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DIVISION OF
WATER QUALITY

BINGHAM CANYON MINE 2003 RECLAMATION AND WATER MANAGEMENT PLAN

DOGM PERMIT NUMBER M/035/002

GROUND WATER DISCHARGE PERMIT NUMBER UGW350010

APPENDIX D

Submitted to

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1.0 INTRODUCTION

This report is intended to provide the Utah Division of Oil, Gas and Mining (DOGM) with an update to the Reclamation Plan for mining-related disturbance within the boundaries of Permit Number M/035/002. This report is also designed to fulfill the requirements for a conceptual closure plan required by Ground Water Discharge Permit UGW350010 (Bingham Canyon Mine and Leach Collection System). Kennecott Utah Copper Corporation (KUCC) submitted the original Mining and Reclamation Plan to DOGM in 1976. It was incorporated into the final Mined Land Reclamation Contract signed on September 28, 1978. Reclamation bonding was waived in lieu of a personal guarantee on the part of KUCC.

The original reclamation plan is still valid for KUCC's existing operations and consistent with the reclamation activities described in this report. However, the original plan could not be very specific about future reclamation options because of the long life expectancy of the mining operation. These same planning difficulties exist in 2003 because the surface mine is currently expected to be in operation for at least another 10 years.

This report proposes tentative reclamation actions and attempts to establish a decision-making framework for selecting optimum reclamation actions in the future. To aid in this process, this report also identifies information needed to make reclamation decisions that is not currently available but that will be collected in the future.

1.1 PERMIT NUMBER M/035/002 1976 RECLAMATION PLAN

A copy of the 1976 Mining and Reclamation Plan is attached in Appendix A. Figure 1-1 is a map showing the boundaries of Permit M/035/002 and all subsequent DOGM permits. The original plan divided the permit area into seven operational land use categories and specified maximum areas that could be disturbed within each category: 1) Mine - 3100 acres, 2) Mine Waste Disposal - 8000 acres, 3) Excess Mine Water Disposal - 2700 acres, 4) Ore Transfer - Mine to Process - 400 acres, 5) Ore Processing Facilities - 1800 acres, 6) Tailings Disposal - 6000 acres, and 7) Excess Process Water Disposal - 1000 acres. For each land use category, the plan described the physical setting in 1976 and the land use and vegetation that was present before mining began. It also presented potential post-mining land uses and general reclamation strategies.

1.2 SUBSEQUENT RECLAMATION PLANS

A series of new reclamation plans have been submitted to DOGM since 1976 for new construction projects or land uses that are different from the original 1978 Permit. A new DOGM permit number was issued for each of these projects and bonding was required. These new permits include the Fourth Line/Copperton Concentrator, Pine Canyon, and the North Impoundment Expansion. None of these new permit areas is discussed in detail in this report because they each have their own detailed reclamation plan. Several additional reclamation plans relating to dust control and groundwater quality protection for the existing tailings impoundment have also been submitted to various State agencies.

1.2.1 Copperton Concentrator/Fourth Line Expansion Reclamation Plan

A reclamation plan for the Copperton Concentrator, ore conveyor and tailings pipeline corridor was initially submitted to DOGM in April 1986. Amended plans were subsequently submitted for the addition of the Molybdenum Plant and for a fourth mill line. These plans describe building demolition and reclamation activities and costs for the ore conveyor and Copperton Concentrator. Total bonding for these facilities is currently $19,029,000. The original pipelines within the tailings pipeline corridor were exempted from bonding because of plans to use the pipelines for post-mining water management. However, the second tailings pipeline within the corridor is bonded in order to provide coverage for reclamation costs in the event that it is not used for post-mining water management. These facilities are all managed under DOGM Permit Number M/035/011.

1.2.2 Tailings Pond Reclamation Plans

Several reclamation plans have been submitted for the South Tailings Impoundment and for the North Impoundment expansion. The Tailings Pond Final Reclamation Plan was submitted to the Utah Air Conservation Committee and DOGM in July 1988. The plan focused on revegetation strategies and techniques for dust control on the impoundment. It assumed that the South Impoundment would be in operation for another 30 to 35 years, but this plan became obsolete when the North Impoundment expansion was initiated. The initial notice of intent for the North Impoundment expansion was submitted in 1994 and contained a detailed reclamation plan for the new impoundment. Permit number M/035/015 was issued for the North Impoundment in February 1996 and is currently bonded for $20,628,000. Two more recent reclamation plans have been submitted to State agencies that describe closure and reclamation of the South Impoundment. The Tailings Modernization Fugitive Dust Abatement Program, submitted to the Utah Division of Air Quality in 1994, contains a detailed revegetation plan for the surface of the South Impoundment. The Final Closure Plan for Groundwater Issues, submitted to the Utah Division of Water Quality in 1997, describes how surface and groundwater will be managed on the South Impoundment at closure. These plans are attached in Appendices B and C.

1.2.3 Pine Canyon Reclamation Plan

A reclamation plan for the Pine Canyon Mine and Mill Site was submitted in 1988. The plan was approved and has largely been implemented. Total bonding for Permit M/045/004 is $120,800 for reclamation of the few remaining structures and disturbed acres in the canyon.

1.3 OTHER PERMITS AND LAWS GOVERNING RECLAMATION AND POST-CLOSURE LAND USE

KUCC will have to comply with all applicable permits and laws governing surface water, groundwater, air emissions, hazardous wastes and soil contamination both during and after closure. Many of these laws and permits will influence the extent and character of reclamation that takes place at closure. In particular, as described below, Ground Water Discharge Permit UGW350010 requires the submittal of a closure plan that addresses groundwater quality issues around the mine and waste rock disposal areas.

1.3.1 Groundwater Discharge Permits

Ground Water discharge permits are managed by the Utah Division of Water Quality (DWQ). KUCC's permits require ground water monitoring, reporting and corrective actions if an out of compliance situation exists.

Ground Water Discharge Permit UGW350010 for the Bingham Canyon Mine and Leach Collection System (Part I, K.3) requires the submittal of a conceptual closure plan. The plan is required to "provide detail on all aspects of closure that are related to or have an impact on water quality". This includes preliminary designs and a schedule to modify the waste rock dumps to minimize infiltration, and a description of post-closure monitoring. The permit also requires that a final closure plan be submitted one year before closure. The Bingham Canyon Mine 2003 Reclamation and Water Management Plan (this document) is intended to fulfill the permit's requirements for a conceptual closure plan.

The Groundwater Discharge Permit for the tailings disposal area may also require post-closure maintenance and long-term monitoring. It is likely that the groundwater discharge permit for the North Concentrator area will have fewer post-closure requirements after demolition and reclamation have been completed there.

1.3.2 National Historical Site Registry for Bingham Pit

The Bingham Canyon open pit was designated as a National Historic Landmark in 1966. The designation was based upon the historical significance of the pit as well as its overall physical appearance. The National Historic Preservation Act was passed with the specific intention of identifying and assuring the continued existence of National Historic landmarks. Furthermore, State law requires that each State agency take into account the effect of an undertaking on any district, site, building, structure or specimen that is included in or eligible for inclusion in the National Historic Register of Historic Places or the State Register. Accordingly, reclamation obligations that would alter or amend the Landmark should consider the implications of the activities on the Landmark.

1.3.3 UPDES Permit

The DWQ will also manage the UPDES permit for surface water discharges off the property after closure. The UPDES permit will specify water quality criteria at each permitted outfall point and may specify storm water management practices. KUCC or its designate will continue to manage both surface water and captured groundwater of various qualities from throughout the property after closure.

1.3.4 Air Permits

The Utah Division of Air Quality (DAQ) manages Air Approval Orders, Title V Operating Permits and sections of the State Implementation Plan at the Mine, Concentrators and Tailings Impoundment. Air emissions at the concentrators will end at closure, though certain air quality requirements may apply during demolition and reclamation. The level of dust emissions from the mine, waste rock disposal areas and tailings impoundment will be highly dependent upon the reclamation actions that are selected. It is likely that the DAQ will continue to require oversight of these facilities during and after closure.

1.3.5 CERCLA Sites and NRDC for Acid Plume

Under the terms of various Environmental Protection Agency (EPA) Comprehensive Environmental Response Compensation and Liability Act (CERCLA) administrative orders and a 1995 Memorandum of Understanding (MOU), the EPA and the State Division of Environmental Response and Remediation (DERR) provide oversight and specify minimum cleanup standards during remediation activities at historically contaminated sites. As part of the 1995 MOU, KUCC agreed to "complete environmental assessments of currently identified on-site historic facilities and their associated wastes and conduct cleanups of these wastes if shown necessary by the ecological and human health risk assessments". Figures 1-2 and 1-3 are maps and lists of historical sites within the boundaries of DOGM permit M/035/002. To date, the majority of sites that fall within the permit boundaries have received a "No Further Action" status from the EPA and DERR as identified in two Records of Decision dated December 13, 2000 and September 28, 2001. Most of the remaining sites will be addressed many years before closure, but it is possible that new sites will be identified or that remediation will continue after closure at other sites.

Historical leach water and acid rock drainage (ARD) losses that occurred at the base of the waste rock disposal areas, from the former Bingham Creek Reservoirs and from the South Jordan Evaporation Ponds contaminated portions of the alluvial aquifer in the southwest Jordan Valley. Concentrations of sulfate and metals in some parts of the aquifer are above human health standards for some constituents.

Several corrective measures were taken in the early to mid 1990s to prevent additional releases to the aquifer. These included: 1) taking the South Jordan evaporation ponds out of service, removing and/or consolidating sludges on-site, and capping and reclaiming the area; 2) temporarily taking the Bingham Creek reservoirs out of service and replacing them with reservoirs that have a triple-layer liner system; and 3) improving the capture of seepage from the Eastside waste rock disposal areas by upgrading the surface and subsurface collection systems. In addition, active leaching of the waste rock disposal areas was terminated in Fall 2000. These steps are important source control measures for protecting the regional aquifer against further contamination.

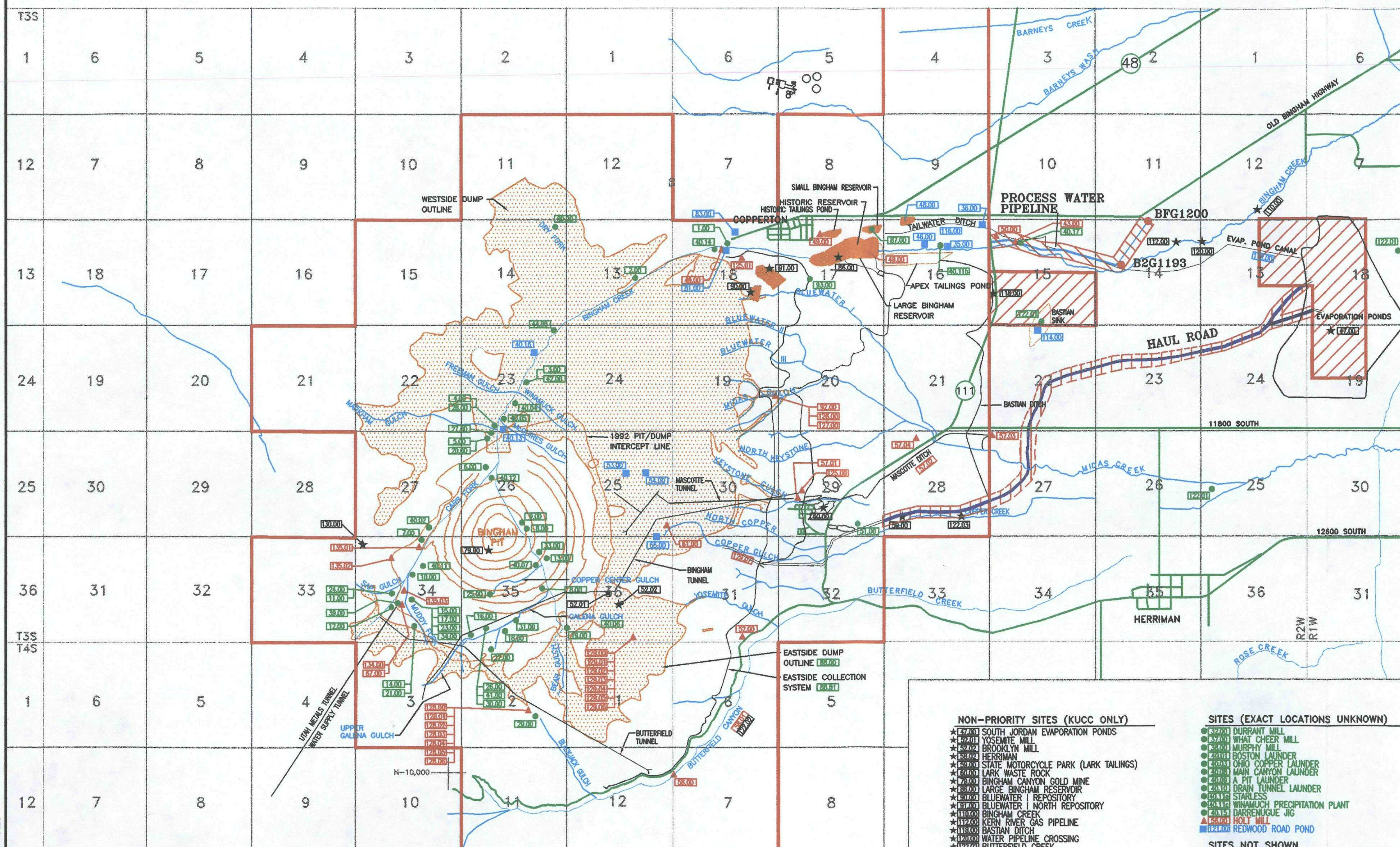
Development of a plan to efficiently remediate the existing groundwater contamination involved groundwater management and treatment specialists, state and federal regulators, local community leaders and local water purveyors. Settlement of the Natural Resources Damage Claim made by the State of Utah for the Bingham Creek Groundwater plume requires, among other things, that the acidic portion of the groundwater plume be extracted. Barrier wells installed at the plume's terminus will be pumped in perpetuity to contain the sulfate portions of the plume. These activities will take place before, during and after closure.

1.4 1998 UPDATE OF MINING OPERATIONS

The final draft of the 1998 Update on Mining Operations Conducted Under DOGM Permit Number M/035/002 was submitted to DOGM on September 30, 1998. The 1998 Update describes in detail the mining operations that existed within the permit boundaries in 1998 and provides a brief history of the operations since the original permit was received in 1978.

1.5 REPORT ORGANIZATION

This reclamation report is organized in the same general manner as the 1976 Mining and Reclamation Plan. Section 2.0 describes general reclamation strategies that are common to each land use category described in the original plan. Sections 3.0 through 9.0 present tentative reclamation activities for each land use category. These sections also describe the issues and data requirements that need to be addressed in order to refine and finalize the selected tentative activities. Section 10.0 describes post-closure water management activities and Section 11.0 briefly describes future and on-going research that is being conducted in support of reclamation and closure.



BINGHAM CREEK ROD HISTORICAL FACILITIES

- ● 1.00 LEAD MINE MILL
- ● 2.00 UTAH COPPER CO. MILL
- ● 3.00 WINNAMUCK MILL
- ● 4.00 MARKHAM MILL
- ● 5.00 WALLS MILL
- ● 6.00 SHAWMUT MILL
- ● 7.00 UTAH APEX MILL
- ● 8.00 ROGERS MILL (MOVED 1 MILE DOWN GRADIENT)
- ● 9.00 BOSTON CONSOLIDATED MILL
- ● 10.00 STEWART NO.2 MILL
- ● 11.00 HIGHLAND BOY MILL
- ● 12.00 BINGHAM–NEW HAVEN COPPER & GOLD MILL
- ● 13.00 COLUMBIA COPPER CO. MILL
- ● 14.00 LAST CHANCE MILL
- ● 15.00 NEW ENGLAND GOLD & COPPER CO. MILL
- ● 16.00 JORDAN MILL (GALENA MILL)
- ● 17.00 STEWART NO.1 MILL
- ● 18.00 SPANISH MILL (NIAGARA MILL)
- ● 19.00 TELEGRAPH MILL (US MINING CO. MILL)
- ● 20.00 BEMIS MILL
- ● 21.00 WEST MTN. MINING CO. CONCENTRATOR
- ● 22.00 SILVER SHIELD MILL
- ● 23.00 BINGHAM MINING & MILLING CO. MILL
- ● 24.00 UTAH CONSOLIDATED GOLD MINE MILL
- ● 25.00 BINGHAM GOLD MINING CO.
- ● 26.00 UTAH CONCENTRATOR (AKA UTAH MILL)
- ● 27.00 HEASTON CONCENTRATOR JIGS
- ● 28.00 MASSASOIT MILL
- ● 30.00 UTAH MILL (AKA UTAH CONCENTRATOR)
- ● 31.00 BROOKS MILL
- ● 33.00 EAGAN & BATES MILL
- ● 34.00 BINGHAM–NEW ENGLAND MILL
- ■ 35.00 ROBBE CELLS
- ● 40.02 APEX YARDS
- ● 40.04 TIEWAUKEE DUMP
- ● 40.05 McGUIRES GULCH
- ● 40.06 GALENA GULCH
- ● 40.07 COPPER CENTER GULCH
- ● 40.11 INGERSOLL GULCH
- ● 40.11b McGREGOR PLANT
- ● 40.12 COPPER PLACER PLANT
- ■ 40.13 CUPRUM PRECIPITATION PLANT
- ● 40.14 C.W. WATSON'S JIG
- ■ 40.16 VERONA URANIUM PLANT
- ● 40.17 NEW YORK & UTAH MILL
- ● 41.00 UTAH SMELTER
- ● 42.00 WINNAMUCK SMELTER
- ▲ 43.00 REVERE SMELTER
- ● 44.00 YAMPA SMELTER
- ■ 83.00 YELLOW CAKE PLANT

NON–BINGHAM ROD HISTORICAL FACILITIES

- ● 29.00 QUEEN MILL
- ■ 36.00 PROLER
- ■ 46.00 MIXED TAILS
- ■ 48.00 CEMETERY POND
- ▲ 49.00 COPPERTON DUMPS (3 LOCATIONS)
- ▲ 50.00 REVERE SWITCH TAILINGS POND
- ● 51.00 OHIO COPPER CO. MILLS
- ▲ 52.00 REVERE MILL
- ■ 53.00 FORTUNE MILL
- ■ 54.00 NEW MAMMOTH MILL
- ■ 55.00 DALTON & LARK MILL
- ▲ 57.01 MASCOTTE TUNNEL
- ▲ 57.02 MASCOTTE DITCH
- ▲ 57.03 MASCOTTE POND
- ▲ 57.04 MASCOTTE TAILINGS
- ▲ 58.00 BUTTERFIELD MINE WASTE ROCK
- ▲ 58.01 BUTTERFIELD CANYON
- ▲ 61.00 COPPER GULCH MINES
- ■ 81.00 PRECIPITATION PLANT IN COPPERTON
- ● 87.00 SMALL BINGHAM RESERVOIR
- ● 88.00 EAST SIDE DUMPS
- ● 88.01 EAST SIDE COLLECTION SYSTEM
- ● 89.00 DRY FORK DUMPS
- ▲ 92.00 MIDAS POND
- ● 93.00 EAST SIDE RESERVOIR
- ■ 114.00 BASTIAN SINK
- ■ 116.00 TAILWATER DITCH
- ■ 119.00 EVAPORATION PONDS CANAL
- ● 122.01 MINE WASH AREAS (3 LOCATIONS)
- ▲ 125.00 BINGHAM TUNNEL
- ▲ 125.01 5490 TUNNEL
- ▲ 126.00 OLD BINGHAM TUNNEL
- ▲ 127.00 UNNAMED ADIT
- ▲ 128.00 TO 128.08 BLACK JACK GULCH MINES
- ▲ 129.00 TO 129.06 YOSEMITE & SAINTS REST MINES
- ▲ 129.07 COPPER GULCH
- ▲ 135.01 APEX (PARVENU) TUNNEL
- ▲ 135.02 ARMSTRONG TUNNEL
- ▲ 135.03 HIGHLAND BOY TUNNEL

NON–PRIORITY SITES (KUCC ONLY)

- ★ 47.00 SOUTH JORDAN EVAPORATION PONDS
- ★ 52.01 YOSEMITE MILL
- ★ 52.02 BROOKLYN MILL
- ★ 58.02 HERRIMAN
- ★ 59.00 STATE MOTORCYCLE PARK (LARK TAILINGS)
- ★ 60.00 LARK WASTE ROCK
- ★ 79.00 BINGHAM CANYON GOLD MINE
- ★ 86.00 LARGE BINGHAM RESERVOIR
- ★ 90.00 BLUEWATER I REPOSITORY
- ★ 91.00 BLUEWATER I NORTH REPOSITORY
- ★ 110.00 BINGHAM CREEK
- ★ 112.00 KERN RIVER GAS PIPELINE
- ★ 118.00 BASTIAN DITCH
- ★ 120.00 WATER PIPELINE CROSSING
- ★ 122.02 BUTTERFIELD CREEK
- ★ 122.03 COPPER CREEK

SITES (EXACT LOCATIONS UNKNOWN)

- ● 32.00 DURRANT MILL
- ● 37.00 WHAT CHEER MILL
- ● 38.00 MURPHY MILL
- ● 40.01 BOSTON LAUNDER
- ● 40.03 OHIO COPPER LAUNDER
- ● 40.08 MAIN CANYON LAUNDER
- ● 40.09 A PIT LAUNDER
- ● 40.10 DRAIN TUNNEL LAUNDER
- ● 40.11a STARLESS
- ● 40.11c WINAMUCH PRECIPITATION PLANT
- ● 40.15 DARRENUGUE JIG
- ▲ 56.00 HOLT MILL
- ■ 121.00 REDWOOD ROAD POND

SITES NOT SHOWN

- ★ 123.00 SW JORDAN VALLEY GROUNDWATER PLUME
- ★ 124.00 UPPER BINGHAM CREEK GROUNDWATER CONTAMINATION

LEGEND

- ▲ =PRIORITY ONE SITES
- ■ =PRIORITY TWO SITES
- ● =PRIORITY THREE SITES
- ★ =NON–PRIORITY SITES
- =PERMIT BOUNDARY (M/035/002)
- =RELEASE UPON COMPLETE REMOVAL (M/035/002).
- =HAUL ROAD RELEASE UPON COMPLETE REMOVAL. DASHED AREA NOT INCLUDED IN ORIGINAL DOGM PERMIT BOUNDARY (M/035/002).
- =BFG1200 AND B2G1193 PIPELINE (M/035/002).

GRAPHIC SCALE

5400 0 2700 5400 10800

(IN FEET)

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ENVIRONMENTAL ENGINEERING PROJECTS GROUP				
APPROVAL	DATE	SCALE: 1"= 5400'		DATE
		DESIGNED BY	VP	12/14/2004
		DRAWN BY	JI	12/14/2004
		CHECKED BY		
		PROJECT ENGINEER		
		PROJECT MANAGER		

KENNECOTT
UTAH COPPER

FIGURE 1–2
MAP OF HISTORICAL SITES WITHIN THE SOUTHERN BOUNDARIES OF PERMIT M/035/002

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2.0 GENERAL RECLAMATION STRATEGY

The following sections describe the general decision making processes that were used to determine if and when a site should be reclaimed, and to select the most appropriate actions at sites that have been scheduled for reclamation.

2.1 RECLAMATION TIMING

The ultimate fate of facilities that currently exist within the permit boundaries is: 1) to be reclaimed during the life of the mine, 2) to be reclaimed during mine closure, or 3) to not be reclaimed. Any facilities that are to be left in place after closure will need to have a confirmed post-closure use.

It may be logical to close and reclaim some facilities before general mine closure. For example, changes in process or economics may make some facilities obsolete. Facilities that reach the end of their designed operational life, such as the South Tailings Impoundment, may also be reclaimed before general mine closure. Facilities that are inactive and that may pose a risk of contaminant release to the environment will generally be demolished and remediated before general closure.

Under current plans, most facilities will be reclaimed at the time of general mine closure. However, some facilities may be left in place if they have a demonstrated post-mining use and if they do not pose a threat to human health or the environment.

2.2 SELECTION OF RECLAMATION ACTIVITIES

Tentative reclamation actions for each land use category specified in the 1978 Permit are selected according to the following steps:

- closure issues are identified
- possible post-closure land uses are identified
- information that is needed before final closure options can be selected is identified
- tentative reclamation actions are selected.

The following subsections provide a general description of each of these steps. Sections 3.0 through 9.0 are also organized according to the format described here.

2.2.1 Closure Issues

Regulations and permits governing closure, in particular, actions required by the 1976 Mining and Reclamation Plan or Groundwater Discharge Permit UGW350010, are identified for each land use category. Known hazards and environmental liabilities that will exist at closure are also described, and the environmental goals of the reclamation process are listed.

2.2.2 Possible Post-Closure Land Uses

Possible post-closure land uses are identified based upon the limitations imposed by the regulatory, chemical and physical setting that will exist at closure. In the future, land use may also be selected based upon cleanup standards derived from exposure and risk assessments. Sites without long-term maintenance requirements and where all physical and chemical hazards are removed, may have an unrestricted post-closure land use. At the other extreme, sites that will require continuous maintenance after closure, or that will still pose physical or chemical hazards, will have a more limited set of possible post-closure land uses. The identification of these limitations early in the planning process can help define the reclamation strategy.

2.2.3 Data Requirements

This section identifies information that is not currently available but is needed in order to refine the tentative reclamation actions.

2.2.4 Reclamation Activities

Tentative reclamation activities are selected for each land use category based upon the incomplete data set that is currently available. These actions may be refined in the future as necessary data requirements are filled and as new technologies become available.

2.3 RECLAMATION OF BUILDINGS AND STRUCTURES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified that all surface facilities, utilities, railroads, paved areas and equipment would be razed and/or removed except for those with a post-mining use. This is a common requirement to each of the operational areas specified in the 1978 Permit, and reclamation will generally be conducted in a similar fashion at each site.

Table 2-1 lists the major facilities and structures that currently exist within the permit boundaries, and specifies the closure approach and status currently planned for each facility. Figures 2-1 and 2-2 show the locations of buildings and structures around the mine and the North Concentrator/Magna Tailings area. The closure approach consists of one or more activities for each facility. A brief description of the principle activities is provided below:

- Demolition (Demo) involves the removal of salvageable equipment and destruction of buildings or structures and foundations.
- Remediation (Remed) involves excavation and removal of contaminated soils and debris.

Table 2-1 Facilities and Structures within the Permit Boundaries

FACILITY DESCRIPTION	CLOSURE APPROACH	STATUS
MINE		
Water Tanks	Demo and Reclaim	Final
General Buildings	Demo and Reclaim	Final
Visitors Center and Parking Area	Leave in Place	N/A
Lead Mine Townsite	Demo and Reclaim	Final
Lark Mine Buildings	Demo and Reclaim	Final
Yosemite Road	Demo and Reclaim	Final
Yosemite Truck Shop & Dispatch Tower	Demo	Final
Explosive Storage	Demo and Reclaim	Final
Dry Fork Warehouse & Shops	Demo	Interim
In-Pit Crusher	Demo	Final
6190 Truck Shop	Demo	Final
Code 80 Fuel & Lube Shop	Demo and Reclaim	Final
Miscellaneous Shafts	Demo and Reclaim	Final
44 KV Power Distribution Line	Leave in Place	N/A
Power Lines associated with dewatering	Leave in Place	N/A
Miscellaneous Power Lines	Demo and Reclaim	Final
Miscellaneous Tunnels	Demo and Reclaim	Final
Mine Access Road	Leave in Place	N/A
Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
MINE WASTE DISPOSAL		
Small Bingham Reservoir	Leave in Place	N/A
Large Bingham Reservoir System	Leave in Place	N/A
Precipitation Plant	Demo, Remed and Reclaim	Interim
Water Management System Facilities	Leave in Place	N/A
ARD Collection System Facilities	Leave in Place	N/A
Leach Water Pumping Facilities	Demo and Reclaim	Final
6600 ARD Storage and Evaporation Ponds	Leave in Place	N/A
Pilot-Scale Water Treatment Facilities	Demo and Reclaim	Interim
SX-EW Pilot Plant	Demo and Reclaim or move	Interim
Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
EXCESS MINE WATER DISPOSAL		
Evaporation Ponds and Associated Facilities	Demo, Remed and Reclaim	Completed(1)
ORE TRANSFER-MINE TO PROCESS		
Ore Reload	Demo and Reclaim	Final
Rail Tracks and ties	Demo and Reclaim	Interim
Rail Ballast	Remed and Reclaim	Interim

Copperton Rail Yard	Demo and Reclaim	Final
Railroad Car Repair Shop	Demo and Reclaim	Final
Ore Conveyor (in pit and 5490 Tunnel)	Demo	Final
Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
ORE PROCESSING FACILITIES		
Magna Concentrator Area	Demo, Remed and Reclaim	Interim
Magna Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
Arthur Shops Area	Demo and Reclaim	Final
Arthur Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
Bonneville Area	Demo and Reclaim	Final
Bonneville Asphalt/Concrete Parking Areas	Demo and Reclaim	Final
Pipelines	Demo and Reclaim	Final
TAILINGS DISPOSAL		
Magna Tailings Pond Structures	Demo and Reclaim	Interim
EXCESS PROCESS WATER DISPOSAL		
Excess Process Water Disposal Structures	Leave in Place	N/A
NOTE: Any facilities to be left in place will have a post mining use.		
(1) As described in Section 5, follow-up remediation is currently planned to remove gypsum-bearing sludge from the repository in the Evaporation Pond area.		

- Reclamation (Reclaim) involves regrading and revegetating the affected areas except for structures located in the Bingham Pit, on the waste rock surfaces or on the tailings impoundment. These sites will be reclaimed according to the reclamation activities described in Sections 3, 4 and 8 respectively.

- Leave in Place indicates that the facility will remain for future commercial, water management or other uses. Any facility to be left in place will have a demonstrated post-mining use at closure.

The closure status options listed in Table 2-1 are:

- Interim - indicates that the facility will probably become inactive and be reclaimed before general mine closure.

- Final - indicates that the facility will probably become inactive and be reclaimed during general mine closure.

- Not Applicable (N/A) - indicates that the facility may have a post-mining use or that the final closure option has not been selected.

- Completed - indicates that the facility has already been reclaimed.

Before each facility closes, residual feedstock materials and products will be identified, collected and processed, sold or otherwise removed. During demolition, salvageable and recyclable materials will also be sold or recycled. Uncontaminated construction debris that remains after all commercially valuable materials have been removed will either be transported to a Class IV landfill on KUCC property or buried on-site. Wherever possible, construction debris will be used as fill material to minimize the need to excavate and transport fill material from elsewhere. Shaft, adit and tunnel portals that are both within the permit boundaries and on Kennecott property will be assessed to determine if they would pose a risk to the public after closure. Those portals identified as a risk by the hazard assessment will be gated or sealed.

Soils beneath and adjacent to buildings and structures will be sampled during and/or after demolition. Sampling will be performed if it is believed that contamination may be present because of historical activities or field observations. Soils, construction debris or other materials that are determined to be contaminated with metals or organic compounds will be sent to an appropriate disposal or treatment facility. Selected materials may be decontaminated and recycled. Hazardous wastes will be sent to an off-site hazardous waste landfill, or may be disposed of on-site in the Arthur Repository if they meet the requirements of the corrective action management unit. According to their chemical characteristics, other materials will be bioremediated, sent to an industrial landfill, or sent to the waste rock disposal areas. Contaminated materials will be handled in compliance with all existing permits and regulations. However, within this legal framework, material-handling decisions will be based upon cleanup standards derived from exposure and risk assessments. For example, if the post-mining land use is industrial, then the cleanup standards for soils will address industrial worker exposures. If the post-mining land use is wildlife habitat, the clean up standards will be based upon exposures to potentially impacted species.

The footprint of demolished facilities within the Bingham Pit, on the waste rock dumps or on the tailings impoundment will be treated in accordance with the reclamation activities described in Sections 3, 4 and 8 respectively. For facilities that are not underlain by the pit, waste rock or tailings surfaces, fill material will be imported, drainages will be reconstructed, and the land surface will be graded and contoured consistent with the surrounding terrain. If the existing soils or fill materials do not provide a suitable growth media, topsoil will be imported and spread to a minimum depth of six inches. Subsoil will also be imported in addition to topsoil if required to provide a minimum of two feet of rooting media. Wherever possible, topsoil will be taken from nearby existing stockpiles. Reclaimed sites will be planted with native and select non-native species. Species mixes will be adjusted based upon parameters such as elevation and slope orientation. If field assessments indicate it is required, all the surfaces to be revegetated will also receive a light application of chemical fertilizer to provide nitrogen, phosphorus and potassium (not to exceed 50 lbs/acre available nitrogen) or may receive biosolids at application rates not to exceed 10 tons/acre of pure biosolids. If biosolids have been mixed with wood chips or another carbon source, the application rate of the mixture may be as high as 30 dry tons/acre, as long as the biosolids component of the mixture does not exceed 10 dry tons/acre. In general, phosphorus application rates will be higher than nitrogen application rates, which will be higher than potassium application rates.

3.0 MINE AREA

The Bingham Pit is currently about 13,000 feet across at its widest point and covers approximately 2300 acres. The associated support facilities cover about 170 acres and are generally sited on top of old waste rock disposal areas adjacent to the pit. A list of the support facilities is provided in Table 2-1. The open pit extends from approximately 8000 feet above mean sea level (amsl) to about 4500 feet amsl. Overall pit slopes will range between 32 and 52 degrees at closure and will be composed of a series of benches that average about 50 to 100 feet high and 40 to 50 feet wide. The Conveyor Tunnel connects the pit with the Salt Lake Valley. It has a western portal on the northeastern side of the pit at an elevation of about 5490 feet amsl and an eastern portal at an elevation of 5465 feet amsl in lower Bingham Canyon about 2000 feet west (up gradient) of the Bingham cutoff wall and reservoirs (Figure 2-1). According to the current surface mine plan, the pit will be approximately 300 feet deeper and cover several hundred additional acres at closure.

The distribution of sulfide mineralization within the walls of the Bingham pit provides the primary control on contact water chemistry and on the chemistry of soils that form on the pit benches. As the sulfides are oxidized, they produce acid that may be neutralized in situ if sufficient acid neutralizing minerals such as calcium carbonate are present in the rock. The amount of acid that a rock could produce if it is completely oxidized is termed its acid potential (AP) and the amount of acid that a rock can neutralize is termed its neutralization potential (NP). The net neutralization potential (NNP) is calculated by subtracting the AP from the NP and the neutralization potential ratio (NPR) is calculated by dividing NP by AP. A rock with a negative NNP or an NPR of less than one will likely generate acid rock drainage (ARD) as it weathers. In theory, a rock with a positive NNP or NPR greater than one will not generate ARD and may neutralize acidic solutions with which it comes into contact. However, because of the uncertainties created by differential reaction kinetics, leaching rates and mineral distribution in the rock, a commonly used screening criteria assumes that rocks with NNP values above zero and NPR values above one are possibly acid-generating unless the sulfide sulfur content is less than 0.3 % (AP < 10 tons/1000 tons) or the NPR is greater than 2 (Price et al., 1997).

Figure 3-1 is a map of acid potential on the current pit walls and Figure 3-2 is a graph showing the vertical distribution of acid potential. The acid potential is likely overestimated by about ten percent on these figures because it has been calculated from total sulfur analyses and so includes sulfur from non-acid-generating sulfate and sulfide minerals. On average, all of the current pit benches above 6900 feet amsl and most of the benches below 5000 feet amsl contain less than 0.3 percent sulfur (Figure 3-2). The primary acid-generating sulfide minerals in the Bingham Pit are pyrite, chalcopyrite, bornite and molybdenite. Pyrite is generally the most abundant and reactive of these sulfides and its distribution is the most significant control on the AP of the pit walls. Figure 3-3 is a graph showing the vertical distribution of AP derived from pyrite alone on the current pit walls. Below 5100 feet, the average pyrite AP varies between about two and ten tons/1000 tons. Much of the rest of the AP in the bottom of the pit is provided by molybdenite. Although molybdenite may generate acidity under some surface weathering conditions, in practice it is one of the most resistant sulfide minerals to oxidation and so is likely to be a minor contributor to acid production (Plumlee, 1999). The center of the pyrite halo around the ore

Figure 3-2 Average Total Sulfur Acid Potential versus Current Pit Elevation

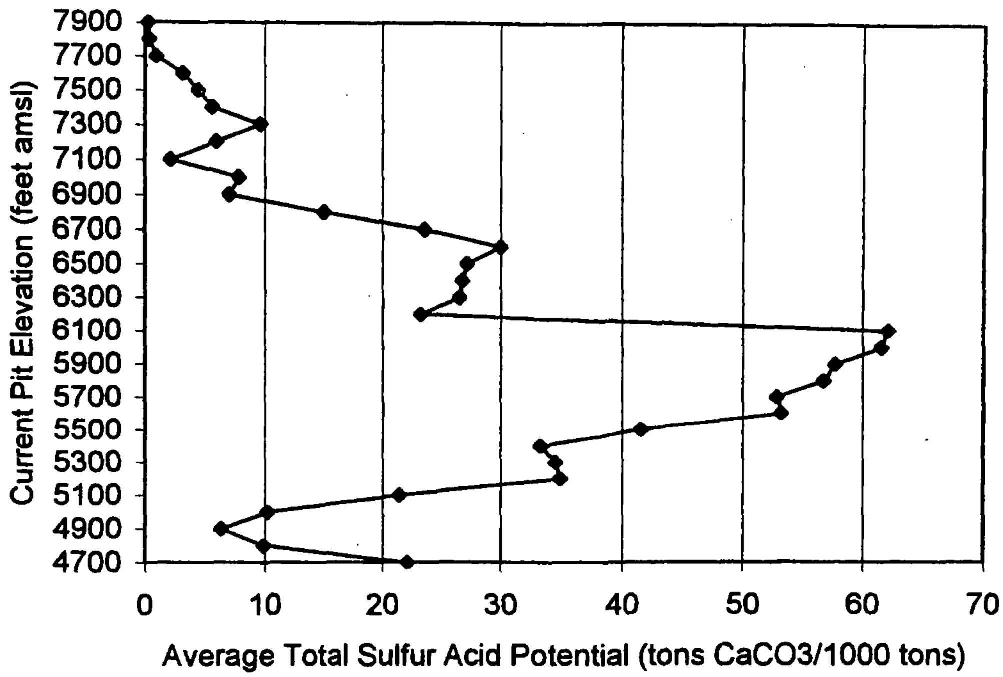
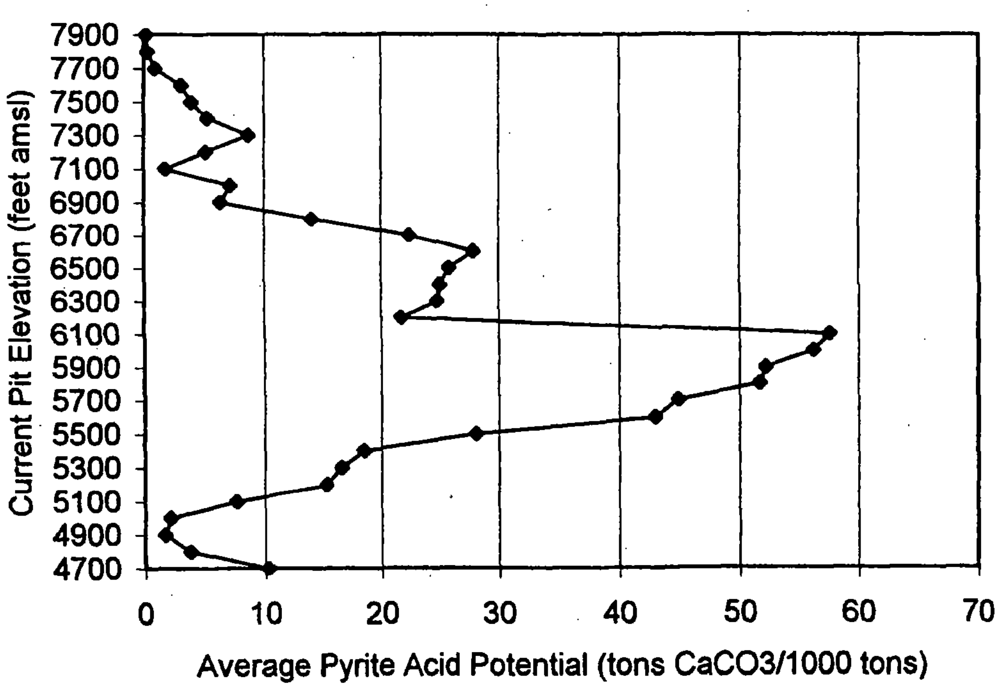


Figure 3-3 Average Pyrite Acid Potential versus Current Pit Elevation



body, where rock has the strongest potential to generate acid is largely confined to a band between 5500 and 6200 feet amsl.

The NP of the current pit walls is highly variable. Limestone beds tend to have the highest NP values while quartzites and late stage intrusive rocks tend to have the lowest (Table 3-1). Most of this NP is provided by calcium carbonate, but a small amount is also provided by various silicate minerals. For each sedimentary rock type, NP tends to be highest on the uppermost benches of the pit and decreases towards the center of the pit. In general, the sedimentary sequence on the northeast side of the pit has much less NP than in other areas. Within the igneous rocks, NP values tend to be highest in areas adjacent to limestone beds.

The distribution of NNP on the current pit surface is shown on Figures 3-4 and 3-5a. In plan view, the distribution of NNP in the pit can be visualized as donut shaped, with a positive (net-neutralizing) 3500-foot diameter core surrounded by a negative (net acid-generating) 10,000-foot diameter ring. As shown on Figure 3-4, the center of the low-grade core of the ore body has NNP values above 25 tons/1000 tons. The current pit walls are generally net acid-neutralizing below about 5200 feet amsl, are net acid-generating between 5200 and 6600 feet amsl, and are net acid-neutralizing again above about 6600 feet amsl (Figure 3-5a). The rock exposed in the lower 400 feet of the pit has average NPR values of two or higher (Figure 3-5b). As mining continues, more and more of the net neutralizing core will be exposed in the bottom of the pit. Figures 3-6a and 3-6b are vertical profiles of NNP and NPR for an ultimate pit that extends to a depth of 4240 feet amsl. The profiles are based on approximately 250 borehole intercepts with the estimated ultimate pit surface. The exact depth and geometry of the planned ultimate pit changes on a regular basis in response to new analytical data, changing copper prices and technological advances, but the 4240 ft amsl depth represents one of the deeper pit versions currently being considered. Based upon data from the current and 4240 ft ultimate pits, at closure almost all of the rock exposed in the lower 700 feet of the pit will likely be net neutralizing. The lower 200 feet will have average NNP values of greater than 20 tons/1000 tons and NPR values of greater than two. A more detailed description of the acid/base accounting geochemistry of the ore body is presented in the paper "Environmental Geochemistry of the Bingham Canyon Porphyry Copper Deposit, Utah" (Borden, 2003). This paper is attached in Appendix D.

The pit is surrounded by several small waste rock disposal areas (Figure 2-1). Some upper pit benches were mined through these old waste rock deposits as the pit expanded. This waste rock is generally net acid generating.

Surface and ground water inflows into the pit currently average about 1000 gallons per minute (gpm). Dewatering of the pit, combined with pumping from underground workings surrounding the pit, has created a large cone of depression in the groundwater table and caused radial flow towards the pit from all surrounding areas. These waters are currently pumped out of the pit and enter the process water circuit. Without pumping, water levels in the pit would recover to some elevation significantly higher than 5212 feet amsl. This was the maximum surface elevation of the lake that formed in the pit after only three years of filling and with intermittent pumping during the shutdown in the mid 1980s.

