowmelt; high liquid:solid ratio may underestimate leachability.
Short-term leach tests	MWMP (Meteoric Water Mobility Procedure)	Place 5 kg of <2-in mine rock (crush material >2 in and combine with fraction < 2 in) in 15-cm OD PVC column, apply a volume of reagent-grade water equal to mass of dry solids in column (assume 1 mL/g) to top of column over <48 hr, collect effluent and measure pH, elements of interest (filtered).	Nevada Mining Association, 1996.	Same as for SPLP.	Commonly used in Nevada; uses larger sample size than SPLP and solution more similar to rainwater in western US; higher solid:liquid ratio than SPLP.	Similar to SPLP but weaker (less aggressive) than SPLP (uses only water).
Short-term leach tests	California WET (waste extraction test)	0.2 M sodium citrate (pH 5.0), 10:1 liquid:solid ratio, 2mm maximum particle size, 48 hrs.	http://www.epa.gov/epaoswer/non-hw/industd/guide.htm (for all leach tests).	Same as for TCLP.	Commonly used in California; lower liquid:solid ratio and longer tests time than SPLP and TCLP.	Similar to EP Toxicity test, but sodium citrate makes test more aggressive; sodium citrate not appropriate for mining applications.
Short-term leach tests	EP Toxicity (Extraction Procedure, Method 1310)	0.5N acetic acid, pH 5.0, 16:1 liquid:solid ratio during extraction, 20:1 final dilution, 24 hrs.	US EPA, 1996.	Similar to TCLP.	Applicable standards.	Replaced by TCLP.

Character-ization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Short-term leach tests	BC SWEP (British Columbia Special Waste Extraction Procedure) and Modification	Mix 50 g crushed/ground (<9.5mm) sample and reagent water, measure pH, if >5.2, lower to 5.2 with 0.5N acetic acid, if <5, make no adjustments. Cap bottle and place in tumbling apparatus, check pH after 1, 3, 6, 22 hr; if >5.2, lower to 5.2 with acetic acid. Record amount acid added and final pH. Separate liquid and solid phases, filter, analyze for metals, etc. <u>Modification</u>: use reagent water instead of acetic acid; Cap bottle and agitate in rotary extractor for 1 hr total. (in BC, DI or 0.1N HCl is used as extractant at a 3:1 liquid:solid ratio for 24 hr).	Province of British Columbia, 1992.	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification.	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification. Lower liquid:solid ratio than other short-term leach tests.	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification.
Short-term leach tests	Sequential Extraction	To 1 gm dry sample add $MgCl_2$, shake for 1 hr (salts); to residue add Na-acetate, shake 5 hr (adsorbed); to residue add hydroxylamine HCl in 96°C waterbath for 6 hr (amorphous Fe oxyhydroxides); to residue add ammonium acetate solution in 85°C waterbath for 5 hr (Mn oxides); to residue add HF extract, digest. Analyze extracts from different extractions for constituents of interest.	Tessier et al., 1979; Ribet et al., 1995.	To evaluate associations of constituents of interest, especially metals, with different solid phases (e.g., salts, loosely-bound/adsorbed, iron and manganese oxides/hydroxides, inside mineral lattice); to determine how easily metals can be released to the environment	Understanding associations of metals with different phases of the solid will assist in understanding geochemical conditions under which they may be released to environment	Long procedure, many reagents, mostly research application, no applicable standards/criteria.
Short-term leach tests	Modification of Shake Extraction of Solid Waste with Water	Dilution water is ASTM D1987 water adjusted to pH 5.5 by carbonic acid, use a 4:1 liquid:solid ratio, agitate for 18 hr, decant surface water and analyze for pH, metals, etc.	ASTM, 1992; Mills, 2004d: Metal leaching test procedures.	For extraction of tailings solids.	Can simulate conditions where the solid waste is the dominant factor in determining the pH of the extract; lower liquid:solid ratio than some other leach tests.	Test only approved for certain inorganic constituents, and is not applicable to organic substances and volatile organic compounds (VOCs).

Characterization Tool	Test Names	Method Description	Method Reference	Use in Water-Quality Predictions	Advantages	Limitations
Laboratory kinetic testing	Humidity cell tests (HCT)	Before test analyze sample for ABA, TIC, metal concentrations, size fractions, mineralogy, petrology. For material 100% passing 6.3mm (waste rock), use 10.2 cm ID x 20.3 cm h column, for material passing 150 µm (fine tailings), use 10.2-cm high x 20.3-cm diameter, expose material to 3-day alternating wet (humid air) and dry cycles, then pour water over sample every week and measure pH, SO_4, alkalinity, metals, etc. in leachate. HCT can run for 20 weeks to years. Modification: ASTM, 2003.	Sobek et al., 1978; ASTM, 2003; Mills, 2004c; Lapakko, 2003a.	To estimate longer-term potential of fully oxygenated mined materials to generate/consume acid and produce contaminated leachate; to estimate rates of sulfide oxidation and neutralizing mineral dissolution; to evaluate acid generation lag time; to determine relative reactivities of rocks of a given mineral assemblage as a function of solid-phase compositional variation; to provide rates for modeling.	Standardized test; provides kinetic and steady-state leaching information and information on weathering rates of primary minerals (e.g., sulfides).	Additional size reduction, if used, causes discrepancies between laboratory results and field conditions; not appropriate for saturated mined materials (e.g., submerged tailings); if NP>AP, AG lag time for metal/acid production may be longer than test (Benzaazoua et al., 2001; Mills, 2004e; Nicholson and Rinker, 2000; Lapakko, 2003a and b).
Laboratory kinetic testing	Column tests	Analyze sample before test, as for HCT's set-up options available, including maintaining water over sample, alternating flooding and draining, and recirculating leachate to top of column. Sub-aerial columns = "trickle leaching." Column typically 76-, 152-mm diameter x 1- to 3-m high; generally DI water used as leachate; commonly run on material <~25 mm; test length variable.	Tremblay and Hogan, 2000; Lawrence and Day, 1997.	As above, but can simulate leaching conditions in variably saturated or oxygen-deprived conditions; to simulate effects of mixing mined material with lime/alkaline additions.	Closer to field conditions than HCT; can simulate different weathering/ saturation conditions and mitigations; simulates combined weathering of primary and secondary phases.	Channeling of leachate along preferential flow paths or sides of column; must examine mineralogy before and after tests for estimation of weathering rates of primary minerals (Tremblay and Hogan, 2000).
Field testing of mined materials	Multiple; waste rock or tailings test piles; wall washing; Minewall Approach	Application of characterization methods to existing tailings, waste rock, (also oxidation depth, depth to water table, pore gases and fluxes); creation of waste rock/tailings test piles for new material; wall washing: isolate section of pit wall or underground working, spray water on wall, collect and analyze resulting leachate.	Tremblay and Hogan, 2000; for estimation of field oxidation rates: Blowes and Jambor 1990 (as cited in Shaw and Mills, 2004); Nicholson et al. 1995; Morin and Hutt, 1997, 2004.	To estimate long-term potential of mined materials to generate acid and contaminated leachate.	Tests are conducted under actual field conditions; can collect samples after transient events, such as thunderstorms and snowmelt.	For field test piles: requires consideration of sampling and sample handling for proper scaling to full-scale system (e.g., for particle distribution, chemical composition, water movement, rate of weathering, effect of climate, gas transport, etc.).

dimensional block model of the ore body and wastes, and structural and rock competency information.

Whole rock analysis determines the total concentrations of constituents in a rock sample, which can assist in identifying constituents of concern. Paste pH is used to evaluate the effect of soluble salts on the short-term pH of mined materials. Mineralogic examinations identify minerals that can affect acid generation and neutralization potential and include optical microscopy, X-ray diffraction (XRD), reflected and transmitted light petrographic analysis, scanning electron microscopy/energy dispersive system (SEM/EDS), electron microprobe, sulfide alteration index, and refinement of the XRD information using the Rietveld technique.

Sulfur analysis is used to help determine the potential of samples to generate acid and is used in static testing methods. Static testing determines the total amount of acid-generating (using sulfur analysis and titrations) and acid-neutralizing (using various tests) material in a mine sample and includes the acid-base accounting methods and modifications, net acid-generating test, and net carbonate value test. Neutralization potential procedures, which are part of acid-base accounting, include the Lapakko pH_6 method and the BC Research Initial and confirmation tests. Total inorganic carbon determinations are used to measure the total amount of carbon for estimations of the carbonate content in a sample (also used in acid-base accounting).

Short-term leach tests measure the readily soluble components of mine wastes and include the synthetic precipitation leaching procedure (SPLP), the multiple extraction procedure (MEP), the toxicity characteristic leaching procedure (TCLP), the Nevada meteoric water mobility procedure (MWMP), the California waste extraction test (WET), the extraction procedure toxicity test (EP Toxicity), the British Columbia special waste extraction procedure and modification (BC SWEP), various sequential extraction techniques, and the shake extraction test.

Kinetic testing is used to estimate the longer-term potential of mined materials to generate and consume acid and produce contaminated leachate and to estimate rates of oxidation and dissolution of materials. Kinetic tests include the humidity cell test and column tests. Finally there are a number of field tests for mined materials that are also used to estimate the long-term potential of mined materials to generate contaminants under direct field conditions. Field tests include waste rock or tailings test piles, wall washing, and the Minewall approach (Morin and Hutt, 2004).

Additional and general references used to create the table, especially the advantages and limitation of geochemical characterization methods, include Tremblay and Hogan (2000), Price (1997), Blowes and Jambor (1990, as cited in Shaw and Mills, 2004), Downing and Mills (2004), Jambor (1994), White et al. (1999), Mills (2004a-d), Lawrence and Wang (1997), Logsdon (2002), Kwong (2000), Lawrence and Day (1997), EPA (1994 and 1978), Smart et al. (2000), Zhu and Anderson (2002), White et al. (1999), Smith (1997), and Lapakko (2003a and b). Lapakko (2003a) provides a review of the history of humidity cell testing methods. Lapakko (2002) also contains an overview of geochemical characterization methods, including non-invasive techniques such as AVIRIS (Airborne Visual and Infra-Red Imaging Spectrometer). MEND has a produced a list of information requirements that can serve as a starting point for assessment of metal leaching and acid drainage (Price, 2005).

6.3 Sources of Uncertainty in Geochemical Characterization and Recommendations for Improvement

The validity of geochemical characterization data is linked to a number of issues, including those related to sample representativeness, methods used to extrapolate characterization results to field conditions, and the use of and interpretation of mineralogic information and test conditions. Some of the more important issues related to uncertainty in geochemical characterization are discussed below, and recommendations for improvements are provided. General issues discussed include: extent of environmental sampling (representativeness of field conditions); compositing of samples, changes in geochemical characterization as the mine evolves; and field/laboratory discrepancies. The issues related to static testing include: the effect of particle size; the effect of temperature, pH, and test duration on neutralization potential estimates; the effect of mineralogy and organic matter on neutralization and acid generation potential; estimating neutralization potential (NP) and acid production potential (AP) in low-S, low NP wastes; and interpretation of static testing results using NP/AP ratios. Issues related to short-term leach testing include: the water:rock ratio; the use of unweathered materials; and the interpretation and use of test results. The issues related to kinetic testing include: the effect of particle size and mineral availability; the length of kinetic tests; the effect of column size and shape; the effect of temperature; and the applicability of standard kinetic testing for materials under low-oxygen or reducing conditions.

The geochemical characterization issues are discussed in terms of problems statements, background information, and recommendations to address the stated problem.

6.3.1 General Issues

Extent of environmental sampling (representativeness of field conditions).

Problem Statement: The extent of sampling of mined materials is often inadequate for representing the range of potential environmental impacts at a mine site, especially for mines with variable geology and mineralogy.

Background: The purpose of environmental sampling is to have the information necessary to tailor waste management strategies to the potential for adverse impacts to the environment. Environmental sampling of mined materials can be done as a parallel to economic resource evaluation in terms of both method and timing. Bennett et al. (1997), for example, discuss the application of geological block models to environmental management. Both environmental and economic evaluations delineate, based on representative samples, the extent of rock units of interest/concern and quantify pertinent aspects of their composition (Lapakko, 1990). In practice, the number of representative samples for resource evaluation is almost always substantially larger than that for environmental evaluation. According to Robertson and Ferguson (1995), "Placer (Dome) has adopted the principle that the economic significance of acid drainage liability is as important to a project as the ore reserve inventory." To put this principle into practice, the number of samples for environmental impact prediction (e.g., acid generation potential) should be more commensurate with the number of assays for ore reserve, although in practice, economics dictate that fewer environmental samples will be analyzed because of the greater number of parameters that must be examined to predict future water quality. The analytes determined for resource evaluation, however, can be extensive, especially for platinum group metals, for example. Analyses for resource evaluation are similar to whole rock analysis and can provide direction for future environmental sampling.

According to Farmer (1992), "The principal reason that current methods rarely, if ever, provide a reliable result is the failure to test a representative number of samples in each geologic rock unit in the proposed mine." Price and Errington (1994) recognized that the most important phase of the prediction program is sampling and that a sufficient number of samples should be analyzed to accurately characterize the potential for environmental impact. They suggest the guidelines contained in Table 2 as the minimum number of samples that should be collected for each rock type during initial sampling. Samples must be representative of all geologic, lithologic, and alteration types and of the relative amounts and particle size of each type of material; the compositional range within mineral assemblages or rock types must be known (Downing, 2004).

Table 2. Example of Recommended Minimum Number of Samples of Each Rock Type for Geochemical Characterization of Mined Materials for Potential Environmental Impact.
(adapted from Price and Errington, 1994)

Mass of Each Separate Rock Type (tonnes)	Minimum Number of Samples
<10,000	3
<100,000	8
<1,000,000	26
10,000,000	80

Runnells et al. (1997), however, argue against this approach and emphasize the importance of site-specific variability in dictating the number of samples collected and analyzed. Using this approach, more homogeneous materials such as tailings would require fewer samples than the more heterogeneous waste rock at any given site. This approach reflects the fact that fundamental error, which results from the compositional heterogeneity of particles, is often the main source of sampling error (Pitard, 1993). Important factors in the fundamental error include heterogeneity, particle size, and sample mass. If the population is very heterogeneous or the particle size is large, more sample mass is required to minimize the fundamental error associated with sampling. Smith et al. (2000) provide a discussion of sampling errors.

Given that a 200-ft deep drill hole can be used to project ore resources 100 ft away from the hole in all directions, a core from such a drill hole would represent approximately 200,000 tonnes of material. According to the recommendations of Price and Errington (1994), at a minimum, between eight and 26 samples would be required to adequately characterize the rock type represented in this particular drill hole. If the drill hole were split and sampled on 10-ft intervals, 20 samples would be taken, approximately meeting the recommendations. This amount of sampling is consistent with industry practice for ore resource estimates; however, this extent of sampling is rarely performed for environmental characterization.

An alternative approach to characterizing existing waste-rock dumps was suggested by Wickham et al. (2001) using a model to integrate lithology and mineralogy from the exploration core-hole database with information on pit development, ore handling (to separate out rock sent to processing facilities and waste rock), and dispatch records. The approach is less costly than extensive sampling of the waste rock piles and relies on existing mine information. It also was found to provide an accurate accounting of total tonnage and lithologic characterization in the waste rock dumps, distinguishing between total sulfur, sulfide-sulfur, and pyrite-sulfur materials for each dump. A geochemical sampling program for acid potential was based on the model, and the classification scheme accurately classified waste rock exhibiting similar geochemical behavior, as determined by static and kinetic testing. The approach allowed a proportional sampling according to total tonnage for each compositional type (using cores and test pits in each dump), and the results were used to estimate net acid potential for each dump. The approach is not applicable to a prospective mine, but aspects of the method, particularly the essential Bayesian approach, could be adapted for new mines, with some customizing.

In addition to an adequate level of sampling, every study of acid generation potential or other type of environmental characterization at mine sites should include a sampling and analysis plan with data quality objectives and a quality assurance/quality control (QA/QC) plan. The QA/QC plan should include using standard reference samples (e.g., Canadian Reference Material for Standard Acid Base Accounting) and chain-of-custody forms to help increase the confidence in the results of the environmental analyses (Downing and Mills, 2004). The best QA/QC programs are multi-level and involve both the corporate culture and every level of operations. QA/QC reports should be available and provided with every analysis. The basic elements of any QA/QC program should include the following: laboratory accreditation; proficiency testing; documentation; assessment procedures, sample preparation; quality control; and confidentiality of data and data security.

Recommendation: The variability in the potential to impact the environment should be examined initially by extensive geologic and mineralogic analysis of all mined materials and wastes. The extent of geologic and mineralogic sampling should be commensurate with the extent of sampling for ore characterization. The observed degree of geologic and mineralogic variability should then dictate the extent of sampling for environmental characterization. Fewer samples should be required for tailings than for waste rock, wall rock, and other types of heterogeneous material. The minimum number of samples suggested in Table 2 should be applied to each different type of mineralogy (for example, addressing the range of hydrothermal and supergene alteration for each lithology), rather than to each rock type. The mine proponent must be responsible for showing that the data provided are sufficient for environmentally protective decision making.

Compositing of samples.

Problem Statement: Compositing of samples for environmental characterization leads to a lack of knowledge about where potential environmental problems can develop on the mine site.

Background: Compositing rock samples across rock types leads to the masking of potential acid drainage and other potential environmental problems due to the mixing of different rock types in the composites that may not be representative of the actual placement of the rock types in the mining process (Farmer, 1992). For example, compositing has the effect of assuming a perfect mixture of rock types will occur, whereas in the real world the different rock types might be mined from different places and at different times and might be placed in separate repositories or processed during different periods. Price and Errington (1994) recommend that compositing be avoided in the absence of highly certain information indicating it is advisable (e.g., compositing could be advisable for a highly homogenous deposit). Compositing also obfuscates information on the source of any potential environmental problem related to the mined materials because there are too many variables.

Depending on the objectives of the sampling, compositing of mine waste samples can be appropriate, especially if the "average" properties of a deposit are of interest. Smith et al. (2000) uses a statistically based compositing approach to sample waste rock dumps at abandoned mines. Their target population for sampling was the upper 15 cm of a mine waste dump, because this surficial material is most likely to impact runoff from snowmelt and rain storms (although the approach could be modified to apply to drilling or subsurface trench sampling). They collected the <2mm size fraction of the material, assuming that smaller size fractions are generally the most reactive and would control leaching behavior over the short term. This hypothesis was tested and confirmed by performing the synthetic precipitation leaching procedure (SPLP, EPA Method 1312) on various size fractions. To minimize grouping and segregation errors (another type of error associated with sampling), they collected at least 30 sub-samples for each composite sample. The results showed that the <2-mm size fraction provided a worse-case scenario for short-term leaching of acidity and zinc.

Recommendation: Compositing of samples is only recommended for mined material that is consistent in size and composition, for example, existing tailings material that is known to be from a consistent ore type and a single process. For example, autoclaved and non-autoclaved tailing should not be composited, and complex ore bodies, such as those including skarn adjacent to intrusive rocks in a porphyry copper, should be evaluated carefully in terms of understanding the compositional range of tailing. Compositing should not be used for any other types of mined materials or for water-quality samples. Compositing can be appropriate if the average properties of mined materials are of interest. Guidelines recommended above should be used to determine the extent of sampling of mined materials for environmental characterization.

Changes in geochemical characterization as mine evolves.

Problem Statement: Geochemical characterization conducted before mining begins may not accurately reflect conditions after mining has progressed.

Background: As mining progresses, there is an opportunity to test assumptions upon which mined-material characterization and water-quality predictions are based. Changes in geology, such as a change in rock type or in the mineralogy (sulfide versus oxide minerals, for example), as the mine expands or develops, can impact all aspects of mining from development to waste disposal (SME, 1992). Changes in geology can result in significant changes in the results of materials characterization and water-quality predictions and in environmental impacts.

Recommendation: Geochemical characterization should be conducted throughout the active life of the mine and used to continually evaluate potential environmental impacts.

Field/lab discrepancies.

Problem Statement: Laboratory geochemical characterization tests are generally not representative of field conditions. Results from laboratory tests will generally overestimate field weathering rates and underestimate the length of contaminant generation from mined materials.

Background: For most mine waste, laboratory oxidation and weathering rates are generally two to three orders of magnitude higher than field rates (Ritchie, 1994; Banwart et al., 2002; Schnoor, 1990; Sverdrup and Warfvinge, 1995; Drever and Clow, 1995). This discrepancy can be explained by considering a relatively small number of bulk physical and chemical properties of mine rock at field sites: temperature, particle size, spatial variability of sulfide-bearing rock at the site, hydrological factors such as preferential flow, and the availability of oxygen (Banwart et al., 2002; Banwart et al., 2004). Malmstrom et al. (2000) was able to obtain reasonable agreement between field and laboratory weathering rates when these factors were taken into account numerically (Banwart et al., 2002, Banwart et al., 2004). Bennett et al. (2000) found that in the shorter term, oxidation rates should be similar under laboratory and field conditions, although this would apply only to materials with similar mineralogy and leaching behavior. However, extrapolation of decreases in humidity cell oxidation rates over time may underestimate longer term field rates because larger-sized particles will still be oxidizing under field but not under humidity cell test (HCT) conditions, due to the small particle size (max size = 2 mm) used in the test. This issue can be avoided by using larger-scale cells (or columns), rather than HCT's, for waste rock. These results also imply that the size distribution and available surface areas for sulfide and neutralizing minerals in a waste pile must be known to accurately predict long-term oxidation rates of sulfides under field conditions. Sverdrup and Warfvinge (1995) were able to completely resolve discrepancies between laboratory and field (watershed scale) weathering rates for individual minerals by taking into account partial wetting of field minerals, temperature differences between the laboratory and the field, and the effect of product inhibition (of aluminum and base cations) in the field. Laboratory conditions such as the effect of buffers, using freshly ground minerals in laboratory experiments, and CO_2 overpressure in experiments contributed in a minor way to laboratory-field discrepancies. Generally, if weathering rates are expressed on a per available surface area basis, rather than on a unit time or unit mass basis, the agreement between field and laboratory rates is improved. The bulk of the surface area occurs in the fine fraction, which should not be ignored in laboratory testing.

The accumulation of solutes that are not flushed from the system is an important factor in accounting for the apparently slower weathering rates under field conditions. Banwart et al. (2004) were able to successfully model field solute concentrations when water and solutes held in stagnant zones in a waste pile were included in the model. Smith and Beckie (2003) also found that incomplete knowledge about hydrologic processes controlling unsaturated flow in waste rock made modeling of drainage water quality difficult. In addition to controlling the chemical reactivity in mine waste deposits, grain-size variability can lead to structural heterogeneities that affect fluid flow in the piles, including preferential flow. Mineralogy (including secondary phases), porewater chemistry, sequential and other extractions for different size fractions, and measuring the grain-size distribution were considered important characterization approaches for predicting the geochemical and hydrologic behavior of solutes in waste piles (Smith and Beckie, 2003).

Recommendation: Site-specific measurements of temperature, particle-size distributions, available sulfide and neutralization mineral surface areas, spatial variability of sulfide-bearing rock, hydrological factors such as preferential flow, and the availability of oxygen should be determined for all waste units, especially waste rock and leach dumps. Mineralogic analysis, including mineral availability, should be completed before laboratory testing begins. To the extent possible, field-scale testing or laboratory columns, with minimal changes in grain size distribution compared to the actual mined material, should be conducted as supplements to or replacements for laboratory characterization testing, especially for waste rock. Site-specific estimates of scaling factors between laboratory and field conditions should be determined and used in predictive modeling studies.

6.3.2 Issues Related to Static Testing

Effect of particle size.

Problem Statement: Static ABA tests use crushed rock, which will overestimate the association of acid-producing and acid-neutralizing minerals under field conditions and overestimate the neutralizing, and possibly the acid-generation, potential of the samples.

Background: When a sample is crushed or ground, it makes grains more reactive. Producing a fine-grained, homogenous assemblage changes the spatial relationship between the acid-generating and acid-neutralizing minerals. If the newly-exposed surfaces have a significantly different composition from those available to weathering under field conditions, the laboratory test will not effectively simulate reality (Price, 1997). If sulfide mineralization, for example, occurs in veins or along fractures, crushing the rock will tend to underestimate AGP and overestimate NP. Static testing does not consider the association of the sulfide in the rock under field conditions (e.g., disseminated, inclusions, fully liberated along fractures); rocks with the same pyrite content would show the same AP, regardless of their availability to weathering because of sample crushing. White et al. (1999) noted that the reduction of particle size leads to overestimation of the NP. The largest size fraction examined in their experiments (- ¼ inch) approximates the particle size commonly used in HCT's. The overestimation of NP was attributed to increased dissolution of acid-neutralizing minerals that were not available for weathering under field conditions. Stromberg and Banwart (1999) found that particles <0.25 mm contributed ~80% of the sulfide and silicate dissolution, and calcite particles larger than 5 to 10 mm react too slowly (due to intra-particle diffusion) to neutralize acid produced from sulfides. Scharer et al. (2000b) also found that the availability of neutralization potential (NP) from limestone was mass-transfer limited when particles were >6.4 mm. Under mass-transfer limitations, the rate of pyrite oxidation may exceed the rate of neutralization by buffering minerals. Therefore, under field conditions where limestone or other neutralizing minerals are larger grained, crushing will overestimate the contribution of that mineral to neutralization potential. The same conditions may apply to the crushing of larger sulfide grains and the overestimation of acid generation potential.

Recommendation: Static ABA tests cannot be used to quantify acid generation and neutralization under field conditions and should only be used as an initial screening technique to estimate the total amount of acid-generating and acid-neutralizing material present in rock that is representative of the samples collected. Evaluation of mineralogy, including available weathering surface area for sulfides and carbonates, may be a more accurate approach than ABA testing for estimating the acid generation potential of mined materials.

Effect of temperature, pH, and test duration on neutralization potential estimates.

Problem Statement: Neutralization potential tests that are conducted at elevated temperatures or that use pH endpoints of <6.0 will overestimate the amount of neutralization potential available under field conditions. For samples with low carbonate content, neutralization potential tests conducted for short time frames may underestimate the neutralization potential.

Background: The U.S. Bureau of Mines examined the NP of five samples using the NP(pH6) test (Lapakko modification) at 4, 24, and 120 hrs (White et al., 1999). NP increased consistently with time, with 120-hr tests typically having 1.1 to 2.3 times higher NP values than the 4-hr tests. The calcite-containing samples produced NP relatively quickly (≤ 4 hr), while samples with magnesium carbonate dissolved more slowly (4 to 120 hr). The Lapakko modification NP procedure has the longest test duration (up to 1 week), while the original Sobek procedure has the shortest (3 hr); the BCRI Initial test lasts for 16-24 hr, and the modified Sobek has a 24-hr duration (Mills, 2004a). Downing and Madeisky (1997, as cited in Mills, 2004a) used the BCRI Initial Method to evaluate changes in NP over time (up to 40 to ~92 hours) for four low-carbonate samples and the Canadian Reference Material for Standard Acid Base Accounting (NBM-1), and found that NP did not change substantially over time for samples dominated by carbonate (NBM-1), while samples with low carbonate content had increasing NP values over time and the NP was contributed by mica, chlorite, pyroxene and amphibole. The conclusion reached by Mills (2004a) was that the Lapakko modification and TIC methods will give the lowest NP values (only carbonates are credited), Sobek will give the maximum NP values (lowest test pH and elevated temperature), and BCRI Initial and Modified Sobek will give intermediate results (carbonates and only most reactive silicates credited).

Neutralization potential is defined operationally as the buffering of a sample by minerals at a pH of at least 6.0 (White et al., 1999). Buffering at lower pH values will not be adequate to keep site waters in compliance with regulatory standards. Conducting the neutralizing potential test at pH values <6 will overestimate field neutralization potential because under field conditions, calcite may produce bicarbonate ion rather than CO_2 gas (for tests that use fizz method (Sobek and NAG tests) and all NP tests with endpoint pH values <6). Conducting NP tests at elevated temperature values or low pH values (<6) will also overestimate NP because minerals that do not contribute to neutralization potential at pH values >5 (silicates such as kaolinite, montmorillonite, albite) will be included in NP at these elevated temperatures and low pH values (for original Sobek method, NAG test, BC Research tests) (Tremblay and Hogan, 2000).

Recommendation: Evaluation of mineralogy is a necessary step for determining the neutralization potential of mined materials. If using ABA testing, some general guidelines include: for most mineralogies, the original Sobek method will overestimate neutralization potential; use NAG testing only as a screening method for estimating neutralization potential; assuming siderite is not a dominant carbonate mineral, Lapakko and modified Sobek methods are the most reliable and reasonably conservative tests for estimating NP.

Effect of mineralogy and organic matter on neutralization and acid generation potential.

Problem Statement: Mineralogy is the most important control on acid-generation and neutralization potential, yet until the last few years, mineralogy has rarely been confirmed as part of static or kinetic testing procedures. Lack of knowledge about the mineralogy of mined material can cause either overestimation or underestimation of net acid-generation potential.

Background: ***Effect on NP***. As an example of the importance of mineralogy, the presence of siderite, a reduced-iron carbonate, can cause an overestimation of

NP, depending on the pH of the static test method back titration. If siderite dissolves at low pH values, it can contribute to alkalinity; if it dissolves at pH values above about 3.5 under oxidizing conditions, ferric hydroxide will precipitate and add acidity (Balestrieri et al., 1999; Plumlee, 1999; Nordstrom, 2000). The higher pH of the NP(pH6) resulted in good agreement between test results and known neutralization potential (NP) values for a pure siderite sample, while the Sobek and modified Sobek methods, which use a lower titration pH, caused an overestimation of NP (White et al., 1999). White et al. (1999) also discuss "mineralogic NP," which is an estimate of NP from the amount of calcium and magnesium carbonate minerals present. Values for NP derived from ABA testing can be compared to mineralogic NP values as a check on the validity or calibration of the ABA results. If NP values from ABA testing are higher than the mineralogic NP, minerals with less effective buffering capabilities (e.g., silicates) are being counted as contributing to the neutralization potential.

The extent to which minerals other than calcium and magnesium carbonates contribute to the ability to neutralize acid at reasonable rates is debatable and dependent on the pH at which the material weathers in the field over time. Certain silicates can contribute neutralizing potential to mine wastes over the long term or if the wastes are in a low-pH environment (Nicholson, 2003; Bliss et al., 1997). In static tests conducted on three pure feldspars (oligoclase – the sodic plagioclase, bytownite, and microcline – the potassic K-feldspar), bytownite, the calcic-endmember plagioclase feldspar, was the only feldspar that produced measurable NP in static tests (White et al., 1999). Kwong and Ferguson (1997), using XRD and NP tests, determined that biotite, chlorite, and amphibole contributed to NP, while quartz, muscovite, plagioclase, and K-feldspar did not. After reviewing the contribution of many silicates to the results of static tests, Jambor (2000) recommends that the most realistic measure to use for predicting whether rocks will be acid producing is the carbonate content. In ultramafic rocks, olivine and its deuteric alteration products such as lizardite can provide efficient neutralization (Jambor, 2000 and 2003). If ferrous iron is present in silicate minerals and it dissolves and subsequently oxidizes to ferric iron/iron oxyhydroxide, the buffering capability of the silicate will be reduced (Nicholson, 2003). Generally, feldspars will only be effective neutralizing agents if they are largely calcic and if the sulfur content is relatively low. Morin and Hutt (1994) found that feldspar (50% calcium) effectively neutralized acid produced by the oxidation of 1.9% pyrite in tailings. However, the subaqueous conditions may have limited the rate of pyrite oxidation in the tailings.

Aluminosilicates weather (releasing base cations such as calcium that can neutralize acidity) at slower rates than carbonates (Lawrence and Wang, 1997; Sverdrup and Warfvinge, 1995; Brantley and Chen, 1995). This discrepancy in weathering rates has led some researchers to propose a short-term index based on carbonate content and a long-term index based on Ca+K content (Downing and Madeisky, 1997, as cited in Mills, 2004a) and relative reactivity rates, based on the minerals present (Mills, 2004a and Plumlee, 1999, pg. 74). However, as noted above, White et al. (1999) observed that potassium feldspars were not effective neutralizing agents.

Effect on AGP. If sulfates and organic S are present (only expected in certain sediment-hosted sulfide deposits, or if secondary sulfates have formed), using total S may overestimate AGP. However, some soluble sulfates can store and produce acid when solubilized, especially certain iron sulfates (Nordstrom and Alpers, 1999; Mills, 2004a). Depending on the type of sulfide present (and the pH and oxidant present in the natural setting), using sulfide S for acid potential (AP) tests may also overestimate AGP. For example, when oxygen (rather than ferric iron) is the oxidant, Plumlee (1999) states that sphalerite, galena, and chalcopyrite will not generate acid. On the other hand, he notes that chalcopyrite and other sulfide minerals that do not contain iron will produce acid when oxidized by ferric iron (which could be present at low pH values). Although balanced equations can be written for these reactions, there does not appear to be empirical evidence for the results, and more experiments need to be conducted to conclusively evaluate oxidation of sulfides by oxygen and ferric iron.

By closely examining mineralogy in humidity-cell experiment samples, Newbrough and Gammons (2002) found that pyrite in samples with higher leachate pH values was coated with chalcocite, which can consume protons. Stewart et al. (2003a) has shown that there are significant differences among the acid-generation potentials of sulfide minerals, using the net acid generation (NAG) test. According to their results, only pyrite, pyrrhotite, arsenopyrite, and chalcopyrite are able to produce leachate with a pH <4.5. The presence of carbonaceous matter can produce organic acids during the peroxide oxidation step in the NAG test and lead to overestimation of acid generation potential by this method (Stewart et al., 2003b). The effects were most pronounced in samples with sulfur content <0.5% and total organic carbon contents >7%, which would be rare in most hardrock mines. The precipitation of gypsum (mostly in kinetic tests) can underestimate the AGP because there will be lower concentrations of sulfate in the effluent after gypsum precipitates. However, Morin and Hutt (1998) found this was rare in kinetic results from the International Kinetic Database (IKD, version 98.3, MDAG Publishing, 1998).

Recommendation: Mineralogy should be thoroughly examined as part of the environmental characterization process, with special attention paid to identifying the types of metal sulfides, silicates, and carbonates in mined materials and the surface area of these minerals available for reaction. In many cases, this will involve mineralogical examination that is more detailed and sophisticated than simple bulk powder X-ray diffraction. If siderite is a dominant carbonate, the NP tests should be modified to ensure that siderite is not included in NP. As a check on NP, use mineralogic NP (based on the amount of calcium and magnesium carbonates present) for samples of lithologies of interest. Use of total sulfur for AGP may result in slight overestimations of AGP, but using total S would result in more protective and supportable management decisions. However, if there is a substantial amount of non-acid producing sulfates or organic sulfur, they should be subtracted from the total sulfur value.

Estimating NP and AP in low-S, low NP wastes.

Problem Statement: Rocks with low sulfur content can produce acid, and rocks with low NP can buffer acid, yet standard ABA tests may not predict these results.

Background: Rocks with low sulfur content can produce acid, and rocks with low neutralization potential can produce neutralizing ability. For example, Lapakko and Antonson (1994) observed that samples from the Duluth Complex in northeastern Minnesota (a large copper/nickel resource with elevated levels of platinum group metals) with %S values from 0.41 to 0.71% produced pH values from 4.8 to 5.3, and samples with %S values from 1.12 to 1.64% produced pH values of 4.3 to 4.9 after 150 weeks. Also, as noted above, a number of researchers have found that certain feldspars can effectively neutralize acid at low %S values. Li (2000) presents a method for predicting the acid drainage potential for wastes in this category. He defines low-sulfide, low-neutralization potential waste as those with sulfur contents <1% and neutralizing potential <20 kg $CaCO_3$ equivalents per ton (eq/t). Li notes that there are many documented cases of acid generation by mine waste with a sulfide-sulfur content of 0.1 to 1.0% S. At these low S contents, the addition of neutralizing potential by silicates becomes more important, and the procedure includes using mineralogic and kinetic information to evaluate the importance of silicate buffering. If the silicate dissolution rate is greater than the sulfate production rate, the material may be buffered initially but eventually form acid, although the common silicates do not yield alkalinity at appreciable rates until the pH falls to <3 (Stumm, 1997). In this case, the relative availability of acid-producing and -neutralizing material is evaluated to determine whether or not the waste is expected to generate acid. Scharer et al. (2000a) note that wastes with neutral drainage (such as some in the low-S, low-NP category) will have slower sulfide oxidation rates (because sulfides oxidize more slowly at neutral pH values) but can produce elevated concentrations of sulfate, base cations, and metals.

Recommendation: For rocks with low S content and/or low NP, standard ABA testing must be supplemented early in the mining process with additional information on mineralogy, availability of acid-producing and neutralizing material, and kinetic tests to determine the relative weathering rates of sulfides and neutralizing minerals.

Interpretation of static testing results using NP/AP ratios.

Problem Statement: NP/AP ratios are routinely used to predict the likelihood of acid generation at a mine site. Depending on the amount and availability of neutralizing material, material with even “safe” ratios (e.g., >3:1) may produce acid in the longer-term.

Background: The results of static ABA tests are usually presented as either NNP (NP – AP) or NP/AP. Use of the NP/AP ratio is preferred because it allows comparison of acid generation and neutralization potentials over a wide range of results (Tremblay and Hogan, 2000). Practitioners of ABA methods have used various NP/AP ratios to define acid-generating, uncertain, and non-acid-generating screening criteria for mined materials, with suggested non-acid-generating ratios ranging from 1:1 to 4:1 (White et al., 1999). The use of ratios assumes that measured NP and AP values are representative of field conditions, and this premise has been questioned by many practitioners, as discussed above. Ferguson and Morin (1991, as cited in US EPA, 1994) discussed the validity of extrapolating a sample's ability to generate acid into short (< 1 year), medium (a few years), and long-term (many years) time frames, with ABA tests being appropriate only for short-term projections. Robertson and Ferguson (1995) used a non-acid-generating NP/AP ratio of 2:1; Price (1997) and Mills (2004a) recommended a conservative screening criterion of 4:1; and Morin and Hutt (1994) used a range of >1.3 to 4.0. Scharer at al. (2000b) concluded that for heterogeneous waste rock piles, the NP/AP ratio is a reliable indicator only for short-term predictions, and that kinetic data on depletion rates of neutralizing minerals suggest that NP/AP ratios as high as 5.0 may become acidic in the long term. Mined materials with NP/AP values below the selected screening criterion and above a ratio of 1:1 are considered to have an uncertain ability to form acid and would fall into a "gray zone" that would require longer term kinetic testing. Skousen et al. (2002) found that NNP and NP/MPA (MPA = maximum potential acidity using total S, ~NP/AP) ratio were best at predicting actual drainage pH from surface coal mines, and that 96% (50/54 mines, excluding 4 anomalous sites) of the mines had good agreement between NNP or NP/AP ratios and drainage pH. They used NP/AP ratio ranges of <1 (acid drainage), 1-2 (acid or alkaline drainage), and >2 (alkaline drainage) for predicting post-mining drainage quality. Although the predictability is quite high for these mines, all are coal mines. Hardrock mines have more complicated mineralogy and likely more variability in the predictability of drainage water quality. Lapakko (2003a) states that there is no agreement on a "safe" value for NP/AP ratios, and that determining sample-specific mineralogy is a better approach for predicting drainage quality.

Recommendation: Static ABA tests and NP/AP ratios should only be used as initial screening tools for samples to be used for kinetic testing and as estimates of the total amount of acid-generating and neutralizing material present. Knowledge of mineralogy is essential in interpreting ABA results. To estimate medium- and longer-term acid-generation and metal-leaching potential, static test results must be supplemented with mineralogic, mineral availability, and kinetic testing data.

6.3.3 Issues Related to Short-Term Leach Testing

Water:Rock Ratio, Use of Unweathered Materials, and Interpretation and Use of Short-Term Leach Testing Results.

Problem Statement: Short-term leach tests are used routinely to determine the identity and concentrations of constituents of concern leaching from mined materials. Although the intent of the tests is to simulate short-term leaching conditions, the results of the tests are often misapplied to longer-term leaching. Two other issues that confound the interpretation and of the tests is the water:rock ratio and the use of unweathered mined materials.

Background: The purpose of short-term leach tests, as the name implies, is to simulate the leaching of constituents of concern over short time frames by meteoric water. The majority of the constituents (hydrated metal sulfate salts) that are rapidly released from mined materials are on the weathered surfaces of the fine fraction (< 2 mm) of the sample (Smith et al., 2000; Hageman and Briggs, 2000). Therefore, without a weathered surface, short-term leach tests are meaningless, and only the longer-term weathering behavior can be studied. Fresh drill core generally will not have a weathered surface, and short-term leach tests should not be conducted on this material until a weathered surface develops.

The water:rock ratio is never known definitively, but the 20:1 ratio used in many of the US EPA leach test methods is too dilute. The higher ratio used may ensure the complete solubility of all products (Hageman and Briggs, 2000), but the dilution may cause leached concentrations to be below detection limits, especially if lower detection limits (e.g., for metals) cannot be achieved in the laboratory performing leachate analysis. On the other hand, a low water:rock ratio (e.g., MWMP test) may underestimate the amount of poorly soluble constituents such as arsenic that may be released.

Recommendations: The use of unweathered materials in leach tests should be avoided. Short-term leach tests may have limited use as a scoping tool if weathered rock is used, but the results should only be applied to short-term leaching of mined materials after they have been weathered in the field. Involving an experienced geochemist in testing design and analysis will minimize misinterpretation of test results. Taking short-term leach test results from long-term kinetic tests (e.g., "first flush" results from humidity cell or column tests) would eliminate the need for separate short-term leach tests and would better link short-term and long-term predictions for leaching of contaminants. In addition, releases can then be quantified on a per unit mass basis if short-term leach results are taken from kinetic testing.

6.3.4 Issues Related to Kinetic Testing

There are two distinct purposes for conducting kinetic tests: to predict the onset of acid drainage, especially in samples with equivocal results for static testing; and to generate data that can be used to model or predict water chemistry. For kinetic testing conducted before the early- to mid-1990's, the main purpose was to predict the onset of acid drainage. Today, most projects would require the development of a technical basis for estimating future water quality, and the prediction of the onset of acid drainage would come as a byproduct of that analysis. The purpose of conducting kinetic testing must be understood by all parties, and then the details of how to conduct the test can be worked out for decision-making purposes.

Effect of particle size and mineral availability.

Problem Statement: With the exception of tailings, crushing is required for humidity cell tests, yet, especially for heterogeneous and larger grained material, such as waste rock, humidity cell test results will not accurately represent field conditions.

Background: The effect of particle size on static testing results and field/laboratory discrepancies has been discussed above, and these same issues apply to kinetic testing. In particular, the availability of acid-generating and neutralizing minerals to weathering will be overestimated if the sample is crushed (Lapakko, 2003a). This is especially true for minerals in the rock groundmass or those coated in less reactive minerals or precipitates. Benzaazoua et al. (2001) showed that both HCT's and column leach tests had similar results for sulfidic mine tailings; however, for more heterogeneous and larger grained material, such as waste rock, the crushing required for HCT's will make results deviate more from actual field conditions. In a column test with minimal grinding, only acid-generating and neutralizing material that is "liberated" (available to weathering, for example, along fractures or on surface of rocks) will be counted as contributing to acid-generation and metal leaching potential (Mills, 2004e). The availability of minerals, especially sulfides and carbonates, is one of the most important factors controlling the rate of acid development and contaminant leaching at mine sites. Lapakko and Antonson (2002) show the importance of determining the sulfur content as a function of particle size and liberation (available surface area) when determining sulfide dissolution rates (also see Lapakko, 2003b). Lapakko (2003a) shows that kinetic test results at 30 weeks (pH values) were dependent on both lithology and particle size. The drainage pH for the mudstone samples decreased as particle size increased, with a large drop in pH for sizes above 2.0 mm. Drainage pH increased with increasing particle size for the latite and gabbro samples, but the drainage pH of the latite sample dropped for sizes above 2.0 mm.

Recommendation: Humidity cell testing should not be used to predict weathering rates for waste rock or wall rock or other types of heterogeneous, large-grain size material unless the results are expressed in terms of available mineral surface area. This requires that the surface area of specific minerals in the kinetic-test samples be known and – to permit scaling up to field conditions – that the surface area of minerals in the actual waste be known or well estimated. Column testing with no or minimal reduction of particle size or field techniques, such as mine wall washing, will provide results that will be more representative of field conditions. Samples must be well characterized in terms of mineralogy and mineral availability before and after tests are conducted.

Length of kinetic tests.

Problem Statement: The minimum recommended length of time for kinetic testing is 20 weeks, but a number of practitioners of kinetic testing have shown that this time frame is inadequate for accurate prediction of the onset of acid drainage and/or metal leaching, especially in samples with higher neutralization potential.

Background: Many different lengths of time are recommended for kinetic testing, but none are shorter than 20 weeks. As noted in Section 6.3.2, silicates weather more slowly than carbonates, and carbonates weather more slowly than sulfides. The relative weathering rates of carbonates, sulfides, and silicates can produce drainage with changing quality over time. Depending on mineralogy and availability of minerals for reaction, a 20-week kinetic test may not capture all the potential changes in drainage quality over time, in particular the production of acid. Price (1997) recommends that HCT's should last until weekly rates become relatively stable (then use the average of the last five weeks); this could require substantially more than 20 weeks and possibly more than a year. Robertson and Ferguson (1995) state that kinetic tests should be at least 20 weeks in duration, but suggest that this is inadequate unless samples are extremely high in sulfur content, low in buffering capacity and/or potentially highly reactive, and recommend that typical lengths should be two to three years. ASTM (2003) requires a minimum of 20 weeks duration for HCT's. Lapakko (2003a) states that the 20-week duration recommended by ASTM is too short to allow for potential acidification from mine-waste samples in general, and recommends substantially longer periods if the objective is to see if the rock will acidify over the long term. Morin and Hutt (1997) recommend 60 to 120 weeks or longer.

Lapakko notes that a tailings sample with 1.3 wt% calcite and 6.6 wt% pyrite generated circumneutral drainage for 112 weeks before generating acidic drainage, and that a mixture of rotary kiln fines and rock with 2.1 wt% sulfur from the Duluth complex had a lag time of 581 weeks before it started producing acid (Lapakko, 2003a). Samples with higher NP or NP/AP>1 can have large lag times before generating acid, and Tremblay and Hogan (2000) recommend that the length of the HCT should depend on sample composition, but be at least 20 weeks long and typically last at least one year. Nicholson and Rinker (2000) show that sulfate and nickel concentrations in leachate from both humidity cell and column leach tests did not start to increase until after 20 weeks, and that peak concentrations of nickel in humidity cell tests were not reached until over 60 weeks had passed (Figure 7 a and b). The results further showed that a substantial amount of nickel was leached from the wastes under neutral pH conditions.

The length of kinetic tests also depends on the objectives of the test. For example, if the objective is to examine relative weathering rates, tests may be longer or shorter than if the objective is to determine if the sample will ever produce acid.

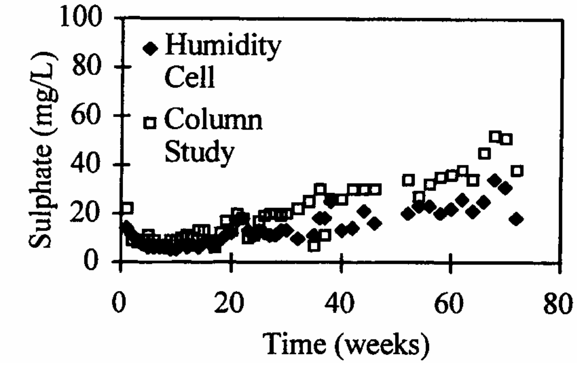

Figure 7a. Sulfate vs. time for humidity cell and column tests. (Source: Nicholson and Rinker, 2000.)

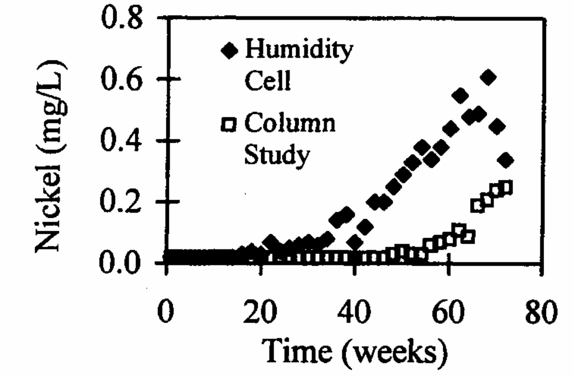

Figure 7b. Nickel vs. time for humidity cell and column tests. (Source: Nicholson and Rinker, 2000.)

Recommendation: The objectives of kinetic testing should be clearly stated. If the objective is to determine if the sample will produce acid, kinetic tests should be conducted for longer than 20 weeks, unless earlier results indicate that acid will be produced. The length of the test should depend on the sample composition. Mineralogy (including available surface areas) should be examined initially and after the test and used to help determine if the sample could eventually produce significant amounts of acid or contaminants. For kinetic test samples with static test NP:AP>1 that have not produced acid within one year, test lengths should be longer than one year.

Effect of column size and shape.

Problem Statement: Column testing of larger grain size material may result in incomplete contact of leachate with the sample material and inaccurate prediction of water quality unless the experiment is carefully designed and implemented.

Background: Leachate may be channeled down the sides of a column if the ratio of the column diameter to the size of the largest particles is low; a ratio of ≥6 is recommended (Tremblay and Hogan, 2000). Ratios of 10 and as high as 40 have been discussed as well. Channeling is more likely to occur in column rather than humidity cell tests (HCT's). The larger the column, and the more representative the size distribution is of that of the actual mine unit, the less scaling is required to approximate full-scale field conditions.

Recommendation: For larger grain size material, such as waste rock, larger columns should be used for kinetic testing, using a ratio of column diameter to largest particle size of six or greater. To reduce grain size somewhat, the material can be broken by hand, for example, using a hammer, if necessary, so that the breakage would occur along faces that would naturally be exposed to weathering.

Effect of temperature and weather conditions.

Problem Statement: Laboratory temperatures and conditions deviate from field conditions, and these deviations may result in under- or overestimation of metal leaching and acid production rates and concentrations.

Background: The temperature of kinetic tests conducted in the laboratory generally will be different and more consistent than actual field conditions. Kinetic tests conducted in the laboratory will not simulate weather conditions in the field, such as precipitation, snowmelt, and the variability in ambient temperatures, nor or they designed to. Cooler temperatures can slow the rate of mineral dissolution, including sulfide oxidation, and warmer temperatures will increase weathering rates. For small molecules, reaction rates double for every 10°C increase in temperature (Pauling, 1970).

Recommendation: To the extent possible, field kinetic tests should be conducted as a supplement to laboratory kinetic testing. Mine proponents and regulators should acknowledge that the results of kinetic testing, unless the tests are conducted in the field, will not represent dynamic hydrologic and weathering conditions such as snowmelt and precipitation. Results from kinetic tests conducted under oxygenated conditions can be used to model the effect of different temperatures on sulfate production using experimental data on the effect of temperature on activation energies for the reactions (e.g., Ritchie, 2003).

Applicability of standard kinetic testing for materials under low-oxygen or reducing conditions.

Problem Statement: Humidity cell tests have been used, among other things, to estimate leaching characteristics of tailings material, some of which may be fully saturated under field conditions. Humidity cell tests are not designed to represent low-oxygen or reducing conditions.

Background: Humidity cell tests are conducted under partially saturated and high oxygen-content conditions and are not intended to simulate acid production and consumption or contaminant generation under fully saturated and anoxic conditions (Tremblay and Hogan, 2000; Price, 1997), such as would exist in portions of tailings impoundments. Column tests more closely simulate the leaching processes operating in mine waste deposits and can be adapted to conditions other than complete oxygen saturation (Mills, 2004c) using experimental data on the relationship of reaction rates to the fugacity of oxygen.

Recommendation: Humidity cell tests should not be used to represent leaching characteristics of materials under low-oxygen or reducing conditions. Continuous-flow column tests or batch tests can be used to estimate the behavior of mined materials under low-oxygen conditions.

6.4 State-of-the-Art Methodology for Geochemical Characterization of Mined Materials

The steps for state-of-the-art geochemical characterization of mined materials are described below and shown schematically in Figure 8. The rationale for the selection of these approaches is contained in the preceding sections. The full list of steps is most appropriate for proposed or expanding

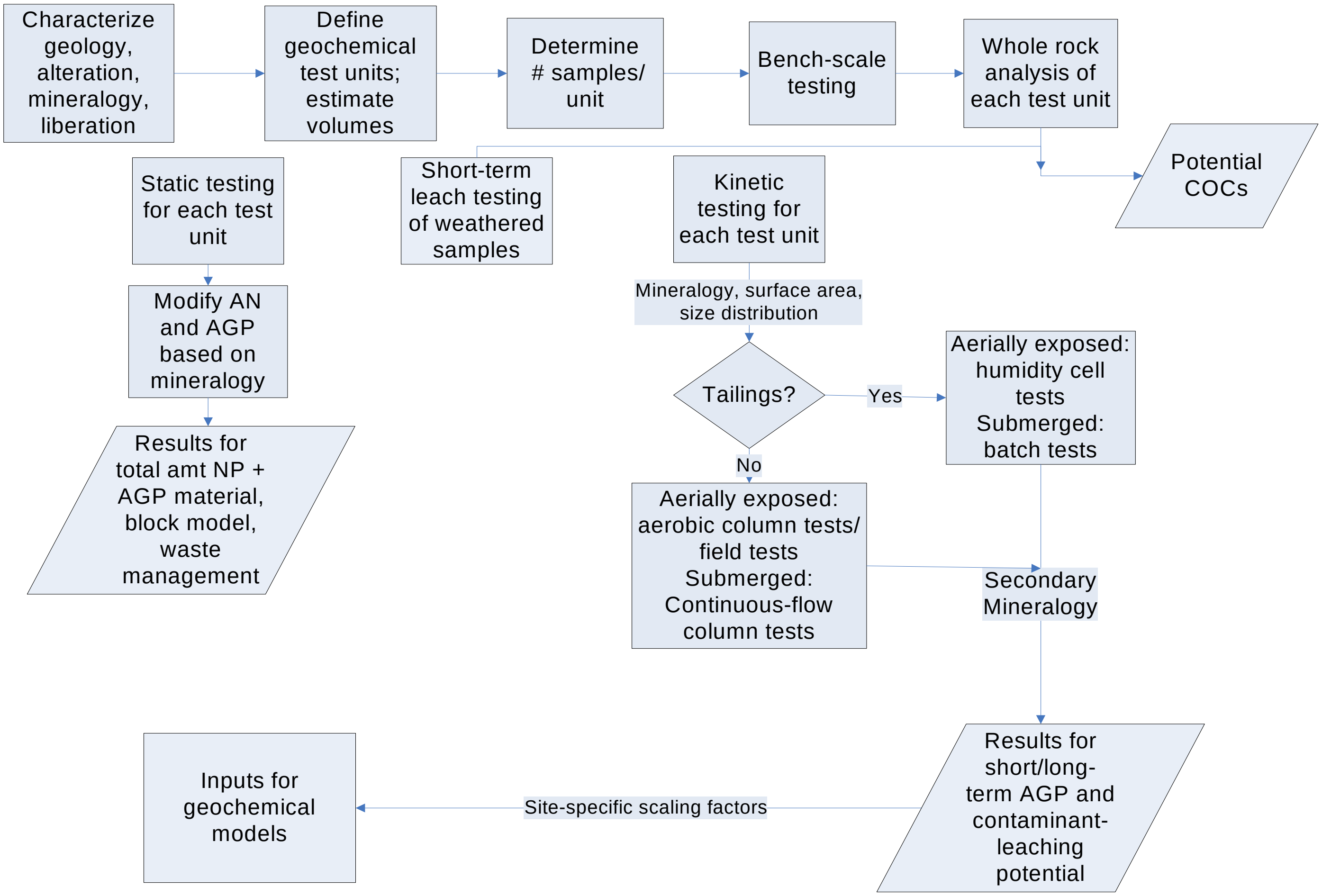

Figure 8. Steps for state-of-the-art geochemical characterization of mined materials.

operations. Characterization of mined materials at inactive or abandoned mines sites would instead rely more on existing site- or unit-specific water chemistry (e.g., seep, pore water, pit water, surface water, or groundwater quality) or a smaller list of approaches.