Table 3-1 Neutralization Potential of Various Rock Types Exposed Within the Bingham Pit

Lithology	Number of Samples	Average Sobek NP (1)	Average Carbonate NP (2)	Maximum Sobek NP	Maximum Carbonate NP	Minimum Sobek NP	Minimum Cabonate NP
Limestone	13	163	144	517	363	13	12
Parnell Beds	13	50	42	177	173	0	0
Quartzites	39	11	9	70	63	0	0
Monzonite	33	27	13	76	66	6	0
Other Intrusives (3)	18	11	3	31	13	0	0

(1) The Sobek neutralization potential (NP) is a measure of the neutralizing potential contributed by all minerals in the rock. It is reported in terms of tons $CaCO_3$/1000 tons.

(2) The carbonate neutralization potential (NP) is a measure of the neutralizing potential contributed by calcium carbonate in the rock. It is reported in terms of tons $CaCO_3$/1000 tons.

(3) This includes late stage intrusives that were emplaced after the monzonite and includes quartz monzonite porphyry, latite porphyry and quartz latite porphyry. The Bingham Stock is predominantly composed of Monzonite.

Figure 3-5a Average NNP versus Current Pit Elevation

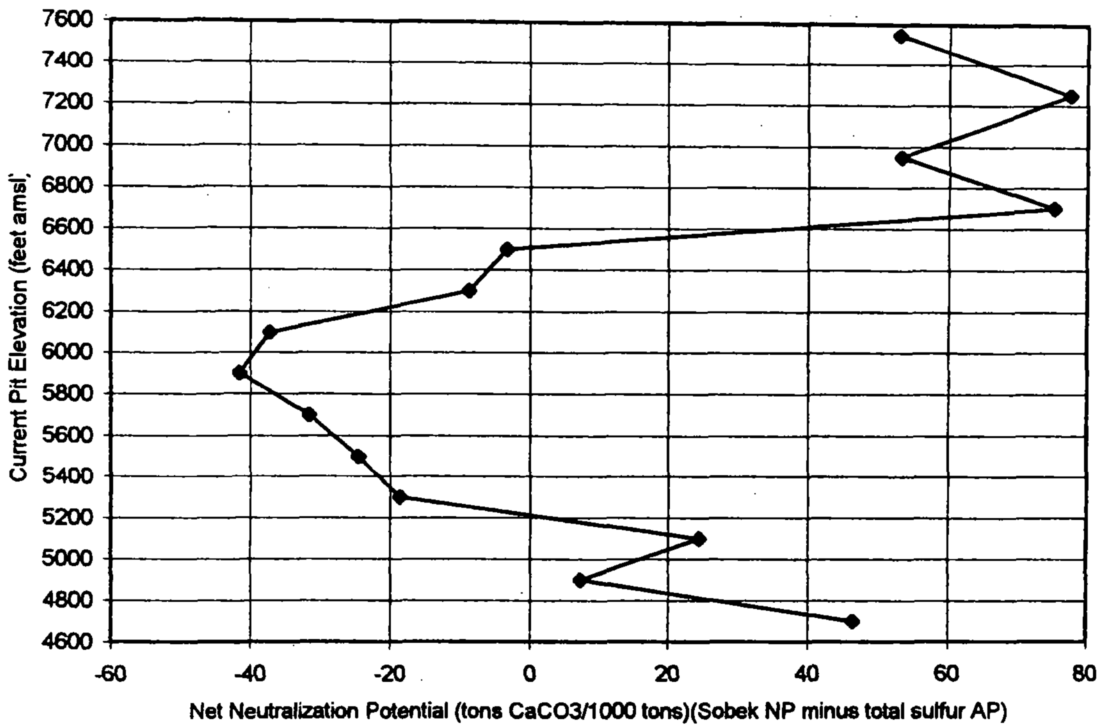


Figure 3-5b Average NPR versus Current Pit Elevation

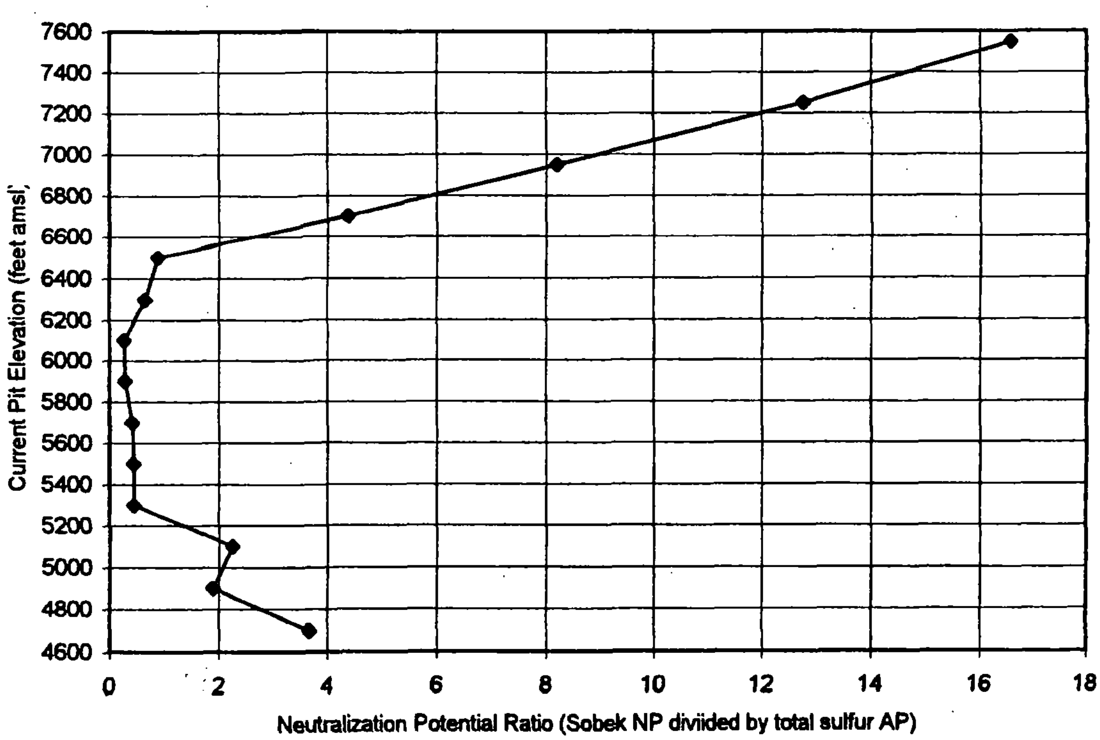


Figure 3-6a NNP versus Elevation for Ultimate Pit with Bottom Elevation at 4240 ft AMSL

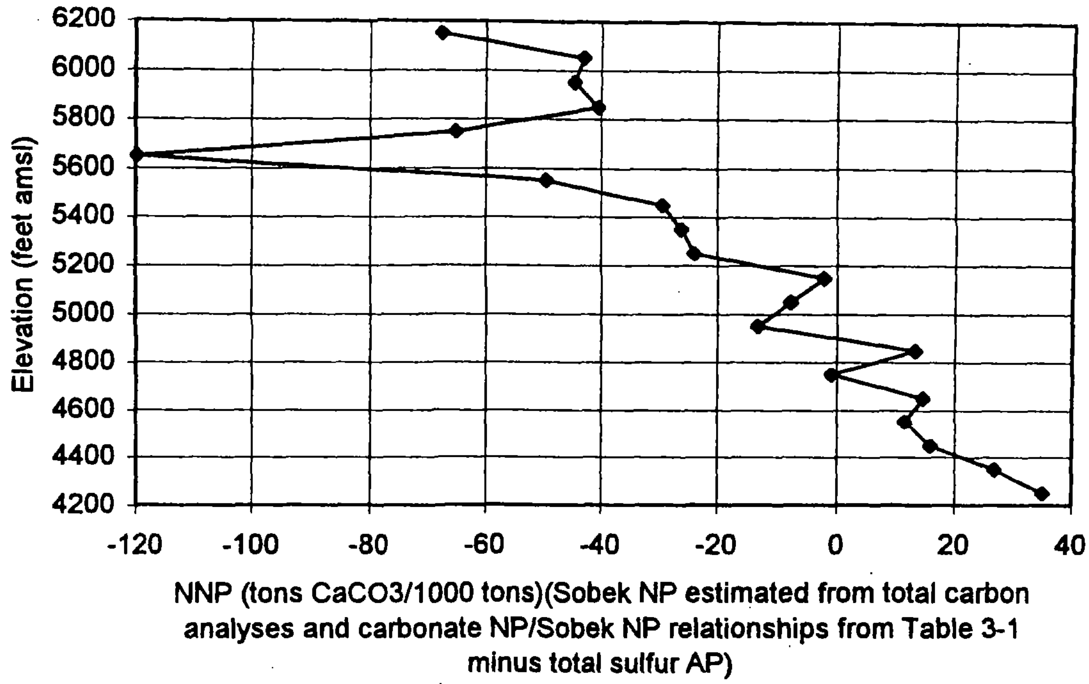
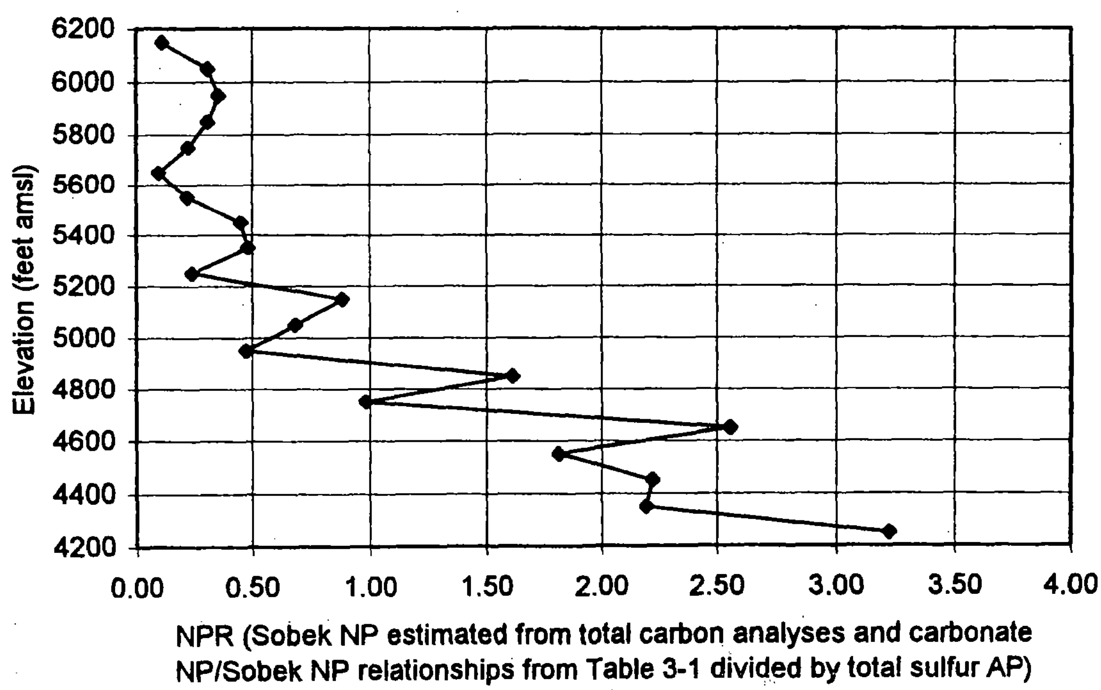


Figure 3-6b NPR versus Elevation for Ultimate Pit with Bottom Elevation at 4240 ft AMSL



The pit is almost entirely surrounded by bedrock ridges and mountains that vary between 6800 and 9200 feet amsl. The lowest point on the pit walls is at the intersection with upper Bingham Canyon, here the bedrock elevation is 5900 ft amsl. As shown on Figure 3-7, the bedrock water table surrounding the open pit tends to mimic the topography. In 2001, the dry bottom of the pit was at approximately 4600 feet amsl and water was being pumped from underground workings on the west and northeast sides of the pit. Despite this peripheral dewatering, the down-gradient water table beneath Bingham Canyon and the 6800 to 7400 ft high ridge to the east of the pit was everywhere above 5449 ft amsl. In 2001, there was thus at least 800 feet of head driving water flow towards the pit from the down-gradient (east) side of the pit. This probably underestimates the actual gradient towards the pit because few of the monitoring points are located beneath the ridge crest, where water levels are likely highest. In 1998, immediately before pumping of the North Ore Shoot began, the bottom of the pit was at 4750 ft amsl and the water level in the North Ore Shoot was at 5647 ft amsl. The North Ore Shoot is located at the upper end of Bingham Canyon, about 5500 feet north-northeast from the bottom of the pit. In 1998, the head difference here was thus 900 feet and the gradient was 160 ft/1000 ft towards the bottom of the pit.

At closure, if other pumping on the perimeter of the pit is discontinued, the estimated annual average inflow could be as much as 2500 gpm. Water quality from different areas on the pit walls is variable depending on the characteristics of the bedrock with which the water has come into contact, and its residence time on the surface or within the surrounding rock mass.

Figure 3-8 is a conceptual model of water movement and water quality in and adjacent to the pit. The primary assumption made to create the conceptual model is that water will be pumped from the pit after closure to limit the elevation of pooled water in the bottom of the pit. If the pit is allowed to partially flood, the lake surface will be maintained at a low enough level to ensure radial groundwater flow into the pit and to minimize contact with the net acid-generating portions of the ore body and pyrite halo. The most significant chemical and physical controls on pit water chemistry are labeled with letters and the most significant flow paths and chemical interactions are labeled with numbers.

Physical and Chemical Controls

A) The low-grade core of the ore body exposed in the bottom of the pit contains few acid generating sulfide minerals and is generally net neutralizing.

B) The main copper-bearing zone of the ore body and the surrounding pyrite halo contain abundant pyrite and chalcopyrite and are generally composed of net acid-generating rock. For convenience in the following discussions this entire rock mass is described as the pyrite halo.

C) Bedrock exposed on the uppermost benches of the pit and surrounding the pyrite halo in the subsurface contains few acid generating sulfide minerals and is generally net neutralizing.

D) Historic waste rock disposal areas fill most of the tributary drainages that discharge into the open pit. This waste rock contains abundant acid-generating sulfide minerals and is typically net

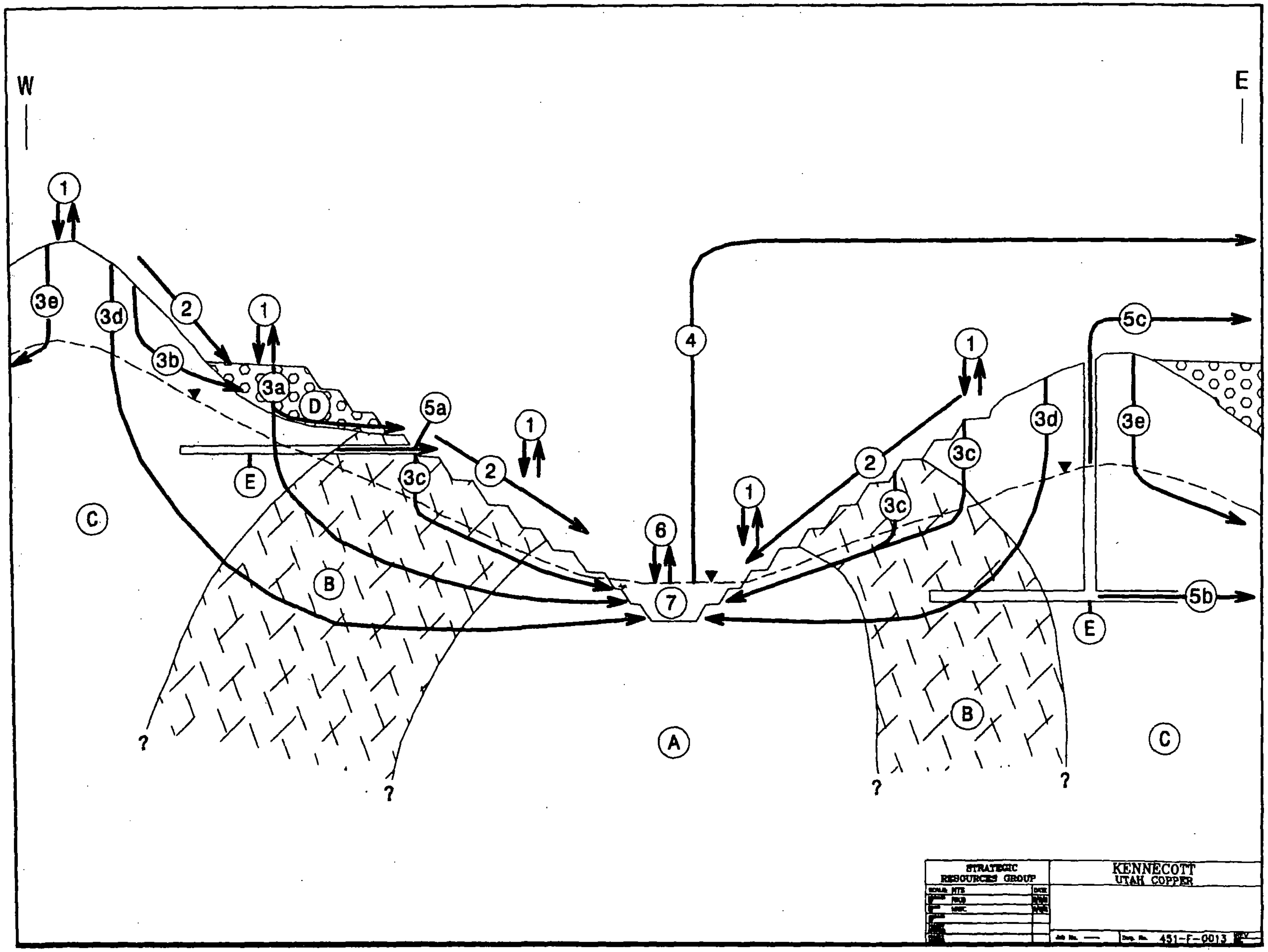


Figure 3-8 Conceptual Model of Water Movement In and Around the Bingham Pit

acid generating. The waste rock not only contains abundant pyrite, but it has been rubblized so the release of sulfide oxidation products is much more rapid than for undisturbed bedrock.

E) Numerous underground workings surround the open pit and some intersect the pit surface. These workings provide flow conduits for groundwater and if dewatered allow the access of oxygen into the deep bedrock, accelerating sulfide oxidation reactions. Most of these underground workings were used for mining lead-silver deposits surrounding the copper ore body, and are located outside of the pyrite halo (see Figure 3-7 for a map of underground workings above the regional water table in 2001).

Flow Paths and Chemical Interactions

1) Precipitation falls everywhere within the drainage basin created by the open pit. This includes undisturbed mountain slopes surrounding the pit, waste rock disposal areas surrounding the pit, pit walls above the pyrite halo, pit walls within the pyrite halo and pit walls below the pyrite halo. Precipitation water is removed from the ground surface via evapotranspiration thereby reducing the amount of water that is available to infiltrate or run off. Evapotranspiration is most efficient on well-vegetated surfaces.

2) Water that does not infiltrate or evaporate immediately will flow towards the bottom of the pit as runoff. Runoff is greatest on sloped and compacted or otherwise impermeable surfaces. This water will either flow all the way to the pit bottom as runoff, infiltrate at a location down gradient from where it originally fell or be removed by evapotranspiration at a down gradient location. Runoff from undisturbed mountain slopes surrounding the open pit generally flows onto waste rock surfaces where it infiltrates, contributing to the flow described in 3a. Runoff water that reaches the bottom of the pit by flowing over the pyrite halo will transport some dissolved and suspended contaminants to the pit floor. However, because the contact time is relatively short this water will generally contain fewer dissolved constituents than water that has percolated through waste rock or through unsaturated portions of the pyrite halo.

3) Precipitation that is not removed by evapotranspiration or runoff to the pit floor will infiltrate. There are five general paths by which this water may migrate in the subsurface:

3a) Water that infiltrates into the net acid generating waste rock disposal areas will generally become the poorest quality ARD that drains into the pit. This water will either perch at the bedrock/waste rock contact and discharge onto the upper surface of the pit, or it will pass through the bedrock/waste rock contact and will discharge onto a lower pit surface.

3b) Some of the water that infiltrates into the undisturbed mountainsides surrounding the pit may flow in the shallow subsurface (colluvial and shallow bedrock flow) and discharge into waste rock that covers buried seeps and springs, thereby contributing to the flows described in 3a. This is generally the best quality groundwater surrounding the open pit, but after contacting the waste rock it degrades into the poorest quality ARD reporting to the pit.

3c) Some of the water that infiltrates in the pit drainage basin will pass through the net acid-generating pyrite halo in the vadose zone before it reaches the water table. This water will generally become poor quality ARD because it is in contact with the oxygenated portion of the pyrite halo. Once this water reaches the water table, it will flow laterally and discharge into the bottom of the pit.

3d) Some of the water that infiltrates in the pit drainage basin will pass through net neutralizing bedrock in the vadose zone before it reaches the water table. This water will then flow laterally below the water table and will ultimately discharge into the bottom of the pit. Neutralization reactions may take place below the water table if the water contacts reactive neutralizing minerals, but sulfide oxidation reactions will be inhibited by a lack of oxygen. The quality of this water will remain relatively good because it only contacts the reduced portion of the pyrite halo below the water table.

3e) Water that infiltrates into the bedrock surrounding the pit that is beyond the zone of groundwater capture for the pit will not discharge to the pit floor. The quality of this ground water will be relatively good because it typically will not contact the pyrite halo. The lower the water level that is maintained in the pit, the further from the center of the pit the zone of capture will extend.

4) Water that discharges into the pit will be pumped out. The rate of pumping will be highest for a nearly dry pit and will decrease as the height to which the pit is allowed to flood increases. The lower the water level that is maintained in the pit, the greater the thickness of the pyrite halo that will be exposed above the water table in the bedrock surrounding the pit.

5) Water flows in many of the underground workings surrounding the pit. The majority of underground workings are located outside of the pyrite halo, but some are within the pyrite halo. Water in unflooded workings within the pyrite halo may become poor quality ARD similar to flows described in 3c. Water quality in flooded workings within the pyrite halo may be intermediate in quality between 3c and 3d, and water in workings outside the pyrite halo may be similar to that described in 3e.

5a) Some underground workings drain groundwater into the open pit. If not captured, this water contributes to infiltration and runoff within the pit (flows 2, 3c and 3d). This water may be similar in quality to the flows described in 3c or 3d.

5b) Some underground workings gravity drain groundwater away from the open pit. This water discharges at tunnel portals in Butterfield Canyon and along the east and west side of the Oquirrh Mountains. This water may be similar in quality to flows described in 3d or 3e.

5c) Some underground workings are currently dewatered by pumping and could continue to be dewatered after closure. If not captured, much of this water would contribute to flow 3c or 3d and would need to be removed from the pit (flow 4).

6) If a pit lake is allowed to form in the bottom of the pit, water will be added directly to the lake by precipitation. Water will be removed from the lake by evaporation from the water surface. In this geographical area, evaporation exceeds precipitation on an average annual basis, so this will ultimately reduce the amount of water that must be removed from the pit, but will also increase the concentration of dissolved constituents in the pit lake. The surface area of any lake that is allowed to form in the pit increases with increasing water depth, so the evaporative losses are likely to increase with an increasing depth of flooding.

7) If a pit lake is allowed to form, sulfide oxidation reactions will be inhibited by the lack of oxygen in the surrounding wall rock that is fully and permanently saturated, but neutralization reactions between the lake water and the small percentage of carbonate minerals in the wall rock will continue. Wall rock interactions, water mixing, the potential addition of neutralizing agents and biological activity may cause the precipitation and settling of some metals and other dissolved constituents. These chemical sediments will accumulate on the pit floor along with detrital sediments. Older sediments will become isolated from significant pit water contact by overlying younger sediments, but under certain circumstances, materials may also be redissolved from the upper portion of the sediment column.

The chemistry of water that collects in and is removed from the bottom of the pit will be determined by a complex interaction of each of the flow paths and chemical reactions described above. However, the long-term average water quality in the pit may be roughly similar to water that is currently removed from the pit floor or that collected in the pit during the shutdown of the mid-1980s. A small number of the samples collected from pit dewatering flows in 2000 through 2002 had the following average characteristics: pH – 6.9, alkalinity – 100 mg/L, total dissolved solids (TDS) – 2600 mg/L, sulfate – 1700 mg/L, copper – 2 mg/L, manganese – 0.9 mg/L and zinc – 0.8 mg/L. Iron, aluminum and nickel averaged less than 0.1 mg/L, and arsenic, cadmium, chromium, selenium and silver all averaged less than 0.01 mg/L. A limited amount of data is also available from a lake that formed in the bottom of the pit during the shutdown in the mid 1980s. The pit floor during the shutdown was at an elevation of 5168 feet and so was likely at the base of the net acid-generating portion of the ore body and pyrite halo. The pit lake existed for three years and reached a maximum depth of about 50 feet. The lake was pumped periodically throughout the period and never contained more than about 650 acre-feet of water. Typical values for this pit water were: pH - 6.0, total dissolved solids (TDS) - 2500 mg/L, sulfate - 1500 mg/L, copper - 10 mg/L and cadmium - 30 ug/L. Water that will be removed from the pit may not meet water quality standards acceptable for irrigation, drinking water or discharge to surface water without treatment. At closure, when this water is no longer used in the process water circuit, it may have to undergo some form of treatment for pH, TDS, sulfate, copper and trace metals before it can be released from the property (Section 10.0).

3.1 CLOSURE ISSUES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the mine area at closure:

- pit sides will be stabilized at a slope of 30 to 50 degrees from horizontal
- it is unlikely that the pit will be revegetated because most of the exposed surface will be solid rock containing natural sulfide mineralization
- surface facilities including buildings, railroad tracks, power lines and poles and equipment will be removed.

The primary closure issues at the pit are driven by the need to ensure long-term groundwater and surface water quality protection. The most significant water management issues are:

- ensuring that contaminated water does not escape from the pit into the surrounding groundwater system
- managing water movements in and around the pit to minimize water quality degradation
- ensuring that any surface water discharges from the pit meet applicable water quality criteria
- minimizing the impacts of pit dewatering on surrounding aquifer recharge and water levels
- minimizing ecological risks posed by water that may accumulate in the pit.

The mine has also been placed on the National Historic Register. This may require that public access be permanently maintained to some point within or adjacent to the pit. However, safety considerations around steep and potentially unstable areas on the pit walls will require the public be excluded from most of the mine area.

3.2 POSSIBLE POST-CLOSURE LAND USE

Based upon the requirement for long-term water management in and around the mine, and the public safety issues associated with steep and potentially unstable areas on the pit walls, post-mining land uses will, by necessity, be limited.

Whatever final closure scenario is ultimately selected, the entire open pit will have to be a water management facility with limited public access. Parts of the pit where vegetation can become established will also become wildlife habitat, and selected areas of the pit may be established as public access points to the National Historic Site.

3.3 DATA REQUIREMENTS

In order to select a final closure scenario the following data requirements will have to be addressed:

- final geometry of the ultimate pit
- acid/base accounting geochemistry of ultimate pit walls
- hydrogeology of the post-closure pit
- geochemistry of water extracted from a largely dry pit or a partially flooded pit, in particular how lake and outflow water chemistry would vary with pit flooding level

Unfortunately, many of these data requirements cannot be addressed until the mine is nearing the end of its life and the geometry and geochemical characteristics of the ultimate pit can be predicted with more certainty.

3.4 RECLAMATION ACTIVITIES

Tentative reclamation activities have been selected based upon the existing incomplete data set and on the assumption that the current mine plan adequately predicts the ultimate geometry of the pit. These tentative plans will be refined as the data gaps identified in Section 3.3 are filled.

All surface facilities including buildings, railroad tracks, most power lines and equipment will be removed from the mine area at closure except for those with a confirmed post-mining use. Demolition of these facilities will be conducted as described in Section 2.3 and reclamation of the underlying footprints will vary depending on the geochemistry of the underlying bedrock (See Sections 3.4.1 through 3.4.4 for details). The only facilities that may be left in place are those related to long-term water management or directly related to public access to the National Historic Site. These facilities may include water pipes, tanks, pump houses, some repair shops, offices, access roads, some power lines and the Visitors Center. Public access to most of the pit will be limited with a combination of engineering and institutional controls. Shaft, adit and tunnel portals within the pit area will be sealed or gated. Roads will be blocked off, and fences and signs will be erected.

Water levels in the pit will be maintained below 4900 feet amsl. Depending upon the final geometry of the ultimate pit floor, water will either be present in 1) a collection pool at the very bottom of the pit, 2) a series of collection pools at various elevations between the bottom of the pit and 4900 feet amsl, or 3) a single lake in the bottom of the pit with a surface elevation of less than 4900 feet amsl. This elevation insures that pooled water is below the pyrite halo on the pit walls. As discussed earlier in this section and as illustrated on Figure 3-7, even at the maximum filling elevation of 4900 feet, there would be more than 500 feet of head driving water flow towards the pit from all sides, insuring that radial flow into the pit is maintained. In reality this value likely underestimates the gradient driving radial flow towards the pit, because water levels will also recover in the down-gradient bedrock if the pit were allowed to partially fill, increasing the calculated head difference. The 4900 ft elevation is also more than 1000 feet below the bedrock and topographic low where Bingham Canyon intersects the pit, about 2000 feet below the bedrock ridge line that separates the pit from Jordan Valley to the east, and about 4000 feet below the bedrock ridge line that separates the pit from Tooele Valley to the west.

If a pit lake is allowed to form, lime or another neutralizing agent will be added if required, in order to maintain a circumneutral pH and minimize metals solubility during flooding. If neutralizing agents are used, they will be added in a manner that assures appropriate mixing. Other options that will also be considered to maximize pit water quality will be the addition of organic matter and the active promotion of biological activity (Castro and Moore, 2000). To maintain water levels below 4900 feet amsl, water will have to be removed from the pit in perpetuity. Water will be pumped from the collection pond(s) or lake surface to the 5490 tunnel and then will be piped to lower Bingham Canyon. If the Elton Tunnel is ever rehabilitated and connected to the open pit, it could also potentially be used to transmit water out of the pit. In order to reduce pit inflows, some water may also be removed in perpetuity from underground workings that surround the pit. This water has a circumneutral pH, but a water treatment facility may be required to treat these outflows to acceptable levels for discharge or sale (Section 10.0).

In order to minimize water quality degradation in and around the pit, and to improve the quality of water that collects in the bottom of the pit, the following activities will also be completed prior to or at closure. These activities are generally designed to minimize water contact with the waste rock disposal areas surrounding the pit and with the pyrite halo in the vadose zone.

3.4.1 Adjacent Waste Rock Disposal Areas

In order to limit infiltration into waste rock surfaces surrounding the open pit (flow 3a on Figure 3-8), most waste rock surfaces will be recontoured to reduce pooling and selected surfaces will also be revegetated to maximize evapotranspiration (Section 4.0). In order to minimize flows from the surrounding unimpacted mountainsides to the waste rock disposal areas (flows 2 and 3b on Figure 3-8), water collection systems will be placed up gradient in drainages that have significant surface or shallow groundwater flow (Section 10.0). These collection systems may include surface impoundments, horizontal drains, collection sumps and shallow groundwater extraction wells. These flows are likely of drinking water quality and will be piped out of the mine area for use or sale.

3.4.2 Pit Benches above the Pyrite Halo

In order to minimize infiltration and runoff (flows 2, 3c and 3d on Figure 3-8), vegetation establishment will be encouraged on pit benches that are above the pyrite halo. These are generally areas that have an NNP that is greater than zero on Figure 3-4 (typically above 6600 feet amsl). Most pit benches are not safely accessible, but benches that are safely accessible with a dozer will be ripped. This will generally limit the ripping to haul and support roads that do not have a post-closure use. Ripped areas will be seeded and seed will also be broadcast onto pit benches that do not have a nearby seed source. Where practicable, surface flows that occur above the pyrite halo from seeps, springs, horizontal drains, tunnel and adit portals and runoff will be captured on the upper benches of the pit and either piped out of the pit or piped to the bottom of the pit so that the water does not contact the pyrite halo (Section 10.0).

3.4.3 Pit Benches within the Pyrite Halo

No revegetation efforts are possible within the pyrite halo because the soils forming on roads and benches will generally be acidic and have high salinity. These are generally areas that have an NNP that is less than zero on Figure 3-4 (typically between 5200 and 6600 feet amsl). In order to minimize infiltration (flow 3c on Figure 3-8) runoff will be encouraged. All roads will be left in a compacted condition. Where practicable, surface flows that occur within the pyrite halo from seeps, springs, horizontal drains, tunnel and adit portals and runoff will be captured and either piped out of the pit or piped to the bottom of the pit so that the water does not infiltrate through the pyrite halo (Section 10.0).

3.4.4 Pit Benches Below the Pyrite Halo

Depending upon the final closure scenario that is selected, much of this area may be flooded. However, in order to minimize infiltration and runoff, vegetation establishment will be encouraged on selected pit benches that are below the pyrite halo. These are generally areas that have an NNP that is greater than zero on Figure 3-4 (typically below 5200 feet amsl). Most pit benches are not safely accessible, so no reclamation work will be completed on the benches. However, seed will be broadcast onto pit benches that do not have a nearby seed source. Road surfaces that are not needed after closure will be also be ripped and broadcast seeded

4.0 MINE WASTE DISPOSAL AREA

The mine waste rock disposal area currently covers about 5100 unreclaimed acres and contains approximately 4 billion tons of material. An additional 410 acres at the foot of the Eastside disposal areas have already been reclaimed. About 250 acres surrounding the disposal areas are being used to manage leach water drain-down and meteoric water flows (ARD) that have contacted the waste rock. A list of the support facilities associated with the disposal areas and water management systems is provided in Table 2-1. The large angle-of-repose (35 to 37 degrees) slopes on the eastern margins of the waste disposal areas are the most prominent visual features from the Salt Lake Valley, but they actually cover less than 15 percent of the total disturbed area. The highest inactive slope is 1200 feet high, but currently no active slopes are higher than 500 feet. Most of the disposal area is composed of flat to slightly irregular waste rock surfaces and angle of repose slopes that are less than 150 feet tall.

Future mine plans call for the placement of nearly one billion additional tons of waste rock before mine closure. The majority of this material will be placed in Bingham Canyon or in lifts on top of existing disposal areas. In some areas waste rock will have to be placed on previously unimpacted ground, so the total area impacted by disposal activities may increase by approximately 200 acres before closure. The additional disturbed acreage will be within the boundaries of DOGM permit number M/035/002 and will not exceed the 8000 acre area allocated for waste rock disposal in the 1978 Mining and Reclamation Plan. The impacted acreage could also increase during reclamation activities when angle of repose slopes are reduced, thereby increasing the waste rock footprint in some areas.

Mine waste is composed of a mixture of intrusive rocks, quartzite, limestone and limestone skarn. Except for copper, average total metals concentrations are relatively low, as illustrated from a 66-sample average for the following elements: arsenic 31 mg/kg, barium 70 mg/kg, cadmium 2.0 mg/kg, chromium 55 mg/kg, copper 809 mg/kg, lead 380 mg/kg, selenium 2.6 mg/kg and zinc 311 mg/kg. The average sulfide concentration, predominantly pyrite, in unweathered waste rock from the pit is about three percent, but sulfides are generally less abundant in waste rock exposed on the surface of the disposal areas. The pyrite begins to oxidize immediately after the waste rock is placed, causing a decline in sulfide abundance and a release of sulfate, iron and acidity. Soils forming on the waste rock surface have paste pH values between 2 and 8; and paste conductivities, a measure of soil salinity, of between 20 and 9000 umhos/cm. Figure 4-1 is a map of the waste rock disposal areas showing the distribution of soil pH and salinity characteristics. The primary controls on soil pH are the percentage of sulfides in the waste rock, the percentage of limestone in the waste rock and the age of the waste rock surface on which the soil is forming. The primary controls on soil conductivity are the percentage of sulfides in the rock and the age of the waste rock surface. In general, the older the waste rock surface, the lower the pH, the lower the conductivity, and the fewer sulfide minerals that are present. On the oldest surfaces with little intact pyrite, flushing of the soil by precipitation will eventually create a soil with a pH above 5 and low salinity. The geochemistry of the waste rock soils is described in detail in the paper "Geochemical evolution of sulphide-bearing waste rock soils at the Bingham Canyon Mine, Utah (Borden 2001). This paper is attached in Appendix E.

Volunteer vegetation is becoming established on almost all dump surfaces that have favorable soil chemistry. Botanical surveys were conducted on the waste rock disposal areas in 1999, 2001 and 2002. One hundred sites with various soil pH and salinity conditions were visited during these surveys and species counts and estimates of total vegetation cover were made at each site. Waste rock surfaces where any historic reclamation activities had occurred were excluded from the survey. The percent gravel (percent not passing a 2 mm sieve) and the compaction (blows with a four pound hammer to drive a one half inch diameter rebar eight inches) at most of the sites were also measured. As shown on Figures 4-2 through 4-5, vegetation has become established on most sites with soil pH above 4.0 and with conductivity below 1000 umhos/cm. Below a pH of 6, nitrogen and phosphorus availability begins to decline in most soils, and below a pH of 5 the toxicity of soluble aluminum and manganese also becomes significant in most soils and will inhibit plant growth (Tucker et al. 1987). Volunteer vegetation density and diversity is highest on surfaces that have a soil pH above 5 and a conductivity of less than 500 umhos/cm. The volunteer vegetation cover for the 31 survey sites with a pH above 5 and conductivity below 500 umhos/cm varied between 0% and 98% and averages 29%. The number of species observed at the sites varies between 0 and 26 and averages 12. Waste rock surfaces that had favorable soil chemistry but which do not support abundant vegetation generally have clear physical barriers to plant establishment. These physical barriers include strongly compacted surfaces, steep slopes with surface creep or lack of fine-grained material on the waste rock surface. Correlation coefficients and the square of the correlation coefficients (R^2 values) were calculated to illustrate the relationship between each of these variables and vegetation cover and species occurrence. A positive correlation coefficient indicates that the two variables are positively related (an increase in one leads to an increase in the other). A negative correlation indicates that the two variables are inversely related. Both the correlation coefficient and the R^2 value vary between 0 and 1. A value of 0 indicates that there is no relationship between the variables and a value of 1 indicates that there is a perfect correlation. The R^2 value can be interpreted as the proportion of the variance in one variable that is attributable to the variance in the other variable. For flat surfaces with favorable chemistry, the correlation coefficient between vegetation cover and the degree of compaction is –0.40 (r^2=0.16) and between diversity and compaction it is –0.41 (r^2=0.17). Generally, end dumped or deeply ripped surfaces do not exhibit any negative impacts due to compaction. For relatively low compaction surfaces with favorable chemistry, the correlation coefficient between cover and slope angle is -0.35 (r^2=0.12), and between diversity and slope angle is -0.43 (r^2=0.18). On average, angle of repose slopes have about 2/3 as much cover as comparable flat surfaces. There is no significant correlation between vegetation cover, diversity and the percent gravel comprising the waste rock surface (r^2=<0.01 and r^2=0.04 respectively) but at gravel concentrations above about 90%, most surfaces support little or no vegetation.

For the nine waste rock survey sites that had no significant physical or chemical barriers (flat, ended dumped or ripped surfaces with gravel <90%, pH > 5 and conductivity < 500 umhos/cm), the percent vegetation cover varied from 20% to 98% and averaged 47% with a 95% confidence interval of 16%. The number of species observed at each site varied between 9 and 22 and averaged 15 with a 95% confidence interval of 3. These surfaces vary between 15 and 40 years old and average 25 years old.

Figure 4-2 Percent Vegetation Cover versus Soil Paste pH (excluding samples with conductivity >500 umhos/cm)

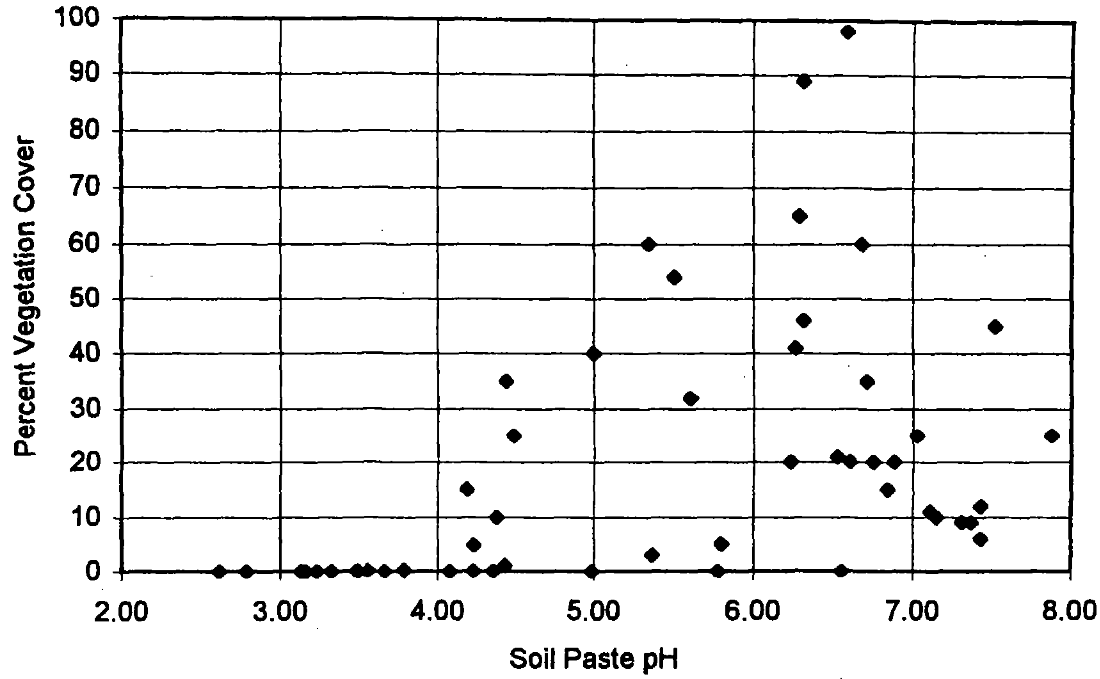


Figure 4-3 Number of Species Identified versus Soil Paste pH (excluding samples with conductivity >500 umhos/cm)

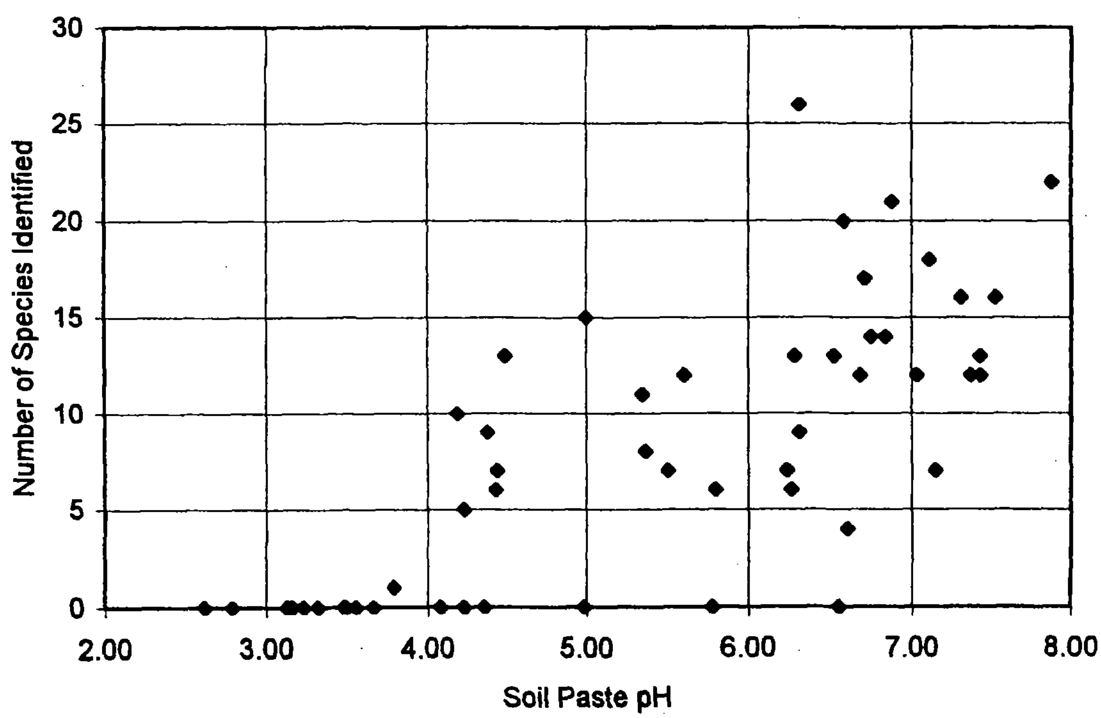


Table 4-1 Most Common Species Volunteering on the Bingham Canyon Mine Waste Rock Disposal Areas

Common Name (1)	Scientific Name	% of Vegetated Sites Where Observed	% of Vegetated Sites Where Dominant (2)
Grasses			
Kentucky Bluegrass	Poa pratensis	32%	0%
Bluebunch Wheatgrass	Agropyron spicatum	29%	0%
Bottlebrush Squirreltail	Sitaniion hystrix	26%	0%
Sedge Species	Carex Species	19%	0%
Fescue Species (3)	Festuca species	16%	10%
Forbs			
Lanceleaf Phacelia	Phacelia hastata	68%	6%
Milfoil Yarrow	Achillea millifolium	65%	3%
Douglas' Dusty-maiden	Chaenactis douglasii	61%	0%
Wasatch Penstemon	Penstemon cyananthus	52%	6%
Sulfur Buckwheat	Eriogonum umbellatum	39%	13%
Penstemon Species (4)	Penstemon species	39%	0%
Beautiful Blazingstar	Mentzelia laevicaulis	29%	3%
Rydbergs Sweetpea	Lathyrus brachycalyx	23%	3%
Hoary Aster	Machaeranthera canescens	23%	3%
Scarlet Gilia	Gilia aggregata	23%	0%
Lupine Species	Lupinus species	13%	10%
Trees and Shrubs			
Rubber Rabbitbrush	Chrysothamnus nauseosus	45%	32%
Big Sagebrush	Artemisia tridentata	35%	3%
Douglas Fir	Pseudotsuga menziesii	32%	10%
Curl Leaf Mountain Mahogany	Cercocarpus ledifolius	26%	16%
Bigtooth Maple	Acer grandidentatum	19%	3%
Quaking Aspen	Populus tremuloides	16%	0%
Rocky Mountain Maple	Acer glabrum	13%	3%
Deer-brush	Ceanothus velutinus	10%	6%
Mountain Snowberry	Symphoricarpos oreophilus	6%	6%
Black Sagebrush	Artemisia nova	6%	3%
Noxious Weeds (5)			
Dalmation Toadflax	Linaria dalmatica	68%	13%
Thistle Species (6)	Cirsuim species	42%	3%
Cheatgrass	Bromus tectorum	39%	0%
Woolly Mullein	Verbascum thapsus	35%	0%

(1) This table is compiled from 31 sample sites on the Bingham waste rock dumps with soil paste pH > 5 and paste conductivity < 500 umhos/cm. Species are only listed if they occurred at 15% or more of the sites or if they were the dominant species at one or more sites. The 31 site population includes three sites with no vegetation because of extremely unfavorable physical characteristics. NOTE: All of these sites are located above 6500 feet in elevation.