The first step in characterizing mined materials is to determine the geology and mineralogy of the rocks at the mine site. Such analyses include the determination of rock type, alteration, primary and secondary mineralogy, the availability of acid-producing and -neutralizing and metal-leaching minerals (liberation, e.g., veins, disseminated, encapsulated, etc.), and the locations and dimensions of oxidized and unoxidized zones for all waste types, pit walls, and underground workings. The geologic and mineralogic analysis also includes defining all geologic units that will become waste, pit or underground workings walls (and areas behind the walls), and stockpiles, and defining the ore types by delineating ore grades.

The next step in the geochemical characterization of mined materials is defining the geochemical test units. Geochemical test units are rock types of distinctive lithology, mineralogy, and/or alteration. The units should be as homogeneous as possible, based on information on lithology, mineralogy, alteration, and the availability of minerals to weathering. Geochemical test units should be maintained throughout the life of the mine, although new test units may be defined based on future exploration. Examples of geochemical test units are peridotites, feldspathic peridotites, pyroxenites, gabbros, and olivine gabbros (possibly for ultramafic deposits), an oxidized marble skarn, or propylitically-altered rhyolite. Extensive geochemical characterization should be performed on each of the identified test units. Depending on the results of the characterization, some of the test units may be grouped together in the mine waste management plan. Alternatively, if an initial unit designation provides a wide range of test outcomes, it may be necessary to subdivide the unit for waste management purposes. For example, if the initial designation included sulfur concentrations < 0.2 wt %, but the characterization data showed widely varying results for acid generation potential, the samples would be reclassified and a more prudent sulfur limit would be determined. Within a given lithology and mineralogy, the sulfide content can often be the controlling factor in determining the ability of a test unit to produce acid and leach contaminants.

The third step in characterizing mined materials is to estimate the volumes of each type of material to be generated and the distribution of types of material in waste, pit, and underground workings. The number of samples for geochemical testing of each unit should be based on the volume of material in each unit. The information on geochemical test units should be coordinated with the mine waste management plan.

The fourth step in characterization is conducting bench-scale testing of the ore, which involves creating tailings and/or heap leach materials in a laboratory. In addition to any metallurgical testing, the tailings or heap leach material can be subjected to geochemical and hydraulic testing. The general categories of geochemical testing that will be performed on the geochemical test units are whole rock analysis, static testing, short-term leach testing, and kinetic testing.

Whole rock analysis includes analyzing the samples for potential contaminants of concern and major element chemistry in each test unit. Results from whole rock analysis can be used to define constituents of concern. Whole rock analysis should be performed on the identified geochemical test units, including the ore, tailings, and leached heap materials.

Static testing is then performed on potential sources of acid drainage, including waste rock, pit wall rock, underground working wall rock, tailings, ore, leached heap materials, and stockpile materials. The number of samples for each unit will be defined by the volume of material to be generated. For acid-generation potential (AGP), the modified Sobek method using total sulfur is recommended. The mineralogy and composition of the sulfides should be confirmed using mineralogic analysis. For the acid-neutralizing potential (NP), the modified Sobek method, and the Lapakko modification for siderite, are recommended. Carbonate and silicate mineralogy should be confirmed using mineralogic analysis. For interpretation of static test results, mineralogy should be used to stoichiometrically modify the AGP and NP results. For example, if sulfides are present that will not generate acid, or if sulfur is present from organic or non-acid-generating sulfate salts, the AGP should be reduced accordingly. If the NP is from siderite or silicates, the NP should be reduced accordingly. At this stage of geochemical testing, no credit should be given for siderite or silicates, and the results should apply only to estimating the total potential acid generation and neutralization potentials. However, depending on the mineralogy and sulfide content, certain silicates in ultramafic rocks – olivine and lizardite – can neutralize low percentages of sulfide and could be given credit, if kinetic test work shows that these silicates can neutralize acidity at reasonable rates. Thus, at the static-testing stage, an "effective" NP should be assigned to olivine and lizardite on a contingent basis that requires confirmation through kinetic testing.

Another possible characterization test is short-term leach testing if it has been performed on materials that have had an opportunity to weather before the test is conducted. Short-term leach tests on fresh core, for example, have no significant relevance to field conditions for managed mine wastes. Results from short-term leach tests can be used to estimate the concentrations of constituents of concern after a short event (e.g., a storm event) but are not appropriate to use for estimation of long-term leaching. Standard short-term leach tests with a lower liquid:solid ratio (e.g., MWMP or BC SWEP modification – see Table 1) can be conducted on samples from each geochemical test unit. However, using first flush results from longer-term kinetic testing will help coordinate the short-term and longer-term weathering results and will allow the determination of weathering on a per mass basis. The leachate samples should be analyzed for constituents of concern (based on whole rock analysis and known contaminants of concern) using detection limits that are at least ten times lower than relevant water quality standards (e.g., for arsenic, which has a drinking water standard of 10 µg/L, the detection limit should be 1 µg/L or lower). Major cations and anions should also be determined on the leachate samples, and the cation/anion balance should be checked for each sample.

The last step in geochemical characterization is kinetic testing. The objectives of kinetic testing should be clearly defined. Kinetic testing should be conducted on a representative number of samples from each geochemical test unit. Special emphasis should be placed on kinetic testing of samples that have an uncertain ability to generate acid. Column tests are recommended over humidity cell tests for all aerially-exposed mined materials, including natural on-site construction materials, with the exception of tailings. However, either type of kinetic test can be useful depending on the objectives of the testing and if the available surface areas for reaction are determined in advance of the testing. Grinding of samples should be minimized to avoid exposure of acid-producing or acid-neutralizing minerals that would not be exposed under field conditions. If necessary, samples could be broken by hand or using another method so that the breaks occur, as much as possible, along preferential structures such as fractures. This is especially important if mineralogic analysis shows that the acid-generating and -neutralizing minerals are largely present in veins or as coatings along fracture surfaces. The dimensions of the column should be appropriate for the size of material in the sample.

Surface area, particle size distribution, and volume of the material in the column should be measured before the test begins. If not available already, the mineralogy and whole rock chemistry of each kinetic test sample should be defined. The particle size distribution for the kinetic samples can be performed using sieves. The overall available surface area for sulfides, carbonates, and silicates (and also within a given size fraction, if possible) should be determined on a small subset of samples. It is often the small size fractions (<~2mm) that will control weathering behavior on a short-term basis, and the larger size fractions that will control weathering/leaching on a longer-term basis (Diehl et al., 2004; Smith et al., 2000; see Table 1). Particle size distribution is needed not only for the test samples, but also for field-scale wastes. A field-scale particle size distribution can be estimated by direct measurement (sieving) or calculated from the blasting plan. During the column test, pH, specific conductance, effluent volumes and flow rates, and all constituents of concern (as defined by whole rock analysis and leach testing) should be determined for each sample of column effluent. Detection limits should be at least ten times lower than relevant standards, and major cations and anions should also be determined in order to check for cation/anion balance. Secondary minerals should be identified in column material at the beginning and at the end of the column test. The tests should be conducted for one to two years, or until effluent pH values drop below 4.5 or contaminant concentrations are greater than ten times relevant standards.

For the interpretation of column tests, the tests should be continued until effluent parameter values are relatively constant with time. The amount of sulfide and carbonate (or neutralizing silicates, if relevant) depleted over the course of the test should be noted to ensure that sulfide grains have been sufficiently weathered. Initial concentrations and pH values should also be noted, as these "first flush" concentrations and values are relevant for behavior in storm events. The effect of secondary mineralogy on oxidation and dissolution rates for minerals of interest should be evaluated for use as inputs to geochemical or mass balance models. Weathering rates from kinetic tests should be applied to field-scale materials and on a surface-area basis.

Humidity-cell tests can be used for aerially-exposed tailings, without grinding the samples. Tests should be conducted on well characterized samples, and the objectives of the test should be defined. The same measurements of surface area and volume, mineralogy and whole rock chemistry, and effluent parameters, volumes, and flow rates, and length of testing are relevant for both column tests and humidity cell tests. For waste rock and heap or dump leach materials, field-scale kinetic tests (e.g., on pads) are recommended rather than humidity-cell tests. Minewall washing can be used to evaluate leaching from the walls of open pits. Loads, weathering rates, and concentrations in leachate from the field-scale test should be measured over time and related to site climate/meteorology. For example, leachate should be collected during or immediately after a storm event. The surface area of material in the field test should also be measured before the test begins. For subaqueously deposited non-tailings materials (e.g., waste rock), continuous flow-through tests can be conducted (see, e.g., Newbrough and Gammons, 2002). Batch tests can be used for subaqueously-deposited tailings.

The results of the characterization tests should be applied to the block model of the deposit or to a watershed model of the mine to predict the ability of the wastes or mined materials to generate acid and contaminants across the entire mine site and to affect specific drainages or groundwater. Any new materials encountered in mining will require full characterization, as described above.

7.0 MODELING TOOLBOX

A scientific model is a testable idea, hypothesis, theory, or combination of theories that provide new insight or a new interpretation of an existing problem (Nordstrom, 2004). Therefore, a model is not necessarily limited to mathematical formulations or always performed on a computer. In addition, models should be able to explain a large number of observations while maintaining simplicity (Occam's razor), and are always a simplification of reality (Nordstrom, 2004).

As discussed in Section 2.0, predictions of the future using forward, or scenario, (non-scientific) modeling cannot be checked until the future comes to pass. However, regulatory agencies can directly or indirectly require the use of forward modeling at some level as part of ensuring that mining operations will not contaminate groundwater and surface water resources. Predicting the effect of mine facilities and operations on future water quality often involves the use of multiple models to simulate the important processes occurring at the mine site. In many cases, the output from one model may be used as input for another model, or the models may be used iteratively to develop a prediction. In this document, a distinction is made between a code and a model. A code is a computer program, or set of commands, that is used to solve the governing equations that describe biological and physicochemical processes. A code is generic in the sense that it can be applied to many different sites, using different input parameters and conditions. A model is a simplified representation of the site-specific conditions at a particular site, and may be a conceptual model or one created using a computer code. For example, MODFLOW is a computer code that can be used to create a model of groundwater flow at a particular mine site.

Because codes are continually being revised, and new codes may be developed to replace older ones, this section is not intended to provide a complete review of all available codes, or to be an endorsement of any particular code. The codes listed in this section are examples of commonly applied codes that can be used to simulate specific processes at mine sites. This section describes the preparatory steps for predictive modeling (Section 7.1), available codes for predicting water quantity and quality (Section 7.2), modeling water quality from specific mine units (Section 7.3), and sources of uncertainty in modeling and recommendation for improvement (Section 7.4).

7.1 Preparatory Steps for Predictive Modeling of Water Quality at Hardrock Mine Sites

The stages in developing a predictive hydrogeochemical model of water quality for a mine site include developing a conceptual model and selecting an appropriate computational code; gathering site-specific geologic, geochemical, and hydrologic data and fundamental (e.g., thermodynamic) information as inputs for the model; verification and calibration of the model (for hydrologic models); and analysis of uncertainty.

7.1.1 Development of a Conceptual Model and Selection of Appropriate Predictive Codes

The conceptual model is the foundation and starting point of the creation of a model. As discussed in section 5, a conceptual model is a qualitative description of the hydrology and chemistry of the site and their effects on mined and natural materials. Models are always simplifications of reality, and a conceptual model may not be unique. The completeness of a conceptual model is limited and affected by numerous factors that must be considered and identified. The site conceptual model must be representative of the most important processes and reactions that will occur over time on the mine site, and it can change with time at the mine site and as more information is collected (Bredehoeft, 2005). The type of general information needed for such a model is depicted schematically in Figure 9.

The baseline conditions are those that exist before a project commences; in a number of cases, baseline conditions also include pre-existing mining sources. The modeler must determine the potential receptors and possible pathways through which contaminants travel from sources to receptors. The modeler must also identify the hydrologic and geochemical processes that operate on the sources, along the pathways, and in the receptors. The conceptual model also includes mine-project activities such as mitigation

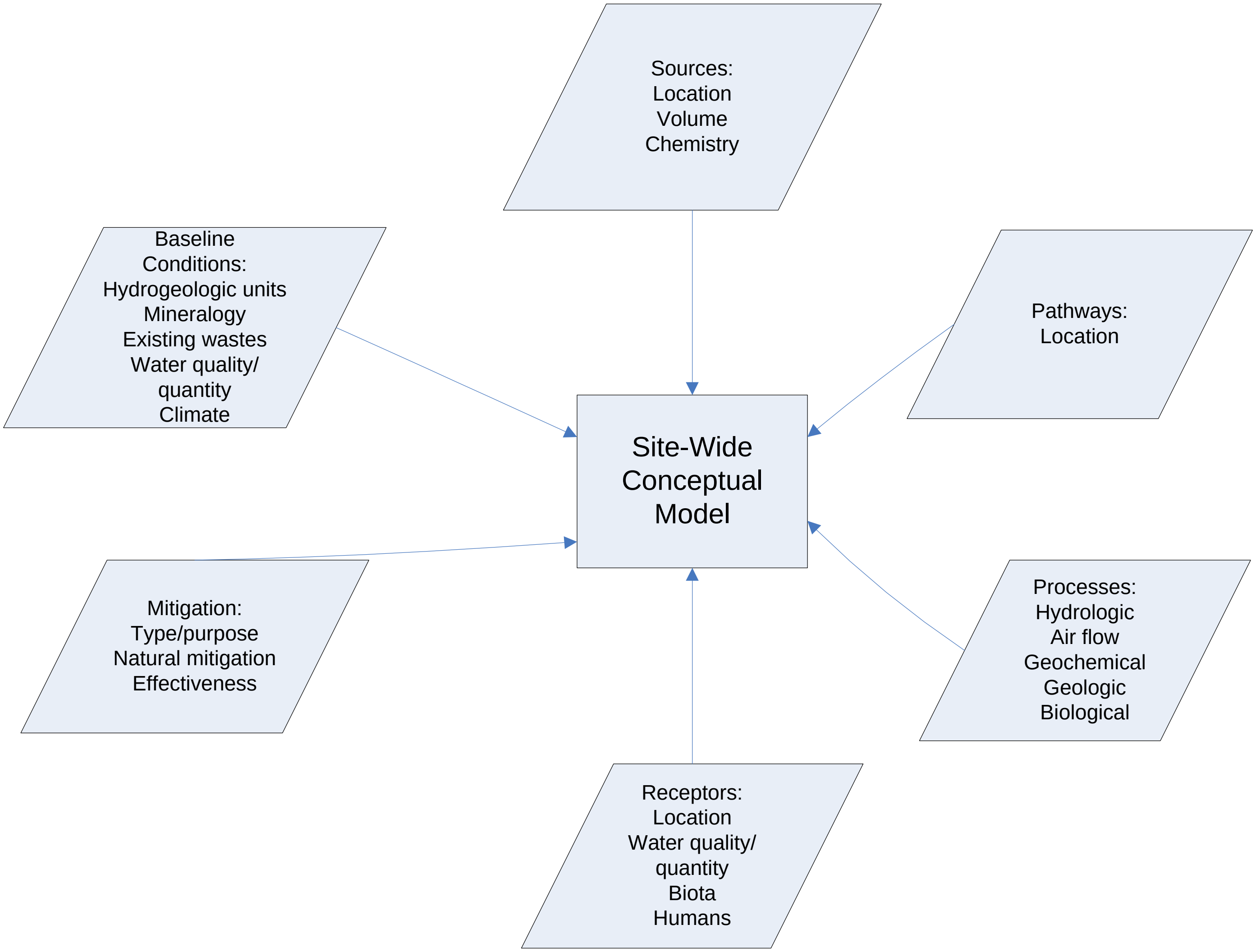

Figure 9. General information needed for development of a site-wide conceptual model.

measures and movement of process and mine-related waters at the site. The type of information needed for a site-wide conceptual model includes:

- Baseline conditions
  - Description of all geologic units (lithology/mineralogy)
  - Spatial characteristics of geologic units (e.g., depth, thickness, locations)
  - Physical, hydraulic, and geochemical characterization of any existing wastes or contaminant sources (including mineralogy, volumes, locations, physical characteristics, acid-drainage potential, contaminant-leaching potential)
  - Location and quality of springs and seeps, including seasonal/temporal variability in water quality
- Existing groundwater and surface-water quality, including seasonal/temporal variability in water quality
- Hydrology and hydrogeology, including depth to groundwater, composition and location of unsaturated zone and aquifers/aquitards; spring and stream flow rates, recharge/infiltration rates, groundwater flow directions and fluxes, gaining/losing reaches of stream, hydrologic parameters (hydraulic conductivity, porosity, permeability, etc.), seasonal/temporal variability of all hydrologic components, and the effect of man-made structures (e.g., dams, wells, intake structures) on water flows and levels
- Climatic conditions (precipitation, evaporation, climate type, seasonal/long-term climatic variability, dominant wind directions,

    - typical storm events, temperature) for locations at or close to mine
- Sources
    - Location, volume, mass, chemistry of proposed mining-related sources
    - Nature and extent of natural background sources
- Pathways
    - Possible travel paths from movement of contaminants from sources to receptors (e.g., air, infiltration, runoff, vadose zone, groundwater, transport in streams, transfer among solid and aqueous phases in groundwater and surface water)
- Processes
    - Hydrologic (e.g., advection/diffusion, dispersion, mixing, convection)
    - Geochemical (e.g., sorption, precipitation, dissolution, redox)
    - Air flow (e.g., movement of air into mined material/waste units)
    - Biological (e.g., uptake of contaminants by wildlife, aquatic biota; oxidation/reduction of contaminants by bacteria)
- Receptors
    - Streams, springs, lakes, groundwater, wildlife, aquatic biota, human, etc.
    - Location
    - Quality and quantity (covered under baseline conditions)
    - Interconnectedness of receptors
- Mitigation
    - Proposed mitigations for mine units
    - Natural mitigation (e.g., dilution in surface water/groundwater, adsorption onto alluvial material)
    - Effectiveness of mitigation measures

Predictive water-quality models are nearly entirely dependent on the conceptual model on which they are based and on the parameterization of the different geochemical or hydrogeologic units (e.g., alteration zones superimposed on lithologies) in the model (in other words, how the characteristics of aquifers or other geologic units are represented in the model, including thickness, hydraulic properties, ability to sorb contaminants, etc.). In many cases, there may be more than one conceptual model that could fit the data at the site, and it is important that these different conceptual models be tested (Neuman and Wierenga, 2003). The modeler should consider whether more than one conceptual model could be described and if collection of additional information would better constrain the conceptual model. If the conceptual model is flawed, the model will be flawed, and its predictive capability will be questionable. New information can make an existing conceptual model invalid and lead to major uncertainties in terms of long-term predictions (Bredehoeft, 2005).

Selection and use of the most complex hydrogeochemical code to predict water quality at a mine site does not necessarily provide realistic predictions. As noted by Nordstrom (2004), the sophistication of software has outdistanced our capacity to evaluate, constrain, and test the software. Selection of a computer code to develop a prediction of water quality should be based on factors such as: 1) modeling objectives; 2) capability of the code to simulate important processes affecting water quality at the mine site, as described by the site conceptual model(s); 3) ability of the code to simulate spatial and temporal distribution of key input parameters and boundary conditions; 4) availability of the code and its documentation to the public; and 5) ease of use of the code, including availability of pre- or post-processors and graphical interfaces.

Prior to initiating a modeling project to predict water quality at mining sites, currently available codes should be reviewed, and a code should be selected that simulates the processes identified in the conceptual model that are relevant to the specific mine site. The overall objectives of the modeling project and the availability of supporting data should be considered in selecting a code. The code or codes chosen to predict water quality should be representative of the site (as reflected in the site conceptual model) and be applied at a level of complexity that is appropriate for the available data and the regulatory decisions that must be made. In many cases, available data may limit the code application, and it may be more appropriate to develop a less-complex, screening-level model when data are not available to support a more complex model. Some of the issues to consider when selecting a code include:

- What are the objectives and endpoints of the modeling
- What specific processes at the mine site will influence water quality, and what codes are capable of simulating these processes
- Whether reactions are better represented by equilibrium or kinetic codes (or both)
- Whether to use coupled or separate water quantity and quality codes

- The type and quality of environmental data available (or that could be collected) versus the type of data needed for the code
- Importance of colloids, microbiology, and transport by bacteria to resulting water quality
- Presence of graphical interfaces in codes and ease of use
- Availability of the code to others.

These issues are discussed in more detail in Sections 7.1.2 and 7.4.

7.1.2 Collection of Data for Modeling Inputs

Site-specific inputs to computer codes are needed to make a model that will have relevance to a given mine site. The quality and representativeness of input data will affect the results of the models. Site-specific inputs to hydrogeochemical codes used to predict water quality are similar to certain information needed for conceptual models and can include:

- Spatial characteristics of geologic or geochemical units (e.g., depth, thickness)
- Hydraulic characteristics (e.g., hydraulic conductivity, porosity, storage characteristics) of mined materials, aquifers, and vadose zone)
- Water (leachate) quality and quantity of contaminant sources
- Rate of leaching of contaminants from mined materials
- Rate of pyrite oxidation
- Mineralogy of mined materials
- Reactive surface area of wastes
- Presence and type of bacteria
- Oxygen diffusion rates
- Partitioning of contaminants between soil/rock/waste/sediment and water
- Groundwater and surface water quality and temporal variability in quality
- Groundwater and surface water flow and temporal variability in flow
- Depth to groundwater and distance to surface water
- If a pit lake will form, pit lake bathymetry and dimensions
- Climate data (precipitation, temperature, wind speed, solar radiation, etc.)
- Information on mitigations.

Issues related to site-specific inputs that may affect the accuracy of models are discussed in the Modeling Issues section (Section 7.4). The inputs required for specific codes or types of codes are included in Tables 3, 4, and 5.

Site-specific values used as inputs to codes must be as representative of the range of conditions at a mine site as possible. Modelers need to request and use input data that are appropriate for their conceptual model and provide a rationale for why the values used are appropriate for site-specific conditions. Modelers also need to explain how inadequacies in the characterization and input data used lead to uncertainties in predictions. Sensitivity and uncertainty analysis is discussed in Section 7.1.4.

In addition to site-specific data used as inputs to a code, data usually included in a code (e.g., thermodynamic data) should also be reviewed to ensure that the data are adequate for the intended purpose of the model and the site-specific conditions. Examples of data or parameters that can be included in hydrogeochemical codes include:

- Thermodynamic data, including thermodynamic data for secondary minerals (Perkins et al., 1995, p. 54), solid solutions, and aqueous species (e.g., iron, arsenic, selenium)
- Activity coefficient corrections capable of handling high-ionic strength solutions (e.g., Pitzer formulations) (Perkins et al., 1995; Alpers and Nordstrom, 1999)
- Reaction rate/kinetics data (Perkins et al., 1995; Zhu and Anderson, 2002) if non-equilibrium reactions are expected to be important
- Microbiological data (Nordstrom, 2000). The rate of production of acid, sulfate, and metals is dependent on the presence of microbes such as *T. ferrooxidans*. Information on rates with and without microbes can be used in certain codes.
- Geochemical reactions (e.g., sorption).

Hydrologic and geochemical data or parameters used in codes should be representative of site conditions and include parameters and reactions that are relevant for a given site. In most cases, a range of values (e.g., sensitivity analysis) will be needed to characterize the site, and an explicit evaluation of uncertainties in the data and model structure should be conducted (Section 7.1.4).

7.1.3 Code Verification and Model Calibration

A water-quality model is a simplified representation of the complex hydrologic and geochemical conditions at a mining site. The success of the model predictions will depend on how well the model represents the actual conditions and processes that influence water quality at the site. Verification of the modeling software and calibration of the selected model should be performed as part of hydrologic modeling; geochemical codes are neither verified nor calibrated, although test cases can be used to determine that the code is operating properly. "Verification" of the modeling software means that the code that is selected for the predictive modeling accurately solves the mathematical equations that describe the processes that the code simulates for conditions similar to those at the site in question. For hydrologic codes, the software is verified by comparison to analytical solutions for simple simulations, and this provides some assurance that the basic programming in the code is accurate. Modeling software may also contain "bugs" that will be identified and corrected as a code is used and applied by more users in more situations; therefore, more widely-used and available codes are generally more reliable in predicting water quality at mine sites.

Model calibration is the process of comparing site-specific observations (e.g., stream flows, groundwater elevations, or pit lake concentrations) with model simulations. Calibration includes adjusting model parameters (e.g., hydraulic conductivity or porosity) so that the output from the model reproduces observed field conditions (see, e.g., Hill, 1998). Several authors have suggested that environmental models can be calibrated but never validated. Oreskes and Belitz 2001) state that even the term validation is unfortunate, because "valid" implies a legitimacy that may not be justified.

At mine sites, much of the modeling performed is "forward" modeling, or modeling of conditions that do not yet exist. In the case of pit lakes, steady-state water quality and quantity conditions may not exist for hundreds of years, yet predictions about the quality of pit water are often required for regulatory purposes. Even though "final" water quality in pit lakes and other receptors may not develop for decades to centuries, water quality at other similar mines can be used to estimate the degree of uncertainty in the prediction. For example, limnologic and water quality conditions at existing pit lakes can be used to understand possible conditions at other mines where pit lakes do not yet exist. Wetting front migration and water in existing waste rock dumps can be used to understand possible conditions in future dumps. Inconsistencies with observed conditions are cause for concern. For example, if a model indicates that no seepage will be observed from a waste rock dump for hundreds of years, and toe seepage has been observed from existing waste rock dumps in the field, the model's predictive capability and degree of uncertainty should be questioned. After several years of site-specific data have been collected at the mine site, the model can be calibrated to a longer data record that will incorporate more temporal variability, and confidence in the model predictions can increase.

7.1.4 Estimation of Uncertainty

The inherent uncertainty in model predictions is rarely stated or recognized. Substantial uncertainty is inherent in determining many of the parameters that are required for modeling water-quality evolution at mining sites, especially hydrologic parameters such as hydraulic conductivity and recharge. Uncertainties in hydrologic modeling may be very large as a result of the inherent range in hydraulic conductivity and other hydrologic parameters, and the effects of these uncertainties on net water-quality predictions (via mass flux) need to be addressed in the uncertainty evaluation. The uncertainty may derive from incomplete characterization or incomplete knowledge of the geochemical and hydrogeologic conditions at the site. Many authors have written about the necessity of quantifying uncertainty in model predictions (Beven, 1993 and 2000; Draper, 1995; Kundzewicz, 1995; Meyer and Gee, 1999; Neuman and Weirenga, 2003). Methods used to evaluate or account for model uncertainty include Monte Carlo analysis, stochastic methods, and evaluating a range of model parameters to develop a range of deterministic outcomes (e.g., a range of water quality in a given receptor). These methods account for the fact that, rather than being well described by a single value as required in the model, parameters are better described with a probability distribution (i.e., a mean, variance, skewness, etc.).

Another aspect of uncertainty relates to estimating the efficiency of mitigation or remediation measures, which often cannot be completely quantified. The predicted water quality from a facility will in part determine what kind of mitigation measures will be taken. If the predictions aren't realistic, it is much harder to "retrofit" mine design than to make it right or prevent pollution in the first place. Adaptive management in the absence of predictions can be useful only if mitigations can be designed and implemented at a later date and be effective. Regulators will still need to rely on predictions for the initial design of the mine waste unit.

Model uncertainty should be acknowledged in predicting water quality at mining sites, and some methodology (conducting sensitivity analyses using a range of values as input parameters, Monte Carlo approaches) should be employed to evaluate the effect of uncertainty on model output. For example, a desired confidence level could be determined (e.g., 95%), and this confidence level on environmental data could be used throughout the model. The computer program Excel has add-ins that can be used to incorporate parameter distributions into a model for the evaluation of uncertainty. The add-ins include @Risk (available from www.palisade.com), and Crystal Ball (available from www.decisioneering.com). These approaches will be useful only if the uncertainty derives from site variability in parameters but will not address uncertainties in the conceptual model. Uncertainties in the conceptual model can be addressed by collecting as much site-specific hydrogeochemical data as possible and keeping an open mind to rethinking the original conceptual model (Bredehoeft, 2005).

7.2 Hydrogeochemical Models Used to Predict Water Quality at Hardrock Mine Sites

Many of the hydrogeologic and geochemical codes available for use in predicting water quality at hardrock mine sites are listed in tables 3 and 4, respectively. Table 3 lists the category and subcategory of hydrogeologic code (near-surface process, vadose zone, groundwater, limnologic, stream/river codes, sediment generation, and integrated hydrologic/watershed codes), commonly used codes, the inputs required, and the processes that are modeled/outputs. Table 4 lists the category of geochemical code (speciation and reaction path, pyrite oxidation, and coupled reaction path/flow codes), available codes, special characteristics of the codes, inputs required, and the type of simulation that the code performs. Figure 10 depicts a mine site, pathways, and receptors and shows where hydrologic and geochemical models are used at mine sites.

Table 3. Description of Selected Hydrogeologic Codes Used for Predicting Water Quality at Hardrock Mine Sites.

Category of Code	Subcategory	Available Codes	Inputs Required	Modeled Processes/Output
Near Surface Process Hydrologic Codes	Water balance (infiltration, runoff, evapotranspiration)	HELP (Schroeder et al., 1994a, b); SOILCOVER (MEND 1994) CASC2D; CUHP; CUHP/SWMM; DR3M; HEC-HMS (US ACOE 2000); PRMS; PSRM; SWMM; TR20	Precipitation, temperature, wind speed, incident solar radiation, vegetative cover (for evapotranspiration) (climate data can be estimated using CLIGEN or WGEN; USDA ARS); hydraulic conductivity/permeability of soil/geologic material; soil moisture storage and transmission requirements.	Partitioning of precipitation into runoff, evapotranspiration, infiltration; estimation of runoff, infiltration, evaporation rates through/from mine facilities and covers; estimation of amount of precipitation entering pit lake.
	Water balance (infiltration, runoff, evapotranspiration) + contaminant transport	SESOIL (Bonazountas and Wagner, 1981, 1984); PRZM 3 (Version 3, Carsel et al., 1984; US EPA, 2003a); HSPF (Bicknell et al., 1997); LEACHM (Wagenet and Hudson, 1987)	Same as above plus source concentrations/loads, initial soil concentrations, contaminant fate/transport parameters (e.g., adsorption, precipitation).	Quantity and quality of infiltration and runoff from/to mine facilities.
Vadose Zone Codes	Vadose zone percolation	1D codes: SESOIL; HELP; CHEMFLO-2000 (US EPA, 2003b); Hydrus-1D (U.S. Salinity Lab; Simonek et al., 1998); SWACROP (IGWMC); SWIM HEAPCOV (Sulphide Solutions); Unsat-1 (IGWMC); Unsat-H (Pacific Northwest Laboratory); 2D codes: Hydrus-2D (U.S. Salinity Lab); FEFLOW (Waterloo Hydrogeologic); SEEP/W (Geo-slope Intl., 1994); SUTRA (USGS); VS2D (Lappala et al. 1987; Healy, 1990; USGS)	Infiltration rates; any layering or heterogeneity in geologic materials; hydraulic properties of soils/geologic units such as moisture retention properties (measured or modeled).	Seepage through unsaturated portions of mine facilities (e.g., waste dumps) and underlying vadose zone .
	Vadose zone percolation and contaminant transport	SUTRA (USGS); VS2D/T (USGS, Lappala et al., 1987; Healy, 1990); FEFLOW (Waterloo Hydrogeologic)	Same as above plus quality of water entering the vadose zone and initial concentrations of constituents in vadose zone; parameters describing partitioning between soil/rock and water.	As above, but with contaminant transport.

Category of Code	Subcategory	Available Codes	Inputs Required	Modeled Processes/Output
Groundwater Codes	Groundwater flow	MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996; MODFLOW 2000); FEFLOW (Waterloo Hydrogeologic)	Hydraulic conductivity, porosity, storage characteristics, thickness of geologic units, areal recharge, surface water recharge, pumping or re-injection of water from wells, discharge to surface water; model boundaries (streams, flow barriers, etc.). For fracture flow/transport: also need fracture spacing, orientation, aperture.	Simulate mine dewatering and reflooding; flow and transport in saturated tailings.
	Groundwater flow + contaminant transport	MODFLOW with MT3D; MODFLOW-SURFACT; SUTRA (USGS); FEFLOW (Waterloo Hydrogeologic); FEMWATER (US EPA). Groundwater flow and solute transport in fractured rock: FRAC3DVS and FRACTRAN (Waterloo Hydrogeologic); TRAFRAP-WT (IGWMC)	Same as above plus contaminant input concentrations; dispersion properties of aquifer, retardation characteristics of contaminant. For fracture flow/transport: also need fracture spacing, orientation, aperture.	Contaminant transport and loading from a mine facility to groundwater or surface water.
Limnologic Codes	2D, finite difference hydrodynamic and water quality model.	CE-QUAL-W2 (Cole and Wells, 2001)	Detailed bathymetry, flow rates, climate data, nutrient concentrations of inflows.	Can be applied to rivers, lakes, reservoirs, and estuaries to simulate nutrient/primary productivity of lakes and mixing characteristics (e.g., turnover), sediment, eutrophication kinetics.
	1D (DYRESM) or 3D (ELCOM) hydrodynamic and aquatic ecological (CAEDYM) models	DYRESM/ELCOM-CAEDYM (University of Western Australia, 2005)	Nutrient and suspended sediment concentrations; Fe, Mn, Al concentrations; dissolved oxygen; biota (e.g., zooplankton, fish, macroinvertebrates, algae).	Primary/secondary production, nutrient and metal cycling (Fe, Mn, Al only), oxygen dynamics, sediment movement, changes in biomass.

Category of Code	Subcategory	Available Codes	Inputs Required	Modeled Processes/Output
Stream/River Codes	Streamflow/ quantity	Single-event rainfall-runoff codes: HEC HMS (US ACOE, 2000); TR-20, TR-55 (USNRCS). Continuous streamflow simulations: SWRRB (USDA); PRMS (USGS); SHE (European Hydrologic System code). Flood hydraulics codes: HEC-2 (US ACOE); FLDWAV (US Nat. Weather Service).	Channel geometry, flow data, tributary flow data.	Flood hydrograph simulation from a specific hydrologic event. Simulate continuous streamflow, effect of transient runoff events on streamflow, evapotranspiration changes in soil moisture, base-flow recharge. Flood hydraulics: predict surface flow in rivers and engineered channels.
	Stream water quality and quantity	WASP4 (US EPA); OTIS-OTEC (USGS); SWMM (US EPA); Mike-11 (Danish Hydraulic Institute)	Point and non-point contaminant source data; concentrations in stream and tributary inputs, temporal streamflow data; channel geometry; sediment/water contaminant partitioning.	Fate and transport of constituents in surface water.
Sediment-Generation Codes	Soil erosion from rainfall and overland flow	Revised Universal Soil Loss Equation-RUSLE (USDA ARS National Sedimentation Laboratory)	Soil characteristics, slope, rainfall/runoff relationship.	Sediment production rates.
Integrated Hydrologic/ Watershed Codes		MIKE SHE (British Institute of Hydrology, Danish Hydraulic Institute); PRMS/MMS (Leavesley et al., 1981; 1983; USGS); HSPF (Bicknell et al., 1997; US EPA)	Same as near-surface process and groundwater codes.	Simulate all components of hydrologic flow regime (snowmelt, overland, channelized, unsaturated/saturated zone flow) and interaction between components.

Table 4. Description of Selected Geochemical Codes Used for Predicting Water Quality at Hardrock Mine Sites.

Category of Code	Available Codes	Special Characteristics	Inputs Required	Modeled Processes/ Outputs
Geochemical Speciation and Reaction Path Codes	WATEQ4F v.2 (Ball and Nordstrom, 1991 and database updates)	Most complete mineral database for acid drainage, redox species; database updates for uranium, chromium, and arsenic redox species.	Variable, can include: concentrations in inflows and other waters of interest (filtered), pH, temperature, redox species concentrations and/or Eh, mass and surface area, identity of minerals, infiltration rates/volume, reactive surface area; bacteria, rate constants.	Estimate concentrations of species in solution, amount of minerals precipitating from solution/dissolving from rock, pH, Eh, amount adsorbed to/desorbed from solids.
	MINEQL (Schecher and McAvoy, 1991); MINEQL+ v. 4.5 (Environmental Research Software, 2005)	Basis for MINTEQ (along with WATEQ); v. 4.5 is windows MINTEQA2 with a user interface for relational databases; temp = 0-50°C, ionic strength <0.5M.		
	MINTEQ (Allison et al., 1991)	Most complete ion exchange and sorption, supported/approved by EPA, with PHREEQE, most often applied to acid drainage problems.		
	HYDRAQL (Papelis et al., 1988)	Speciation, adsorption, organic ligands.		
	Geochemist's Workbench (Bethke, 1994; 1996 - REACT is mass transfer module)	Can include bacteria, Pitzer formulation, evaporation, mass transfer, isotopic calculations, temperature dependence for 0-300°C, sorption, complex kinetics and decoupled redox reactions.		
	PHREEQE/PHRQPITZ (Parkhurst, 1995; Plummer and Parkhurst, 1990); PHREEQC v. 2 (Parkhurst and Appelo, 1999)	With MINTEQ, most often applied to acid drainage problems, includes Pitzer formulation, can define kinetic reactions, mass transfer, reaction path, ion exchange fluid mixing, sorption, solid-solution equilibria, 1D transport, inverse modeling (NETPATH; Plummer et al., 1991; Parkhurst, 1997), carbon isotope compositions.		
	SOLMINEQ.88 (Kharaka et al., 1988); SOLMINEQ.GW (explained in Hitchon et al., 1996)	Most user-friendly, Pitzer, organic ligands, covers temperature range from 0-350°C and 1-1,000 bar pressure, mass transfer options (fluid mixing, mineral precipitation/dissolution, ion exchange, sorption).		
	GEOCHEM (Parker et al., 1995)	Speciation and mass transfer, adsorption, soil-water interactions.		

Category of Code	Available Codes	Special Characteristics	Inputs Required	Modeled Processes/ Outputs
	EQ3/6 (Wolery and Daveler, 1992)	Path-finding, Pitzer, evaporation, solid solution, best documented mass transfer program, kinetics, organic species.		
	SOLVEQ-CHILLER (Spycher and Reed, 1990a and b)	Reaction of fluids with solid phases, mixing of fluids, gases, evaporation, boiling, requires user to define rates and step size for reactant addition.		
	PATHARC (Alberta Research Council; Bill Gunter and Ernie Perkins)	Most user-friendly reaction path program, dissolution/ precipitation kinetics and equilibrium reactions, gases, evaporation; isothermal, does not include solid solution.		
Pyrite Oxidation Codes	PYROX implementation of the Davis/Ritchie shrinking core model (Wunderly et al., 1995)	Simulates diffusion-limited pyrite oxidation only.	Geometry/structure of waste rock dump, pyrite content, particle size distribution, water content of rock matrix, estimates of diffusion rates of oxygen in bulk and rock matrix.	Simulate generation of acid and sulfate from oxidation of sulfides in mine units; results used with kinetic test results to estimate release of metals from oxidation; effects of barometric pumping not incorporated into the models.
	Davis/Ritchie approach (Davis and Ritchie, 1986; Davis et al., 1986; Davis and Ritchie, 1987; Ritchie, 2003)	Simulates oxygen diffusion as only mechanism for pyrite oxidation using analytical solutions.		
	FIDHELM (Kuo and Ritchie, 1999; Pantelis, 1993; Pantelis and Ritchie, 1991)	Simulates oxygen diffusion and convection as mechanisms of pyrite oxidation; output also tracks temperature.		
	TOUGH AMD (Lefebvre et al., 2002; Lefebvre and Gelinas, 1995)	Simulates unsaturated water flow, oxygen diffusion and convection, heat generation and transfer, and solute transport.		
Coupled Reaction Path/Flow Codes	PHREEQM (Appelo and Postma, 1993)	1D, uses PHREEQE, no kinetics, mixing cell, simple.	Variable, can include: infiltration rates, concentrations in inflows (e.g. kinetic test results and background groundwater), moisture contents, reactive surface area, porosity, hydraulic conductivity, soil hydraulic function parameters, diffusion coefficients, dispersivities, bacteria (if used in model),	Fate and transport of constituents in and downgradient of mine waste units, mineralogy, porosity, fluid composition.
	REACTRAN (Ortoleva et al., 1987)	1D, user-defined reaction rates, temperature gradients.		
	MPATH (Lichtner, 1985)	1D, concentration varies only with distance along flow path.		
	MINTRAN (Walter et al., 1994)	2D, uses MINTEQA2 but more rigorous calculation of flow/transport than PHREEQM, for transport in groundwater, assumes total equilibrium between fluid and rock, like PHREEQM, includes shrinking core model and 1D gas oxygen diffusion, kinetics.		

Category of Code	Available Codes	Special Characteristics	Inputs Required	Modeled Processes/ Outputs
	CIRF.A (Potdevin et al., 1992; University of Illinois)	2D, T and P corrections for thermodynamic properties, multiple rate laws; output = mineralogy, porosity, fluid composition, etc.	equilibrium constants, mineralogy of downgradient aquifer and mine unit, secondary mineral-phase formation (from reaction of mine seepage with aquifer minerals), rate constants, sorption/cation-exchange capacity.	
	1DREACT (Steefel, 1993)	1D, finite difference, steady-state and transient, uses rate laws.		
	FMT (Novak, 1993 and 1994)	2D, finite difference, can simulate flow through fractures, Pitzer and Extended Debye-Huckel activity coefficient corrections.		
	TOUGHREACT and TOUGH2-CHEM (Xu et al., 2001)	Can simulate acid generation and buffer reactions in unsaturated media, kinetics.		
	TOUGH-AMD (Lefebvre et al., 2001)	Designed specifically for waste rock and heap leach systems, includes heat generation by acid production and oxygen convection, no attenuation mechanisms.		
	KGEOFLOW (Sevougian et al., 1992)	1D, similar to 1DReact, uses simple kinetic equations, uses EQ3/6.		
	RETRASO (Saaltink et al., 2002)	Kinetics, sulfide mineral oxidation, transient flow, secondary mineral precipitation.		
Coupled Reaction Path/Flow Codes (cont.)	OTIS-OTEC (Runkel et al, 1996, 1999)	1D in-stream solute transport and stream-bank storage combined with MINTEQA2, can simulate redox chemistry and sorption.		
	RT3D (Clement, 1997)	3D, multi-species, reactive transport in groundwater.		
	SULFIDOX (based on Ritchie, 1994; see Appendix 1)	Release and attenuation of acid drainage in waste rock and heap leach pads.		
	MINTOX (Gerke et al., 1998)	Tailings, 2D, sulfide oxidation and transport, diffusive gas transport.		
	MIN3P (Mayer et al., 2002)	Update of MINTOX; Finite element, steady-state and transient, variably saturated, user-set rate laws, diffusive gas transport in unsaturated zone, kinetics, sulfur redox, pH buffering, can define rate expressions.		
	MULTIFLO (Lichtner, 1996)	Comprehensive general-purpose code of reactive transport, kinetic dissolution of aluminosilicate minerals.		

Category of Code	Available Codes	Special Characteristics	Inputs Required	Modeled Processes/ Outputs
	PHAST (USGS)	3D transport; combines solute-transport code HST3D (Kipp, 1998) and iterates at every time step with PHREEQC.		
	CRUNCH (Steefel, 2000; see Appendix 1)	Unsaturated-zone processes, can simulate release and attenuation of acid drainage.		
Biogeochemical and Reactive Transport Codes	BIOKEMOD (Salvage and Yeh, 1998) coupled to HYDROGEOCHEM (Yeh and Tripathi, 1989)	Simulation of reactive transport modeling with biogeochemical transformation of pollutants in groundwaters.		Complexation, adsorption, ion-exchange, precipitation/ dissolution, biomass growth, degradation of chemicals by metabolism of substrates, metabolism of nutrients, and redox, biogeochemical transformations in groundwater.

Alpers and Nordstrom (1999) provide a review of the history of geochemical codes used to simulate water-rock interactions in mining environments. Nordstrom (2004) provides a good summary of geochemical modeling approaches and available codes, some of which are summarized in Table 4. Some of the codes listed are no longer in use and have been superseded by newer versions or by codes that use different approaches. Mayer et al. (2003) provide a history and recent summary of reactive transport modeling. Web resources for obtaining selected environmental codes are presented in Appendix 1.

A general type of modeling that can incorporate hydrologic, geochemical, economic, and other types of codes and models is dynamic modeling. Dynamic modeling can be used to see how systems change over time and can be useful when evaluating oscillating systems and systems with feedback loops. An example of a feedback loop would be the oxidation of pyrite to form ferric iron, which in turn would oxidize pyrite. The filling of an open pit with water after mining can be simulated using dynamic modeling. A dynamic model can be set up so that discharge of pit water to groundwater would occur at a certain pit water elevation or volume, and this in turn would change groundwater chemistry. Dynamic modeling codes vary in cost and complexity, ranging from Vensim to STELLA (probably the most widely used in the mining industry) to GoldSim, which is the most expensive and the most comprehensive of the currently available dynamic models (see Appendix 1). One potential drawback of dynamic modeling is that because there is no standard way to assemble a dynamic model and because they can become so complex (because of pulling in many types of information), they can become difficult to evaluate or replicate. However, for understanding systems with temporal and other types of changes, they are a valuable addition to the modeling toolbox.

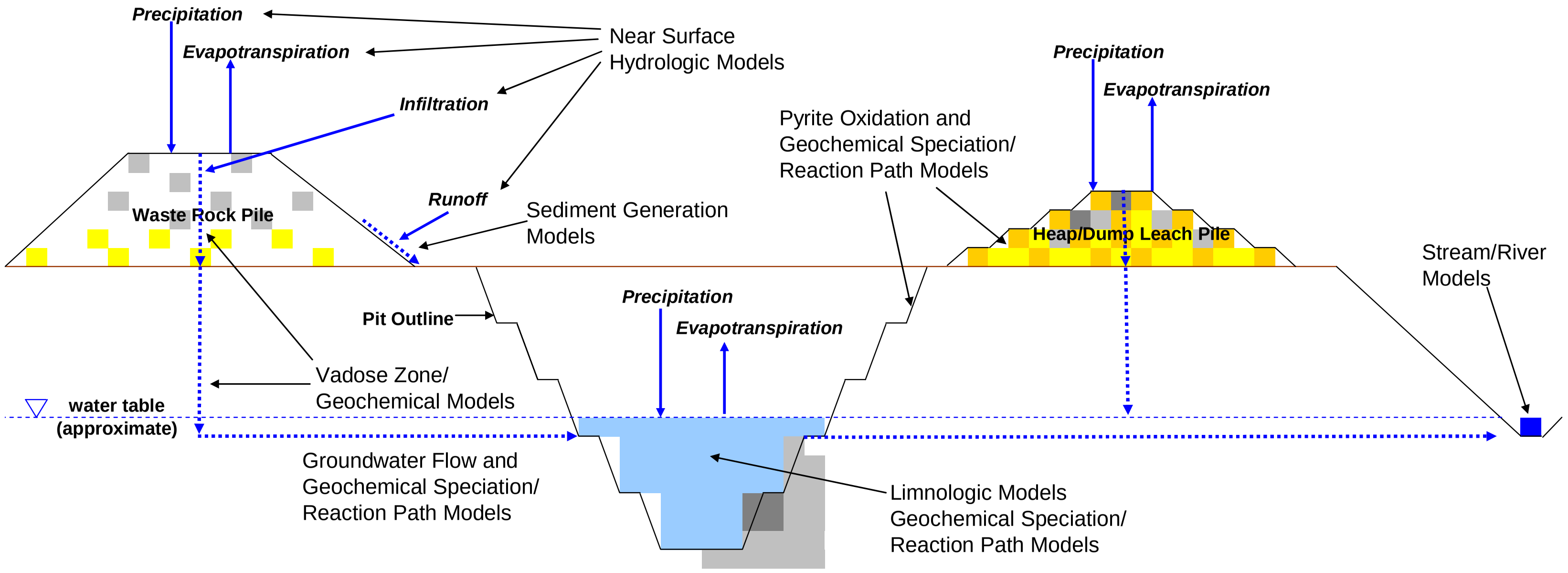

Figure 10. A mine site, pathways, and opportunities for hydrologic and geochemical modeling, using codes in Tables 3 and 4.

7.3 Modeling Water Quality at Specific Mine Sites

The geochemical characterization and modeling tools discussed in Sections 6 and 7 can be used to predict water quality in and from specific mine units or facilities at hardrock mine sites, such as waste rock piles, pits, heap leach pads, and tailings impoundments. The modeling of water quality in or emanating from mine units requires the use of a combination of hydrogeologic and geochemical modeling approaches and inputs from site characterization studies. In some cases, codes have been created to predict water quality from specific mine units. Such codes couple and combine the basic codes shown in Tables 3 and 4 (coupled hydrologic and geochemical codes are also listed in Table 4). As discussed in the following section, there are issues with coupling hydrologic and geochemical processes, as is generally done in facility-specific codes. Modeling of waste rock piles is especially challenging because of physical and chemical heterogeneities and the fact that local equilibrium is not universally applicable (Perkins et al., 1995). Table 5 lists, by mine facility, the types of water-quality predictions that are typically performed using models; the characterization and modeling inputs required for these predictions; the potentially applicable hydrogeochemical codes; and any facility-specific codes that are available.

After the development of a conceptual model and the gathering and checking of model input data, the use of a hydrogeochemical code to predict water quality requires entering site-specific characterization data into a computer code. General step-by-step procedures for predicting water quality related to pit lakes, dry pits, underground workings, waste rock dumps, tailings impoundments, and heap leach facilities are included in this section. Refer to Table 5 for facility-specific inputs to codes (geochemical and hydrologic characterization), potentially applicable hydrogeochemical codes, and available facility-specific codes.

The prediction of water-quality in a mine facility and in downgradient groundwater and surface water involves the following general steps. Depending on the modeling objectives, not all steps may be required:

1. **Develop site-specific conceptual model:** Develop a conceptual model for prediction of water quality from the mine unit of interest (see Section 7.1). Identify all significant processes and pathways that could influence water quality. Also determine the end point of modeling (e.g., composition of pore fluid in tailings impoundment vs. concentrations of constituents at a receptor). The modeling end point will determine which of the following steps need to be implemented.

2. **Characterize hydrogeologic and chemical conditions:**

   - Estimate the length of time that mined materials will be exposed to the atmosphere, based on the mine plan
   - Determine the geochemical test units
   - Characterize the geology, geochemistry, and hydrology of the facility and the site using the relevant tests and procedures described in Table 1, Section 6.4, and Section 7.1.
   - Determine the number and type of hydrogeologic units
   - Estimate sulfide mineral oxidation rates during exposure (ideally using laboratory-measured rates on site-specific materials (e.g., from long-term kinetic testing) or field-scale measurements
   - Evaluate contaminant releases (constituents, rates, and chemical mass load) from mined material using results from kinetic tests and/or water quality samples
   - Assess chemical loads and volume of water from any other water sources entering the facility, if relevant (e.g., tailings pond seepage, process water, stormwater runoff collected from mine area or waste rock, water pumped into the pit to enhance/accelerate pit infilling).

Table 5. Application of Characterization and Modeling Toolboxes to Modeling of Water Quality at Mine Units.