(2) At each site between 0 and 4 species were identified as being the dominant species at the site based upon a comparison of percent cover contributed by each species.

(3) Includes Sheep Fescue (Festuca ovina).

(4) Penstemon species other than Wasatch Penstemon.

(5) These species are listed on the official State Noxious Weed lists for Utah or surrounding States (NV, ID, WY, CO, NM and AZ)

(6) Includes Canada Thistle (Cirsium arvense)

Waste rock contact flows are currently routed to the concentrator process water circuit. During peak runoff periods, excess water is temporarily stored in the Large Bingham Reservoir. Anticipated post-closure flows associated with the waste rock disposal areas are discussed in Section 10.0.

Erosional events and failures have occurred on various waste rock slopes in the past. Since the termination of active dumping on the high slopes facing the Salt Lake Valley in 1984 the frequency and magnitude of slope failures have decreased significantly. However, several shallow surface slumps and debris flows have occurred in the past decade. Precipitation greater than the 25-year, 24-hour storm event (the minimum system requirements specified by the storm water regulations) that falls on the slopes has also exceed the capacity of some down gradient storm water and sediment collection systems in tributary drainages to Butterfield Creek. North of the Butterfield Creek tributary drainages, the Eastside Collection System was designed to handle leach water base flows plus the 10-year, 24-hour storm event. With the termination of leach water applications, base flows in this area have declined from greater than 25,000 gpm to less than 1000 gpm, so the collection system is likely able to handle flows that are greatly in excess of the 25-year, 24 hour storm event. Erosional events may also fill the sedimentation basins of the water collection systems with sediment, increasing the frequency and cost of maintenance. In the past decade these events have most commonly occurred on the waste rock disposal areas above Butterfield Creek on the southeast side of the pit. In only two cases has contaminated sediment or water escaped the property since the ECS was upgraded between 1993 and 1996. Both events occurred in tributary drainages to Butterfield Creek and corrective actions were taken to minimize the risk of future releases in these areas.

4.1 CLOSURE ISSUES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the mine waste disposal area at closure:

- all dumps will be left in a safe and stable condition
- collection systems will be provided to contain natural seepage in the area
- dikes and ponds will be constructed on the upper levels of the dumps to prevent slope wash and possible mud slides
- no major revegetation is planned because the majority of the waste material contains natural sulfide mineralization
- if and when revegetation practices or methods are developed which would make vegetation economically practicable, such practices and methods will be employed on the dumps

- when no longer needed in mining, mineral extraction or subsequent operations, surface facilities including buildings, above ground utilities, railroads, piping and equipment will be removed.

Current permits and regulations require KUCC to control contact water flows from the waste rock disposal areas in order to protect surface and groundwater quality. The goal of these regulations is to prevent any unpermitted discharge of contaminated water or sediment from the property. Groundwater Discharge Permit number UGW350010 also requires that KUCC take steps to minimize the infiltration of meteoric water into the waste rock. After closure, KUCC will continue to maintain the existing groundwater and surface water collection systems at the foot of the disposal areas to comply with all applicable requirements. In order to ensure compliance after closure in the most cost effective manner, the following goals must be considered during closure planning:

- ensure that catastrophic events cannot compromise the water collection systems and transport contaminated water and sediment off KUCC property

- reduce long-term ARD generation from the disposal areas to minimize the risk of down gradient groundwater contamination and long-term water handling and treatment costs

- minimize the loading of sediment and debris from the disposal areas to reduce long-term maintenance costs for the water collection systems.

4.2 POSSIBLE POST-CLOSURE LAND USE

Based upon the requirement for long-term water management on and around the waste rock disposal areas, the acidic nature of the waste rock, and the public safety issues associated with steep slopes, post-mining land uses in these areas will, by necessity, be limited.

Whatever final closure scenario is ultimately selected, most of the waste rock disposal areas will likely be operated as a water management facility with limited public access. Those parts of the disposal area that are revegetated will also become wildlife habitat.

4.3 DATA REQUIREMENTS

In order to identify the final reclamation options for each portion of the waste rock disposal area, the following data requirements will have to be filled:

- final geometry of the waste rock disposal areas, in particular the location and soil chemistry characteristics of future waste rock piles

- base ARD flows from various parts of the disposal area

- relative effects of each reclamation technique on infiltration and runoff

Many of these data requirements are being addressed by ongoing reclamation programs on the waste rock disposal areas and by the operation of pilot-scale water treatment facilities. The final geometry and geochemistry of the waste rock surface cannot be determined until waste rock disposal and recontouring has been completed.

4.4 RECLAMATION ACTIVITIES

Tentative reclamation activities have been selected based upon the existing incomplete data set and on the assumption that the current mine plan adequately predicts the final geometry of the waste rock disposal area. Figure 4-6 is a map of the waste rock disposal area showing the reclamation activities that are currently planned. The actual acreage and boundaries of the various reclamation treatments may be modified in response to changes in the mine plan or other new information as it becomes available. Long-term water management plans on and adjacent to the waste rock disposal area are described in Section 10.0.

All surface debris, utilities and facilities without a post-closure use will be removed from the entire waste rock disposal area at closure. Reclamation of these facilities will be as described in Section 2.3. Based upon current assumption of post-mining use, the only facilities that may be left in place within the waste rock disposal area will be those related to long-term water management such as the Large and Small Bingham Reservoirs, cutoff walls, sumps, drains, settling ponds, monitoring wells, utilities, selected roads and associated pipes and lined ditches. Public access will be controlled with a combination of engineering and institutional controls. Roads below the waste rock dumps without a post-mining use will be recontoured, ripped and seeded. These roads will also be blocked off if appropriate, and fences and signs will be erected. Additional reclamation activities planned for selected portions of the waste rock dumps are described in the following sections.

4.4.1 Completed Reclamation Activities

Reclamation work has already been completed on about 410 acres of the waste rock disposal area. The sites that have been reclaimed are located on the northeast portion of the disposal area and in drainages along the eastern edge of the disposal area (Figure 4-6). It should be noted that this acreage estimate only includes areas that were directly impacted by Bingham Canyon Mine waste rock disposal. It does not include several hundred additional acres that have also been reclaimed within the DOGM permit boundaries, but that were impacted by historic leach water contact or by other historic mining operations unrelated to open pit mining at Bingham Canyon. Most of these areas are in drainages located between the foot of the Eastside waste rock disposal area and Highway 111.

Waste rock has been removed from about 80 acres within drainages below the Eastside disposal area (Figure 4-6). Some of this waste rock was transported into the drainages by erosion caused by the historic leaching operations and some was intentionally placed in the drainages to create dams and settling ponds for the historic leach collection system. All of this waste rock was moved back to the foot of the waste rock disposal areas and the drainage surfaces were recontoured, had topsoil applied if needed and were seeded.

About 330 acres on the northeast margin of the Eastside disposal area were recontoured, capped and revegetated. The angle of repose slopes were reduced to slopes of 2.5:1 or less and between 18 and 48 inches of growth media were placed on top of the waste rock before the surfaces were revegetated.

4.4.2 Areas to be Recontoured and Revegetated

Approximately 900 acres of the waste rock surface are currently planned to be recontoured and revegetated. Most of the areas that are intended to be revegetated are located above 6800 feet on the southwest, south and east sides of the pit (Figure 4-6). Almost all of these sites are underlain by waste rock soils that will support vegetation after relatively minor soil modification. The waste rock soils in these areas contain very few intact sulfide minerals, generally have conductivity values that are less than 500 umhos/cm and have pH values between 2.5 and 8.

The anticipated benefits of the recontouring and revegetation activities will be:

- To reduce infiltration into these waste rock surfaces by enhancing evapotranspiration. This will reduce the amount of waste rock contact water that must be collected and treated at the toe of the disposal area and that may reach the regional water table (Section 10.0).

- To provide wildlife habitat.

- To provide a native seed source for surrounding waste rock surfaces that currently cannot support vegetation but that may be able to after additional weathering.

- To enhance slope stability and limit erosion.

- To create a surface that resembles the surrounding natural landforms.

Most angle of repose slopes will be reduced to 2.5:1 or less and will be cross-ripped. On flat or gently sloping surfaces, depressions will be filled, end dump piles will be smoothed out and most areas will be deeply ripped. This ripping will loosen compacted surfaces, will limit erosion potential on slopes, will bring fine material to the surface and will create microhabitats to encourage plant establishment. Studies at other mines have indicated that truck-induced compaction declines dramatically within the first two feet below the waste rock surface, so ripping will extend to a depth of at least two feet (Uhrie and Koons, 2001). Surfaces will be recontoured to minimize the transport of runoff from large relatively flat surfaces to adjacent slopes. Wherever possible, native mature volunteer vegetation on the dump surface will be left undisturbed during these recontouring and ripping activities. This will enhance surface stability and will supply a native seed source to the surrounding recontoured waste rock surface. The recontouring will also be designed to limit the amount of previously unimpacted land that is disturbed. Many of these waste rock disposal surfaces surround small islands of native hillside that can also provide a valuable seed and mycorrhizae source to the surrounding waste rock surface. In some locations angle of repose slopes will be left in place if they already support native vegetation or if the recontouring will cover important unimpacted areas below them. It is anticipated that the recontouring and ripping will remove most physical barriers to vegetation establishment except for the relatively small percentage of the surfaces that are underlain by very coarse gravel (sites where >90% of the soil is composed of gravel).

The pH of acidic surfaces will be raised above 6 by the addition of crushed limestone or another neutralizing agent that does not inhibit plant growth. Because there are few intact acid-generating sulfides in the waste rock, these surfaces will not reacidify once the pH has been raised. This technique has been successfully used for direct planting of weathered acidic waste rock and soil surfaces at many other mine and smelter sites (Winterhalder 1988; Nawrot et. al. 1988). Depending on the initial soil chemistry at each site, anywhere from 0 to 10 tons/acre of crushed limestone or equivalent will be applied to the surface. In general, no limestone will be added to surfaces that already have a pH above 6.5. Surfaces with a pH of less than 4 will receive a minimum of 5 to 10 tons/acre of limestone, surfaces with pH values of 4 to 5 will receive a minimum of 3 to 5 tons/acre of limestone, and surfaces with a pH of 5 to 6.5 will receive a minimum of 0.5 to 3 tons/acre of limestone. The actual application rate will be dependent upon the average pH, the soil salinity and the amount of intact sulfides that are present. Generally, within each pH range, if the paste conductivity is above 500 umhos/cm the higher application rate will be used and if the conductivity is below 100 umhos/cm the lower rate will be used. If field assessments indicate it is required, all the surfaces will also receive a light application of chemical fertilizer to provide nitrogen, phosphorus and potassium (not to exceed 50 lbs/acre available nitrogen) or may receive biosolids at application rates not to exceed 10 tons/acre of pure biosolids. If biosolids have been mixed with wood chips or another carbon source, the application rate of the mixture may be as high as 30 dry tons/acre, as long as the biosolids component of the mixture does not exceed 10 dry tons/acre. In general, phosphorus application rates will be higher than nitrogen application rates, which will be higher than potassium application rates. Studies at Bingham Canyon and elsewhere indicate that over-fertilization with nitrogen in biosolids or chemical fertilizers promotes the establishment of weedy species and inhibits species succession (Black and Borden 2002; McLendon and Redente 1992). The study that was conducted at Bingham Canyon is summarized in the attached paper (Appendix F).

A seed mix that is predominantly composed of native grasses, forbs, shrubs and trees will be broadcast or drill seeded onto the surface. The seed mixes that are used will largely be composed of native species that are already volunteering onto the waste rock surface or closely related species (Table 4-1). However, the exact composition of the seed mixes will vary depending on elevation and slope aspect of the surface to be seeded, and on species availability and assessments of earlier revegetation efforts. For sites with elevations below about 6500 feet, the seed mix may be altered significantly from the species listed in Table 4-1. For instance, Douglas fir, Bigtooth maple and Aspen may not be appropriate for most low elevation sites. Conversely, other species that are not listed on Table such as Western wheatgrass, Slender wheatgrass and Fourwing saltbush have been very successful on reclaimed sites at lower elevations on the waste rock disposal areas (Black and Borden, 2002).

Most of these reclamation activities will occur between the present and mine closure.

4.4.3 Areas to be Recontoured

Approximately 3200 acres of the waste rock surface are currently planned to be recontoured without revegetation. This area includes flat and irregular surfaces as well as angle of repose slopes that are less than 150 feet high (Figure 4-6). These areas will not be revegetated because they currently contain abundant unweathered sulfides, have elevated soil salinity and generally have low pH. If limestone were applied to neutralize the acidity in these areas, continued sulfide oxidation would cause most surfaces to reacidify (Doolittle and Hossner 1997). Even if the surface pH could be maintained at near neutral, the salinity of these soils would prevent native vegetation establishment because they will continue to contain abundant gypsum precipitated during the in situ neutralization of acid generated from the oxidizing sulfides (Borden 2001). Water in contact with gypsum will maintain a conductivity of approximately 2000 umhos/cm, well above the salinity tolerance of most native species growing on the waste rock surfaces and in the surrounding mountains (Figures 4-4 and 4-5) (Richards 1954; Wali 1999).

The anticipated benefits of the recontouring activities will be:

- To reduce infiltration into these waste rock surfaces by reducing pooling on the surface. This will reduce the amount of waste rock contact water that must be collected and treated at the toe of the disposal area and that may reach the regional water table (Section 10.0).
- To create a surface that resembles the surrounding natural landforms.
- To remove physical barriers to vegetation establishment such as steep slopes with surface creep and compacted surfaces. Continued weathering and sulfide oxidation on these surfaces will eventually create soils that are geochemically favorable to native vegetation establishment.
- To enhance slope stability.

Most angle of repose slopes that are less than 150 feet tall will be reduced to 2.5:1 or less, depressions in the surface will be filled and end dump piles will be smoothed out. Surfaces will be recontoured to minimize the transport of runoff from large relatively flat surfaces to adjacent slopes. Neutralizing agents such as cement kiln dust, waste lime or waste limestone may be applied to selected surfaces if they become available in the future and if they can be placed economically. Some relatively short angle of repose slopes may be left in place if the slope reduction would cover important facilities or previously unimpacted land. Slopes will be cross-ripped to minimize surface flow and potential erosion. These areas will generally be recontoured between the termination of waste rock production and one to two years after mine closure.

It is anticipated that in the future, continued weathering on these waste rock surfaces will create additional waste rock soils that may be revegetated by direct planting (Borden 2001). After closure and after all recountering has been completed, a follow-up soil chemistry survey will be performed on this portion of the waste rock surface. Large, contiguous areas that contain few intact sulfides and that have soil paste conductivity values below 500 umhos/cm will be revegetated in the same manner as described in Section 4.4.3. This will include ripping or re-ripping most surfaces followed by limestone, fertilizer and seed application.

4.4.4 Areas to Undergo Slope Stabilization Study

A slope stabilization study is being performed on approximately 200 acres located on the southeast margin of the waste rock disposal areas (Figure 4-6). This area covers the angle of repose slopes that are located at the upper end of six dry tributary drainages to Butterfield Creek, a perennial stream. The individual drainages are listed along with selected physical characteristics on Table 4-2. The maximum height of the angle of repose slopes in these drainages ranges from approximately 700 to 900 feet and they are all less than a mile from Butterfield Creek. A preliminary assessment of these areas indicates that they have the greatest potential of any slopes to release contaminated sediment and contact water from the property. All six of the drainages are well-defined, narrow channels with generally thin alluvial deposits and relatively steep gradients. The gradients vary between 650 feet/mile and 990 feet/mile from the toe of the waste rock angle of repose slope to the drainage intersection with Butterfield Creek. Since the Eastside Collection System at the foot of the Eastside disposal area was upgraded between 1993 and 1996, there have only been two incidents in which contaminated sediment or water have escaped the property. These incidents occurred in the Olsen and Castro drainages at the southern end of the 200-acre area. Sediments deposited down gradient during these incidents were cleaned up and returned to the waste rock disposal area.

The slope stabilization study will involve a detailed assessment of the risk of contaminated water and sediment release in each drainage. An assessment of long-term maintenance costs in each drainage with and without slope stabilization will also be made. The study also will involve an engineering assessment of the cost and efficacy of various slope stabilization methods in each drainage. The study is planned for completion in the next two years and slope stabilization plans for each drainage will be created. It is possible that the angle of repose slopes in the Olsen, Butterfield, Castro, South Saints Rest and Saints Rest drainages will need to be reduced, capped with a growth media and revegetated unless another suitable stabilization alternative can be identified. Waste rock with favorable physical and chemical characteristics may be used as a growth media if available in sufficient quantities (pH > 6.5, conductivity < 500 umhos/cm, % gravel < 85%). The requirements for the slopes within the Yosemite drainage cannot be identified until the assessment is completed. This drainage generally poses a lesser risk of contaminant release because it has a lower gradient and has a longer travel distance to reach Butterfield Creek than the other drainages (Table 4-2).

Table 4-2 Physical Characteristics of Drainages Below the Eastside Waste Rock Disposal Areas

Drainage (1)	Distance from Dump Toe to Butterfield Creek	Approximate Drainage Gradient (2)
Tributary Drainages to Butterfield		
Olsen	3500 ft	770 ft/mile
Butterfield	3500 ft	990 ft/mile
Castro	4500 ft	800 ft/mile
South Saints Rest	4000 ft	840 ft/mile
Saints Rest	3400 ft	780 ft/mile
Yosemite	5000 ft	650 ft/mile
Other Eastside Drainages		
Copper	Not a Tributary (3)	480 ft/mile
Keystone	Not a Tributary (3)	450 ft/mile
Bingham	Not a Tributary (3)	160 ft/mile

(1) These drainages all contain or will contain angle of repose waste rock slopes associated with the Eastside waste rock disposal area. None of these drainages contain perennial streams. The drainages are listed in order from south to north.

(2) The gradient is expressed in terms of feet vertical drop per mile of drainage length. The gradient for the tributary drainages to Butterfield Creek is measured from the toe of the angle of repose waste rock slope to the intersection with Butterfield Creek. The gradient for the other drainages is measured from the toe of the angle of repose waste rock slope to a point one mile down the drainage.

(3) These drainages ultimately intersect the Jordan River more than nine miles down gradient. The closest body of water is the Provo Reservoir Canal more than five miles down gradient. The closest public access point is highway 111 more than a mile down gradient.

4.4.5 Areas to be Recontoured, Capped and Revegetated

The extension of waste rock disposal operations into lower Bingham Canyon will allow a stair-stepped outer dump face to be created that will be reclaimed (Figure 4-6). The reclaimed face will be about 850 feet high and will cover approximately 140 acres. It will tie into native ridges on either side of the canyon and will be recontoured to a maximum slope of 2.75:1. The slope will have 15-foot wide benches every 150 vertical feet. These benches will slope approximately two degrees towards the north or south edge of the dump face. The soils forming on the waste rock surface will likely be acidic and/or saline, so the outer face will be capped with an average of two feet of growth media. The thickness of the growth media will be varied so that approximately 30 % of the face will be capped with up to three feet of material and about 70% will be capped with 18 inches of material. The outer dump face will be cross-ripped or otherwise roughened before placement of the growth media. At least a portion of the cap material will likely come from the growth media stockpile on the 5900 ft level of the waste rock dumps about 3000 feet south of Bingham Canyon (approximate mine coordinates N3500, E13800 and N1500, E13500). The areas with a thick cap will be able to support some trees and woody shrubs, but grasses and forbs will likely dominate the areas with a thinner cap. This will create a natural mosaic of plant communities on the outer face. The face will again be cross-ripped or pitted after the placement of the cap and before it is seeded. Cross ripping will be shallow enough to avoid mixing waste rock into the cap material. The 140-acre outer dump face will be seeded with the seed mix listed in Table 4-3. In addition to seed application, Gambel oak and Curl leaf mountain mahogany seedlings will be planted at a rate of 40 plants/acre each (80 seedlings/acre total) on the three-foot thick portions of the cap. The three-foot cap areas will also receive 0.05 lbs/acre of Curl leaf mountain mahogany seed. If field assessments indicate it is required, the capped surface will receive a light application of chemical fertilizer to provide nitrogen, phosphorus and potassium (not to exceed 50 lbs/acre available nitrogen) or may receive biosolids at application rates not to exceed 10 tons/acre pure biosolids. If biosolids have been mixed with wood chips or another carbon source, the application rate of the mixture may be as high as 30 dry tons/acre, as long as the biosolids component of the mixture does not exceed 10 dry tons/acre. In general phosphorus application rates will be higher than nitrogen rates, which will be higher than potassium application rates.

Reclamation will be completed within two years of the termination of waste rock placement on the outer dump face.

4.4.6 Areas Where No Further Action is Currently Planned

No further action is currently planned for approximately 800 acres within the waste rock disposal area. These acres are entirely comprised of angle of repose slopes that are greater than 150 feet tall. The majority of these slopes are located on the eastern margin of the waste rock dumps, north of the Butterfield Canyon tributary drainages, but this area also includes the angle of repose slopes in upper Dry Fork Canyon and Freeman Gulch, and miscellaneous slopes on top of the waste rock disposal area (Figure 4-6). As described earlier in this section, surface debris, utilities and facilities without a post-mining use will be removed from these slopes. The upper crest of the

Table 4-3 Seed Mix for the Capped Lower Bingham Canyon Dump Face

Common Name (1)	Species Name	PLS lb/acre
SEEDED SPECIES ON All CAPPED AREAS		
Grasses		**8.5**
Kentucky Bluegrass	Poa pratensis	0.5
Sheep Fescue	Festuca ovina	2.0
Great Basin Wildrye	Leymus cinereus	1.0
Slender Wheatgrass	Agropyron trachycaulum (Elymus trachycaulus)	1.5
Western Wheatgrass	Agropyron smithii (Pascopyrum smithii)	2.0
Bluebunch Wheatgrass	Agropyron spicatum (Pseudoroegneria spicata)	1.5
Legumes		**4.0**
Wild Lupine	Lupinus perennis	2.5
Mountain Lupine	Lupinus alpestris	0.5
American Vetch	Vicia americana	1.0
Forbs		**2.2**
Milfoil Yarrow	Achillea millefolium	0.2
Small Burnett	Sanguisorba minor	1.5
Wasatch Penstemon	Penstemon Cyananthus	0.3
Rocky Mountain Penstemon	Penstemon Strictus	0.2
Trees/shrubs		**1.5**
Rubber Rabbitbrush	Chrysothamnus nauseosus	0.3
Mountain Big Sagebrush	Artemisia tridentata(vaseyana)	0.2
Fourwing Saltbush	Atriplex canescens	1.0
TOTAL SEED		**16.2**
ADDITIONAL PLANTINGS ON 3 FT CAP		
Curl Leaf Mtn Mahogany Seed (2)	Cercocarpus ledifoluis	0.05
Gambel Oak Seedlings	Quercus gambelli	40 seedlings/acre
Curl Leaf Mtn Mahogany Seedlings	Cercocarpus ledifoluis	40 seedlings/acre
(1) Depending upon seed availability at the time of planting, some species may be replaced with similar,		
available species.		
(2) Curl Leaf Mtn Mahogany seed will be hand planted 1/4 to 1/2 inch deep and then have soil compacted over the top.		

angle of repose slopes will also be bermed, and the overlying waste rock surfaces will be contoured, to prevent runoff from flowing onto the slopes.

None of these slopes pose a significant risk of contaminant transport off the property and the costs of slope stabilization would not be offset by the reductions in long-term maintenance costs for the sediment and water collection systems located down gradient from the slopes. All of these slopes are either located above relatively flat waste rock surfaces or are above relatively low gradient, poorly defined drainages. All of these slopes are also relatively distant from any down gradient public access points or water bodies (Table 4-2). These slopes are tall, so the cost per acre for slope reduction would be prohibitively high. All of these slopes are also composed of waste rock with abundant pyrite, high salinity and low pH, so revegetation would not be practicable. However, if additional stability assessments identify slopes that pose a significant risk of offsite waste rock and contaminant transport, or if new reclamation techniques are developed that would make the recontouring of these slopes practicable in the future, some of these slopes may be partially or fully reclaimed at closure.

About half of the east-facing angle of repose slopes where no further action is planned are located immediately above large, flat waste rock surfaces. Shallow failures or erosional events on these slopes will merely deposit material onto the lower waste rock surface. The remaining east-facing angle of repose slopes are located above broad, poorly defined, alluvium-floored and relatively low-gradient dry drainages (Copper and Keystone drainages on Table 4-2). The Eastside Collection System at the base of the east-facing slopes north of the Butterfield tributary drainages was designed to handle leach water base flows plus the 10-year, 24-hour storm event. With the termination of leach water applications, base flows in this area have declined from greater than 25,000 gpm to less than 1000 gpm, so the collection system is likely able to handle flows that are greatly in excess of the 25-year, 24 hour storm event. The closest water body of any kind is the Provo Reservoir Canal more than five miles down gradient and the closest public access point is Highway 111 more than one mile down gradient. The Jordan River is located more than nine miles down gradient.

The tall angle of repose slopes in upper Dry Fork Canyon and Freeman gulch are facing up-canyon, so the risk of significant up gradient transport of sediment and water from these slopes is minimal. If these slopes were reduced it would also cover previously unimpacted, forested areas within these drainages.

5.0 EXCESS MINE WATER DISPOSAL AREA

At present there are no areas devoted to this activity as it was defined in the 1978 Permit. Mine water generated by pit dewatering operations, surface runoff and groundwater capture other than from leaching areas is currently piped to the Copperton Concentrator and used in the process water circuit. Between 1936 and 1986 this water was sent to the South Jordan Evaporation Ponds area. The ponds were located seven miles east of the Bingham Mine, one mile south of Bingham Creek and five miles west of the Jordan River. At closure in 1986, the site contained approximately four million tons of neutralized sludges in 25 individual ponds covering 530 acres. Total metals analysis of the material showed it to contain elevated concentrations of arsenic, cadmium, copper, lead and zinc. However, batch leach testing indicated that the metal-bearing material was not leachable and therefore did not pose a significant risk of migration. Leachable sulfate, which is not regulated, was the most significant contaminant of concern at the site because of its concentration and solubility.

Groundwater beneath the site contains elevated sulfate and total dissolved solids concentrations, but does not contain elevated metals concentrations. Much of this water is above the Utah Groundwater Quality Protection standard of 500 mg/L for sulfate but below the health limit of 1500 mg/L.

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the excess mine water disposal area at closure:

- stabilization will be accomplished consistent with subsequent land use and may include removal or covering of accumulated salts, treatment with neutralizer, grading and revegetation work

- the area will be left in a safe, stable condition suitable for future use and without hazard of erosion or surface water accumulation

- any revegetation work would likely be accomplished to suit farming requirements.

5.1 COMPLETED RECLAMATION PROGRAM

In 1994 and 1995, KUCC reclaimed the evaporation ponds with oversight by EPA and DERR. The remediation and reclamation activities were completed in accordance with the Administrative Order on Consent for the South Jordan Evaporation Ponds (USEPA Docket Number CERCLA-VIII-18) and the Record of Decision, Kennecott South Zone Site (USEPA, Region 8, 2001). A completion certificate for this removal has been issued by the EPA. Some of the material in the ponds was returned to the waste rock disposal areas at Keystone Notch or was placed in the Bluewater I Repository. The remaining materials, composed of gypsum and gypsum-contaminated soils, were consolidated into a 210-acre low mound within the northern footprint of the ponds. The entire area was regraded, and the mound was capped with three to five feet of clean topsoil and seeded. During the reclamation an estimated seven million cubic yards of contaminated soils were moved and four million cubic yards of clean soil were emplaced.

The removal of materials with elevated metals concentrations, and the consolidation and capping of the remaining sediments, has minimized this site as a source of groundwater contamination. Infiltration of precipitation and irrigation canal water in the area is diluting and dispersing the remains of the historic sulfate groundwater plume.

5.2 FUTURE RECLAMATION PLANS

The 210-acre repository was designed to hold the gypsum and gypsum-bearing soils in perpetuity. However, current plans are to remove this material and place it in a repository with a much smaller footprint that is located up-gradient of the Eastside Collection System at the mine. The likely repository location is in Copper Notch at the foot of the Eastside waste rock dumps.

5.3 POST-CLOSURE LAND USE

The majority of the excess mine water disposal area can now be used for non-mining purposes without restriction. Most of the reclaimed site is currently open space, but in the future it may also be used for agricultural, residential, recreational, commercial, industrial or other purposes. After the remaining gypsum-bearing sludge has been removed, the 210-acre repository area may also be used without restriction.

6.0 ORE TRANSFER AREA - MINE TO PROCESS

Ore was transferred 15 miles by standard gauge rail from the Mine to the North Concentrator until the concentrator was permanently closed in 2001. The track and railroad maintenance facilities associated with ore transfer cover about 330 acres. The railway network and operations are largely the same as described in the 1978 Permit. The entire ore haulage track is owned by KUCC and is within the permit boundaries. A conveyor transfers ore from the in-pit crusher to the Copperton Concentrator. Demolition and reclamation of the conveyor below the open pit and the 5490 tunnel is covered by DOGM permit M/045/004

6.1 CLOSURE ISSUES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the ore transfer area at closure:

- at such time as the railroad is no longer needed in the mining or processing operations or for subsequent use, trackage and surface facilities will be removed and the area left in a condition suitable for conversion to other use

- revegetation will be accomplished if appropriate for the subsequent use.

Some areas adjacent to the tracks may contain historic ore spillage or other materials associated with rail haulage. If left in place these materials could inhibit the reestablishment of vegetation.

6.2 POSSIBLE POST-CLOSURE LAND USE

After the removal of all process materials, demolition and reclamation have been completed, there will be no restrictions on post-closure land use. Much of the land will probably be returned to farming, wildlife habitat or to some other use. Some sections of track may be left in place to service sites of post-mining industrial or commercial development.

6.3 DATA REQUIREMENTS

The only information still needed to select final reclamation activities is the determination of post-closure land use. In particular, segments of track that should be left in place and areas that will be returned to farming after closure will need to be identified.

6.4 RECLAMATION ACTIVITIES

Tentative reclamation activities have been selected based upon the existing incomplete data set.

Before closure, the entire ore transfer area will be surveyed for ore and other process materials. Identified materials will be removed and either processed, placed on the waste rock disposal areas or properly handled in another manner. Any other contaminated areas will be cleaned up as described in Section 2.3. The ore conveyor in the open pit and in the 5490 tunnel will be removed. Those sections of track with a post-mining use will be left in place, and all other track and buildings will be demolished. All steel and as many ties as possible will be salvaged. Any materials that are not salvageable will be properly disposed. Based upon its volume and chemical characteristics, ballast and fill material from some areas may be excavated and removed for proper disposal.

All sites except those located on waste rock disposal areas will be regraded to conform to the surrounding land surface and natural surface drainage will be reestablished. All areas will be reseeded, except for those that will be used for farming within one growing season or where post-mining construction activities are planned immediately after closure.

7.0 ORE PROCESSING FACILITIES AREA

The North Concentrator consists of the Bonneville Crushing and Grinding Plant, the Magna Flotation Plant, a few remaining structures from the Arthur Concentrator and the Arthur maintenance shops and warehouse (Table 2-1 and Figure 2-2). The entire complex covers approximately 220 acres. In 1997 the complex processed 9,700,000 tons of ore and produced 229,866 tons of concentrate. The North Concentrator was permanently closed in 2001.

The North Concentrator Complex is located immediately west of the town of Magna, and has good access to the interstate highway and railroad systems. The area also has a well-developed infrastructure including water supply systems, electrical transmission lines, sewage treatment facilities and arterial roadways and rail lines. The western limits of Magna, adjacent to the North Concentrator Complex, is zoned for heavy industrial use.

In the past, soils in and around the North Concentrator complex were contaminated with metal-bearing process materials, hydrocarbons and reagents in the course of normal operations. Soils with elevated lead and arsenic concentrations have already been identified and cleaned up at the old Arthur Concentrator, the Magna Concentrator and the Bonneville Crushing and Grinding Plant. Clean-up levels were established to allow industrial use of the site in the future. It is possible that other contaminated soils are present beneath existing structures.

7.1 CLOSURE ISSUES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the ore processing facilities area at closure:

- surface facilities including buildings, utilities, railroads and equipment that are no longer needed for ore processing or related purposes and are not convertible to some other use, will be razed and/or removed

- all hazardous conditions will be eliminated and ground surfaces stabilized and planted.

In addition to these DOGM requirements several other issues should be considered during closure planning:

- at closure the land should be left in a condition which maximizes its value and minimizes restrictions that will be placed on post-closure land use

- materials or conditions that may have a significant negative impact on surface or groundwater quality will need to be removed or corrected before closure

7.2 POSSIBLE POST-CLOSURE LAND USE

The primary limits on post-closure land use are the concentration and extent of soil and groundwater contamination that remains on the site at closure. To comply with the requirements of the 1976 Mining and Reclamation Plan and to maximize the post-closure value of the land, remediation and reclamation will be designed at a minimum to allow industrial/commercial land use at closure. Within much of the disturbed area it is assumed that there will be unrestricted land use at closure that could include industrial/commercial, residential and wildlife habitat.

7.3 DATA REQUIREMENTS

In order to select final and detailed reclamation actions, the following data requirements will have to be filled:

- the character and extent of soil or groundwater contamination that may remain on site
- the regional economic and demographic conditions at the time of closure and the viability of selling or leasing specific buildings to another party for industrial development.

7.4 RECLAMATION ACTIVITIES

Tentative reclamation activities have been selected based upon the existing incomplete database. Before closure all process materials will be processed, sold or otherwise remediated. Currently it is assumed that all facilities will be demolished unless a valid post-mining use can be identified in the future. Contaminated soils and debris that are identified before or during demolition activities will be removed, treated or buried in place to allow at least industrial/commercial land use after closure. After demolition and remediation have been completed all sites will be reclaimed as described in Section 2.3.

8.0 TAILINGS DISPOSAL AREA

The South Tailings Impoundment currently contains about two billion tons of material and until recently received about 55 million additional tons annually. The original footprint of the impoundment was about 5800 acres, of which less than 2000 acres are currently not reclaimed. The current flat, interior portion of the impoundment covers about 3500 acres and the embankment covers about 2300 acres. Since 1999, the area of active tailings deposition has been reduced on top of the impoundment and new tailings deposition is currently only occurring intermittently on the eastern quarter of the impoundment. Interim and permanent reclamation activities are currently being performed on the inactive interior areas. Approximately 1100 acres of the embankment have been permanently reclaimed with trees and shrubs, and most of the remaining embankment area has undergone reclamation with a mix of fast growing grasses and forbs for dust control. The top of the impoundment is almost 250 feet high and the overall embankment slope is maintained at approximately 11 degrees.

The South Tailings Impoundment has almost reached its operational capacity and construction of the new North Impoundment expansion began in 1996. The transition to the North Impoundment is scheduled to extend from 1998 to 2004.

The tailings contain fewer sulfides and a lower acid potential (AP) than the ore produced in the mine because almost all of the chalcopyrite, bornite and molybdenite, and some of the pyrite, is removed during the beneficiation process and sent to the Smelter as concentrate. Samples of tailings from the Magna and Copperton Concentrators collected between 1996 and 2002 contain about 0.6 percent sulfide sulfur on average. If all of these sulfides were oxidized, the weighted average AP would be about 18 tons of calcium carbonate per 1000 tons of tailings. The sampling program also indicates that the tailings contain the equivalent long-term weighted average neutralization potential (NP) of about 29 tons of calcium carbonate per 1000 tons of tailings. The seven year weighted average net neutralization potential (NNP) of the tailings is thus 11 tons/1000 tons with a 95% confidence interval of 5 tons/1000 tons. The neutralization potential ratio (NPR) of the Magna and Copperton tailings has a weighted average of 1.6. However, coarse tailings material, which generally accumulates on the margins of the impoundment near the discharge points, has a higher concentration of sulfide minerals and tends to be more acid-generating than the impoundment tailings as a whole. More than 250 samples were collected from the surface and subsurface of the embankment between 1994 and 1996 (Shepard Miller, Inc. and Schafer and Associates, 1995; Shepard Miller, Inc., 1997). These samples represent a historical record of tailings deposition spanning several decades. The average AP of the data set was 22 tons/1000 tons and the average NP was 28 tons/1000. The average NNP was 6 tons/1000 tons with a 95% confidence interval of 6 tons/1000 tons. The average NPR of the tailings embankment samples was 1.3.

These NNP and NPR values are not clearly diagnostic of ARD potential under field conditions, so kinetic tests are also being performed on tailings samples in compliance with Utah Ground Water Discharge Permit UGW350011. Kinetic net acid generation (NAG) tests have recently been completed on 21 tailings samples with a range of NNP and NPR values. During NAG tests, tailings are mixed with a hydrogen peroxide solution for 24 hours and the pH and temperature of the mixture are continuously monitored. Hydrogen peroxide is a strong oxidizing agent, so the sulfides in the sample are oxidized at a rapid rate, mimicking years or decades of surface weathering during the short-term test. As shown on Figures 8-1a and 8-1b, the NNP and NPR are very good predictors of the final pH of the oxidized tailings. Samples with an NNP of less than –2 tons/1000 tons (NPR=0.8) all acidified, whereas samples with an NNP of greater than 3 tons/1000 tons (NPR=1.2) maintained a neutral pH throughout the test. Sulfide oxidation reactions are strongly exothermic, and samples with an excess of AP all exhibited very elevated temperatures during the tests (Figure 8-2a and 8-2b). Samples with an excess of NP all remained near room temperature throughout the test.

These results indicate that, although portions of the South Impoundment will acidify, the overall risk of ARD from the impoundment as a whole is low. On a mass basis, it is estimated that less than ten percent of the South Impoundment material has the potential to become acidic because of its NNP characteristics or because it will remain saturated in perpetuity. (Shepard Miller Inc. and Schafer and Associates, 1995). Most of the tailings will remain saturated in perpetuity. The sulfides in tailings that are below the water table are unlikely to ever be oxidized, but the NP of these saturated tailings will be able to neutralize any acidic solutions that they may contact.

Portions of the embankment surface will likely acidify because 1) sulfides are preferentially partitioned to the margins of the impoundment, and 2) oxygen is more readily available in the well-drained and coarse-grained embankment than in the fine-grained interior. Based upon the data collected between 1994 and 1996 and the new NAG test results, approximately 50 % of the tailings exposed on the embankment surface have the potential to acidify in the long term (assuming that all tailings with an NNP of less than 0 could ultimately acidify). Recent tailings deposited on some portions of the existing interior surface of the South Impoundment have also been more acid-generating than the long-term average. Acid-base accounting and kinetic NAG testing of new tailings deposited in the impoundment will continue in the future.

Some tailings may also have elevated salinity, predominantly associated with NaCl, because they are deposited by saline process water. The process water tends to be saline because some of it is derived from water with a relatively high total dissolved solids content and because it is continuously recirculated and undergoes evaporative concentration. In some locations, the salinity may be high enough to inhibit vegetation establishment.

Except for copper, the tailings have relatively low average total metals concentrations, as illustrated by a 61-sample average for the following elements: arsenic 25.1 mg/kg, barium 199 mg/kg, cadmium 0.3 mg/kg, chromium 47.3 mg/kg, copper 785 mg/kg, lead 23.0 mg/kg and selenium 1.2 mg/kg. Synthetic Precipitation Leaching Procedure analyses (EPA Method 1312) conducted on 30 un-weathered tailings samples yielded average leachate concentrations of less than detection for all of these elements.

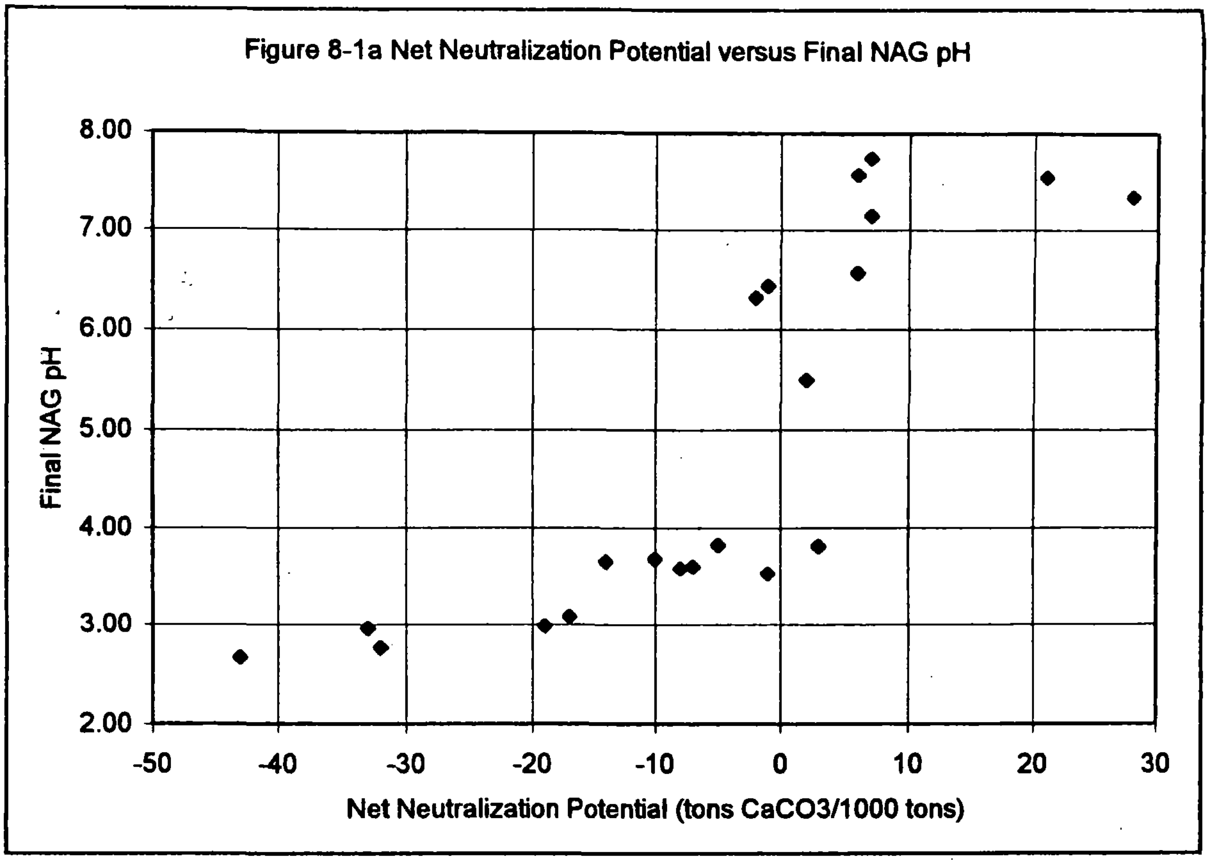


Figure 8-1a Net Neutralization Potential versus Final NAG pH
Final NAG pH
8.00
7.00
6.00
5.00
4.00
3.00
2.00
-50
-40
-30
-20
-10
0
10
20
30
Net Neutralization Potential (tons CaCO3/1000 tons)

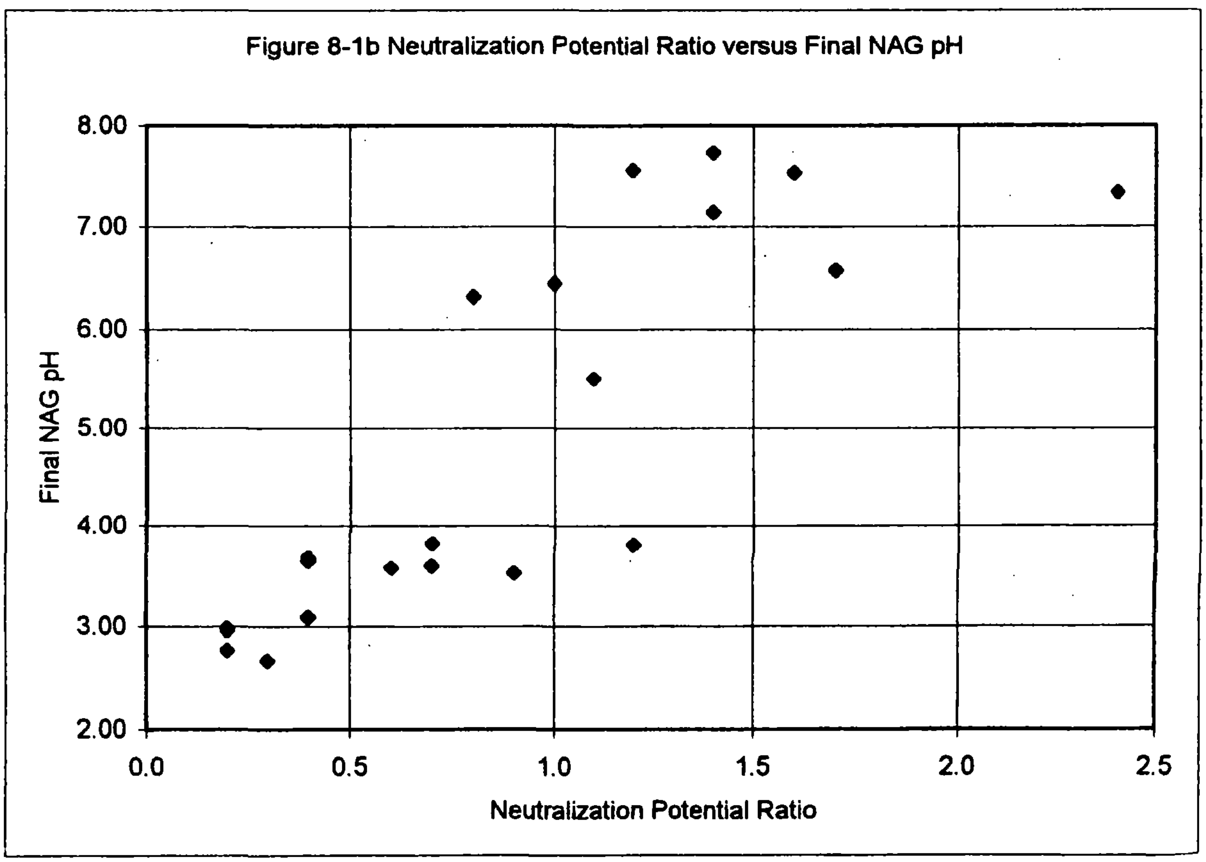


Figure 8-1b Neutralization Potential Ratio versus Final NAG pH
Final NAG pH
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0.0
0.5
1.0
1.5
2.0
2.5
Neutralization Potential Ratio

Figure 8-2a Net Neutralization Potential versus Maximum NAG Temperature

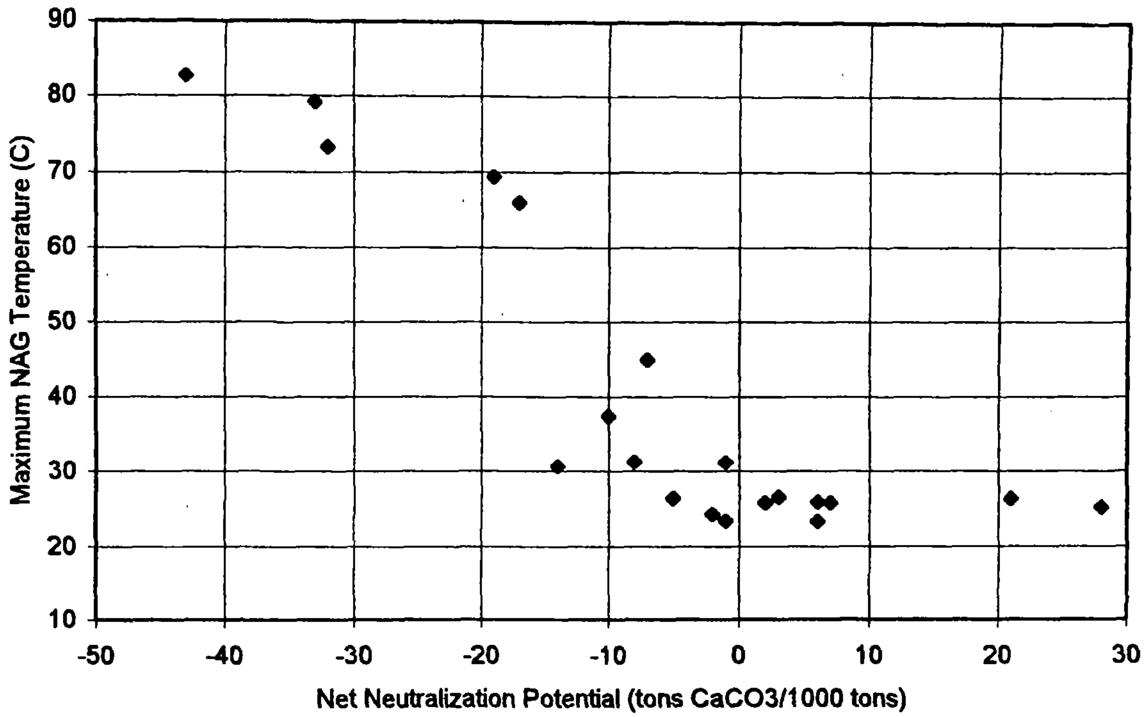
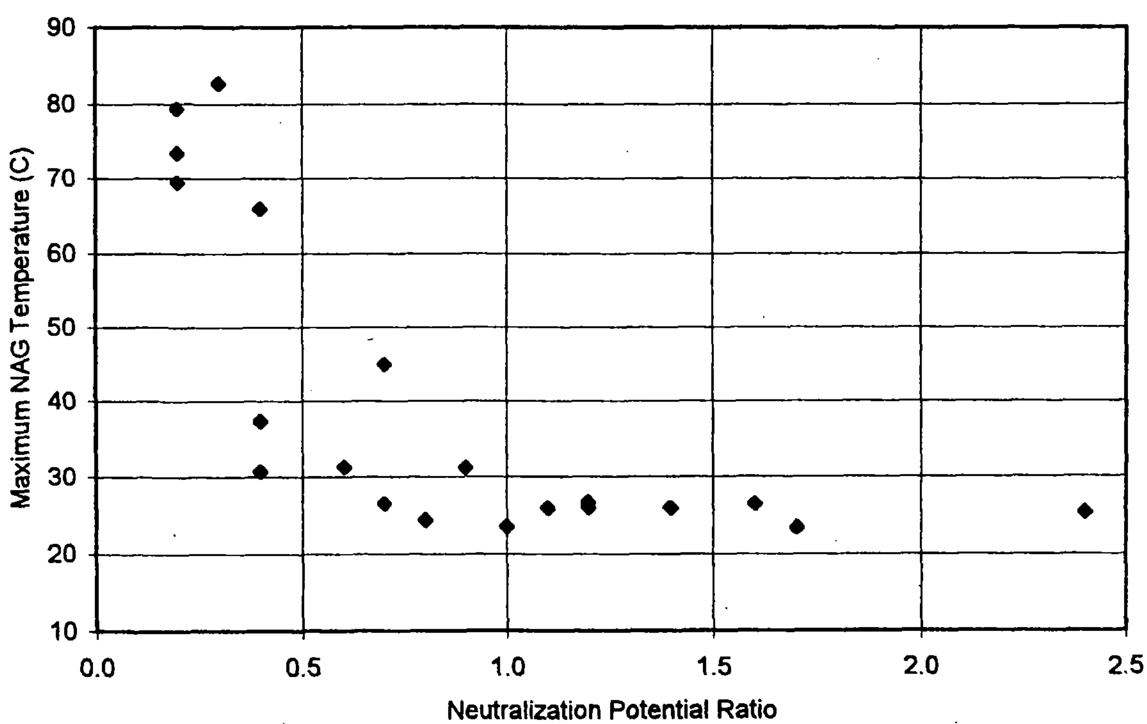


Figure 8-2b Neutralization Potential Ratio versus Maximum NAG Temperature



8.1 CLOSURE ISSUES

The original mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the South Tailings Impoundment at closure:

- when no longer needed for tailings deposition, mineral recovery or material source, grading and revegetation of dike slopes not already done will be completed
- the surface of the tailings pond will be stabilized using the most practicable technology available upon the termination of the deposition of the tailings.

In addition to the DOGM requirements, the primary closure issues at the South Tailings Impoundment include:

- dust must be controlled from the impoundment in perpetuity
- surface water runoff and surface seepage of tailings water from the impoundment must be captured and conveyed to a designated outfall point where it must meet applicable water quality criteria to be discharged
- groundwater quality must not be degraded
- long-term slope stability must be maintained.

8.2 SUMMARY OF EXISTING CLOSURE PLANS

The existing closure plans described in Section 1.2.2 and attached in Appendices B and C detail the reclamation activities that will occur when the South Impoundment closes. The ultimate goal for the surface of the South Impoundment is to establish a permanent, self-sustaining vegetative cover to minimize dust generation, water infiltration and erosion, while improving wildlife habitat, slope stability and aesthetics. In some areas of the South Impoundment interior, where vegetation establishment may be difficult because of salinity issues, the primary goal will be to create a stable surface that will inhibit dust generation.

Areas of the South Impoundment have been taken out of service sequentially, from west to east, to allow continued use of the decant pond until final closure of the existing impoundment. This has been done by constructing access dikes to subdivide the existing active surface. The peripheral discharge system has been reestablished on each new dike to keep the remaining active surface properly wetted. As each new area is isolated and begins to dry, it has been initially stabilized by one or more of the following methods: planting of rapid-growing grass seed, hydromulching, or temporary dust control using water or suppressants. Permanent revegetation of the surface is being conducted after the surface has dried sufficiently or in the next appropriate season. For tailings that have acidified or that may acidify in the future, limestone or another neutralizing agent will be added to maintain a near-neutral pH in the long-term. For some tailings with elevated salinity, final reclamation may need to be delayed several years to allow the salts to be removed by precipitation, infiltration and runoff. Recent sampling and historical studies indicate that this natural leaching process likely occurs within several years on the embankment surface and on portions of the interior, but it may involve decades on portions of the flat interior surface underlain by very saline, very fine-grained tailings (Utah State University, 1974). It may not be possible to establish vegetation on some very saline interior surfaces. In these areas other methods of permanent surface stabilization may be employed such as capping with a growth media, capping with coarse material, capping with a growth media underlain by a capillary break or promoting the formation of salt crusts.

At final closure, the flat, upper tailings surface will be constructed so that all precipitation will be retained on the surface. Captured precipitation will either infiltrate or will be removed by evapotranspiration. Water falling on the embankment and seepage that discharges from the base of the embankment, will report to the toe collection ditch. Ultimately, this water will be discharged through a UPDES outfall (Section 10.0). Groundwater monitoring will continue for some time after closure to ensure that there are no adverse impacts to groundwater quality.

More detailed descriptions of the closure activities are provided in the attached plans.

9.0 EXCESS WATER MANAGEMENT AREA

Facilities that are currently used for excess water management cover about 100 acres. As defined in the 1978 Permit under the land use category of excess process water disposal, this includes all the facilities that handle water from the tailings impoundment for disposal or recycling. Excess water from the South Impoundment is transferred from the decant pond to the clarification canal. From the canal, water flows around the southeast side of the impoundment to a pump station that returns it to the concentrator. Excess water not subject to recycle requirements is discharged to the Great Salt Lake from a series of permitted outfall points.

All of the other areas included under the excess process water land use category in the 1978 Permit are either closed or are only used by the Smelter or Refinery and so are not covered by DOGM permits. This includes the former wastewater treatment plant (WWTP) and its associated sludge lagoons that were demolished and reclaimed in 2001. Metals-bearing gypsum sludge generated during the neutralization process at the WWTP was discharged to five lagoons. Approximately 1.1 million cubic yards of sludge were moved from the lagoons to the Arthur Step Back Repository on the southwest side of the existing tailings impoundment. This repository was constructed under EPA oversight to meet the conditions of a RCRA Subtitle C facility. A portion of the repository underwent permanent capping and closure in 2001. The remainder has been temporarily capped and is authorized by EPA for future hazardous material disposal that meets the conditions of the corrective action management unit. It will be filled, closed and capped at closure.

9.1 CLOSURE ISSUES

The original Mining and Reclamation Plan submitted to DOGM in 1976 specified the following activities for the excess process water disposal area at closure:

- surface facilities that are no longer needed, and that are not convertible to some other use will be razed and/or removed
- sludge ponds and evaporation ponds will be left in a condition suitable for conversion to other uses, this may involve filling or covering, or other stabilization and revegetation work
- canals will most likely be left indefinitely for conveyance of natural surface flows and drainage to the Great Salt Lake.

After closure some of the facilities associated with excess water management will have to be used in perpetuity to handle surface water flows and seepage from the South Impoundment and the North Impoundment. It is also probable that some waters from the mine area and the mine waste disposal area will need to be routed through the existing process water disposal systems and into the Great Salt Lake. After closure all discharges will continue to be regulated under UPDES permit UT0000051 or a subsequent UPDES permit.

9.2 POSSIBLE POST-CLOSURE LAND USE

Based upon the long-term need to handle water from the tailings impoundments and possibly other areas, much of the area will be used for water management in perpetuity after closure. Some of the area may also be preserved as wetlands wildlife habitat. Selected areas, particularly those associated with process water recycling, may have an unrestricted land use after closure, demolition and reclamation.

9.3 DATA REQUIREMENTS

Some of the data requirements that will need to be filled before final post-mining closure options are selected include:

- the ultimate character of the post-mining water management system in the Oquirrh Mountains

- the final geometry of the tailings impoundments and their required water management systems.

9.4 RECLAMATION ACTIVITIES

Tentative reclamation activities have been selected based upon the existing incomplete data set. An outfall point or multiple points will be maintained in perpetuity to discharge water from the tailings impoundments and from other sources in the Oquirrh Mountains into the Great Salt Lake. Selected waters from the mine and the mine waste disposal areas will likely be transported north in existing pipelines within the tailings pipeline corridor. Most existing canals and ditches will be left in place to use for water management and to provide wildlife habitat. Structures currently associated with process water recycling, such as pump houses and pipes, will be removed unless they are determined to have a post-mining use. All buildings and structures that do not have a post-mining use will be demolished and reclaimed as described in Section 2.3.

10.0 POST-CLOSURE WATER MANAGEMENT

After closure the surface and shallow groundwater flows listed on Table 10-1 will need to be captured and managed in perpetuity. The table generally lists flows that have been impacted by contact with waste rock, tailings, underground workings or the open pit. Figure 10-1 is a map of the Bingham Canyon mine area showing watersheds that contribute to these flows and the existing surface water collection systems. Generally, watersheds that contain waste rock surfaces where leach water was historically applied have the lowest water quality. Watersheds that contain waste rock that was never leached have intermediate water quality and up gradient watersheds that are undisturbed contain potable quality water. Currently the surface and shallow groundwater flow in all of the up gradient drainages except for Dry Fork infiltrates into the down gradient waste rock dumps and is ultimately captured as ARD below the dumps. These up gradient watersheds also tend to receive significantly more precipitation than the areas below, so they will contribute relatively more water to the collection systems than is implied by their surface areas. Some watersheds near the range crest of the Oquirrh Mountains receive more than 30 inches/year average precipitation compared to an average of around 16 inches/year near the base of the waste rock disposal areas. Potable quality water discharging from springs, seeps or adits has been identified in several drainages. Listed in decreasing order of annual surface flow these include: Dry Fork, Freeman, Zelnora, Log Fork, Cottonwood and Sap gulches (Figure 10-1). Although Markham Gulch does not currently have any surface flow, historical records indicate that in the past it has produced as much water as Freeman Gulch.

Also listed on Table 10-1 is the water that will be produced as part of the Southwest Jordan Valley Plume remediation. Not included in the table are natural surface flows elsewhere within the permit boundaries in the Oquirrh Mountains or surrounding the Tailings Impoundment. Water extracted from the acid plume remediation contains the largest amount of acidity that will need to be treated, but the great majority of the acid plume will be removed before closure. It is anticipated that the water discharging from the toe of the north Eastside waste rock disposal areas and water flowing in the Bingham Canyon alluvium will contain the great majority of the acidity that must be managed in perpetuity. Both of these areas have been impacted by acid-generating waste rock disposal and historic leach water applications.

Most of the water quality data used to construct Table 10-1 was collected between 2000 and 2002. It is likely that before closure, flushing by precipitation and relatively clean groundwater flow will cause an improvement in water quality in some areas; particularly those that were impacted by historic leach water applications. Proper management of up gradient water, as well as reduced infiltration because of vegetation establishment may also improve some water quality. Conversely, it also is possible that continued sulfide oxidation in the pyrite halo of Bingham pit, the Magna Tailings Impoundment or in the newer waste rock disposal areas in Bingham Canyon may cause water quality in some of these areas to worsen with time.

Table 10-1 Estimated Surface and Groundwater Flows at the Bingham Canyon Mine After Closure

Location	Flow Rate (gpm) (1)	Typical pH (2)	Typical TDS (2)	Typical Sulfate (2)	Typical Alkalinity (2)	Equivalent tons of CaCO3/day (3)
MINE AND TAILINGS FLOWS						
North Eastside Dumps (4)	410	3.0	81000	52000	-26000	-64.0
Dry Fork Extraction Well (5)	100	3.2	27000	20000	-7900	-4.7
South Eastside Dumps (6)	130	4.7	15000	10000	-1500	-1.2
Bingham Canyon Alluvium (7)	520	3.7	6300	4600	-1500	-4.7
Utah Metals Tunnel	70	3.9	3600	2400	-700	-0.3
Carr Fork Flows (8)	220	6.5	3400	2400	>0	>0
Bingham Pit Dewatering (9)	2500	6.9	2600	1700	100	1.5
Barneys Heap Drainage (10)	20	7.0	3500	1300	110	0.0
Magna Tailings Seeps (11)	100	7.2	6100	2300	150	0.1
Bingham Tunnel	830	7.4	1900	1200	210	1.0
Queen Mary Drop Well (12)	470	7.1	500	100	220	0.6
Other Eastside Tunnels (13)	30	7.3	3200	1500	230	0.0
Butterfield Tunnel	300	7.5	800	300	230	0.4
ACID PLUME REMEDIATION						
Acid Wells (14)	2500	3.3	45000	32000	-15000	-225.3
Sulfate Wells (14)	2500	7.0	2700	1500	170	2.6

NOTE: Actual flow rates and water quality will vary depending upon the pit closure scenario selected, the amount of clean water that is captured up gradient of the waste rock disposal areas, and if pumping from the underground workings surrounding the pit is continued after closure.

(1) Unless otherwise noted the flow rates are based upon average measured or estimated flows in 1999, 2000 or 2001. In each case, the highest annual average was used and values were rounded up.

(2) Unless otherwise noted analytical results are average values for samples collected in 2000 and/or 2001. If multiple sources were averaged, the average was weighted by flow rate. All pH and alkalinity values were rounded down and all TDS and sulfate values were rounded up. All values in mg/L. A negative alkalinity indicates that the value represents the acidity of the sample in mg/L as CaCO3.

(3) This is the neutralization capacity that is theoretically provided by alkaline water flows in tons of calcium carbonate per day and the tons per day of calcium carbonate that would be needed to neutralize acidic flows. The values are based upon the typical flow rate and alkalinity or acidity of each flow.

(4) This includes all flows collected along the Eastside dumps north of Yosemite drainage and south of Bingham Canyon. Leach water application to the Eastside dumps was terminated in fall, 2000 and flows from the base of the dumps are still declining. The ultimate base flow is estimated by scaling up the current flow from the south Eastside Dumps (which were never leached) according the larger surface area of the north Eastside dumps. It is probable that pH will increase and TDS, sulfate and acidity will decrease as the leach water component of the base flow decreases. A significant improvement in water quality has already been noted in the Dry Fork Tunnel.

(5) As part of the Dry Fork Corrective Action Plan this will likely have to be pumped at 100 gpm.

(6) This includes all flows collected along the Eastside dumps between the Yosemite and Queen drainages.

(7) Includes flows currently collected at the Bingham Cutoff Wall, the Copperton well, the West Mountain Shaft or its replacement, Curtis Springs and the west side collection system. Water quality data collected at the cutoff wall was assigned to the entire flow. Flow data from 2000 and 2001 were used because leach water was still being applied to the area in 1999.

(8) Flows collected from the upper NW side of the pit. Includes flows from seeps, runoff and the Parvenu Tunnel. The analytical results are based upon sampling conducted in 1993 from tunnels and seeps exposed on the northwest side of the pit.

(9) It is estimated that up to 2500 gpm will ultimately need to be removed from the pit if no peripheral pumping is performed. If a pit lake is allowed to form, it may take up to 30 years before any water needs to be removed from the pit depending on the flooding depth that is allowed. The estimated water quality is based upon the character of water that is currently being removed from the bottom of the pit.

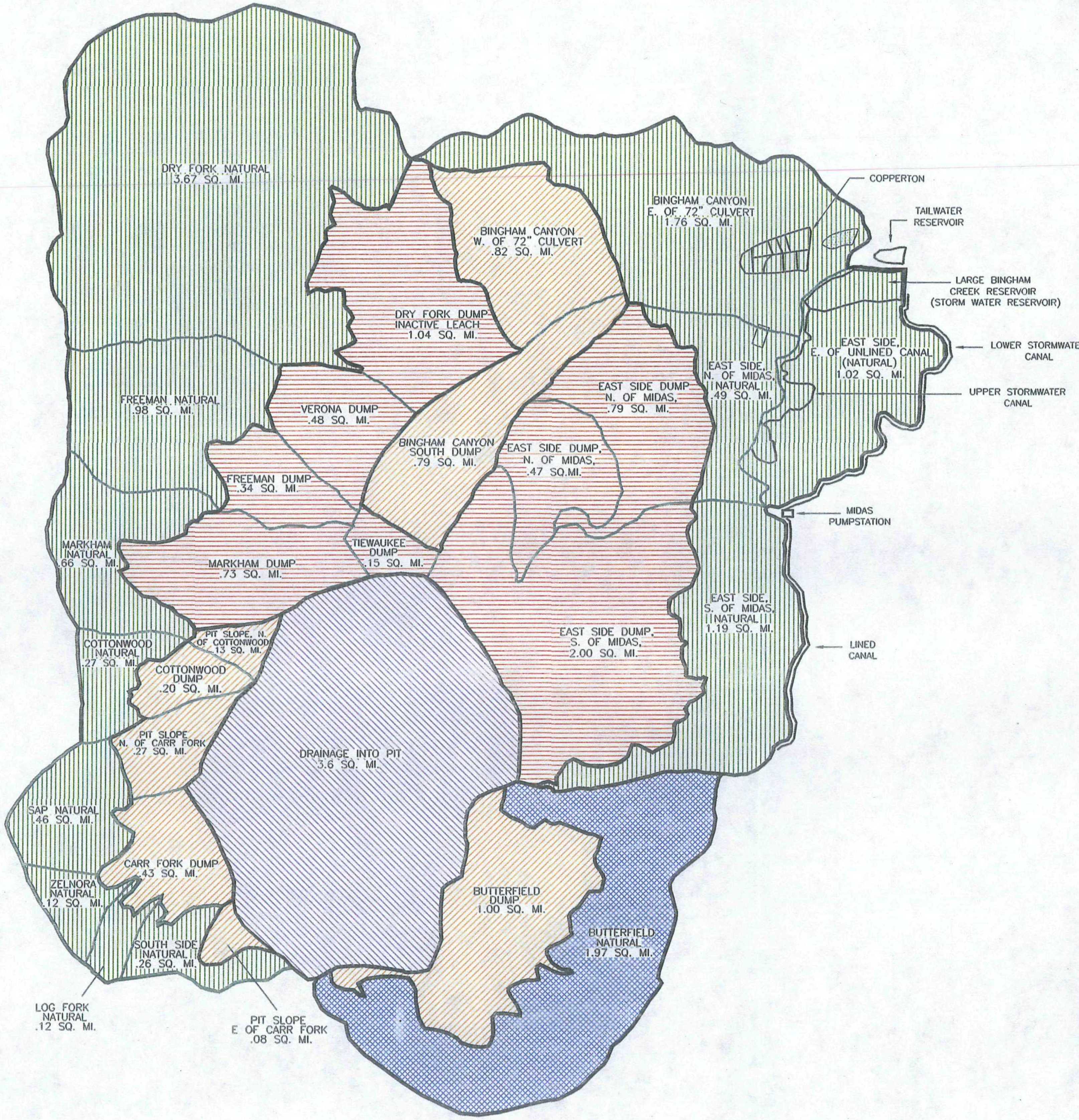
(10) After draindown of the heap leach pads at the Barneys Canyon gold mine has been completed, the base flow will be piped into the water management system for the Bingham Canyon Mine.

(11) The combined flow rate from seeps on the Magna Impoundment in 2000 was less than 100 gpm. It is likely that flows will decrease substantially after water applications to the impoundment are terminated and as the impoundment surface becomes vegetated.

(12) It is assumed that with the cessation of leaching in the Dry Fork area, the water in the Queen Mary drop well will eventually become similar to up gradient groundwater. The analytical data shown are based upon samples from upgradient wells. In the future this water may be extracted from the Mid-Valley well instead.

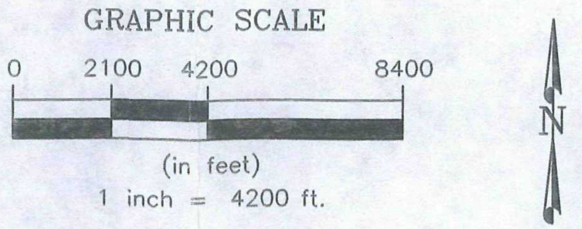
(13) Includes the Old Bingham Tunnel, Mascott Tunnel and the 5490 Tunnel.

(14) It is estimated that the acid wells will be pumped until approximately 2030 at the latest and the sulfate wells will be pumped in perpetuity. The peak annual pumping rates are listed for both the acid and sulfate wells, so the average rates for the entire remediation period may be somewhat lower. In reality, the maximum pumping rate from the acid well may be as low as 1500 gpm. It is also anticipated that water quality will improve during remediation, so sulfate and acidity concentrations may be significantly lower at closure than listed here.



	TOTAL AREA		LEGEND
	Sq. Mi.	Acres	
(red horizontal hatch)	6.0	3800	WATERSHEDS THAT CONTAIN WASTE ROCK DISPOSAL AREAS WHERE LEACH WATER WAS APPLIED IN THE PAST TO RECOVER COPPER. ALL LEACH WATER APPLICATIONS WERE TERMINATED IN 2000. MAY ALSO INCLUDE SOME UNDISTURBED GROUND.
(orange diagonal hatch)	3.7	2400	WATERSHEDS THAT CONTAIN WASTE ROCK DISPOSAL AREAS WHERE LEACH WATER WAS NEVER APPLIED. MAY ALSO INCLUDE SOME UNDISTURBED GROUND.
(purple diagonal hatch)	3.6	2300	BINGHAM CANYON MINE OPEN PIT WATERSHED. NOTE: ALL OF THE CARR FORK AND COTTONWOOD WASTE ROCK DISPOSAL AREAS, UPGRADIENT NATURAL DRAINAGES, AND PORTIONS OF THE MARKHAM WATERSHEDS (TOTAL OF 1400 ACRES) DRAIN TOWARDS THE PIT ALTHOUGH THEY ARE LISTED UNDER OTHER CATAGORIES.
(green vertical hatch)	11.0	7000	UNDISTURBED WATERSHEDS WITHIN THE CAPTURE ZONE OF THE MINE'S RUNOFF COLLECTION SYSTEMS. APPROXIMATELY 4200 ACRES OF THIS AREA ARE LOCATED IMMEDIATELY UP GRADIENT OF WASTE ROCK DISPOSAL AREAS.
(blue cross hatch)	2.0	1300	UNDISTURBED WATERSHED WITH DRAINAGE THAT DOES NOT REPORT TO THE MINE'S RUNOFF COLLECTION SYSTEMS.

NOTE: DRAINAGE AREAS ARE LISTED IN ORDER OF GENERALLY IMPROVING WATER QUALITY.



NO.	DATE	REVISION	BY	CHK	APP	REFERENCE DRAWINGS	NUMBER
2	1/22/02	REDRAWN	MWC			ORIGINAL VERSION OF MAP	451-T-0020
1	6/30/94	REDRAWN	PT	LJW	LJW	SUB-DRAINAGE BASIN MAP	451-T-023

ENGINEERING SERVICES

APPROVAL	DATE			DATE
		SCALE:	1"= 4200'	
		DESIGNED BY	PT	6/94
		DRAWN BY	MWC	1/8/02
		CHECKED BY	BV	6/00
		PROJECT ENGINEER		
		PROJECT MANAGER		

KENNECOTT
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FIGURE 10-1 MAP OF BINGHAM CANYON MINE AREA SHOWING WATERSHEDS AND SURFACE WATER COLLECTION SYSTEMS

Job No. --- Dwg. No. 454-T-0007 REV 2

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10.1 CLOSURE ISSUES

The primary closure issues associated with water management are defined by the need to comply with all surface and groundwater regulations and permits in the most cost effective manner. The primary water management issues that will need to be addressed after closure are to:

- comply with the requirements of the UPDES and groundwater discharge permits
- minimize contact of precipitation, surface and groundwater with waste rock, tailings and sulfide-bearing bedrock
- capture contaminated water that has contacted waste rock, tailings and sulfide-bearing bedrock
- segregate different quality water flows to avoid contaminating relatively good quality water with poor quality water
- minimize contaminant loading into down gradient surface and groundwater
- remediate down gradient waters that have been impacted by historical contaminant loading
- treat water to a quality that is consistent with its ultimate end use
- transport water to the appropriate end users or discharge point
- perform groundwater and surface water quality monitoring to ensure down gradient areas are not being adversely impacted

10.2 POST-CLOSURE WATER MANAGEMENT ACTIVITIES

Post-closure water management will involve the collection, treatment and transport of relatively good quality up gradient waters, contaminated contact waters and contaminated waters extracted during remediation activities. Table 10-2 lists the facilities that may be left in place after closure to complete these tasks and lists their locations where available. The final location and configuration of many facilities cannot be determined yet. The final facility designs will be dependent upon water quality and flow data collected between now and closure. Most of the water management facilities are already in existence or will be constructed before closure. After closure on-going management of these facilities will include periodic inspections, routine maintenance and repairs.

10.2.1 Up Gradient Water Collection Systems

As described in Sections 3.0 and 4.0, collection facilities will be constructed up gradient from the waste rock disposal areas and the pyrite halo in the open pit to capture relatively clean water

Table 10-2 *Summary of* Water Management Facilities that are Anticipated to be left in Place at Closure

General Location	Figure/Location	Facility	Anticipated Use
Mine	10-1, up gradient drainages	Up gradient collection systems (1)	Capture good quality water before it contacts sulfide-bearing materials
	2-1, mine area	Pit wall collection systems (2)	Capture of surface contact water before it infiltrates into pyrite halo
	2-1, mine area	Pit floor collection systems (3)	Removal of pit inflows to maintain a nearly dry or partially flooded pit
	2-1, vicinity of # 40	Upper Bingham/Lower Dry Fork collection systems (4)	Capture of leach impacted water before it reaches lower Bingham Canyon
	2-1, ECS	Eastside Collection System (5)	Capture of contact water down-gradient from the waste rock disposal areas
	2-1, # 2	Small Bingham Reservoir	Temporary water storage
	2-1, # 4 and # 29	Large Bingham Reservoir	Temporary water storage
	2-1, # 12	6600 Storage and Evaporation Ponds	Temporary water storage and contact water evaporation
	2-1, vicinity of # 4	*Zone A Reverse Osmosis Plant (6)*	Treatment of Bingham sulfate plume waters
	2-1, vicinity of # 4 or 1-1, # 7	Lime Treatment Plant(s)	Treatment of acidic contact and Bingham remediation waters
	2-1, vicinity of # 6	Copper Recovery Facility	Treatment of selected contact waters to recover copper before lime treatment
SW Jordan Valley	NA	Bingham Plume Collection Systems (7)	Removal of water from the Bingham acid and sulfate plumes
	NA	*SW Jordan Valley Treated Water Pipelines*	*Transport treated or up-gradient waters to points of use in the SW Jordan Valley*
	1-1, # 6	Pipelines within the Tailings Pipeline Corridor (8)	Transport of treated and/or up-gradient waters to points of discharge or use
Tailings Impoundment	1-1, vicinity of # 1 and # 2	Tailings water collection systems (9)	Capture contact water from the tailings impoundment
	1-1, vicinity of # 1	UPDES discharge points	Release selected flows from the collection system into the Great Salt Lake
Not Yet Determined	NA	Water Treatment Sludge Repository	Disposal of sulfate and metals-bearing sludges generated by water treatment

(1) May include pipes, collection sumps, ponds and ditches, cutoff walls, horizontal drains, shallow wells and water removal from underground workings.
(2) May include horizontal drains, pipes, collection sumps and ditches.
(3) May include a lake or collection ponds and sumps with pumps and piping. Water will be piped out via the 5490 tunnel.
(4) May include extraction wells and pipes.
(5) Includes cutoff walls, collection sumps, sedimentation ponds, pipes, canals and pump stations.
(6) KUCC may or may not own and operate this plant at closure.
(7) Will include acid and sulfate extraction wells and pipelines.
(8) This area not included in Permit M/035/002.
(9) May include the clarification canal, collection sumps and ditches, pipes and pump facilities.
NA - The facility locations have either not been determined or are not covered by any accompanying maps.

before it contacts sulfide-bearing waste rock and bedrock. These facilities will generally be located in drainages that have significant surface or shallow groundwater flow which discharges to the waste rock disposal areas. Selected surface water flows from the upper, net neutralizing benches in the open pit will also be captured and removed before they contact the pyrite halo. Collection sites will be located in upper Dry Fork Canyon, upper Freeman Gulch, selected drainages surrounding the open pit (most likely in Zelnora, Log Fork, Cottonwood, Sap and Markham Gulches) and on selected upper pit benches (Figure 10-1). In most cases the collection sites will be designed to capture water flowing on the surface or in alluvium, colluvium or shallow bedrock. Collection structures may include ponds, sumps, ditches, cutoff walls, horizontal drains or extraction wells. Once captured the water will be piped out of the area so that it does not contact any sulfide-bearing material. Pipes will likely transport the water to the mouth of Bingham Canyon, where it can be distributed to end-users. Small recharge areas, poor water quality, lack of surface flow and low bedrock porosity on undisturbed land within Muddy Gulch and Galena Gulch (South Side Natural on Figure 10-1) will generally prevent any significant water capture in these areas.

Gravity flow from some underground workings such as the Bingham, Mascotte, Utah Metals and Butterfield tunnels will continue to dewater some bedrock on the pit margins after closure (Figure 3-7). Selected up gradient underground workings may also continue to be dewatered by pumping after closure. Water is currently being removed from the North Ore Shoot shaft in upper Bingham Canyon and the Carr Fork workings in Pine Canyon. A shaft within the Utah Metals tunnel may also provide a viable up gradient dewatering point. Extraction from these workings would keep the north and west sides of the pit dewatered. After closure, the continued removal of water from selected underground workings surrounding the open pit will prevent groundwater quality from degrading as it flows through the pyrite halo towards the bottom of the pit. In most cases, the captured up gradient water will be of good quality and could be used or discharged without any restrictions.

10.2.2 Contact Water Collection Systems

As described in Sections 3.0, 4.0 and 8.0, contact water collection systems will be maintained after closure to capture water that has been degraded by contact with sulfide-bearing waste rock, tailings and bedrock. The anticipated flows that will need to be captured and treated in perpetuity are listed in Table 10-1. However, the capture of up gradient flows, and the increase in evapotranspiration on recontoured and revegetated surfaces may ultimately reduce the amount of contact water that must be collected.

The Eastside Collection System will continue to operate after closure. This system collects water that has contacted the Eastside, Bingham Canyon and Dry Fork waste rock disposal areas. The collection system captures water that discharges from the toe of the Eastside waste rock disposal areas and that flows in the alluvium of Bingham Creek and several other drainages. The Eastside Collection System is composed of a series of collection sumps and ponds, settling ponds, cutoff walls, pipes, canals and pump stations. Water will also continue to be extracted in upper Bingham Canyon and lower Dry Fork Canyon after closure. Collection systems will include pumping from the West Mountain Shaft or its replacement and pumping from an extraction well located at the intersection of Dry Fork and Bingham Canyons. This collection system is designed to minimize the migration of contaminated water from the Dry Fork/Bingham Canyon area into lower Bingham Canyon. Water extraction at these sites in upper Bingham Canyon will likely decrease the quantity and improve the quality of water that must be captured at the cutoff wall.

Surface water collection systems will also be established on the lower, net acid-generating walls of the open pit to capture water from runoff, springs, and underground workings before it can infiltrate into the pyrite halo. The water will be captured in collection sumps and will either be piped to the bottom of the pit, or it will be piped directly out of the pit. Water that discharges into the bottom of the pit will ultimately be pumped out via the 5490 tunnel.

Collection systems on the margins of the South Tailings Impoundment will also need to be maintained after closure. Contact water from seeps and springs on the lower embankment slopes will be captured in ponds, sumps or ditches. This water will then be managed in conjunction with contact waters from other parts of the operation.

In most cases, contact water that is captured will have to be treated before it will meet standards acceptable for irrigation, drinking water or discharge to surface water.

10.2.3 Bingham Creek Groundwater Remediation

The historic groundwater contamination in the southwest Jordan Valley has been subdivided into two zones, Zone A and Zone B, for management purposes. Zone B, includes an area east and southeast of the former KUCC evaporation ponds in South Jordan, and is characterized by sulfate concentrations averaging approximately 700 mg/L. Zone B treatment will be addressed through a Reverse Osmosis (RO) treatment plant which will be constructed by the Jordan Valley Water Conservancy District (JVWCD) located at approximately 1300 West and 8200 South.

The most significant portion of Zone A, is located immediately down gradient from the Large Bingham Reservoir. Water in the core of Zone A is characterized by low pH (<4.5), elevated heavy metals, and high sulfate (>20,000 mg/L). The settlement of a Natural Resource Damage (NRD) claim made by the State of Utah against KUCC for contamination of groundwater in the southwestern Jordan Valley required among other things that the acidic portion of the plume be pumped at an annual rate of 250 gpm based on a rolling five year average. The principal objective of the NRD claim is to "restore, replace or acquire the equivalent" of the damaged groundwater resource. There are portions of the settlement that overlap the scope of CERCLA remedial actions that are also required. These include among others, preventing the migration of contaminated groundwater into previously uncontaminated portions of the aquifer. The U.S. Environmental Protection Agency's Record of Decision (ROD) for the CERCLA action also provides that KUCC:

- Monitor the plume to follow the progress of natural attenuation for the portions of the Zone A plume which contain sulfate in excess of the state primary drinking water standard for sulfate (500 ppm sulfate).

- Disposal of treatment concentrates via the existing pipeline used to slurry tailings to the tailings impoundment prior to mine closure.

- Develop a post-mine closure plan to handle treatment residuals for use when the mine and mill are no longer operating.

Recent groundwater modeling suggests a much higher pumping rate than 250 gpm is required to contain the plume. The Remedial Investigation and Feasibility Study (RI/FS) for the contaminated groundwater demonstrated that the plume will continue to flow towards the Jordan River unless hydraulically contained and that the extracted acidic water must be treated before discharge. The RI/FS calls for the installation of additional groundwater extraction wells in the acidic portion of the plume that will be pumped at a rate of approximately 2000 to 2500 gpm. The pumping rate will remove most of the acidic plume before closure and will satisfy the NRD settlement and CERCLA corrective action requirements. Additionally, as proposed in the RI/FS, a barrier well system to extract elevated sulfate in groundwater and hydraulically contain the plume will be installed at the plume terminus.