Mine Unit	Water Quality Prediction	Characterization/Modeling Inputs	Potentially Applicable Codes	Available Facility-Specific/Reactive Transport Codes
Pit Lakes and Backfilled Pits (at least partially below the water table)	• Pit water quality over time • Downgradient water quality (if pit lake discharges to groundwater) • Surface water quality (if pit lake discharges to springs, streams, lakes)	• Pit wall mineralogy, specifically sulfide content • Inflowing groundwater quality and quantity; exiting groundwater flow rate • Rate of rise of water in pit • Release rates from wall rock • Release rates from backfill, if relevant • Oxidation rate of sulfides in wall rock • Quantity and quality of water entering pit due to runoff from pit high walls • Precipitation rate • Evaporation rate • Pit dimensions • Pit lake limnology/ hydrodynamics • Mitigation (e.g., enhanced filling, partial backfill) • Groundwater transport characteristics, if pit lake discharges to groundwater • Surface water characteristics, if pit lake discharges to surface water	1,2,3,4,5,7,8,9, 10	• Proprietary codes typically developed by consultants to the mining industry. • There is no publicly available, commonly used model for simulating pit lake water quality, with the exception of MINEWALL (MEND, 1995), but it does not calculate chemical speciation and geochemical reactions in the pit water, nor does CAEDYM (University of Western Australia, 2005).
Underground Workings/Dry Pits	• Water quality in underground workings, if flooded • Runoff/infiltration from dry pits • Downgradient water quality (if underground working/dry pit infiltration impacts groundwater) • Surface water quality (if underground working/dry pit infiltration impacts springs, streams, lakes)	• Wall rock mineralogy, specifically sulfide content • Release rates from wall rock Oxidation rate of sulfides in wall rock • Inflowing groundwater quality and quantity • Rate of flooding of mine workings • Groundwater elevation/depth over time • Groundwater transport characteristics, if UW/dry pit infiltration impacts groundwater • Surface water characteristics, if underground working/dry pit infiltration discharges to surface water • Releases/effects of plugging/backfilling, if relevant	2,3,4,6,7,10	• MINEWALL (MEND, 1995)

Mine Unit	Water Quality Prediction	Characterization/Modeling Inputs	Potentially Applicable Codes	Available Facility-Specific/Reactive Transport Codes
Waste Rock Dumps	• Potential for and quality of seepage from waste rock dumps • Downgradient groundwater quality • Surface water quality (if waste rock seepage impacts seeps, springs, streams, lakes)	• Waste rock mineralogy (sulfide content) • Oxidation rate of sulfides in waste rock • Chemical release rates from waste rock • Quantity and quality of waste rock seepage • Infiltration rates through unsaturated zone • Runoff (amount and chemistry) • Dump dimensions • Physical composition of waste rock dump • Mitigations (cover, liners, etc.) • Upgradient groundwater quality • Distance to water table over time • Distance to surface water • Characteristics of vadose zone and aquifer that affect hydraulics and transport • Groundwater transport characteristics, if waste rock seepage impacts groundwater • Surface water characteristics, if waste rock seepage discharges to surface water	1,2,3,4,5,6, 7,10	• ACIDROCK (Scharer, et al., 1994) • FIDHELM (Pantelis, 1993) • TOUGHAMD (Lefebvre, 2001) • SEEP/W and SOILCOVER (quantity only) • SULFIDOX (See Appendix 1)
Tailings Impoundments	• Tailings pore water quality • Potential for and quality of seepage from impoundments • Downgradient groundwater quality • Surface water quality (if tailings seepage impacts seeps, springs, streams, lakes)	• Tailings mineralogy (sulfide content) • Contaminant release rates from tailings • Dimensions of tailings impoundment • Tailings impoundment water management during mining and post-closure (presence of pool, degree of saturation) • Sulfide mineral oxidation rates • Liner specifications (release/zero discharge) • Surface water proximity • Distance to water table over time • Infiltration rate through unsaturated zone • Characteristics of vadose zone and aquifer that affect hydraulics and transport • Groundwater transport characteristics, if tailings seepage impacts groundwater • Surface water characteristics, if tailings seepage discharges to surface water	1,2,3,4,5,6, 7,10	• WATAIL (Scharer et al., 1993) • RATAP (Scharer et al., 1994) • MINTRAN (Walter et al., 1994) • MIN3P (Mayer et al., 2002)

Mine Unit	Water Quality Prediction	Characterization/Modeling Inputs	Potentially Applicable Codes	Available Facility-Specific/Reactive Transport Codes
Heap Leach Facilities	• Potential for release from heap leach facility (often designed to be zero-discharge) • Quality of runoff/seepage water • Downgradient groundwater quality • Surface water quality (if heap leach pad seepage impacts seeps, springs, streams, lakes)	• Concentrations of constituents in process solutions • Contaminant release rates (from kinetic tests) • Liner specifications (permeability/hydraulic conductivity) • Upgradient groundwater quality and quantity • Dimensions of heap • Distance to groundwater over time, and surface water • Heap leach pad water management during mining and post-closure (presence of pool, degree of saturation) • Infiltration rates through heap after closure • Characteristics of vadose zone and aquifer that affect hydraulics and transport • Groundwater transport characteristics, if heap leach seepage impacts groundwater • Surface water characteristics, if heap leach seepage discharges to surface water	(1,2,3,4,5,6, 7,10)	• FIDHELM (Pantelis, 1993) • TOUGHAMD (Lefebvre, 2001) • SULFIDOX (See Appendix 1)

Refer to Tables 3 and 4 for specific codes. 1 Equilibrium thermodynamic geochemical codes 2 Mass transfer codes 3 Coupled mass transfer/flow codes 4 Pyrite oxidation codes 5 Near surface process hydrologic codes	6 Vadose zone codes 7 Groundwater codes 8 Watershed codes 9 Limnologic codes 10 Stream/river codes

3. **Determine mass fluxes into the facility:**

   - Determine *water balance* for the facility using basic meteorological data and numerical or analytical models. For pit lakes, estimate precipitation and evaporation from lake surface, runoff from pit high walls, groundwater flow rate into and out of the pit (if relevant), discharge rate of any surface water entering or leaving the pit. The water balance can be used to predict rate of inundation of pit walls with groundwater. For underground mines, estimate the rate of flooding of the mine workings. For tailings and waste rock, estimate the infiltration of meteoric water into the facilities.

   - Determine *chemical releases* to the unit from mined material outside of the facility, using short-term and/or long-term leaching data (depending on objectives) or water quality samples. For pits, these releases may be derived from oxidized wall rock, runoff from pit high walls, and possibly waste rock backfill. Oxidation of sulfide minerals in the walls of underground workings and dry pits may also release metals and acid to the environment. Run-on water entering tailings and waste rock facilities may be affected by leaching of upgradient mined or unmined materials.

   - Determine *mass flux rates into facility*. For pits or underground workings, determine the amounts of contaminants entering the facility from surrounding groundwater and run-on by combining fluid flow rates and representative water-chemistry values for each flow component. This provides both a water and chemical mass flux input to the facility.

4. **Determine water quality in the facility:** If water quality samples are available, and the modeling endpoint is downgradient of the facility, modeling of water quality in the facility may not be required. If water quality in the facility is a modeling endpoint (e.g., pore water quality for waste rock, tailings, leach dumps; pit or mine water quality for pit lakes and underground workings), use inflowing water chemistry (if relevant), releases from mined material, and water balance information. A mass-balance geochemical code (e.g., PHREEQE) can be used to mix waters and calculate concentrations of constituents, taking precipitation and adsorption into account. Include an uncertainty analysis in the prediction of water quality. Consider physical, chemical, and biological processes that can change the water quality within the facility. For example, in pit lakes, limnologic conditions in the lake may influence water quality. If relevant, limnologic conditions in the lake can be predicted over time using empirical observations on analogue lakes in the area, or using a numerical or analytical lake model.

5. **Evaluate mass fluxes out of the facility:** Evaluate migration of contaminants from the mine unit. For waste rock, tailings, or dry pits, this could require estimating water and chemical mass fluxes discharging from the bottom or toes of the dump or tailings impoundment, or infiltrating through the floor of the dry pit. For a pit lake or flooded underground workings, the chemical mass flux out of the facility would be the amount of water and quantity of constituents released to groundwater or the vadose zone.

6. **Evaluate migration to environmental receptors:** Environmental receptors include groundwater and surface water resources where water will be used by humans or wildlife, or where water quality standards are relevant (e.g., points of compliance). In some cases, a receptor can be pit water (discussed in 4 above). If considering vadose zone transport to groundwater (mass flux from facility initially enters vadose zone rather than groundwater), use an unsaturated zone flow and transport analytical or numerical code (see vadose zone percolation and contaminant transport codes in Table 3). Downgradient transport of constituents in groundwater can be evaluated using a groundwater flow and solute transport code, or a reaction path code (see groundwater flow + contaminant transport codes in Table 3). For evaluating potential surface water quality impacts, transport and mixing processes can be evaluated using a surface-water-quality code (see stream water quality and quantity codes in Table 3). In some cases, it may be necessary or desirable to link models that simulate water quality in different environmental media (e.g., groundwater and surface water), or to use an integrated hydrologic/watershed model. An uncertainty analysis should be included for the prediction of

water quality and quantity in the unsaturated zone, groundwater, or surface water.

7. **Evaluate effects of mitigation:** Assessing the effects of mitigations on the predicted water quality at downgradient locations may require creating a conceptual model for mitigations. Based on the conceptual model, values for releases of water and constituents from or to the facility can be modified. For example, if a cover will be added to a tailings impoundment at Year 10, the infiltration rates to the impoundment would need to be decreased after Year 10 in the model. Decreasing infiltration rates will affect the flux of constituents leaving the facility and migrating to receptors.

7.4 Sources of Uncertainty in Hydrogeologic and Geochemical Modeling and Recommendations for improvement

The computational capabilities of today's codes and advanced computers far exceeds the ability of hydrogeologists and geochemists to represent the physical and chemical properties of the site or to test the outcome of the model (Nordstrom, 2004; Oreskes, 2000). The degree of confidence in the models is severely limited in part because the models are so complex that they cannot be easily reviewed by regulatory staff and the public. Considering the difficulty in representing physical and chemical properties of mined materials, the meaning of "accuracy" in water-quality modeling must be reconsidered in the regulatory process. Many of the issues in modeling relate to the conceptual model of the mine site and the data used as inputs to the code, which have been discussed in Section 7.1. And, as discussed in the previous section, the uncertainties inherent in predictions should be evaluated as part of the modeling process. Predictions for conditions outside of the calibration data, such as those that occur in transient hydrologic systems (e.g., stream flows), are especially suspect. Regulatory decisions using models should recognize these limitations and be based on a conservative approach that takes into account the likelihood and consequences of all reasonably foreseeable outcomes.

Some of the major issues that affect uncertainty in modeling are discussed in the following section and address: general issues, including coupling of models, timeframe for predictions, and use of proprietary codes; issues related to modeling inputs, including hydrogeologic and geochemical inputs; and issues related to modeling limitations or lack of information.

7.4.1 General Issues

Coupling of models.

Problem Statement: Water quantity and water quality must be jointly considered in predictions of water quality at mine sites. Often, the uncertainty and variability in water quantity and flow are not adequately considered in predictive modeling of water quality. Coupling of water quantity and quality (and different aspects of each) in a reactive-transport model has certain advantages in terms of ease of use but may result in loss of information in dealing with a complex chemical system.

Background: Some codes couple different physical and chemical processes together such as flow, transport, and chemical speciation, whereas other codes simulate a smaller number of closely related processes, sometimes in more detail. The codes that couple hydrologic and geochemical processes are listed in Table 4 under the heading "Coupled Reaction Path/Flow Codes." In addition, some of the codes listed in Table 3 couple different hydrologic processes. For example, codes such as VS2DT and HSPF can simulate near-surface hydrologic processes as well as flow and transport in the vadose zone. These codes are useful in assessing solute transport in unsaturated waste rock and tailings, but they have simplified algorithms for computing the partitioning of rainfall into runoff, evapotranspiration, and infiltration - processes that can be assessed in greater detail and with a more extensive climate record in a code such as HELP. However, HELP contains a more simplified algorithm for simulating unsaturated zone flow. In general, the more sophisticated a code becomes, the more difficult it is to test its reliability (Oreskes, 2000). Coupling hydrologic and geochemical processes in a reactive-transport code can make it more difficult to add or delete a process and to independently choose time steps for the transport and chemistry functions. In addition, changes in one portion of the model, whether geochemical or hydrologic (e.g., calibration of the hydrologic portion of the model), may result in changes in the results that could be wrongly attributed to other processes.

However, coupling of codes in a reactive-transport model will allow the simultaneous treatment of all processes in time, physical space, and chemical reaction space (Mayer et al., 2003).

Recommendations: If separate codes are to be used for different processes or spatial or temporal domains, there must be a careful evaluation of how those codes are coupled so that the output will be useable. Site-conceptual models and modeling efforts should include the effect of varying water quantity on water quality. Often, prediction should be evaluated using both coupled and discrete-process codes to help determine processes that control critical model results, such as the movement of constituents through a waste rock dump.

Timeframe for predictions.

Problem Statement: Hydrologic and geochemical conditions change over time at a mine site. The timeframe over which predictions are made can vary considerably from site to site and for different predictions at the same site. Depending on the timeframe chosen, substantially different modeling results can be obtained.

Background: In many situations, the model-predicted water quality is influenced by the time frame over which the predictions are made. Particularly in arid and semi-arid environments, the impacts of mining on downgradient water quality may be delayed. For example, in waste rock, infiltrating precipitation will result in a wetting front migrating through the dump over time. This wetting front will provide a mechanism for the migration of oxidation products (i.e., sulfate and metals) through the waste rock dump. However, it may take tens to thousands of years for metals to migrate through a waste rock pile and the unsaturated zone and affect downgradient groundwater quality in an arid environment (Kempton and Atkins, 2000; Swanson et al., 1998). Pit lakes with no outflow will evaporatively concentrate over time, with concentrations of constituents of concern steadily increasing (Shevenell, 2000), and the length of time for future forecasts is a technical and policy issue (Kempton et al., 1996). In other cases, water quality may improve over time, due to increased dilution with uncontaminated waters, or depletion of unoxidized sulfide minerals. As an example of the importance of time frame in water-quality predictions, Scharer et al. (2000b) determined, through modeling based on laboratory experiments that the availability of neutralizing potential in mined materials affected the time period for onset of acidification. Simulations with 33% calcite availability began to produce acid after 12.5 years, while piles with 67% of the calcite available started to produce acid after ~30 years. Therefore, using identical simulation methods would produce different conclusions if a short-term (e.g., 10-yr) or a long-term (e.g., 500-yr) simulation period were chosen.

Furthermore, uncertainty in the model predictions increases as the timeframe for forward predictions increases. For longer-term predictions, such factors as global climatic change may influence water quality.

The time frame over which model predictions of water quality are to be made may be determined by a regulatory statute, such as a required period of post-closure monitoring. However, this does not provide assurance that the predictions will be made sufficiently far into the future to include delayed impacts. For example, CERCLA requires an assessment period of 30 years after closure at Superfund sites, and the Nevada Department of Environmental Protection has frequently adopted this timeframe for environmental impact assessments at mine sites. However, particularly in arid and semi-arid environments, impacts may not be predicted to occur for hundreds to thousands of years after mining ceases at a site.

Recommendation: To the extent possible, while still recognizing the uncertainty, predictions must be extended to the timeframe required by the regulatory context (such as 100 or more years for financial assurance determination purposes). However, timeframes for model predictions should not end at an arbitrary cutoff point (based on regulatory guidance or precedent, for instance), but rather should be based on the physical conditions of the modeled system. For example, pit lake chemistry could be modeled until steady state water quality is reached or certain ecological thresholds are exceeded. Models should be used to predict the timing and magnitude of impact from waste rock units even if these impacts are far into the future.

Use of proprietary codes.

Problem Statement: The use of proprietary codes prevents the independent examination by other consultants, regulators, and public interests and creates uncertainty about the legitimacy of modeling results.

Background: Codes used to predict water quality at mine sites can be categorized based on their availability, ownership, and restrictions on use. Some codes were developed by public agencies, such as the USGS and US EPA, and are available, free of charge, for use. These "public domain" codes are typically supported by the government agency that developed them, although they may also be sold and supported by another entity, such as the International Groundwater Modeling Center (IGWMC) or Scientific Software. In many cases, pre- and post-processors (i.e., user interfaces) for public domain codes have been developed to assist model users with developing model input files and viewing and processing the output from the models. Although some pre- and post- processors are available free of charge, many are only available for purchase through a company or other entity. Other codes have been developed by a specific group or company and can be purchased for use from that company or another entity. The code often is sold with pre- and post-processing software, a user interface, and is maintained and supported by that entity. Proprietary codes are developed by a group or company, and are used solely by that company. In general, these codes may not have been verified and have not been widely applied by the modeling community. According to Sverdrup and Warfvinge (1995), a "good" model is one that is transparent (possible to inspect and understand the rules and principles the model is using) and able to be tested (inputs can be defined and determined and outputs can be observed). On both counts, most proprietary codes fall short.

Recommendation: Codes developed by a group or company that are not available for sale or distribution outside of that company should not be used in predicting water quality at mining sites. These codes cannot be verified or tested by those outside of the company. It is uncertain whether such codes accurately simulate the processes that are important for predicting water quality at the mine site. They may have "bugs" that have not been identified by wide code use. Furthermore, because the code itself is not available, it is not possible for a reviewer to reproduce the model simulations. In the same vein, any code that is so expensive that it is not feasible for a reviewer to purchase or lease the code should be avoided. Codes used for prediction of water quality at mining sites should be available for purchase and use by anyone. Similarly, models created using available codes but that do not provide an understandable record of all inputs and approaches should not be accepted for use by regulatory agencies.

In most cases, several widely-available, reasonably-priced codes are available to simulate the relevant processes influencing water quality at mining sites. Some may argue that a specific proprietary code is necessary to simulate a specific process, and that no other more available codes simulate this process. In this case, the importance of the simulated process to the water- quality predictions should be carefully considered prior to selecting a proprietary code.

7.4.2 Issues Related to Modeling Inputs

A number of important issues related to modeling inputs are listed below, with abbreviated problem statements, background, and recommendations.

Hydrologic and hydrogeologic inputs

- *Limited data on aquifer properties*. Predicted contaminant transport rates in the vadose zone and groundwater are highly influenced by hydrologic parameters for geologic units in the models. For example, groundwater velocity is dependent on hydraulic conductivity values assigned to the aquifer materials. Hydraulic conductivity can range over many orders of magnitude, and, therefore, corresponding estimated transport rates can vary over many orders of magnitude. Hydraulic conductivity measurements of aquifer materials are often quite limited and may not be representative of different conditions within the aquifer. Pump tests and lithologic descriptions may provide initial hydraulic and transport parameters, but these must be fine-tuned by calibration. The uncertainty in hydraulic parameters should be acknowledged, and an effort should be made to account for uncertainty in the model predictions, as described in Section 7.1.4.

- *Improper representation of hydrogeologic units*. After a modeler parameterizes the hydrogeologic units, each unit typically is treated as completely homogeneous in the model. Within a hydrogeologic unit, aquifer properties and geochemical characteristics are effectively averaged over the unit. Hydrogeologically complex areas such as those with fractures or variable mineralization may require more units than more homogeneous areas. Alternatively, a range of aquifer properties and geochemical characteristics can be used for a single unit.

- *Simulation of recharge.* In arid environments, potential evaporation (i.e., the amount of water that could evaporate from a surface if the surface was perpetually wet) is greater than precipitation. However, this does not mean that there will be no infiltration or recharge to groundwater. Even in arid or semi-arid environments, infiltration can occur during precipitation events and be transferred to depths in waste piles beyond the evaporative zone, resulting in infiltration. The timing and nature of precipitation events are key determinants of whether water will infiltrate the surface of the facility or evaporate. The wetting front will move downward into the waste pile over time, bringing with it solutes dissolved from the waste material. The code used to simulate infiltration and percolation of meteoric water into mine facilities such as waste rock dumps must be sophisticated enough to account for infiltration resulting from individual storm events (e.g., HELP, HSPF, PRMS, MIKE-SHE).

- *Handling of preferential flow, macro-pores, and fractures in models.* Many hydrologic models assume uniform soil properties in geologic materials and are unable to simulate macro-pores, preferential flow, and fractures in the vadose or saturated zones, or in a groundwater aquifer. In many mining areas, the subsurface is composed of fractured bedrock. Although codes are available that simulate fracture flow and transport, application of such codes requires an extensive amount of data related to fracture density, aperture, and orientation that is not typically available at sites. In many cases, the fractured rock is assumed to behave as an "equivalent porous medium." This may be adequate for some sites, but could also result in inaccurate predictions of flow and contaminant migration. The inaccurate modeling of preferential flow paths and fractures could result in errors in prediction of flow and contaminant transport rates in the vadose zone or saturated zone. The prediction of flows in springs resulting from dewatering and groundwater rebound after mining are complicated by difficulties in accurately modeling flow along fractures and preferential flow paths. Even the most sophisticated code cannot accurately predict the fine detail of flow of fluids at a mine site, which may encompass thousands of hectares and billions of tons of rock, in the absence of currently-unattainable site-specific data. In many cases, preferential flow, macro-pores, and fractures control real-world flow (e.g., the location of springs), and the inability to model preferential flow represents a major shortcoming in water-quality predictions that must be acknowledged. Additional research is needed in this area if predictions are to be considered at all accurate or useful in determining potential for impacts and identifying mitigations to address such impacts.

Geochemical inputs

- *Completeness of water quality data used in modeling* (Perkins et al., 1995; Alpers and Nordstrom, 1999). Analytical data used to characterize groundwater, surface water, leachate, or porewater chemistry may not include all the important and necessary analytes. For example, if major cations and anions are not included, charge balances cannot be calculated, and a good charge balance is one indication that the laboratory analysis is adequate. A full analytical suite should be used for analysis of leachate from kinetic and short-term leach testing, and any identified constituents of concern should be included in the model. If thermodynamic data for an important constituent of concern is not present in the code, the modeler should consider modifying the database to include that constituent or selecting a code that has thermodynamic data for that/those constituents. If modeling is conducted using a limited water quality database, the user should state explicitly that the results do not adequately consider reactions involving the missing constituents.

- *Elevated detection limits.* For some minor and trace constituents, analytical detection limits can be higher than concentrations that could pose a risk to human health or the environment. For a number of mining-related metals, criteria for the protection of aquatic life can be lower than drinking water standards (e.g., copper, zinc, cadmium, lead), especially in low-hardness waters common in mountain streams. Detection limits should be substantially lower than the most protective and relevant water-quality standards.

- *Incomplete characterization of medium- and long-term environmental behavior of mined materials*. As noted in the geochemical characterization issues section, longer term leaching of metals, acid, and other constituents may not be well represented by results from acid-base accounting, short-term leach, or even kinetic tests. Extrapolation of data applicable to short-term conditions to longer-term conditions will add to uncertainty of longer-term water-quality predictions. Well designed long-term kinetic leaching tests should be conducted on representative materials that pose a potential threat to water quality, and results from these tests (including how leachate concentrations change over time) can be used as inputs to hydrogeochemical models.

- *Use of distribution coefficient (K_d) values in transport models*. Distribution coefficients, or K_d values, describe the tendency of dissolved constituents to adhere to solid surfaces (e.g., soils and aquifer materials) and are only relevant to equilibrium conditions (Stumm and Morgan, 1996), yet they have been used extensively to model fate and transport of kinetically controlled reactions in aquifers. K_d values are often taken from the literature rather than conducting site-specific experiments on adsorption/desorption reactions in alluvial and bedrock aquifers. Their improper use in hydrogeochemical models can produce errors in the prediction of contaminant transport rates in groundwater and of recovery times. Site-specific information on the transport of contaminants in aquifers and mined materials should be used as inputs to predictive models.

- *Application of characterization data as source terms to reaction path/mass balance models*. Steady-state pH values and concentrations from humidity-cell tests are often used as input data for geochemical reaction path or mass balance models. These inputs are used to predict future water quality based on laboratory or field-scale experiments. However, differences in weathering rates and reactants produced under field and laboratory conditions can cause large differences between experimental and actual conditions, especially if reactive surface areas are not included in the model. Applying an across-the-board scaling factor (e.g., 10^{-3} or 10^{-4}) to account for higher oxidation rates in laboratory tests (compared to field conditions) is not warranted without examining the longer term leaching behavior of the wastes. If appropriate long-term kinetic testing has been conducted (see Section 6.4), steady-state concentrations can be used without scaling factors, or site-specific scaling factors can be applied. A number of scaling issues are discussed in Section 6.3.1, Field and Laboratory Discrepancies.

- *Concentrations of contaminants that are affected by seasonal variability* (e.g., seepage and streams downgradient of mine facilities). The timing of precipitation events and other types of climatic processes can affect water chemistry. During dry periods, weathering products (secondary minerals) from the oxidation of sulfide minerals will accumulate in test piles, mine units, and unmined materials (Tremblay and Hogan, 2000). Early snow melt and storm precipitation following a dry period will flush these accumulated products from the piles and result in high concentrations of solutes and generally low pH values, while more continuous rain will result in a more constant volume of acid and other contaminants and lower concentrations in surface water and groundwater (Jambor et al, 2000; Maest et al., 2004). Sampling of mined materials, field-scale characterization tests, and water quality and quantity sampling must at least initially be conducted to capture the variability in seasonal and climatic conditions. A sensitivity analysis using linked end-members of the environmental data (i.e., concentrations and flows most likely to occur under, for example, high and low flow conditions) will better bracket actual field conditions than an average or median value.

8.0 THE STATE-OF-THE-ART IN PREDICTIVE MODELING

Over the last 20 years, the inner workings of hydrologic and geochemical codes have not changed substantially. Hydrologic and geochemical codes still solve the same basic equations and reactions that were identified 80 or more years ago. There have been improvements in the thermodynamic databases used in geochemical codes, in particular for clay mineral dissolution and precipitation and iron oxyhydroxide precipitation, and there have also been additions for the kinetics of dissolution using rate equations established in the laboratory. One of the most notable improvements in both hydrologic and geochemical codes are the operating systems (MS DOS vs. Windows) and the graphic interfaces, which allow more user-friendly operation of the codes and better visual output of the modeling results. In general, there has been movement toward the use of codes that will handle multiple processes simultaneously (e.g., coupled hydrogeologic and geochemical codes).

For modeling at mine sites, the most commonly used groundwater flow code is MODFLOW (MODFLOW 2000), and the most commonly used geochemical speciation and reaction path code is PHREEQE (Parkhurst, 1995; Plummer and Parkhurst, 1990; Parkhurst and Appelo, 1999). However, modelers can chose from a variety of hydrologic and geochemical codes, as shown in Tables 3 and 4, and from a number of coupled codes, as shown in Tables 4 and 5. Individual codes have slight advantages and disadvantages, depending on the application, but the experience of the modeler, the choice of input parameters and data (see Tiedeman et al., 2001 for guidance in selecting model input parameters for hydrologic modeling), and the interpretation of the modeling output are more important than the choice of the code itself.

A generalized flow chart for state-of-the-art modeling of water quality at hardrock mine sites is shown in Figure 11. Many of the steps have been discussed in more detail in Sections 6 and 7. The first step in predictive modeling is to identify the objectives of the modeling and develop a site (or unit) conceptual model (see Figure 7, Section 7.1.1). The next step is to gather geochemical, physical, and hydrogeologic input data for the geochemical test units and receptors (see Figure 7 and Section 7.1.2). An appropriate code is selected for predicting water quality from mine units and in receptors (see Tables 3-5, Section 7.1.1). Much of the input data for the model may already be available, but required inputs for the selected code(s) can help guide additional field and laboratory data collection.

Using site-specific input data, hydrogeochemical modeling is conducted to determine potential concentrations at receptors or other points of interest. A numeric uncertainty analysis should be conducted using possible ranges of input values. Presenting potential contaminant concentrations at receptors as ranges rather than absolute values will better reflect the uncertainty inherent in predictive modeling.

If the modeled ranges of potential concentrations are all below relevant water quality standards, additional mitigation measures will not be necessary (e.g., natural attenuation in aquifers or dilution may be sufficient to limit concentrations in receptors). However, when realistic modeled concentrations at receptors exceed water quality standards, mitigation measures will be necessary to ensure that concentrations of contaminants at receptors meet regulatory requirements. The efficacy of the mitigation measures should also be tested using predictive models and later confirmed with active monitoring. For this analysis, possible ranges in effectiveness of the mitigation measures (e.g., ranges in permeability values of liners) should be used in predictive models. If the mitigation measure is determined to be ineffective at limiting concentrations of contaminants at receptors, alternative mitigation measures should be chosen and tested again, using predictive modeling and active monitoring.

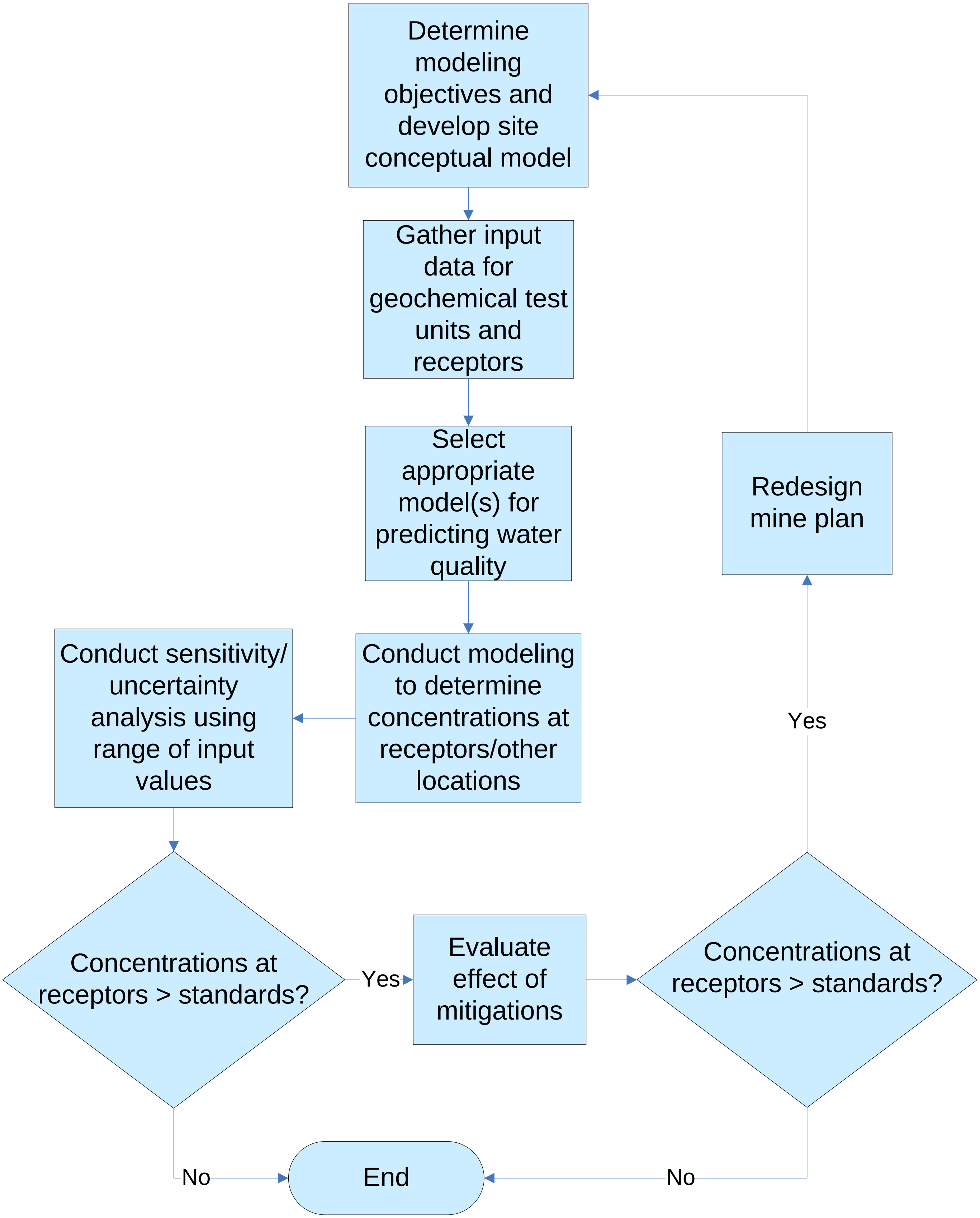

Figure 11. Steps for state-of-the-art predictive modeling at hardrock mine sites.

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Appendix 1. Web Resources for Environmental Models

Because model state-of-the-art and availability changes frequently, this appendix provides a list of web resources that offer up-to-date versions of models as well as the current availability status. This list is not meant to be comprehensive nor endorse any particular agency or vendor, but merely to provide information.

Models available from U.S. government agencies free of charge:

U.S. Geological Survey (USGS) Water Resources Applications Software (http://water.usgs.gov/software/). The software and related material (data and (or) documentation) are made available by the USGS to be used in the public interest and in the advancement of science. Models include assessment tools for groundwater (including the MODFLOW groundwater model and MT3D contaminant transport model), vadose zone flow and contaminant transport (VS2DT), continuous stream flow (HSPF and PRMS), geochemistry (PHREEQC) and water quality (OTIS). Many other models for specific applications are also available.

U.S. Environmental Protection Agency (USEPA) Center for Exposure Assessment and Modeling (CEAM) (http://www.epa.gov/ceampubl/). Models focus on groundwater (PRZM, MULTIMED) and surface water (QUAL2E, SWMM, WASP) quality and contaminant transport.

U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) (http://www.ars.usda.gov/) develops and distributes models to simulate erosion, crop production, and watershed hydrology. The Hydrology and Remote Sensing Laboratory also distributes the Snowmelt Runoff Model (SRM) that simulates the hydrograph in snowmelt dominated systems.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), http://www.nrcs.usda.gov/technical/techtools/, develops and distributes the TR-20 and TR_55 single-event rainfall-runoff models.

U.S. National Weather Service (http://www.nws.noaa.gov/) develops and distributes weather forecasting tools and flood models.

Hydrological models available from agencies and other entities for purchase:

Environmental Modeling Systems, Inc. distributes models developed by the U.S. Department of Defense and Brigham Young University including GMS (Groundwater Modeling System), SMS (Surface Water Modeling System), and WMS (Watershed Modeling System) (http://www.ems-i.com/home.html).

ESRI (the developers of the ARC-View and ARC-Info GIS software) have developed GIS based environments for rainfall/runoff models such as the U.S. Army Corps of Engineers HEC models (http://www.esri.com/news/arcuser/arcuser498/hydrology.html).

The Danish Hydraulic Institute develops and distributes watershed models for planning and flood management including MIKE SHE, MIKE BASIN, MIKE FLOOD, and MIKE 11 (http://www.dhisoftware.com).

The Centre for Ecology and Hydrology, Wallingford, United Kingdom develops and distributes a wide range of models (http://www.ceh.ac.uk/).

Waterloo Hydrogeologic distributes a variety of modeling tools and modeling environments for publicly available models primarily oriented toward groundwater (http://www.waterloohydrogeologic.com/index.htm).

Entities that distribute and provide support for models developed by government agencies or companies:

The International Groundwater Modeling Center at the Colorado School of Mines, Golden, Colorado, evaluates and distributes groundwater, geochemical and contaminant transport models (http://www.mines.edu/igwmc/).

Rockware distributes earth science software with more focus on geology, geochemistry and groundwater hydrology (http://www.rockware.com/).

The Scientific Software Group distributes groundwater, surface water and water quality models (http://www.scisoftware.com/).

Boss International develops and distributes public domain models such as the U.S. Army Corps of Engineers HEC models with a custom interface, the Danish Hydraulic Institute MIKE models, and the DOD/BYU GMS, SMS, and WMS models. (http://www.bossintl.com/).

Sources that describe characteristics and identify contact information for a wide range of hydrologic models:

The USGS Surface Water and Water Quality Models Information Clearinghouse (SMIC). Allows downloads of a number of models, including: CE-QUAL, DR3M, HEC, HSPF, MIKE, MIKE SHE, OTEC, OTIS, PRMS, QUAL2E, WASP5, and others. http://smig.usgs.gov/SMIC/SMIC.html

The Hydrological Operational Multipurpose System (HOMS) of the World Meteorological Organization (WMO), Geneva, Switzerland, (http://www.wmo.ch/web/homs/).

The University of Kassel, Germany, irrigation software database (http://www.wiz.uni-kassel.de/kww/irrisoft/irrisoft_i.html).

The University of Kassel, Germany index of ecological models, which contains a detailed section on hydrologic and contaminant transport models (http://eco.wiz.uni-kassel.de/ecobas.html).

The Batelle Memorial Institute environmental software resource list (http://terrassa.pnl.gov:2080/EESC/resourcelist/hydrology/software.html).

The United Nations University surface water modeling software list (http://www.inweh.unu.edu/inweh/environmental_software/surfacewatermodelling.htm).

The InfoMine technology web site (http://technology.infomine.com/hydromine/tools/GWModeling.asp).

Information for Specific Models:

Geochemist’s Workbench: www.rockware.com/catalog/pages/gwb.html.

SULFIDOX: www.ansto.gov.au./sulfide/sulfidox.html

CRUNCH: http://wwwearthsci.unibe.ch/ggww/WebCrunch/WebCrunch.htm

RT3D: http://bioprocess.pnl.gov/rt3d.htm

CAEDYM: http://www2.cwr.uwa.edu.au/~ttfadmin/cwrsoft/doc/caedym_science/index.html

MINEQL + v. 4.5: http://www.mineql.com/

Visual MINTEQ (a Windows version of MINTEQA2 v. 4.0, available at no cost from the Royal Institute of Technology, Sweden; supported by two Swedish research councils, VR and MISTRA): http://www.lwr.kth.se/English/OurSoftware/vminteq/

Vensim® PLE: www.vensim.com

STELLA: www.iseesystems.com

ModelMaker: www.modelkinetix.com

GoldSim: www.goldsim.com

This document is an unofficial consolidation of all amendments to National Instrument 43-101 *Standards of Disclosure for Mineral Projects*, effective as of June 9, 2023. This document is for reference purposes only. The unofficial consolidation of the Instrument is not an official statement of the law.

National Instrument 43-101
Standards of Disclosure for Mineral Projects

Table of Contents

PART **TITLE**

National Instrument 43-101
Standards of Disclosure for Mineral Projects

PART 1 DEFINITIONS AND INTERPRETATION

Definitions

1.1 In this Instrument

"acceptable foreign code" means the JORC Code, the PERC Code, the SAMREC Code, SEC Industry Guide 7, the Certification Code, or any other code, generally accepted in a foreign jurisdiction, that defines mineral resources and mineral reserves in a manner that is consistent with mineral resource and mineral reserve definitions and categories set out in sections 1.2 and 1.3;

"adjacent property" means a property

(a) in which the issuer does not have an interest;
(b) that has a boundary reasonably proximate to the property being reported on; and
(c) that has geological characteristics similar to those of the property being reported on;

"advanced property" means a property that has

(a) mineral reserves, or
(b) mineral resources the potential economic viability of which is supported by a preliminary economic assessment, a pre-feasibility study or a feasibility study;

"Certification Code" means the Certification Code for Exploration Prospects, Mineral Resources and Ore Reserves prepared by the Mineral Resources Committee of the Institution of Mining Engineers of Chile, as amended;

"data verification" means the process of confirming that data has been generated with proper procedures, has been accurately transcribed from the original source and is suitable to be used;

"disclosure" means any oral statement or written disclosure made by or on behalf of an issuer and intended to be, or reasonably likely to be, made available to the public in a jurisdiction of Canada, whether or not filed under securities legislation, but does not include written disclosure that is made available to the public only by reason of having been filed with a government or agency of government pursuant to a requirement of law other than securities legislation;

"early stage exploration property" means a property for which the technical report being filed has

(a) no current mineral resources or mineral reserves defined; and
(b) no drilling or trenching proposed;

“effective date” means, with reference to a technical report, the date of the most recent scientific or technical information included in the technical report;

“exploration information” means geological, geophysical, geochemical, sampling, drilling, trenching, analytical testing, assaying, mineralogical, metallurgical, and other similar information concerning a particular property that is derived from activities undertaken to locate, investigate, define, or delineate a mineral prospect or mineral deposit;

“historical estimate” means an estimate of the quantity, grade, or metal or mineral content of a deposit that an issuer has not verified as a current mineral resource or mineral reserve, and which was prepared before the issuer acquiring, or entering into an agreement to acquire, an interest in the property that contains the deposit;

“**initial deposit period**” has the meaning ascribed to that term in section 1.1 of National Instrument 62-104 *Take-Over Bids and Issuer Bids*;

“JORC Code” means the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves prepared by the Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia, as amended;

“mineral project” means any exploration, development or production activity, including a royalty or similar interest in these activities, in respect of diamonds, natural solid inorganic material, or natural solid fossilized organic material including base and precious metals, coal, and industrial minerals;

“PERC Code” means the Pan-European Code for Reporting of Exploration Results, Mineral Resources and Reserves prepared by the Pan-European Reserves and Resources Reporting Committee, as amended;

“preliminary economic assessment” means a study, other than a pre-feasibility or feasibility study, that includes an economic analysis of the potential viability of mineral resources;

“producing issuer” means an issuer with annual audited financial statements that disclose

(a) gross revenue, derived from mining operations, of at least $30 million Canadian for the issuer’s most recently completed financial year; and

(b) gross revenue, derived from mining operations, of at least $90 million Canadian in the aggregate for the issuer's three most recently completed financial years;

"professional association" means a self-regulatory organization of engineers, geoscientists or both engineers and geoscientists that

(a) is
  (i) given authority or recognition by statute in a jurisdiction of Canada, or
  (ii) a foreign association that is generally accepted within the international mining community as a reputable professional association;
(b) admits individuals on the basis of their academic qualifications, experience, and ethical fitness;
(c) requires compliance with the professional standards of competence and ethics established by the organization;
(d) requires or encourages continuing professional development; and
(e) has and applies disciplinary powers, including the power to suspend or expel a member regardless of where the member practises or resides;

"qualified person" means an individual who

(a) is an engineer or geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining;
(b) has at least five years of experience in mineral exploration, mine development or operation or mineral project assessment, or any combination of these, that is relevant to his or her professional degree or area of practice;
(c) has experience relevant to the subject matter of the mineral project and the technical report;
(d) is in good standing with a professional association; and
(e) in the case of a professional association in a foreign jurisdiction, has a membership designation that

  (i) requires attainment of a position of responsibility in their profession that requires the exercise of independent judgment; and
  (ii) requires

    A. a favourable confidential peer evaluation of the individual's character, professional judgement, experience, and ethical fitness; or
    B. a recommendation for membership by at least two peers, and demonstrated prominence or expertise in the field of mineral exploration or mining;

“quantity” means either tonnage or volume, depending on which term is the standard in the mining industry for the type of mineral;

“SAMREC Code” means the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves prepared by the South African Mineral Resource Committee (SAMREC) under the Joint Auspices of the Southern African Institute of Mining and Metallurgy and the Geological Society of South Africa, as amended;

“SEC Industry Guide 7” means the mining industry guide entitled “Description of Property by Issuers Engaged or to be Engaged in Significant Mining Operations” contained in the Securities Act Industry Guides published by the United States Securities and Exchange Commission, as amended;

“specified exchange” means the Australian Stock Exchange, the Johannesburg Stock Exchange, the London Stock Exchange Main Market, the Nasdaq Stock Market, the New York Stock Exchange, or the Hong Kong Stock Exchange;

“technical report” means a report prepared and filed in accordance with this Instrument and Form 43-101F1 Technical Report that includes, in summary form, all material scientific and technical information in respect of the subject property as of the effective date of the technical report; and

“written disclosure” includes any writing, picture, map, or other printed representation, whether produced, stored or disseminated on paper or electronically, including websites.

Mineral Resource

1.2 In this Instrument, the terms “mineral resource”, “inferred mineral resource”, “indicated mineral resource” and “measured mineral resource” have the meanings ascribed to those terms by the Canadian Institute of Mining, Metallurgy and Petroleum, as the CIM Definition Standards on Mineral Resources and Mineral Reserves adopted by CIM Council, as amended.

Mineral Reserve

1.3 In this Instrument, the terms “mineral reserve”, “probable mineral reserve” and “proven mineral reserve” have the meanings ascribed to those terms by the Canadian Institute of Mining, Metallurgy and Petroleum, as the CIM Definition Standards on Mineral Resources and Mineral Reserves adopted by CIM Council, as amended.

Mining Studies

1.4 In this Instrument, the terms “preliminary feasibility study”, “pre-feasibility study” and “feasibility study” have the meanings ascribed to those terms by the Canadian Institute of Mining, Metallurgy and Petroleum, as the CIM Definition Standards on Mineral Resources and Mineral Reserves adopted by CIM Council, as amended.

Independence

1.5 In this Instrument, a qualified person is independent of an issuer if there is no circumstance that, in the opinion of a reasonable person aware of all relevant facts, could interfere with the qualified person's judgment regarding the preparation of the technical report.

PART 2 REQUIREMENTS APPLICABLE TO ALL DISCLOSURE

Requirements Applicable to All Disclosure

2.1 All disclosure of scientific or technical information made by an issuer, including disclosure of a mineral resource or mineral reserve, concerning a mineral project on a property material to the issuer must be

(a) based upon information prepared by or under the supervision of a qualified person; or
(b) approved by a qualified person.

All Disclosure of Mineral Resources or Mineral Reserves

2.2 An issuer must not disclose any information about a mineral resource or mineral reserve unless the disclosure

(a) uses only the applicable mineral resource and mineral reserve categories set out in sections 1.2 and 1.3;
(b) reports each category of mineral resources and mineral reserves separately, and states the extent, if any, to which mineral reserves are included in total mineral resources;
(c) does not add inferred mineral resources to the other categories of mineral resources; and
(d) states the grade or quality and the quantity for each category of the mineral resources and mineral reserves if the quantity of contained metal or mineral is included in the disclosure.

Restricted Disclosure

2.3 (1) An issuer must not disclose

(a) the quantity, grade, or metal or mineral content of a deposit that has not been categorized as an inferred mineral resource, an indicated mineral resource, a measured mineral resource, a probable mineral reserve, or a proven mineral reserve;

(b) the results of an economic analysis that includes or is based on inferred mineral resources or an estimate permitted under subsection 2.3 (2) or section 2.4;

(c) the gross value of metal or mineral in a deposit or a sampled interval or drill intersection; or

(d) a metal or mineral equivalent grade for a multiple commodity deposit, sampled interval, or drill intersection, unless it also discloses the grade of each metal or mineral used to establish the metal or mineral equivalent grade.

(2) Despite paragraph (1) (a), an issuer may disclose in writing the potential quantity and grade, expressed as ranges, of a target for further exploration if the disclosure

(a) states with equal prominence that the potential quantity and grade is conceptual in nature, that there has been insufficient exploration to define a mineral resource and that it is uncertain if further exploration will result in the target being delineated as a mineral resource; and

(b) states the basis on which the disclosed potential quantity and grade has been determined.

(3) Despite paragraph (1) (b), an issuer may disclose the results of a preliminary economic assessment that includes or is based on inferred mineral resources if the disclosure

(a) states with equal prominence that the preliminary economic assessment is preliminary in nature, that it includes inferred mineral resources that are considered too speculative geologically to have the economic considerations applied to them that would enable them to be categorized as mineral reserves, and there is no certainty that the preliminary economic assessment will be realized;

(b) states the basis for the preliminary economic assessment and any qualifications and assumptions made by the qualified person; and

(c) describes the impact of the preliminary economic assessment on the results of any pre-feasibility or feasibility study in respect of the subject property.

(4) An issuer must not use the term preliminary feasibility study, pre-feasibility study or feasibility study when referring to a study unless the study satisfies the criteria set out in the definition of the applicable term in section 1.4.

Disclosure of Historical Estimates

2.4 Despite section 2.2, an issuer may disclose an historical estimate, using the original terminology, if the disclosure

(a) identifies the source and date of the historical estimate, including any existing technical report;
(b) comments on the relevance and reliability of the historical estimate;
(c) to the extent known, provides the key assumptions, parameters, and methods used to prepare the historical estimate;
(d) states whether the historical estimate uses categories other than the ones set out in sections 1.2 and 1.3 and, if so, includes an explanation of the differences;
(e) includes any more recent estimates or data available to the issuer;
(f) comments on what work needs to be done to upgrade or verify the historical estimate as current mineral resources or mineral reserves; and
(g) states with equal prominence that

(i) a qualified person has not done sufficient work to classify the historical estimate as current mineral resources or mineral reserves; and
(ii) the issuer is not treating the historical estimate as current mineral resources or mineral reserves.

PART 3 ADDITIONAL REQUIREMENTS FOR WRITTEN DISCLOSURE

Written Disclosure to Include Name of Qualified Person

3.1 If an issuer discloses in writing scientific or technical information about a mineral project on a property material to the issuer, the issuer must include in the written disclosure the name and the relationship to the issuer of the qualified person who

(a) prepared or supervised the preparation of the information that forms the basis for the written disclosure; or
(b) approved the written disclosure.

Written Disclosure to Include Data Verification

3.2 If an issuer discloses in writing scientific or technical information about a mineral project on a property material to the issuer, the issuer must include in the written disclosure

(a) a statement whether a qualified person has verified the data disclosed, including sampling, analytical, and test data underlying the information or opinions contained in the written disclosure;
(b) a description of how the data was verified and any limitations on the verification process; and
(c) an explanation of any failure to verify the data.

Requirements Applicable to Written Disclosure of Exploration Information

3.3 (1) If an issuer discloses in writing exploration information about a mineral project on a property material to the issuer, the issuer must include in the written disclosure a summary of

- (a) the material results of surveys and investigations regarding the property;
- (b) the interpretation of the exploration information; and
- (c) the quality assurance program and quality control measures applied during the execution of the work being reported on.

(2) If an issuer discloses in writing sample, analytical or testing results on a property material to the issuer, the issuer must include in the written disclosure, with respect to the results being disclosed,

- (a) the location and type of the samples;
- (b) the location, azimuth, and dip of the drill holes and the depth of the sample intervals;
- (c) a summary of the relevant analytical values, widths, and to the extent known, the true widths of the mineralized zone;
- (d) the results of any significantly higher grade intervals within a lower grade intersection;
- (e) any drilling, sampling, recovery, or other factors that could materially affect the accuracy or reliability of the data referred to in this subsection; and
- (f) a summary description of the type of analytical or testing procedures utilized, sample size, the name and location of each analytical or testing laboratory used, and any relationship of the laboratory to the issuer.

Requirements Applicable to Written Disclosure of Mineral Resources and Mineral Reserves

3.4 If an issuer discloses in writing mineral resources or mineral reserves on a property material to the issuer, the issuer must include in the written disclosure

- (a) the effective date of each estimate of mineral resources and mineral reserves;
- (b) the quantity and grade or quality of each category of mineral resources and mineral reserves;
- (c) the key assumptions, parameters, and methods used to estimate the mineral resources and mineral reserves;
- (d) the identification of any known legal, political, environmental, or other risks that could materially affect the potential development of the mineral resources or mineral reserves; and

(e) if the disclosure includes the results of an economic analysis of mineral resources, an equally prominent statement that mineral resources that are not mineral reserves do not have demonstrated economic viability.

Exception for Written Disclosure Already Filed

3.5 Sections 3.2 and 3.3 and paragraphs (a), (c) and (d) of section 3.4 do not apply if the issuer includes in the written disclosure a reference to the title and date of a document previously filed by the issuer that complies with those requirements.

PART 4 OBLIGATION TO FILE A TECHNICAL REPORT

Obligation to File a Technical Report Upon Becoming a Reporting Issuer

4.1 (1) Upon becoming a reporting issuer in a jurisdiction of Canada an issuer must file in that jurisdiction a technical report for each mineral property material to the issuer.

(2) Subsection (1) does not apply if the issuer is a reporting issuer in a jurisdiction of Canada and subsequently becomes a reporting issuer in another jurisdiction of Canada.

(3) Subsection (1) does not apply if

(a) the issuer previously filed a technical report for the property;
(b) at the date the issuer becomes a reporting issuer, there is no new material scientific or technical information concerning the subject property not included in the previously filed technical report; and
(c) the previously filed technical report meets any independence requirements under section 5.3.

Obligation to File a Technical Report in Connection with Certain Written Disclosure about Mineral Projects on Material Properties

4.2 (1) An issuer must file a technical report to support scientific or technical information that relates to a mineral project on a property material to the issuer, or in the case of paragraph (c), the resulting issuer, if the information is contained in any of the following documents filed or made available to the public in a jurisdiction of Canada:

(a) a preliminary prospectus, other than a preliminary short form prospectus filed in accordance with National Instrument 44-101 *Short Form Prospectus Distributions*;
(b) a preliminary short form prospectus filed in accordance with National Instrument 44-101 *Short Form Prospectus Distributions* that discloses for the first time

- (i) mineral resources, mineral reserves or the results of a preliminary economic assessment on the property that constitute a material change in relation to the issuer; or
- (ii) a change in mineral resources, mineral reserves or the results of a preliminary economic assessment from the most recently filed technical report if the change constitutes a material change in relation to the issuer;

(c) an information or proxy circular concerning a direct or indirect acquisition of a mineral property where the issuer or resulting issuer issues securities as consideration;
(d) an offering memorandum, other than an offering memorandum delivered solely to accredited investors as defined under securities legislation;
(e) for a reporting issuer, a rights offering circular;
(f) an annual information form;
(g) a valuation required to be prepared and filed under securities legislation;
(h) an offering document that complies with and is filed in accordance with Policy 4.6 - *Public Offering by Short Form Offering Document* and Exchange Form 4H - *Short Form Offering Document,* of the TSX Venture Exchange, as amended;
(i) a take-over bid circular that discloses mineral resources, mineral reserves or the results of a preliminary economic assessment on the property if securities of the offeror are being offered in exchange on the take-over bid; and
(j) any written disclosure made by or on behalf of an issuer, other than in a document described in paragraphs (a) to (i), that discloses for the first time

- (i) mineral resources, mineral reserves or the results of a preliminary economic assessment on the property that constitute a material change in relation to the issuer; or
- (ii) a change in mineral resources, mineral reserves or the results of a preliminary economic assessment from the most recently filed technical report if the change constitutes a material change in relation to the issuer.

(2) Subsection (1) does not apply for disclosure of an historical estimate in a document referred to in paragraph (1) (j) if the disclosure is made in accordance with subsection 2.4.

(3) If a technical report is filed under paragraph (1) (a) or (b), and new material scientific or technical information concerning the subject property becomes available before the filing of the final version of the prospectus or short form prospectus, the issuer must file an updated technical report or an addendum to

the technical report with the final version of the prospectus or short form prospectus.

(4) The issuer must file the technical report referred to in subsection (1) not later than the time it files or makes available to the public the document listed in subsection (1) that the technical report supports.

(5) Despite subsection (4), an issuer must

(a) file a technical report supporting disclosure under paragraph (1) (j) not later than

(i) if the disclosure is also contained in a preliminary short form prospectus, the earlier of 45 days after the date of the disclosure and the date of filing the preliminary short form prospectus;
(ii) if the disclosure is also contained in a directors' circular, the earlier of 45 days after the date of the disclosure and 3 business days before the expiry of the initial deposit period; and
(iii) in all other cases, 45 days after the date of the disclosure;

(b) issue a news release at the time it files the technical report, disclosing the filing of the technical report and reconciling any material differences in the mineral resources, mineral reserves or results of a preliminary economic assessment, between the technical report and the issuer's disclosure under paragraph (1) (j).

(6) Despite subsection (4), if a property referred to in an annual information form first becomes material to the issuer less than 30 days before the filing deadline for the annual information form, the issuer must file the technical report within 45 days of the date that the property first became material to the issuer.

(7) Despite subsection (4) and paragraph (5) (a), an issuer is not required to file a technical report within 45 days to support disclosure under subparagraph (1) (j) (i), if

(a) the mineral resources, mineral reserves or results of a preliminary economic assessment

(i) were prepared by or on behalf of another issuer who holds or previously held an interest in the property;
(ii) were disclosed by the other issuer in a document listed in subsection (1); and
(iii) are supported by a technical report filed by the other issuer;

(b) the issuer, in its disclosure under subparagraph (1) (j) (i),

(i) identifies the title and effective date of the previous technical report and the name of the other issuer that filed it;
(ii) names the qualified person who reviewed the technical report on behalf of the issuer; and
(iii) states with equal prominence that, to the best of the issuer's knowledge, information, and belief, there is no new material scientific or technical information that would make the disclosure of the mineral resources, mineral reserves or results of a preliminary economic assessment inaccurate or misleading; and

(c) the issuer files a technical report supporting its disclosure of the mineral resources, mineral reserves or results of a preliminary economic assessment;

(i) if the disclosure is also contained in a preliminary short form prospectus, by the earlier of 180 days after the date of the disclosure and the date of filing the short form prospectus; and
(ii) in all other cases, within 180 days after the date of the disclosure.

(8) Subsection (1) does not apply if

(a) the issuer previously filed a technical report that supports the scientific or technical information in the document;
(b) at the date of filing the document, there is no new material scientific or technical information concerning the subject property not included in the previously filed technical report; and
(c) the previously filed technical report meets any independence requirements under section 5.3.

Required Form of Technical Report

4.3 A technical report that is required to be filed under this Part must be prepared

(a) in English or French; and
(b) in accordance with Form 43-101F1.

PART 5 AUTHOR OF TECHNICAL REPORT

Prepared by a Qualified Person

5.1 A technical report must be prepared by or under the supervision of one or more qualified persons.

Execution of Technical Report

5.2 A technical report must be dated, signed and, if the qualified person has a seal, sealed by

(a) each qualified person who is responsible for preparing or supervising the preparation of all or part of the report; or
(b) a person or company whose principal business is providing engineering or geoscientific services if each qualified person responsible for preparing or supervising the preparation of all or part of the report is an employee, officer, or director of that person or company.

Independent Technical Report

5.3 (1) A technical report required under any of the following provisions of this Instrument must be prepared by or under the supervision of one or more qualified persons that are, at the effective and filing dates of the technical report, all independent of the issuer:

(a) section 4.1;
(b) paragraphs (a) and (g) of subsection 4.2 (1); or
(c) paragraphs (b), (c), (d), (e), (f), (h), (i) and (j) of subsection 4.2 (1), if the document discloses

  (i) for the first time mineral resources, mineral reserves or the results of a preliminary economic assessment on a property material to the issuer, or
  (ii) a 100 percent or greater change in the total mineral resources or total mineral reserves on a property material to the issuer, since the issuer's most recently filed independent technical report in respect of the property.

(2) Despite subsection (1), a technical report required to be filed by a producing issuer under paragraph (1) (a) is not required to be prepared by or under the supervision of an independent qualified person if the securities of the issuer trade on a specified exchange.

(3) Despite subsection (1), a technical report required to be filed by a producing issuer under paragraph (1) (b) or (c) is not required to be prepared by or under the supervision of an independent qualified person.

(4) Despite subsection (1), a technical report required to be filed by an issuer concerning a property which is or will be the subject of a joint venture with a producing issuer is not required to be prepared by or under the supervision of an independent qualified person, if the qualified person preparing or supervising the preparation of the report relies on scientific and technical

information prepared by or under the supervision of a qualified person that is an employee or consultant of the producing issuer.

PART 6 PREPARATION OF TECHNICAL REPORT

The Technical Report

6.1 A technical report must be based on all available data relevant to the disclosure that it supports.

Current Personal Inspection

6.2 (1) Before an issuer files a technical report, the issuer must have at least one qualified person who is responsible for preparing or supervising the preparation of all or part of the technical report complete a current inspection on the property that is the subject of the technical report.

(2) Subsection (1) does not apply to an issuer provided that

(a) the property that is the subject of the technical report is an early stage exploration property;
(b) seasonal weather conditions prevent a qualified person from accessing any part of the property or obtaining beneficial information from it; and
(c) the issuer discloses in the technical report, and in the disclosure that the technical report supports, that a personal inspection by a qualified person was not conducted, the reasons why, and the intended time frame to complete the personal inspection.

(3) If an issuer relies on subsection (2), the issuer must

(a) as soon as practical, have at least one qualified person who is responsible for preparing or supervising the preparation of all or part of the technical report complete a current inspection on the property that is the subject of the technical report; and
(b) promptly file a technical report and the certificates and consents required under Part 8 of this Instrument.

Maintenance of Records

6.3 An issuer must keep for 7 years copies of assay and other analytical certificates, drill logs, and other information referenced in the technical report or used as a basis for the technical report.

Limitation on Disclaimers

6.4 (1) An issuer must not file a technical report that contains a disclaimer by any qualified person responsible for preparing or supervising the preparation of all or part of the report that

(a) disclaims responsibility for, or limits reliance by another party on, any information in the part of the report the qualified person prepared or supervised the preparation of; or

(b) limits the use or publication of the report in a manner that interferes with the issuer's obligation to reproduce the report by filing it on SEDAR+.

(2) Despite subsection (1), an issuer may file a technical report that includes a disclaimer in accordance with Item 3 of Form 43-101F1.

PART 7 USE OF FOREIGN CODE

Use of Foreign Code

7.1 (1) Despite section 2.2, an issuer may make disclosure and file a technical report that uses the mineral resource and mineral reserve categories of an acceptable foreign code, if the issuer

(a) is incorporated or organized in a foreign jurisdiction; or

(b) is incorporated or organized under the laws of Canada or a jurisdiction of Canada, for its properties located in a foreign jurisdiction.

(2) If an issuer relies on subsection (1), the issuer must include in the technical report a reconciliation of any material differences between the mineral resource and mineral reserve categories used and the categories set out in sections 1.2 and 1.3.

PART 8 CERTIFICATES AND CONSENTS OF QUALIFIED PERSONS FOR TECHNICAL REPORTS

Certificates of Qualified Persons

8.1 (1) An issuer must, when filing a technical report, file a certificate that is dated, signed, and if the signatory has a seal, sealed, of each qualified person responsible for preparing or supervising the preparation of all or part of the technical report.

(2) A certificate under subsection (1) must state

(a) the name, address, and occupation of the qualified person;

(b) the title and effective date of the technical report to which the certificate applies;
(c) the qualified person's qualifications, including a brief summary of relevant experience, the name of all professional associations to which the qualified person belongs, and that the qualified person is a "qualified person" for purposes of this Instrument;
(d) the date and duration of the qualified person's most recent personal inspection of each property, if applicable;
(e) the item or items of the technical report for which the qualified person is responsible;
(f) whether the qualified person is independent of the issuer as described in section 1.5;
(g) what prior involvement, if any, the qualified person has had with the property that is the subject of the technical report;
(h) that the qualified person has read this Instrument and the technical report, or part that the qualified person is responsible for, has been prepared in compliance with this Instrument; and
(i) that, at the effective date of the technical report, to the best of the qualified person's knowledge, information, and belief, the technical report, or part that the qualified person is responsible for, contains all scientific and technical information that is required to be disclosed to make the technical report not misleading.

Addressed to Issuer

8.2 All technical reports must be addressed to the issuer.

Consents of Qualified Persons

8.3 (1) An issuer must, when filing a technical report, file a statement of each qualified person responsible for preparing or supervising the preparation of all or part of the technical report, dated, and signed by the qualified person

(a) consenting to the public filing of the technical report;
(b) identifying the document that the technical report supports;
(c) consenting to the use of extracts from, or a summary of, the technical report in the document; and
(d) confirming that the qualified person has read the document and that it fairly and accurately represents the information in the technical report or part that the qualified person is responsible for.

(2) Paragraphs (1) (b), (c) and (d) do not apply to a consent filed with a technical report filed under section 4.1.

(3) If an issuer relies on subsection (2), the issuer must file an updated consent that includes paragraphs (1) (b), (c) and (d) for the first subsequent use of the

technical report to support disclosure in a document filed under subsection 4.2 (1).

PART 9 EXEMPTIONS

Authority to Grant Exemptions

9.1 (1) The regulator or the securities regulatory authority may, on application, grant an exemption from this Instrument, in whole or in part, subject to such conditions or restrictions as may be imposed in the exemption in response to an application.

(2) Despite subsection (1), in Ontario, only the regulator may grant such an exemption.

(3) Except in Ontario, an exemption referred to in subsection (1) is granted under the statute referred to in Appendix B to National Instrument 14-101 *Definitions* opposite the name of the local jurisdiction.

Exemptions for Royalty or Similar Interests

9.2 (1) An issuer whose interest in a mineral project is only a royalty or similar interest is not required to file a technical report to support disclosure in a document under subsection 4.2 (1) if

(a) the operator or owner of the mineral project is

(i) a reporting issuer in a jurisdiction of Canada, or
(ii) a producing issuer whose securities trade on a specified exchange and that discloses mineral resources and mineral reserves under an acceptable foreign code;

(b) the issuer identifies in its document under subsection 4.2 (1) the source of the scientific and technical information; and
(c) the operator or owner of the mineral project has disclosed the scientific and technical information that is material to the issuer.

(2) An issuer whose interest in a mineral project is only a royalty or similar interest and that does not qualify to use the exemption in subsection (1) is not required to

(a) comply with section 6.2; and
(b) complete those items under Form 43-101F1 that require data verification, inspection of documents, or personal inspection of the property to complete those items.

(3) Paragraphs (2) (a) and (b) only apply if the issuer

(a) has requested but has not received access to the necessary data from the operator or owner and is not able to obtain the necessary information from the public domain;

(b) under Item 3 of Form 43-101F1, states the issuer has requested but has not received access to the necessary data from the operator or owner and is not able to obtain the necessary information from the public domain and describes the content referred to under each item of Form 43-101F1 that the issuer did not complete; and

(c) includes in all scientific and technical disclosure a statement that the issuer has an exemption from completing certain items under Form 43-101F1 in the technical report required to be filed and includes a reference to the title and effective date of that technical report.

Exemption for Certain Types of Filings

9.3 This Instrument does not apply if the only reason an issuer files written disclosure of scientific or technical information is to comply with the requirement under securities legislation to file a copy of a record or disclosure material that was filed with a securities commission, exchange, or regulatory authority in another jurisdiction.

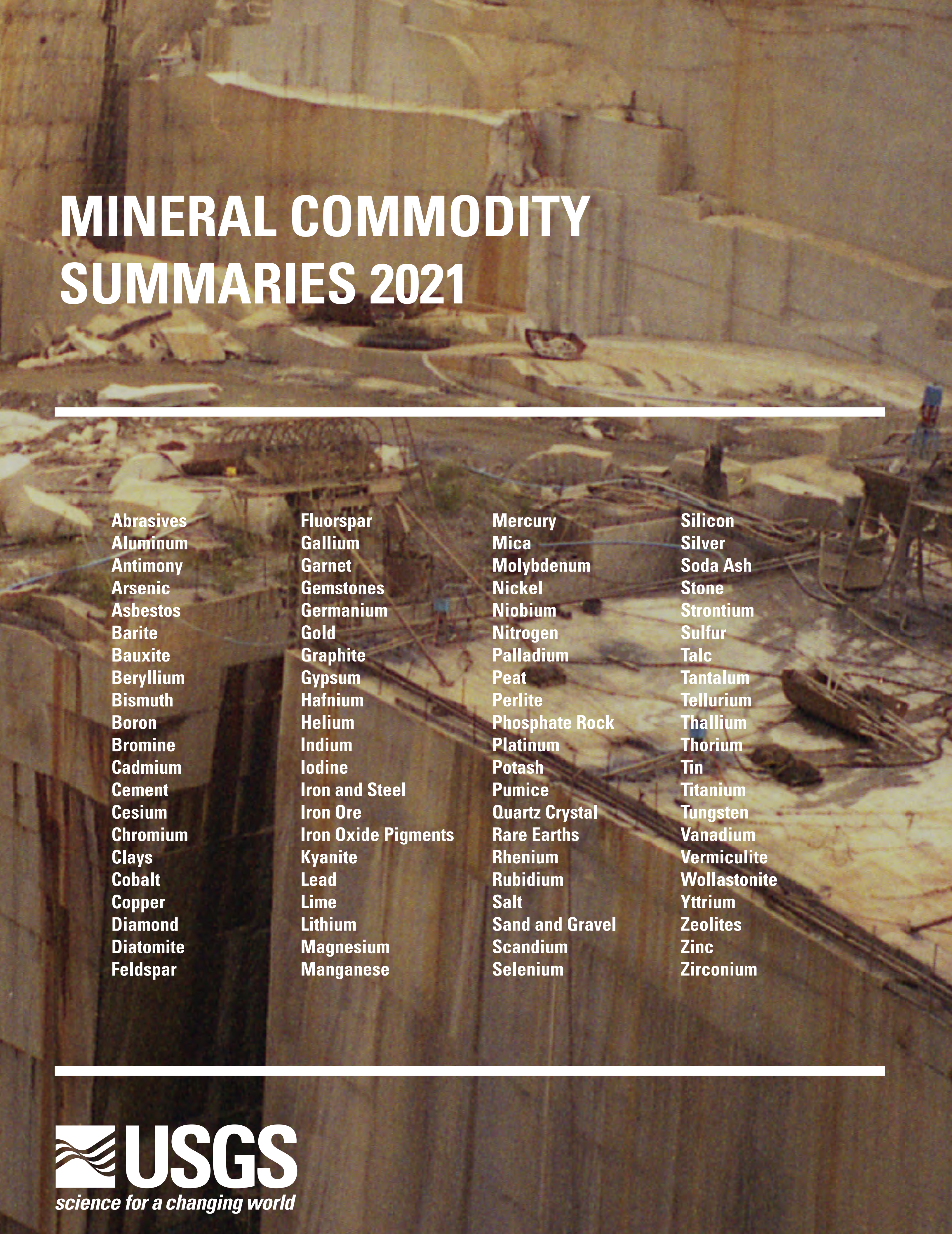
PART 10 EFFECTIVE DATE AND REPEAL

Effective Date

10.1 This Instrument comes into force on June 30, 2011.

Repeal

10.2 National Instrument 43-101 *Standards of Disclosure for Mineral Projects,* which came into force on December 30, 2005, is repealed.



MINERAL COMMODITY SUMMARIES 2021

Abrasives
Aluminum
Antimony
Arsenic
Asbestos
Barite
Bauxite
Beryllium
Bismuth
Boron
Bromine
Cadmium
Cement
Cesium
Chromium
Clays
Cobalt
Copper
Diamond
Diatomite
Feldspar
Fluorspar
Gallium
Garnet
Gemstones
Germanium
Gold
Graphite
Gypsum
Hafnium
Helium
Indium
Iodine
Iron and Steel
Iron Ore
Iron Oxide Pigments
Kyanite
Lead
Lime
Lithium
Magnesium
Manganese
Mercury
Mica
Molybdenum
Nickel
Niobium
Nitrogen
Palladium
Peat
Perlite
Phosphate Rock
Platinum
Potash
Pumice
Quartz Crystal
Rare Earths
Rhenium
Rubidium
Salt
Sand and Gravel
Scandium
Selenium
Silicon
Silver
Soda Ash
Stone
Strontium
Sulfur
Talc
Tantalum
Tellurium
Thallium
Thorium
Tin
Titanium
Tungsten
Vanadium
Vermiculite
Wollastonite
Yttrium
Zeolites
Zinc
Zirconium

USGS
science for a changing world

Cover: Photograph of Fletcher Granite Co.'s Chelmsford Grey Quarry in Westford, MA, taken in about 2000. This quarry has been in continual operation since 1881 and is the source of the company's Chelmsford Grey product. Over the years, granite from this quarry has been used in numerous building and civil engineering projects. According to the company, Chelmsford Grey granite was used for the Thurgood Marshall Federal Judiciary Building and the National Cathedral, both in Washington, DC. Photograph by Thomas P. Dolley, U.S. Geological Survey.

U.S. Department of the Interior
U.S. Geological Survey

MINERAL COMMODITY SUMMARIES 2021

Abrasives
Aluminum
Antimony
Arsenic
Asbestos
Barite
Bauxite
Beryllium
Bismuth
Boron
Bromine
Cadmium
Cement
Cesium
Chromium
Clays
Cobalt
Copper
Diamond
Diatomite
Feldspar
Fluorspar
Gallium
Garnet
Gemstones
Germanium
Gold
Graphite
Gypsum
Hafnium
Helium
Indium
Iodine
Iron and Steel
Iron Ore
Iron Oxide Pigments
Kyanite
Lead
Lime
Lithium
Magnesium
Manganese
Mercury
Mica
Molybdenum
Nickel
Niobium
Nitrogen
Palladium
Peat
Perlite
Phosphate Rock
Platinum
Potash
Pumice
Quartz Crystal
Rare Earths
Rhenium
Rubidium
Salt
Sand and Gravel
Scandium
Selenium
Silicon
Silver
Soda Ash
Stone
Strontium
Sulfur
Talc
Tantalum
Tellurium
Thallium
Thorium
Tin
Titanium
Tungsten
Vanadium
Vermiculite
Wollastonite
Yttrium
Zeolites
Zinc
Zirconium

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Mineral Commodities:

INSTANT INFORMATION

Information about the U.S. Geological Survey, its programs, staff, and products is available from the internet at https://www.usgs.gov or by calling (888) ASK–USGS [(888) 275–8747].

This publication has been prepared by the National Minerals Information Center. Information about the Center and its products is available from the internet at https://www.usgs.gov/centers/nmic or by writing to Director, National Minerals Information Center, 988 National Center, Reston, VA 20192.

KEY PUBLICATIONS

Minerals Yearbook—These annual publications review the mineral industries of the United States and of more than 180 other countries. They contain statistical data on minerals and materials and include information on economic and technical trends and developments and are available at https://www.usgs.gov/centers/nmic/publications. The three volumes that make up the Minerals Yearbook are volume I, Metals and Minerals; volume II, Area Reports—Domestic; and volume III, Area Reports—International.

Mineral Commodity Summaries—Published on an annual basis, this report is the earliest Government publication to furnish estimates covering nonfuel mineral industry data and is available at https://www.usgs.gov/centers/nmic/mineral-commodity-summaries. Data sheets contain information on the domestic industry structure, Government programs, tariffs, and 5-year salient statistics for more than 90 individual minerals and materials.

Mineral Industry Surveys—These periodic statistical and economic reports are designed to provide timely statistical data on production, shipments, stocks, and consumption of significant mineral commodities and are available at https://www.usgs.gov/centers/nmic/mineral-industry-surveys. The surveys are issued monthly, quarterly, or at other regular intervals.

Materials Flow Studies—These publications describe the flow of minerals and materials from extraction to ultimate disposition to help better understand the economy, manage the use of natural resources, and protect the environment and are available at https://www.usgs.gov/centers/nmic/materials-flow.

Recycling Reports—These studies illustrate the recycling of metal commodities and identify recycling trends and are available at https://www.usgs.gov/centers/nmic/recycling-statistics-and-information.

Historical Statistics for Mineral and Material Commodities in the United States (Data Series 140)—This report provides a compilation of statistics on production, trade, and use of approximately 90 mineral commodities since as far back as 1900 and is available at https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states.

WHERE TO OBTAIN PUBLICATIONS

- *Mineral Commodity Summaries* and the *Minerals Yearbook* are sold by the U.S. Government Publishing Office. Orders are accepted over the internet at https://bookstore.gpo.gov, by email at ContactCenter@gpo.gov, by telephone toll free (866) 512–1800; Washington, DC, area (202) 512–1800, by fax (202) 512–2104, or through the mail (P.O. Box 979050, St. Louis, MO 63197–9000).

- All current and many past publications are available as downloadable Portable Document Format (PDF) files through https://www.usgs.gov/centers/nmic.

INTRODUCTION

Each mineral commodity chapter of the 2021 edition of the U.S. Geological Survey (USGS) Mineral Commodity Summaries (MCS) includes information on events, trends, and issues for each mineral commodity as well as discussions and tabular presentations on domestic industry structure, Government programs, tariffs, 5-year salient statistics, and world production and resources. The MCS is the earliest comprehensive source of 2020 mineral production data for the world. More than 90 individual minerals and materials are covered by 2-page synopses.

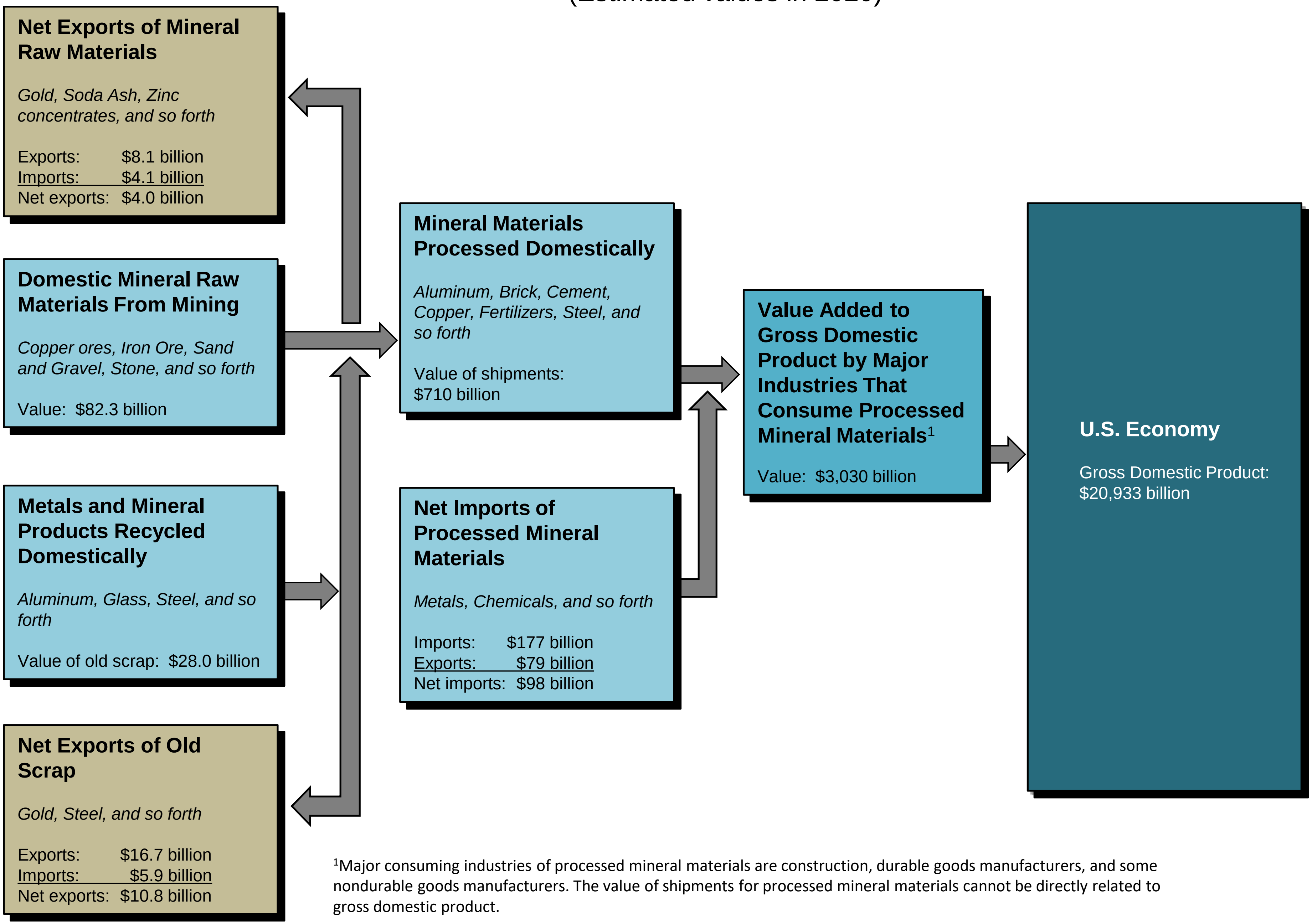
For mineral commodities for which there is a Government stockpile, detailed information concerning the stockpile status is included in the 2-page synopsis.

Abbreviations and units of measure and definitions of selected terms used in the report are in Appendix A and Appendix B, respectively. Reserves and resources information is in Appendix C, which includes “Part A—Resource and Reserve Classification for Minerals” and “Part B—Sources of Reserves Data.” A directory of USGS minerals information country specialists and their responsibilities is in Appendix D.

The USGS continually strives to improve the value of its publications to users. Constructive comments and suggestions by readers of the MCS 2021 are welcomed.

Figure 1.—The Role of Nonfuel Minerals in the U.S. Economy

(Estimated values in 2020)



Net Exports of Mineral Raw Materials

Gold, Soda Ash, Zinc concentrates, and so forth

Exports: $8.1 billion
Imports: $4.1 billion
Net exports: $4.0 billion

Domestic Mineral Raw Materials From Mining

Copper ores, Iron Ore, Sand and Gravel, Stone, and so forth

Value: $82.3 billion

Metals and Mineral Products Recycled Domestically

Aluminum, Glass, Steel, and so forth

Value of old scrap: $28.0 billion

Net Exports of Old Scrap

Gold, Steel, and so forth

Exports: $16.7 billion
Imports: $5.9 billion
Net exports: $10.8 billion

Mineral Materials Processed Domestically

Aluminum, Brick, Cement, Copper, Fertilizers, Steel, and so forth

Value of shipments:
$710 billion

Net Imports of Processed Mineral Materials

Metals, Chemicals, and so forth

Imports: $177 billion
Exports: $79 billion
Net imports: $98 billion

Value Added to Gross Domestic Product by Major Industries That Consume Processed Mineral Materials[1]

Value: $3,030 billion

U.S. Economy

Gross Domestic Product:
$20,933 billion

[1] Major consuming industries of processed mineral materials are construction, durable goods manufacturers, and some nondurable goods manufacturers. The value of shipments for processed mineral materials cannot be directly related to gross domestic product.

Sources: U.S. Geological Survey and the U.S. Department of Commerce.

SIGNIFICANT EVENTS, TRENDS, AND ISSUES

In 2020, the estimated total value of nonfuel mineral production in the United States was $82.3 billion, a decrease of 2% from the revised total of $83.7 billion in 2019. The estimated value of metals production increased by 3% to $27.7 billion. Increased prices for precious metals, such as gold, which reached a record-high price of $2,060 per troy ounce in August, contributed to the increased value of metal production. The total value of industrial minerals production was $54.6 billion, a 4% decrease from that of 2019. Of this total, $27.0 billion was construction aggregates production (construction sand and gravel and crushed stone). Crushed stone was the leading nonfuel mineral commodity in 2020 with a production value of $17.8 billion and accounted for 22% of the total value of U.S. nonfuel mineral production.

Decreases in consumption of nonfuel mineral commodities in commercial construction, oil and gas production, steel production, and automotive and transportation industry were attributed to the financial impacts of the global COVID-19 pandemic. For the metals sector, the aluminum, iron ore, steel, and titanium industries were particularly affected by reduced demand from manufacturing. For the industrial minerals sector, the largest decreases in production were in barite and industrial sand and gravel, commodities that are closely tied to the performance of the natural gas and oil well-drilling industry. In general, mines were not subject to COVID-19-related stay-at-home orders because they were deemed critical industries, but decreased demand from downstream industries resulted in reduced production at some operations.

In 2020, additional import duties were put in place for certain products that were derivatives of aluminum and steel articles, and the additional duties continued for most countries as a result of the U.S. Department of Commerce findings in 2018 of harm to national security under section 232 of the Trade Expansion Act of 1962 (19 U.S.C. §1862, as amended). As of December 2020, aluminum and derivative product imports from all countries except Argentina, Australia, Canada, and Mexico remained subject to a 10% ad valorem tariff, and steel and derivative product imports from all countries except Argentina, Australia, Brazil, Canada, the Republic of Korea, and Mexico remained subject to a 25% ad valorem tariff.

Under section 301(b) of the Trade Act of 1974 (19 U.S.C. §2411, as amended), in August 2020, the Office of the United States Trade Representative (USTR) published additional ad valorem duty rates on approximately $7.5 billion of imported items from specified European countries related to the Large Civil Aircraft dispute (85 FR 50866). In November, the European Union imposed additional duties on approximately $4 billion of imports from the United States. Most of the listed items were aircraft, agricultural items and spirits.

The additional 25% ad valorem duty for products imported from China (Lists 1, 2, and 3) and the 7.5% ad valorem duty for products imported from China (List 4) imposed under section 301(b) of the Trade Act of 1974, (19 U.S.C. §2411, as amended) by the USTR continued in 2020. Likewise, China imposed additional import duties for certain items originating in the United States. The United States imposed an additional tariff on approximately $309 billion of imports from China. China imposed additional tariffs on approximately $77 billion of imports from the United States.

Actions to achieve the goals and objectives of Executive Order 13817, “A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals,” issued in December 2017, continued in 2020. As outlined in a report issued by the U.S. Department of Commerce, a strategy was developed to reduce the Nation’s reliance on critical minerals; an assessment of progress toward developing critical minerals recycling and reprocessing technologies and technological alternatives to critical minerals; options for accessing and developing critical minerals through investment and trade with our allies and partners; a plan to improve the topographic, geologic, and geophysical mapping of the United States and make the resulting data and metadata electronically accessible, to the extent permitted by law and subject to appropriate limitations for purposes of privacy and security, to support private sector mineral exploration of critical minerals; and recommendations to streamline permitting and review processes related to developing leases; enhancing access to critical mineral resources; and increasing discovery, production, and domestic refining of critical minerals.

In February 2020, the U.S. Geological Survey (USGS) published a new methodology to evaluate the global supply of and U.S. demand for 52 mineral commodities for the years 2007 to 2016. It identified 23 mineral commodities, including aluminum, antimony, bismuth, cobalt, gallium, germanium, indium, niobium, platinum-group metals, rare-earth elements, tantalum, titanium, and tungsten, as posing the greatest supply risk for the U.S. manufacturing sector (Nassar and others, 2020).

On September 30, 2020, Executive Order 13953, “Addressing the Threat to the Domestic Supply Chain Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries,” was issued to address the national emergency described. Several actions by Federal agencies were ordered including tasking the Secretary of the Interior, in consultation with the Secretary of the Treasury, the Secretary of Defense, the Secretary of Commerce, and the heads of other agencies, as appropriate, to investigate the Nation’s reliance on critical minerals.

On December 7, 2020, Open-File Report 2020–1127, “Investigation of U.S. Foreign Reliance on Critical Minerals—U.S. Geological Survey Technical Input Document in Response to Executive Order No. 13953 issued September 30, 2020,” was published by the USGS. The report identified and categorized the main sources of U.S. mineral commodity imports according to existing security of supply agreements with the United States and the U.S. Department of Commerce's list of nonmarket economies; quantified the concentration of import sources; identified net import reliance considerations, trends, and technical options salient for each mineral commodity; highlighted factors that may obscure the true net import reliance; and provided a general framework for evaluating strategies that may help reduce U.S. net import reliance.

On November 17, 2020, the U.S. Department of Defense announced contracts and agreements with rare-earth-element producers under the authorities of title III of the Defense Production Act. These agreements were put in place to support and strengthen the domestic rare earth supply chain in response to the Presidential Determinations, signed on July 22, 2019, pursuant to section 303 of the Defense Production Act of 1950, as amended (50 U.S.C. §4501 et seq.).

As shown in figure 1, minerals remained fundamental to the U.S. economy, contributing to the real gross domestic product at several levels, including mining, processing, and manufacturing finished products. The estimated value of nonfuel minerals produced at mines in the United States in 2020 was $82.3 billion. The value of net exports of mineral raw materials increased to $4.0 billion from $3.7 billion in 2019. Domestically recycled products totaled $28 billion, and iron and steel scrap contributed $9 billion to that total. Domestic raw materials and domestically recycled materials were used to produce mineral materials worth $710 billion. These mineral materials as well as imports of processed mineral materials, which increased by 83% in 2020, were, in turn, consumed by downstream industries creating an estimated value of $3.03 trillion in 2020, a 3% decrease from that in 2019.

Figure 2 illustrates the reliance of the United States on foreign sources for raw and processed mineral materials. In 2020, imports made up more than one-half of the U.S. apparent consumption for 46 nonfuel mineral commodities, and the United States was 100% net import reliant for 17 of those. Of the 35 minerals or mineral material groups identified as “critical minerals” published in the Federal Register on May 18, 2018 (83 FR 23295), 14 of the 17 mineral commodities with 100% net import reliance were listed as critical minerals, and 14 additional critical mineral commodities had a net import reliance greater than 50% of apparent consumption.

Figure 3 shows the countries from which the majority of these mineral commodities were imported and the number of mineral commodities for which each highlighted country was a leading supplier. China, followed by Canada, supplied the largest number of nonfuel mineral commodities.

The estimated value of U.S. metal mine production in 2020 was $27.7 billion, 3% higher than the revised value of 2019 (table 1). Principal contributors to the total value of metal mine production in 2020 were gold (38%), copper (27%), iron ore (15%), and zinc (6%). The estimated value of U.S. industrial minerals production in 2020, including construction aggregates, was $54.6 billion, about 4% less than the revised value of 2019 (table 1). The value of industrial minerals production in 2020 was dominated by crushed stone, 32%; cement (masonry and portland), 20%; construction sand and gravel, 17%; and industrial sand and gravel, 6%.

In 2020, U.S. production of 12 mineral commodities was valued at more than $1 billion each. These commodities were, in decreasing order of value, crushed stone, gold, cement, construction sand and gravel, copper, iron ore, industrial sand and gravel, salt, lime, phosphate rock, zinc, and soda ash.

In 2020, 12 States each produced more than $2 billion worth of nonfuel mineral commodities. These States were, in descending order of production value, Nevada, Arizona, Texas, California, Minnesota, Florida, Alaska, Utah, Missouri, Michigan, Wyoming, and Georgia (table 3, fig. 4).

The Defense Logistics Agency Strategic Materials (DLA Strategic Materials) is responsible for the operational oversight of the National Defense Stockpile (NDS) of strategic and critical materials. Managing the security, environmentally sound stewardship, and ensuring the readiness of all NDS stocks is the mission of DLA Strategic Materials. The NDS currently contains 48 unique commodities stored at 12 locations within the continental United States. In fiscal year 2020, approximately $9.2 million of new stocks were acquired and $56.85 million of excess materials were sold. Revenue from the Stockpile Sales Program fund the operation of the NDS and the acquisition of new stocks. As of September 30, 2020, the NDS inventory had a fair market value of $887.9 million. For reporting purposes, NDS stocks are categorized as held in reserve or available for sale. The majority of stocks are held in reserve. Additional detailed information can be found in the “Government Stockpile” sections in the mineral commodity chapters that follow. Under the authority of the Defense Production Act of 1950 (Pub. L. 81–774), the USGS advises the DLA Strategic Materials on acquisitions and disposals of NDS mineral materials.

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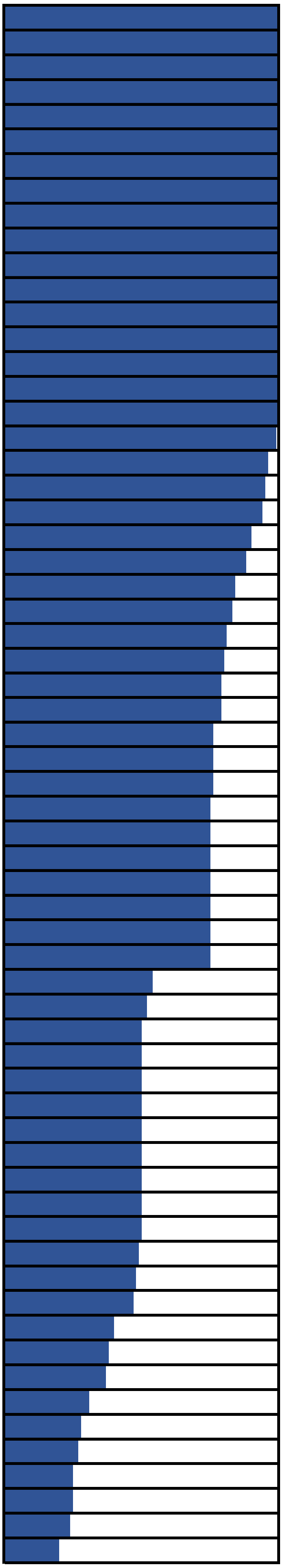
Figure 2.—2020 U.S. Net Import Reliance[1]



Commodity	Percent	Major import sources (2016–19)[2]
ARSENIC, all forms	100	China, Morocco, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, China, South Africa
GALLIUM	100	China, United Kingdom, Germany
GRAPHITE (NATURAL)	100	China, Mexico, Canada, India
INDIUM	100	China, Canada, Republic of Korea
MANGANESE	100	Gabon, South Africa, Australia, Georgia
MICA (NATURAL), sheet	100	China, Brazil, Belgium, India
NEPHELINE SYENITE	100	Canada
NIOBIUM (COLUMBIUM)	100	Brazil, Canada, Germany, Russia
RARE EARTHS,[3] compounds and metal	100	China, Estonia, Japan, Malaysia
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	China, Germany, Australia, Indonesia
YTTRIUM	100	China, Republic of Korea, Japan
GEMSTONES	99	India, Israel, Belgium, South Africa
VANADIUM	96	Brazil, South Africa, Austria, Canada
TELLURIUM	>95	Canada, China, Germany, Philippines
BISMUTH	94	China, Republic of Korea, Mexico, Belgium
POTASH	90	Canada, Belarus, Russia
TITANIUM MINERAL CONCENTRATES	88	South Africa, Australia, Madagascar, Mozambique
DIAMOND (INDUSTRIAL), stones	84	South Africa, India, Botswana, Congo (Kinshasa)
ZINC, refined	83	Canada, Mexico, Peru, Spain
ANTIMONY, metal and oxide	81	China, Belgium, Thailand, India
SILVER	80	Mexico, Canada, Peru, Poland
PLATINUM	79	South Africa, Germany, Italy, Switzerland
STONE (DIMENSION)	79	China, Brazil, Italy, India
COBALT	76	Norway, Canada, Japan, Finland
PEAT	76	Canada
RHENIUM	76	Chile, Germany, Canada, Kazakhstan
ABRASIVES, crude fused aluminum oxide	>75	China, France, Canada, Russia
ABRASIVES, crude silicon carbide	>75	China, Netherlands, South Africa
BARITE	>75	China, India, Morocco, Mexico
BAUXITE	>75	Jamaica, Guyana, Australia, Brazil
IRON OXIDE PIGMENTS, natural and synthetic	>75	China, Germany, Brazil
CHROMIUM	75	South Africa, Kazakhstan, Mexico, Russia
TIN, refined	75	Indonesia, Malaysia, Peru, Bolivia
MAGNESIUM COMPOUNDS	54	China, Israel, Brazil, Netherlands
GOLD	52	Mexico, Canada, Peru, Colombia
GERMANIUM	>50	China, Belgium, Germany, Russia
IODINE	>50	Chile, Japan
LITHIUM	>50	Argentina, Chile, China, Russia
TITANIUM, sponge	>50	Japan, Kazakhstan, Ukraine
TUNGSTEN	>50	China, Bolivia, Germany, Austria
NICKEL	50	Canada, Norway, Finland, Russia
CADMIUM	<50	Australia, China, Canada, Germany
MAGNESIUM METAL	<50	Canada, Israel, Mexico, Russia
SELENIUM	<50	China, Philippines, Mexico, Germany
ALUMINA	49	Brazil, Australia, Jamaica, Canada
GARNET (INDUISTRIAL)	48	South Africa, India, China, Australia
DIAMOND (INDUSTRIAL), dust, grit, and powder	47	China, Ireland, Republic of Korea, Russia
PALLADIUM	40	Russia, South Africa, Germany, United Kingdom
SILICON, metal and ferrosilicon	38	Brazil, Russia, Canada
COPPER, refined	37	Chile, Canada, Mexico
MICA (NATURAL), scrap and flake	31	Canada, China, India, Finland
PERLITE	28	Greece, China, Mexico, Turkey
SALT	27	Chile, Canada, Mexico, Egypt
BROMINE	<25	Israel, Jordan, China
ZIRCONIUM, ores and concentrates	<25	South Africa, Senegal, Australia, Russia
LEAD, refined	24	Canada, Republic of Korea, Mexico, India
VERMICULITE	20	South Africa, Brazil, Zimbabwe, Kenya

[1] Not all mineral commodities covered in this publication are listed here. Those not shown include mineral commodities for which the United States is a net exporter (boron; clays; diatomite; helium; iron and steel scrap; iron ore; kyanite; molybdenum concentrates; sand and gravel, industrial; soda ash; titanium dioxide pigment; wollastonite; zeolites; and zinc concentrates) or less than 20% net import reliant (abrasives, metallic; aluminum; beryllium; cement; feldspar; gypsum; iron and steel; iron and steel slag; lime; nitrogen (fixed)–ammonia; phosphate rock; pumice; sand and gravel, construction; stone, crushed; sulfur; and talc and pyrophyllite). For some mineral commodities (hafnium; mercury; quartz crystal, industrial; thallium; and thorium), not enough information is available to calculate the exact percentage of import reliance.

[2] Listed in descending order of import share.

[3] Data include lanthanides.

BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

100-Day Reviews under Executive Order 14017

June 2021

A Report by
The White House

Including Reviews by
Department of Commerce
Department of Energy
Department of Defense
Department of Health and Human Services

THE WHITE HOUSE
WASHINGTON

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BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

June 2021

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INTRODUCTORY NOTE

FROM NATIONAL ECONOMIC COUNCIL DIRECTOR BRIAN DEESE AND NATIONAL SECURITY ADVISOR JAKE SULLIVAN TO THE PRESIDENT

Mr. President:

It is our privilege to transmit to you the first set of reports that your Administration has developed pursuant to Executive Order 14017, "America's Supply Chains." The enclosed reports assess supply chain vulnerabilities across four key products that you directed your Administration to review within 100 days: semiconductor manufacturing and advanced packaging; large capacity batteries, like those for electric vehicles; critical minerals and materials; and pharmaceuticals and advanced pharmaceutical ingredients (APIs).

The enclosed reports are the work of a task force that we convened across more than a dozen departments and agencies, consultations with hundreds of stakeholders, public comments submitted by industry and experts, and deep analytic research by experts from across the government. We would like to particularly thank the four agencies that took the lead in authoring each of the enclosed reports: the Department of Commerce on semiconductor manufacturing and advanced packaging; the Department of Energy on large capacity batteries; the Department of Defense on critical materials and minerals; and the Department of Health and Human Services, particularly the Food and Drug Administration, on pharmaceuticals and APIs. This work has complemented other work your Administration has undertaken to strengthen U.S. supply chains, including the work to dramatically expand the supply of COVID-19 vaccines and other products essential to American's health.

Departments and Agencies across your Administration have already begun to implement the reports' recommendations. These include steps to strengthen U.S. manufacturing capacity for critical goods, to recruit and train workers to make critical products here at home, to invest in research and development that will reduce supply chain vulnerabilities, and to work with America's allies and partners to strengthen collective supply chain resilience. Both the public and private sector play critical roles in strengthening supply chains, and your Administration will continue to work with industry, labor, and others to make America's supply chains stronger.

We have already launched the second phase of the supply chain initiative you directed in E.O. 14017, which reviews six critical industrial base sectors that underpin America's economic and national security: the defense industrial base, public health and biological preparedness industrial base, information and communications technology industrial base, energy sector industrial base, transportation industrial base, and supply chains for production of agricultural commodities and food products. We will report back to you on those sectors by February 24, 2022, the one-year mark of your signing E.O. 14017.

The 100-day reports make clear: more secure and resilient supply chains are essential to our national security, our economic security, and our technological leadership. The work of strengthening America's critical supply chains will require sustained focus and investment. Building manufacturing capacity, increasing job quality and worker readiness, inventing and commercializing new products, and strengthening relations with America's allies and partners will not be done overnight. We are committed to carrying this work forward across your Administration to ensure that America's critical supply chains are resilient and secure for the years to come.

JAKE SULLIVAN, Assistant to the President for National Security Affairs

BRIAN DEESE, Assistant to the President for Economic Policy and Director of the National Economic Council

EXECUTIVE SUMMARY

FOR E.O. 14017 REPORTS DUE JUNE 4, 2021

I. Introduction:

The COVID-19 pandemic and resulting economic dislocation revealed long-standing vulnerabilities in our supply chains. The pandemic's drastic impacts on demand patterns for a range of medical products including essential medicines wreaked havoc on the U.S. healthcare system. As the world shifted to work and learn from home, it created a global semiconductor chip shortage impacting automotive, industrial, and communications products, among others. In February, extreme weather events—exacerbated by climate change—further exacerbated these shortages. In recent months the strong U.S. economic rebound and shifting demand patterns have strained supply chains in other key products, such as lumber, and increased strain on U.S. transportation and shipping networks.

On February 24, 2021, President Biden signed Executive Order (E.O.) 14017, "America's Supply Chains," in which he directed the U.S. government to undertake a comprehensive review of critical U.S. supply chains to identify risks, address vulnerabilities and develop a strategy to promote resilience. When the President signed the order, he invoked an old proverb: "For want of a nail, the shoe was lost. For want of a shoe, the horse was lost." And on, and on, until the kingdom was lost. Small failures at even one point in supply chains can impact America's security, jobs, families, and communities.

To undertake this comprehensive review, the Biden Administration established an internal task force spanning more than a dozen Federal Departments and Agencies. Administration officials consulted with hundreds of stakeholders from labor, business, academic institutions, Congress, and U.S. allies and partners to identify vulnerabilities and develop solutions. Federal Departments and Agencies received hundreds of written submissions in response to requests for public input into the supply chain initiative. Dozens of experts across the interagency have been conducting detailed studies of U.S. supply chains for critical products and developing policies that will strengthen resilience.

What follows summarizes the findings of the initial set of reviews of the supply chains of four critical products: semiconductor manufacturing and advanced packaging; large capacity batteries; critical minerals and materials and pharmaceuticals and active pharmaceutical ingredients (APIs).

Why Resilient Supply Chains Matter

More secure and resilient supply chains are essential for our national security, our economic security, and our technological leadership.

National security experts, including the Department of Defense, have consistently argued that the nation's underlying commercial industrial foundations are central to our security. Reports from both Republican and Democratic administrations have raised concerns about the defense industry's reliance on limited domestic suppliers;[1] a global supply chain vulnerable to disruption; and competitor country suppliers. Innovations essential to military preparedness—like highly specialized lithium-ion batteries—require an ecosystem of innovation, skills, and production facilities that the United States currently lacks. The disappearance of domestic production of essential antibiotics impairs our ability to counter threats ranging from pandemics to bio-terrorism, as emphasized by the FDA's analysis of supply chains for active pharmaceutical ingredients.

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[1] Department of Defense, "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency," 2018 (https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND-DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF).

Our economic security—steady employment and smooth operations of critical industries—also requires secure and resilient supply chains. For more than a decade, the Department of Defense has consistently found that essential civilian industries would bear the preponderance of harm from a disruption of strategic and critical materials supply. The Department of Energy notes that, today, China refines 60 percent of the world's lithium and 80 percent of the world's cobalt, two core inputs to high-capacity batteries—which presents a critical vulnerability to the future of the U.S. domestic auto industry.

Finally, our domestic innovation capacity is contingent on a robust and diversified industrial base. When manufacturing heads offshore, innovation follows. The Department of Commerce notes that large-scale public investment in semiconductor fabrication has allowed Korean and Taiwanese firms to outpace U.S.-based firms. As the Department of Commerce warns, "ultimately, volume drives both innovation and operational learning; in the absence of the commercial volume, the United States will not be able to keep up […] with the technology, in terms of quality, cost, or workforce."

A New Approach

A resilient supply chain is one that recovers quickly from an unexpected event. Our private sector and public policy approach to domestic production, which for years, prioritized efficiency and low costs over security, sustainability and resilience, has resulted in the supply chain risks identified in this report. That approach has also undermined the prosperity and health of American workers and the ability to manage natural resources domestically and globally. As the Administration sets out on a course to revitalize our manufacturing base and secure global supply chains, rebuilding for resilience at the national level requires a renewed focus on broad-based growth and sustainability.

America's approach to resilient supply chains must build on our nation's greatest strengths—our unrivaled innovation ecosystem, our people, our vast ethnic, racial, and regional diversity, our small and medium-sized businesses, and our strong relationships with allies and partners who share our values.

As multiple reports note, the United States maintains an unparalleled innovation ecosystem with world-class universities, research centers, start-ups and incubators, attracting top talent from around the world. The Administration must double-down on our innovation infrastructure, reinvesting in research and development (R&D) and accelerating our ability to move innovations from the lab to the marketplace.

American workers must be the foundation for resilience. Resilient production requires quick problem-solving, driven by the knowledge, leadership, and full engagement of people on the factory floor. Decades of focusing on labor as a cost to be controlled—not an asset to be invested in—have depressed real wages and driven down union-density for workers, while also contributing to companies' challenges finding and keeping skilled talent. We must focus on creating pathways for all Americans to access well paid jobs with the free and fair choice to organize and bargain collectively.

We must ensure that economic opportunities are available in all parts of the country and for women, people of color, and others who are too often left behind. Inequality in income, race, and geography is keeping millions of potential workers, researchers, and entrepreneurs from contributing fully to growth and innovation. Today, children with the talents to become inventors, are less likely to become patent holders if they are low-income, women, African American, Latino, or from disadvantaged regions[2]. The Administration's approach must provide access and pathways for these "lost Einsteins"—workers, researchers, and businesses-owners in the growing industries of the 21st century.

A robust and resilient supply chain must include a diverse and healthy ecosystem of suppliers. Therefore, we must rebuild our small and medium-sized business manufacturing base, which has borne the brunt of the hollowing out of U.S. manufacturing. We also need to diversify our international suppliers and reduce

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[2] Alex Bell, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenan, "Who Becomes an Inventor in America? The Importance of Exposure to Innovation," November 2018, Harvard University, (http://www.equality-of-opportunity.org/assets/documents/inventors_summary.pdf).

geographic concentration risk. It is neither possible nor desirable to produce all essential American goods domestically. But for too long, the United States has taken certain features of global markets—especially the fear that companies and capital will flee to wherever wages, taxes and regulations are lowest—as inevitable. In the face of those same pressures, other countries successfully invested in policies that distributed the gains from globalization more broadly, including to workers and small businesses. We must press for a host of measures—tax, labor protections, environmental standards, and more—that help shape globalization to ensure it works for Americans as workers and as families, not merely as consumers. The Administration's approach to resilience must focus on building trade and investment partnerships with nations who share our values—valuing human dignity, worker rights, environmental protection, and democracy.

Finally, a new set of risks confronts U.S. policy makers and business leaders. Technological change and the power of cyber-attacks to derail the critical industries—from energy to agriculture—require new public-private approaches to resilience. And, we must confront the climate crisis. Meeting U.S. decarbonization aims will involve a massive domestic build out of clean energy technology; for an issue so central to U.S. economic and national security, we cannot afford to be agnostic to where these technologies are manufactured and where the associated supply chains and inputs originate.

A sector-by sector approach

The Biden-Harris Administration has already begun to take steps to address supply chain vulnerabilities. The Administration's COVID-19 Response Team has dramatically expanded the manufacture of vaccines and other essential supplies, enabling more than 137 million Americans to be fully vaccinated. The Administration has also worked with companies that manufacture and use computer chips to identify improvements in supply chain management practices that can strengthen the semiconductor supply chain over time. Just this year, the Department of Defense announced an investment in the expansion of the largest rare earth element mining and processing company outside of China. The Biden-Harris Administration is also working to address critical cyber vulnerabilities of U.S. supply chains and critical infrastructure, including issuing E.O. 14028 on "Improving the Nation's Cyber Security" just last month. The recommendations we are releasing today build on this work and provide a path forward for greater investment and growth.

Not all recommendations will be relevant to all sectors, and a sector by sector approach will continue to be necessary. Methods of guarding against single-source risk in the critical minerals supply chain, for example, is limited in part by where natural resources exist. Tools including ally and friend-shoring, and stockpiling, along with investments in sustainable domestic production and processing will all be necessary to strengthen resilience. Sectors where we seek to advance our technological competitiveness—like high-capacity batteries—will require an ecosystem-building approach that includes supporting domestic demand, investing in domestic production, recycling and R&D, and targeting support of the U.S. automotive workforce.

The remainder of this executive summary covers the E.O. 14017 process, key vulnerabilities across the four initial critical supply chains; recommendations for securing these vulnerable supply chains; and immediate actions the administration should take to address transitory supply chain challenges.

II. Critical Supply Chains Identified in E.0. 14017:

E.O. 14017 directed the government to focus initially on four key sets of products during the first 100 days following its signing. These initial priority products are:

- **Semiconductor manufacturing and advanced packaging:** Semiconductors are an essential component of electronic devices. The packaging, which may contain one or more semiconductors, provides an alternative avenue for innovation in density and size of products. Semiconductors have become ubiquitous in today's world. They enable telecommunications and grid infrastructure, run critical business and government systems, and are prevalent across a vast array of products from fridges to fighter jets. A new car, for example, may require more than 100 semiconductors for touch screens, engine controls, driver assistance cameras, and other systems.[3] The U.S. share of global semiconductor production has dropped from 37 percent in 1990 to 12 percent today, and is projected to decline further without a comprehensive U.S. strategy to support the industry.[4]

- **Large capacity batteries:** As the United States transitions away from fossil fuels for power generation and electrifies our automotive and trucking fleets, large capacity batteries for electric vehicles (EVs) and grid storage will be essential to U.S. economic and national security. Global demand for EV batteries is projected to grow from approximately 747 gigawatt hours (GWh) in 2020 to 2,492 gigawatt hours by 2025.[5] Absent policy intervention, U.S. production capacity is expected to increase to only 224 GWh during that period, but U.S. annual demand for passenger EVs will exceed that capacity.[6] Maintaining America's innovative and manufacturing edge in the automotive sector and other key industrial sectors will require the United States to undertake a concerted effort to shore-up sustainable critical material supply and processing capacity, expand domestic battery production, and support EV and storage adoption.

- **Critical minerals and materials:** The United States and other nations are dependent on a range of critical minerals and materials that are the building blocks of the products we use every day. Rare earths metals are essential to manufacturing everything from engines to airplanes to defense equipment. Demand for many of these metals is projected to surge over the next two decades, particularly as the world moves to eliminate net carbon emissions by 2050. For example, global demand for lithium and graphite, two of the most important materials for electric vehicle batteries, is estimated to grow by more than 4000 percent by 2040 in a scenario where the world achieves its climate goals, with graphite projected to grow nearly 2500 percent.[7] China was estimated to control 55 percent of global rare earths mining capacity in 2020 and 85 percent of rare earths refining.[8] The United States must secure reliable and sustainable supplies of critical minerals and metals to ensure resilience across U.S. manufacturing and defense needs, and do so in a manner consistent with America's labor, environmental, equity and other values.

- **Pharmaceuticals and active pharmaceutical ingredients (APIs):** The COVID-19 pandemic highlighted the critical importance of a resilient U.S. public health industrial base. We continue to address resilience challenges in the broader pandemic supply chain through actions prescribed in EO 14001, including a pandemic supply chain resilience strategy to be completed in July that will outline objectives and actions for long-term resilience. Thanks to the work by both government and the private sector, in less than a year the United States dramatically increased its capacity for vaccine production. But shortages of critical generic drugs and APIs have plagued the United States for years. Multiple factors, including lack of incentives to manufacture less profitable drugs and underinvestment in quality management, both at home and abroad, have resulted in

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[3] Jack Ewing and Don Clark, "Lack of Tiny Parts Disrupts Auto Factories Worldwide," January 13, 2021, *The New York Times,* (https://www.nytimes.com/2021/01/13/business/auto-factories-semiconductor-chips.html).

[4] Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing," September, 2020, Boston Consulting Group and Semiconductor Industry Association, (https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf).

[5] "Lithium-Ion Battery Megafactory Assessment," Benchmark Mineral Intelligence, March 2021, (https://www.benchmarkminerals.com/megafactories/).

[6] Alice Yu and Mitzi Sumangil, "Top Electric Vehicle Markets Dominate Lithium-Ion Battery Capacity Growth," February 16, 2021, (https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth).

[7] International Energy Agency, "The Role of Critical Minerals in Clean Energy Transitions," May 2021, (https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf).