The acidic water removed from the core of Zone A will be neutralized with lime and tailings and will be discharged to the tailings line during the active life of the mine. It is anticipated that before closure, one or more lime treatment plants will be built somewhere near the mouth of Bingham Canyon. The lime treatment capacity will be sized to handle the anticipated post-closure flows. A plant for treating Zone A sulfate water from the margins of the plume will be constructed by KUCC near the barrier wells. The treatment system will use RO treatment technology to produce approximately 3500 acre-feet/year of drinking quality water. As required by the EPA ROD, the clean RO permeate water will be sent to municipal supply for delivery through the Jordan Valley Water Conservancy District (JVWCD) distribution pipelines to affected users. The RO concentrate will be discharged to the tailings line during the active life of the mine. Studies have been conducted as part of the Remedial Design Workplan to ensure that the deposition of treatment sludges and precipitates in the North Tailings Impoundment (DOGM permit number M/035/015) will not adversely impact the geochemical stability of the tailings. Geochemical monitoring will also continue for the life of the project.

The current assumptions for the post-closure management of RO concentrate and lime-neutralized water is for it to be discharged to the Great Salt Lake through a future permitted discharge outfall. Further studies, to confirm the feasibility of this option and address post-closure management of lime treatment sludges will be conducted over the next few years as part of the Remedial Design Workplan. Options to be evaluated include stabilization of the sludge and placement on the waste rock disposal areas or construction of a repository.

10.2.4 Mine Water Treatment and Discharge

Acidic post-closure flows from the mine area may total about 1500 gpm (Table 10-1). Depending on the final closure scenario selected for the pit, up to about 2500 gpm may also need to be treated at closure (pit with a small collection pond or ponds) or treatment may be delayed for up to 30 years after closure (partial flooding scenario). It is anticipated that all of these post-closure flows will be treated by lime neutralization, sedimentation and clarification. It is also possible that a small pretreatment plant may also remain in place after closure to recover copper from selected copper-bearing flows that discharge from the waste rock disposal areas. This plant would likely be located above the cutoff wall in lower Bingham Canyon and will feed water to the lime plant.

As indicated in section 10.2.3, KUCC intends to remove most of the acidic groundwater plume before closure. At closure, the reduction in treatment needs for the acid plume, will allow for lime treatment plant capacity to be available for the mine flows. The treated effluent may be pumped to the tailings pipeline and ultimately discharged into the Great Salt Lake. Some of the water may also be provided for municipal use if it is treated sufficiently. The sludges generated during the treatment of mine waters will be handled in a similar manner to the sludges generated by the acid plume remediation. During active operations these sludges will be discharged to the tailings impoundment, but after closure they will be handled as determined in the Remedial Design Workplan.

10.2.5 Long-Term Monitoring

Long-term monitoring of surface water and groundwater quality will be required after closure to ensure that remediation objectives have been attained and to ensure that down gradient areas are not negatively impacted by waste rock, tailings and sulfide-bearing bedrock. Monitoring will generally be accomplished by the periodic sampling of wells and surface flows. Figures 10-2 and 10-3 are maps showing the existing wells owned by Kennecott within the permit boundaries. The wells are designated as permit monitoring wells, production wells and other monitoring wells. After closure it is likely that many of the monitoring wells required by groundwater discharge permits and most of the production wells will be left in place. Continued access to some of the non-permit monitoring wells will also be needed after closure. Those wells that do not have a post-mining use will be abandoned in accordance with all applicable regulations including with the State Engineers specifications.

It is anticipated that after closure at least 25 years of monitoring will be required for Groundwater Discharge Permits UGW350010 and UGW350011. These permits are associated with the waste rock disposal areas and the tailings impoundment respectively. Post-closure monitoring requirements for the groundwater discharge permit associated with the North Concentrator may be of a shorter duration. After all process materials and facilities have been removed from the North Concentrator site and the land has been reclaimed, there will be no potential contaminant sources remaining. Other than general assumptions about the duration of monitoring, it would be premature to try to designate post closure sampling points and frequencies at this time. A detailed post closure monitoring plan for the ground discharge permits will be prepared a short time before closure based upon the surface and groundwater conditions at that time.

11.0 FUTURE AND ON-GOING RESEARCH IN SUPPORT OF CLOSURE

KUCC has been conducting research in support of reclamation and closure since 1978. Much of this work has focused on long-term management of water resources and on the development and testing of reclamation techniques.

In particular, since 1992 KUCC has developed and tested several revegetation methods for the waste rock and tailings disposal areas. This work has been focused on several technologies including slope reduction techniques, the use of biosolids and other soil amendments, the placement of various types and thicknesses of cap materials, the use of acid-neutralizing agents and the planting of mycorrhizae-inoculated and un-inoculated seeds and seedlings. These efforts began with test plots and culminated in the slope reduction, capping and revegetation of 330 acres of low pH waste rock surfaces and additional acres on the existing tailings impoundment. Investigations have recently focused on direct planting onto older waste rock surfaces that have favorable soil chemistry. To date approximately 200 acres of waste rock surfaces with favorable soil chemistry have been recontoured into natural landforms, amended with liming agents and have been directly planted. This research will continue in the future, testing new technologies as they become available and existing techniques in new physical and geochemical environments.

Preliminary studies of waste rock soil geochemical evolution, volunteer vegetation establishment on waste rock surfaces, reclamation and infiltration modeling, direct planting on waste rock surfaces, long-term implications of biosolids application and pit wall acid/base accounting geochemistry have also been completed recently. There are many other ongoing or planned research projects that are designed to fill some of the data requirements identified in Sections 3.0 through 10.0. These studies include:

<u>Study Description</u>	<u>Status</u>
Acidification Potential of the Tailing Impoundments	On-going
Acid Base Accounting Study of Current and Ultimate Pit Walls	On-going
Waste Rock Revegetation Test Plots with Various Soil Amendments	On-going
Botanical Surveys of Past Reclamation Sites	On-going
Pit-Slope Stability Analysis	On-going
Waste Rock Stability Analysis	On-going
Waste Rock Disposal Area Water Balance	On-going
Treatability Study of the Bingham Groundwater Plume	On-going
Treatability Studies of Leach Water and ARD	On-going
Ecological/Human Health Risk Assessment	On-going
Regional Numeric Groundwater Modeling	On-going
Land Use Master Plan	On-going
Waste Rock Disposal Area Design Studies	On-going
Geochemical Evolution of Tailings Impoundment Soils	On-going
Slope Stabilization Study of South Eastside Waste Rock Disposal Areas	On-going
Survey of Surface and Shallow Groundwater Flow Around the Open Pit	On-going
Precipitation Plant Closure Plan	Planned

Hydrogeology of the Post-closure Pit	Planned
Water Chemistry of the Post-Closure Pit	Planned
Long-Term Sustainability Plan	Planned
Closure Waste Rock Soil Geochemistry Survey	Planned

12.0 REFERENCES

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APPENDIX A - 1976 MINING AND RECLAMATION PLAN

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL, GAS, AND MINING
1588 West North Temple
Salt Lake City, Utah 84116
(801) 533-5771

October 2, 1978

ACT/035/002

Mr. Chuck Stillman
Kennecott Copper Corporation
P.O. Box 11299
Salt Lake City, Utah 84147

Re: Final Approval for
Kennecott Copper Corporation's
Mining and Reclamation Plan
Bingham Canyon Mine

Dear Mr. Stillman:

The Board of Oil, Gas, and Mining, at its September 28, 1978 executive meeting, approved your previously submitted surety contract for reclamation of the Bingham Canyon Mine.

Enclosed herewith is Kennecott's copy of the fully executed Mined Land Reclamation Contract. Therefore I hereby issue final approval to the Kennecott Copper Corporation's Bingham Canyon Mine to operate under the Utah Mined Land Reclamation Act.

Sincerely,

Cleon Feight

CLEON B. FEIGHT
DIRECTOR

CBF/sp
enc: Reclamation Contract

Do not retype Copy + insert

RECEIVED SEP 8 1978

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
BOARD OF OIL, GAS, AND MINING
1588 WEST NORTH TEMPLE
SALT LAKE CITY, UTAH 84116

*** MINED LAND RECLAMATION CONTRACT ***

THIS CONTRACT, made and entered into this 28TH day of SEPTEMBER, 1978, between Kennecott Copper Corporation a corporation duly authorized and existing under and by virtue of the laws of State of Utah as party of the first part, and hereinafter called the Operator, and the BOARD OF OIL, GAS, AND MINING, duly authorized and existing by virtue of the laws of the State of Utah, as party of the second part hereinafter called the Board.

WITNESSETH:

WHEREAS, the Operator is the owner and in possession of certain mining claims and/or leases hereinafter more particularly mentioned and described in Exhibit "A" attached hereto.

WHEREAS, the Operator did on the Ninth day of August 1976, file with the Division of Oil, Gas, and Mining, a "Notice of Intention to Commence Mining Operations" and a "Mining and Reclamation Plan" to secure authorization to engage, or continue to engage, in mining operations in the State of Utah, under the terms and provisions of the Mined Land Reclamation Act, Section 40-8, U.C.A., 1953.

WHEREAS, the Operator is able and willing to reclaim the above mentioned "lands affected" in accordance with the approved Mining and Reclamation Plan, the Mined Land Reclamation Act of 1975 and the rules and regulations adopted in accordance therewith.

WHEREAS, the Board has considered the factual information and recommendations provided by the Staff of the Division of Oil, Gas, and Mining as to the magnitude, type and costs of the approved reclamation activities planned for the land affected.

WHEREAS, the Board is cognizant of the nature, extent, duration of operations, the financial status of the Operator and his capability of carrying out the planned work.

NOW THEREFORE, for and in consideration of the mutual covenants of the parties by each to the other made and herein contained, the parties hereto agree as follows:

1. The Operator promises to reclaim the land affected in accordance with its Mining and Reclamation Plan which was approved by the Board on February 22, 1978, the Mined Land Reclamation Act, and the rules and regulations adopted in accordance therewith.

2. The Board, in lieu of accepting the posting of a bond or other surety, accepts the personal guarantee of the Operator to reclaim the land affected in accordance with its approved reclamation plan.

3. The Board and Operator both agree that the Operator will be obligated to expend a minimum average, excluding salaries, but not operating wages, of $50,000 - 1978 dollars per year for each three (3) year period, in maintaining a program of experimentation and in the application of the best available technology toward rehabilitation of land associated with or affected by mining or processing operations.

4. The Board and Operator further agree that the annual expenditure as set forth in paragraph three (3) above, unless waived by the Board, will continue until mining as described in the notice of intention is permanently terminated, and that said annual expenditure will not constitute the fulfillment of the obligations of the Operator as to mined land reclamation. The Operator further agrees to waive the requirements for the fixed sum as surety as required in Section 40-8-14 (8), U.C.A., 1953.

5. The Operator agrees to provide to the Board and Division annually, a detailed report of reclamation work performed during the preceeding year, including a cost accounting for said reclamation work in 1978 dollars.

6. The Operator further agrees to work jointly with the Division in establishing annual reclamation plans for each forthcoming year. Said plan will be subject to the review of the Board. Consideration will be given to the annual report of the previous year in establishing such plans.

7. The Operator agrees to designate a responsible individual who is involved in the Operator's on-going reclamation efforts, who will serve as liaison to the Division.

8. This contract shall be binding on all successors and assigns, to the Operator.

IN WITNESS THEREOF, the parties of the first and second parts, here to have respectively set their hands and seals this 28 day of Sept.

1978

KENNECOTT COPPER CORPORATION

By: [signature]

Its President ~~Metal Mining Division~~

ATTEST:

[signature]

Ass't Secretary

APPROVED

[signature]

BOARD OF OIL, GAS, AND MINING

By: [signature]

Chairman

Note: If the Operator is a corporation, the agreement should be executed by its duly authorized officer with the seal of the corporation affixed.

MINING APPLICATION
NO. ACT-035-002

Date August 9, 1976

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL, GAS AND MINING
1588 West North Temple
Salt Lake City, Utah 84116

NOTICE OF INTENTION TO COMMENCE MINING OPERATIONS
(See Rule M of General Rules and Regulations)

1. Name of Applicant or Company Kennecott Copper Corporation, Utah Copper Division
Corporation (X) Partnership ( ) Individual ( )

2. Address P. O. Box 11299, Salt Lake City, Utah 84147
Permanent

3. Name and title of person representing company B. B. Smith, General Manager

4. Address P. O. Box 11299, Salt Lake City, Utah 84147 Office Phone 322-1533

5. Location of Operations Salt Lake and Tooele County within the following sections:

Sec 7, 8, 9, 10, 11, 17, 18, 19, 20, 21, 30, 31 & 32, T1S, R2W, SLB&M;
Sec 9, 10, 11, 12, 13, 14, 15, 16, 22, 23, 24, 25, 26 & 36, T1S, R3W, SLB&M;
Sec 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16, 17, 22, 23, 27, 28 & 33, T2S, R2W, SLB&M;
Sec 7, 17, 18 & 19, T3S, R1W, SLB&M;
Sec 4, 8, 9, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 25, 28, 29, 30, 31 & 32, T3S, R2W, SLB&M;
Sec 11, 12, 13, 14, 15, 21, 22, 23, 24, 25, 26, 27, 33, 34, 35 & 36, T3S, R3W, SLB&M;
Sec 6 & 7, T4S, R2W, SLB&M;
Sec 1, 2, 3, 11 & 12, T4S, R3W, SLB&M.

6. Name of Mine Bingham Canyon Mine

7. Mineral to be mined:

( ) Coal
(X) Copper
( ) Manganese
( ) Iron Ore
( ) Phosphate
( ) Potash
( ) Fluorspar
( ) Flagstone
( ) Gravel
( ) Shale
( ) Uranium
( ) Gilsonite
( ) Bituminous Sandstone
( ) Tungsten
(X) Other (specify) Minerals associated with copper.

Mining methods:

Open pit, waste leaching, insitu leaching, underground.

8. Have you or any person, partnership or corporation associated with you received an approved Notice of Intention to Commence Mining Operations by the State of Utah for operations other than described herein?
( ) Yes (X) No *
If yes, list all approval numbers now under surety:
* Kennecott's Tintic Mines Division may have requested approval.

9. Owner/Owners of record o– the surface area within the la(o be affected:

Kennecott Copper Corporation	Address	161 East 42nd Street, New York, NY 10017
U. V. Industries	Address	(Local Office) University Club Bldg, Salt Lake City, UT
The Anaconda Company	Address	(Local Office) 1849 West North Temple, Salt Lake City, UT

10. Owner/Owners of record of minerals to be mined:

Kennecott Copper Corporation	Address	161 East 42nd Street, New York, NY 10017
U. V. Industries	Address	(Local Office) University Club Bldg, Salt Lake City, UT

11. Owner/Owners of record of all other minerals within any part of the land affected:

The Anaconda Company	Address	(Local Office) 1849 West North Temple, Salt Lake City, UT

11a. Have the above owners been notified in writing?
(X) Yes ( ) No

12. Source of Operator's legal right to enter and conduct operations on land to be covered by the Notice:

Legal documents, including deeds, easements, mining claims, agreements, licenses, etc.

13. Approximate acreage to be disturbed:

Mine	3,100 acres
Mine waste disposal	8,000 acres
Excess mine water disposal	2,700 acres
Ore transfer - mine to process	400 acres
Ore processing facilities	1,800 acres
Tailing disposal	6,000 acres
Excess process water disposal	1,000 acres
Total	23,000 acres

14. Give the names and post office addresses of every principal Executive, Officer, Partner, (or person performing a similar function) of Applicant:

	Name:	Title:	Address:
a.	B. B. Smith	General Manager Utah Copper Division	P. O. Box 11299 Salt Lake City, UT 84147
b.	H. H. Kremer	President Metal Mining Division	161 East 42nd Street New York, NY 10017
c.	F. B. Milliken	President	161 East 42nd Street New York, NY 10017

15. Has Applicant, any subsidiary or affiliate of any person, partnership, association, trust, or corporation controlled by or under common control with Applicant, or any person required to be identified by Item 14, ever had an approval of a Notice of Intention withdrawn or has surety relating thereto ever been forfeited?

( ) Yes (X) No

If yes, explain:

STATE OF UTAH)
: ss
COUNTY OF SALT LAKE)

I, B. B. Smith, having been duly sworn depose and attest that all of the representations contained in the foregoing application are true to the best of my knowledge; that I am authorized to complete and file this application on behalf of the Applicant and this application has been executed as required by law.

KENNECOTT COPPER CORPORATION
Utah Copper Division

By [signature]
Its General Manager

Taken, subscribed and sworn to before me the undersigned authority in my said county, this 9th day of August, 1976.

Keith L. Hansen
Notary Public

My Commission Expires:
November 1, 1979

MINING APPLICATION

NO. ACT-035-002

DATE: August 9, 1976

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL, GAS AND MINING
1588 WEST NORTH TEMPLE
SALT LAKE CITY, UTAH 84116

MINING AND RECLAMATION PLAN

PREAMBLE

Planning for rehabilitation of an operation mine is always difficult. This difficulty is magnified many times when the expected life of the mine may be decades or even a century. Such is the case of the Bingham Mine. It is not even possible to determine the approximate land uses at the end of the mining operation. For that reason, this rehabilitation plan cannot be as specific as that of other, more short-lived, operations.

However, regardless of the end use of the land, it is the intention of Kennecott to leave the land in a stable and productive condition consistent with location, possible uses, and topography, recognizing that since the mine is open pit in nature that the land itself cannot be restored as it was prior to commencement of mining.

To accomplish these objectives, Kennecott will maintain a program of experimentation and will apply the best available technology toward rehabilitating each piece of land as it moves from mining to other uses. A detailed annual report of reclamation work performed during the preceding year will be developed for review by the Board of Oil, Gas and Mining. These annual reports will be utilized by Kennecott and the Division in jointly establishing reclamation plans for the forthcoming year with the intent of accomplishing the overall objectives.

The following plan represents an attempt to outline some of the possible land uses and describe the steps the company will take to reach the general objectives.

MINING AND RECLAMATION PLAN

A. Applicant - Kennecott Copper Corporation, Utah Copper Division.

B. Type of Operation - Mining and processing for mineral extraction. Mining method and processing facilities are continually modified and updated to meet natural and physical requirements and conditions of market, technology, governmental regulation, economics and other factors. Large scale mining operation has been underway since about 1904. Remaining life of the mining operation will depend upon many things including the likelihood that eventual mineral shortages and improved technology will justify mineral extraction from materials now considered waste. It is, therefore, impossible to predict a terminal point for the mining and processing operations. However, it is not expected that this terminal point will occur within the next 50 years.

The Utah Copper Division operations extend from in and around the Bingham Mine to just beyond the north end of the Oquirrh Mountains near Magna (see CONFIDENTIAL map, Exhibit A). The operation is divided into the following areas which are identified on Exhibit A, shown in schematic arrangement on process diagram Exhibit B, and covered separately herein:

1. Mine
2. Mine Waste Disposal
3. Excess Mine Water Disposal
4. Ore Transfer-Mine to process
5. Ore Processing Facilities
6. Tailing Disposal
7. Excess Process Water Disposal

1. Mine Area

The mine area from which overburden and ore is removed comprises approximately 3100 acres.

Prior to open pit mining which began in 1904, this mountainous area had been a source of timber and was being used for underground mining operations with associated surface facilities, residences, businesses, etc. As open pit mining has expanded, these other used have been discontinued.

Determination of a definite use for the area after mining operations cease is difficult due to many uncertainties involved, but will be determined in light of potential use of the land and the condition of the land after reclamation by means that are technologically and economically practicable. Possibilities include:

Scenic attraction.

Historical landmark.

Other public or private use.

Very little vegetation remains in the mining area because of the considerable volume of material having been displaced. The remaining vegetation consists of grasses, forbs, shrubs, and trees such as aspen, mountain mahogany, Utah juniper and fir. The pH of undisturbed soils ranges from 4.5 to 7.5 as determined by mixing 100 gm of soil with 100 ml of distilled water. Most materials removed from or exposed in the mine are acidic. Surface elevation ranges from approximately 5240 feet to over 7800 feet above sea level.

Underground workings and natural bedrock aquifers have been, and will continue to be, encountered during mining operations. The drainage from these abandoned mines and fault-related aquifers is discharged through a railroad tunnel to supply make up water for leaching operations. At times the water is bypassed by pipeline and canal to a disposal area (see Area 3). Typical analysis of this water is listed below:

pH	4.7	Fe	100 ppm
TDS	2,400 ppm	Cl	70 ppm
SO_4	1,400 ppm	Ca	500 ppm
Al	5 ppm	Cu	4 ppm
Mg	50 ppm		

Experiments are being conducted to determine if this water can be used for irrigation.

Since open pit mining began, over 1,350,000,000 tons of ore and 2,400,000,000 tons of waste have been removed. This is one of the largest mining operations ever undertaken, having produced more copper than any other mine in history. The present excavation is approximately 2-1/4 miles wide and 1/2 mile deep (see photograph Exhibit C). There are now 56 levels or benches in the mine which typify open-pit mining, a feasible and economical system for handling the low grade ore and overburden in vast quantities. Height of the benches ranges between 40 and 50 feet. Material is now being removed from 20 lower benches and from upper benches by truck.

After crushing, the ore will be conveyed out of the pit to a new grinding facility located approximately one mile north of Copperton. Waste will be hauled by truck to the existing waste dumps.

The ore body is in the shape of a plug, or an inverted cone. As the mine progressively develops in depth, all benches must be pushed farther and farther back to gain necessary operating space and assure safety by maintaining a stable slope ranging from 25 1/4 to 29 1/4 from horizontal. Modernization and other technological advances, such as innovative dewatering techniques, will allow maintenance of stable pit slopes as a function of specific rock type and moisture conditions in the various sections of the mine. At the conclusion of mining, pit sides will be stabilized at a slope of 30° to 50° from horizontal as a function of location in the mine.

The mining sequence includes drilling, blasting, loading by shovel and haulage by trucks, waste cars and ore cars. At the present time, approximately 108,000 tons of ore and 380,000 tons of waste are removed during each operating day. Ore is transported by rail to process plants, and waste is deposited in outlying areas of the mine (see Area 2). Equipment size continues to increase through improved materials and technology. Haulage trucks now in use at the mine range in capacity from 65 tons to 150 tons. Shovels range from 6-yard to 25-yard capacity.

It is expected that in the future other mining methods such as underground mining and in-situ extraction may become economically feasible and practiced for recovery of lower lying minerals in the Bingham mine area.

At present, it is not possible to perform any revegetation on active dumps or in the pit as open pit mining progresses because the total area is continually being disturbed. At the conclusion of open pit mining, sides will be stabilized at a slope in the range of 32 1/4 to 37 1/4 from horizontal. It is very unlikely that the pit could be revegetated at that time because most of the exposed surface will be solid rock containing natural sulfide mineralization. Meteoric water and atmosphere will generate acidic conditions from these minerals. The bottom of the pit may eventually fill with water; however, the level can be limited by discharge through one of the available railroad tunnels. Such discharge water would either be processed for mineral extraction and neutralization, impounded, used for other acceptable purposes or otherwise safely disposed of as may be determined in the future by the appropriate regulatory agency.

Surface facilities including buildings, railroad tracks, power lines and poles and equipment will be removed from the mine area when no longer needed in the mining or subsequent operations.

2. Mine Waste Disposal Area

Waste material or overburden removed from the mine is deposited in outlying areas in Bingham Canyon, on the west front of the Oquirrhs and in Butterfield Canyon. Total area comprises approximately 8000 acres. Leaching and precipitation operations are conducted for recovery of minerals from this waste material.

Prior to use for waste disposal, the area ranged in elevation from 5200 feet to 7900 feet above sea level and had been a source of timber, was used for dry farming, grazing, and underground mining with associated facilities, residences, business, etc. These uses have been discontinued as waste material has covered the area. However, some grazing and dry farming continues on low lying perimeter areas.

It is expected that leaching and precipitation operations and possibly other processing methods will be used for mineral extraction from the dumps long after final deposition of mine waste is completed. Some possible ultimate uses of the area may include:

A source of borrow and granular material
Residential, commercial or industrial development
Recreational
Scenic
Other

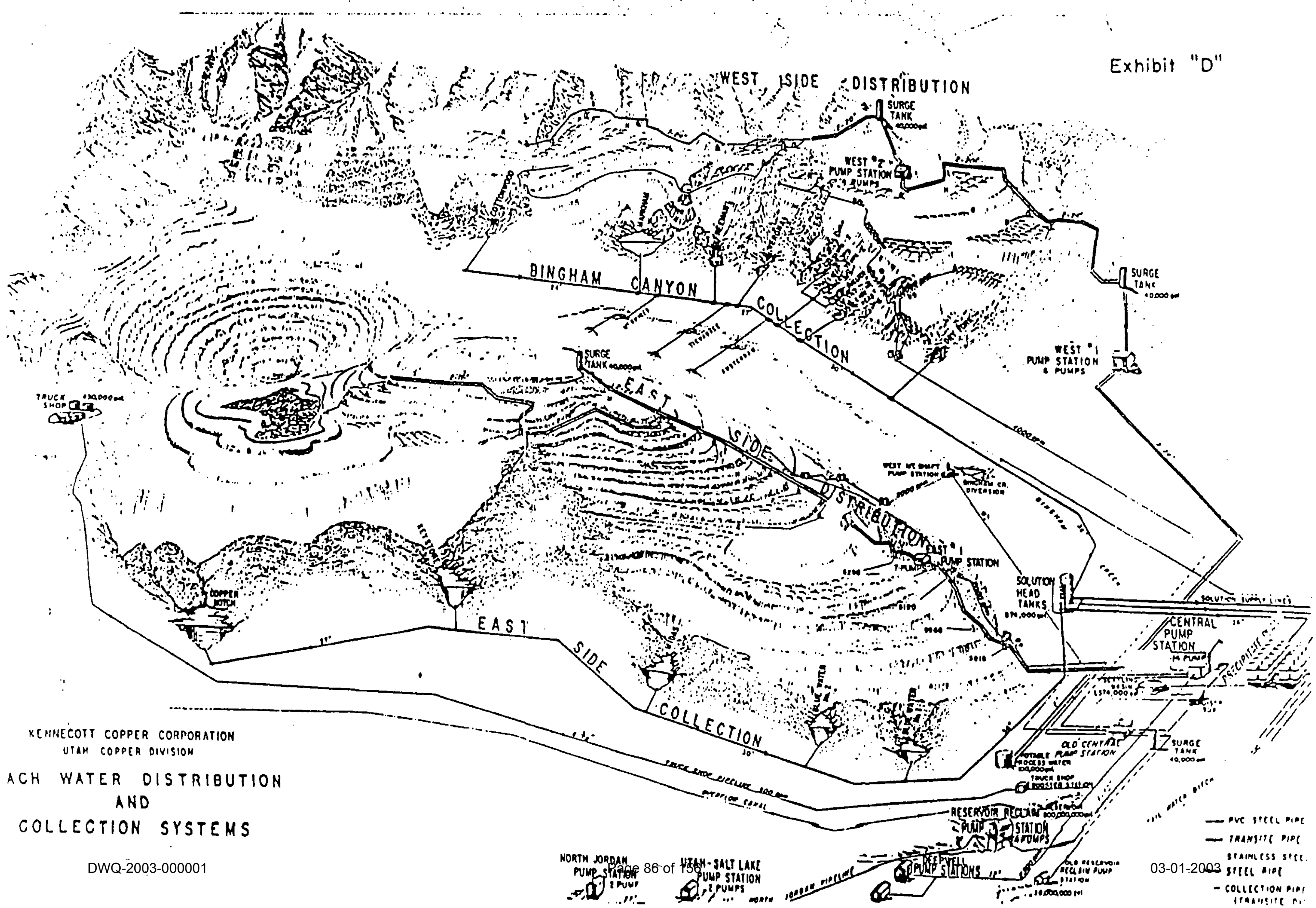
Little or no vegetation exists on areas covered by waste dumps. Vegetation on area that will eventually be covered consists of grasses, forbs, shrubs and trees such as juniper, mountain mahogany and maple. The pH of undisturbed soils ranges from 4.5 to 7.5 as determined by mixing 100 gm of soil and 100 ml of distilled water. Waste dumps tend to become acidic from meteoric water and atmosphere and from the leach solutions (pH 3 - 3.5) that are distributed over the dumps.

The leaching and collection system, including the protection against escape of leach water from waste dumps into lower lying areas, is shown in schematic arrangement on Exhibit D. It consists of reservoirs, pumps and piping to distribute solution on the dumps, pipelines from dams to the precipitation plant and an overflow canal to collect and convey any escaping solution to the reservoir. Leach solution is processed at the precipitation plant for mineral recovery. During extremely wet or high runoff period, excess leach solution may accumulate in the reservoirs and require discharge to the Excess Mine Water Disposal Area (Area 3).

As noted under Area 1, waste dumps presently comprise approximately 2,400,000,000 tons of material and are increasing at the rate of 380,000 tons per day. Waste is transported from the mine by trucks and is dumped over the banks to a natural angle of repose. Rail dumps are terraced at approximately 100 foot levels which progress out generally in a uniform manner. Truck dumps are higher and are extended out at the same level without terracing. Problems in dumps stability have been encountered on some large truck dumps which are generally associated with inadequate foundation material underlying the dumps. Slides have occurred from failure of this underlying or foundation material. However, because these dumps are active, no attempt is needed to stabilize these areas other than monitoring and precautionary systems for safety. Movement detection switches and movement noise detectors have been installed to detect any dump movement prior to failure. These systems will continue to be maintained and improved as mining progresses. In addition, computer models have been developed to simulate conditions in dumps to estimate the position of the dump crest when stability becomes critical. In the future, control points or a survey net may be established to check dump movement and settlement. After dumps become inactive for dumping, other steps will be implemented so that all dumps are left in a safe and stable condition. Techniques to accomplish this may include terracing and hydraulic methods consistent with subsequent use determined at that time. Necessary collection systems will be provided to contain natural seepage in the area. Dikes and ponds will be constructed on the upper levels of dumps to prevent slope wash and possible mud slides.

No major revegetation is planned because the majority of the waste material contains natural sulfide mineralization which becomes acidic when exposed to meteoric waters and the atmosphere. However, in some small areas of the dumps where there is little or no sulfide mineralization, tests are being conducted to determine possible methods and types of vegetation suitable for these areas. These tests include aerial

Exhibit "D"



KENNECOTT COPPER CORPORATION
UTAH COPPER DIVISION

ACH WATER DISTRIBUTION
AND
COLLECTION SYSTEMS

seeding of approximately 20 acres with grasses, forbs and shrubs, and hand planting of a two-acre control area for more detailed study which is being conducted jointly with the U. S. Forest Service. If and when revegetation practices or methods are developed which would make vegetation economically practicable, such practices and methods will be employed on the dumps. When no longer needed in the mining, mineral extraction or subsequent operations, all surface facilities, including buildings, above ground utilities, railroads, piping and equipment will be removed. Much of this type effort has been accomplished in the past, including demolition of buildings in the city of Bingham Canyon, removal of trackage from old rail dumps and removal of bridges in Carr Fork and other demolition and clean up work. Appropriate revegetation of these areas will take place.

3. Excess Mine Water Disposal Area

This involves an approximate 2700-acre area upon which excess mine water is transported and contained in ponds for evaporation. Facilities may be installed at a later date for treatment of water prior to disposal.

Prior to use for excess mine water disposal, which commenced in 1935, the land was used for grazing and dry farms. After construction of the Bingham Creek reservoir at the mouth of Bingham Canyon in 1965, discharge to the evaporation pond area was considerably reduced and now required only during extremely wet or high runoff periods. Currently, much of the land is used for dry farming and sand and gravel operations.

Possible future uses of the land when no longer needed in the mining operation may include one or more of the following:

- Sand and gravel operations
- Farming
- Water storage and evaporation
- Recreational
- Sludge or water disposal by others
- Residential, commercial or industrial development
- Other

In addition to dry-farm wheat, the area contains natural grasses, forbs and shrubs. The pH of the natural soils ranges from 6.5 to 7.5 as determined by mixing 100 gm of soil and 100 ml of distilled water. Surface elevation ranges from approximately 4675 feet to 5200 feet above sea level.

Residues of evaporation are acidic and contain soluble ions of iron, aluminum, magnesium and sulfate. Depending upon specific source of excess water from mine operation, water analysis will range between the following values:

pH	4.7 - 3.2	Fe	100 - 2,400 ppm
TDS	2,400 - 6,700 ppm	Cl	70 - 180 ppm
SO_4	1,400 - 52,000 ppm	Ca	400 - 500 ppm
Al	5 - 4,600 ppm	Cu	4 - 100 ppm
Mg	50 - 6,300 ppm		

Evaporation ponds are contained and separated by dikes constructed of earth from the area. Dikes are approximately four feet high and twelve feet wide on top. Side slopes are approximately two horizontal to one vertical. Dikes are monitored and maintained to prevent spill of solution.

At such time as area is no longer needed for excess water disposal or other purposes associated with mining operation, stabilization will be accomplished consistent with subsequent use determined at that time. Stabilization will take into account all pertinent factors including surrounding land usage, potential use, and may include removal or covering accumulated salts, treatment with neutralizer, grading and revegetation work. In any event, area will be left in a safe, table condition suitable for future use and without hazard of erosion or surface water accumulation.

Because the area appears better suited for future uses in farming than other vegetative purposes, any revegetation work would most likely be accomplished to suit farming requirements. In the event of farming, or soil stabilization, this would involve testing by standard agricultural analysis (e.g. Utah State Soils Laboratory), application of fertilizer and cultivation. Such crops as wheat, barley, alfalfa, wheatgrass and clover could be raised. irrigation could be considered if sufficient water becomes available.

There will be no changes in the excess mine water disposal area as a result of modernization. Kennecott is conducting an extensive surface water study. The results of this study may change water usage practice. Kennecott is also conducting a detailed five-year study relevant to this area in cooperation with the State of Utah and Salt Lake County. Any recommendations for amendment of this area will be forthcoming after the study is completed.

4. <u>Ore Transfer - Mine to Process Area</u>

From the mine area at Bingham, ore was transported to the processing plants near Magna by railroad cars. Instead, the ore will be conveyed to a grinding plant located one mile north of Copperton. Approximately 37 acres of right-of-way between the mine and grinding plant will be disturbed by the construction of the conveyor. After construction is completed, the right-of-way will be replanted with a mixture of grass seeds. When the conveyor is no longer needed for mining or other activities, the surface structures will be removed. The area will then be returned to the farming and pasture usage currently ongoing on the property.

The existing railroad between the mine and the facilities near Magna will be maintained and will be used for the transport of precipitate copper and general freight.

Land along the railroad is used primarily for dry farming. It may have been previously used for grazing.

When no longer needed in the mining operation, the railroad may be used to serve future industrial or commercial needs. Otherwise, the railroad right-of-way will have potential use for:

Residential, commercial or industrial development
Utility right-of-way
Roadway
Other

In addition to dry farm wheat, the area contains natural grasses, forbs and shrubs. The pH of the soils ranges from 6.5 to 7.5 as determined by mixing 100 gm of soil and 100 ml of distilled water. Surface elevation ranges from approximately 5400 feet to 4500 feet above sea level.

At such time as the railroad is no longer needed in the mining or processing operations or for subsequent use, trackage and surface facilities will be removed and area left in condition suitable for conversion to other use determined at that time. Revegetation will be accomplished if appropriate for the subsequent use when the trackage and surface facilities are removed and the right-of-way has no future use as such.

5. <u>Ore Processing Facilities Area</u>

Over the years ore processing facilities have been added, changed, enlarged and improved to suit needs and conditions. Many more such modifications are expected in the future. Facilities at one time consisted of the Arthur, Magna, and Bonneville concentrators, power plant, railroad car and engine shops, lime plant, foundry and other supporting and related surface structures and utilities. Total land area comprises approximately 1600 acres. Other separated facilities include water supply and distribution systems and maintenance shops. This represents a total additional area of approximately 200 acres.

As modernization takes place, ore will be received via conveyor at a coarse ore stockpile located at a new ore grinding plant north of Copperton. Ore will be reclaimed from beneath the pile and will be ground in semi-autogenous (SAG) mills and ball mills. The ground ore will be gravity slurried, via pipeline, to the existing concentrators for additional processing through the existing facilities.

The grinding plant will be located on a 100-acre site currently under cultivation for wheat. Following construction, the disturbed but undeveloped areas will be replanted. When the grinding plant is no longer needed for mining or other activities, the surface structures will be removed. The area will then be returned to agriculture or will be available for other types of development.

The pipeline corridor will pass through areas used for wheat cultivation, pasturage, railroad right-of-way, manufacturing, and mining. Approximately 210 acres of the corridor will be on land previously undeveloped for mining or manufacturing purposes. After construction is completed, the disturbed areas within the pipeline right-of-way will be replanted with a mixture of grass seeds. When the slurry pipeline is no longer needed for mining or other activities, the surface structures will be removed. The area will be returned to agriculture or will be available for other types of development.

Possible future uses of the area when no longer needed for ore processing may include one or more of the following:

Other industrial or commercial operations
Residential
Other public or private use

Prior to construction of initial process facilities in about 1906, vegetation consisted of natural grasses, forbs and shrubs such as sagebrush, oak, service, mahogany and juniper. Most of this vegetation remains in undisturbed portions of the area. Other vegetation has been added for stabilization and appearance. This includes trees such as Russian Olive and Chinese Elm, and plants such as alfalfa, clover and various grasses. The pH of natural soils ranges from 6.5 to 7.5 as determined by mixing 100 gm of soil and 100 ml of distilled water. Surface elevation ranges from approximately 4200 feet to 5400 feet above sea level.

At such time as the surface facilities, including buildings, utilities, railroads, equipment, etc., are no longer needed for ore processing or related purposes and if not convertible to some other use, they will be razed and/or removed. All hazardous conditions will be eliminated and ground surfaces stabilized and planted using vegetation types natural or subsequently determined to be best suited to the area.

6. Tailings Disposal Area

Tailing produced from the ore concentrators is discharged as a slurry into a 6000-acre tailing pond adjacent to north of the concentrators. The original ground surface which ranged in elevation from 4210 feet to 4340 feet above sea level is believed to have been a sparsely vegetated, highly alkaline soil such as present perimeter areas. Prior to use for trailing disposal, which began about 1916, some limited livestock grazing may have been attempted.

In its terminal condition for deposition, the tailing pond may be considered as a resource. It will contain unrecovered minerals that eventually may justify reprocessing for recovery. Tailing material also has value as fill for land reclamation and construction such as currently used for highway embankment work. Studies have demonstrated that mixing tailing material with alkali soils enhances capability of sustaining a wide range of vegetation. Considerable areas of Western Utah and Nevada may be reclaimed for agricultural and other purposes by this material.

When no longer needed for foregoing purposes, the tailing disposal area will have potential use for one or more of the following:

Farming
Residential, commercial or industrial development
Recreational
Scenic Attraction
Other

Natural vegetation in the area includes salt grass, wire swamp grass, cattails and salt bush. The pH of the natural soils ranges from 8.5 to 9.0 as determined by mixing 100 gm of soil and 100 ml of distilled water. High clay content of the soil, close proximity to Great Salt Lake, and poor drainage would have contributed to the highly alkaline condition.

The tailing pond is a continually rising area (currently rising at about 3-1/2 feet per year) and is contained by a dike which extends completely around its perimeter. This dike must also be continually raised and be maintained in a stable condition. Initially, dike fill was rock waste from the mine; later fill hauled from areas adjacent to the concentrator plants was used; and more recently, dike build up is being accomplished by relocation of previously placed dike fill material by drag line. This is followed by sealing of the pond side of the dike with a berm of coarse tailing distributed by a perimeter pumping system. To obtain adequate dike stability, the outside of the dike is maintained at 5 to 1 slope as recommended by consultants on slope stability. Periodic inspections are conducted by consultants to assure long-range stability of the system. Present elevation of the pond surface averages approximately 4345 feet above sea level. Dewatering of the tailing pond is by means of two buoy-supported siphon lines which remove clear water, most of which is reclaimed as concentrator process water.

The area near the top of the dike which is subject to being disturbed in the subsequent dike build up, and roads on the dike, are stabilized and will be stabilized to prevent wind erosion. Farther down the outside slope where the surface is permanent, revegetation is practiced. Current plantings include several plant and tree species along the dike slopes. Success has been achieved with Japanese millet, rye, yellow sweet clover, wheatgrass, brome, range alfalfa and vetch plants, and Russian olive, larch and elm trees. Because of the continually rising tailing deposition, permanent stabilization or revegetation of the pond surface is not possible as long as operation continues. However, wind erosion control is and will be practiced. About 90% of the pond surface is kept moist at all times by the natural meandering of the tailing stream discharged into the pond. The remaining areas are treated by several different methods to stabilize the surface. Where possible, the surface is wetted by tailing distribution lines installed for this purpose. If this is not feasible, and the dry areas are accessible to land vehicles, the surface is treated with stabilizing agents.

If not accessible by land vehicles, dry areas are treated by application of a polymer product with aircraft. Use of fast growing grasses is also being investigated for wind erosion control.

Based upon current operating rates and practices, by the year 2025, the tailing pond surface will be reduced to approximately 3,000 acres and the average elevation will be approximately 4560 feet above sea level.

When no longer needed for tailing deposition, mineral recovery or material source, grading and revegetation of dike slopes not already done will be completed. Drainage will not be a problem. As noted previously, the outer surface of the dike will have an average 5 to 1 slope. The pond surface will have, or will be graded to, a natural slope which will be more than adequate for drainage needs, considering that this is a region of low precipitation and the surface can adequately absorb normal precipitation.

Revegetation is also receiving consideration by Kennecott and other mining companies for stabilization and subsequent reclamation of inactive tailing pond surfaces. To this end, test work is being conducted to ascertain which species of vegetation are suitable, and procedures required to obtain adequate vegetation growth. Planting Japanese millet at the rate of 10 to 15 pounds per acre with fertilizer may be a means of vegetating the tailing pond surface after deposition is completed and to a limited extent during the deposition process. The surface of the tailing pond will be stabilized using the most practicable technology available upon the termination of the deposition of the tailing.

7. Excess Process Water Disposal Area

This comprises a treatment plant, sludge disposal area, canals and diversion facilities now existing, as well as possible additional treatment facilities, water storage and evaporation ponds and other facilities that may be required in the future. It involves perimeter areas around the tailing disposal area (Area 6) comprising a total of approximately 1000 acres. Any excess water is discharged under the provisions of NPDES Permit UT-0000051. The discharge criteria may be modified in the future as a result of the surface water study cited in Section 3.

Most of the area remains in a natural state and may have been used for very limited grazing prior to the early 1900's.

Possible future uses of the area when no longer needed for water treatment and disposal may include one or more of the following:

Other industrial or commercial operations
Residential development
Other public or private use

Natural vegetation in the areas includes salt grass, wire swamp grass, cattails and salt bush. The pH of the natural soils ranges from 8.5 to 9.0 as determined by mixing 100 gm of soil and 100 ml of distilled water. The area is comparable to the original ground surface of the tailing disposal area. Surface elevation ranges from 4210 feet to 4300 feet above sea level.