[8] Carl A. Williams, "China Continues Dominance of Rare Earths Markets to 2030, says Roskill," February 26, 2021, Mining.Com, (https://www.mining.com/china-continues-dominance-of-rare-earths-markets-to-2030-says-roskill).

fragile supply chains vulnerable to disruption. Further, 87 percent of generic API facilities are located overseas which has helped reduce costs by trillions of dollars in the past decade, but has left the U.S. health care system vulnerable to shortages of essential medicines.[9] While lack of data and supply chain transparency make it difficult to estimate the precise share of key U.S. drugs and APIs imported from abroad, China and India are estimated to control substantial parts of the supply chain.[10] A new approach is needed to ensure that Americans have reliable access to the life-saving medicines they need.

III. Drivers of Supply Chain Vulnerability:

Across the four critical products—and the diverse supply chains that underpin them—the Administration assessed a wide range of supply chain risks and vulnerabilities. The Administration examined risks throughout the supply chains, from the sourcing of raw materials through the manufacture and distribution of finished goods. Across the reports, there are a set of inter-related themes and findings that contribute to supply chain vulnerabilities. These are:

1. **Insufficient U.S. manufacturing capacity:** U.S. manufacturing capabilities have declined over the several decades. The first decade of the century was particularly devastating for U.S. manufacturing with the loss of one-third of manufacturing jobs between 2000 and 2010.[11] Small and medium enterprises (SMEs) were particularly hard hit. Some of this decline can be attributed to competition from low wage nations—economists have estimated that about 25 percent of the job losses can be attributed to the rise of China, particularly following its entrance into the World Trade Organization.[12] But the United States has also seen productivity growth stagnate internally and compared to economic peers, for example, trailing Germany on average and in most industries.[13] Today, in the Unites States, SMEs are often less productive than large manufacturers. Counter to popular beliefs that "the robots are coming," many SME manufacturers are underinvesting in new technology to increase their productivity.

   Our loss of manufacturing capabilities has led to a loss in innovation capacity. [14] Manufacturing capabilities underpin innovation in a range of products and once lost, are challenging to build back. In recent decades, when production capacity headed overseas, the R&D and broader industrial supply chains often followed.

2. **Misaligned Incentives and short-termism in private markets:** All four reports make clear that current U.S. market structures fail to reward firms for investing in quality, sustainability or

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[9] Food and Drug Administration, Testimony before the House Committee on Energy and Commerce, Subcommittee on Health regarding "Safeguarding Pharmaceutical Supply Chains in a Global Economy," October 30, 2019, (https://www.fda.gov/news-events/congressional-testimony/safeguarding-pharmaceutical-supply-chains-global-economy-10302019).

[10] Yangzong Huang, "U.S. Dependence on Pharmaceutical Products from China," August 14, 2019, Council on Foreign Relations Blog, (https://www.cfr.org/blog/us-dependence-pharmaceutical-products-china).

[11] Organization for Economic Cooperation and Development (OECD), "U.S. Manufacturing Decline and the Rise of New Production Innovation Paradigms," 2016, (https://www.oecd.org/unitedstates/us-manufacturing-decline-and-the-rise-of-new-production-innovation-paradigms.htm#:~:text=The%20number%20of%20manufacturing%20jobs,just%2012.3%20million%20in%202016).

[12] David H. Autor, David Dorn, and Gordon H. Hanson, "The China syndrome: Local Labor Market Effects of Import Competition in the United States." *American Economic Review* 103, no. 6, 2013 (https://pubs.aeaweb.org/doi/pdfplus/10.1257/aer.103.6.2121).

[13] Martin Neil Baily, Barry Bosworth, and Siddhi Doshi, "Productivity Comparisons: Lessons from Japan, the United States, and Germany," 2019, The Brookings Institution (https://www.brookings.edu/wp-content/uploads/2020/01/ES-1.30.20-BailyBosworthDoshi.pdf).

[14] Gary P. Pisano and Willy C. Shih, Producing *Prosperity: Why America Needs a Manufacturing Renaissance* (Boston: Harvard Business Press, 2012).

long-term productivity. For example, about drug shortages over the past decade, the Department of Health and Human Services writes in its report, "the core of these failures is the inability of the market to reward quality." A lower-wage and lower-skilled workforce may increase a firm's quarterly earnings, but research suggests that "high-road' strategies can improve wages without harming profits.[15] Other kinds of investments—in capabilities for continuous improvement or in reducing lead time—incur an upfront cost, but lead to improved performance in both normal and crisis periods.[16] Under-investment in cyber security has left companies and critical infrastructure vulnerable to hacks and other cyberattacks.

A focus on maximizing short-term capital returns has led to the private sector's underinvestment in long-term resilience. For example, firms in the S&P 500 Index distributed 91 percent of net income to shareholders in either stock buybacks or dividends between 2009 and 2018.[17] This has meant a declining share of corporate income going into R&D, new facilities or resilient production processes.

3. **Industrial Policies Adopted by Allied, Partner, and Competitor Nations:** As U.S. investment in the domestic industrial base has declined, our allies, partners and competitors have adopted strategic programs to advance their own domestic competitiveness. The Department of Energy's analysis of the advanced battery supply chain documents the European Union's (EU) support for demand policies, investment incentives, and regulatory tools—at both the EU and member-state level—to stimulate domestic production of electric vehicles and lithium-ion batteries. After a 2019 EU report designating the battery of "strategic interest," the EU announced a $3.5 billion R&D fund to increase the industry's competitiveness. The Department of Commerce's analysis of the global semiconductor supply chain notes Taiwan—the global leader in production of the most advanced semiconductor chips—provides subsidies for fabrication facilities including 50 percent for land costs, 45 percent for construction and facilities and 25 percent for semiconductor, in addition to R&D investments and other incentives. South Korea's and Singapore's semiconductor subsidies reduce the cost of facility ownership by 25-30 percent.

   Across all four reports, China stands out for its aggressive use of measures—many of which are well outside globally accepted fair trading practices—to stimulate domestic production and capture global market share in critical supply chains. Several strategies, including public investments in R&D, domestic demand incentives, and strategic international partnerships have been used to support both resilience and competitiveness of key economic sectors.

4. **Geographic concentration in global sourcing:** To ensure resilient supply chains, it is essential that they be globalized. However, the search for low-cost production, combined with the effective industrial policy of key nations, has led to geographic concentrations of key supply chains in a few nations, increasing vulnerabilities for United States and global producers. Such concentration leaves companies vulnerable to disruption, whether caused by a natural disaster, a

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[15] Thomas A. Kochan, Eileen Appelbaum, Jody Hoffer Gittell, and Carrie R. Leana, "The Human Capital Dimensions of Sustainable Investment: What Investment Analysts Need to Know," February 22, 2013 (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2222657).

[16] Suzanne de Treville and Lenos Trigeorgis, "It May Be Cheaper to Manufacture at Home." *Harvard Business Review,* October 2010, (https://hbr.org/2010/10/it-may-be-cheaper-to-manufacture-at-home). JP MacDuffie, Daniel Heller, and Takahiro Fujimoto, "Building Supply Chain Continuity Capabilities for a Post-Pandemic World," Wharton School Working Paper, 2021 (https://mackinstitute.wharton.upenn.edu/2021/building-supply-chain-continuity-capabilities-for-a-post-pandemic-world).

[17] William Lazonick, Mustafa Erdem Sakinç, and Matt Hopkins, "Why Stock Buybacks are Dangerous for the Economy," *Harvard Business Review,* January 7, 2020 (https://hbr.org/2020/01/why-stock-buybacks-are-dangerous-for-the-economy).

geopolitical event or indeed, a global pandemic. From the studies conducted pursuant to E.O. 14017, it is clear in the Department of Commerce's report that the United States is dangerously dependent on specific countries for parts of the value chain of all of these products. The global economy depends on Taiwanese firms for 92 percent of leading-edge semiconductor production. China has over 75 percent of global cell fabrication capacity for advanced batteries, as noted in the Department of Energy's report. While the Department of Health and Human Services' data suggests India and China compete for market share of many U.S. medicines, industry analysis suggests India imports nearly 70 percent of its APIs from China.

5. **Limited International Coordination:** Prior to the COVID-19 pandemic, the U.S. government under-invested in international diplomatic efforts to develop collective approaches to supply chain security. While expanded domestic production of critical goods must be part of the solution to America's supply chain vulnerabilities, the United States cannot manufacture all needed products at home. Moreover, the United States has a strong national interest in U.S. allies and partners improving the resilience of their critical supply chains in face of challenges—such as the COVID-19 pandemic, extreme weather events due to climate change, and geopolitical competition with China—that affect both the United States and our allies. Yet aside from a handful of pilot projects and other comparatively small diplomatic and multilateral initiatives to secure supply chains, the United States has not systematically focused on building international cooperative mechanisms to support supply chain resilience.

It will take a concerted effort over the short-, medium- and long-term to adequately address these and put U.S. supply chains on stronger footing. The following recommendations provide an overarching framework for doing so that will ensure the country's national and economic security as well as technological leadership going forward.

RECOMMENDATIONS

The four reports delivered to the President today contain numerous recommendations to strengthen the individual product supply chains. There are also several cross-cutting themes and recommendations that, collectively, will not only strengthen the four prioritized supply chains, but also will rebuild the U.S. industrial base and innovation engine.

We divide the recommendations into six categories: 1) Rebuilding our production and innovation capabilities; 2) supporting the development of markets with high road production models, labor standards, and product quality; 3) leveraging the government's role as a market actor; 4) strengthening international trade rules, including trade enforcement mechanisms; 5) working with allies and partners to decrease vulnerabilities in the global supply chains; and 6) partnering with industry to take immediate action to address existing shortages.

1. Rebuild our production and innovation capabilities

Long-term competitiveness will require an ecosystem of production, innovation, skilled workers, and diverse small and medium-sized suppliers. Those ecosystems, grounded in regions across the country, are the infrastructure needed to spur private sector investment in manufacturing and innovation. But that infrastructure will not be rebuilt or sustained without the support and leadership of the federal government. Specific recommendations to rebuild our industrial base include:

Enact new federal legislation that will strengthen critical supply chains and rebuild our industrial base—including transformative investments within the American Jobs Plan:

- **Provide dedicated funding for semiconductor manufacturing and R&D:** We recommend that Congress support at least $50 billion in investments to advance domestic manufacturing of leading edge semiconductors; expand capacity in mature node and memory production to support critical manufacturing, industrial, and defense applications; and promote R&D to ensure the next generation of semiconductors in developed and produced in the United States.

- **Provide consumer rebates and tax incentives to spur consumer adoption of EVs:** We recommend Congress authorize new and expanded incentives to spur consumer adoption of U.S.-made electric vehicles. In addition, we recommend Congress approve $5 billion to electrify the federal fleet with U.S.-made EVs and $15 billion in infrastructure investment to build a national charging infrastructure to facilitate the nationwide adoption of EVs.

- **Provide financing across the full battery supply chain**: In line with the American Jobs Plan, we recommend that Congress establish new incentives to support battery cell and pack manufacturing in the United States, including grant programs that can help entrepreneurs who do not have the ability to access tax credits in the short run. In the immediate term, the Department of Energy's Loan Programs Office should use the Advanced Technology Vehicles Manufacturing Loan Program, which has approximately $17 billion in loan authority, to expeditiously review applications from critical material and mineral refining and processing facilities and to re-equip, expand, or establish facilities for manufacturing advanced technology vehicle battery cells and packs in the United States.

- **Establish a new Supply Chain Resilience Program:** We recommend that Congress enact the proposed Supply Chain Resilience Program at the Department of Commerce, to monitor, analyze, and forecast supply chain vulnerabilities and partner with industry, labor, and other stakeholders to strengthen resilience. We recommend Congress back this program with $50 billion in funding that will give the federal government the tools necessary to make transformative investments in strengthening U.S. supply chains across a range of critical products.

- **Deploy the Defense Production Act (DPA) to expand production capacity in critical industries:** We recommend establishing a new interagency DPA Action Group to recommend ways to leverage the authorities of the DPA to strengthen supply chain resilience to the extent permitted by law. The DPA has been a powerful tool to expand production of supplies needed to combat the COVID-19 pandemic, and has been used for years to strengthen Department of Defense supply chains. The DPA has the potential to support investment in other critical sectors and enable industry and government to collaborate more effectively.

Increase public investments in R&D and commercialization of key products:

- **Invest in the development of next generation batteries***:* We recommend that the Energy Department and other federal agencies continue to support technologies that will reduce the critical mineral requirements of next generation electric vehicle and grid storage technologies, and that improve U.S. competitiveness in this critical sector. Among other priorities, the United States should focus on: (1) reducing or eliminating critical or scarce materials needed for EV or stationary storage, including cobalt and nickel; (2) accelerating battery technology advances including next generation lithium ion and lithium metal batteries and solid state design, and (3) developing innovative methods and processes to profitably recover "spent" lithium batteries, reclaim key materials, and re-introduce those materials to the battery supply chain.

- **Invest in the development of new pharmaceutical manufacturing and processes**: We recommend the Department of Health and Human Services, the Department of Defense, and other agencies increase their funding of advanced manufacturing technologies to advance continuous manufacturing and the biomanufacturing of APIs. American Rescue Plan funds could be targeted to increase production of key pharmaceuticals and ingredients, including using both traditional manufacturing techniques and accelerating on-demand manufacturing capabilities for supportive care fluids, API and finished dosage form drugs in modular, highly portable platforms.

Use immediate administrative authorities to support an ecosystem of producers and innovators including SMEs and skilled workers:

- **Work with industry and labor to create pathways to quality jobs, with a free and fair choice to join a union, through sector-based community college partnerships, apprenticeships and on-the-job training:** The Department of Labor's Employment and Training Administration (ETA) should support sector-based pathways to jobs, for example in the semiconductor industry. We recommend that the Administration use ETA funds to work with industry and labor, community colleges, and non-profit partners to support pathways to advanced manufacturing employment through Registered Apprenticeship programs and by supporting other labor-management training programs.

- **Support small, medium and disadvantaged businesses in critical supply chains:** The Small Business Administration (SBA) should support the diversification of critical suppliers through a targeted effort to better coordinate SBA's range of investment and technical assistance programs for small businesses and disadvantaged firms in the four targeted industries and firms seeking to enter those industries. SBA lending and investment products provide vital capital to small businesses, and the Small Business Investment Company program offers long-term equity investment in critical competitiveness sectors. The Small Business Innovation Research and Small Business Technology Transfer competitive programs, will support a diverse portfolio of small businesses to meet research and development needs, and increase commercialization.

- **Examine the ability of the U.S. Export-Import Bank (EXIM) to use existing authorities to further support domestic manufacturing:** We recommend that EXIM develop a proposal for Board consideration regarding whether and how to implement a new Domestic Financing Program to support the establishment and/or expansion of U.S. manufacturing facilities and infrastructure projects in the United States that would support U.S. exports. The proposal would support and facilitate U.S. exports while rebuilding U.S. manufacturing capacity.

2. Support the development of markets that invest in workers, value sustainability, and drive quality

The resilience of national supply chains is only as good as the resilience of supply chains at the firm level. Harnessing and unleashing the power and ingenuity of the private sector to improve resilience will lead to stronger national supply chain resilience. Standards and data are powerful tools that allow firms to differentiate their products and services on more than just price and create market "pull" toward a "race to the top". These reports identify key areas where government could play a more active role in setting standards and incentivizing high-road business practices. By establishing strong domestic standards or advocating for the establishment of global standards, the United States can support the private sector's ability to create and adopt resilient practices.

- **Create 21st century standards for the extraction and processing of critical minerals:** We recommend that the government, working with private sector and non-governmental stakeholders, encourage the development and adoption of comprehensive sustainability standards for essential minerals, such as lithium, cobalt, nickel, copper, and other minerals. We further recommend establishing an interagency team with expertise in mine permitting and environmental law to identify gaps in statutes and regulations that may need to be updated to ensure new production meets strong environmental standards throughout the lifecycle of the project; ensure meaningful community consultation and consultation with tribal nations, respecting the government-to-government relationship, at all stages of the mining process; and examine opportunities to reduce time, cost, and risk of permitting without compromising these strong environmental and consultation benchmarks.

- **Identify potential U.S. production and processing locations for critical minerals:** We recommend that federal agencies, led by the Department of Interior with the support of the White House Office of Science and Technology Policy, establish a working group comprised of agencies such as the Department of Agriculture, the Environmental Protection Agency, and others to identify potential sites where critical minerals could be sustainably and responsibly produced and processed in the United States while adhering to the highest environmental, labor, community engagement, and sustainability standards. We recommend that federal agencies work with the private sector, states, tribal nations, and stakeholders—including representatives of labor, impacted communities, and environmental justice leaders—to expand sustainable, responsible critical minerals production and processing in the United States.

- **Improve transparency throughout the pharmaceuticals supply chain:** HHS should develop and make recommendations to Congress on providing the department with new authorities to track production by facility, track API sourcing, and require API and finished dosage form sources can be identified on labeling for all pharmaceuticals sold in the United States. Currently, there is little transparency into the origins of API within generic drugs, which represent, 90 percent of all pharmaceuticals consumed in the United States.

3. Leverage the government's role as a purchaser of and investor in critical goods

As a significant customer and investor, Federal Government has the capacity to shape the market for many critical products. The public sector can deploy this power in times of crisis—such as in the recent public-private partnerships to facilitate development and delivery of a COVID-19 vaccine—or in normal times. The Administration should leverage this role to strengthen supply chain resilience and support national priorities.

- **Use federal procurement to strengthen U.S. supply chains:** We recommend that, in connection with the Administration's "Made in America" process directed by E.O. 14005, the Biden Administration establish a list of designated critical products that it recommends receive additional preferences under the Buy American Act and FAR Council regulations to ensure that the federal government procures U.S.-made critical products. President Biden has directed the Administration to strengthen federal Buy American requirements, which require that U.S. taxpayer dollars generally be spent on products made in the United States. Federal procurement has the potential to support U.S. production of critical products by creating a stable source of demand for U.S.-made products—thereby providing an incentive for the private sector to invest in U.S. manufacturing.

- **Strengthen domestic production requirements in federal grants for science and climate R&D:** In line with the President's campaign commitments, we recommend that Biden-Harris Administration should update manufacturing requirements in federal grants, cooperative agreements and R&D contracts to ensure that taxpayer funded R&D leads to products made in the United States. We recommend that the Department of Energy immediately strengthen domestic manufacturing requirements for grants, cooperative agreements and R&D contracts, including those related to lithium batteries, using the Determinations of Exceptional Circumstances under the Bayh-Dole Act and other legal means. In addition, an interagency working group should be established to identify best-practices and develop and implement further improvements across the government.

- **Reform and strengthen U.S. stockpiles:** For too long, the strategic stockpiles of the United States have been neglected, and at times, its funds have been used to offset other costs. The rehabilitation of stockpiles of medical goods and devices, especially those to fight the ongoing COVID-19 pandemic, is already under way. However, similar action needs to be taken to recapitalize and restore the National Defense Stockpile of critical minerals and materials. In the private sector, we recommend that industries that have faced shortages of critical goods evaluate mechanisms to strengthen corporate stockpiles of select critical products to ensure greater resilience in times of disruption.

- **Ensure that new automotive battery production in the United States adheres to high labor standards:** Tax credits, lending and grants offered to businesses to produce batteries domestically should, to the extent permitted by law, ensure the creation of quality jobs with the free and fair choice to organize and bargain collectively for workers. In new appropriations, we recommend that Congress include prevailing wage requirements, similar to those included in the American Recovery and Reinvestment Act of 2009. We recommend that Congress also include standards that cover construction, such as: (1) mandated hiring percentages from registered apprenticeships and other labor or labor-management training programs; (2) project labor, community labor and local hire requirements; and (3) employer neutrality agreements. We recommend implementing similar standards for production workers. The resulting high productivity allows these firms both to pay high wages and be profitable. [18]

4. Strengthen international trade rules, including trade enforcement mechanisms

While the Administration welcomes fair competition from abroad, in too many circumstances unfair foreign subsidies and other trade practices have adversely impacted U.S. manufacturing and more broadly, U.S. competitiveness. The practice of "pumping and dumping," in which countries heavily subsidize an industry, gain market share and then flood the market with cheaper products to wipe out competition, has been documented in a number of industries including pharmaceuticals and clean energy.[19] The U.S. government must implement a comprehensive strategy to push back on unfair foreign competition that erodes the resilience of U.S. critical supply chains and industries more broadly.

- **Establish a trade strike force:** We recommend the establishment of a U.S. Trade Representative-led trade strike force to identify unfair foreign trade practices that have eroded U.S. critical supply chains and to recommend trade actions to address such practices. We also recommend that supply chain resilience be incorporated into the U.S. trade policy approach towards China. We also recommend that the trade strike force examine how existing U.S. trade agreements and future trade agreements and measures can help strengthen the United States and collective supply chain resilience.

- **Evaluate whether to initiate a Section 232 investigation on imports of neodymium magnets:** Neodymium (NdFeB) permanent magnets play a key role in motors and other devices, and are important to both defense and civilian industrial uses. Yet the U.S. is heavily dependent on imports for this critical product. We recommend that the Department of Commerce evaluate whether to initiate an investigation into neodymium permanent magnets under Section 232 of the Trade Expansion Act of 1962.

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[18] Susan Helper, Ryan Noonan, Jessica R. Nicholson, and David Langon, "The Benefits and Costs of Apprenticeship: A Business Perspective," Department of Commerce with Case Western Reserve University, November 2016 (https://files.eric.ed.gov/fulltext/ED572260.pdf).

[19] Chris Martin, "China Flooded U.S. with Solar Panels Before Trump's Tariffs," *Bloomberg*, February 16, 2018 (https://www.bloomberg.com/news/articles/2018-02-16/china-flooded-u-s-with-solar-panels-before-trump-s-tariffs).

5. Work with allies and partners to decrease vulnerabilities in the global supply chains

The United States cannot address its supply chain vulnerabilities alone. Even as we make investments to expand domestic production capacity for some critical products, we must work with allies and partners to secure supplies of critical goods that we will not make in sufficient quantities at home. Moreover, in an interconnected world, the United States has a strong interest in ensuring its allies and partners have resilient supply chains as well. We must work with America's allies and partners to strengthen our collective supply chain resilience, while ensuring high standards for labor and environmental practices are upheld.

- **Expand multilateral diplomatic engagement, including hosting a new Presidential Forum:** We recommend expanding multilateral diplomatic engagement on supply chain vulnerabilities, particularly through groupings of like-minded allies such as the Quad and G7. We also recommend that the President convene a global forum on supply chain resilience that will convene key government officials and private sector stakeholders from across key U.S. allies and partners to collectively assess vulnerabilities and develop collective approaches to supply chain resilience.

- **Leverage the U.S. Development Finance Corporation (DFC) and other financing tools to support supply chain resilience:** We recommend that the DFC increase capacity for investments in projects that will expand production capability for critical products, including critical minerals and other products identified pursuant to the E.O. 14017 process. U.S. development and international finance tools offer a powerful avenue for working with allies and partners to strengthen supply chains for key products. While the United States cannot manufacture or mine all products, it can use financial tools to ensure that the manufacturing and mining that takes place elsewhere supports supply chain resilience and upholds international standards of environmental and social performance.

6. Monitor near term supply chain disruptions as the economy reopens from the COVID-19 pandemic

The U.S. economic relief efforts, paired with the Administration's successful vaccination campaign, have helped to revive the U.S. economy after a historic pandemic. As the United States and the broader global economy emerge from the pandemic, we have already seen signs of new pressures on supply chains as shifts in demand and supply emerge, and as the global vaccination campaign continues.

While these short-term disruptions are to be expected, the Administration has the responsibility to monitor these developments closely and identify actions that can be taken to minimize the impacts on workers, consumers, and businesses.

Building off the lessons from the 100-day review, the Administration should:

- **Establish a Supply Chain Disruptions Task Force:** We recommend the Administration establish a new Supply Chain Disruptions Task Force that will provide an all-of-government response to address near-term supply chain challenges to the economic recovery. The Task Force will be led by the Secretaries of Commerce, Transportation, and Agriculture and will focus on areas where a mismatch between supply and demand has been noted over the past several months: homebuilding and construction, semiconductors, transportation, and agriculture and food. The Task Force will bring the full capacity of the federal government to address near-term supply/demand mismatches. It will convene stakeholders to diagnose problems and surface solutions—large and small, public or private—that could help alleviate bottlenecks and supply constraints.

- **Create a data hub to monitor near term supply chain vulnerabilities:** We recommend that the Commerce Department lead a coordinated effort to bring together data from across the federal government to improve the federal government's ability to track supply and demand disruptions and improve information sharing between federal agencies and the private sector to more effectively identify near term risks and vulnerabilities.

ECONOMICS

Evaluating the mineral commodity supply risk of the U.S. manufacturing sector

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Trade tensions, resource nationalism, and various other factors are increasing concerns regarding the supply reliability of nonfuel mineral commodities. This is especially the case for commodities required for new and emerging technologies ranging from electric vehicles to wind turbines. In this analysis, we use a conventional risk-modeling framework to develop and apply a new methodology for assessing the supply risk to the U.S. manufacturing sector. Specifically, supply risk is defined as the confluence of three factors: the likelihood of a foreign supply disruption, the dependency of U.S. manufacturers on foreign supplies, and the ability of U.S. manufacturers to withstand a supply disruption. The methodology is applied to 52 commodities for the decade spanning 2007–2016. The results indicate that a subset of 23 commodities, including cobalt, niobium, rare earth elements, and tungsten, pose the greatest supply risk. This supply risk is dynamic, shifting with changes in global market conditions.

INTRODUCTION

Together, population growth, economic development, and the accelerating pace of technological innovation are driving the demand for natural resources to unprecedented levels. This is especially the case for nonfuel mineral commodities that are increasingly used in emerging and low-carbon technologies, including cobalt in rechargeable batteries (*1*), tellurium in certain thin-film solar photovoltaics (*2*), and rare earth elements in permanent magnets (*3*). It is these and other mineral commodities that will be required in greater quantities to fulfill the needs and desires of an increasingly affluent, growing global population (*4*).

While demand for mineral commodities will likely continue to grow, the reliability of their supply is not necessarily assured. A number of trends, including the concentration of production in a few countries (*5*), declining mineral ore grades (*6*), in-use dissipation (*7*), and limited end-of-life recycling (*8*), raise concerns regarding the reliability of supplies. These concerns are compounded by the fact that many of the mineral commodities used in emerging technologies are produced mainly or solely as by-products and may have inelastic supply (*9*). Moreover, the potential for material substitution is often limited (*4*, *10*), especially as manufacturers strive for smaller, faster, lighter, and smarter technologies by using each commodity for its particular properties that are uniquely suited for the desired function.

While several of the aforementioned factors may affect availability of mineral commodities in the long term (i.e., >10 years), recent trade tensions, geopolitical instability, conflict-associated artisanal and small-scale mining [e.g., (*11*)], persistent mine labor strikes [e.g., (*12*)], as well as calls for resource nationalism [e.g., (*13*)] have served to underscore concerns for the short to medium term (i.e., 5 to 10 years), especially for countries that are highly import reliant (*14*). Concerns regarding access to and availability of natural resources are not new. Industrialized nations have been concerned with the security of mineral supplies and "mineral independence" since at least the early 1900s (*15*, *16*). These concerns have waxed and waned throughout most of the 20th century [e.g., (*17*)]. A 2008 report by the U.S. National Research Council (*18*), which coincided with China's growing role as both a supplier and a consumer of a large number of mineral commodities, heightened awareness of these underlying issues and concerns. These concerns were realized in 2010 when a territorial dispute between China and Japan threatened to disrupt the supply of the rare earth elements and have since reemerged over the past few months with rising trade tensions between the United States and China.

These developments have renewed interest in assessing the supply risk (SR) of mineral commodities among governmental agencies [e.g., (*19*)], nongovernmental organizations [e.g., (*20*)], academic researchers [e.g., (*21*)], and corporations [e.g., (*22*)] who have developed their own assessment of "criticality." These assessments vary in purpose, scope, and methodology (*23*, *24*). Some focus on specific countries or regions [e.g., (*25*)], while others assess the global situation [e.g., (*26*)]. Some focus on a specific issue [e.g., renewable energy (*27*)], while others examine only a narrow set of commodities or a single commodity [e.g., (*28*)].

In the United States, existing and new efforts to address concerns regarding critical minerals were recognized and accelerated in December 2017 when the President issued Executive Order 13817 (*29*). This Order highlighted U.S. foreign reliance as a strategic vulnerability and directed the publication of a list of critical minerals, which were defined as follows:

"(i) a non-fuel mineral or mineral material essential to the economic and national security of the United States, (ii) the supply chain of which is vulnerable to disruption, and (iii) that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for our economy or our national security."

Using the work of the Subcommittee on Critical and Strategic Mineral Supply Chains at the U.S. National Science and Technology Council (NSTC), a list of 35 critical mineral commodities and commodity groups was issued in the Federal Register on 18 May 2018 (*30*).

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The analysis presented here builds upon the NSTC's work by addressing a very specific question: which nonfuel mineral commodities pose the greatest SR to the U.S. manufacturing sector? Our analysis focuses on the U.S. manufacturing sector because it is the sector of the economy that would be most directly affected by a mineral commodity supply disruption. To address this question, we use a conventional risk-modeling framework. Specifically, risk is defined as the confluence of three factors: a hazard (i.e., the likelihood of a disruptive event of a certain severity to occur), the degree of exposure to the said hazard, and the vulnerability to it. From the U.S. perspective of mineral commodity SR, the hazard is a foreign (i.e., non-U.S.) mineral commodity supply disruption, exposure is the U.S. manufacturing sector's dependence on foreign supplies, and vulnerability is the U.S. manufacturing sector's ability (or lack thereof) to withstand a supply disruption. This "risk triangle" (*31*)—consisting of hazard, exposure, and vulnerability—indicates that the combination of these factors is necessary, but each alone is an insufficient condition for risk. The U.S. manufacturing sector may, for example, be vulnerable to a supply disruption, but if the likelihood of that supply disruption is low, then the overall risk is low. Similarly, if the likelihood of a supply disruption is high but the U.S. manufacturing sector is not reliant on foreign supplies or is not vulnerable to supply disruptions, then the overall risk to the U.S. manufacturing sector would also be low.

Overall, the analysis includes 52 nonfuel mineral commodities (with several commodities being delineated at multiple supply chain stages) and spans the years 2007–2016. While the scope of commodities and time period covered was selected, in part, due to data availability, it provides an opportunity to examine trends and insights across a wide breadth of commodities—ranging from industrial minerals to precious metals and from base metals to their by-products—and over a period of time that includes various market and geopolitical dynamics including the aforementioned 2010 rare earth crisis.

MATERIALS AND METHODS

SR was calculated as the geometric mean of three indicators: disruption potential (DP), trade exposure (TE), and economic vulnerability (EV) (Eq. 1)

$$\mathrm{SR} = (\mathrm{DP} \cdot \mathrm{TE} \cdot \mathrm{EV})^{\frac{1}{3}} \tag{1}$$

These indicators aim to capture the three complementary aspects of risk, respectively: hazard, exposure, and vulnerability. For ease of comparability, each indicator was normalized on a common 0 to 1 scale, with higher scores indicating a greater degree of risk.

The following sections explain the calculation of each indicator, with details regarding data sources and assumptions for each commodity provided in the Supplementary Materials. There are eight commodities (aluminum, cobalt, copper, lead, nickel, tin, titanium, and zinc) for which data are available for multiple production stages. For these eight commodities, the highest indicator score among the production stages in a given year was used. This "bottleneck" approach allows for the identification of commodities that may have issues at different supply chain stages. Further information on the analysis of multiple production stages is also provided in the Supplementary Materials. For a few commodities, namely, dysprosium, neodymium, praseodymium, samarium, and tellurium, data are not available to complete the analysis for all years.

Disruption potential

A variety of factors can trigger a supply disruption including those that are caused by nature (e.g., earthquakes) and those that are man-made (e.g., labor strikes) (*32*, *33*). Furthermore, man-made disruptions may be deliberate (e.g., trade disputes), while others may be involuntary or accidental (e.g., mine accidents). This analysis focuses on man-made supply disruptions and therefore addresses a producing country's ability and willingness to supply the United States. From this perspective, "ability" encompasses factors such as a producing country's political stability, infrastructure, and availability of skilled labor that may affect its ability to continue to supply raw materials, while "willingness" encompasses factors such as a producing country's trade ties, shared values, and military cooperation with the United States that may affect the likelihood that it would deliberately disrupt supplies to the United States. All other things being equal, the likelihood of a supply disruption is greater for a commodity whose production is concentrated in a few countries that are more likely to become unable or unwilling to supply the United States than a commodity with production that is highly distributed among many willing and able producing countries. The following equation calculates the DP for a given commodity in a given year

$$\mathrm{DP}_{i,t}^{\mathrm{raw}} = \sum_{c} (\mathrm{PS}_{i,t,c}^{2} \cdot \mathrm{ASI}_{t,c} \cdot \mathrm{WSI}_{t,c}) \tag{2}$$

where for commodity i in year t, PS is the share of world production attributable to country c, ASI is a country-specific Ability to Supply Index, and WSI is a country-specific Willingness to Supply Index. The squaring of the production share simulates the Herfindahl-Hirschman Index (HHI). HHI, a metric that was developed to provide a measure for market concentration (*34*), is most commonly known for its use by the U.S. Department of Justice to assess horizontal mergers and acquisitions. It has since been used by most criticality assessments (*23*). Whenever possible, both primary and secondary (i.e., postconsumer or old scrap) country-level production quantities were used in the calculation of HHI. However, for many commodities, only primary production data are available at the country level. Prompt or "new" scrap, as well as "home" scrap, was excluded from the analysis because it does not, on a net basis, provide additional supply. Because the analysis was conducted from the perspective of a supply disruption to the United States, production in the United States was excluded from the HHI calculation. Table S1 provides details regarding data sources for primary and secondary production used in this analysis.

To assess ASI, the Fraser Institute's Policy Perception Index (PPI) was used (*35*). PPI was selected in this analysis over other country-level indicators that have been used in other criticality assessments, such as the World Bank's Worldwide Governance Indicators, because it encompasses factors that are more directly related to a country's ability to continue to perform mining activities. Specifically, PPI is part of an annual survey of mining and exploration executives that rates jurisdictions on 15 different policy factors including availability of skilled labor, access to infrastructure and power, level of security and political stability, taxation regime, and uncertainties regarding laws and regulations. Responses that best describe each jurisdiction on a five-tiered scale across each policy factor were aggregated to provide a single score on a 100-point scale. As illustrated in Eq. 3, PPI scores for each country c and year t were normalized in this analysis by reversing the scores, such that higher

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scores indicate a higher DP, and linearly scaling the scores to a maximum of 1

$$\mathrm{ASI}_{t,c} = \frac{100 - \mathrm{PPI}_{t,c}}{100} \tag{3}$$

Note that in 2016, the Fraser Institute revised its methodology for calculating PPI. Previously, the PPI was calculated by examining only the top 2 response categories, while the new methodology accounts for all five response categories. To avoid the impact of this methodological change on the results, the new PPI methodology has been applied to all years by using the raw data in the reports provided by the Fraser Institute. In addition, PPI scores that are provided at the subnational level for several countries, namely, Canada, Australia, and Argentina, were aggregated by averaging all subnational jurisdiction scores provided.

To assess WSI, three new indicators have been developed: trade ties (TT), shared values (SV), and military cooperation (MC). The rationale underlying WSI is that the stronger the relations (be they trade, ideological, or military) between a country and the United States, the less likely it is for that country to deliberately disrupt its supplies to U.S. manufacturers. Specifically, TT refers to the amount of trade that a country has with the United States and is measured as the monetary sum of its imports and exports with the United States relative to its gross domestic product (GDP) in a given year; SV refers to the extent to which the ideological values of a country align with those of the United States and is measured as the Euclidean "distance" between the country in question and the United States across indicators of political rights and civil liberties (electoral process, political pluralism and participation, functioning of government, freedom of expression and belief, associational and organizational rights, rule of law, and personal autonomy and individual rights), as quantified by Freedom House's Freedom in the World (FIW) index (*36*); and MC refers to whether the country has a current collective defense arrangement with the United States. Details regarding the calculation of each WSI indicator, as well as the country-level annual results from 2007 to 2016, are presented in the Supplementary Materials. Overall, WSI was calculated as the average of TT and SV, both of which have a maximum score of 1 for the "least willing" countries (i.e., those with greatest DP), and was reduced by 0.1 for countries that have a collective defense arrangement with the United States (MC).

To obtain scores that range from 0 to 1, the raw DP scores (Eq. 2) were normalized on the basis of the observed minimum and maximum scores across all commodities and years

$$\mathrm{DP}_{i,t} = \frac{\mathrm{DP}_{i,t}^{\mathrm{raw}} - \mathrm{DP}^{\mathrm{min}}}{\mathrm{DP}^{\mathrm{max}} - \mathrm{DP}^{\mathrm{min}}} \tag{4}$$

Note that ASI and WSI scores are available for most, but not all, countries. For producing countries without either an ASI or WSI score, the available index was instead used twice (i.e., the available index is squared in Eq. 2). There were no instances in the analysis in which both ASI and WSI were not available for a producing country.

Trade exposure

U.S. manufacturers that can obtain their supplies of a commodity completely from domestic sources are, to a considerable degree, insulated from supply disruptions that occur in other countries. Conversely, manufacturers that must obtain all their supplies of a commodity from abroad have full exposure to foreign supply disruptions. The TE indicator thus measures the degree of exposure to foreign supply disruptions by calculating the U.S. net import reliance as a percentage of apparent consumption for each commodity

$$\mathrm{TE}_{i,t} = \frac{I_{i,t} - E_{i,t} + \Delta S_{i,t}}{\mathrm{AC}_{i,t}} \tag{5}$$

where for commodity i in year t, I and E are the U.S. import and export quantities, respectively, of the applicable Harmonized Tariff Schedule trade codes, ΔS is the adjustments of U.S. industry and government stocks, and AC is the U.S. apparent consumption. AC was calculated as follows

$$\mathrm{AC}_{i,t} = \mathrm{PP}_{i,t} + \mathrm{SP}_{i,t} + I_{i,t} - E_{i,t} + \Delta S_{i,t} \tag{6}$$

where for commodity i in year t, PP and SP are the primary and secondary (old scrap) production quantities of the United States. Most of the commodities analyzed use this method to calculate TE. For a few commodities, including several of the rare earth elements, a reported consumption (RC) quantity was used in combination with (or instead of) apparent consumption due to limited specific trade data for that commodity. In those cases, TE was calculated as follows

$$\mathrm{TE}_{i,t} = 1 - \frac{\mathrm{PP}_{i,t} + \mathrm{SP}_{i,t} + \Delta S_{i,t}}{\mathrm{RC}_{i,t}} \tag{7}$$

Table S2 presents specifics regarding the data, data sources, and assumptions for U.S. primary and secondary production, trade codes, and stock changes. Net imports can be negative if exports are greater than imports (i.e., the United States is a net exporter). However, TE is limited to range from 0 to 1 such that commodities with net exports receive a score of zero.

Economic vulnerability

Faced with a supply disruption that increases the price of their mineral commodity inputs, manufacturers can undertake one or more actions: They can absorb the price increase; reduce their use via either enhanced manufacturing techniques, "thrifting," or substitution; secure supplies through long-term contracts or strategic inventories; or pass part or all of the price increase to their customers. While circumstances vary by the individual manufacturer and commodity, in general, many of these options are undesirable and often have real and substantial limitations and costs. For example, substitution may be possible if an alternative technology is readily available but will often require manufacturers to pay higher prices or accept lower performance (*4*, *10*, *37*). Committing to long-term contracts reduces flexibility, while maintaining large inventories increases costs and ties up working capital. Manufacturers with market power may be able to pass commodity price increases to their customers but that may erode demand over time.

All other things being equal, manufacturers that are less profitable are less able to use any of these options and are thus less able to withstand a commodity price shock that may result from a supply disruption compared to manufacturers that are more profitable. Similarly, manufacturers that have large expenditures on a given commodity (either due to its high price or large quantities required) are more vulnerable than those that expend very little on that commodity. The ratio of an industry's expenditure on a given commodity

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relative to that industry's profitability thus provides a useful metric for assessing an industry's relative vulnerability. Summing the industry-specific vulnerabilities across applicable industries generates a commodity-specific assessment. Given that not all industries are of equal importance to the U.S. economy, industries that provide a greater contribution to the economy are weighted more heavily. Taking these factors into account, the following equation assesses the EV of the U.S. manufacturing sector for each commodity

$$\mathrm{EV}_{i,t}^{\mathrm{raw}} = \sum_{j}\left(\frac{\mathrm{VA}_{t,j}}{\mathrm{GDP}_{t}} \cdot \frac{\mathrm{EXP}_{i,t,j}}{\mathrm{OP}_{t,j}}\right) \tag{8}$$

where $\mathrm{EXP}_{i,t,j}$ is industry j's expenditure on commodity i in year t, OP is that industry's operating profit, and VA is the industry's value added (i.e., its contribution to GDP). The ratio of EXP to OP provides a measure of each industry's vulnerability, while that of VA to GDP provides a measure of that industry's economic importance to the economy.

The United States defines economic industries by the North American Industry Classification System (NAICS) in a hierarchical structure at the two-digit sector (e.g., 31-33 manufacturing), three-digit subsector (e.g., 334 computer and electronic product manufacturing), four-digit industry group (e.g., 3341 computer and peripheral equipment manufacturing), and five- and six-digit NAICS and national industry (e.g., 334112 computer storage device manufacturing) levels, with more digits signifying a more narrowly defined industry. Wherever possible, the most detailed level applicable (typically six-digit NAICS) was used in this analysis. Data regarding specific economic conditions of each NAICS-defined industry were obtained from the U.S. Census Bureau's Economic Census, which occurs every year that ends with 2 and 7 (*38*). For interim years, the U.S. Census Bureau provides similar data in its Annual Survey of Manufactures (ASM) (*39*). These surveys are mandatory and provide statistics on all manufacturing establishments with one or more paid employees. To estimate an industry's operating profitability (OP), the following costs were subtracted from its total value of shipments and receipts for services: payroll, fringe benefits (e.g., employee health insurance), cost of materials and energy, rental or lease payments, changes in inventories (including finished goods, work in progress, and materials and supplies), and other operating expenses.

Multiplying a commodity's total apparent or reported consumption quantity by the fraction that is associated with a specific industry and an appropriate commodity unit price generates industry-specific EXP estimates for that commodity. In most cases, consumption fractions (i.e., the fraction of demand associated with a given use) are available on an application basis rather than being industry specific (e.g., approximately 8% of aluminum is used in electrical applications). These consumption fractions by application are thus linked to an appropriate set of industries, with OP and VA of the individual industries being aggregated across the set. Table S4 presents details on the demand fractions for each application and the associated NAICS codes, while table S1 presents details on the commodity prices used.

Figure 1 provides an example of the EV calculation for aluminum in 2008. Each aluminum application is linked to either an individual NAICS manufacturing industry or a set of industries (see table S4). Aluminum's consumption in these applications is multiplied by aluminum's annual average price to provide an estimate of EXP, while the OP and VA of the associated industries are derived from Economic Census or ASM data and, where applicable, aggregated on an application basis. In the figure, each application is represented as an individual column, with the ratio of EXP to OP plotted as the height of each column on the vertical axis and the ratio of VA to GDP plotted as the width of each column on the horizontal axis. The 21 identified applications that use aluminum are plotted cumulatively in descending order of their EXP-to-OP ratio. The area of each column (i.e., EXP/OP × VA/GDP) represents the EV of each application (presented with darker shading indicating greater vulnerability). The sum of the areas for all applications across the entire figure represents the overall EV of aluminum.

Note that, on the vertical axis, a column with a height of 100% specifies that EXP equals OP, indicating that the expenditure on this specific commodity by that industry (or set of industries) was equal to that industry's operating profit. Another way to interpret the vertical axis is that its numerical inverse indicates the percentage increase in a commodity's price that would be necessary to eliminate the industry's profits for the year. For example, an EXP-to-OP ratio of 50% indicates that a commodity price increase of 200% (i.e., a tripling of price of this specific commodity) would effectively eliminate the industry's operating profits for the year, while an EXP-to-OP ratio of 100% suggests that a price increase of 100% (i.e., a doubling of the commodity's price) would eliminate the industry's operating profits.

In this aluminum example, the width of the column for passenger cars and light trucks is large in comparison to that of metal cans and semi-rigid food containers. In contrast, the height of the metal cans column is notably taller than that of passenger cars. This indicates that the industries associated with passenger cars provide a larger contribution to GDP than the industries associated with metal cans, but the metal cans industries are much more vulnerable to aluminum price shocks because the ratio of their expenditures on aluminum to operating profits is greater than that of the passenger cars industries. Overall, these two applications contribute the most to aluminum's total vulnerability (as indicative of their areas and their darker shading), with passenger cars providing a slightly greater contribution than metal cans for this particular year (2008). Notably, the sum of VA across applications on the horizontal axis indicates that more than 6% of U.S. GDP (or just under $917 billion) was associated with aluminum in the manufacturing sector in 2008. For comparison, the entire manufacturing sector accounted for approximately 12% of U.S. GDP that year.

The raw EV scores were normalized to range from 0 to 1, with higher scores indicating greater vulnerability, based on the observed minimum and maximum scores across all commodities and years using the following equation

$$\mathrm{EV}_{i,t} = \frac{\ln(\mathrm{EV}_{i,t}^{\mathrm{raw}} \cdot 10^{9}) - \ln(\mathrm{EV}^{\min} \cdot 10^{9})}{\ln(\mathrm{EV}^{\max} \cdot 10^{9}) - \ln(\mathrm{EV}^{\min} \cdot 10^{9})} \tag{9}$$

RESULTS AND DISCUSSION

The results are presented in Fig. 2 for 2016, with similar figures for years 2007–2015 presented in the Supplementary Materials. Figure 2 is a scatterplot, with each point's location representing a commodity's DP (horizontal axis) and EV (vertical axis), its size representing a commodity's TE, and its shade representing a commodity's overall SR. An initial observation of the two-dimensional space (DP and EV)

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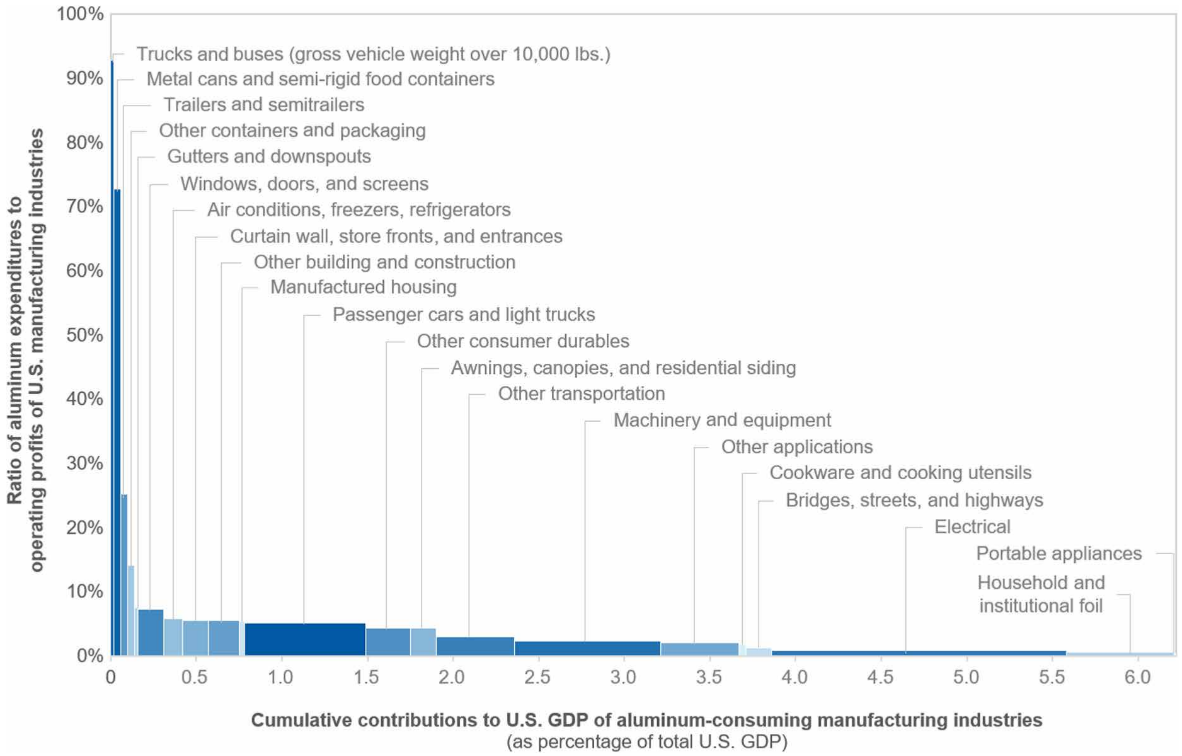

Fig. 1. Assessing the EV of aluminum by application for the year 2008. Each of the 21 aluminum applications is represented by an individual column, with height depicting the ratio of EXP to OP and width representing the ratio of VA to GDP. The area of each column represents the application's vulnerability, with darker shades indicating a greater contribution to aluminum's overall vulnerability.

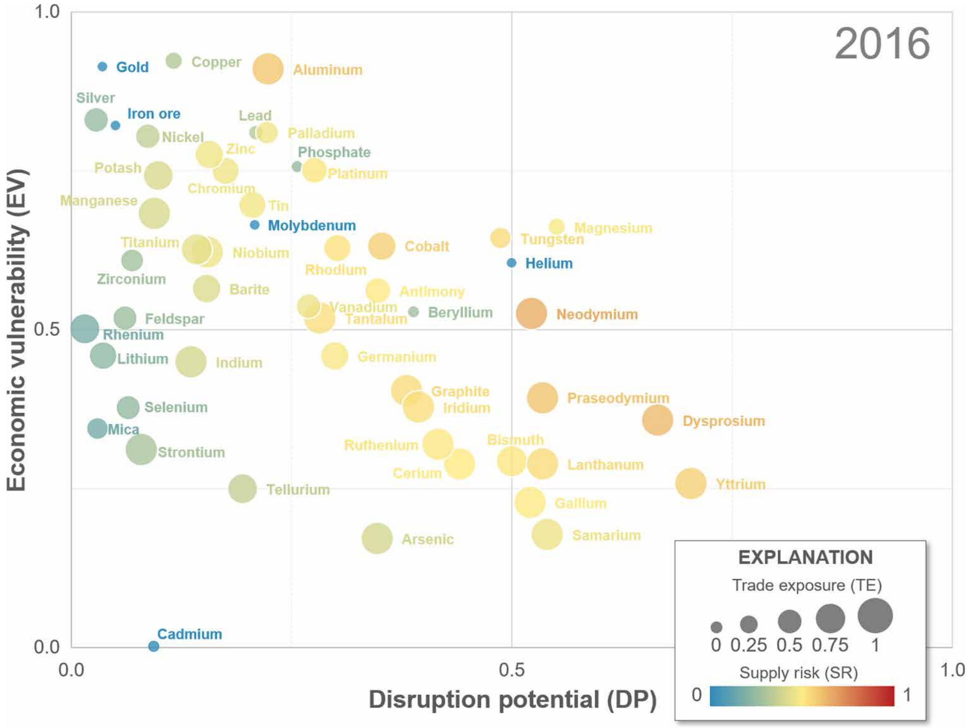

Fig. 2. Assessment of SR for year 2016. DP (horizontal axis), EV (vertical axis), TE (point size), and SR (point shade) are shown. For some commodities, indicator scores are rounded to avoid disclosing company proprietary data.

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indicates that commodities extend from the top left corner (low DP, high EV) to the bottom right (high DP, low EV). This general trend makes sense given that commodities that are used extensively throughout the economy are those that have been used by societies for millennia and are produced by a diverse set of countries, while mineral commodities used in niche applications are typically produced by only a small number of countries.

In three-dimensional space, with TE as the third dimension, the situation is more complex and less intuitive to decipher visually. A hierarchical cluster analysis—a statistical mechanism for grouping objects based on similarities in their attributes—based on the Euclidean distance across the three indicators is used to help interpret the results and identify natural groupings (see the Supplementary Materials for details). One cluster includes arsenic, indium, strontium, and tellurium. These commodities have moderate to low DP (0.1 to 0.3) and EV (0.2 to 0.4) but very high TE (0.9 to 1.0), thereby resulting in moderate overall SR (0.3 to 0.4). These scores reflect the relative diversity of countries that produced these commodities, the lack of significant domestic production, and their use in a limited number of specialized applications.

A nearby cluster with similarly moderate EV (0.3 to 0.6) but notably lower DP (<0.1) and TE (0.5 to 0.8) includes feldspar, lithium, mica, rhenium, selenium, and zirconium. Greater production diversity and a significant amount of domestic production distinguish commodities in this cluster from those in the previous one. Their overall SR scores are thus lower (0.2 to 0.3).

On the upper end of the EV scale are copper, gold, iron ore, lead, molybdenum, and phosphate. These commodities have very high EV (0.7 to 0.9) but low DP (0 to 0.3) and TE (0 to 0.3) because they are used extensively throughout the U.S. manufacturing sector and are produced by a large number of countries, including the United States. The United States is a net exporter for several of these commodities. Their overall SR scores are thus also low (0 to 0.3).

Another cluster includes beryllium, helium, magnesium, and tungsten. These commodities have moderate DP (0.4 to 0.6) and EV (0.5 to 0.7) and either very low (for helium and beryllium) or moderate (for tungsten and magnesium) TE. While the United States is the largest global producer of both beryllium and helium, it is not a major producer of tungsten or magnesium (metal). In the case of tungsten, U.S. production is exclusively secondary (i.e., recycling). This dissimilarity in TE causes these two sets of commodities within this cluster to have notably different overall SR scores, with magnesium and tungsten at around 0.5 and beryllium and helium at less than 0.3.

Commodities with high DP (0.4 to 0.7), very high TE (0.9 to 1.0), and moderate EV (0.2 to 0.5) form yet another cluster. Commodities in this cluster, which includes bismuth, cerium, dysprosium, gallium, natural graphite, iridium, lanthanum, neodymium, praseodymium, ruthenium, samarium, and yttrium, generally have the highest overall SR for this specific year (0.5 to 0.6). These commodities are mainly produced in one or two countries (of which the United States is not one) and often have niche or specialized applications.

The remaining commodities (aluminum, antimony, barite, chromium, cobalt, germanium, manganese, niobium, nickel, palladium, platinum, potash, rhodium, silver, tantalum, tin, titanium, vanadium, and zinc) form another cluster also with high TE (0.5 to 0.9), but in contrast to the previous cluster, their DP is low (0 to 0.4) and their EV is high (0.5 to 0.9). Their SR scores have a wide range (0.2 to 0.6), reflecting the diversity of commodities within this group that includes both high-volume commodities such as aluminum and low-volume precious metals such as rhodium.

Aside from these six clusters stands cadmium with exceptionally low scores in all three dimensions. These low scores reflect cadmium's limited use by U.S. manufacturers, a lack of a single dominant global producer, and the ability of domestic suppliers to provide sufficient quantities for domestic consumption.

The SR of a commodity can and does change with market dynamics. Figure 3 presents these changes for each of the indicators and the overall SR for the years 2007–2016. From this figure, several interesting trends emerge. In Fig. 3A, for example, the DP of several commodities, including aluminum, arsenic, bismuth, cobalt, gallium, germanium, helium, molybdenum, phosphate, tantalum, and tungsten, has increased over the years 2007–2016. This is mainly due to an increase in global production concentration. Despite the overall increase in DP, there is also a notable decline in DP in the latter years for several of these commodities. For some commodities, such as molybdenum, this is mainly attributable to a decrease in global production concentration stemming from a decline in production from one or more major producers. For other commodities, such as tantalum, the decline in production concentration is instead due to an increase in production in countries that are not the dominant producers. Increased production diversification is also the reason DP for the rare earth elements decreased in the past few years, as production outside of China ramped up. For most commodities, DP has remained relatively constant or has changed only modestly.

As illustrated in Fig. 3B, some commodities have seen sporadic changes in their TE due to the dynamics of domestic production, trade, consumption, and stock releases. However, TE for most commodities has remained relatively or completely constant. Throughout the decade, TE for helium, iron ore, molybdenum, and gold has been 0 (i.e., the United States was a net exporter of these commodities), while TE for 12 other commodities including natural graphite (listed under C), indium, and gallium has been 1 (i.e., the United States was 100% net import reliant for these commodities). There are, however, a few noteworthy trends. For lanthanum and cerium, the decline and subsequent increase in TE reflect the shifting operations of the Mountain Pass mine in California over the decade. The mine has since restarted operations but currently ships the concentrate to China for processing.

As displayed in Fig. 3C, EV for most commodities have also been relatively constant throughout the decade, with some commodities including aluminum, copper, gold, iron ore, lead, and silver having consistently high EV, while others including arsenic, iridium, strontium, and tellurium having consistently low EV. A few exceptions include bismuth, ruthenium, and rhodium for which EV has decreased notably. In each of these cases, EV declined mainly because of a decline in the commodity's price and (or) a decrease in its consumption. The price spike of rare earths in 2011 and subsequent decline are also evident in the EV peak for lanthanum, cerium, and yttrium.

Some commodities have notable movements in more than one indicator. The movements for several of these commodities are displayed in Fig. 4. For bismuth, the increases and subsequent decreases in DP are driven by the production outside of China, which has fluctuated throughout this period. Decreases in bismuth's price and its consumption by the U.S. manufacturing sector explain the decreases in its EV. For ruthenium, a notable decline in its price and domestic consumption drove EV significantly lower, while an estimated

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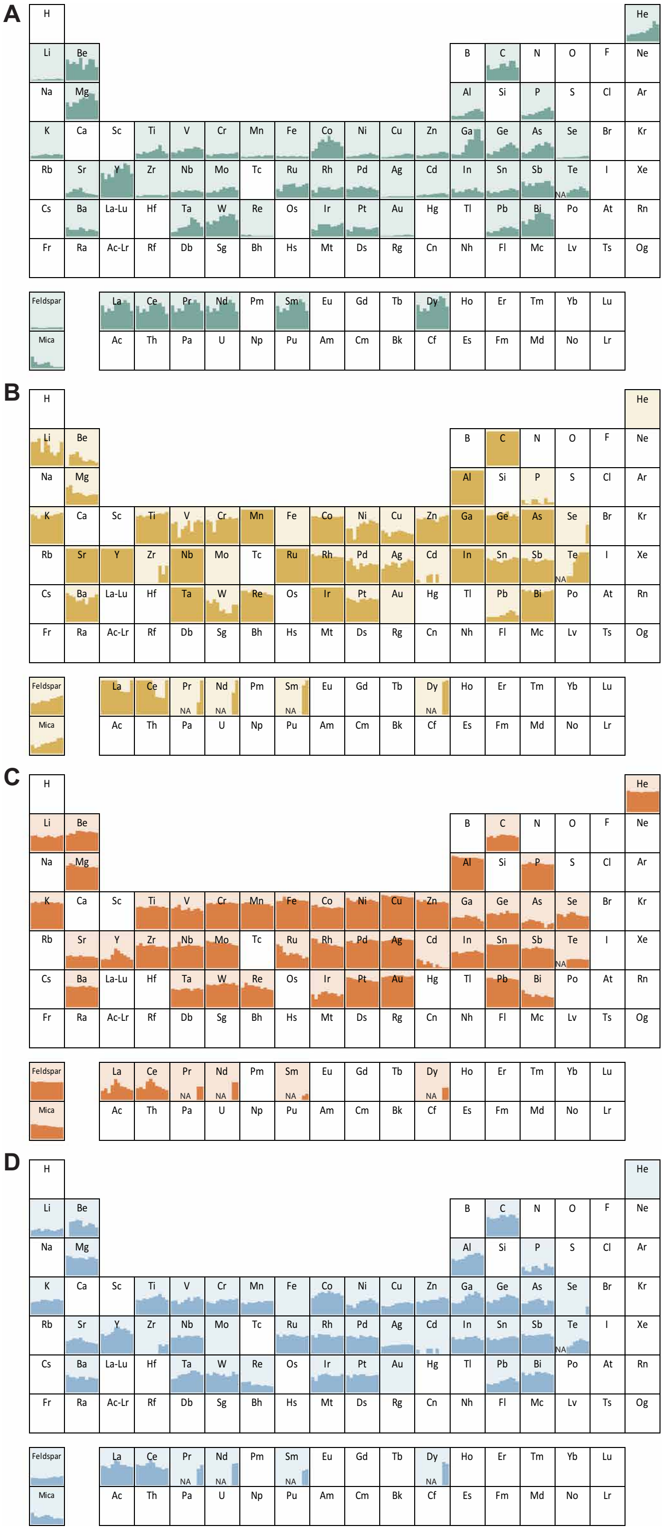

Fig. 3. SR by indicator for years 2007–2016. DP (**A**), TE (**B**), EV (**C**), and SR (**D**) scores for all commodities examined for the years 2007–2016 are shown. For each box, the vertical axis represents scores ranging from 0 to 1, while the horizontal axis represents the years 2007–2016. No results are available for tellurium (Te) before 2011 or neodymium (Nd), praseodymium (Pr), samarium (Sm), and dysprosium (Dy) before year 2015, as indicated by "NA" in their box. For some commodities, indicator scores are rounded to avoid disclosing company proprietary data.

increase in production concentration in South Africa increased DP modestly. For gallium, DP increased significantly from 2007 to 2014 because of the rapid increase in production in China. In 2016, Chinese production decreased notably because of an effort to reduce excess supply, which has also been driving down the price of low-purity (≤99.99%) gallium. Consumption of gallium by U.S. manufacturers also decreased notably from 2015 to 2016, especially in laser diodes and light-emitting diodes, possibly because of a shift of production of these optoelectronic devices overseas. As a result, both DP and EV for gallium declined significantly in 2016. For the rare earth elements cerium, lanthanum, and yttrium, scores moved in a clockwise direction in the DP and EV space, reaching a peak EV score in 2011 at the height of the rare earth crisis when prices spiked before reaching a peak DP in 2014. The 2016 scores returned to nearly the same position they were at in 2007 (especially in the case of yttrium) as countries outside of China ramped up their production.

The movements of these individual indicators are reflected in the trends of the overall SR in Fig. 3D. Some commodities including aluminum, gallium, germanium, and tantalum have generally increasing SR, while commodities including magnesium, mica, and strontium have generally decreasing SR. Aside from these and a few other notable movements, SR for most commodities has remained relatively consistent such that commodities with generally high SR and those with generally low SR maintained those levels throughout the decade. This is best illustrated in Fig. 5, which displays a heat map for SR (with orange to red shades indicating a greater degree of risk) for all the commodities analyzed over this period. The commodities are listed in descending order based on their average SR across the decade.

A second hierarchical cluster analysis, this time on the 2007–2016 average SR for each commodity (see the Supplementary Materials for details), identifies four clusters as indicated in the first column of Fig. 5. Cluster 1 consists of 23 commodities with the highest SR scores and thus poses the greatest SR to the U.S. manufacturing sector. These commodities include rare earth elements, platinum-group elements, cobalt, tungsten, and tantalum. Figure 5 also identifies the largest producing country (or top 2 countries if the largest producer produced less than half of world production from 2007 to 2016). China is the largest producer for 16 of the 23 commodities identified as having the greatest SR. This is, perhaps, not surprising given China's increasing role over the past few decades as a major producer of numerous mineral commodities. In addition, 15 of these 23 commodities are produced mainly or solely as by-products. This is aligned with previous criticality assessments (*24*) and is not unexpected given that by-product commodities typically have highly concentrated production (*9*). Moreover, despite differences in methodological approaches and scopes of previous assessments, 21 of the 23 commodities identified in this analysis as having the greatest SR have previously been designated as "critical" in at least 71% of studies in which they were examined (*24*). Aluminum and titanium are the two exceptions having been identified as critical in only 22 and 26% of previous studies in which they were examined, respectively (*24*). The reason for this divergence stems primarily from the use of the bottleneck approach in this assessment in which indicator scores for a commodity with data at multiple production stages are derived from the production stage that yields the highest scores. In the case of both aluminum and titanium, different production stages provide higher indicator scores for different indicators. Specifically, the high TE scores for aluminum and titanium are driven by bauxite

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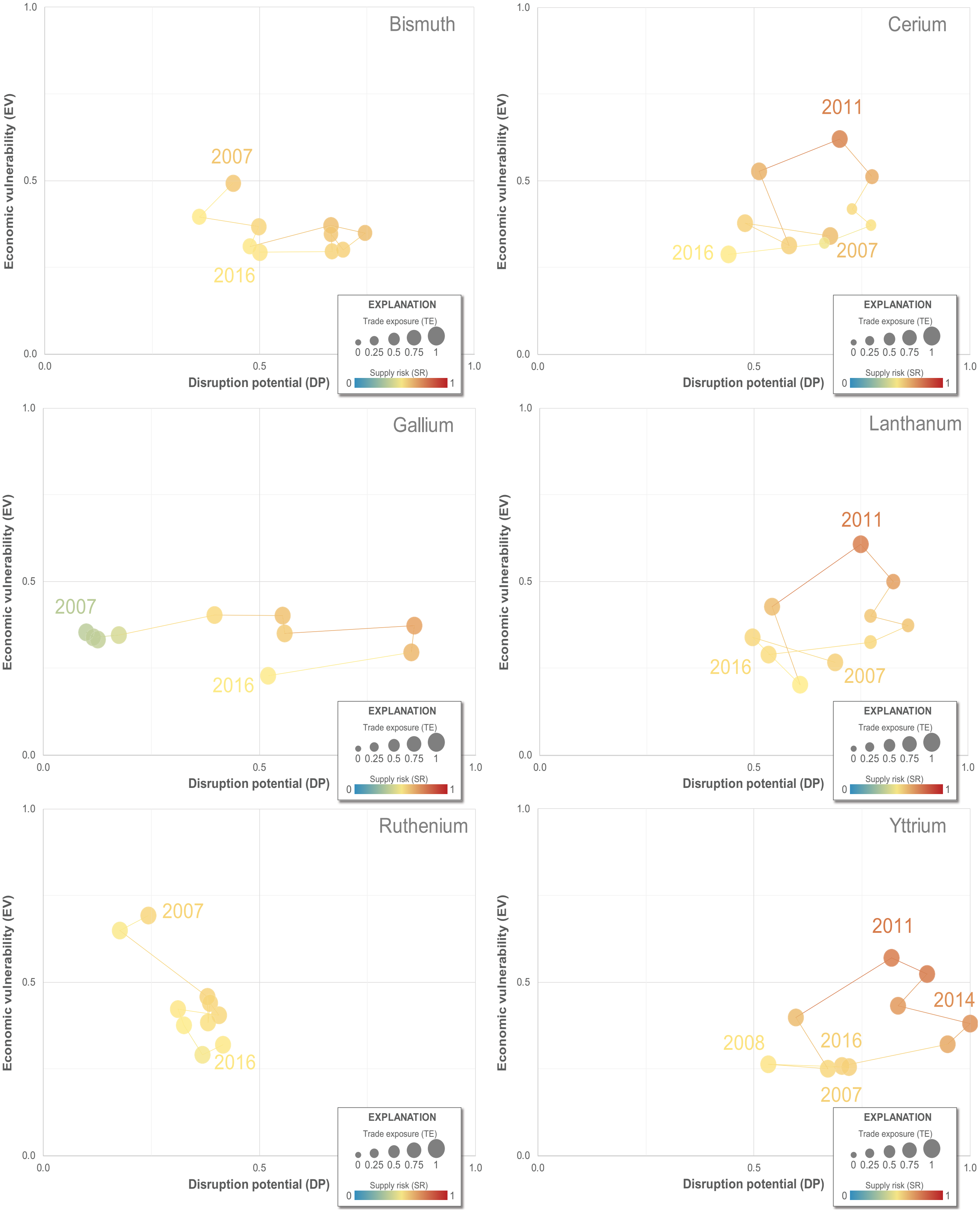

Fig. 4. Dynamic SR indicators for selected commodities. DP (horizontal axis), EV (vertical axis), TE (point size), and SR (point shade) for the years 2007–2016 for selected commodities are shown. For some commodities, indicator scores are rounded to avoid disclosing company proprietary data.

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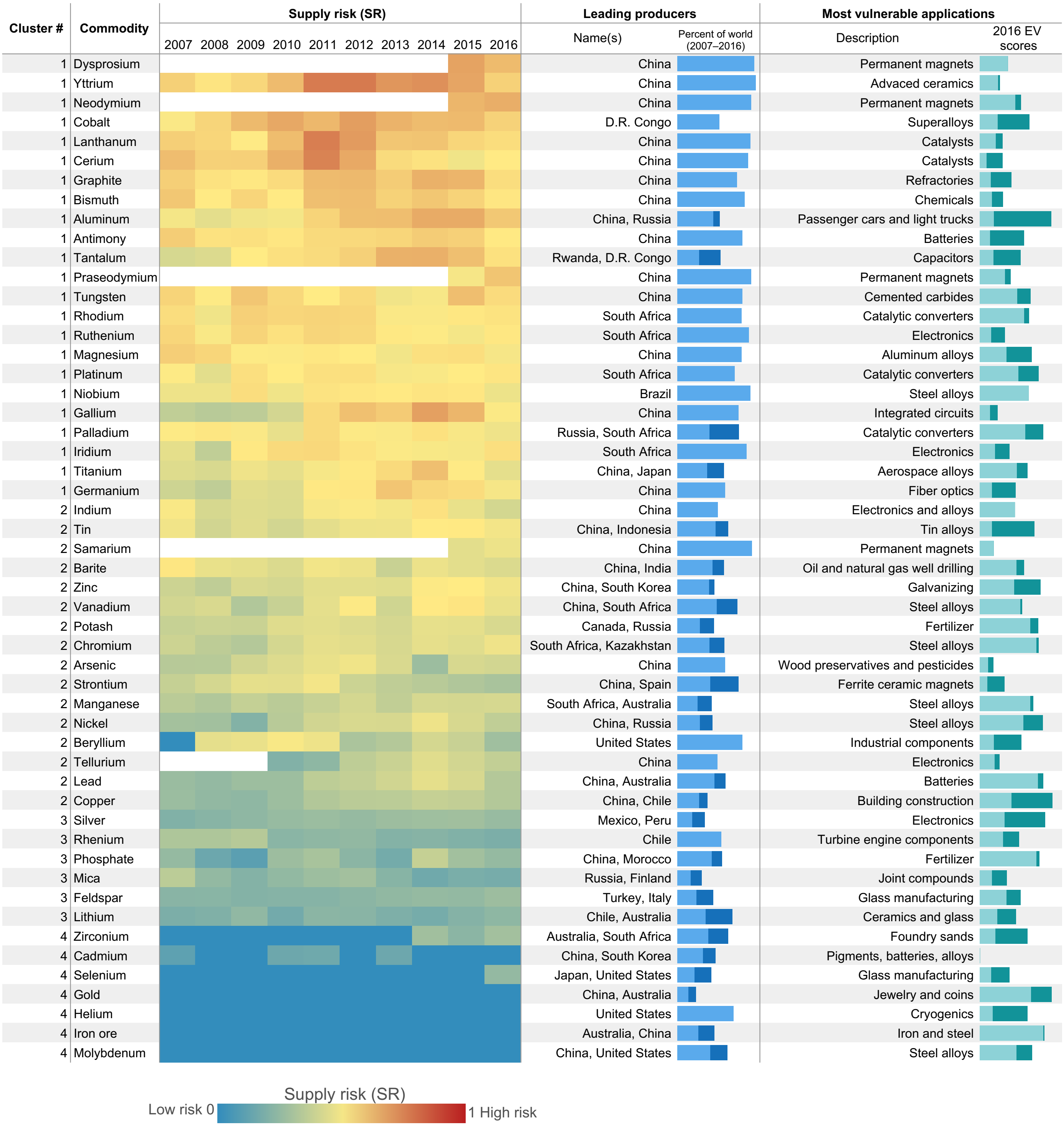

Fig. 5. Heat map displaying the SR for all commodities examined for years 2007–2016. Warmer (i.e., orange to red) shades indicate a greater degree of SR. Commodities are listed in descending order of their 2007–2016 average SR and identified by cluster based on a hierarchical cluster analysis. Leading producing countries, based on primary production, are identified, and their share of world production from 2007 to 2016 is displayed in the stacked blue bars. The most vulnerable applications in 2016 are identified, and their contribution and the contribution of all other applications to a commodity's overall EV are depicted in the stacked teal and dark teal bars, respectively.

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and titanium mineral concentrate production, respectively, while the high DP and EV scores are driven by aluminum smelter and titanium metal production. This bottleneck approach thus appropriately identifies risks that reside at different supply chain stages that would otherwise be overlooked if examined separately.

The applications that are most vulnerable to a supply disruption for each commodity are also displayed in Fig. 5. Specifically, these applications contributed the most to the overall EV score of that commodity for year 2016. The contributions of the most vulnerable applications and the contributions of all other applications are depicted in the teal and dark teal colors, respectively. Notably, for many commodities, the vulnerability is driven by a single application (e.g., permanent magnets for dysprosium, neodymium, praseodymium, and samarium; catalytic converters for rhodium; and cemented carbides for tungsten), while for others, the vulnerability stems from many different applications (e.g., aluminum).

CONCLUSIONS

For the decade spanning 2007–2016, these results identify a subset of mineral commodities, including rare earth elements, platinum-group elements, cobalt, niobium, tantalum, and tungsten, that pose the greatest SR for the U.S. manufacturing sector. This subset includes commodities that have a high degree of production concentration in countries that may become unable or unwilling to supply to the United States, are mainly imported from other countries, and are consumed in economically important manufacturing industries that may be less able to withstand a price shock that may result from a supply disruption. It is this subset of commodities for which further investigations are necessary.

No set of indicators alone can perfectly capture the complex set of issues that are unique to each commodity and the manufacturing industries that consume it. Moreover, SR is dynamic, increasing and decreasing with changing global market conditions that are specific to each commodity and industry. A commodity with supply that is not at high risk today may become at high risk in the future as production and consumption patterns shift. Nevertheless, the analysis indicates that significant changes in SR over short periods of time are rare, seeming to have occurred for only a few commodities examined in this analysis over the past decade. Moreover, although SR scores can and do change markedly, the subset of commodities with the highest SR has been largely consistent throughout the time period examined. This is noteworthy given that both policies and corporate actions cannot be driven by year-to-year fluctuations.

Once identified as having high SR, it is then important to determine how best to reduce that risk for that commodity. As noted in Introduction, risk arises at the confluence of three factors: hazard, exposure, and vulnerability. The combination of these three factors is necessary, but each alone is insufficient. In turn, reducing the risk of a supply disruption can be achieved by reducing any one of these three factors. As indicated by a recent report from the U.S. Department of Commerce in response to Executive Order 13817 (*40*), diversifying supply, securing supplies through trade relationships, developing domestic primary and secondary resources and capabilities, using less of a material through improved or alternative manufacturing techniques and recycling, and stockpiling are all means by which the risk can be reduced. The degree to which any one of these strategies can be successful at minimizing the risk to an acceptable level depends on the specific commodity and the industries involved, as well as what is deemed to be an acceptable level of risk.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/8/eaay8647/DC1

Supplementary Materials and Methods
Fig. S1. WSI and constituent components by year.
Fig. S2. SR, DP, EV, and TE scores for years 2007–2015.
Fig. S3. Hierarchical cluster analysis based on 2016 DP, EV, and TE scores.
Fig. S4. Hierarchical cluster analysis based on 2007–2016 average SR scores.
Table S1. Description of data for world primary and secondary production and prices for each commodity.
Table S2. Description of data for U.S. apparent consumption calculation by component for each commodity.
Table S3. Estimated elemental content of various steel alloys.
Table S4. Description of applications, associated NAICS codes, and U.S. demand fractions for each commodity.
Table S5. Rare earth oxide distribution (in percent of total) for various world regions.
Table S6. Rare earth oxide distribution (in percent of total) for various regions in China.

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The Role of Critical Minerals in Clean Energy Transitions

World Energy Outlook Special Report

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 8 association countries and beyond.

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Foreword

Ever since the International Energy Agency (IEA) was founded in 1974 in the wake of severe disruptions to global oil markets that shook the world economy, its core mission has been to foster secure and affordable energy supplies.

Today, the global energy system is in the midst of a major transition to clean energy. The efforts of an ever-expanding number of countries and companies to reduce their greenhouse gas emissions to net zero call for the massive deployment of a wide range of clean energy technologies, many of which in turn rely on critical minerals such as copper, lithium, nickel, cobalt and rare earth elements.

An evolving energy system calls for an evolving approach to energy security. As clean energy transitions accelerate globally and solar panels, wind turbines and electric cars are deployed on a growing scale, these rapidly growing markets for key minerals could be subject to price volatility, geopolitical influence and even disruptions to supply.

This *World Energy Outlook* special report on *The Role of Critical Minerals in Clean Energy Transitions* identifies risks to key minerals and metals that – left unaddressed – could make global progress towards a clean energy future slower or more costly, and therefore hamper international efforts to tackle climate change. The IEA is determined to play a leading role in enabling governments around the world to anticipate and navigate possible disruptions and avoid damaging outcomes for our economies and our planet.

This special report is the most comprehensive global study of this subject to date, underscoring the IEA's commitment to ensuring energy systems remain as resilient, secure and sustainable as possible. Building on the IEA's detailed, technology-rich energy modelling tools, we have established a unique and extensive database that underpins our projections of the world's future mineral requirements under different climate and technology scenarios.

This is what energy security looks like in the 21st century. We must pay close attention to all potential vulnerabilities, as the IEA did in our recent series on electricity security for power systems, which covered challenges such as growing shares of variable renewables, climate resilience and cyber security.

Today's supply and investment plans for many critical minerals fall well short of what is needed to support an accelerated deployment of solar panels, wind turbines and electric vehicles. Many minerals come from a small number of producers. For example, in the cases of lithium, cobalt and rare earth elements, the world's top three producers control well over three-quarters of global output. This high geographical concentration, the long lead times to bring new mineral production on stream, the declining resource quality in some areas, and various environmental and social impacts all raise concerns around reliable and sustainable supplies of minerals to support the energy transition.

These hazards are real, but they are surmountable. The response from policy makers and companies will determine whether critical minerals remain a vital enabler for clean energy transitions or become a bottleneck in the process.

Based on this special report, we identify the IEA's six key recommendations to ensure mineral security. An essential step is for policy makers to provide clear signals about their climate ambitions and how their targets will be turned into action. Long-term visibility is essential to provide the confidence investors need to commit to new projects. Efforts to scale up investment should go hand-in-hand with a broad strategy that encompasses technology innovation, recycling, supply chain resilience and sustainability standards.

There is no shortage of resources worldwide, and there are sizeable opportunities for those who can produce minerals in a sustainable and responsible manner. Because no single country will be able to solve these issues alone, strengthened international cooperation is essential. Leveraging the IEA's long-standing leadership in safeguarding energy security, we remain committed to helping governments, producers and consumers tackle these critical challenges.

Finally, I would like to thank the excellent team behind this ground-breaking report, led by Tae-Yoon Kim under the direction of Tim Gould, for their work in producing analysis of such high quality, and many other colleagues from across the Agency who brought their expertise to bear on this crucial topic.

Dr. Fatih Birol
Executive Director
International Energy Agency

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Executive summary

In the transition to clean energy, critical minerals bring new challenges to energy security

An energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources. Building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally requires more minerals than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant. Since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables has risen.

The types of mineral resources used vary by technology. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Rare earth elements are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies.

The shift to a clean energy system is set to drive a huge increase in the requirements for these minerals, meaning that the energy sector is emerging as a major force in mineral markets. Until the mid-2010s, the energy sector represented a small part of total demand for most minerals. However, as energy transitions gather pace, clean energy technologies are becoming the fastest-growing segment of demand.

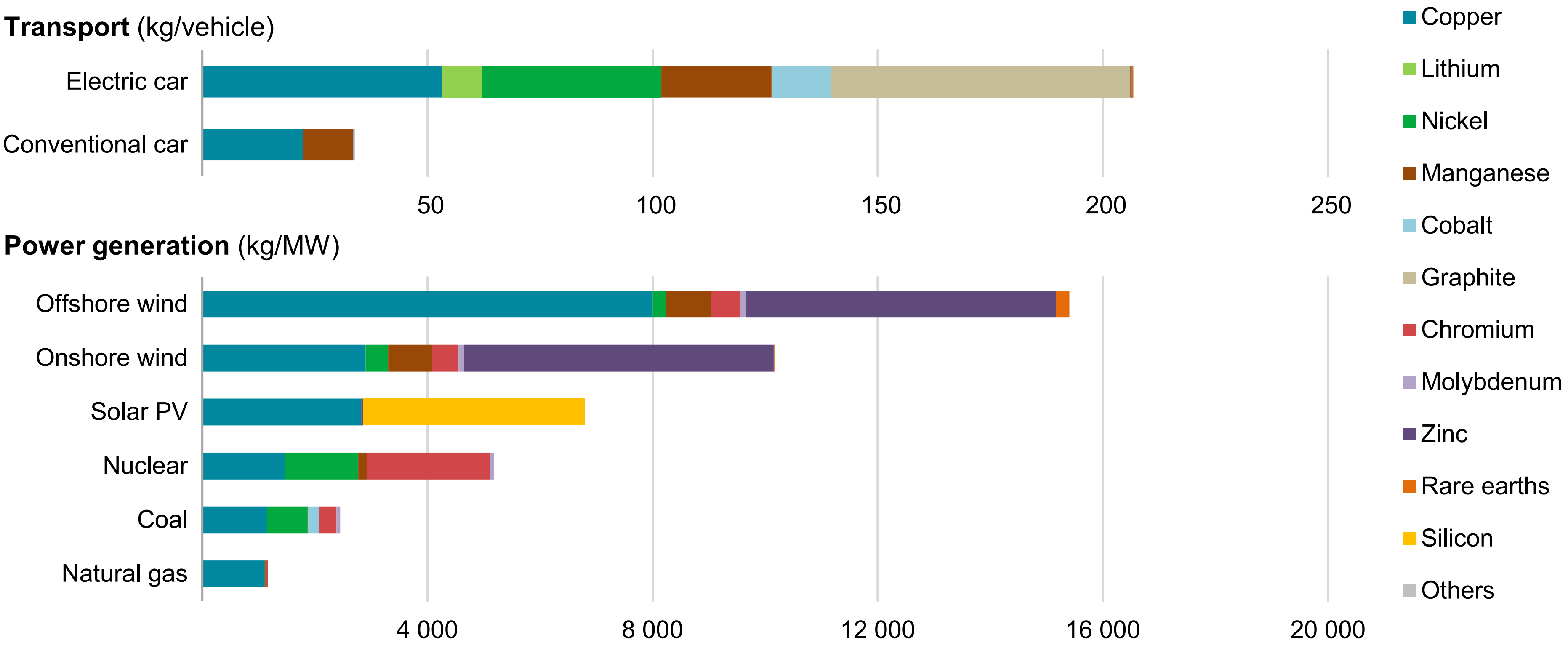
In a scenario that meets the Paris Agreement goals, clean energy technologies' share of total demand rises significantly over the next two decades to over 40% for copper and rare earth elements, 60-70% for nickel and cobalt, and almost 90% for lithium. EVs and battery storage have already displaced consumer electronics to become the largest consumer of lithium and are set to take over from stainless steel as the largest end user of nickel by 2040.

As countries accelerate their efforts to reduce emissions, they also need to make sure their energy systems remain resilient and secure. Today's international energy security mechanisms are designed to provide insurance against the risks of disruptions or price spikes in supplies of hydrocarbons, particularly oil. Minerals offer a different and distinct set of challenges, but their rising importance in a decarbonising energy system requires energy policy makers to expand their horizons and consider potential new vulnerabilities. Concerns about price volatility and security of supply do not disappear in an electrified, renewables-rich energy system.

This is why the IEA is paying close attention to the issue of critical minerals and their role in clean energy transitions. This report reflects the IEA's determination to stay ahead of the curve on all aspects of energy security in a fast-evolving energy world.

The rapid deployment of clean energy technologies as part of energy transitions implies a significant increase in demand for minerals

Minerals used in selected clean energy technologies



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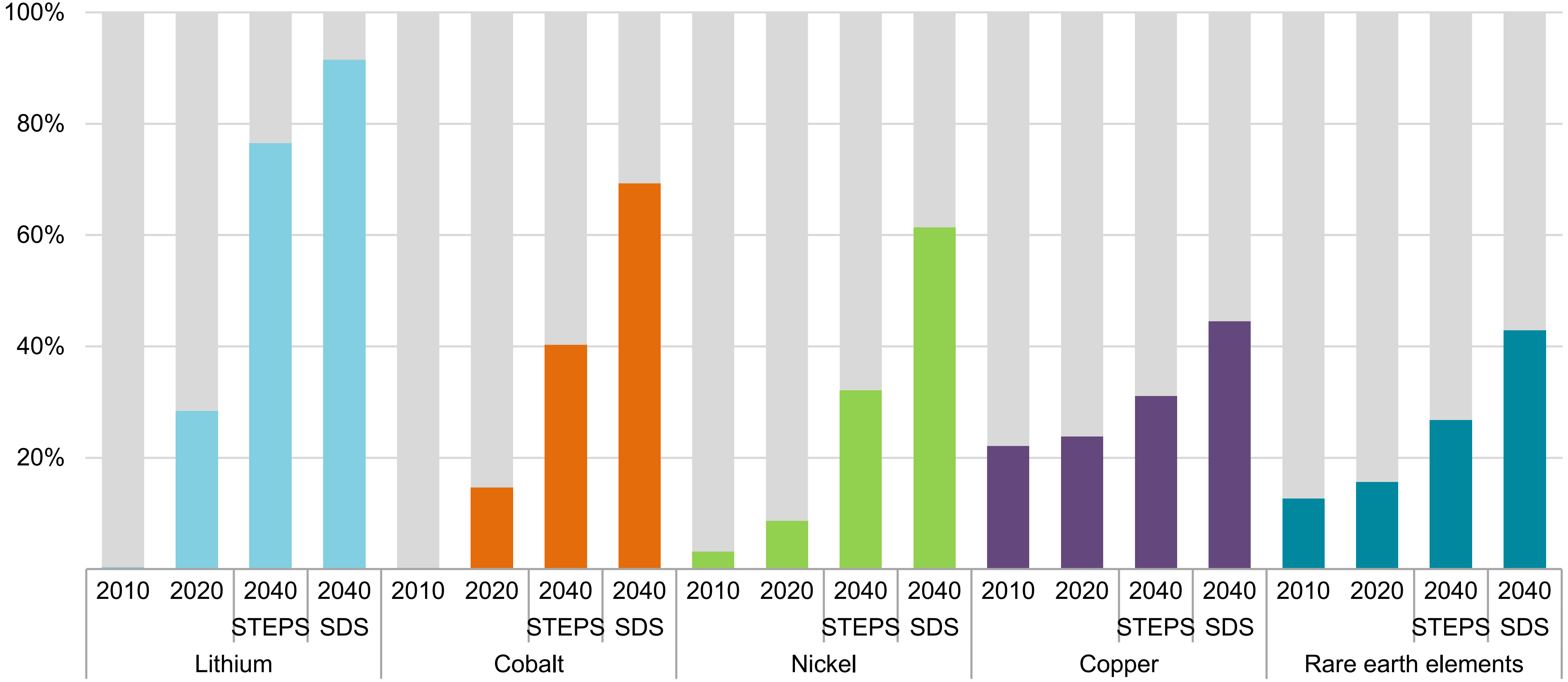
Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

The energy sector becomes a leading consumer of minerals as energy transitions accelerate

Share of clean energy technologies in total demand for selected minerals



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Notes: Demand from other sectors was assessed using historical consumption, relevant activity drivers and the derived material intensity. Neodymium demand is used as indicative for rare earth elements. STEPS = Stated Policies Scenario, an indication of where the energy system is heading based on a sector-by-sector analysis of today's policies and policy announcements; SDS = Sustainable Development Scenario, indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

Clean energy transitions will have far-reaching consequences for metals and mining

Our bottom-up assessment suggests that a concerted effort to reach the goals of the Paris Agreement (climate stabilisation at “well below 2°C global temperature rise”, as in the IEA Sustainable Development Scenario [SDS]) would mean a quadrupling of mineral requirements for clean energy technologies by 2040. An even faster transition, to hit net-zero *globally* by 2050, would require six times more mineral inputs in 2040 than today.

Which sectors do these increases come from? In climate-driven scenarios, mineral demand for use in EVs and battery storage is a major force, growing at least thirty times to 2040. Lithium sees the fastest growth, with demand growing by over 40 times in the SDS by 2040, followed by graphite, cobalt and nickel (around 20-25 times). The expansion of electricity networks means that copper demand for power lines more than doubles over the same period.

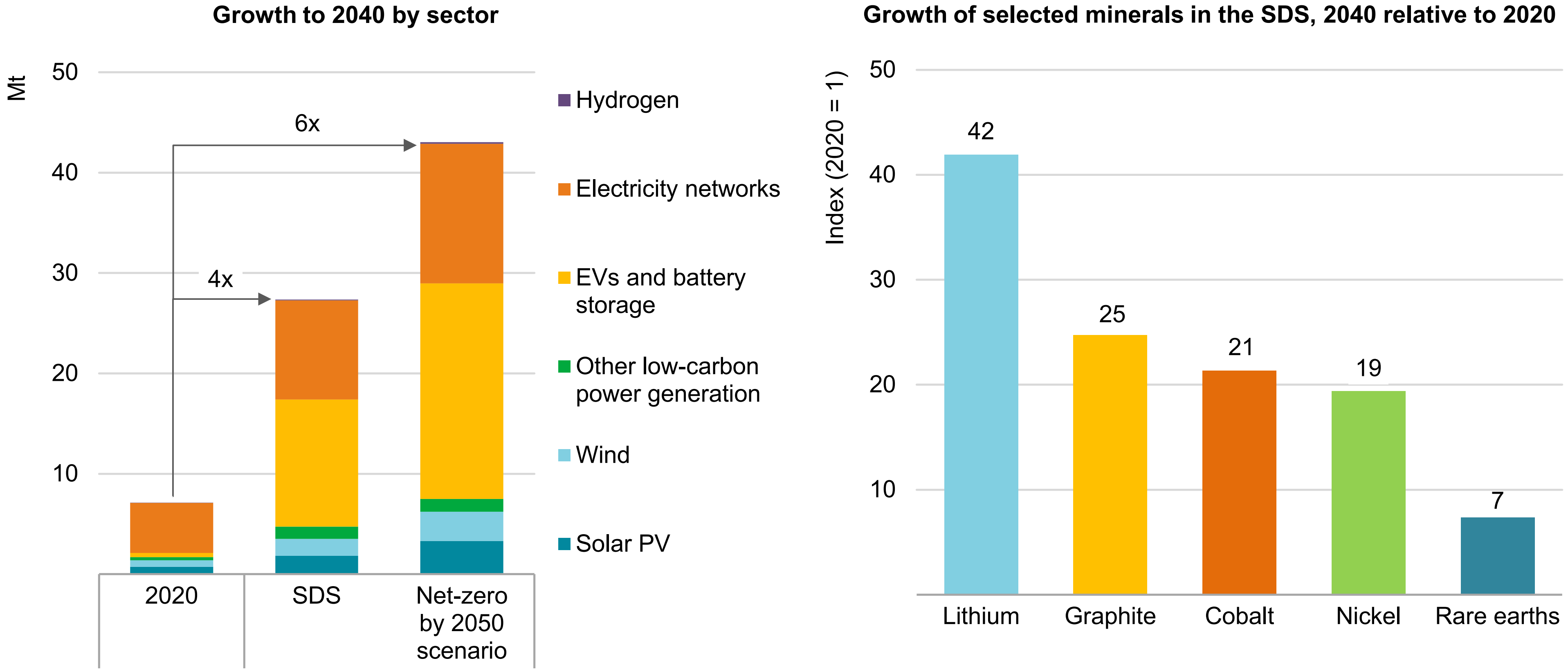
The rise of low-carbon power generation to meet climate goals also means a tripling of mineral demand from this sector by 2040. Wind takes the lead, bolstered by material-intensive offshore wind. Solar PV follows closely, due to the sheer volume of capacity that is added. Hydropower, biomass and nuclear make only minor contributions given their comparatively low mineral requirements. In other sectors, the rapid growth of hydrogen as an energy carrier underpins major growth in demand for nickel and zirconium for electrolysers, and for platinum-group metals for fuel cells.

Demand trajectories are subject to large technology and policy uncertainties. We analysed 11 alternative cases to understand the impacts. For example, cobalt demand could be anything from 6 to 30 times higher than today’s levels depending on assumptions about the evolution of battery chemistry and climate policies. Likewise rare earth elements may see three to seven times higher demand in 2040 than today, depending on the choice of wind turbines and the strength of policy support. The largest source of demand variability comes from uncertainty around the stringency of climate policies. The big question for suppliers is whether the world is really heading for a scenario consistent with the Paris Agreement. Policy makers have a crucial role in narrowing this uncertainty by making clear their ambitions and turning targets into actions. This will be vital to reduce investment risks and ensure adequate flow of capital to new projects.

Clean energy transitions offer opportunities and challenges for companies that produce minerals. Today revenue from coal production is ten times larger than those from energy transition minerals. However, there is a rapid reversal of fortunes in a climate-driven scenario, as the combined revenues from energy transition minerals overtake those from coal well before 2040.

Mineral demand for clean energy technologies would rise by at least four times by 2040 to meet climate goals, with particularly high growth for EV-related minerals

Mineral demand for clean energy technologies by scenario



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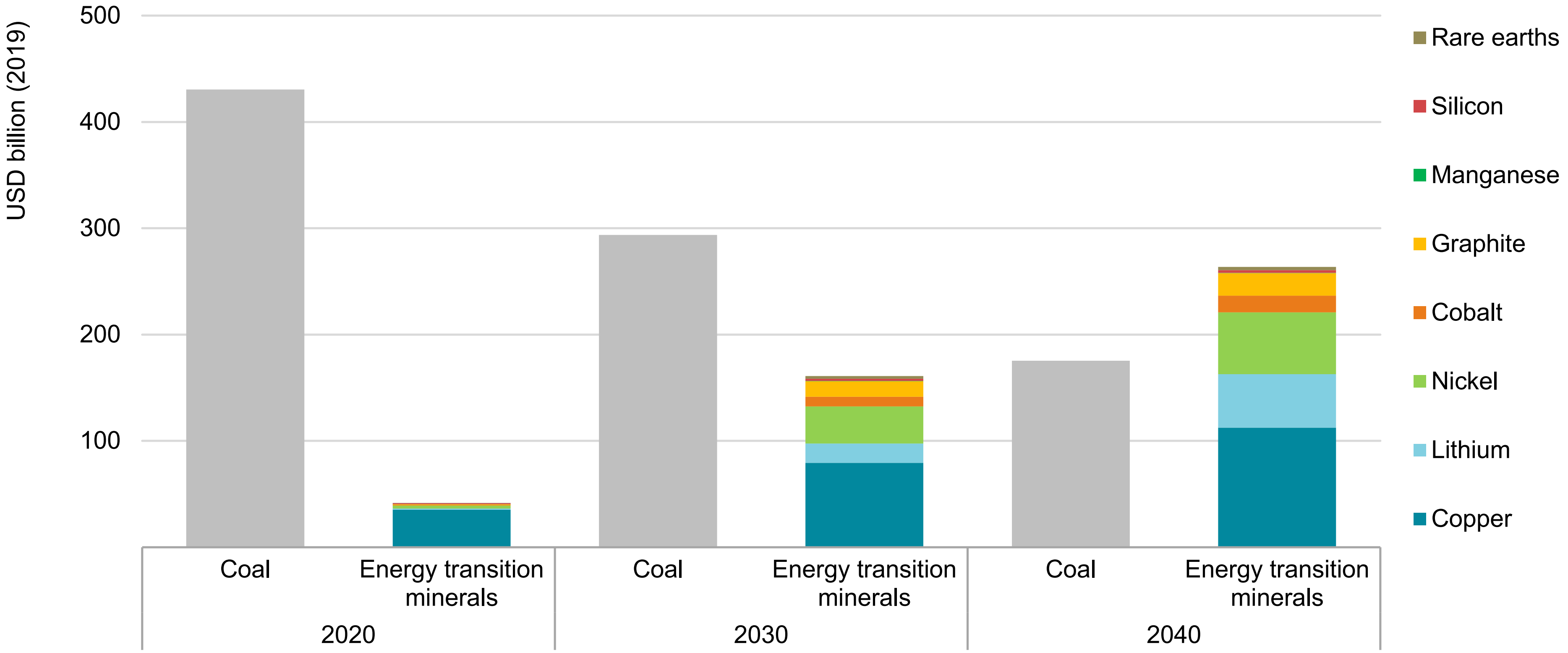
Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium. See Annex for a full list of minerals.

Changing fortunes: Coal vs energy transition minerals

Revenue from production of coal and selected energy transition minerals in the SDS



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Notes: Revenue for energy transition minerals includes only the volume required in clean energy technologies, not total demand. Future prices for coal are projected equilibrium prices in *WEO 2020* SDS. Prices for energy transition minerals are based on conservative assumptions about future price trends (moderate growth of around 10-20% from today's levels).

Today’s mineral supply and investment plans fall short of what is needed to transform the energy sector, raising the risk of delayed or more expensive energy transitions

The prospect of a rapid increase in demand for critical minerals – well above anything seen previously in most cases – raises huge questions about the availability and reliability of supply. In the past, strains on the supply-demand balance for different minerals have prompted additional investment and measures to moderate or substitute demand. But these responses have come with time lags and have been accompanied by considerable price volatility. Similar episodes in the future could delay clean energy transitions and push up their cost. Given the urgency of reducing emissions, this is a possibility that the world can ill afford.

Raw materials are a significant element in the cost structure of many technologies required in energy transitions. In the case of lithium-ion batteries, technology learning and economies of scale have pushed down overall costs by 90% over the past decade. However, this also means that raw material costs now loom larger, accounting for some 50-70% of total battery costs, up from 40-50% five years ago. Higher mineral prices could therefore have a significant effect: a doubling of lithium or nickel prices would induce a 6% increase in battery costs. If both lithium and nickel prices were to double at the same time, this would offset all the anticipated unit cost reductions associated with a doubling of battery production capacity. In the case of electricity networks, copper and aluminium currently represent around 20% of total grid investment costs. Higher prices as a result of tight supply could have a major impact on the level of grid investment.

Our analysis of the near-term outlook for supply presents a mixed picture. Some minerals such as mined lithium and cobalt are expected to be in surplus in the near term, while lithium chemical products, battery-grade nickel and key rare earth elements (e.g. neodymium and dysprosium) might face tight supply in the years ahead. However, looking further ahead in a scenario consistent with climate goals, expected supply from existing mines and projects under construction is estimated to meet only half of projected lithium and cobalt requirements and 80% of copper needs by 2030.

Today’s supply and investment plans are geared to a world of more gradual, insufficient action on climate change (the STEPS trajectory). They are not ready to support accelerated energy transitions. While there are a host of projects at varying stages of development, there are many vulnerabilities that may increase the possibility of market tightness and greater price volatility:

- **High geographical concentration of production:** Production of many energy transition minerals is more concentrated than that of oil or natural gas. For lithium, cobalt and rare earth elements, the world’s top three producing nations control well over three-quarters of global output. In some cases, a single country is responsible for around half of worldwide production. The Democratic Republic of the Congo (DRC) and People's Republic of China (China) were responsible for some 70% and 60% of global production of cobalt and rare earth elements respectively in 2019. The level of concentration is even higher for processing operations, where China has a strong presence across the board. China's share of refining is around 35% for nickel, 50-70% for lithium and cobalt, and nearly 90% for rare earth elements. Chinese companies have also made substantial investment in overseas assets in Australia, Chile, the DRC and Indonesia. High levels of concentration, compounded by complex supply chains, increase the risks that could arise from physical disruption, trade restrictions or other developments in major producing countries.

- **Long project development lead times:** Our analysis suggests that it has taken on average over 16 years to move mining projects from discovery to first production. These long lead times raise questions about the ability of suppliers to ramp up output if demand were to pick up rapidly. If companies wait for deficits to emerge before committing to new projects, this could lead to a prolonged period of market tightness and price volatility.

- **Declining resource quality:** Concerns about resources relate to quality rather than quantity. In recent years, ore quality has continued to fall across a range of commodities. For example, the average copper ore grade in Chile declined by 30% over the past 15 years. Extracting metal content from lower-grade ores requires more energy, exerting upward pressure on production costs, greenhouse gas emissions and waste volumes.

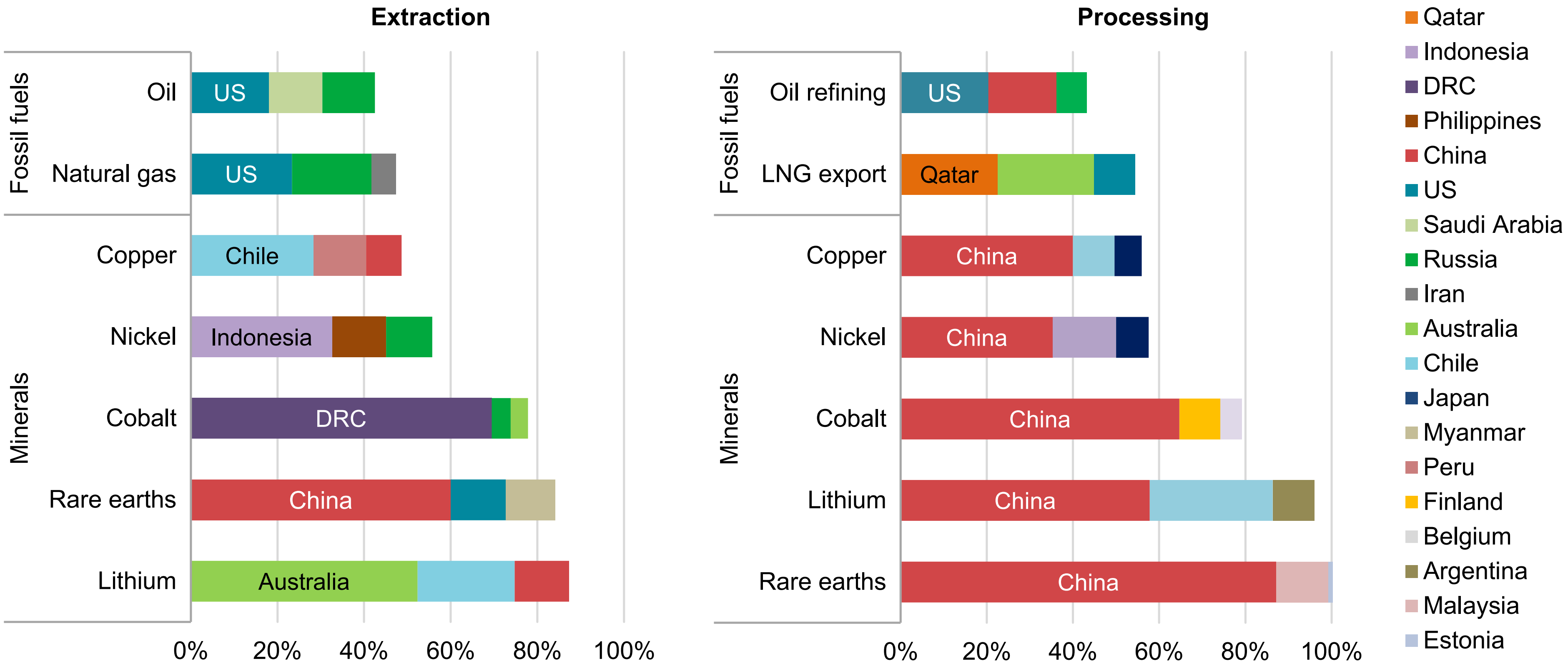
- **Growing scrutiny of environmental and social performance:** Production and processing of mineral resources gives rise to a variety of environmental and social issues that, if poorly managed, can harm local communities and disrupt supply. Consumers and investors are increasingly calling for companies to source minerals that are sustainably and responsibly produced. Without broad and sustained efforts to improve environmental and social performance, it may be challenging for consumers to exclude minerals produced with poor standards as higher-performing supply chains may not be sufficient to meet demand.

- **Higher exposure to climate risks:** Mining assets are exposed to growing climate risks. Copper and lithium are particularly vulnerable to water stress given their high water requirements. Over 50% of today's lithium and copper production is concentrated in areas with high water stress levels. Several major producing regions such as Australia, China, and Africa are also subject to extreme heat or flooding, which pose greater challenges in ensuring reliable and sustainable supplies.

These risks to the reliability, affordability and sustainability of mineral supply are manageable, but they are real. How policy makers and companies respond will determine whether critical minerals are a vital enabler for clean energy transitions, or a bottleneck in the process.

Production of many energy transition minerals today is more geographically concentrated than that of oil or natural gas

Share of top three producing countries in production of selected minerals and fossil fuels, 2019



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Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.
Sources: IEA (2020a); USGS (2021), World Bureau of Metal Statistics (2020); Adamas Intelligence (2020).

New and more diversified supply sources will be vital to pave the way to a clean energy future

As energy transitions gather pace, security of mineral supply is gaining prominence in the energy security debate, a realm where oil has traditionally occupied a central role.

There are significant differences between oil security and mineral security, notably in the impacts that any disruption may have. In the event of an oil supply crisis, all consumers driving gasoline cars or diesel trucks are affected by higher prices. By contrast, a shortage or spike in the price of a mineral affects only the supply of *new* EVs or solar plants. Consumers driving existing EVs or using solar-powered electricity are not affected. In addition, the combustion of oil means that new supply is essential to the continuous operation of oil-using assets. However, minerals are a component of infrastructure, with the potential to be recovered and recycled.

Nonetheless, experience from oil markets may offer some valuable lessons for an approach to mineral security, in particular to underscore that supply-side measures need to be accompanied by wide-ranging efforts encompassing demand, technology, supply chain resilience and sustainability.

Rapid, orderly energy transitions require strong growth in investment in mineral supplies to keep up with the pace of demand growth. Policy makers can take a variety of actions to encourage new supply projects: the most important is to provide clear and strong signals about energy transitions. If companies do not have confidence in countries' energy and climate policies, they are likely to make investment decisions based on much more conservative expectations. Given the long lead times for new project developments, this could create bottlenecks when deployment of clean energy technologies starts to grow rapidly. Diversification of supply is also crucial; resource-owning governments can support new project development by reinforcing national geological surveys, streamlining permitting procedures to shorten lead times, providing financing support to de-risk projects, and raising public awareness of the contribution that such projects play in the transformation of the energy sector.

Reducing material intensity and encouraging material substitution via technology innovation can also play major roles in alleviating strains on supply, while also reducing costs. For example, 40-50% reductions in the use of silver and silicon in solar cells over the past decade have enabled a spectacular rise in solar PV deployment. Innovation in production technologies can also unlock sizeable new supplies. Emerging technologies, such as direct lithium extraction or enhanced metal recovery from waste streams or low-grade ores, offer the potential for a step change in future supply volumes.

A strong focus on recycling, supply chain resilience and sustainability will be essential

Recycling relieves the pressure on primary supply. For bulk metals, recycling practices are well established, but this is not yet the case for many energy transition metals such as lithium and rare earth elements. Emerging waste streams from clean energy technologies (e.g. batteries and wind turbines) can change this picture. The amount of spent EV batteries reaching the end of their first life is expected to surge after 2030, at a time when mineral demand is set to still be growing rapidly. Recycling would not eliminate the need for continued investment in new supplies. But we estimate that by 2040, recycled quantities of copper, lithium, nickel and cobalt from spent batteries could reduce combined primary supply requirements for these minerals by around 10%. The security benefits of recycling can be far greater for regions with wider deployment of clean energy technologies due to greater economies of scale.

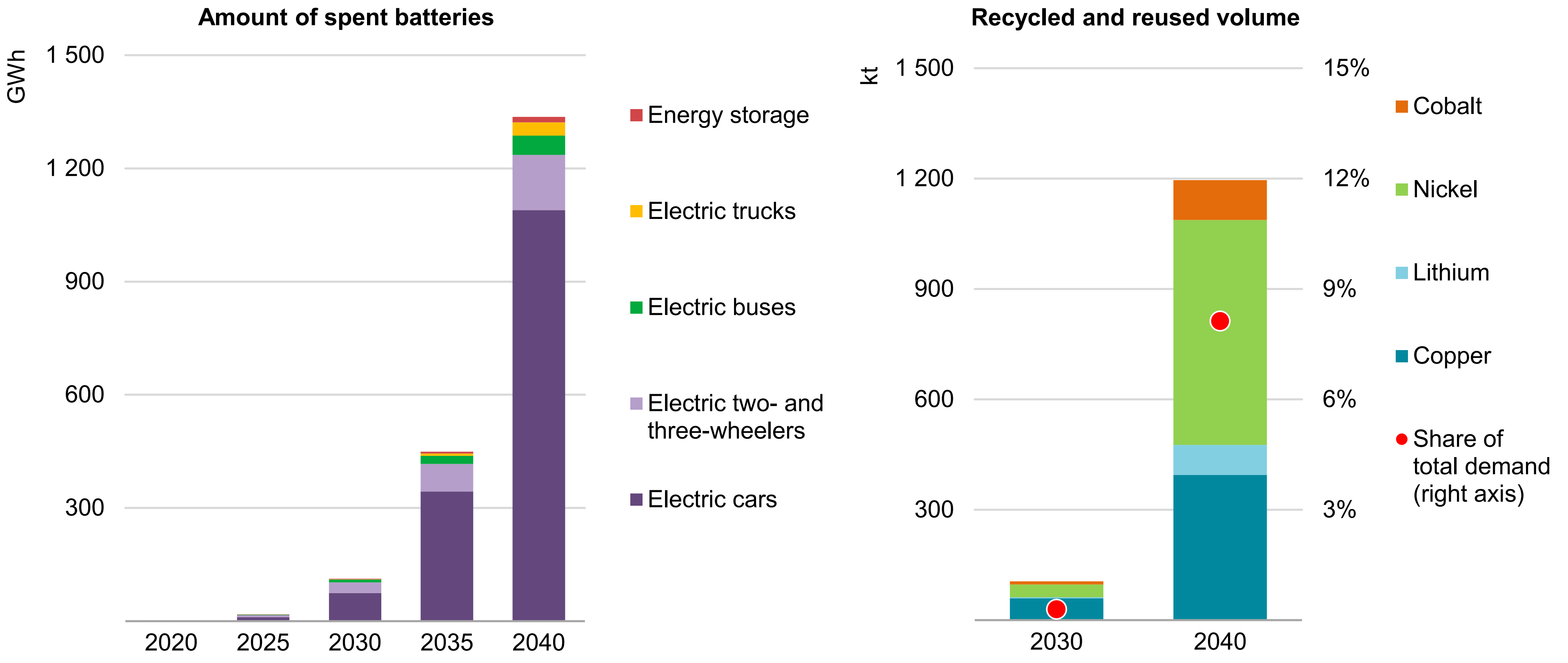
Regular market assessments and periodic stress tests, coupled with emergency response exercises (along the lines of the IEA's existing emergency response programmes), can help policy makers identify possible weak points, evaluate potential impacts and devise necessary actions. Voluntary strategic stockpiling can in some cases help countries weather short-term supply disruptions. Such programmes need to be carefully designed, and based on a detailed review of potential vulnerabilities. Some minerals with smaller markets have low pricing transparency and liquidity, making it difficult to manage price risks and affecting investment decisions. Establishing reliable price benchmarks will be a crucial step towards enhancing transparency and supporting market development.