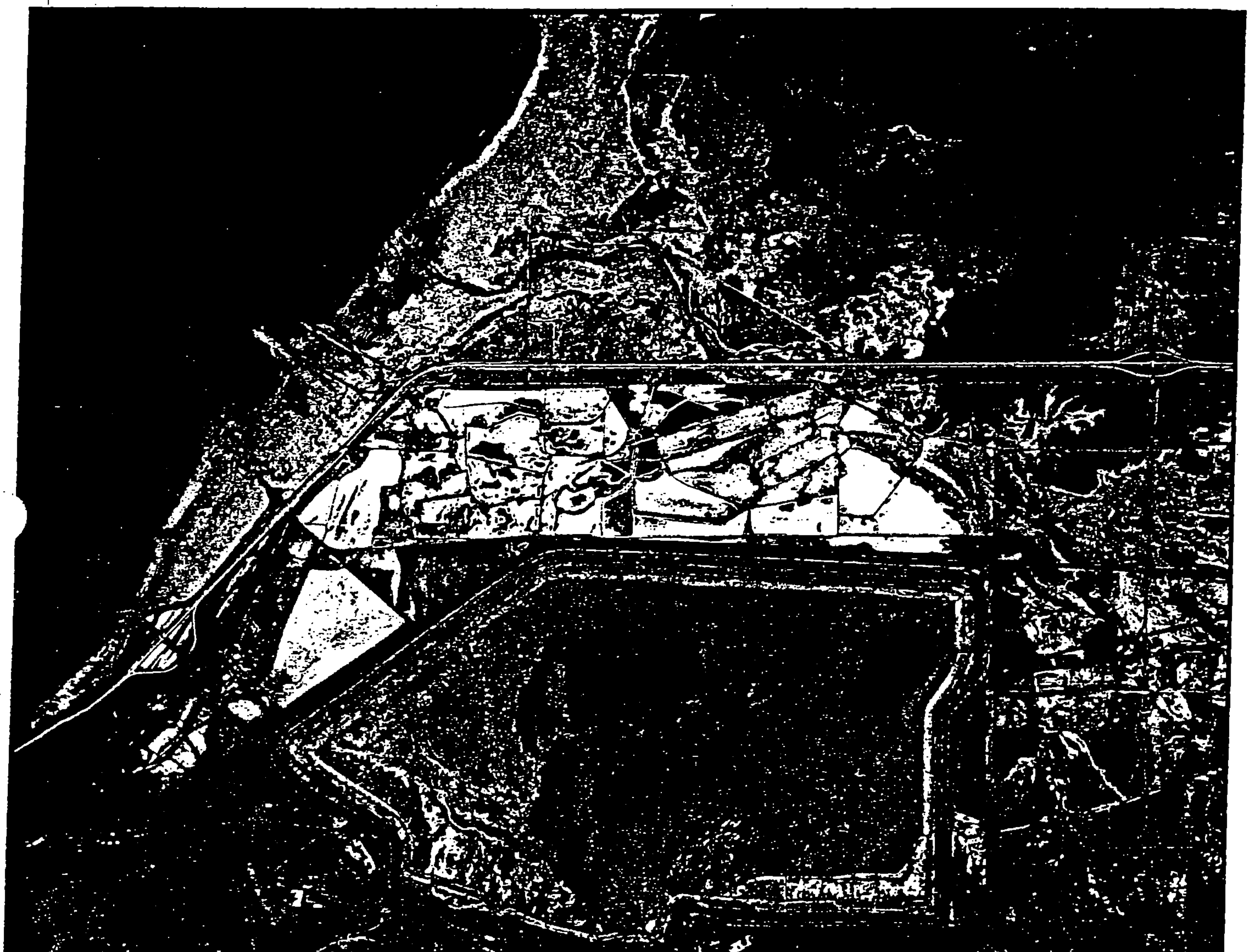
Canals have been constructed around the tailing pond area to convey natural flows and drainage and excess water from tailing pond and treatment plant to the Great Salt Lake. Sludge from the treatment plant is deposited in a low diked area.

At such time as the surface facilities including treatment plant, piping and utilities are no longer needed, and if not convertible to some other use, they will be razed and/or removed. Sludge ponds, evaporation ponds and possible other areas will likewise be left in condition suitable for conversion to other use determined at that time. This may involve filling or covering with tailing and other stabilization and revegetation work comparable to that designated for the tailing disposal area. Canals will most likely be left indefinitely for conveyance of natural surface flows and drainage to Great Salt Lake.

APPENDIX B - TAILINGS MODERNIZATION PROJECT FUGITIVE DUST ABATEMENT PROGRAM (PAGES ADDRESSING THE EXISTING IMPOUNDMENT ONLY)

TAILINGS MODERNIZATION PROJECT

FUGITIVE DUST ABATEMENT PROGRAM



Kennecott Utah Copper

Fugitive dust emissions from the constructed dikes will be minimized by periodic application of water and dust suppressants and seeding of slopes.

Placement of tailings distribution pipelines and tailings management facilities for operation of the North Impoundment are not anticipated to be a potentially significant source of dust. Potential fugitive dust emissions will be minimized by periodic application of water in work areas. North Impoundment construction is scheduled for completion in 1998 with use of the North Impoundment scheduled to commence in late 1998 or early 1999.

Existing Tailings Impoundment Transition Construction - 1997-2004.

Construction pertaining to the transition off the existing Tailings Impoundment will involve phased revegetation coordinated with downsizing of the peripheral discharge system. This transition is described below.

Revegetation plan. The revegetation goal is to establish a self-sustaining vegetative cover for long-term dust control, stability, and wildlife habitat. Kennecott conducts an ongoing revegetation program to vegetate the exterior side slopes and stepback dikes of the existing Tailings Impoundment. This program has been in operation for many years, and has produced a vigorous community of grasses, forbs, shrubs, and trees.

Because the top surface of the existing Tailings Impoundment is large, the revegetation plan calls for subdivision of the surface into smaller, more manageable areas. These areas will be revegetated in a systematic, sequential manner, while tailings continue to be deposited onto the unrevegetated beach areas to control dust. Revegetation of the top of the impoundment will begin by building the first of a series of approximately 6 to 10 foot-high main revegetation dikes to separate the area to be revegetated from operational areas and to provide access across the impoundment surface. Main revegetation dikes and revegetation areas are shown on Figure 2.

Revegetation is anticipated to begin in 1997 and continue for five to ten years. In Figure 2, the roman numerals indicate the revegetation sequence for the areas. Revegetation will begin in the western portion of the impoundment and proceed towards the decant pond in the northeast corner. This will allow adequate time for the decant pond, which contains saturated slimes, to consolidate prior to revegetation.

While the revegetation dikes are constructed to isolate each revegetation area, the tailings spigotting or peripheral discharge system will continue to operate within the revegetation area. The main revegetation dikes have been located to take maximum advantage of the surface wetting provided by the existing peripheral spigotting system. Also, the design of the dike system, shown on Figure 2, was closely coordinated with the operation of the cyclone station so that the overflow produced by the cyclone operations can be spigotted off the main revegetation dikes to supplement the peripheral spigotting system.

Prior to planting, the sections of the spigotting system in the revegetation area will be sequentially shut off and the revegetation area will be planted using direct seeding. In areas with poor trafficability, smaller revegetation dikes will be built out from the main dike or a low ground pressure crawler type tractor (commonly referred to as a "swamp taxi") will be used to allow access for hydroseeding equipment. A tackifier may be applied if planting would not occur promptly.

Typically, completion of revegetation dikes, shutting off of spigot sections, and planting will be carried out in the late fall, winter, or spring, since germination and establishment of a vegetative crop are more

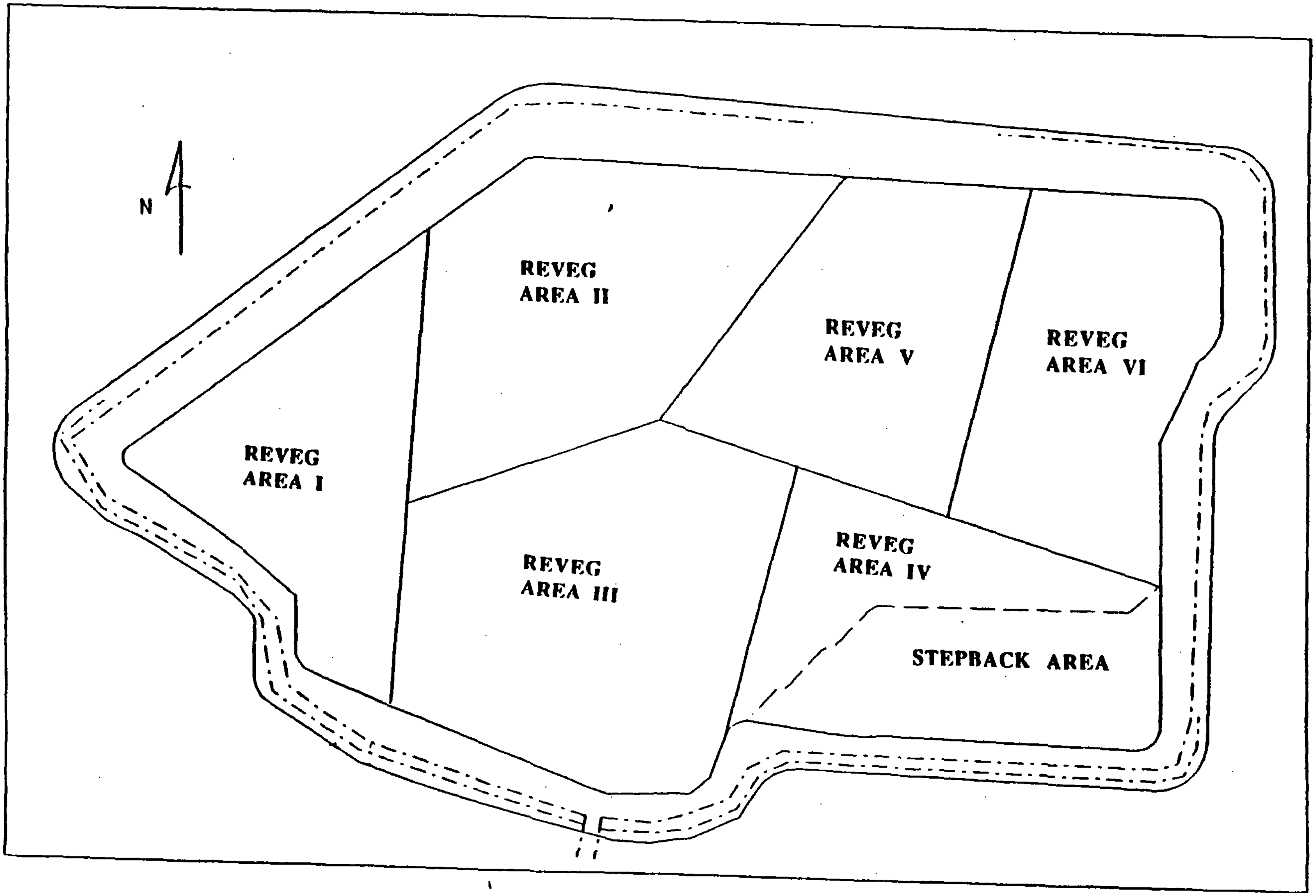


FIGURE 2

REVEGETATION PLAN FOR EXISTING IMPOUNDMENT

successful when planting is done to take advantage of winter and spring moisture. Furthermore, frozen ground helps to control fugitive dust, allows the equipment a wider range of operation, and provides the newly planted seeds with moisture from winter snows.

The revegetation steps and seed mixes to be used to establish vegetation will be those that have been successful to date on Kennecott's existing Tailings Impoundment. Fast growing cereal rye grasses will be planted initially with subsequent planting of nitrogen fixing species. Establishment of a vegetative cover will provide long-term dust control.

Table 1 estimates operational, beach, revegetated, and other acreages, by year, for both the existing Tailings Impoundment and the North Impoundment. As indicated in the table, the existing Tailings Impoundment had a beach area of approximately 4,252 acres in 1988 when the existing peripheral discharge system became operational and effective in controlling fugitive dust emissions. The transition was designed to minimize the combined Existing and North Impoundment beach and embankment areas. The combined beach and embankment areas must fluctuate during the transition years due to construction constraints; however, this acreage will never exceed the 1988 acreage on the Existing Impoundment. To control fugitive dust during the transition to the North Impoundment, tailings will be spigotted through the peripheral discharge system to the unrevegetated areas on the Existing Impoundment. North Impoundment construction activities will be accompanied by control measures described in this Program.

Transitional usage of peripheral discharge system on existing Tailings Impoundment. As revegetation progresses from west to east, unused portions of the existing peripheral spigotting system in the western side of the existing impoundment will be relocated to the main revegetation dikes so that wetting of the entire unrevegetated surface of the impoundment will continue. After tailings storage has shifted to the North Impoundment in 1999, the peripheral spigotting system will continue to wet all unrevegetated surfaces of the existing Tailings Impoundment. Thus, Kennecott will continue to use the peripheral discharge system for fugitive dust control on the existing Tailings Impoundment during the transition.

ABLE 1

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ANNUAL SUMMARY OF OPERATIONAL TAILNGS AND REVEGETATED AREAS

Acreage Presented Below Is Limited To The Top Surface of Impoundment

All Figures Are In Acres And Are Approximate, Unless Otherwise Noted

Info.	EXISTING IMPOUNDMENT							NORTH IMPOUNDMENT						TOTAL
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
As Of End Of:	Total Surface Area (a)	Revegetated Area (b)	Revegetated Area As % Of Total Surface Area ((2/1) x 100%)	Operational Area (1-2)	Decant Pond Area	Active Revegetation Area	Beach Area (4-(5+6))	Embankment Top Surface & Berm Area	Inside Embankment (Includes gypsum tailings)	Gypsum Tailings Impoundment	Decant Pond Area	Beach Area (9-(10+11))	Beach + Embankment Area (8+12)	Combined Beach & Embankment Areas (7+13)
1918	5,700						N/A							5,700
1988	4,553	0	0	4,553	301		4,252			322				4,252
1989	4,481	0	0	4,481	301		4,180			322				4,180
1990	4,409	0	0	4,409	301		4,108			322				4,108
1991	4,337	0	0	4,337	301	147	3,889			322				3,889
1992	4,265	147	3	4,118	301	38	3,779			322				3,779
1993	4,193	185	4	4,008	301		3,707			322				3,707
1994	4,121	185	4	3,936	301	30	3,605			322				3,605
1995	4,049	215	5	3,834	301		3,533	0		322			0	3,533
1996	3,977	215	5	3,762	301		3,461	271	0	322			271	3,732
1997	3,905	215	6	3,690	301		3,389	543	0	322	0		543	3,932
1998	3,905	215	6	3,690	301	558	2,831	543	0	322	1,154	N/A	543	3,374
1999	3,905	773	20	3,132	301	736	2,095	594	2,609	322	1,085	1,202	1,796	3,891
2000	3,905	1,509	39	2,396	301	888	1,207	563	2,630	322	1,017	1,291	1,854	3,061
2001	3,905	2,398	61	1,508	301	322	884	532	2,651	0	1,017	1,634	2,166	3,050
2002	3,905	2,720	70	1,185	0	598	588	501	2,672	0	1,017	1,655	2,156	2,744
2003	3,905	3,317	85	588	0	588	0	470	2,693	0	1,017	1,676	2,146	2,146
2004	3,905	3,905	100	0	0			612	2,714	0	1,017	1,697	2,309	2,309
2005	3,905	3,905	100	0	0			581	2,735	0	1,017	1,718	2,299	2,299
2006	3,905	3,905	100	0	0			550	2,756	0	1,017	1,739	2,289	2,289
2007	3,905	3,905	100	0	0			519	2,777	0	1,017	1,760	2,279	2,279

(a) Operational Areas - Existing Impoundment based on May 1993 mapping and a 72 acre per year shrinking of impoundment area due to raising of the impoundment 1988 to 1996.
Areas based on May 1993 mapping of Site.
(b) Includes Southeast corner Stepback and areas planted during transition.

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APPENDIX C - FINAL CLOSURE PLAN, GROUND WATER ISSUES
KENNECOTT TAILINGS IMPOUNDMENT
(WITHOUT PLATES)

FINAL CLOSURE PLAN

GROUND WATER ISSUES

KENNECOTT TAILINGS IMPOUNDMENT

GROUND WATER DISCHARGE PERMIT UGW350011

Prepared by:

Kennecott Utah Copper
September 1997

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INTRODUCTION

The Division of Water Quality issued Kennecott Utah Copper a ground water discharge permit for the Tailings Impoundment expansion which requires the submission of a closure plan for the Tailings Impoundment. The purpose of this document is to provide a general description of the closure plan for the Tailings Impoundment and to discuss measures that will be taken prior to and after closure to protect ground water in the area. This document fulfills the requirements of Part I Section K Item 9 of the Ground Water Discharge Permit for the Tailings Impoundment (the Permit), permit number UGW350011.

The Tailings Impoundment is located at the north end of the Oquirrh Mountains, near the edge of the Great Salt Lake (see Figure 1). At closure, the impoundment will consist of two major portions, the existing impoundment and the North Expansion. A general layout of the site showing these two portions of the impoundment, as well as other major features, is provided on Plate 1. A diagram, conceptually illustrating the appearance of the impoundment at final closure is provided in Plate 2. Closure of the impoundment will be completed when the new expansion reaches estimated design capacity of 1.9 billion tons, currently projected at 25 to 30 years. Prior to final closure, portions of the existing impoundment will be closed and reclaimed as the North Expansion is placed into operation.

Closure of both the existing and expanded impoundments will be accomplished by separately diking off large areas of the impoundment. As these areas are diked off, they will be vegetated and reclaimed. The location of these dikes is shown in Plate 3 for the existing impoundment and in Plate 4 for the expanded impoundment. The use of dikes will allow for the isolation and separation of these areas and for the gradual closure of the impoundment.

CLOSURE ISSUES

With respect to the ground water, the following closure issues have been identified and will be addressed within this plan:

- Potential for acidification of the tailings after closure.
- Potential process water discharges to ground water.
- Surface water drainage and discharges.
- Tailings Impoundment water balance.
- Potential changes in the quality of ground water discharged.

Of the issues identified, only the potential for the acidification of the tailings could result in conditions at closure being worse than existing and/or future operating conditions. Data collected to date, however, indicate that there is no significant potential for acidification of the tailings that would result in closure problems with respect to ground water.

ACIDIFICATION POTENTIAL

Tailings deposited in the Tailings Impoundment will remain in the impoundment after closure. Water stored within the tailings will have the same quality as the process water deposited in the tailings. There is a potential that sulfide metals stored within the tailings could oxidize and produce low pH waters capable of leaching metals and other substances from the tailings and alter the quality of the water. Kennecott has conducted a number of investigations directed at evaluating the potential for acidification of the tailings. These investigations include:

- "Acidification Potential of the Kennecott Tailings," Schafer and Associates, and Shepherd Miller, Inc., 1995.
- "1996 Data Summary Report for the Test Fill and Step-Back Area," Schafer and Associates, and Shepherd Miller, Inc., 1997
- "Appendix A Sampling Results, Kennecott Utah Copper, Magna Utah," Shepherd Miller, Inc., 1997
- "1996 Annual Operational Monitoring Report for the Tailings Impoundment Ground Water Discharge Permit UGW350011," Kennecott, 1997.

Results of these investigations have indicated that:

- The net acidification potential of the impoundment is positive, i.e., the oxidation of sulfates in the tailings, as a whole, will not generate acidic conditions. While individual surface layers may generate acidic conditions, these acid waters will be neutralized by the excess neutralization potential found in other (deeper) layers.
- Due to the presence of fine-grained layers within the tailings, the depth of oxygen penetration is very limited, generally less than four to six feet. These layers will remain at or near saturation. Under these conditions, migration of oxygen is greatly reduced due to the low permeability of oxygen under saturated conditions. The lack of oxygen at depth will prevent acidification of deeper tailings and also limits potential acidification of the tailings to the upper surficial tailings cover. Any potential degradation of water quality is, therefore, also limited to the shallow surficial depths within the tailings impoundment.
- The shallow depth of potentially acidified areas, coupled with the horizontal nature of tailings water flow within the tailings (discussed in subsequent sections), will restrict any

potential water quality problems to surface water discharges. Even if acidified tailings waters were to migrate vertically, these waters would be neutralized by the tailings as they passed through. Tailings water quality would not be significantly different from existing tailings water which is generally better than the natural water quality of the ground water in the aquifers below the Tailings Impoundment.

- Based on the characterization of acidification potential of the tailings covering the existing impoundment, approximately 25 to 35 percent of the exposed surficial tailings are expected to generate acidic conditions. The extent and possible impacts of this potential acidification are shown in the older portions of the existing impoundment where the tailings have already been oxidized.

- The final lifts of tailings placed on the existing impoundment will contain higher percentages of neutralizing minerals because these tailings will contain the finer grained overflow fraction of the cycloned tailings in which the neutralizing minerals are present at higher concentrations.

Kennecott will continue to characterize the tailings with respect to their potential to generate acidic conditions and this characterization will continue through closure of the North Expansion. Available data indicate that future conditions for the existing impoundment are likely to improve, and that conditions will be better than those that currently exist.

Due to the cycloned nature of the coarser grained underflow tailings, used to construct the embankment of the expanded tailings impoundment, the potential for acidification of these tailings is somewhat greater than for the existing impoundment. These tailings will be fully characterized prior to closure and provisions have been included in the DOGM bonding requirements to cover the costs for correction of acid conditions in the unlikely event that such conditions were to develop.

POTENTIAL DISCHARGES TO GROUND WATER

Kennecott has conducted a number of studies addressing the potential discharge of tailings water to ground water. These studies include:

- "Ground Water Assessment of the Great Salt Lake Area," Engineering Technologies Associates, Inc., 1992.

- "Regional Hydrogeologic Report for the Great Salt Lake Area," GeoTrans Inc., 1992

- "Regional Geochemical Report for the Great Salt Lake Area," GeoTrans Inc., 1992

- "Hydrogeologic Report for the Great Salt Lake Area," Kennecott, 1992.

- "Tailings Impoundment Liner Alternatives Report, Woodward-Clyde Consultants, 1993.

- "Geotechnical Detailed Design Report, Utah Copper Tailings Modernization," Woodward-Clyde Consultants, 1993.

- "Summary Report Gypstack Characterization," Shepherd Miller, Inc., 1995.

These, along with other investigations, were provided to the Division of Water Quality as part of Kennecott's Ground Water Discharge Permit Application and serve as the basis for issuing the Ground Water Discharge Permit for the Tailings Impoundment. These investigations show that the seepage from the Tailings Impoundment is minimal and will not adversely affect underlying ground water.

The hydraulic conditions existing during the operational phase of the Tailings Impoundment (shown in the cross-section of the Tailings Impoundment in Figure 2), will remain largely unaffected after closure. Changes to hydraulic conditions that will occur during closure are:

- Decreased water levels within the impoundment of approximately 33 feet.

- Increased consumption of water discharged to the impoundment by the vegetative cover that will be established on the closed impoundment.

- Decreasing rates of water recharge into the Tailings Impoundment.

These changes will result in a reduction in the rate at which tailings water is potentially discharged to ground water.

The rate of tailings water seepage through the Tailings Impoundment, for the fully saturated condition, was estimated at 875 gallon per minute (gpm) in the Ground Water Discharge Permit Application. Recent estimates of the elevation of tailings water within the Tailings Impoundment at closure (see the following section on surface water discharges during closure) indicate that the hydraulic heads at the tailings-foundation contact will be reduced by an average of 16%. Because the rate of seepage into the underlying aquifers is proportional to the head above the foundation, seepage from the closed impoundment would be reduced by approximately the same percentage (to approximately 730 gpm). At the predicted rates of seepage for the operational impoundment there will be no significant adverse impacts to the underlying aquifers. Potential impacts will be further reduced during closure.

Ground water monitoring is being conducted during the operational phases of the Tailings Impoundment to ensure that there are no adverse impacts to ground water quality. This monitoring will be continued into closure. However, the quantity and frequency of the monitoring performed can be greatly reduced, particularly with time beyond closure.

SURFACE WATER DISCHARGE

Closure of the Tailings Impoundment will modify both surface water and tailings water drainage. Under operational conditions, process water is circulated through the impoundment and used in the process or is discharged at UPDES Outfalls. Storm water falling in and on the impoundment, as well as tailings water seepage, is included in the process water system.

Upon closure, the tailings surface water drainage will be modified such that only storm water falling on the edges of the impoundment will be discharged to the surface water system. Storm water falling on the impoundment will be retained in the impoundment. The toe collection ditch will be used to route all storm and tailings seep water to the UPDES Outfall 007 where it will be discharged to lower Lee Creek. A map showing the site surface water drainage after closure is provided on Plate 5.

The Tailings Impoundment is located in an area of ground water discharge and, therefore, storm waters from the Tailings Impoundment will not infiltrate into the ground water. It is anticipated that this will continue to be an area of ground water discharge after closure, however, even if the direction of recharge were reversed, little surface water would be able to infiltrate into the ground water due to the low permeability of the shallow sediments and the lack of significant heads to drive the infiltration of surface water.

Tailings Seepage

After closure, the only tailings water discharged from the impoundment will be seepage draining from the embankment of the existing impoundment from the blanket drain constructed beneath the embankment of the North Expansion. Although the rate of seepage discharge will diminish once tailings inflows stop, seepage from the Tailings Impoundment will continue indefinitely. Large decreases in the rate of seepage are anticipated to result from the termination of embankment construction during the first year after closure. Beyond the first year, seepage rates will continue to decrease, although more slowly. Additional information concerning the rates of tailings water discharge is provided in the tailings water balance section.

Storm Water Discharge

Precipitation falling on interior portions of the Tailings Impoundment will not be drained as surface water. Dikes, constructed to contain the deposition of the final tailings lift as each section is closed, will be constructed at an elevation high enough to prevent any potential run-off of the interior portions of the closed areas. Collected water will pond internally and either be absorbed or will evaporate. Precipitation falling on the Tailings Impoundment embankment will be drained to the toe collection ditch surrounding the impoundment.

Ground Water Discharge

Under current and anticipated future ground water conditions at closure, it is presumed that ground water will continue to discharge into the toe collection ditch, other ditches, and water conveyance structures surrounding the Tailings Impoundment. These ditches are constructed as topographic lows in this area, therefore, ground water will naturally flow into these structures. The anticipated ground water elevation and direction of flow after closure are shown on Plates 6 and 7 for the Shallow and Principal aquifers respectively. The actual rate of ground water discharge into these ditches is, however, quite small, likely only a few tens of gallons per minute, as a result of the low vertical hydraulic conductivity of the Shallow Aquifer. Water discharged in the toe collection ditch will include tailings water that has entered the shallow aquifer beneath the Tailings Impoundment and then traveled horizontally until discharged.

Because of the poor natural quality of the Shallow and Principal aquifer, it is unlikely that ground water resources in this area will ever be developed sufficiently to change the direction of flow from the toe collection ditch into the underlying aquifers. Even were such a condition to develop, it is unlikely that a significant amount of seepage would occur due to the limited gradients that could be developed and the low vertical hydraulic conductivity of the Shallow Aquifer.

TAILING WATER SEEPAGE

The rate of seepage of tailings water from the existing impoundment has been estimated at 2,500 gpm for existing conditions (Mass Balance Report, 1995, prepared by Shepard Miller Inc.). Seepage from the existing impoundment will be reduced as the expanded impoundment is brought into operation, but much of this reduction will be replaced by seepage from the expanded impoundment. In order to evaluate the potential impacts of this seepage on surface water flows from the impoundment after closure, estimates of seepage rates after closure have been made utilizing two differing approaches, a water balance and numerical hydraulic modeling of the closed impoundment.

WATER BALANCE

A detailed water balance for the Tailings Impoundment after closure was presented in the report "Acidification Potential of the Kennecott Tailings." A copy of this water balance is provided in Appendix A. This model assumed that run-off would be discharged from the impoundment and that any water remaining after accounting for evaporation, evapotranspiration, and run-off would be discharged as seepage. The results of this water balance indicated that, after closure, the volume of water received as precipitation was only slightly (5%) greater than the volume of water lost from the impoundment due to evaporation and evapotranspiration. This model, however, assumed that all areas of the impoundment would have run-off and that the run-off would be discharged from the impoundment. Since only a very limited portion of the impoundment will be allowed to drain as surface water, the volume assumed to be lost as surface water will, instead, be lost as evaporation and seepage. This model was recently updated by its authors (Schafer and Associates) to include the effects of surface water run-off and to include some better estimates of soil parameters. These revisions and their impacts on the original estimates are discussed in Appendix B. Table 1 summarizes the results of these revisions and indicate an estimated seepage rate of 330 gpm.

These calculations assume that there will be no change in the volume of water stored in the impoundment. This is incorrect, as water will be released from storage in the impoundment and, therefore, the initial seepage rate will be higher than predicted by this approach. Once the deposition of new tailings is stopped, the water stored within the tailings will start to drain, both as lateral discharge to surface water and as seepage to ground water. Initially, the rate of discharge will be the same as current rates of discharge and will decline rapidly as time passes beyond closure. The seepage rates at closure is estimated to be:

•	Discharge to ground water at the time of transition off of the Existing Impoundment.*	620 gpm
•	Discharge to ground water from the North Expansion at closure *	206 gpm
•	Seepage to surface water at the time of transition off of the Existing Impoundment *	2500 gpm
•	Seepage to surface water from the North Expansion at closure**	2700 gpm
	Total	6026 gpm

* Estimate obtained from the "Final Environmental Impact Statement for the Kennecott Tailings Modernization"

** Estimate obtained from the report "Mass Balance Report" prepared by Shepard Miller, Inc., 1995

The rate of seepage estimated for the existing impoundment is high because much of the water stored will have drained off by the time the North Expansion is closed. Given that the seepage rate will be the highest at closure, the estimate of 6026 gpm is the maximum seepage rate that could occur. The estimate of 330 gpm, obtained from the post closure water balance, is the lowest rate obtained using these water balance approaches. Hydraulic calculations, discussed in the next section, indicate a potentially lower rate of 190 gpm obtained using the EPA's Hydrologic Evaluation of Landfill Performance (HELP3) model.

The volume of water stored within the combined impoundments at closure will be approximately 130 billion gallons. Using the initial seepage rates as the maximum rate, the volume of water stored in the Tailings Impoundment would take a minimum of 40 years to drain. The actual rate will be much lower since the rate of seepage will decline rapidly in the period immediately after closure. Ground water modeling, discussed in the next section, indicates that most of this drainage will occur within 100 years and that a near steady state condition will develop by that time.

HYDRAULIC MODEL OF TAILINGS WATER SEEPAGE

Schafer and Associates numerically modeled the hydrology of the Tailings Impoundment using the hydraulic properties of the tailings coupled with reasonable assumptions for the water inputs into the impoundment. The results of their modeling are provided in Appendix A and indicate a seepage rate of 4,391 gpm at closure, decreasing to 220 gpm once steady state conditions are achieved.

The soil properties, assumed by the model provided in Table 2, are based on data collected during the design of the tailings expansion that characterize the nature of the tailings and underlying materials. Model boundaries and the configuration of the model is provided in Figure 3. This figure also shows the simulated water level after closure of the impoundment which is approximately 25 feet lower than the operational water level. A comparison of this seepage estimate with those calculated using a mass balance approach is provided in Table 3. Figure 4 shows the change in predicted seepage rates as a function of time. It is anticipated that over one hundred years will be required for the rate of seepage to reach a steady state equilibrium.

The predicted steady state seepage rate of 220 gpm, does not include an estimated 826 gpm (as estimated in the Ground Water Discharge Permit Application) of seepage which is lost through the impoundment foundation directly to ground water. The seepage rate through the impoundment foundation will decrease gradually until upward gradients in the shallow aquifer return and the net seepage into the underlying aquifer goes to zero. This is anticipated to take hundreds, to thousands, of years.

CLOSURE PLAN

This document provides the major elements of the closure plan as related to ground water issues. Additional details concerning the general closure of the impoundment are provided in the document "Tailings Modernization Project DOGM Consolidated App'n" submitted to the Division of Oil Gas and Mining (DOGM) on March 15,1996.

The Tailings Impoundment will be closed in two phases. The first phase will be the transition of operations from the existing impoundment as the North Expansion becomes available for tailings storage, with the second phase being the subsequent closure of the North Expansion at the end of its useful life.

TRANSITION PLAN FOR THE EXISTING IMPOUNDMENT

Transition of tailings storage activities from the existing impoundment will include the following activities:

- Removal of unnecessary facilities.

- Reclamation and vegetative stabilization of disturbed areas.
- Vegetation of the embankment and surface of the impoundment.
- Monitoring.

Reclamation and vegetation of the existing impoundment will be achieved in stages as the transition is made between the existing impoundment and the North Expansion. Because the top surface of the existing impoundment is large, this area will be subdivided into a number of smaller areas (shown on Plates 3 and 4), while tailings continue to be deposited onto unreclaimed areas. This procedure is designed to minimize fugitive dust emissions to the air. Reclamation is anticipated to begin in the western portion of the impoundment and proceed towards the decant pond in the northeast corner over a period of several-years. Thus, portions of the existing impoundment will be reclaimed and removed from use as the North Expansion is brought on-line. Closure of the top of the existing impoundment is anticipated to be complete by the year 2005. Structures used for operation of the North Expansion, located on the sides of the existing impoundment, will be removed when the closure of the final phase of the North Expansion is completed.

CLOSURE PLAN FOR THE NORTH EXPANSION

Closure of the expanded impoundment will involve the removal of remaining above-ground, man-made, structures from the existing and expanded portions of the impoundment. Structures such as the toe ditch and the 007 Outfall will remain to control drainage from the impoundment. Reclamation of the impoundment will be performed in accordance with a reclamation plan approved by DOGM. Techniques employed will be similar to those used to transition operations from the existing impoundment, with updated technology as appropriate. As with the transition from the existing impoundment, the surface of the impoundment will be subdivided into a number of smaller areas that will be reclaimed in a systematic, sequential manner, while tailings continue to be deposited onto operational areas. The locations of these areas are shown on Plate 4.

Reclamation

Reclamation of the Tailings Impoundment will occur during operation of the impoundment and at closure. The main reclamation objectives during construction and operation are to:

- Vegetatively stabilize all areas disturbed by construction activities as soon as possible after the activity is completed,
- Reclaim the rises of the exterior slopes of the impoundment on a seasonal basis, and
- Establish a vegetative community suited to wildlife habitat.

Primary objectives for final reclamation are to:

- Reclaim the top surface of the impoundment for long-term fugitive dust and erosion control, with minimal maintenance requirements,

- Establish a vegetative community best suited to wildlife habitat, and

- Provide for the long-term vegetative stabilization of the impoundment.

Kennecott's ongoing reclamation program has produced a vigorous community of grasses, forbs, shrubs, and trees on the Tailings Impoundment which is used as a habitat by a variety of wildlife. This proven approach will be the basis for reclamation of the impoundments at closure. Specific methods used to achieve these objectives are detailed in the document "Tailings Modernization Project DOGM Consolidated App'n."

Storm Water

The remaining storm water and tailings seepage water will be routed through the toe ditch and eventually discharged to Lee Creek. The toe drain will be left in place after closure to facilitate drainage of surface and seepage water from the tailings embankment to the C-7 ditch, Lee Creek, and ultimately to the Great Salt Lake. The discharge of this water from the impoundment will occur at the 007 Outfall and will be in accordance with the regulatory requirements and limits set forth at that time.

Ground Water

Neither the quality nor the quantity of potential discharges to ground water will change significantly upon closure. The elevation of the saturated tailings water surface will begin to decline once the deposition of new tailings water is stopped. However, the rate of decline in the saturated tailings water surface will be so small that it will not significantly affect the rate of tailings water seepage through the foundation surface. Since no additional water will be applied to the surface of the impoundment, the waters potentially discharged are those stored during tailings deposition and precipitation onto the impoundment surface. The quality of this water will be the same after closure as is currently being discharged.

MONITORING DURING CLOSURE

Monitoring of the Tailings Impoundment will continue, as specified in the Permit for operating conditions, as sections of the impoundment surfaces are taken out of service. However, additional samples of the tailings will be collected as the final lift (last three feet) of tailings is placed in the section being closed. These samples will be "grab" samples collected from the tailings spigots located in the area being closed. The sampling rate will be approximately one sample per each 200 acres closed. These samples will be analyzed to determine their acid generating potential. If these analyses indicate that a significant acid generating condition is likely to exist within the surfical tailings, remedial actions will be considered and, if necessary, implemented. Evaluation of the potential for developing significant acid generating conditions will be based on our past history in meeting reclamation goals given similar test results. Tailings samples will also be collected from the surface of closed sections of the impoundment after the final lift of tailings is placed, but prior to vegetation. These samples will also be collected at a rate of one sample per each 200 acres closed. These samples will be analyzed to determine their acid generating potential. Sampling and analyses will be as specified in Appendix A of the Permit.

POST-CLOSURE MONITORING

A detailed closure monitoring plan will be submitted to the DWQ six months prior to closure of the North Expansion. This monitoring plan will specify the actual compliance and operational monitoring required after closure. After closure, the closure monitoring plan will be reviewed and, where necessary, revised every five years and submitted with each Ground Water Discharge Permit renewal application. The following sections outline the major elements of the anticipated Post-Closure Monitoring plan.

MONITOR POINTS

Post-closure monitoring will consist of ground, surface, and tailings water monitoring and will be implemented upon closure of the North Expansion. The location of each monitoring point is shown on Plate 8.

Ground Water

The network of ground water monitoring wells used for operational monitoring, identified in Table 4 and shown on Plate 8, will be used for the post-closure monitoring. If these monitoring wells are damaged, contain more than two feet of sediment, or have a substantially decreased yield, they will be redeveloped or replaced. Samples collected from these wells will be analyzed for the parameters as specified for operational monitoring in the Permit (see Table 5). The analytical methods used will be those specified in Table 6. Analytical results will be evaluated as specified in Part I Section H of the Permit to determine whether ground water quality has been affected by the impoundments.

These wells will be sampled semi-annually for five years after closure. If, after five years, no statistically evident degradation of the water quality is measured, the sampling frequency will be reduced to annually for the next five years. Ten years after closure, the results of the monitoring data collected during closure will be reviewed and the number of wells required for monitoring and frequency of sampling reviewed. Based on the results of this review, the monitoring program will be revised. It is anticipated that the number of wells monitored and the frequency of monitoring will be reduced to once every five years. Ground water monitoring of the impoundment will end 30 years after closure, unless conditions warrant otherwise. Should the post-closure ground water monitoring data indicate that additional monitoring is not necessary, Kennecott will petition the Executive Secretary to discontinue post-closure monitoring.

Monitoring data collected during the post-closure period will be reviewed to ensure that none of the compliance limits specified in the permit are exceeded at the time of closure. Should any compliance limits be exceeded, the well would be immediately resampled. If the resampled data still show exceeded water quality compliance limits, the statistical significance will be evaluated using the methods described in the Statistical Methods For Evaluating Ground Water Monitoring Data for

Hazardous Waste Facilities, Volume 53, No. 196 of the Federal Register, October 11, 1988. If this evaluation indicates the exceedance is statistically significant, the cause will be determined using the procedures outlined in Section R317-6.15 of the Ground Water Quality Protection regulations. If the exceedance is related to the Tailings Impoundment, the need for corrective actions will be evaluated and a Contamination Investigation and a Corrective Action Plan will be prepared and implemented. A compliance/contingency decision schematic is provided in Figure 5.

The analytical methods used in the analysis will be those identified in Table 6. Procedures for installing monitoring wells, collecting and analyzing ground waters, and QA/QC samples are provided in KUC's Ground Water Characterization and Monitoring Plan (1996). This plan will be updated as necessary to reflect post-closure requirements.

Surface Water

Table 7 identifies the surface water sampling points and sampling frequency during the post-closure period. The locations of these sampling points are shown on Plate 8. Surface water monitoring will include the discharge from the toe collection ditch to Lee Creek (the UPDES discharge point 007), sampling point CLC452, located in the Clarification Canal, and three tailings water seeps. The water quality data collected at these points will be used for informational monitoring purposes only. All discharges from the Tailings Impoundment will be required to meet the terms of the UPDES permit in effect at that time.

Surface water samples will be collected using the procedures detailed in Kennecott's "Procedures for Water Quality Sampling." Samples will be analyzed for the list of parameters specified in Table 5, and the methods of analyses used will be those identified in Table 6.

Tailings Water

The interstitial water stored within the Tailings Impoundment will be monitored using monitor wells and lysimeters completed within the tailings. The points to be sampled are listed on Table 8 and their locations are shown on Plate 8. Water quality data collected at these points will be used for informational monitoring purposes only.

Sampling will be conducted as specified in Kennecott's "Procedures for Water Quality Sampling." Samples will be analyzed for the list of parameters specified in Table 5 and the methods of analyses used will be those identified in Table 6.

REPORTING AND NOTIFICATION

Monitoring Reports

KUC will prepare a summary of the post-closure monitoring results. During the first ten years following closure, the report will be submitted by the end of March for the preceding calendar year. After the tenth year, the report will be part of the permit renewal application submitted every five years. Information regarding monitoring well logs and construction details for replacement or new monitoring wells installed will be submitted to the DWQ within 30 days of the completion of the work.

Determination of Compliance

Compliance for monitor wells will be determined as specified by the requirements of Part I Section H of the Permit. Should any compliance problems be encountered, the actions specified in this section would be taken.

Surface water and tailings water monitoring will be conducted for informational purposes only and no compliance conditions are specified.

Table 1
Water Balance at Closure

WATER BALANCE INPUT DATA AND MONTHLY CLIMATIC SUMMARY

	DATE	WATER YR DATE
DATE WHEN SNOW ACCUMULATES	10/01/79	0
DATE WHEN SNOWMELT BEGINS	03/31/80	182
DATE WHEN SNOWMELT ENDS	04/29/80	211

	TOP	SLOPE
WATERSHED AREA (ACRES)	7886.00	1580
UPPER LIMIT SOIL STORAGE (in/ft)	2.4	2.4
LOWER LIMIT SOIL STORAGE (in/ft)	1.2	1.2
SOIL THICKNESS (ft)	1.5	1.5
PERCENT FULL AT BEGIN	61	61
MAXIMUM Ks	0.001	0.001
MAXIMUM DAILY PERC (in)	219.5	219.5
SCS CURVE NUMBER (II)	35	72
SCS CURVE NUMBER (I)	16	53

		PET	CROP	AET	ACTUAL PPT	EFFECT PPT	SNOW
OCTOBER	1	2.62	30	0.30	0.26	0.26	0.00
NOVEMBER	2	2.87	20	1.42	2.49	2.49	0.00
DECEMBER	3	0.68	10	0.31	1.19	1.19	0.00
JANUARY	4	1.19	10	0.40	0.82	0.82	0.00
FEBRUARY	5	1.3	10	0.36	0.38	0.38	0.00
MARCH	6	5.67	30	3.08	1.54	1.54	0.00
APRIL	7	9.98	40	2.65	2.68	2.68	0.00
MAY	8	11.34	40	0.42	0.40	0.40	0.00
JUNE	9	6.5	40	2.50	2.79	2.79	0.00
JULY	10	5.78	40	0.45	0.16	0.16	0.00
AUGUST	11	5.35	40	0.89	0.89	0.89	0.00
SEPTEMBER	12	6.12	40	1.18	1.18	1.18	0.00
ANNUAL TOTAL		59.3		13.95	14.78	14.78	

IMPOUNDMENT INPUT DATA

IMPOUNDMENT THICKNESS (ft)	200
VALUE OF N	1.37
VALUE OF ALPHA	0.069
VALUE OF Ks (cm/s)	0.0000133
RESIDUAL THETA (%)	3.4
MAX THETA (%)	48.0
INITIAL THETA	6.83
FINAL THETA	6.83

WATER BALANCE RESULTS

SOIL WATER BALANCE (in/yr)

	TOP	SLOPE	AVERAGE
RAINFALL	14.78	14.78	14.78
RUNOFF	0.00	0.57	0.10
ET	14.00	13.90	13.98
PERCOLATION	0.81	0.35	0.74
STORAGE	-0.04	-0.04	-0.04
DRAIN LAYER	0.00	0.00	0.00

NET PERCOLATION (FT3)	25,297,535
IMPOUNDMENT STORAGE (FT3)	1,868,045
RUN-ON WS1 (FT3)	0
RUN-ON WS2 (FT3)	0
AVERAGE SEEPAGE (GPM)	333.4
MAXIMUM SEEPAGE (GPM)	337.7

Table 2

Model Input Parameters

Material Type	Saturated Hydraulic Conductivity (cm/second)	Saturated Water Content (cm^3/cm^3)	Residual Water Content (cm^3/cm^3)	Van Genuchten Constants	
				α	n
Whole Tailings	$1.3x10^{-5}$	0.48	0.034	0.059	1.37
Cycloned Tailings	$5x10^{-4}$	0.40	0.045	0.124	2.68
Slime Tailings	$7x10^{-6}$	0.45	0.095	0.059	1.31
Embankment (existing Impoundment)	$5x10^{-4}$	0.43	0.065	0.075	1.89
Embankment Drain	$3.8x10^{-2}$	0.42	0.005	4.93	2.19
Foundation	$2.0x10^{-5}$	0.41	0.095	0.019	1.31

Table 3

Tailings Water Seepage Estimates

Estimate	Inflow		Outflow		
	Precipitation	Process Water	Evaporation	Runoff	Seepage
Water balance during operation*	6,300	3,000	23,400	0	6,200
Water balance after closure**	7,200	0	6,800	40	330
HELP3 Model	7,000	0	6,600	200	190
Hydrologic model prior to closure***	6,700	21,000	26,800	0	4,400
Hydrologic model after closure***	6,700	0	6,400	0	220

* "Mass Balance Report", Shepherd Miller Inc., 1995

** "Acidification Potential of the Kennecott Tailings," Schafer and Associates, and Shepherd Miller, Inc., 1995 (See Appendix A) and "Tailings Water Model North Expansion", Schafer and Associates, 1997 (See Appendix B)

*** "Tailings Water Model North Expansion", Schafer and Associates, 1997 (See Appendix B)

\+ Does not include seepage losses to ground water independently estimated at 826 gpm during operation.