Tackling the environmental and social impacts of mineral developments will be essential, including the emissions associated with mining and processing, risks arising from inadequate waste and water management, and impacts from inadequate worker safety, human rights abuses (such as child labour) and corruption. Ensuring that mineral wealth brings real gains to local communities is a broad and multi-faceted challenge, particularly in countries where artisanal and small-scale mines are common. Supply chain due diligence, with effective regulatory enforcement, can be a critical tool to identify, assess and mitigate risks, increasing traceability and transparency.

Emissions along the mineral supply chain do not negate the clear climate advantages of clean energy technologies. Total lifecycle greenhouse gas emissions of EVs are around half those of internal combustion engine cars on average, with the potential for a further 25% reduction with low-carbon electricity. While energy transition minerals have relatively high emission intensities, a large variation in the emissions footprint of different producers suggests that there are ways to minimise these emissions through fuel switching, low-carbon electricity and efficiency improvements. Integrating environmental concerns in the early stages of project planning can help ensure sustainable practices throughout the project life cycle.

The projected surge in spent battery volumes suggests immense scope for recycling

Amount of spent lithium-ion batteries from EVs and storage and recycled and reused minerals from batteries in the SDS



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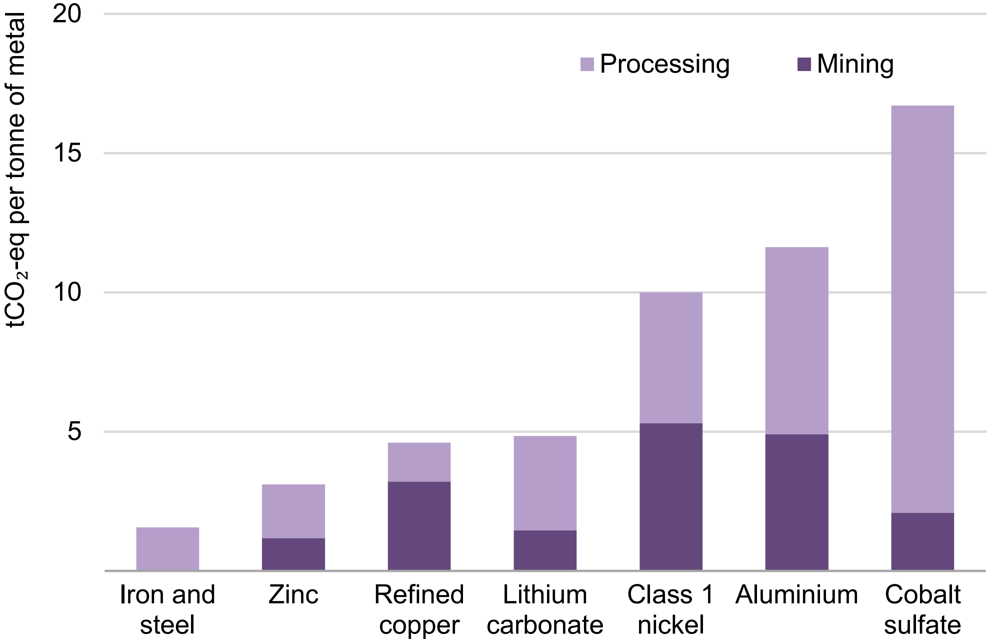
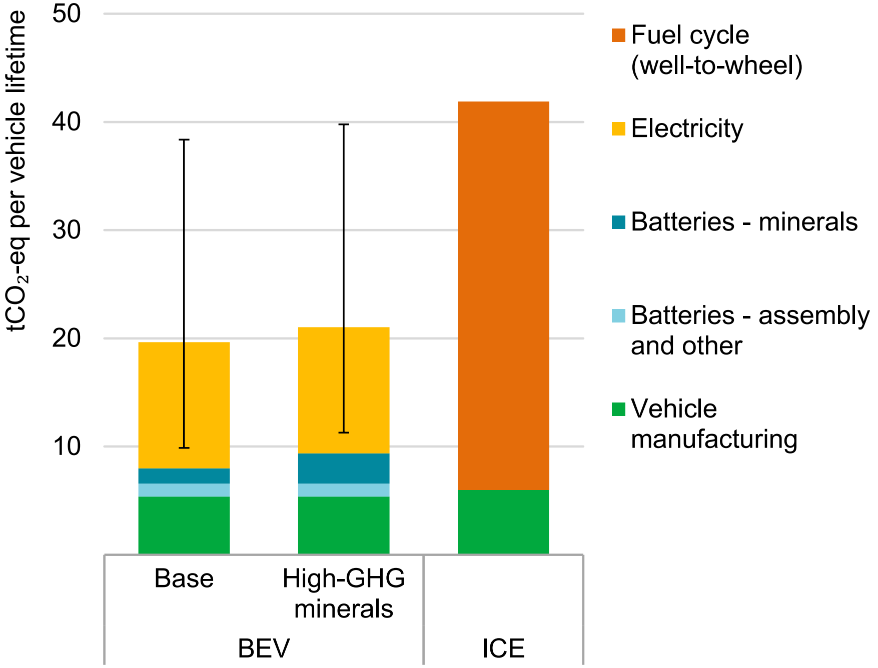
Note: GWh = gigawatt hour.

Stronger actions are required to counter the upward pressure on emissions from mineral production, but the climate advantages of clean energy technologies remain clear

Average GHG emissions intensity for production of selected commodities



Life-cycle GHG emissions of a BEV and ICE vehicle



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Notes: BEV = battery electric vehicle; ICE = internal combustion engine. The “High-GHG minerals” case assumes double the GHG emissions intensity for battery minerals. Includes both Scope 1 and 2 emissions of all GHG from primary production. See Chapter 4 for more detailed assumptions.

Source: IEA analysis based on IEA (2020a); IEA (2020b); Kelly et al. (2020); Argonne National Laboratory (2020); Argonne National Laboratory (2019); Rio Tinto (2020); S&P Global (2021); Skarn Associates (2021); Marx et al. (2018).

IEA’s six key recommendations for a new, comprehensive approach to mineral security

1. **Ensure adequate investment in diversified sources of new supply.** Strong signals from policy makers about the speed of energy transitions and the growth trajectories of key clean energy technologies are critical to bring forward timely investment in new supply. Governments can play a major role in creating conditions conducive to diversified investment in the mineral supply chain.

2. **Promote technology innovation at all points along the value chain.** Stepping up R&D efforts for technology innovation on both the demand and production sides can enable more efficient use of materials, allow material substitution and unlock sizeable new supplies, thereby bringing substantial environmental and security benefits.

3. **Scale up recycling.** Policies can play a pivotal role in preparing for rapid growth of waste volumes by incentivising recycling for products reaching the end of their operating lives, supporting efficient collection and sorting activities and funding R&D into new recycling technologies.

4. **Enhance supply chain resilience and market transparency.** Policy makers need to explore a range of measures to improve the resilience of supply chains for different minerals, develop response capabilities to potential supply disruptions and enhance market transparency. Measures can include regular market assessments and stress tests, as well as voluntary strategic stockpiles in some instances.

5. **Mainstream higher environmental, social and governance standards.** Efforts to incentivise higher environmental and social performance can increase sustainably and responsibly produced volumes and lower the cost of sourcing them. If industry players with strong environmental and social standards are rewarded in the marketplace, this can also bring new suppliers to a more diversified market.

6. **Strengthen international collaboration between producers and consumers**. An overarching international framework for dialogue and policy co-ordination among producers and consumers can play a vital role, an area where the IEA’s energy security framework could usefully be leveraged. Such an initiative could include actions to (i) provide reliable and transparent data; (ii) conduct regular assessments of potential vulnerabilities of supply chains and potential collective responses; (iii) promote knowledge transfer and capacity building to spread sustainable and responsible development practices; and (iv) strengthen environmental and social performance standards to ensure a level playing field.

Introduction

Introduction

Clean energy transitions gained momentum in 2020, despite the major economic and social disruptions caused by the pandemic. Renewable electricity defied the Covid-19 crisis with record growth, and capacity additions are on course to reach fresh heights in the coming years (IEA, 2020). Electric car sales also charged ahead, with a remarkable 40% increase in 2020 amid a sluggish global market (IEA, 2021). Dozens of countries and many leading companies have announced plans to bring their emissions down to net zero by around the middle of this century.

The growing momentum behind clean energy transitions focuses attention on the importance of clean energy supply chains, and the adequate supply of minerals in particular. Minerals have played a vital role in the rise of many of the clean energy technologies that are widely used today – from solar panels and wind turbines to electricity networks and electric vehicles. But ensuring that these and other technologies can continue to draw on sufficient mineral supplies, and therefore support the acceleration of energy transitions, is a major challenge. Debates around energy security have traditionally been associated with oil and natural gas supplies, and more recently also with electricity, but as energy transitions gather pace policy makers need to expand their horizons to include new potential hazards.

With this *World Energy Outlook (WEO)* special report, we aim to: explain the complex links between clean energy technologies and minerals; assess the mineral requirements under varying energy and technology scenarios; and identify the security, environmental and social implications of minerals supply for the energy transition. The report reflects the IEA's determination to ensure it stays ahead of the curve on all aspects of energy security in a decarbonising world.

Our analysis is based on two main IEA scenarios, drawn from *WEO-2020*. The **Sustainable Development Scenario (SDS)** charts a pathway that meets in full the world's goals to tackle climate change in line with the Paris Agreement, improve air quality and provide access to modern energy. The SDS relies on countries and companies hitting their announced net-zero emissions targets (mostly by 2050) on time and in full, which spurs the world as a whole to reach it before 2070. The range of technologies that are required in the SDS provides an essential benchmark for our discussion throughout the report. Reaching net-zero emissions globally by 2050 would demand a dramatic extra push for the deployment of various clean energy technologies.

The other scenario we refer to in the analysis is the **Stated Policies Scenario (STEPS)**, which provides an indication of where today's policy measures and plans might lead the energy sector. These outcomes fall far short of the world's shared sustainability goals. Comparison between the outcomes in these two scenarios provides an indication of the range of possible futures.

Scope

This report assesses the mineral requirements for a range of clean energy technologies, including renewable power (solar photovoltaic [PV], onshore and offshore wind, concentrating solar power, hydro, geothermal and biomass), nuclear power, electricity networks (transmission and distribution), electric vehicles, battery storage and hydrogen (electrolysers and fuel cells). Although this is not an exhaustive list of clean energy technologies, the technologies we cover represent the majority deployed in the SDS. We plan to expand the analysis to other technologies in future publications.

All these technologies require metals and alloys, which are produced by processing mineral-containing ores. Ores – the raw, economically viable rocks that are mined – are beneficiated to liberate and concentrate the minerals of interest. Those minerals are further processed to extract the metals or alloys of interest. Processed metals and alloys are then used in end-use applications. While this report covers the entire mineral and metal value chain from mining to processing operations, we use “minerals” as a representative term for the sake of simplicity.

Minerals are not only used in the clean energy sector, but are also used widely across the entire energy system, in technologies that improve efficiency and reduce emissions. For example, the most efficient coal-fired power plants require a lot more nickel than the least efficient ones in order to allow for higher combustion temperatures. Catalytic converters use platinum or palladium to help reduce harmful emissions from engines using petroleum. However, here we focus specifically on the use of minerals in clean energy technologies, given that they generally require considerably more minerals than fossil fuel counterparts. Our analysis also focuses on the requirements for building a plant (or making equipment) and not on operational requirements (e.g. uranium consumption in nuclear plants).

Our report considers a wide range of minerals used in clean energy technologies, as indicated in the Annex. They include chromium, copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), molybdenum, platinum group metals, zinc, rare earth elements and others. Steel is widely used across a broad range of technologies, but we have excluded it from the scope given that it does not have substantial security implications and the energy sector is not a major driver of growth in steel demand.

Aluminium also plays a crucial role in clean energy transitions, being widely used in applications such as solar cells, wind turbines and vehicle lightweighting. We have excluded it from demand projections as it is regularly assessed as part of the *WEO* and *Energy Technology Perspectives* series. However, we have assessed its use in electricity networks as the outlook for copper is inherently linked with aluminium use in grid lines.

Structure

We have structured this report in four chapters, as follows:

In **Chapter 1 (The State of Play)** we set out the linkages between critical minerals and energy transitions, and the reasons why they are rising up the policy agenda. We provide an overview of today's supply chains and examines their geographical concentration and other potential bottlenecks. We also describe the industry landscape, and recent investment and price dynamics.

In **Chapter 2 (Mineral Requirements for Clean Energy Technologies)** we analyse a range of possible trajectories for mineral requirements in various clean energy technologies. They include low-carbon power generation, batteries for electric vehicles and grid storage, electricity networks and hydrogen. We conducted the assessments using the detailed technology projections in IEA scenarios. We also address how and to what extent demand trajectories could evolve in different directions under a number of alternative technology evolution pathways.

In **Chapter 3 (Reliable Supply of Minerals)** we assess the prospects for supply of the main focus minerals – copper, lithium, nickel, cobalt and rare earth elements – that play a particularly important role in many clean energy technologies. We examine the contributions from existing mines and those under construction, and shed light on specific vulnerabilities that could create pressures on future supply.

In this chapter we also discuss the potential contribution of secondary supply, especially via recycling. We assess how recycling could contribute to reducing requirements for primary supply, taking into account both conventional sources and emerging waste streams such as spent batteries from electric vehicles.

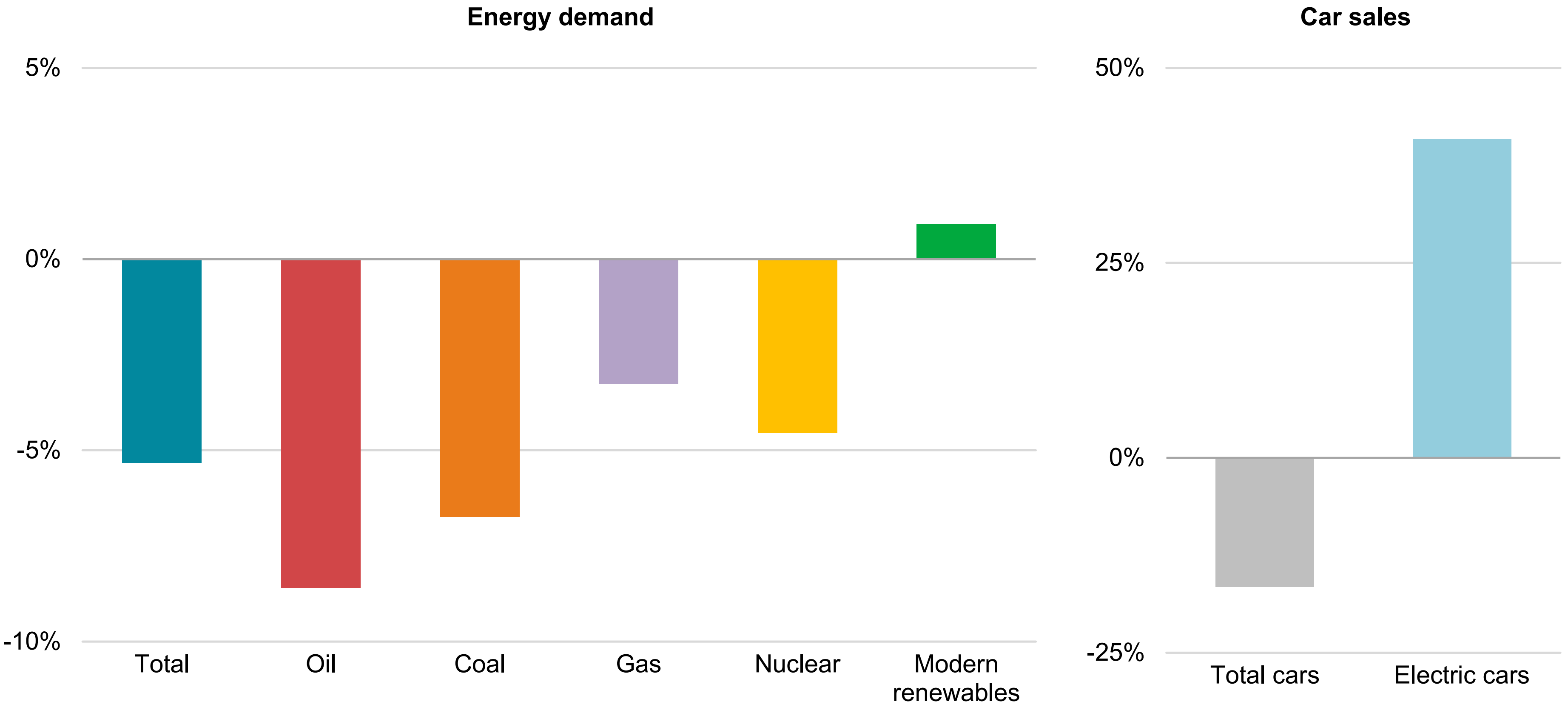
Using our analysis and lessons from historical episodes of disruption, we identify policy approaches to ensure reliable supply of minerals in an evolving market environment.

In **Chapter 4 (Sustainable and Responsible Development of Minerals)** we examine the environmental, social and governance implications of minerals development which, if improperly managed, could offset or negate their positive contributions to clean energy technologies. We assess potential hazards, spanning from emissions during production and processing, to inadequate waste and water management and extending to local community impacts such as corruption, human rights abuses and worker safety. We finally discuss potential policy approaches to mitigate these risks.

The state of play

Clean energy technologies defied the Covid-19 crisis with strong growth, making 2020 a pivotal year for clean energy transitions

Change in energy demand and car sales by type in 2020 relative to 2019



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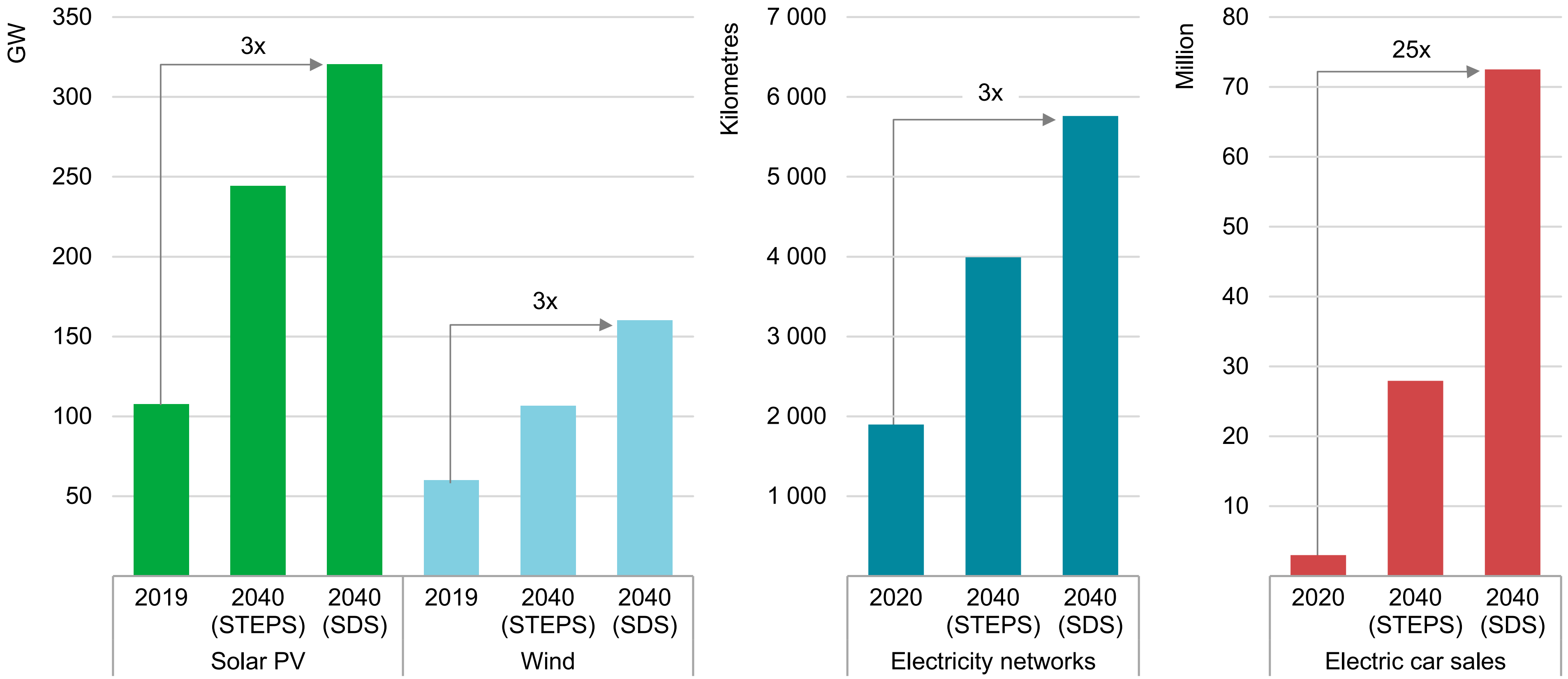
Sources: IEA (2020a) for energy demand; IEA (2021a) for car sales.

But achieving climate goals requires a further rapid acceleration in clean energy deployment

Annual deployment of clean energy technologies by scenario



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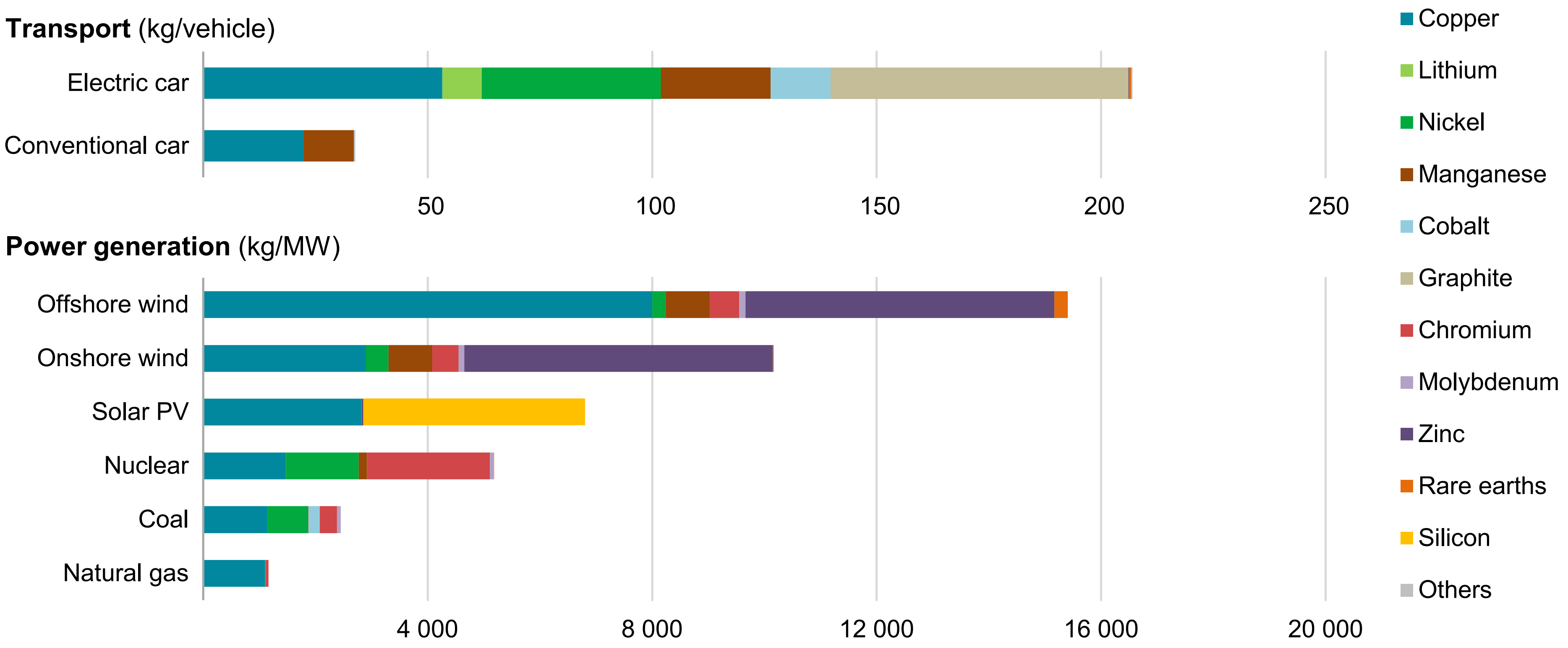
Notes: PV = Photovoltaic; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario.
Sources: IEA (2021a); IEA (2020a).

The rapid deployment of these technologies as part of energy transitions implies a significant increase in demand for minerals

Minerals used in selected clean energy technologies



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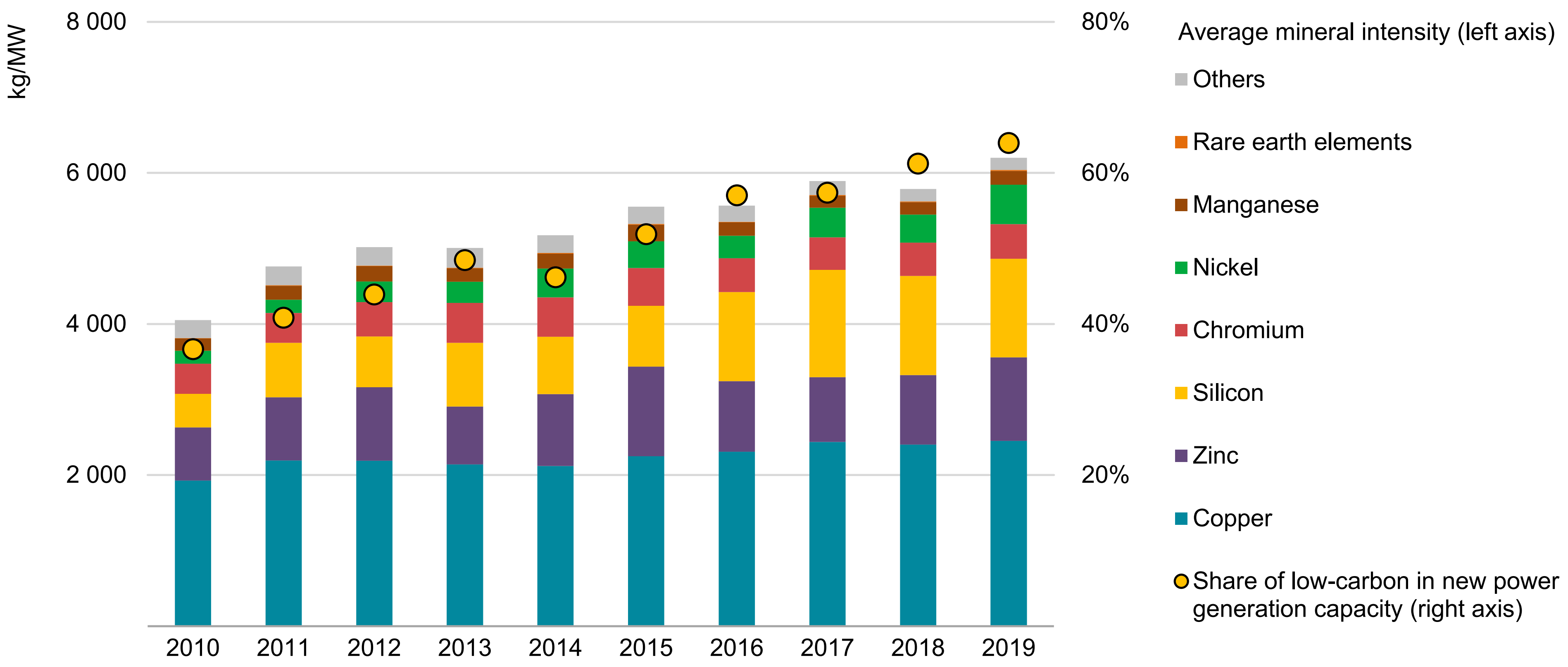
Notes: kg = kilogramme; MW = megawatt. The values for vehicles are for the entire vehicle including batteries, motors and glider. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode. The values for offshore wind and onshore wind are based on the direct-drive permanent magnet synchronous generator system (including array cables) and the doubly-fed induction generator system respectively. The values for coal and natural gas are based on ultra-supercritical plants and combined-cycle gas turbines. Actual consumption can vary by project depending on technology choice, project size and installation environment.

The mineral requirement for new power generation capacity has increased by 50% since 2010 as low-carbon technologies take a growing share of investment

Average mineral intensity of new power generation capacity



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Note: Low-carbon technologies include renewables and nuclear.

The shift from a fuel-intensive to a material-intensive energy system

The Covid-19 pandemic and resulting economic crisis have had an impact on almost every aspect of the global energy system. However, while fossil fuel consumption was hit hard in 2020, clean energy technologies – most notably renewables and electric vehicles (EVs) – remained relatively resilient. As a result, our latest estimates suggest that global energy-related CO_2 emissions fell by 6% in 2020, more than the 4% fall in energy demand (IEA, 2021b).

Nonetheless, as things stand, the world is far from seeing a decisive downturn in emissions – CO_2 emissions in December 2020 were already higher than their pre-crisis level one year earlier. Putting emissions on a trajectory consistent with the Paris Agreement, as analysed in the *World Energy Outlook* Sustainable Development Scenario (SDS), requires a significant scale-up of clean energy deployment across the board. In the SDS, the annual installation of solar PV cells, wind turbines and electricity networks needs to expand threefold by 2040 from today's levels, and sales of electric cars need to grow 25-fold over the same period. Reaching net-zero emissions globally by 2050 would demand an even more dramatic increase in the deployment of clean energy technologies over the same timeframe.

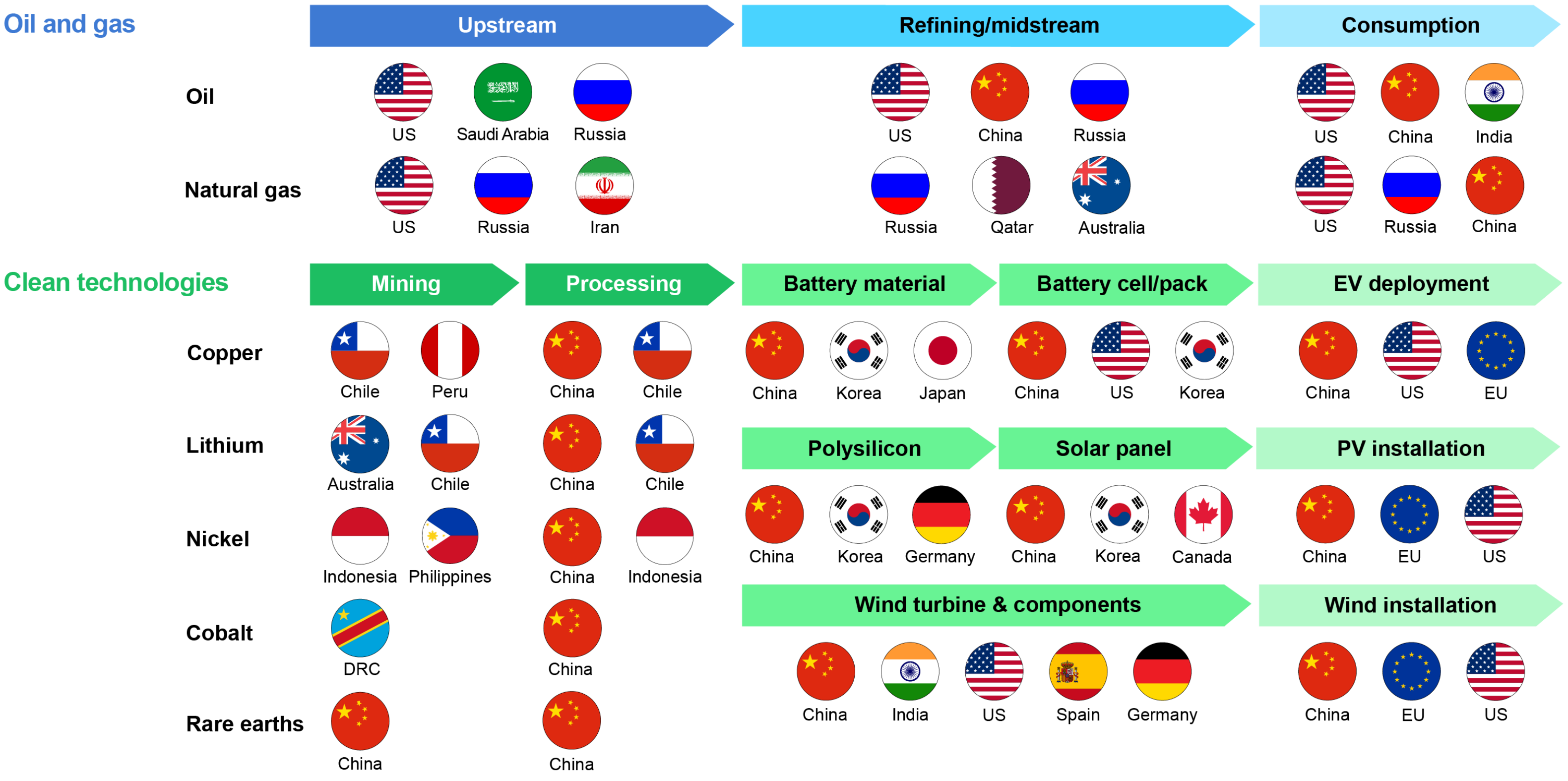
An energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources. While solar PV plants and wind farms do not require fuels to operate, they generally require more materials than fossil fuel-based counterparts for construction. Minerals are a case in point. A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant of the same capacity. Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as renewables increase their share of total capacity additions. The transition to clean energy means a shift from a fuel-intensive to a material-intensive system.

The types of mineral resources used vary by technology. Lithium, cobalt and nickel play a central role in giving batteries greater performance, longevity and higher energy density. Rare earth elements are used to make powerful magnets that are vital for wind turbines and EVs. Electricity networks need a huge amount of copper and aluminium. Hydrogen electrolysers and fuel cells require nickel or platinum group metals depending on the technology type. Copper is an essential element for almost all electricity-related technologies.

These characteristics of a clean energy system imply a significant increase in demand for minerals as more batteries, solar panels, wind turbines and networks are deployed. It also means that the energy sector is set to emerge as a major force in driving demand growth for many minerals, highlighting the strengthening linkages between minerals and clean energy technologies.

The transition to a clean energy system brings new energy trade patterns, countries and geopolitical considerations into play

Indicative supply chains of oil and gas and selected clean energy technologies



Oil and gas

	Upstream	Refining/midstream	Consumption
Oil	US Saudi Arabia Russia	US China Russia	US China India
Natural gas	US Russia Iran	Russia Qatar Australia	US Russia China

Clean technologies

	Mining	Processing
Copper	Chile Peru	China Chile
Lithium	Australia Chile	China Chile
Nickel	Indonesia Philippines	China Indonesia
Cobalt	DRC	China
Rare earths	China	China

Battery material	Battery cell/pack	EV deployment
China Korea Japan	China US Korea	China US EU

Polysilicon	Solar panel	PV installation
China Korea Germany	China Korea Canada	China EU US

Wind turbine & components	Wind installation
China India US Spain Germany	China EU US

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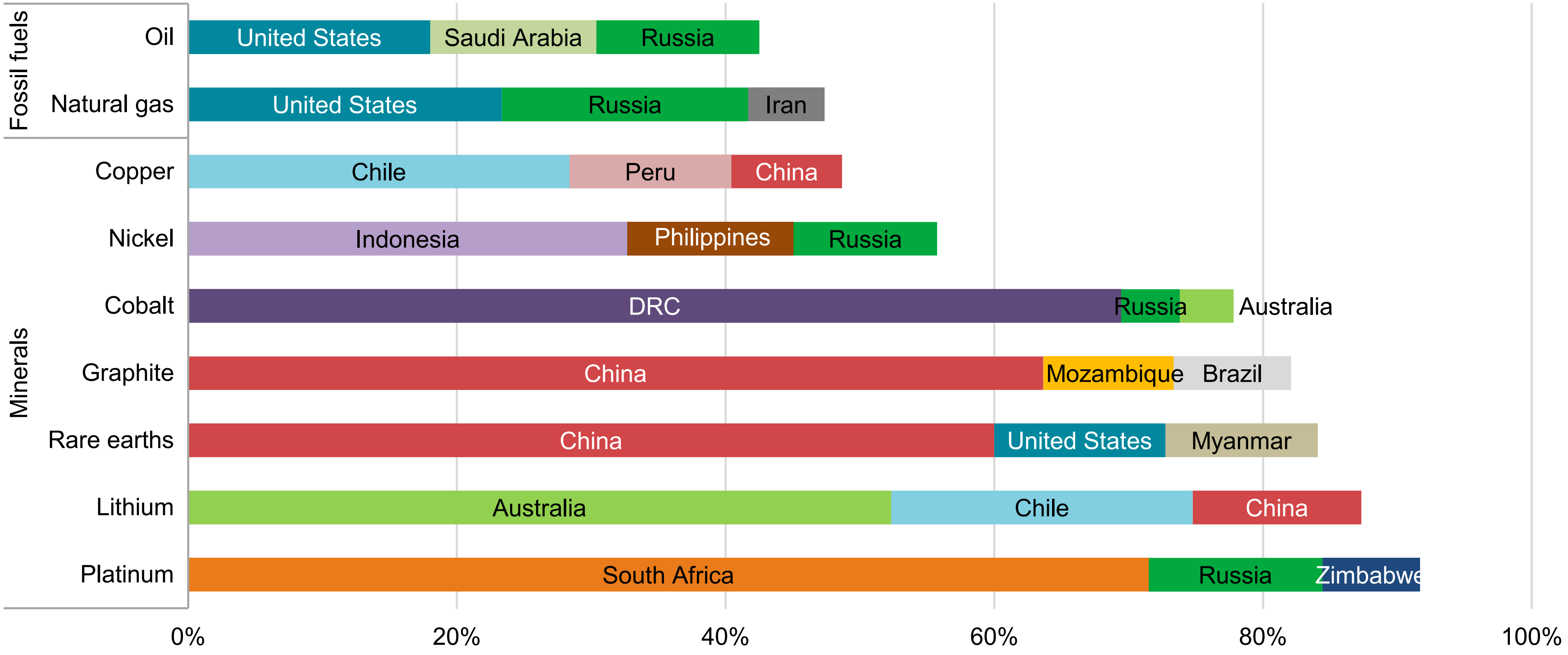
Notes: DRC = Democratic Republic of the Congo; EU = European Union; US = United States; Russia = Russian Federation; China = People’s Republic of China. Largest producers and consumers are noted in each case to provide an indication, rather than a complete account.

Current production of many energy transition minerals is more geographically concentrated than that of oil or natural gas

Share of top three producing countries in total production for selected minerals and fossil fuels, 2019



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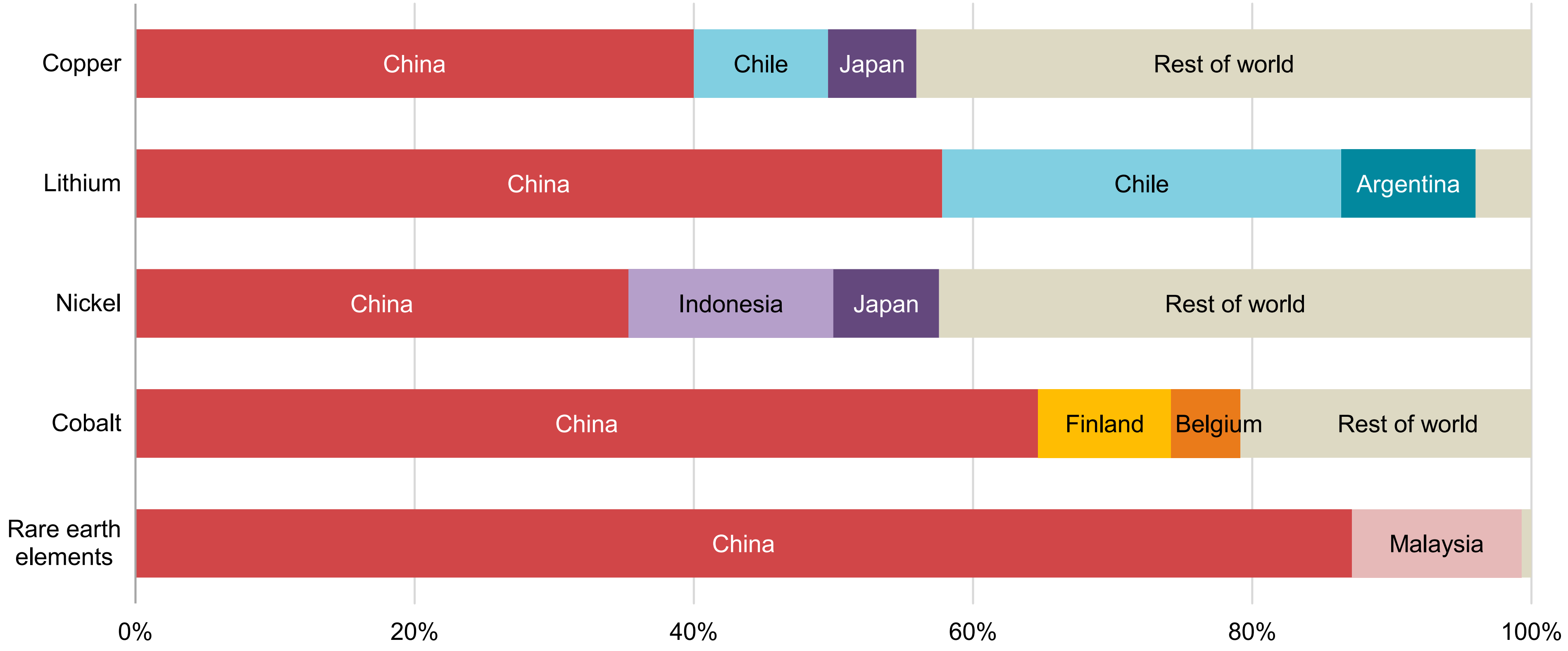
Sources: IEA (2020b); USGS (2021).

The level of concentration is similarly high for processing operations, with China's significant presence across the board

Share of processing volume by country for selected minerals, 2019



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Note: The values for copper are for refining operations.
Sources: World Bureau of Metal Statistics (2020); Adamas Intelligence (2020) for rare earth elements.

Robust and resilient clean energy supply chains are essential, especially for critical minerals

Today's international energy security mechanisms are designed to provide some insurance against the risks of disruption, price spikes and geopolitical events in the supply of hydrocarbons, oil in particular. These concerns do not disappear during energy transitions as more solar panels, wind turbines and electric cars are deployed. However, alongside the many benefits of clean energy transitions, they also raise additional questions about the security and resilience of clean energy supply chains, which policy makers need to address.

Compared with fossil fuel supply, the supply chains for clean energy technologies can be even more complex (and in many instances, less transparent). In addition, the supply chain for many clean energy technologies and their raw materials is more geographically concentrated than that of oil or natural gas. This is especially the case for many of the minerals that are central to manufacturing clean energy technology equipment and infrastructure.

For lithium, cobalt and rare earth elements (REEs), the top three producing nations control well over three-quarters of global output. In some cases, a single country is responsible for around half of worldwide production. South Africa and the Democratic Republic of the Congo are responsible for some 70% of global production of platinum and cobalt respectively, and China accounted for 60% of global REE production in 2019 (albeit down from over 80% in the mid-2010s). The picture for copper and nickel is slightly more diverse, but still around half of global supply is concentrated in the top three producing countries.

The level of concentration is even higher for processing and refining operations. China has gained a strong presence across the board. China's share of refining is around 35% for nickel (the figure becomes higher when including the involvement of Chinese companies in Indonesian operations), 50-70% for lithium and cobalt, and as high as 90% for REE processing that converts mined output into oxides, metals and magnets.

This creates sources of concern for companies that produce solar panels, wind turbines, electric motors and batteries using imported minerals, as their supply chains can quickly be affected by regulatory changes, trade restrictions or political instability in a small number of countries. The Covid-19 pandemic already demonstrated the ripple effects that disruptions in one part of the supply chain can have on the supply of components and the completion of projects.

The implications of any potential supply disruptions are not as widespread as those for oil and gas (see Box 1.1). Nonetheless, trade patterns, producer country policies and geopolitical considerations remain crucial even in an electrified, renewables-rich energy system.

Box 1.1. Oil security vs mineral security

Minerals are increasingly recognised as essential to the good functioning of an evolving energy system, moving into a realm where oil has traditionally occupied a central role. There are similarities, in that threats to reliable supply can have far-reaching consequences throughout the energy system. So traditional concerns over oil security (e.g. unplanned supply disruption or price spikes) are relevant for minerals as well.

However, fundamental differences exist in the impacts that disruption may have. An oil supply crisis, when it happens, has broad repercussions for all vehicles that run on it. Consumers driving gasoline cars or diesel trucks are immediately affected by higher prices.

By contrast, a shortage or spike in the price of a mineral required for producing batteries and solar panels affects only the supply of new EVs or solar plants. Consumers driving existing EVs or using solar-powered electricity are not affected. The main threats from supply disruptions are delayed and more expensive energy transitions, rather than disturbed daily lives.

Notably, oil burns up when it is used, requiring continuous inputs to run assets. However, minerals are a component of infrastructure, with the potential to be recovered and recycled at the end of the infrastructure lifetime (Hastings-Simon and Bazilian, 2020).

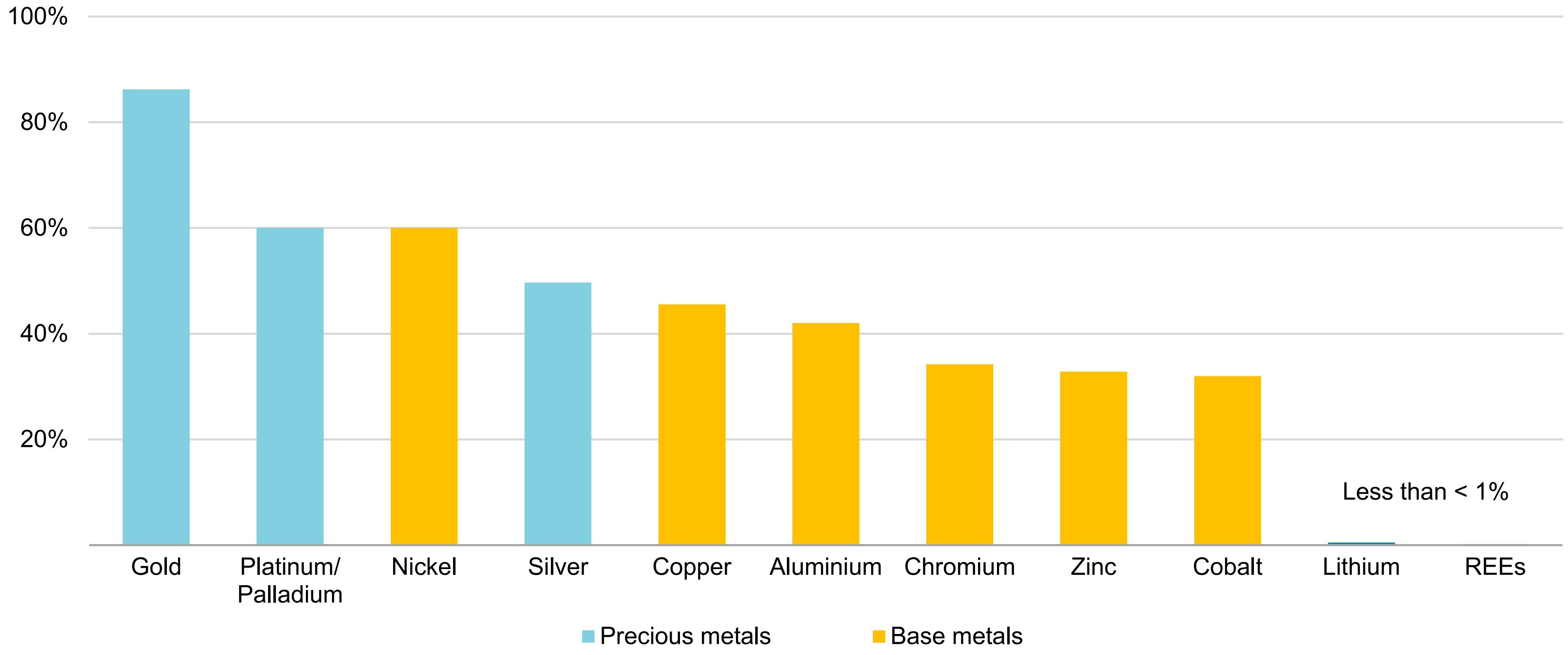
Moreover, while oil is a single commodity with a large, liquid global market, there are multiple minerals now in play for the energy sector, each with its own complexities and supply dynamics. Individual countries may have very different positions in the value chain for each of the minerals that are now rising in prominence in the global energy debate.

Despite these differences, the experience of oil markets may offer a number of lessons for an approach to mineral security. The approach to safeguarding oil security tended to focus on supply-side measures. Strategic stockholding has long been at the centre of the IEA's efforts to ensure oil market security. However, the framework for oil security has evolved over time to encompass demand and resilience aspects, including efforts to identify immediate areas of demand restraint, improve fuel efficiency and review countries' preparedness against potential disruption.

This range of responses and measures provides valuable context for the discussion on minerals security. While supply-side measures (e.g. ensuring adequate investment in production) remain crucial, these need to be accompanied by efforts to promote more efficient use of minerals, assess the resilience of supply chains, and encourage wider use of recycled materials, to be more effective.

Today's recycling rates vary by metal depending on the ease of collection, price levels and market maturity

End-of-life recycling rates for selected metals



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Sources: Henckens (2021); UNEP (2011) for aluminium; Sverdrup and Ragnarsdottir (2016) for platinum and palladium; OECD (2019) for nickel and cobalt.

Scaling up recycling can bring significant security benefits, although the need for continued investment in primary supply remains

One of the major differences between oil and minerals lies in the way that they are used and recovered in the energy system. Unlike oil, which is combusted on an ongoing basis, minerals and metals are permanent materials that can be reused and recycled continuously with the right infrastructure and technologies in place. Compared with oil, this offers an additional lever to ensure reliable supplies of minerals by keeping them in circulation as long as possible.

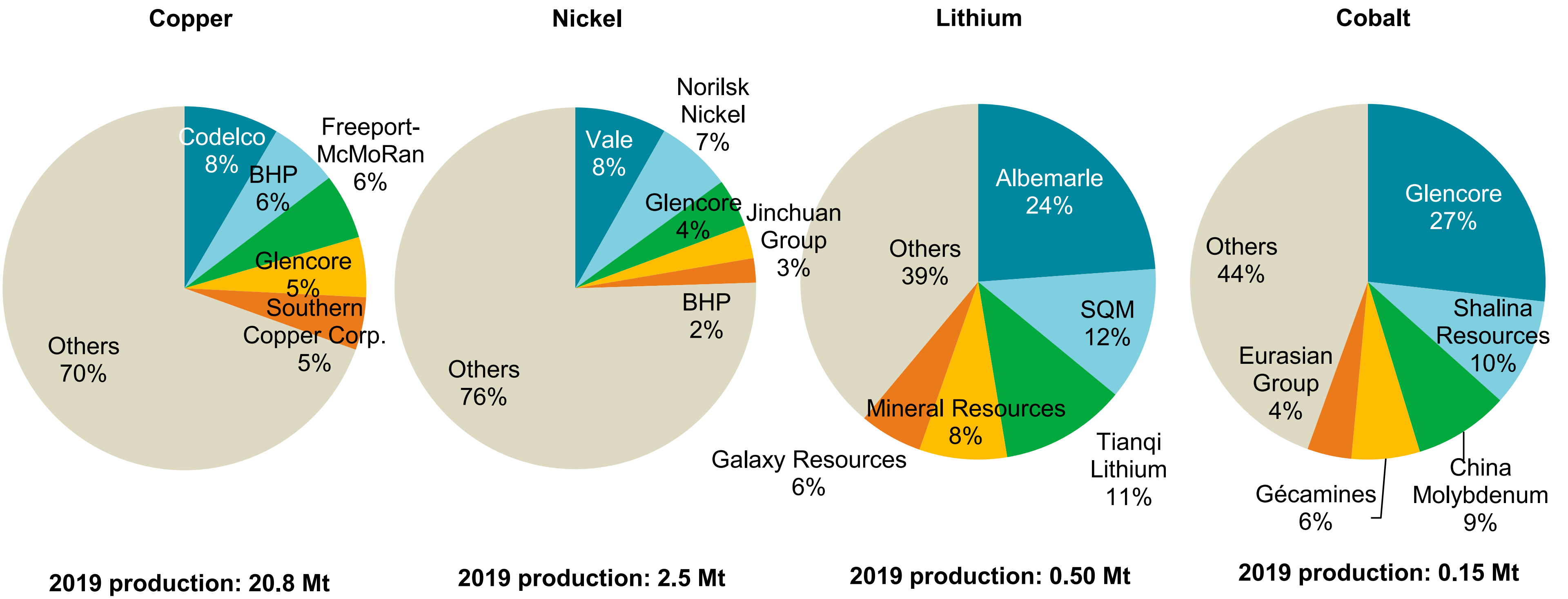
The level of recycling is typically measured by two indicators. End-of-life (EOL) recycling rates measure the share of material in waste flows that is actually recycled. Recycling input rates (also called recycled content rates) assess the share of secondary sources in total supply. EOL recycling rates differ substantially by metal. Base metals used in large volumes such as copper, nickel and aluminium have achieved high EOL recycling rates (Henckens, 2021). Precious metals such as platinum, palladium and gold have also achieved higher rates of recycling due to very high global prices encouraging both collection and product recycling. Lithium, however, has almost no global recycling capabilities due in part to limited collection and technical constraints (e.g. lithium reactivity in thermodynamic and metallurgic recycling), with a similar picture for REEs. There are also regional variances: around 50% of total base metal production in the European Union is supplied via secondary production, using recycled metals, as opposed to 18% in the rest of the world (Eurometaux, 2019).