\+ Estimated for the operational period.

Table 4

Post Closure Sampling Frequency for Monitoring Wells

Sample Type	Sampling Point	Frequency		
		0 - 5 years	5 - 10 years	10 - 30 years*
NET449D	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET531B	Ground Water	Semi-Annual	Annual	Not Sampled
NET532A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET532B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET536A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET536B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET536C	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET604A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET604A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET646A	Ground Water	Semi-Annual	Annual	Not Sampled
NET646B	Ground Water	Semi-Annual	Annual	Not Sampled
NET1380A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1380B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1381A	Ground Water	Semi-Annual	Annual	Not Sampled
NET1381B	Ground Water	Semi-Annual	Annual	Not Sampled
NET1382A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1382B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1382C	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1383A	Ground Water	Semi-Annual	Annual	Not Sampled
NET1383B	Ground Water	Semi-Annual	Annual	Not Sampled
NET1384A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1384A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1385A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1385B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1386A	Ground Water	Semi-Annual	Annual	Not Sampled
NET1386B	Ground Water	Semi-Annual	Annual	Not Sampled
NET1387	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1393A	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1393B	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1492	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1493	Ground Water	Semi-Annual	Annual	Every Fifth Year
NET1494	Ground Water	Semi-Annual	Annual	Every Fifth Year

* These are anticipated frequencies, the actual frequency will be based on the results of a review conducted 10 years after closure.

Table 5

List of Analytes

Parameter	Ground Water Wells	Surface Water Samples	Tailings Wells	Lysimeters
FIELD				
pH	x	x	x	x
Temperature	x	x	x	x
Conductance	x	x	x	x
Depth to Water	x	x	x	
LABORATORY				
TDS	x	x	x	
TSS	x	x	x	
Gross-Alpha	x			
Gross-Beta	x			
Radium 226	x			
Radium 228	x			
Uranium	x			
Chloride (Cl^-)	x	x	x	x
Fluoride (F^-)	x	x	x	x
Sulfate ($SO_4^=$)	x	x	x	x
Calcium (Ca)	x			
Magnesium (Mg)	x			
Potassium (K)	x			
Sodium (Na)	x			
Alkalinity (ALK)	x			
Arsenic (As)	x	x	x	x
Barium (Ba)	x			
Cadmium (Cd)	x	x	x	x
Chromium (Cr)	x			
Copper (Cu)	x	x	x	x
Lead (Pb)	x			
Selenium (Se)	x	x	x	x
Zinc (Zn)	x			

Note: Radio nuclides (Uranium, radium 226, Radium 228, Gross Alpha, and Beta Particle) will be analyzed for in only wells NET1386A, NET1386B, NET1393A and NET1393B.

Table 6

Analytical Methods

Parameter	Analytical Method	Target Detection Limit
FIELD		
pH	150.1	N/A
Temperature	170.1	N/A
Conductance	2510B	10 umho/cm
Depth to Water	N/A	0.01 ft
LABORATORY		
TDS	160.1	10 mg/l
TSS	160.2	3 mg/l
Gross-Alpha	7110C	1 pCi/L
Gross-Beta	7110B	Dependent on TDS
Radium 226	903	2 pCi/L
Radium 228	904	1 pCi/L
Uranium	200.8	0.005 mg/l
Chloride (Cl^-)	325.2	5. mg/l
Fluoride (F^-)	4500F-C/300.0	0.2 mg/l
Sulfate ($SO_4^=$)	375.3, 375.4, 9036	5. mg/l
Calcium (Ca)	200.7	1 mg/l
Magnesium (Mg)	200.7, 242.1	1 mg/l
Potassium (K)	258.1, 200.7	0.1 mg/l
Sodium (Na)	200.7	1 mg/l
Alkalinity (ALK)	2320B	10 mg/l
Arsenic (As)	200.8, 200.9, 200.7	0.005 mg/l
Barium (Ba)	200.7, 200.8, 200.9	0.01 mg/l
Cadmium (Cd)	200.7, 200.8, 200.9	0.002 mg/l
Chromium (Cr)	218.1, 200.7, 200.8, 200.9	0.01 mg/l
Copper (Cu)	200.7, 200.8	0.02 mg/l
Lead (Pb)	239.1, 200.8, 200.9, 200.7	0.005 mg/l
Selenium (Se)	200.7, 200.8, 200.9	0.003 mg/l
Zinc (Zn)	289.1, 289.2, 200.7, 200.8, 200.9	0.01 mg/l

Table 7

Post Closure Monitoring Frequency for Tailings Seeps and Surface Water Sites

Sampling Point	Sample Type	Frequency
SURFACE WATER		
CLC452	Seepage and surface water	Quarterly
UPD007	Seepage and surface water	Quarterly
TAILINGS SEEPS		
TLS1427	Tailings seepage	Every Fifth Year
TLS1430	Tailings seepage	Every Fifth Year
TLS1434	Tailings seepage	Every Fifth Year

Table 8

Post Closure Monitoring Frequency for Tailings Wells and Lysimeters

Sampling Point	Sample Type	Frequency
WELLS		
TLT449C	Tailings Water	Annual
TLT887	Tailings Water	Annual
TLT2452	Tailings Water	Annual
TAILINGS LYSIMETERS		
TLL4100	Interstitial tailings water	Every Fifth Year
TLL4101	Interstitial tailings water	Every Fifth Year
TLL4102	Interstitial tailings water	Every Fifth Year
TLL4103	Interstitial tailings water	Every Fifth Year
TLL4131	Interstitial tailings water	Every Fifth Year
TLL4132	Interstitial tailings water	Every Fifth Year

APPENDIX D – ENVIRONMENTAL GEOCHEMISTRY OF THE BINGHAM CANYON PORPHYRY COPPER DEPOSIT, UTAH

Environmental geochemistry of the Bingham Canyon porphyry copper deposit, Utah

Richard K. Borden

Abstract At the Bingham Canyon porphyry copper deposit, sulfide mineralization progresses outward from a low-grade core through the following general zones: (1) molybdenite, (2) chalcopyrite–bornite, (3) chalcopyrite–pyrite, (4) pyrite, and (5) sphalerite–galena. The low-grade core and the molybdenite zone are composed of net neutralizing rock and will generally not acidify when exposed to surface weathering conditions. The copper-bearing zones of the orebody and the surrounding pyrite halo are net acid-generating and so will tend to acidify when exposed. Rocks in the lead–zinc halo are typically net neutralizing. In plan view, the distribution of net neutralization potential (NNP) is doughnut-shaped, with a positive (net neutralizing) 1,000-m-diameter core surrounded by a negative (net acid-generating) 3,000-m-diameter ring. Rock exposed in the lower 100 m of the current pit has a positive NNP and is overlain by 500 m of rock with a negative NNP.

Keywords Acid rock drainage · Bingham Canyon · Geochemistry · Porphyry copper · Utah

Introduction

Porphyry copper deposits account for more than 40% of world copper production and more than a third of world copper reserves (Vanecek 1994). The mining of porphyry copper ore bodies typically exposes sulfide minerals to the surface weathering conditions, accelerating natural chemical weathering processes and potentially releasing acid, metals and sulfate to the environment. If sulfide-bearing rock acidifies, metal mobility and bioavailability are greatly increased. The proper management of acid-generating mine wastes is one of the largest environmental concerns associated with metals mining operations worldwide (Warhurst and Noronha 2000). It is estimated that in the United States alone more than 17,000 km of streams and rivers have been impacted by acid rock drainage (ARD) from abandoned mines (Skousen 1995). The Bingham Canyon porphyry copper orebody ranks as one of the world's largest metal deposits. The concept of large-scale open-pit mining was first implemented at Bingham Canyon in 1906, and net production from the orebody totals more than 15 million tonnes of copper. The Bingham Canyon open pit is currently more than 3 km in diameter and more than 900 m deep. The Bingham Canyon deposit has also been one of the most intensely studied ore bodies in the world. The geometry of the deposit is well exposed in three dimensions, and it exhibits the classic mineralization and alteration zoning expected for a porphyry copper deposit (Babcock and others 1995). Since the first scientific studies were produced almost a century ago (Boutwell 1905; Boutwell and others 1905), more than 50 papers have been written about Bingham Canyon geology. Most of these papers have focused on various aspects of alteration and sulfide mineralization, but none have examined the environmental geochemistry of the deposit. This study examines the environmental geochemistry of the Bingham Canyon porphyry copper deposit in terms of its acid/base accounting characteristics. The data presented in this study can be used to evaluate the geochemical behavior of similar porphyry copper deposits when they are exposed to accelerated surface weathering conditions by mining operations.

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Acid/base accounting theory

Under typical surface weathering conditions, sulfide minerals such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), and molybdenite (MoS_2) will oxidize to release sulfate, metals, and acidity. A generalized oxidation reaction for pyrite, the most common sulfide mineral is:

$$FeS_2 + 15/4O_2 + 7/2H_2O = Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \quad (1)$$

Sphalerite (ZnS) may sometimes act as an acid-generating mineral, but galena (PbS) and chalcocite (Cu_2S) will not produce acid under typical surface weathering conditions. Sulfate minerals, such as gypsum ($CaSO_42H_2O$) and barite

($BaSO_4$), will not produce acid under any conditions (Plumlee 1999; Jennings and others 2000; Kwong 2000). Acidity that is generated by sulfide oxidation in a rock may be stored in the rock as soluble salts, may contribute to ARD, or may be neutralized in-situ by acid-neutralizing minerals. Most carbonate minerals will react with acidic solutions to maintain a near neutral pH. A generalized neutralization reaction involving calcite ($CaCO_3$) is:

$$CaCO_3 + 2H^+ = Ca^{2+} + H_2CO_3 \qquad (2)$$

In theory, silicate minerals will also neutralize acidity and maintain a near neutral pH. However, in practice, most silicates provide much less neutralizing capacity than carbonates because of their slow reaction kinetics (Plumlee 1999). In most cases, silicate weathering will only provide a significant source of neutralization potential under strongly acidic conditions and in the very long term (Lawrence and Wang 1997; Stromberg and Banwart 1999; Jambor and others 2000).

Most rocks contain a combination of acid-generating sulfide minerals and of acid-neutralizing minerals. The modified Sobek acid/base accounting method uses static tests of sulfur content and acid-consumption to characterize the bulk acid-generating and acid-neutralizing characteristics of a sample (Sobek and others 1978; Lawrence 1990). The acid potential (AP) is calculated by multiplying the weight percent of sulfur associated with acid-generating minerals in the sample by 31.25. This conversion factor, based on the mass balance relationships expressed in Eqs. (1) and (2), expresses the AP in terms of kilograms of calcium carbonate required to neutralize the acid that would be generated by complete oxidation of all of the potentially acid-generating sulfides in 1,000 kg of rock. The neutralization potential (NP) is also expressed in terms of kg of calcium carbonate equivalent per 1,000 kg of rock, although other minerals in addition to calcite may contribute to the NP. The carbonate NP is calculated from a direct measure of the amount of carbonate in the rock. The net neutralization potential (NNP) of the sample is derived by subtracting the AP from the NP. The neutralization potential ratio (NPR) is derived by dividing the NP by the AP. A negative NNP or an NPR of less than one indicates that there is an excess of AP over NP in the rock, and that it will likely generate ARD. In theory, a rock with an excess of NP will not generate ARD. However, because of the uncertainties created by differential reaction kinetics, leaching rates and mineral distribution in the rock, a commonly used screening criteria assumes that rocks with NNP values above 0 and NPR values above 1 are possibly acid-generating unless the sulfide content is less than 0.3% (AP<10 kg/1,000 kg), or the NPR is greater than 2 (Price and others 1997).

Geology of the Bingham Canyon orebody

The Bingham Canyon porphyry copper deposit is centered on the Eocene Bingham Stock (James and others 1961; Lanier and others 1978a). Economic mineralization is hosted in the stock and extends a short distance into the surrounding sedimentary rocks (Fig. 1). From youngest to oldest the stock is composed of monzonite, porphyritic quartz monzonite, quartz monzonite porphyry, latite porphyry, and quartz latite porphyry. The intrusive complex is primarily composed of monzonite with a much smaller volume provided by the other late stage porphyritic intrusive phases. The stock was intruded by magmatic stoping and replacement into the Pennsylvanian Oquirrh Group, a sedimentary sequence composed of quartzite with lesser amounts of interbedded limestone, calcareous sandstone, and siltstone. Two limestone beds that range between 36 and 70 m thick can be traced across the open pit. The Parnell beds, a 120-m-thick sequence of interbedded limestone, calcareous sandstone, and quartzite, are also continuous across the open pit.

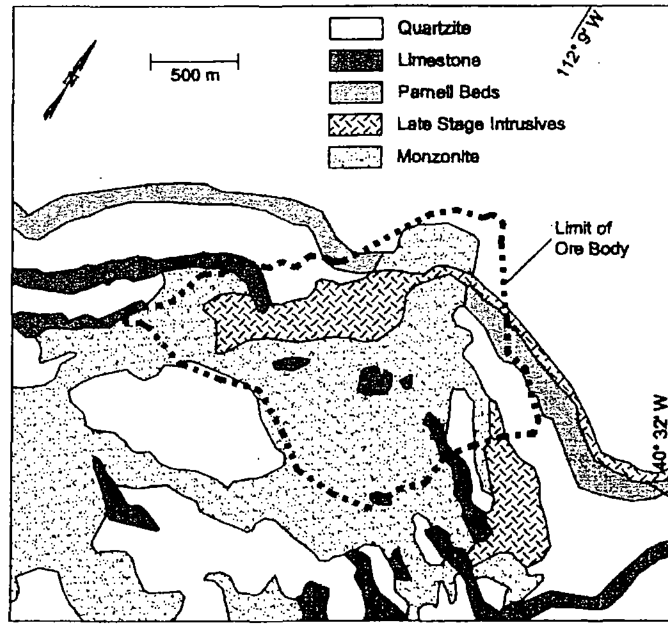

Fig. 1
Simplified geologic map of the Bingham Canyon porphyry copper deposit

Sulfide mineral zones are concentrically arranged around the center of the orebody. Mineral zoning patterns have been described by numerous previous workers including James and others (1961), Rose (1970), John (1978), and Phillips and others (1997). The innermost zone of the deposit, exposed in the bottom of the pit, consists of a low-grade core with generally less than 0.5% total sulfides. It contains low concentrations of molybdenite, pyrite, chalcopyrite, and bornite. Surrounding the low-grade core is a zone of molybdenite mineralization followed by the ring-shaped copper zone of the orebody. The inner portion of the copper zone is dominated by bornite and chalcopyrite mineralization with lesser molybdenite and pyrite. The outer edge of the copper zone is dominated by pyrite and chalcopyrite. The entire orebody is approximately 1,800 m in diameter and currently averages about 0.6% copper. A pyrite halo surrounds the copper zone of the orebody. This zone may contain over 5% pyrite on the immediate margins of the orebody, but pyrite concentrations decrease outward to 1–2% at 600–900 m from the orebody contact. Locally, skarn deposits in the limestone beds may contain as much as 90% sulfides. Sulfide mineralization changes from both disseminated and fracture-controlled within and on the margins of the orebody to almost exclusively fracture-controlled on the outer margins of the pyrite halo. A broad lead–zinc zone with load galena and sphalerite deposits surrounds the pyrite halo between about 1,500 and 2,700 m from the center of the orebody.

The low-grade core and the zones of molybdenite and copper mineralization typically coincide with the zone of potassic hydrothermal alteration. The pyrite halo generally coincides with phyllic and propylitic alteration zones.

Limestone and calcareous sandstone beds become progressively more altered nearer the orebody and the center of the Bingham Stock. From the uppermost exposures in the open pit to the bottom of the pit the following mineralogical zones are present in limestone beds (Reid 1978): (1) unaltered rock, (2) marble, (3) wollastonite, (4) cristobalite, (5) garnet–clay, (6) garnet–quartz, and (7) amphibole–epidote. Garnet composition is believed to be an intermediate member of the grossularite–andradite series. These zones generally reflect a gradual decrease in the percentage of calcium carbonate in the limestone and calcareous sandstone beds, and an increase in calcium-silicate minerals. Reid (1978) noted that the soluble fraction of the limestone decreases from 44% in the marble zone to only 5% in the amphibole–epidote zone.

The oxidized cap of the orebody has been completely removed by mining, and the remaining orebody is unoxidized. However, a deep weathering profile exists in bedrock exposed immediately beneath the pre-mining topographic surface on the outer margins of the open pit. This zone contains few intact sulfides and extends several tens of meters beneath the old topographic surface.

Methods

A total of 88 bedrock samples were collected from recently exposed surfaces in the pit during a preliminary acid/base accounting study. Sample sites were selected to provide a uniform geographic distribution in the pit while insuring that all lithologies were adequately characterized. Samples were composited from 20 to 30 randomly selected locations across several hundred feet of exposure. The Kennecott Utah Copper Environmental Laboratory analyzed all samples by a modified Sobek acid/base accounting technique. Each sample was crushed and homogenized before being ground to minus 200 mesh. The following analyses were then performed: (1) total sulfur, (2) sulfur remaining in the sample after an HCl leach, (3) NP as defined by the amount of 0.10 or 0.50 N HCl consumed by 1 g of the sample, and (4) total metals. It is assumed that almost all sulfate minerals except barite are removed from the sample by an HCl leach. The samples contain very little barium, so almost all the sulfur remaining after the HCl leach is likely in sulfide form. The sulfide sulfur that contributes to AP was calculated by subtracting the sulfur associated with galena and sphalerite from the sulfide sulfur value. Samples were also analyzed for total carbon and carbon remaining after an HCl leach. The carbon removed from the sample by the HCl leach is assumed to be associated with calcite.

In addition to the 88 outcrop samples, there are about 80,000 boring samples collected near the current pit surface that have been analyzed for total sulfur and about 500 that have been analyzed for total carbon. All of the sulfur and carbon analyses were performed with a Leco furnace.

Results and discussion

The analytical results from the 88 outcrop samples indicate that, on average, about 9% of the total sulfur in the rock samples was in the form of non-acid-generating sulfate and sulfide minerals, and about 13% of the total carbon is in a form that was not leachable by HCl. Based upon these results, it was determined that the AP distribution within the open pit can be conservatively mapped using existing total sulfur data available from the borings. AP distribution was mapped by averaging all of the sulfur values in a series of 30×30 m squares on the pit surface and then contouring the averaged values. The following description of NP distribution is based predominantly on the 88 samples collected as part of the preliminary study. However, the total carbon data provided by the 500 boring samples was used to support the outcrop sampling results. The descriptions of NNP and NPR distribution are based upon the total sulfur and Sobek NP data.

Distribution of acid potential

Pyrite and to a lesser extent chalcopyrite, bornite, and molybdenite are the primary minerals contributing to AP in the Bingham Canyon deposit. In plan view, the distribution of AP in the pit is doughnut-shaped with a low AP core surrounded by a 3,000-m-diameter ring with elevated AP (Fig. 2). In vertical profile, the low AP core is exposed in the bottom of the pit and is overlain by 500 m of rock with elevated AP (Fig. 3). The low-grade core of the orebody contains very few sulfide minerals and has AP values as low as 3 kg/1,000 kg. Much of the AP in the low-grade core and the molybdenite zone of the orebody is provided by molybdenite. Although molybdenite can generate acidity under surface weathering conditions, in practice it is one of the most resistant sulfides to oxidation and so is likely to be a minor contributor to acid production (Plumlee 1999). The exposed center of the low grade core, with AP values of less than 10 kg/1,000 kg, is currently 150–300 m wide and 1,200 m long. The inner portion of the copper zone of the orebody contains abundant chalcopyrite and bornite, with very little pyrite, and generally has AP values of between 10 and 30 kg/1,000 kg. Pyrite content increases on the outer margins of the copper orebody, and AP values range from about 30 to more than 80 kg/1,000 kg. Within the orebody, chalcopyrite, bornite,

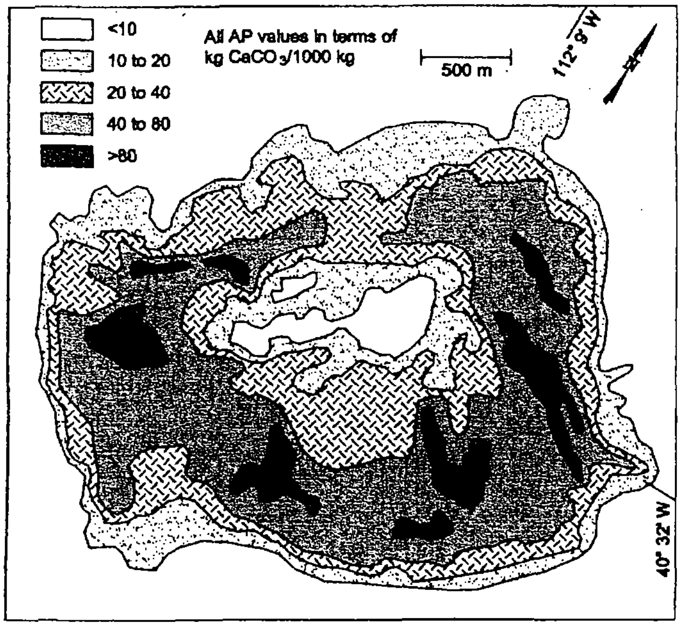

Fig. 2
Plan view distribution of AP in the Bingham Canyon porphyry copper deposit. AP was calculated from total sulfur data

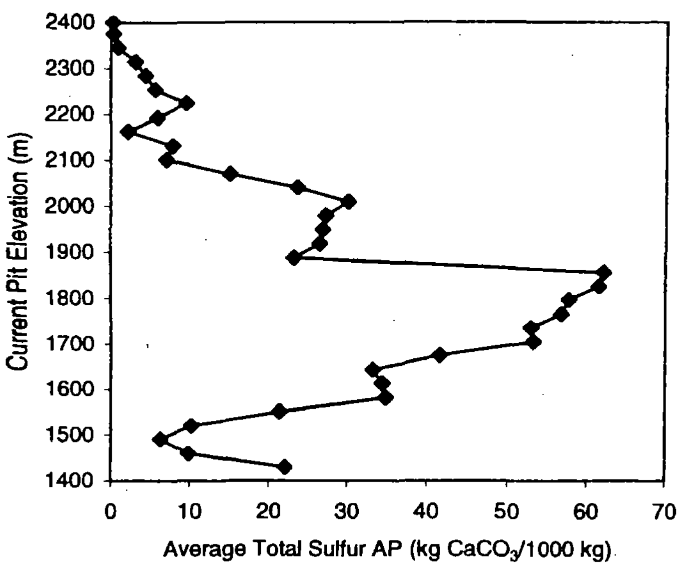

Fig. 3
Average AP versus elevation in the Bingham Canyon open pit. Total sulfur AP is averaged in approximate 30-m vertical increments. Ore grade mineralization extends from the pit bottom to approximately 1,700 m elevation

and molybdenite typically do not contribute more than 20 kg/1,000 kg towards the total AP.

Rocks with the highest AP occur in the pyrite halo immediately surrounding the orebody. In plan view, this zone is about 900 to 1,200 m from the center of the low-grade core. In vertical profile it is about 300 m above the low-grade core on the current pit walls. Locally, maximum AP values within the pyrite halo may reach about 250 kg/1,000 kg. In general, any AP in excess of about 5 kg/1,000 kg within the pyrite halo is provided by pyrite.

AP values decrease dramatically on the outer margins of the pyrite halo. Most of the rock exposed in the lead–zinc zone on the uppermost benches of the pit has AP values of less than 10 kg/1,000 kg, and AP values of 0 kg/1,000 kg are common near the pre-mining topographic surface. This results from both a decrease in the original pyrite mineralization more than 1,500 m from the low-grade core of the orebody, and because much of the pyrite that was originally present has been oxidized by long-term weathering immediately beneath the pre-mining surface.

Distribution of neutralization potential

The distribution of NP on the current pit walls is closely related to the lithologic distribution with significant overprinting by contact metamorphic alteration. As shown in Table 1 and Fig. 4, rocks that contain abundant calcium carbonate, such as limestones and the Parnell beds, have the highest NP values followed by igneous rocks and lastly by quartzites.

About 90% of the NP in sedimentary rocks is provided by calcium carbonate. The remaining NP is probably provided by relatively fast weathering calcium-silicate minerals such as wollastonite, calcium-rich garnet, and diopside, which are related to skarn alternation in the calcareous portions of the sedimentary sequence (Reid 1978; Plumlee 1999). The average NP contributed by non-carbonate minerals is 19 kg/1,000 kg in limestone, 7 kg/1,000 kg in the Parnell beds, and 2 kg/1,000 kg in quartzites. For each sedimentary rock type, NP generally decreases towards the Bingham Stock as calcium carbonate is replaced by less reactive calcium-silicate minerals. Sulfide mineralization in the sedimentary sequence increases towards the stock resulting in an inverse relationship between NP and AP in the limestone and Parnell beds (Fig. 4). Samples from the limestone beds have NP values that range from 517 kg/1,000 kg in relatively unaltered limestone high on the pit walls to 19 kg/1,000 kg in intensely altered limestone skarn near the contact with the Bingham Stock. Similarly, NP values in the Parnell beds vary between 177 kg/1,000 kg and 14 kg/1,000 kg

Table 1
Neutralization potential data for Bingham Canyon lithologies. All NP values are reported in kg $CaCO_3$/1,000 kg

Lithology	Average Sobek NP[a]	Average carbonate NP[a]	Sobek NP range	Carbonate NP range
Limestone	178±85	159±68	19–517	14–363
Parnell beds	60±30	53±31	14–177	0–173
Quartzites	10±4	8±4	0–70	0–68
Igneous rocks	23±4	10±4	6–76	0–66

[a]Includes the 90% confidence interval based on the *t*-statistic for each mean

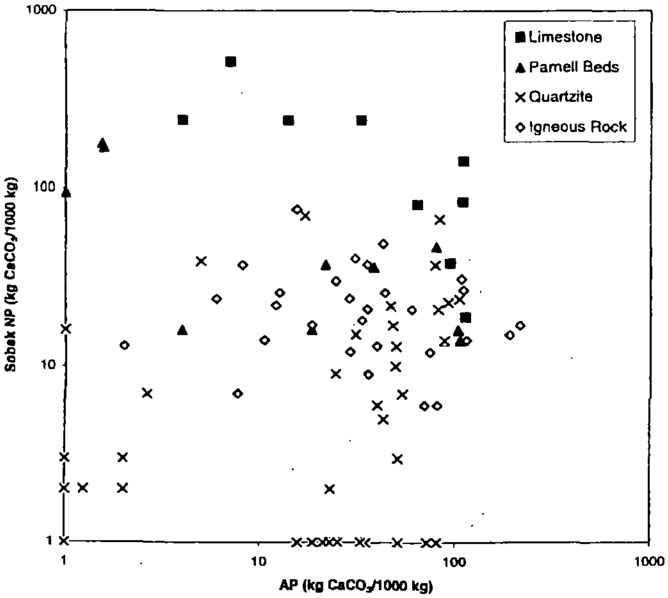

Fig. 4
AP versus Sobek NP for various rock types associated with the Bingham Canyon porphyry copper deposit. Quartzites include some relatively minor calcareous sandstone and limestone interbeds

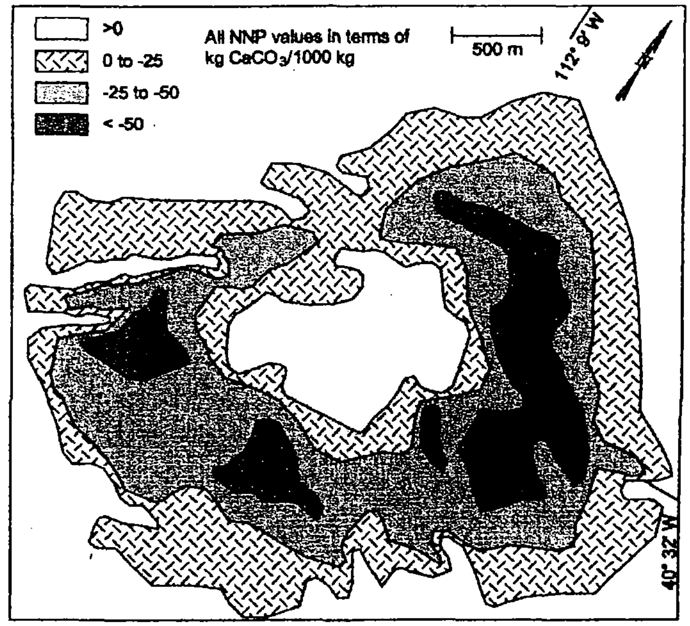

Fig. 5
Plan view distribution of NNP in the Bingham Canyon porphyry copper deposit. NNP is based upon total sulfur AP and Sobek NP

depending on the proximity of an igneous contact. The sedimentary sequence to the northeast of the orebody has much less NP than in any other area. There are no significant limestone beds, and NP values in the quartzite samples from the northeast only average 3 kg/1,000 kg versus an average of 15 kg/1,000 kg for quartzite samples from other areas.

For igneous rocks, calcium carbonate typically provides less than 50% of the total NP. Where present, the carbonate is generally contained within fractures and thin veins. The remaining NP is probably provided by silicate minerals such as plagioclase, biotite, phlogopite, chlorite, actinolite, and augite. On average, these six minerals comprise about 55% of the monzonite, while relatively unreactive orthoclase and quartz comprise an additional 40% (Lanier and others 1978b). The average NP contributed by non-carbonate minerals in the igneous rocks is 13 kg/1,000 kg. This value is broadly consistent with NP values measured for a large suite of aluminosilicate minerals by Jambor and others (2000). On average, the early monzonite and quartz monzonite phases of the intrusion contain more carbonate than the late stage latite porphyry and quartz latite porphyry phases. Within the monzonite and quartz monzonite phases, carbonate contents are generally highest adjacent to limestone beds. NP values are very low in the northeast portion of the stock, adjacent to the low NP portions of the surrounding sedimentary sequence. The correlation coefficient between carbonate content in the monzonite and quartz monzonite, and the distance to the closest limestone contact is –0.3. Carbonate may have been assimilated into the stock from the surrounding sedimentary rocks during emplacement or mineralization. As noted by Reid (1978), the altered limestones adjacent to the Bingham Stock are strongly depleted in CaO and CO_2.

Distribution of net neutralization potential

The distribution of NNP in the Bingham Canyon deposit is doughnut shaped, with a positive 1,000-m-diameter core surrounded by a negative 3,000-m-diameter ring (Fig. 5). Rock exposed in the lower 100 m of the pit is generally net neutralizing, and is overlain by about 500 m of net acid-generating rock (Fig. 6).

NNP values in the low-grade core of the orebody are positive, and the zero NNP contour generally conforms to the outer limit of molybdenum mineralization in the orebody. The center of the low-grade core, where total sulfur is less than 0.3%, typically has NNP values above 10 kg/1,000 kg and NPR values above 2. The highest NNP value sampled in the low-grade core was 28 kg/1,000 kg (NPR =4.6). These values may underestimate the effective NNP of the low-grade core because much of the AP is provided by relatively inert molybdenite. The outer limit of the orebody is generally defined by the –25 or the –50 kg/1,000 kg NNP contour line. Within the pyrite halo, NNP values below –75 kg/1,000 kg and NPR values below 0.1 are locally common about 1,100 m from the center of the low-grade core. Net neutralizing rocks are exposed on the margins of the pyrite halo and in the lead–zinc zone around the top of the pit. As shown in Fig. 5, the 0 kg/1,000 kg contour completely encircles the orebody about 1,500 m from the low-grade core.

Conclusions and implications

The well-developed mineralization and alteration zoning that has been noted by many previous studies at Bingham Canyon is mimicked by the acid/base accounting

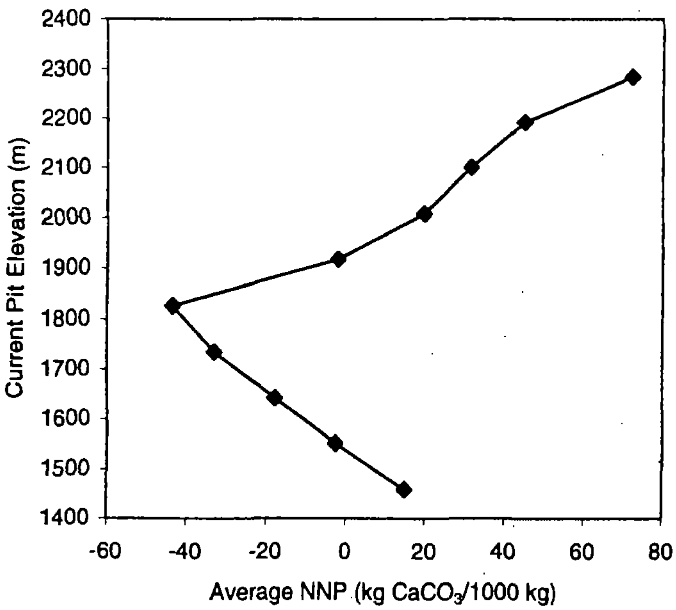

Fig. 6
Average NNP versus elevation in the Bingham Canyon open pit. NNP is based upon total sulfur AP and Sobek NP averaged in approximate 90-m vertical increments. Ore grade mineralization extends from the pit bottom to approximately 1,700-m elevation

characteristics of the deposit. The low-grade core and the molybdenite zone of the orebody, exposed in the bottom of the pit, are generally net neutralizing and rock here is unlikely to generate ARD when exposed to surface weathering conditions. Water currently being pumped from the bottom of the pit, in contact with these net neutralizing rocks, has a near neutral pH and an alkalinity in excess of 50 mg/l as $CaCO_3$. The main copper zone of the orebody and the surrounding pyrite halo are generally net acid-generating and the rock will tend to acidify when exposed. Waste rock mined from the pyrite halo generally acidifies within a decade of exposure to surface weathering conditions, and soils forming on some pyrite-bearing waste rock surfaces attain paste pH values as low as 2.1 (Borden 2001). Rock exposed near the pre-mining topographic surface and in the lead-zinc halo, approximately 1,500 m from the center of the orebody, contains few intact acid-generating sulfides and so poses little risk of acidification. Water that drains from underground workings in the lead-zinc halo surrounding the open pit generally has a neutral pH and an alkalinity in excess of 200 mg/l as $CaCO_3$. Waste rock generated from the upper-pit benches will typically maintain a near-neutral pH, even after several decades of weathering (Borden 2001).
The alteration and metals zoning observed at Bingham Canyon has been noted at other porphyry copper deposits, so these general acid/base accounting relationships are probably repeated at many other ore bodies. The Bingham Canyon acid/base accounting data can also be used to semi-quantitatively compare this deposit's potential to generate ARD with other porphyry copper deposits. For example, samples collected from the Berkeley Pit in Butte, Montana have much higher AP values and much lower NNP values than are typical for the Bingham Canyon deposit (Newbrough and Gammons 2002). The average NNP values reported for the Berkeley pit by Newbrough and Gammons (2002) are at least four times more negative than the average NNP data derived from the Bingham pit. These data indicate that, although significant portions of the Bingham Pit may generate ARD, the current pit as a whole is unlikely to produce the extremely low pH and high sulfate water that has accumulated in the Berkeley Pit since its closure.

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APPENDIX E – GEOCHEMICAL EVOLUTION OF SULPHIDE-BEARING WASTE ROCK SOILS AT THE BINGHAM CANYON MINE, UTAH

Geochemical evolution of sulphide-bearing waste rock soils at the Bingham Canyon Mine, Utah

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ABSTRACT: The soils forming on waste rock dump surfaces at the Bingham Canyon Mine have paste pH values ranging from 2.08 to 7.91. Paste conductivity, a measure of soil salinity, varies between 22 and 8750 μS cm^{-1}. The primary controls on waste rock soil pH and salinity are the sulphide distribution in the waste rock, the amount of limestone present and the age of the waste rock dump surface. The average pH of recently exposed waste rock is 7.0 and the average conductivity is 1120 μS cm^{-1}. Within six years of placement on the waste rock dumps the average pH declines to 4.7, further decreasing to 3.7 after 50 years. The average conductivity increases to 3000 μS cm^{-1} within six years but then declines to 855 μS cm^{-1} after 50 years. The sharp drop in pH, and the peak in salinity shortly after the waste rock is placed on the dumps, reflects the rapid release of acidity and sulphate caused by oxidation of newly exposed pyrite. The salinity of the soils begins to decline as pyrite becomes depleted and sulphate is flushed from the soil by infiltration and runoff more rapidly than it is replenished by sulphide oxidation.

INTRODUCTION

Management of sulphide-bearing waste rock is one of the largest environmental concerns associated with metals mining operations (Warhurst & Noronha 2000). Pyrite and other sulphide minerals in waste rock oxidize when exposed to surface weathering conditions and release sulphate, acidity and metals (Krauskopf & Bird 1995). Soils forming on waste rock dump surfaces may become too acidic or saline to reclaim without the use of expensive chemical amendments or soil caps. Runoff and infiltration from weathered waste rock surfaces may also have adverse impacts on surrounding surface and groundwater quality, requiring the construction of costly collection and treatment systems. Therefore, it is important to understand the geochemical evolution of sulphide-bearing waste rock soils in order to predict future environmental impacts and to select appropriate reclamation and water management strategies.

Many investigators have examined the genesis of soils forming on sulphide-bearing waste rock, but almost all of these studies have been limited to coal spoils (Schafer *et al.* 1980; Ciolkosz *et al.* 1985; Davidson *et al.* 1988; Horbaczewski & Van Ryn 1988; Roberts *et al.* 1988; Chichester & Hauser 1991; Haering *et al.* 1993; Johnson & Skousen 1995). Coal spoils tend to have lower sulphide contents than those of many ore bodies, and are generally composed of sandstone, siltstone and shale. This is a relatively limited number of rock types compared to the suite of igneous, metamorphic and sedimentary rocks that may be contained in waste rock from metals mining operations. Most of these previous studies were located in eastern U.S., so precipitation and weathering rates may be dissimilar to those found in the arid and semi-arid climates of many western U.S. mining sites.

The present study was conducted at the Bingham Canyon porphyry copper deposit near Salt Lake City, Utah. The mine site is located in a semi-arid climate between 1500 and 2500 metres in elevation. Over three billion metric tonnes of waste rock have been produced since open pit mining operations began in 1906. The existing waste rock surfaces cover more than 2000 hectares and vary from <1 to >50 years in age.

Copper mineralization is centred on the Bingham stock, an Eocene monzonite intrusion exposed in the bottom of the open pit. The stock was intruded into the Pennsylvanian Oquirrh Group, a sedimentary sequence of quartzite with lesser amounts of interbedded limestone (James *et al.* 1961; Lanier *et al.* 1978). The copper ore body is surrounded by a pyritic halo that typically contains between 1 and 7% sulphides (James *et al.* 1961; John 1978; Babcock *et al.* 1997). On the outer margins of the pyritic halo, near the deeply weathered pre-mining topographic surface on the upper edge of the open pit, pyrite contents of 0 to 0.5% are common (Kennecott Utah Copper Corporation 1999). A lead–zinc halo surrounds the pyritic halo and small load deposits of sphalerite and galena are exposed on some of the uppermost pit benches (Babcock *et al.* 1997). Most of the copper-depleted leached cap of the Bingham ore body was removed before 1916 (James *et al.* 1961). Since that time, the majority of waste rock produced at Bingham Canyon has come from the pyritic halo with a much smaller contribution from rock exposed on the upper benches of the open pit (James *et al.* 1961; John 1978; Babcock *et al.* 1997). Waste rock is generally composed of a mixture of monzonite intrusive rock and quartzite, with lesser amounts of limestone. Pyrite is by far the most common sulphide mineral in the waste rock, with lesser amounts of chalcopyrite, sphalerite and galena. The variability of pyrite and calcium carbonate content in the rock has produced a series of waste rock surfaces with different acid generating and acid neutralizing characteristics. The diversity of age and mineralogical characteristics on the Bingham Canyon waste rock surfaces has created a unique area to examine the controls on waste rock soil evolution.

The objectives of this study were: (1) to characterize soil pH and salinity conditions on the Bingham Canyon waste rock dumps; (2) to identify the primary waste rock characteristics influencing soil chemistry; and (3) to determine if the dump soil chemistry is changing as the waste rock surfaces are weathered. These data are being used at Bingham Canyon in conjunction with botanical surveys to identify the geochemical limitations on the re-establishment of native vegetation and to plan reclamation strategies for various dump surfaces.

METHODS

Field sampling

A total of 130 field samples and 17 quality assurance/quality control samples were collected from the waste rock dumps during the summers of 1998 and 1999. Approximate sample locations were selected to establish uniformed geographical distribution over the entire waste rock surface and to ensure that dump surfaces of all ages were characterized. Dump surface ages were estimated by comparing topographical maps and aerial photographs from 19 different years, between 1952 and the present. The age of dump surfaces created after 1991 could be estimated to within one year. However, the ages of dump surfaces created between 1987 and 1991 could only be estimated to within ± 2 years, those created between 1952 and 1984 to within ± 1 to 6 years and those created between 1906 and 1952 could not be estimated at all because of the lack of maps for that period.

In the field, the exact sample site was chosen to be most representative of the immediate surrounding area. For example, on generally non-vegetated surfaces with small, scattered areas of volunteer growth, samples were only collected on the non-vegetated areas. The same principle was used for surfaces containing waste rock with significantly different lithological or mineralogical contents. On dump surfaces that contained two visually distinct areas of near equal size, a separate sample was collected from each of the distinct areas.