Recycling does not eliminate the need for continued investment in primary supply of minerals. A World Bank study suggests that new investment in primary supply will still be needed even in the case that EOL recycling rates were to reach 100% by 2050. (World Bank, 2020). However, recycling can play an important role in relieving the burden on primary supply from virgin materials at a time when demand starts to surge. For example, the amount of spent EV batteries reaching the end of their first life is expected to grow exponentially after 2030 in the SDS, offering the potential to reduce the pressure on investment for primary supply (see Chapter 3).

Although various commercial and environmental challenges exist, the competitiveness of the recycling industry is set to improve over time with economies of scale and technology improvement as more players enter the field. Their relative advantages are likely to be further supported by potential upward pressure on production costs for virgin resources. Also, regions with greater deployment of clean energy technology stand to benefit from far greater economies of scale. This highlights the sizeable security benefit that recycling can bring to importing regions and underscores the need to incorporate a circular approach in the mineral security framework.

Companies that mine and process minerals have a major role to play in clean energy transitions

Major mining companies that produce selected energy transition minerals, 2019



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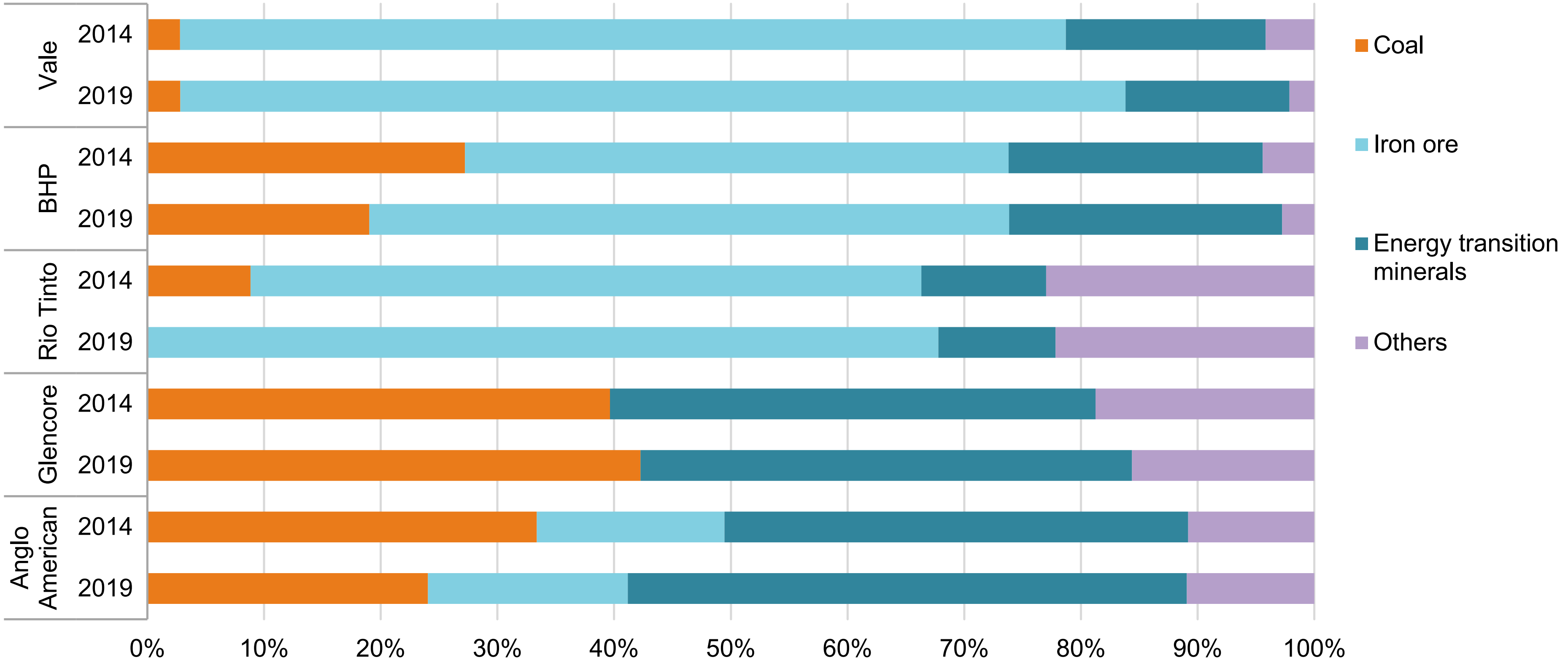
Notes: Mt = million tonnes. Glencore's cobalt production volume includes output from Katanga Mining Ltd. Shalina Resources' cobalt production volume includes output of Chemaf. Lithium production volumes are denoted on a lithium carbonate-equivalent basis.

Source: S&P Global (2021).

Some mining majors have reduced coal exposure in recent years, although a decisive shift towards the minerals required for energy transitions is not yet visible

Production portfolio value of selected diversified major mining companies, 2014 and 2019



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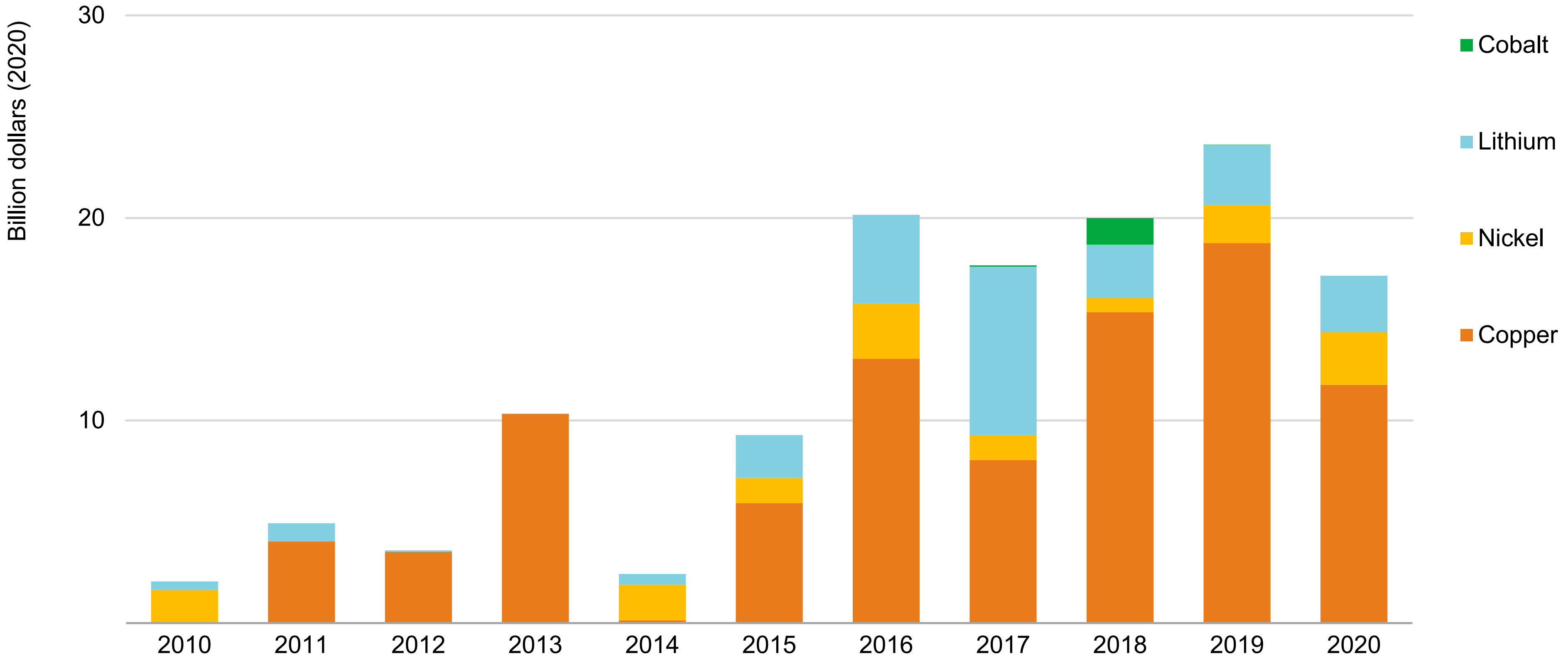
Notes: Energy transition minerals include copper, lithium, nickel, cobalt, manganese, molybdenum and platinum-group metals. The value of the 2014 production portfolio was estimated using 2019 prices to remove price effects.

Source: IEA analysis based on companies' annual reports and S&P Global (2021).

Investment in new mineral supply projects has been on an upward path…

Announced capital cost for greenfield projects for selected minerals



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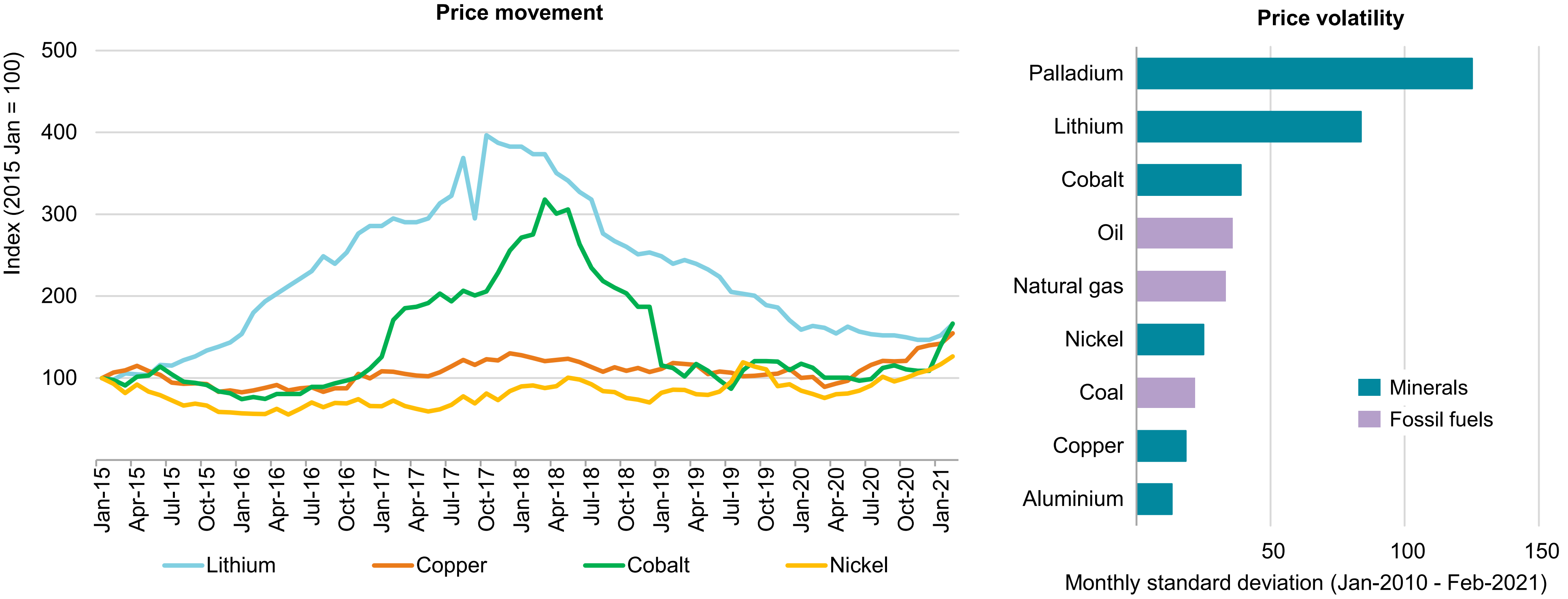
Notes: Capital cost for cobalt includes only those projects whose primary commodity is cobalt. The figures do not include sustaining capital expenditure.
Source: S&P Global (2021).

…but continued investment is needed to manage new price cycles and volatility

Price movement and volatility of selected minerals



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Notes: Assessment based on Lithium Carbonate CIF Asia, LME Copper Grade A Cash, LME Cobalt Cash and LME Nickel Cash prices.
Source: IEA (2020a), S&P Global (2021).

Exploitation of mineral resources gives rise to a variety of environmental and social implications that must be carefully managed to ensure reliable supplies

Selected environmental and social challenges related to energy transition minerals

Areas of risks		Description
Environment	**Climate change**	• With higher greenhouse gas emission intensities than bulk metals, production of energy transition minerals can be a significant source of emissions as demand rises • Changing patterns of demand and types of resource targeted for development pose upward pressure
	Land use	• Mining brings major changes in land cover that can have adverse impacts on biodiversity • Changes in land use can result in the displacement of communities and the loss of habitats that are home to endangered species
	Water management	• Mining and mineral processing require large volumes of water for their operations and pose contamination risks through acid mine drainage, wastewater discharge and the disposal of tailings • Water scarcity is a major barrier to the development of mineral resources: around half of global lithium and copper production are concentrated in areas of high water stress
	Waste	• Declining ore quality can lead to a major increase in mining waste (e.g. tailings, waste rocks); tailings dam failure can cause large-scale environmental disasters (e.g. Brumadinho dam collapse in Brazil) • Mining and mineral processing generate hazardous waste (e.g. heavy metals, radioactive material)
Social	**Governance**	• Mineral revenues in resource-rich countries have not always been used to support economic and industrial growth and are often diverted to finance armed conflict or for private gain • Corruption and bribery pose major liability risks for companies
	Health and safety	• Workers face poor working conditions and workplace hazards (e.g. accidents, exposure to toxic chemicals) • Workers at artisanal and small-scale mine (ASM) sites often work in unstable underground mines without access to safety equipment
	Human rights	• Mineral exploitation may lead to adverse impacts on the local population such as child or forced labour (e.g. children have been found to be present at about 30% of cobalt ASM sites in the DRC) • Changes in the community associated with mining may also have an unequal impact on women

Clean energy transitions offer opportunities and challenges for companies

As the world moves from fuel-intensive systems to more material-intensive systems, companies that produce minerals and metals provide an essential bridge between resources in the ground and the energy technologies that consumers need. As such, there is large scope for mining and refining companies to contribute to orderly clean energy transitions by ensuring adequate supply of minerals. These projects will inevitably be subject to strong scrutiny of their social and environmental performance.

Many of the large mining companies are already involved in the energy sector, as producers of coal. Energy transitions therefore present a challenge, as well as an opportunity, as companies respond to rising stakeholder pressure to clarify the implications of energy transitions for their operations and business models. Some of these companies are already moving away from coal. Rio Tinto entirely exited the coal business in recent years and other companies are heading in a similar direction, largely through reducing thermal coal production. Although there has been growing participation in copper production in recent years, they have yet to make a concerted move into energy transition minerals.

Despite the prospects offered by energy transitions, until recently companies were quite cautious about committing significant capital to new projects; this is largely because of uncertainties over the timing and extent of demand growth (linked to questions about the real commitment of countries to their climate ambitions) as well as the complexities involved in developing high-quality projects.

The picture is starting to change, as countries have sent stronger signals about their net-zero ambitions, and price signals for some minerals in 2017-2018 offered greater encouragement. Investment in new projects picked up in the latter part of the 2010s (although there was a Covid-induced fall in 2020). This trend would need to be sustained in order to support ample supply, although the risk of boom and bust cycles is ever-present for commodities that feature long lead-times from project planning to production (see Chapter 3).

Prices for minerals tend to be volatile, often more so than for traditional hydrocarbons, due to the mismatch between the pace of changes in demand patterns and that of new project development, and also to the opacity of supply chains. In the late 2010s, prices for minerals with relatively smaller markets – such as lithium and cobalt – recorded a dramatic increase in a short time as the adoption of EVs started to grow in earnest. Although prices have since dropped, as higher prices triggered a swathe of supply expansions (in the form of ASMs for cobalt), this has been a wake-up call about possible strains on supply and market balance. This provides additional reasons for policy makers to be vigilant about this critical aspect of a clean energy future.

Mineral requirements for clean energy transitions

Introduction

Minerals and metals[1] have played a critical role in the rise of many of the clean energy technologies that are widely used today – from wind turbines and solar panels to electric vehicles and battery storage. As the deployment of clean energy technology rises, the energy sector is also becoming a vital part of the minerals and metals industry. With clean energy transitions, the linkages between minerals and energy are set to strengthen.

However, this raises the question: will sufficient sustainable and responsibly sourced mineral supplies be available to support the acceleration of energy transitions? The first step to address this is to understand the potential requirements for minerals arising from clean energy transitions.

The type and volume of mineral needs vary widely across the spectrum of clean energy technologies, and even within a certain technology (e.g. wind turbine technologies; EV battery chemistries). In this chapter we assess the aggregate mineral demand from a wide range of clean energy technologies – low-carbon power generation (renewables and nuclear), electricity networks, electric vehicles (EVs), battery storage and hydrogen (electrolysers and fuel cells) – under two main IEA scenarios: the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS).

For each of the clean energy technologies, we estimate overall mineral demand using four main variables: clean energy deployment trends under different scenarios; sub-technology shares within each technology area; mineral intensity of each sub-technology; and mineral intensity improvements.[2] The first two variables were taken from the projections in the *World Energy Outlook 2020*, complemented by the results in the *Energy Technology Perspectives 2020*.

We compiled the mineral intensity assumptions through extensive literature review, and expert and industry consultations, including with IEA Technology Collaboration Programmes. The pace of mineral intensity improvements varies by scenario, with the STEPS generally seeing minimal improvement over time as compared to modest improvement (around 10% in the longer term) assumed in the SDS. In areas that may particularly benefit from economies of scale or technology improvement (e.g. silicon and silver use in solar photovoltaic [PV], platinum loading in fuel cells, rare earth element

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[1] This report considers a wide range of minerals and metals used in clean energy technologies, including chromium, copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), molybdenum, platinum group metals, zinc, rare earth elements and others (see Annex for the complete list). Steel and aluminium are not included in the scope for demand assessment, but aluminium use in electricity networks is exceptionally assessed given that the outlook for copper is closely linked with aluminium use in grid lines (see Introduction).

[2] See Annex for methodologies and data sources.

[REE] use in wind turbines), we applied specific improvement rates based on the review of underlying drivers.

Projected mineral demand is subject to considerable uncertainty. It is highly dependent on the stringency of climate policies (reflected in the difference between the STEPS and SDS), but also on different technology development pathways. As such, in addition to our base assumptions for technology development pathways ("base case") in both the STEPS and SDS, we identified key variables for each technology that could drive mineral demand in different directions. We then built 11 alternative cases under both scenarios to quantify the impacts of varying technology evolution trends.

Alternative technology evolution pathways explored

Technology	Alternative cases
Solar PV	• Comeback of high cadmium telluride • Faster adoption of perovskite solar cells • Wider adoption of gallium arsenide technology
Wind	• Constrained REE supply
Electricity networks	• Increased use of aluminium in underground cables • Wider adoption of direct-current systems
EVs	• Delayed shift to nickel-rich cathodes • More rapid move towards a silicon-rich anode • Faster uptake of lithium metal anode all-solid-state batteries
Battery storage	• Rapid adoption of home energy storage • Early commercialisation of vanadium flow batteries

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While our report focuses on projecting mineral requirements for clean energy technologies, for the five focus minerals – copper, lithium, nickel, cobalt and neodymium (as a representative for REEs) – it also assesses demand from other sectors. This is to understand the contribution of clean energy technologies to overall demand and better assess supply-side challenges. We projected mineral demand for other sectors using historical consumption by end-use applications, relevant activity drivers (e.g. GDP, industry value added, vehicle activities, steel production) and material intensities (see Annex: Scope and methodology).

Mineral needs vary widely across clean energy technologies

Critical mineral needs for clean energy technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◍	○	●	◍	●	○	◍
Hydro	◍	○	○	○	○	◍	◍	○	◍
CSP	◍	○	◍	○	○	●	◍	○	●
Bioenergy	●	○	○	○	○	○	◍	○	◍
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◍	○	◍	○	○	◍	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◍	○	○	●	◍

Notes: Shading indicates the relative importance of minerals for a particular clean energy technology (● = high; ◍ = moderate; ○ = low), which are discussed in their respective sections in this chapter. CSP = concentrating solar power; PGM = platinum group metals.

* In this report, aluminium demand is assessed for electricity networks only and is not included in the aggregate demand projections.

What Are Critical Materials and Critical Minerals?

Critical Minerals & Materials Program

Critical Minerals & Materials Program » What Are Critical Materials and Critical Minerals?

The Energy Act of 2020 defines a "**critical material**" as:

- Any non-fuel mineral, element, substance, or material that the Secretary of Energy determines: (i) has a high risk of supply chain disruption; and (ii) serves an essential function in one or more energy technologies, including technologies that produce, transmit, store, and conserve energy; or
- A critical mineral, as **defined by the Secretary of the Interior**.

The Energy Act of 2020 defines a "**critical mineral**" as:

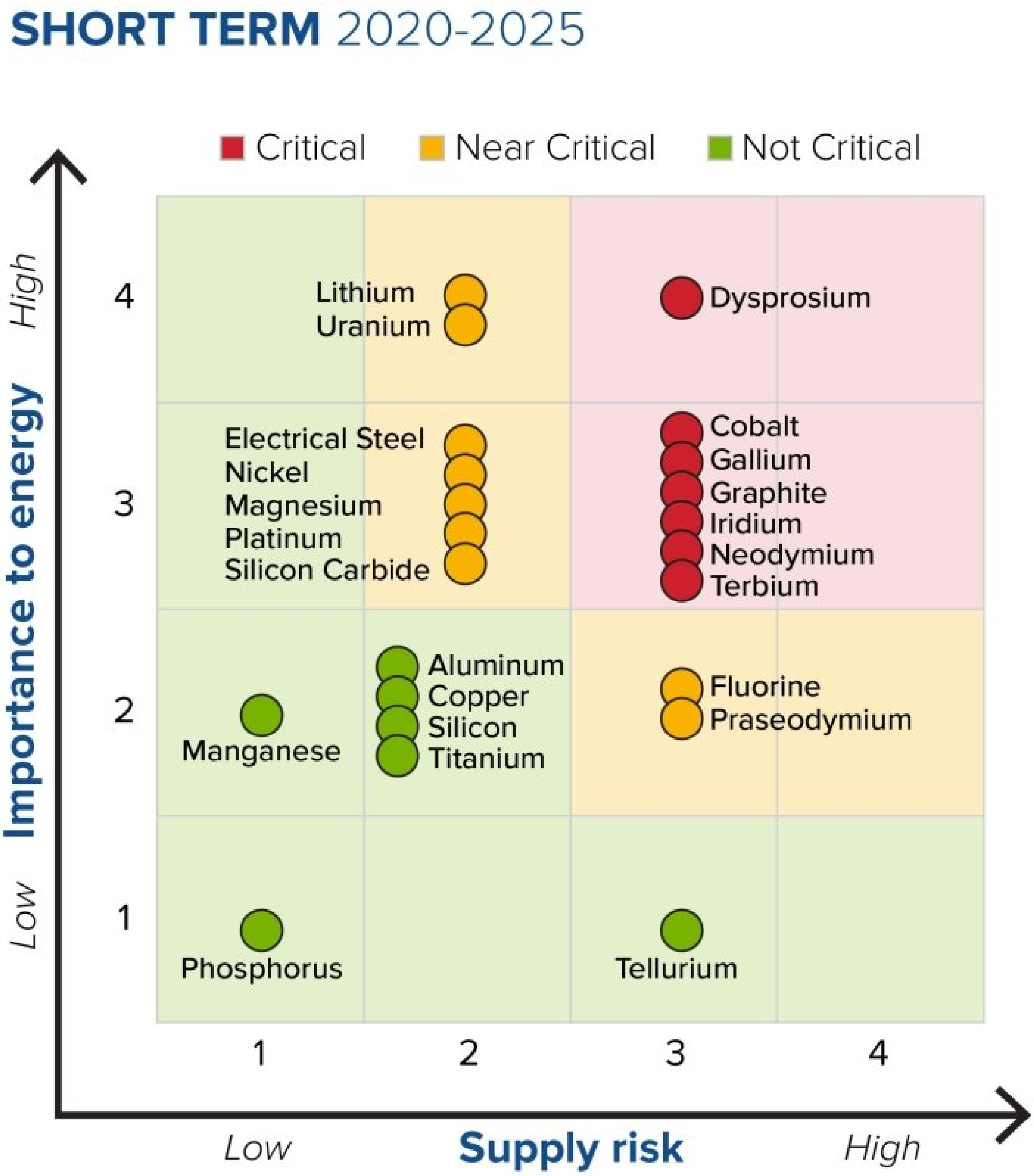
- Any mineral, element, substance, or material designated as critical by the Secretary of the Interior, acting through the Director of the U.S. Geological Survey.

2023 Final Critical Materials List

DOE has determined the final Critical Materials List to include the following:

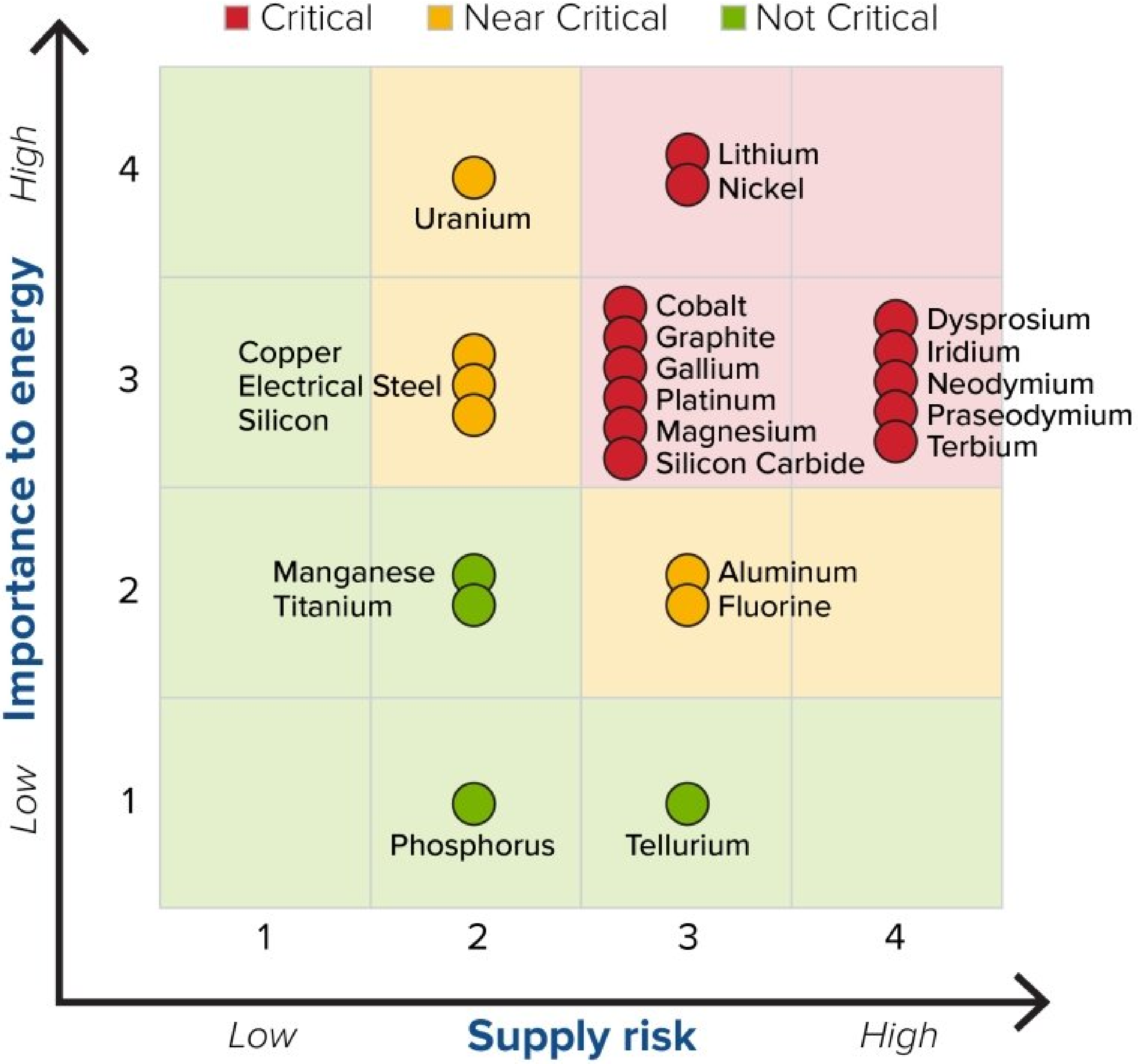
- **Critical materials for energy**: aluminum, cobalt, copper, dysprosium, electrical steel, fluorine, gallium, iridium, lithium, magnesium, natural graphite, neodymium, nickel, platinum, praseodymium, silicon, silicon carbide and terbium.
- **Critical minerals**: The Secretary of the Interior, acting through the Director of the U.S. Geological Survey (USGS), published a **2022 final list of critical minerals that includes the following 50 minerals:** "Aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium."

This list is based on the assessment described in DOE's most recent critical materials assessment, the **2023 DOE Critical Materials Assessment**. The results of the assessment are shown in the criticality matrices below.



Short-term (2020–2025) criticality matrix

MEDIUM TERM 2025-2035



Medium-term (2025–2035) criticality matrix

An official website of the United States government Here's how you know

FREQUENTLY ASKED QUESTIONS MINERALS

How many pounds of minerals are required by the average person in a year?

To maintain our standard of living, each person in the United States requires over 40,630 pounds of minerals each year:

- 10, 765 pounds of stone
- 7,254 pounds of sand and gravel
- 685 pounds of cement
- 148 pounds of clays
- 383 pounds of salt
- 275 pounds of iron ore
- 168 pounds of phosphate rock
- 35 pounds of soda ash
- 34 pounds of aluminum
- 12 pounds of copper
- 11 pounds of lead
- 6 pounds of zinc
- 5 pounds of manganese
- 25 pounds of other metals
- 584 pound of other non-metals

PLUS:

- 956 gallons of petroleum
- 3,593 pounds of coal
- 101,338 cubic feet of natural gas
- 0.12 pounds of uranium

Source: Minerals Education Coalition, 2021

Learn more: Mineral Resources: Out of the ground...into our daily lives

Related Content

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Map of Primary and Secondary Locations Based on the Adopted Rule

MAP NOTES

1. This map illustrates in orange primary and secondary locations based on the rule adopted at the Commission Meeting on April 2, 2019. For more information about the adjacency principle and how the primary or secondary locations work, please visit the Commission's website: https://www.maine.gov/dacf/lupc/projects/adjacency/adjacency.html
2. Primary and secondary locations are established in Section 10.08-A,C,1 and 2 of the draft rules and customized in Section 10.08-A,C,4 and 5. This customization reflects public input and research about service provision and existing development patterns.
3. This map does not show areas where primary or secondary locations overlap with conserved lands.
4. Measurements made from public roads are "as the crow flies" except that the measurement is not carried over a waterbody or the interstate highway, unless the area is contiguous to another primary or secondary location. This is intended to account for situations where development on one side of a waterbody or highway would be effectively separated from a town on the other side by long travel distance.
5. The Comprehensive Land Use Plan and Chapter 10 Land Use Districts and Standards list a management classification for each lake in the Commission's service area. Management classifications indicate suitability for development of each lake, with the goal of maintaining a diversity of lake experiences (e.g., MC3 lakes are potentially suitable for development).

NEVADA DIVISION OF
ENVIRONMENTAL
PROTECTION

STATE OF NEVADA
Department of Conservation & Natural Resources

Bureau of Mining Regulation and Reclamation

GUIDANCE DOCUMENT

WASTE ROCK, OVERBURDEN, AND ORE CHARACTERIZATION AND EVALUATION

1 July 2022

Waste rock, overburden, and ore shall be representatively evaluated for its potential to release pollutants to the environment and for its acid generation/neutralization potential pursuant to Nevada Administrative Code (NAC) 445A.396 and NAC 445A.414. The material shall be managed appropriately based on its potential to degrade Waters of the State (WOTS), specific site conditions, and ultimate placement location. Initial characterization results, methods to be utilized for sample collection and evaluation going forward, and proposed actions to mitigate potential acid generation and any other release of pollutants, as warranted, must be included in a Waste Rock Management Plan (WRMP). The WRMP must be submitted with the Water Pollution Control Permit (WPCP) application, pursuant to NAC 445A.396 or as required by the Nevada Division of Environmental Protection (the Division), Bureau of Mining Regulation and Reclamation.

It is the responsibility of the applicant or Permittee to ensure use of a Nevada-approved certified laboratory, and to request the laboratory use appropriate analytical methods to ensure future data acceptability by the Division. A listing of the Nevada-approved and/or Nevada-certified laboratories may be found on the Division’s website Nevada's Mining Labs.

Initial rock characterization data collected during the exploration phase of the project may be used, if appropriate analytical methods are performed or if the Division approves a representative correlation study between the methods used and the Division-approved methods.

An expansion of a pit, underground workings, or other new mining area must be representatively characterized and approved by the Division prior to the onset of mining, because previous characterization may not be applicable for the new area. The samples must be collected within the proposed new mining area and must be chemically and spatially representative (as reasonably possible) of the entire range of materials that will be encountered during mining. If saturated conditions (e.g. pit lake or flooded underground workings) are predicted to form after the cessation of mining, samples in close proximity to the mined area will be required for characterization and incorporation into the ground water model and pit lake(s) study, as applicable.

In accordance with NAC 445A.XXX (definition of waste rock effective 30 August 2018; number not yet defined [R046-18A]), overburden and any other material that is mined as part of the process to reach the ore, but from which a metallic mineral of economic value cannot be extracted at the time that it is mined, are considered to be waste rock, and must be evaluated per the requirements for waste rock in this guidance.

Please utilize the Reporting Guidelines at the end of this document to allow the Division to review the submittal more efficiently and subsequently decrease the time required for the issuance of a Water Pollution Control Permit.

Contents

1 Material Sample Requirements

For the characterization and evaluation to be meaningful, the sample material must be representative of the entire range of material(s). Characterization must be completed for all the following where applicable:

a. Waste rock, all geochemically distinct type based on lithology, alteration and mineralization;
b. Ore:
    - Mill grade;
    - Heap leach material;
c. Tailings, reject or off-spec material;
d. Ultimate pit wall and pit floor rock;
e. Pit backfill rock (above and below groundwater rebound elevation);*
f. Underground backfill (above and below groundwater rebound elevation);*
g. Cemented paste backfill (all ingredients separately and combined);
    - Cemented waste rock;
    - Waste rock;
h. Cap/cover materials (identified site-specific sources).

*The Division may require a minimum vertical distance above or below the predicted groundwater rebound elevation for placement of certain materials.

The following factors must be considered in establishing a representative sampling program:

a. Sampling density and frequency;
b. Sample size;
c. Lithological variation;
d. Hydrothermal alteration types and extent;
e. Mineralogical variation;
f. Extent and variation of sulfide mineralization;
g. Degree of fracturing;
h. Degree of oxidation;
i. Extent of secondary mineralization;
j. Presence/mass of evaporative mineral precipitates (EMPs) on rock surfaces;
k. Final disposition (ore, waste, pit wall, pit floor, pit backfill, underground backfill, etc.);
l. Historical environmental context (e.g., former mine sites with known issues/concerns);
m. Final conditions at closure (e.g. pit lake, saturated conditions).

Use of existing or operational samples in rock characterization:

a. Drill core and/or rock chip samples of ore and waste collected during initial ore body definition may be used for preliminary material characterization. Pulps are acceptable for the Nevada Modified Sobek Procedure and mineralogical analysis. Pulps are not acceptable for Meteoric Water Mobility Procedure and Humidity Cell Tests.

b. All samples used in the evaluation must be from the volume of rock to be mined or immediately adjacent thereto.

c. Illustrations must be included using cross-sections showing sample locations relative to the current and proposed mining limits.

d. During mining (after Division approval), analyses may be required from blast-hole samples that have been sent to the assay lab.

e. The Division may require all or a portion of the blast-hole materials to be retained and representatively composited, as appropriate, during the quarter for on-going evaluation of waste rock and ore character.

f. During mining, (after Division approval), sampling may also be required during the quarter from the waste rock dump where material has been placed.

2 Nevada-certified and Nevada-approved Laboratory Required

All laboratories performing mining-specific preparation methods and analytical procedures not explicitly covered under the Clean Water Act (CWA) may be subject to approval by the Division pursuant to Nevada Revised Statutes (NRS) 445A.428. All laboratories performing analytical procedures that are explicitly covered under the CWA programs must be certified by the Division per NRS 445A.428. These requirements are a condition of the WPCP.

Effective 1 August 2013, any analyses that are submitted to the Division (including the BLM or USFS) for characterization, permitting, or compliance must be performed by a Nevada-approved and/or Nevada-certified laboratory, as appropriate.

The Lab Certification Branch of the Bureau of Safe Drinking Water manages the Nevada-certified and Nevada-approved methods and procedures.

Please note: If the analytical laboratory is not approved or certified, as applicable, the Division will not accept data for the analyses in question and will require re-testing, re-sampling, and/or re-analysis by a Nevada-approved and/or Nevada-certified laboratory, as applicable, unless the Permittee has received prior Division approval.

A listing of the Nevada-approved and/or Nevada-certified laboratories may be found on the Division’s website at Regulation Branch Guidance Documents and at Nevada's Mining Labs.

2.1 Definition of Nevada-certified vs. Nevada-approved

Nevada-certified is mandatory, enforceable by regulation NAC 445A, certified labs must abide by our regulations and follow State law. Methods and procedures that are certified when meeting all requirements for compliance.

Nevada-approved is for methods that cannot meet the regulatory definition of certified, but the Division has approved the methods or procedures based upon review of standard operating procedures and an acceptable on-site assessment and participation in performance evaluation studies where available. Participation of laboratories in a Nevada-approved method is voluntary but the lab must be deemed Nevada-approved for the Division to accept the data. The Nevada-approved methods are the only methods that BMRR will accept for Permitting and compliance unless prior approval has been granted.

3 Characterization and Evaluation Procedures

3.1 Multi-Element Spectrographic Analysis per NAC 445A.396.4 (a):

The Division has determined that the minimum requirement for a spectrographic analysis is an analysis for Division Profile I and Uranium constituents from a Meteoric Water Mobility Procedure (MWMP). Additional spectrographic analyses (e.g., ICP-MS, etc.) may be provided to augment the required characterization data but will not be accepted as the only characterization completed.

3.2 Evaluation of Samples for the Potential to Releases Pollutants per NAC 445A.396.4 (b):

The Division required static testing and kinetic testing, as applicable, for ore, waste rock, and tailings evaluation but not for metallurgical ore recovery.

The Division has incorporated Net Neutralizing Potential (NNP) and MWMP data as criteria for HCT selection to ensure evaluation of samples for the potential to release neutral mine drainage. Neutral mine drainage is characterized as neutral pH and high metals and has a high potential to degrade the waters of the State.

The Division requires:

I. Collect representative samples and submit a synopsis of the sampling procedures used.

II. Required minimum analytical requirements, mandatory for all mining operations except placer operations that do not include crushing, shall include the following:

  1. Nevada-Modified Sobek Procedure (Acid Based Accounting) and
  2. MWMP – Profile I and Uranium (total).

III. If any potentially acid generating (PAG) material will be mined or if saturated conditions (e.g. pit lake or flooded underground workings) are predicted to form at the site, the Division will require Humidity Cell Testing (HCT) and a complete mineralogical analysis of all rock/alteration/mineralization types, both ore and waste.

The purpose of the complete mineralogical analysis is to evaluate the potential for acid generation and identify the specific sulfide and non-sulfide minerals (e.g., pyrite, pyrrhotite, calcite, dolomite, quartz, silica, etc.) that are involved in acid generation, neutralization, and encapsulation.

4 Summary of Division Approved Testing Procedures

The potential for acid generation shall be evaluated in accordance with the following testing procedures:

4.1 Nevada Modified Sobek Procedure – Static Testing

The Division's approved method for static testing also known as Acid-Base Accounting (ABA) is the Nevada Modified Sobek Procedure (NMSP). The most recent version of the NMSP is located on the Division's website Regulation Branch Guidance Documents.

The NMSP provides a potential for acid generation by utilizing the siderite corrected acid neutralization potential (ANP) and sulfur speciation to evaluate the acid generation potential (AGP).

a. Nevada Modified Net Acid Generation (NV-NAG) Test

Sulfate-bearing minerals (e.g. barite, gypsum, alunite and other similar-type minerals) have been observed to exhibit “false positive” PAG results on repeated occasions when tested under the commonly used and industry-accepted Nevada Modified Sobek Procedure (NMSP). When the presence of sulfate-bearing minerals is suspected and an accurate laboratory PAG determination is necessary, the Division will require samples to be characterized using the NV-NAG test procedure, mineralogical characterization, and NMSP testing of suspect samples by a Nevada-approved/certified laboratory.

Although typically not required for initial characterization, depending on results of ongoing test work, the Division may require the NV-NAG be performed on specific samples or lithologic types.

The most recent version of the Nevada Modified Net Acid Generation (NV-NAG) Test Procedure can be found on the Division’s website: Regulation Branch Guidance Documents.

4.2 Meteoric Water Mobility Procedure

The potential to release pollutants shall be evaluated by the MWMP, ASTM International E2242-13, or the most recent version, “Standard Test Method for Column Percolation Extraction of Mine Rock by the Meteoric Water Mobility Procedure”. The extract shall initially be filtered using a coarse filter paper, e.g. shark skin filter paper (approx. 8 - 12 µm retention). An extract sub-sample for dissolved metals can then be filtered at 0.45 µm and preserved, as applicable, within 12 hours of sample collection, prior to sub-contracting. The extract shall be digested and analyzed for the Division Profile I list of parameters and Uranium, plus any other parameters/constituents required by the Division on a site-specific basis (e.g., radio-chemical analysis). For the purpose of initial characterization studies, the Division also requires analysis for total uranium, i.e. extract shall be unfiltered, preserved, digested, and analyzed for the total concentration. Data generated will aid in determining future monitoring requirements.

To meet the requirements of Paragraph 5.2 of the method, which states "the pH of the extraction fluid used in this test method should reflect the pH of precipitation in the geographic region in which the mine rock is being evaluated,” BMRR has made the determination that the pH of rainwater in Nevada ranges between 5.5 and 6.0 SU.

In the instance of characterization being completed for pit-lake modeling, the extract shall be digested and analyzed for the Division Pit-Lake Characterization Analytical Profile (Profile I, Uranium, plus Profile III), located on the Division’s website Regulation Branch Guidance Documents. Extraction, digestions, and analyses must be performed by Nevada-approved and Nevada-certified laboratories, respectively.

In the instance of MWMP characterization where total recoverable metals of the Division Profile III, or the radiochemical components of the Profile R, are required, the extract shall be unfiltered, preserved, digested (as per method requirements), and analyzed. The Division Pit-Lake Characterization Analytical Profile (Profile I and Uranium plus Profile III) and the Profile R can be found on the Division’s website at Regulation Branch Guidance Documents. Extraction, digestion, and analyses must be performed by Nevada-approved and Nevada-certified laboratories, respectively.

If solution does not percolate through the column, or the material is fine-grained (i.e., tailings, sludge, etc.), see guidance document entitled “Meteoric Water Mobility Procedure Bottle Roll

Extraction Option", located on the Division's website Regulation Branch Guidance Documents or Appendix XI of ASTM E2242-13.

Reporting requirements for the MWMP are located on the Division's website Regulation Branch Guidance Documents. This information is required for all MWMP extractions and must be included with all analytical reporting.

4.3 Mineralogical Analysis

Mineralogical analysis shall be performed using the following methods (listed below), as appropriate, by a Nevada-approved laboratory or as approved by the Division.

1. XRD – X-ray Powder Diffraction;
2. SEM – Scanning Electron Microscopy;
3. Petrography (reflected light, transmitted light);
4. Division Approval Required before analysis:
    - XRF – X-ray fluorescence;
    - EDX – Energy Dispersive X-ray;
    - NIR – Near Infrared;
    - MLA – Mineral Liberation Analyzer;
    - EMPA – Electron Microprobe Analysis;
    - QEMSCAN - Quantitative Evaluation of Materials by Scanning Electron Microscopy;
    - Other analysis proposed by Permittee.

The purpose of this evaluation is to guide geochemical understanding of the reactions occurring during testing, such that appropriate geochemical modeling can be completed for the site. Sample selection for pre- and post-kinetic testing should be made in conjunction with site-specific guidance from the Division. Mineralogical characterization must include primary rock-forming minerals (e.g., silicates, carbonates, etc.), hypogene minerals (e.g., pyrite, galena, etc.), and supergene (secondary) minerals (e.g., melanterite, coquimbite, etc.).

The table below summarizes the minimum required tests for mineralogical analysis:

Scenario	Minimum Required Analysis Unless Otherwise Approved
PAG Material	XRD, SEM
PAG Material and Saturated Conditions	XRD, SEM, optical Petrography (pre and post HCT for all)
Saturated Conditions and no PAG Material	XRD

4.4 Humidity Cell Tests - Kinetic Testing

5 Scenarios for Kinetic Testing

- If the ANP/AGP ratio is ≥1.2, the Net Neutralization Potential (NNP, or ANP – AGP) is greater than 20 tons per kiloton (T/kT), and the MWMP extract analysis does not indicate exceedances of Division Profile 1 reference values (RV) or background for any parameters and no pit lakes will form at the project, then no kinetic testing will be required.

- If saturated conditions (e.g. a pit lake or flooded underground workings) will form at the Project, kinetic testing is required unless otherwise approved by the Division.
- If MWMP analysis indicates exceedances of Profile 1 RV or background, even though ANP/AGP ratio is ≥1.2 and NNP >20, kinetic testing may be required, if necessary to define chemical release functions (e.g. groundwater modeling, pit lake modeling). Contact the Division for further details/discussion.
- If ANP/AGP ≥1.2, but NNP <20 T/kT, kinetic testing may be required. Contact the Division for further details/discussion.
- If ANP/AGP ratio is <1.2, kinetic testing is required, unless previously approved otherwise by the Division.

Note: Federal land management agencies, (e.g., U.S. Bureau of Land Management [BLM], or Forest Service [USFS]) may have different ANP/AGP and NNP limits and requirements. The Division concurs with the use of the most conservative ANP/AGP and NNP limits applicable to the particular mining operation.

6 Kinetic Testing Protocol

The Division minimum test protocol requirements for HCT are:

a. Testing protocols (ASTM D5744-13, Option ‘A’, or the most recent approved method). Each test shall continue for a minimum of 20 weeks. **Tests shall not be terminated without Division approval**; if public lands will be affected, federal land management agency approval may also be required.

   Test protocol calls for weekly cycles composed of three days of dry air (<10% Relative Humidity [RH]) and three days of water-saturated air (approximately 95% RH) pumped up through the sample, followed by a leach with water on day 7.

   Although a test duration as short as 20 weeks may be suitable for some samples, research indicates that test durations well beyond 20 weeks are commonly required depending on the objectives of the test and the test results. Identified test protocols contain specific criteria to determine when tests may end. The determination as to the timeframe for test termination must be made using site-specific considerations such as leachate quality and the consumption rates of acid-generating and acid-neutralizing material. Analytical results shall be submitted to the federal land manager and the Division periodically, the frequency of submittal shall be based on discussion with the applicant. However, Division approval must be obtained prior to terminating each test.

b. The HCT extract shall be initially filtered using a coarse filter paper, e.g. shark skin filter paper (approx. 8 - 12 µm retention). An extract sub-sample for dissolved metals can then be filtered at 0.45 µm and preserved, as applicable, within 12 hours of sample collection, prior to sub-contracting All HCT extractions shall be performed by a Nevada-approved laboratory. All extract analyses shall be performed by a Clean Water Act (CWA) Nevada-certified laboratory.

7 Kinetic Testing Minimum Sampling Requirements

A. Minimum Sampling Requirements

   i. Weekly unfiltered sampling and analysis for:

1. Oxidation/reduction potential (mv);
2. pH (standard units [S.U.]);
3. Specific conductance (µS/cm);
4. Alkalinity, only when pH >4.5 S.U.;
5. Acidity when pH <5.0 S.U.;
6. Sulfate;
7. Iron total (ferric, and ferrous only if pH <5.0 S.U.); otherwise, only iron (total) is required.

ii. Weekly sample extracts for dissolved metals analysis shall be filtered at 0.45um and preserved, as applicable, within 12 hours of sample collection, prior to sub-contracting and analyzed for:

1. Calcium and
2. Magnesium.

Filtered or unfiltered extracts, as applicable, generated per the method will be preserved, digested, and analyzed during weeks 0, 1, 2, 4, and 4-week extracts thereafter (e.g., weeks 12, 16, 20, 24, 28, 32, etc.) for the following:

1. For Projects mining below the groundwater table: Each week shall be sampled for Profile III, total recoverable metals. All metal parameters that are above the corresponding Profile I reference limit shall have the remaining sample filtered at 0.45 µm and analyzed to provide a dissolved concentration as well.

   Typical weekly Profile III extract samples for HCTs should be split into the following sub-samples for analysis (suggested volume only):

   a. 200 milliliters (mls) – unfiltered, preserved with HNO_3 for total recoverable metals,
   b. 300 mls - unfiltered, unpreserved for parameters in IX.C.2.c.i. above; this split may be further sub-sampled for Cl, F, NO_2+NO_3-N, TDS, etc. analysis, as needed.
   c. Unless otherwise requested by the Division, analysis for WAD cyanide is not required.

2. For Project mining above the groundwater table: Each week shall be sampled for Profile I with dissolved metals and Uranium (total recoverable).

   Typical weekly Profile I extract samples for HCTs should be split into the following sub-samples for analysis (suggested volume only):

   a. 200 mls. – filtered at 0.45 um, preserved with HNO_3 for dissolved metals
   b. 300 mls - unfiltered, unpreserved for parameters in IX.C.2.c.i. above, this split may be further sub-sampled for Cl, F, NO_2+NO_3-N, TDS, etc. analysis, as needed.
   c. Unless otherwise requested by the Division, analysis for WAD cyanide is not required.

Please note if total uranium in the first 4 weeks is above 0.03 mg/L then the Division will require an MWMP-Profile I and Profile R analysis, no matter if mining will occur above or below the groundwater table. Please refer to Division's website for specific analytical requirements and reporting requirements.

3. A request to terminate an HCT may be submitted following a minimum 20 weeks of testing. The request shall include, at a minimum, the initial ABA data, all weekly analytical parameters, and all Profile I, III, or R results, as applicable. The HCT shall continue its testing protocol until a decision to approve termination is made by the Division. Under no circumstance will the HCT be placed on 'hold' pending Division review. If the project is on public land, separate concurrence from the BLM or USFS will be required.

7.1 Modifications to Approved Testing Protocols

With prior approval, the Division may allow the use of mine site specific groundwater as the lixiviant for certain extraction procedures, including, but not limited to, MWMP, HCT, attenuation testing, etc.

A request to modify a procedure must be received prior to commencement of any characterization program and include justification for the proposed modification(s).

7.2 Methods Not Approved by the Division

ASTM E1915, Net Carbonate Value (NCV) – The NCV method is currently not approved by the Division. Any use of this method will be supplementary to, not in place of, the analyses required by the Division.

8 Reporting Requirements

Final results reported shall include a Division Profile I, Uranium (total) and Profile R, or Profile III, or combination thereof, as applicable, analysis of the final leachate.

i. NMSP analysis of the leached material using a LECO-type analysis as specified above may be required depending on HCT results.

ii. Mineralogical analysis via appropriate methods, (see item IV of the "Characterization and Evaluation Procedure" section above, within this guidance) is also required for any PAG material characterized as part of a pit-lake study.

iii. The Nevada Modified Net Acid Generation (NV-NAG) Test Procedure may be required for samples undergoing the HCT protocol. If, at the time a request to terminate the HCT is submitted, (e.g. at the 20-week test timeframe), and the initial HCT feed sample indicated an ANP/AGP ratio of ≤1.2, and the HCT data indicates neutral leachate, the Division may require the NV-NAG procedure be performed on the initial HCT feed sample as part of the HCT termination request. The NV-NAG procedure can be found on the Division's website at Regulation Branch Guidance Documents.

8.1 Reporting Guidelines

To increase the efficiency of the Division's review of characterization analyses, please use the following guidelines for reporting characterization data.

Please include in your submittal:

1. A summary table of MWMP test results sorted by rock type.

2. A summary table of the NMSP results sorted by rock type.

   Table should include the following columns: Sample Name, Rock Type (based on lithology, alteration, and mineralization), Paste pH, ANP, AGP, ANP/AGP, NNP. Label the sulfur speciation types as required in the most recent update of the Nevada Modified Sobek Procedure.

3. HCT analyses provided in a reviewable format, including weekly results and Profile 1, Uranium, or Profile III, as applicable, in Excel file format. Within the data file, include the progressive week number and the corresponding extract sample date. Total uranium and MWMP/Profile R shall be reported separately.
4. Map displaying the sample locations in plan view. Display rock type (based on lithology, alteration, and mineralogy), pit shell and/or underground extents (proposed and current if applicable), and cross section locations.
5. Cross-sections of the characterized areas displaying: existing ground surface, pit shell and/or underground extents (proposed and current if applicable), location of samples (ABA and HCT), rock types, faults.
6. A table showing the percent each rock type will make up in each waste rock dump and the percent of each rock type that will be left exposed in the walls/floor of each mine pit and/or underground workings (before and after any backfill is placed including in-pit waste rock facilities).
7. All analyses provided must be accompanied with the laboratory quality control and quality assurance documentation (electronic copy consistent with WPCP Part II.E.5).
8. If any supplemental data in addition to the required characterization were completed, please include all test results in a reviewable format and electronic copy consistent with WPCP Part II.E.5 (e.g. Total Metals, blast hole data).

While the Division will accept other formats for presenting the characterization data, presenting the information as mentioned above will aid in the timely review of the Water Pollution Control Application.

9 Other Considerations

If Uranium is >0.03 mg/L in solution or is known or /suspected to be ≥ 0.05% in the ore, BMRR recommends that the Permittee contact the Nevada Department of Health and Human Services - Radiation Control Program to further discuss characterization and associated potential Permitting or licensing/license requirements.

10 Revisions

Revised 7/1/2022:	Reformatted for ease of use and edited Pit Lake to read saturated conditions (e.g. pit lake or flooded underground workings); Added requirement of coarse filtration of MWMP and HCT extracts.
Revised 4/12/19	