Each sample was made-up of three to five sub-samples collected on the dump surface. Sub-sample locations were generally arranged in a polygon and were about six to nine metres apart from each other. At each sub-sample location a hole was dug to a depth of 10 cm, the sub-sample was then collected by removing the entire 0–10 cm vertical interval from one side of the hole. All the sub-samples were mixed together in a stainless steel bowl and were hand sorted to remove any clasts larger than *c.* 1 cm in diameter. A representative split of the mixed material was then retained for analysis. Laboratory replicates were created by splitting two sub-samples from the mixed material and assigning them unique sample numbers. At some sampling sites, field replicates were taken by collecting a new sample from a different set of sub-sample locations within the same area on the dump surface.

Field observations including estimates of lithological content and sulphide distribution were also made at each sample site. The relative percentage of igneous rock, quartzite and limestone was estimated by selecting 20 or more clasts randomly within the outline of the polygon defined by the sub-sample points. Each clast was cracked open and examined to determine its lithology and if any sulphides were visible within the clast. The abundance of each lithology was assigned a percentage from 0–100% in increments of 5% based upon this technique. If a lithology was determined to be present at a percentage between 0 and 5% it was designated as being present in trace amounts. The sample site was also examined to determi any sulphides could be visually identified within the grained material (sand size and smaller), and on the outside or inside of clasts. This visual survey was performed both with the naked eye and with a 10x hand lens.

Laboratory procedures

All samples were analysed by the Kennecott Utah Copper Corporation Environmental Laboratory for paste pH and conductivity. Paste conductivity is expressed in milliSiemens per centimetre ($\mu S\ cm^{-1}$) and is a measure of the total salinity of the soil. Twenty-four samples were also leached with distilled water so that the individual soluble constituents of the soil could be determined. About half of the samples selected for this leach test were from sites where volunteer vegetation was growing and where botanical surveys were later carried out. Most of these samples had paste pH values >4.2 and conductivities <500 $\mu S\ cm^{-1}$. The other half of the samples were selected in order to be representative of waste rock surfaces that had lower pH or higher conductivity values.

In the laboratory, 5 g of each soil sample was mixed with 10 ml of distilled water. The mixture was then shaken and allowed to sit in a closed container for 24 h. The paste pH and paste conductivity measurements were made on the water sample after it was decanted from the solids. These analyses were performed with an Orion Model 230A pH meter and an Amber Science Incorporated EC Model 2052. For the leach samples, 300 g of soil were mixed with 300 ml of distilled water and continuously agitated for 24 h in a closed container. T water was then filtered through a 0.45 μm filter and analy for alkalinity, acidity, sulphate and metals (Ca, Mg, Na, K, Cl, Al, Cu, Fe and Mn). Alkalinity was determined by titrating to a pH end point of 4.5 with a 0.5 N sulphuric acid solution. Acidity was determined by titrating to a pH end point of 8.2 with a 0.25 N sodium hydroxide solution. Both alkalinity and acidity titrations were performed with a Mettler model DL70ES automatic titrater. Sulphate was analysed with an Alpkem model 300 continuous flow analyser. The metals were analysed with a Perkin-Elmer Optima 3000 inductively coupled plasma emission spectrometer.

RESULTS

Soil paste pH results for samples collected on the Bingham Canyon waste rock dumps range between 2.08 and 7.91 (average 4.5). Paste conductivity varies between 22 $\mu S\ cm^{-1}$ and 8750 $\mu S\ cm^{-1}$ (average 1170 $\mu S\ cm^{-1}$). Table 1 summarizes the laboratory and field replicate results. The results for field replicates showed higher variance than for the laboratory

Table 1. *Replicate sample analytical variability*

	Replicates	
	Laboratory	Field
Number of sample pairs	9	8
Average pH difference	0.12	0.19
Maximum pH difference	0.22	0.[illegible]
pH correlation coefficient	0.998	0.[illegible]
Average conductivity RPD*	5.1%	43.3%
Maximum conductivity RPD*	13.3%	97.9%
Conductivity correlation coefficient	0.996	0.904

*Relative percent difference (=difference between two samples/average of two samples).

Table 2. *Summary of soil distilled water leachate analytical results*

Constituent	Average concentration* (all samples)	Concentration range* (all samples)	Average concentration* (pH<4.1)	Average concentration* (pH>4.5)
Number of samples	24	24	8	16
Sulphate	1145	14–5240	2784	326
Calcium	204	3.5–681	350	131
Magnesium	80	1.1–588	217	11.7
Fe, Al, Cu, Mn	89	1.1–550	262	2.4
Na, K, Cl	12.8	5.9–23.1	12.1	13.2
All analytes (TDS)	1531	27–6625	3625	484

*All concentrations in mg l^{-1}.

replicates, and probably reflect small-scale spatial variability of soil chemistry within the sample area. However, the maximum pH difference between any replicate sample pair was only 0.38 pH units, and only one set of paste conductivity replicate results differed by more than a factor of two.

Table 2 and Figure 1 summarize the results of the soil distilled water leachate analyses. The concentration of total dissolved solids (TDS) measured in the soil leachate varied between 26.7 mg l^{-1} and 6625 mg l^{-1}. Sulphate is the dominant soluble anion detected in the waste rock soils, and calcium and magnesium are the dominant cations. On average, sulphate represents 65% by weight of the measured TDS in each leachate sample. Calcium and magnesium average 20% and 5% of the TDS, respectively. The concentration of other common salts such as sodium, potassium and chloride in each leachate sample averaged only 6%, and the combined concentration of these ions in solution did not exceed 23.1 mg l^{-1} in any sample. The leachate concentration of all of the analytes except for sodium, potassium and chloride increased with decreasing pH. As shown on Figure 2, there is generally good agreement between the soil paste conductivity and the measured TDS in the leachate samples.

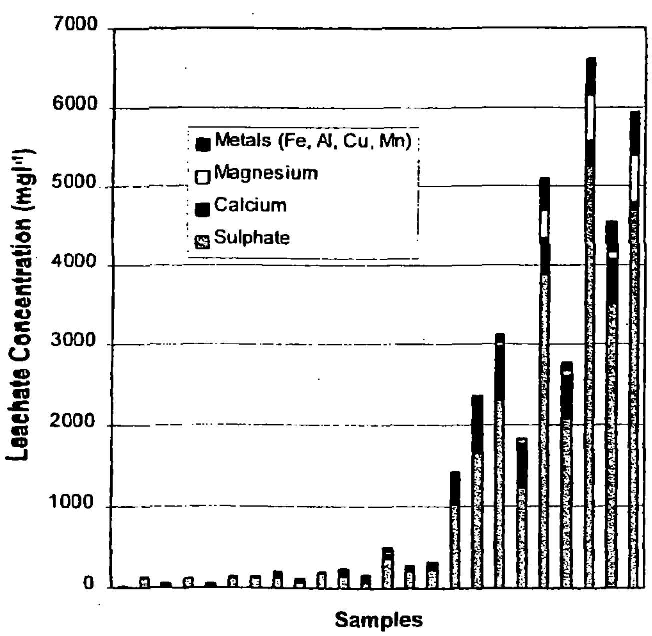

Fig. 1. Distilled water leachate chemistry of waste rock soils. The five samples furthest to the right all have paste pH values of <4.1 and conductivities of >2000 μS cm^{-1}. The eight samples furthest to the left all have pH values of >4.5 and conductivities of <100 μS cm^{-1}.

DISCUSSION

The data presented in Table 3 indicate that waste rock sulphide distribution, limestone content and surface age all influence the soil chemistry. The relationship of these variables to soil pH and salinity are explored in the following sections.

Sulphide distribution

Numerous studies have investigated the geochemistry of sulphide oxidation. Some general references on the subject include publications by Kittrick *et al.* (1982), Williams *et al.* (1982), Blowes & Jambor (1994), Krauskopf & Bird (1995) and Rose & Cravotta (1998). A generalized oxidation reaction for pyrite is:

$$FeS_2 + 15/4O_2 + 7/2H_2O = Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

In soils with abundant pyrite, sulphide oxidation provides a continuous source of acidity and sulphate. Under alkaline or weakly acidic conditions, the iron is immediately precipitated as a hydroxide. However, if soil pH drops <4, much of the iron released by pyrite oxidation remains soluble, and additional iron may be released by the dissolution of pre-existing iron hydroxide in the soil:

$$Fe(OH)_3 + 3H^+ = Fe^{3+} + 3H_2O$$

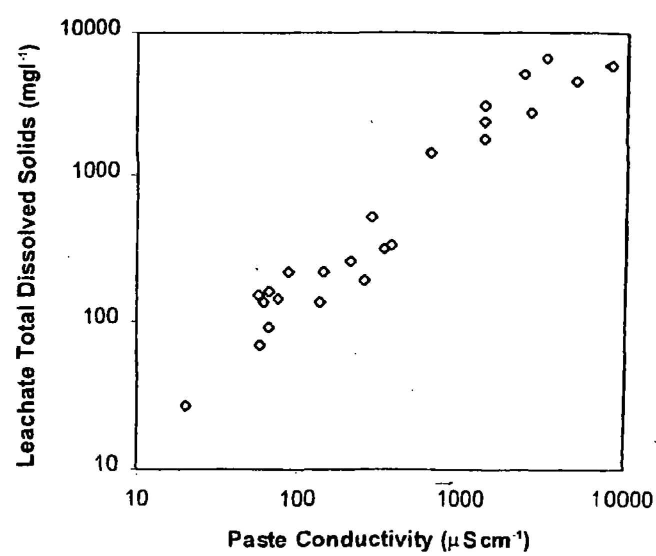

Fig. 2. Log soil paste conductivity versus log measured total dissolved solids (TDS) in the distilled water leachate. The relationship between conductivity and TDS as calculated by the least squares method is: Log TDS=(0.942)(Log Conductivity)+0.314, r^2=0.94. The correlation coefficient between conductivity and TDS is 0.865.

Table 3. *Relationship between soil pH, conductivity and selected waste rock characteristics*

Variable	Average pH*	pH range	Average conductivity (µS cm^{-1})*	Conductivity range (µS cm^{-1})
Sulphide distribution				
No visible sulphides	5.79+0.44	3.23–7.76	125+37	26–500
Only visible inside clasts	4.56+0.49	3.13–7.15	152+45	22–420
Visible on inside/outside of clasts	4.70+0.54	2.32–7.91	845+304	33–4125
Visible in fines and on clasts	3.85+0.46	2.08–7.00	2610+539	310–8750
Limestone content				
None	3.93+0.26	2.08–7.57	1160+345	22–8750
0–5 %	4.89+0.66	2.32–7.29	886+722	50–7240
5–15%	5.82+0.69	2.16–7.61	1270+555	75–5680
>20%	6.85+0.40	5.21–7.91	549+385	68–2110
Surface age				
Recently exposed bedrock	7.03		1120	
1992–1998	4.67+0.86	2.32–6.87	2990+913	1485–7240
1987–1991	4.87+1.11	2.42–7.59	1290+975	87–5485
1973–1984	5.17+0.50	2.08–7.91	1140+430	33–6280
1961–1972	4.42+0.44	2.09–7.57	906+496	22–8750
Created before 1952	3.68+0.83	2.32–6.60	855+559	84–2600

*The 95% confidence interval based on the *T* statistic for each mean is included.

At low pH, this soluble iron in conjunction with hydrogen ions and other metals may be a significant contributor to total soil salinity.

The waste rock at Bingham Canyon is generally composed of sandy gravel or silty, sandy gravel. Visible sulphide minerals were observed both in the sandy matrix and on larger gravel clasts at about 31% of the waste rock sample sites. Visible sulphides were only present on the inside and outside of clasts at about 32% of the sample sites, and were only observed on the inside of clasts at 14% of the sample sites. At the remaining sample sites, no sulphides were observed. Younger waste rock surfaces are more likely to contain sulphides in the fine-grained matrix than older surfaces. Sulphides were observed in the sandy matrix of all samples collected from surfaces younger than 1991, but were only observed in the matrix of 27% of the samples from older surfaces. The average age of surfaces where sulphides were observed in the fine-grained matrix was 17 years compared to 27 years for surfaces where sulphides were only observed on the inside and outside of clasts.

As shown on Table 3 and Figure 3, this sulphide distribution has a significant impact on both soil pH and conductivity. Soils that do not contain any visible sulphides have an average pH of 5.8 and an average conductivity of 125 µS cm^{-1}. As sulphides become more widely distributed in waste rock the average pH declines and the average salinity increases. Soils that contain sulphides in the sandy matrix and on the inside and outside of gravel clasts have an average pH of 3.9 and an average conductivity of 2610 µS cm^{-1}.

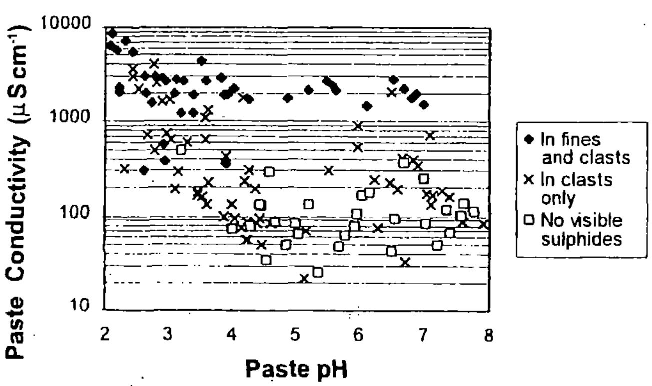

Fig. 3. Soil paste pH v. log paste conductivity (showing the sulphide distribution observed on the waste rock surface at each sample point).

There are several ways in which the observed sulphide distribution may influence the soil pH and salinity. In general, waste rock surfaces where sulphides are present in all size fractions contain a higher percentage of sulphides than surf where sulphides are only present in larger clasts. Sulphide the sandy matrix also have greater exposure to atmospheric oxygen and water and so would be expected to oxidize more rapidly than sulphides inside clasts.

Lithological content

The presence of limestone and monzonite on the waste rock dump surface influences the soil pH and to a lesser extent the soil salinity. Limestone contains abundant calcium carbonate, which provides an *in situ* buffer to the acid generated by pyrite oxidation. Monzonite typically contains calcium carbonate veins as well as abundant calcium-silicate and alumino-silicate minerals, which also provide some buffering capacity (Jambor *et al.* 2000).

Acidity is neutralized by calcite dissolution according to:

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^- \quad \text{(when pH is > 6.3)}$$

Soils in equilibrium with calcite and the atmosphere will maintain a pH of about 8 (Krauskopf & Bird 1995). This is the approximate upper limit for pH observed on the Bingham Canyon waste rock dumps.

When calcite reacts with acid, hydrogen ions are consumed and calcium ions are released. On monzonite-dominated dump surfaces, neutralization capacity and calcium are also supplied by the breakdown of calcium-silicate minerals such as plagioclase, which typically comprises 30% of the rock (Lanier *et* 1978). Some neutralization capacity in the monzonite is a attributed to less abundant and less reactive minerals such as biotite and chlorite. Independent of pH, calcium and sulphate ions in sufficiently high concentration may precipitate to form gypsum:

$$Ca^{2+} + SO_4^{2-} + 2H_2O = CaSO_4 \cdot 2H_2O$$

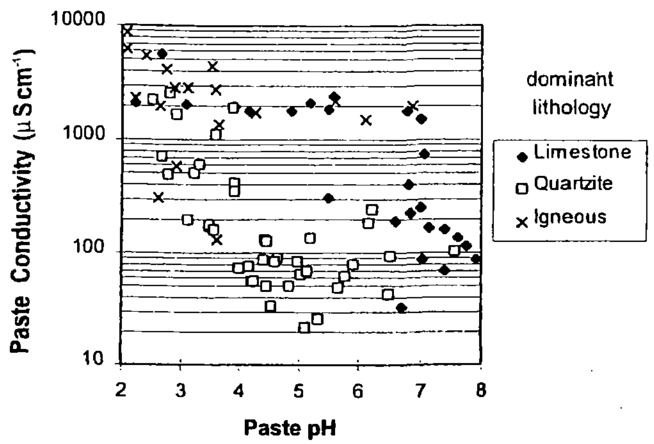

Fig. 4. Soil paste pH v. log paste conductivity (showing the dominant lithologies observed on the waste rock surface at each sample point).

The solubility of gypsum may limit the concentration of dissolved sulphate and calcium in the soil (Rose & Cravotta 1998). According to Richards (1954), a solution of pure water in equilibrium with gypsum will have an electrical conductivity of *c.* 2000 μS cm^{-1}. On the surfaces of waste dumps, elongate, clear to white crystals <2 mm in length were noted in the sandy matrix of about 5% of the samples. These are believed to be gypsum crystals. All of the sample sites at which they were observed contained either limestone or igneous rock and had paste conductivities above 1700 μS cm^{-1}.

The relationships between lithology, pH and conductivity are illustrated on Figure 4. All samples from waste rock surfaces composed of 10% or more limestone are assigned to the limestone dominant population. Samples from waste rock surfaces without any limestone and containing 50% or more monzonite are assigned to the igneous dominant population. Samples from waste rock surfaces composed of 90% or more quartzite with no limestone are assigned to the quartzite dominant population.

For limestone- and quartzite-dominant dump surfaces, pH and salinity exhibit a linear, inverse relationship. All quartzite-dominated soils with elevated conductivities also have low pH values. If any acidity is released by pyrite oxidation in quartzite-dominated soils, the pH declines immediately because these soils possess little or no acid-neutralizing capacity. Conversely, limestone-dominant soils may have conductivities as high as 2000 μS cm^{-1} with a near neutral pH because acidity released by pyrite oxidation is neutralized *in situ*. There is a positive correlation between the amount of limestone present on the dump surface and pH (Table 3). Samples collected from dump surfaces containing >20% limestone have an average pH of 6.9, compared to 3.9 for surfaces with no limestone. The maximum conductivity for soils containing >20% limestone is also limited to about 2000 μS cm^{-1} because the lowest pH for these samples was 5.21.

Soils forming on igneous dominated dump surfaces tend to have low pH values and high conductivities. Igneous rocks generally contain more sulphides than sedimentary rocks and they have a lower buffering capacity than limestone, so they are less likely to maintain a neutral pH as they are oxidized.

Surface age

On average, the pH of waste rock soils decreases with increasing time of exposure. After a rapid initial increase, the average salinity also decreases with time (Table 3, Fig. 5).

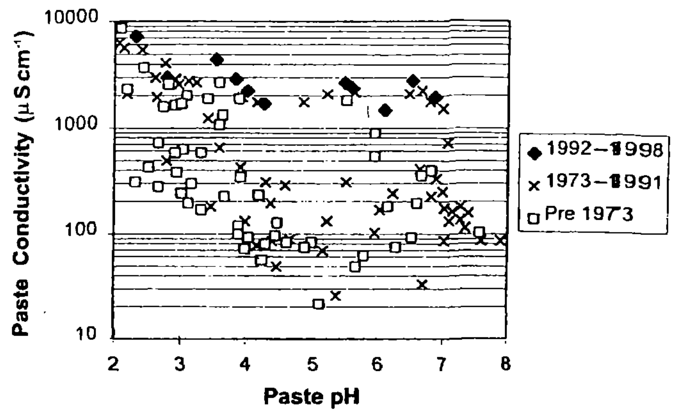

Fig. 5. Soil paste pH v. log paste conductivity (showing the age of the waste rock surface at each sample point).

Samples of newly exposed waste rock collected from the open pit that have been ground to a −200 mesh size have an average paste pH of 7.0 and an average conductivity of 1120 μS cm^{-1} (Kennecott Utah Copper Corporation 1999). The average paste pH of the waste rock soils declines to a pH of <5 within the first six years. Over the next forty years, the average paste pH declines to 3.7. Within the first six years of mining, the average paste conductivity more than doubles from 1120 to 2990 μS cm^{-1}. After about ten years the average conductivity drops to 1290 μS cm^{-1}, then gradually declines to an average of 855 μS cm^{-1} after about 50 years.

The mining process increases the surface area of waste rock that is exposed to atmospheric oxygen and water, accelerating pyrite oxidation and increasing the rate of acid and sulphate production. If carbonates are present, the acid released by sulphide oxidation may be neutralized *in situ*, but soils without acid-neutralizing minerals may acidify rapidly. Recently created waste rock surfaces tend to have elevated paste conductivities because the newly exposed pyrite releases sulphate into the soil more rapidly than it is removed by runoff or infiltration. Through time, most exposed pyrite is either consumed or armoured, and the rate of new sulphate release is eventually surpassed by the rate of sulphate removal by flushing. At this point in time, the soil conductivity will begin to decline. In time, almost all of the exposed sulphides are oxidized and the rate of new sulphate release drops to near zero. Continued flushing may result in soils with relatively low conductivities.

Geochemical evolution

Acid/base accounting (ABA) compares the net acid generating potential of a rock with its net neutralization potential. ABA analysis was initially designed to assess the acid generation potential of coal spoils (Sobek *et al.* 1978). In the past decade, numerous studies have attempted to refine the technique and make it more applicable to metal mining wastes (Lawrence *et al.* 1989; Price *et al.* 1997; Kwong 2000). The acid potential (AP) of a rock is a measure of the amount of calcium carbonate that would be required to neutralize all of the acid generated by complete oxidation of all sulphides in the rock. The neutralization potential (NP) is a measure of the amount of acidity that the rock can consume. Although many minerals may contribute to the NP, it is expressed as the amount of calcium carbonate that would have to be present in the rock to provide the equivalent neutralizing capacity. The AP and NP may be directly compared when expressed in calcium carbonate equivalents. Generally a rock, with an AP that is much higher than its NP, will generate acid rock drainage under surface weathering

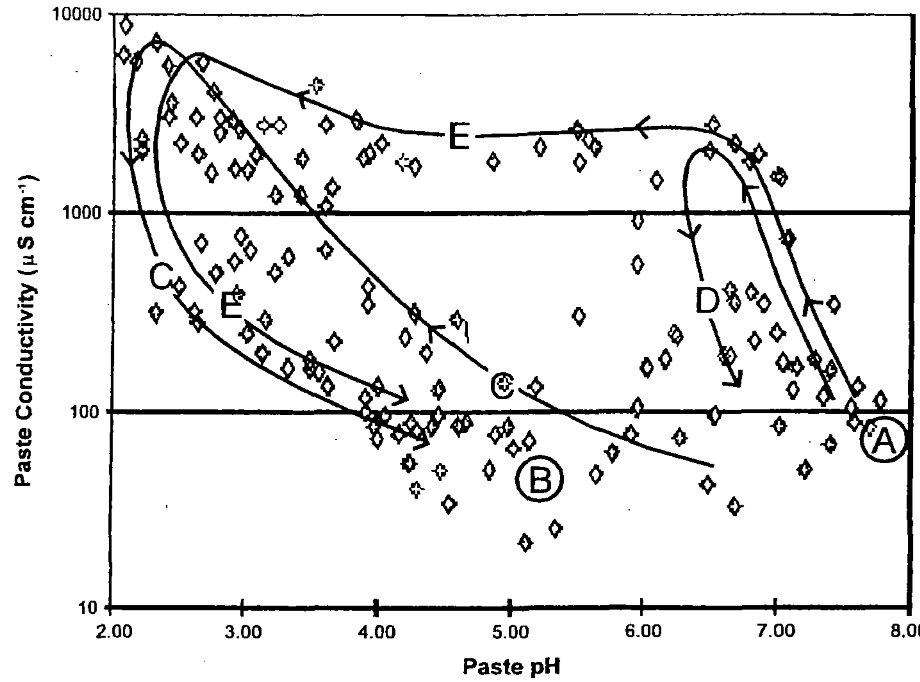

Fig. 6. Evolution of waste rock soil pH and salinity for waste rock surfaces with different initial acid/base accounting characteristics. Point (A) is for waste rock soils where the initial Neutralization Potential (NP)>Acid Potential (AP) near 0; Point (B) is for soils where the initial NP=AP near 0; Line (C) is for soils where the initial AP>NP near 0; Line (D) is for soils where the initial NP>AP>0; Line (E) is for soils where the initial AP>NP>0.

conditions. A rock with a NP much greater than its AP will typically not generate acid rock drainage. At Bingham Canyon, pyrite is the primary contributor to AP, and calcium carbonate and calcium-silicate minerals in limestone, and to a lesser extent in monzonite, are the primary contributors to NP.

Figure 6 is a paste pH v. log paste conductivity diagram that shows how Bingham Canyon waste rock surfaces with different initial ABA characteristics respond through time to surface weathering conditions. Five generalized initial ABA conditions and weathering pathways are shown: point (A) NP is greater than AP, which is near zero; point (B) NP and AP are both near zero; line (C) AP is greater than NP, which is near zero; line (D) NP is greater than AP, which is greater than zero; and line (E) AP is greater than NP, which is greater than zero.

Waste rock that has abundant NP, but little or no AP when placed on the dump will generally maintain a neutral to weakly basic pH and low salinity throughout the weathering process. Soils forming on these surfaces will always plot near point (A) on a paste pH/log paste conductivity diagram. At Bingham Canyon, these soils are generally forming on surfaces with >10% limestone that contain little or no pyrite.

Waste rock that has little or no NP or AP will tend to maintain a neutral to weakly acid pH and low salinity throughout the weathering process. Newly created waste rock soils may have a pH near 7, but because they are not buffered at a neutral pH, older surfaces may evolve towards a pH typical of rainwater. Rainwater in the vicinity of Bingham Canyon typically has a pH of 5.0–5.5 and a conductivity of 10–15 µS cm^{-1} (National Atmospheric Deposition Program (NRSP-3)/ National Trends Network 2000). These soils will plot near point (B) on a paste pH/log paste conductivity diagram. At Bingham Canyon, these soils are generally forming on surfaces composed entirely of non-mineralized quartzite.

Waste rock with a significant AP but with little or no NP will tend to evolve along path (C) during the weathering process. At Bingham Canyon, these soils are generally forming on surfaces composed of mineralized quartzite that contains >1% pyrite. These waste rock soils may acidify within months or a few years after exposure to surface conditions because there is no neutralizing capacity to buffer the initial release of acid when the pyrite begins to oxidize. The rapid release of sulphate also causes the salinity to increase rapidly. Below a pH of 4, other cations and anions also begin to contribute to the salinity. With time, the pyrite that is available for oxidation is consumed, generally within one or two decades, a point is reached where pyrite oxidation products are flushed from the soil faster than they are produced. At this point on path (C) the salinity begins to decline. However, the pH may remain buffered between 2 and 3 for a much longer period of time because of the mineral acidity provided by some sulphate-, iron- and aluminium-bearing minerals in the soil. After many years of additional flushing these minerals are removed, so the pH may increase above 4, and the salinity may drop to paste conductivities of less than 100 µS cm^{-1}.

Waste rock that has some AP but with an excess of NP will tend to evolve along path (D) during the weathering process. At Bingham Canyon, these soils are generally forming on surfaces that contain more than 20% limestone and that contain >1% pyrite. The acidity released by pyrite oxidation is neutralized *in situ*, so the soil maintains a neutral to slightly acid pH throughout the weathering process. However, the release of sulphate may cause the soil salinity to increase to 2000 µS cm^{-1} at which point salinity may be limited by gypsum solubility. Again at some point, sulphide oxidation products are removed from the soil faster than they are being produced and the salinity begins to drop. With enough time, all sulphide oxidation products and soluble secondary minerals like gypsum are flushed from the soil and it may evolve back towards point (A) on the paste pH/log paste conductivity diagram. When the buffering capacity is provided by minerals, such as calcium silicates that have slower reaction kinetics, the pH may drop below 6 early in the weathering process (Jambor *et al.* 2000). However, as the rate of sulphide oxidation and acid production decreases, the pH will eventually increase to neutral conditions.

Waste rock that has some NP, but with an excess of AP when placed on the dump will tend to evolve along path (E) during the weathering process. At Bingham Canyon, these soils are generally forming on surfaces with minor limestone or abundant monzonite that are also strongly mineralized with pyrite. Initially all of the acidity released by pyrite oxidation is neutralized *in situ* and the soil maintains a neutral pH while the salinity increases to about 2000 μS cm^{-1}. However, as pyrite oxidation continues, the neutralization capacity is gradually exhausted and eventually the pH begins to drop. For waste rock surfaces where AP is only a little higher than NP, this process will take much longer than waste rock were AP is much greater than NP. As the pH drops <4, the concentration of sulphate and metals increases conductivity to above 2000 μS cm^{-1}. Eventually, the rate at which sulphide oxidation products are created is exceeded by the rate at which they are flushed from the system. At this point the salinity will begin to drop and the soil will evolve in a similar manner to path (C).

CONCLUSIONS

The primary controls on waste rock soil pH and salinity at the Bingham Canyon Mine are the distribution of sulphides in the waste rock, the amount of NP in the waste rock, and the age of the waste rock dump surface. Waste rock surfaces that contain sulphides in both the sandy matrix and in gravel clasts generally have lower pH values and higher conductivities than waste rock surfaces that only contain sulphides on the inside or outside of clasts. The average pH of the waste rock soils increases with increasing limestone content. The geochemical evolution of individual waste rock soils through time is dependent upon the initial AP and NP of the waste rock. For waste rock soils with excess AP, pH tends to decrease with increasing surface age, but soils with excess NP may remain neutral throughout the weathering process. The salinity of pyrite-bearing waste rock soils tends to peak within the first six years of exposure and declines thereafter.

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APPENDIX F – VEGETATIVE COMMUNITY ANALYSIS OF BIOSOLIDS TEST PLOTS AFTER FIVE YEARS OF GROWTH

VEGETATIVE COMMUNITY ANALYSIS OF BIOSOLIDS TEST PLOTS AFTER FIVE YEARS OF GROWTH

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ABSTRACT

The application of municipal biosolids during reclamation has been gaining acceptance in recent years. A series of reclamation test sites were established at the Bingham Canyon Mine in Utah during 1995 and 1996. These test sites were established on the tailings impoundment surface, on capped waste rock surfaces and on a gravel-borrow area. At each site, biosolids were applied to plots at rates of between 10 and 30 dry tons/acre, and control plots received identical treatments with the exception that biosolids were not applied. Vegetative community surveys were conducted at seven of these paired plots in the summer of 2001. After five to six years of growth, the biosolids plots generally contained a higher percent cover, ~75% of which was provided by volunteer weed species. On average, cheat grass (*Bromus tectorum*) alone accounted for over half of the total cover at the biosolids plots. The control plots, where biosolids were not applied, generally had less total cover, but weedy species accounted for less than 20% of the cover that was present. On average, the absolute cover provided by non-weedy species at the control plots was about twice as high as at the biosolids plots. The species diversity of non-weedy species at the control plots was also higher than at the biosolids plots. Forbs and woody shrubs were most common on the control plots. Most differences between biosolids and control plots were found to be statistically significant at a 0.05 significance level using an ANOVA analysis. The application of biosolids at these rates may favor the growth of weedy species and inhibit the establishment of favorable species. These study results suggest that depending upon the reclamation objectives, biosolids application may not always be beneficial, and that application rates of less than 10 tons/acre may be optimal at reclamation sites.

INTRODUCTION

The Bingham Canyon Mine is located in the Oquirrh Mountains near Salt Lake City, Utah. Several reclamation test sites were established at the mine in 1995 and 1996. These sites were designed to test the effect of biosolids (composted municipal sewage sludge) application during the reclamation of tailings, waste rock and gravel-pit surfaces. Biosolids have been used at many other reclamation sites because they can improve the physical and chemical characteristics of the soil and may act as a slow release fertilizer. The study area has a semi-arid climate and average annual precipitation varies between about 15 and 20 inches/year. The test plots are located between 4400 and 6200 feet above mean sea level.

At each of these test plots, biosolids were applied at rates that varied between zero and thirty dry tons/acre. The biosolids were usually disked into the surface soil before the sites were planted. Data collected from these sites after the first one to two growing seasons generally indicated that the plots where biosolids were applied had produced much more biomass than the control plots that received no biosolids. In these early surveys, weedy species were not observed to dominate any of the test plots (Marrs, 1997b; McNearny, 1998).

During the summer of 2001, seven of these paired test plots were revisited and new vegetative community analyses were performed. Two of the paired test plots were located on the tailings impoundment embankment, three were located on top of sulfide-bearing waste rock surfaces and two were located on a gravel-borrow area.

METHODS

Test plots were selected for analysis if they met the following criteria: 1) documentation was available that detailed the treatments each plot received when it was established, 2) the plots were more than five years old, 3) the plots had not been disturbed since establishment, and 4) the location and boundaries of the plots could be confidently identified in the field.

Vegetation community analyses were performed at each test plot according to the relevÈ, or "sample stand" method (Barbour et al., 1987). Plant identification and nomenclature generally follows Welsh et al. (1993) while exotic species were identified from Whitson et al. (1992). Using the relevÈ method, variable-sized quadrats (sub-sites) were sampled at representative locations within each test plot area. The number of individual quadrats sampled at each test plot varied from one to five, depending upon the size of the plot. Each quadrat was sized to contain at least 90-95% of the dominant plant species identified within the community during the general site reconnaissance. Within each quadrat, three parameters were measured: the absolute % cover of each species present, the sociability of each plant species, and the vigor class of each plant species (Tables 1 through 3). Percent cover estimates were visually estimated within cover classes defined by the Braun-Blanquet cover scale (Mueller-Dombois and Ellenburg, 1974). The cover for each observed species was measured as a category (a number between zero and seven denoting 0-100% cover, respectively) rather than a precise number. An exact estimate of percent cover is thought to give a false sense of precision and cover estimates from multiple observers rarely agree. Although some precision is lost, categorical classification has good repeatability.

Species diversity was approximated with the number of species observed within each test plot. Even though simple diversity based on species counts can be undesirable because it fails to consider the relative abundance of the species present, in conjunction with the percent cover data, the relative abundance can be inferred.

The data from the relevÈ surveys were used to investigate the effects of biosolids application on the revegetation efforts. Percent cover, species diversity, and weed composition were compared between the biosolids and control plots. Weeds were identified by referencing the following three texts:

Noxious Weed Field Guide for Utah, J. Merritt, N.D. Belliston, and S.A. Dewey, 2000
Weeds of the West, T.D. Whitson et al., 1992
Common Weeds of the United States, USDA, 1971

Table 1.
Cover Classes of Braun-Blanquet

Class	Range of % Cover	Median
1	75-100	87.5
2	50-75	62.5
3	25-50	37.5
4	2-25	15.0
5	1-5	3
+	<1- 0.5	0.75
R*	Rare	*

* R=Individuals occurring seldom or only once; cover ignored and assumed to be insignificant. SOURCE: Mueller-Dombois and Ellenburg 1974

Table 2.
Sociability Scale of Braun-Blanquet

Value	Meaning
5	Growing in large, almost pure stands
4	Growing in small colonies or carpets
3	Forming small patches or cushions
2	Forming small but dense clumps
1	Growing singly

SOURCE: Barbour et al. 1987

Table 3.
Vigor Class

Class	Meaning
E	Excellent
G	Good
F	Fair
P	Poor

In general, weedy species that were observed on the test plots were not part of the reclamation seed mixes that were applied. In most cases the weeds are volunteers on the plots. However, four species that are listed as weeds in one or more of these texts were included in some of the seed mixes applied to the test plots. Rubber Rabbitbrush (*Chrysothamnus nauseousus*) is a dominant native species on undisturbed slopes of the Oquirrh Mountains and was included in some of the seed mixes. Yellow and White sweet clovers (*Melilotus officinalis* and *Melilotus albus*, respectively) and Orchard Grass (*Dactylis glomerata*) have also been historically included in revegetation seed mixes. During the analysis of weed content in the test plots, these four species were considered to be non-weedy because they were intentionally seeded onto many of the test plots.

Average Absolute Cover for each test plot was calculated by averaging the median-point of the Braun Blanquet cover classes for each species at each of the quadrats (sub-plots). These average absolute cover values for each species was totaled and reported as total absolute vegetative cover at each plot. The total absolute vegetative cover for any one plot can exceed 100% as there could be several layers of vegetation contributing to the total (grasses, forbs, shrubs).

PAIRED TEST PLOT RESULTS

Table 4 presents the 2001 survey results for each of the paired test plots. The results presented below characterize the vegetation cover at a single point in time five to six years after the plots were established. The character of the vegetation has likely changed since the initial surveys were conducted immediately after planting and it is anticipated that the character of the vegetation will continue to change in the future.

Table 4.
Comparison of Absolute Cover and Species Diversity between Paired Plots

Test Plot	Absolute Cover of Weed Species (%)		# of Weed Species Observed		Absolute Cover of Non-Weed Species (%)		# of Non-Weed Species Observed	
	BSA	NBS	BSA	NBS	BSA	NBS	BSA	NBS
01-04	88	21	2	2	0.2	90	1	5
01-05	54	41	2	2	46	64	2	3
01-06 Tailings Cap	92	6	4	3	0.4	16	2	2
01-06 Soil Cap	101	17	6	7	7	62	7	14
01-07	99	8	8	5	29	120	8	14
01-09 No Treatments	59	1.5	7	6	60	33	6	15
01-09 All Treatments	85	0.7	7	4	25	48	3	14

Note: BSA = Biosolid Application
NBS = No Biosolid Application

The results for the individual sites are detailed below.

Site 01-04

Site 01-04 is located on the east side of the tailings impoundment embankment at an elevation of approximately 4400 feet above mean sea level. This area corresponds to Test Plot 7, set up in 1996 as a demonstration project for biosolids application (McNearny, 1996). Biosolids were applied at rates of between 20 and 30 dry tons/acre to one set of plots and a series of control plots were also established where no biosolids were applied. All of the plots were then drill seeded. When the site was revisited in 2001, the plots that received biosolids were dominated by Cheatgrass (*Bromus tectorum*) (absolute cover equaled 88%). Non-weed species had an absolute cover of less than one percent on the biosolids plots. At the control plots that received no biosolids, the absolute cover provided by non-weedy species, predominantly Western Wheatgrass, Sheep Fescue and Tall Wheatgrass, was about 90%. Weedy species at the control plots had an absolute cover of 21%.

Site 01-05

Site 01-05 is located on the northwest side of the tailings impoundment embankment at an elevation of approximately 4400 feet above mean sea level. This area corresponds to Test Plot 1, set up in 1995 as a demonstration project for biosolids application (McNearny, 1996). At the site, a series of plots were established where biosolids were applied at rates of 0, 10, 20 and 30 dry tons/acre. About 6 tons/acre of slaked lime was also added to all of the plots to raise the pH of the acidic soils that were present. All of the plots were drill seeded. The 2001 survey results show that the plots that received biosolids had an average absolute cover of 100%. About half of this cover was provided by Cheatgrass and the other half was provided by Tall Wheatgrass. The control plot that received no biosolids had an absolute cover of 41 % provided by weedy species and about 64 % provided by non-weed species, predominantly Tall Wheatgrass.

Site 01-06 Tailings Cap

Site 01-06 is located at an elevation of 6150 feet on the Eastside waste rock disposal area at the Bingham Canyon Mine. This area corresponds to the 6190 Test Plot, established by Kennecott Utah Copper in 1995 to test various waste rock caps with and without biosolids application (Marrs, 1997a). The waste rock beneath the cap material is acidic and will not support vegetation. Two sets of paired plots were compared at Site 01-06.

An 18-inch thick tailings cap was used with and without biosolids in one set of paired plots. The 2001 survey found that the tailings cap that received 30 tons/acre biosolids had an absolute cover of 92% provided by weedy species, predominantly Cheatgrass. Non-weedy species contributed less than one percent to the absolute cover. The tailings cap that received no biosolids had an absolute cover of 22%. The majority of the cover was provided by Sheep Fescue and Western Wheatgrass and about six percent of the cover was provided by weedy species.

Site 01-06 Soil Cap

A second set of paired plots at Site 01-06 was constructed with a manufactured soil composed of alluvial sediments mixed with pond sludge. One plot received an 18-inch thick cap without biosolids, and the other plot received a 2 to 12 inch cap with 30 dry tons/acre biosolids. Weedy species, predominantly Cheatgrass and Clasping Pepperweed, had an absolute cover of 101% on the biosolids plot in 2001. Non-weedy species, predominantly Four-wing Saltbush, had an absolute cover of seven percent. The plot that received no biosolids had an absolute cover of 17% provided by weedy species, predominantly Cheatgrass. Non-weedy species had an absolute cover of 62%. The most common non-weed species observed were Western Wheatgrass, Rubber Rabbitbrush, Utah Sweetvetch, Yellow Sweetclover and Four-wing Saltbush.

Site 01-07

Site 01-07 is located at an elevation of 6050 feet on a reclaimed portion of the Eastside waste rock disposal area at the Bingham Canyon Mine. The site is on an east-facing slope that was capped with 18 inches of mixed sludge and alluvium. In 1994 one half of the slope was drill seeded without biosolids application and in 1995 biosolids were applied at 30 tons/acre to the other half of the slope before it was drill seeded (Marrs, 1997a). The 2001 survey indicates that the portion of the slope that received biosolids had an absolute cover provided by weedy-species, predominantly Cheatgrass and Clasping Pepperweed, of 99%. Western Wheatgrass and Slender Wheatgrass were the dominant non-weed species providing 29% of the absolute cover. The portion of the slope that did not receive biosolids had an absolute cover of 128%. Non-weedy species provided 120% of the absolute cover. The dominant species on this portion of the slope were Yellow Sweetclover, Western Wheatgrass, Palmer Penstemon, Utah Milkvetch and Slender Wheatgrass.

Site 01-09 No Treatments

Site 01-09 is in an old gravel borrow area located at an elevation of about 5400 feet above mean sea level at the foot of the Eastside waste rock disposal area. This site corresponds to the Triangle Borrow Test Plots established by Kennecott Utah Copper in 1996 (Marx and Cordell, 1996). At the Triangle Borrow area a series of plots were set up to test the effects of biosolids, mycorrhizae, seed coating gels and soil gels on plant establishment. Two sets of paired plots were compared at Site 01-09.

Biosolids were applied at 0, 15 and 20 tons/acre at one set of test plots. No other treatments were made before the plots were drill seeded. In 2001 when the site was revisited, the absolute cover on the biosolids plots was 119%. Weedy species, predominantly Cheatgrass and Tumble Mustard provided about half of the cover and Intermediate Wheatgrass provided the other half. Non-weedy species provided about 33% of the absolute cover on the control plot and weedy species provided about 2%. The dominant species on the control plot were Slender Wheatgrass and Utah Sweetvetch.

Site 01-09 All Treatments

The second set of paired test plots at Site 01-09 received treatments with mycorrhizae, seed coating gels and soil gels. Biosolids were then applied to the plots at rates of 0 and 15 tons/acre. The biosolids plot had an absolute cover of 110% in 2001. Weedy species, predominantly Cheatgrass provided about 85% of the absolute cover and non-weedy species provided 25%. The dominant non-weed species were Slender Wheatgrass, Intermediate Wheatgrass and Shadscale. Non-weed species had an absolute cover of 48% on the plot that did not receive biosolids and weedy species covered less than one percent. The dominant species on this plot were Big Sagebrush, Slender Wheatgrass, Shadscale, Lewis Blue Flax and California Poppy.

DISCUSSION

Figures 1 and 2 are graphs that average the percent absolute cover provided by each species observed in the seven paired plots. The control plots that were planted without biosolids had an average absolute cover of 76% in 2001. Non-weedy species provided 62% of this cover and weedy species provided 14%. A total of 30 non-weedy species and 11 weedy species were observed growing on the control plots. The dominant species that were observed in order of decreasing abundance were: Tall Wheatgrass, Cheatgrass, Yellow Sweetclover, Western Wheatgrass, Slender Wheatgrass, Sheep Fescue, Palmer's Penstemon, Utah Milkvetch, Utah Sweetvetch, Rubber Rabbitbrush, Big Sagebrush and Clasping Pepperweed. Generally, all of these species except Cheatgrass and Clasping Pepperweed were in the seed mixes that were originally applied to the test plots.

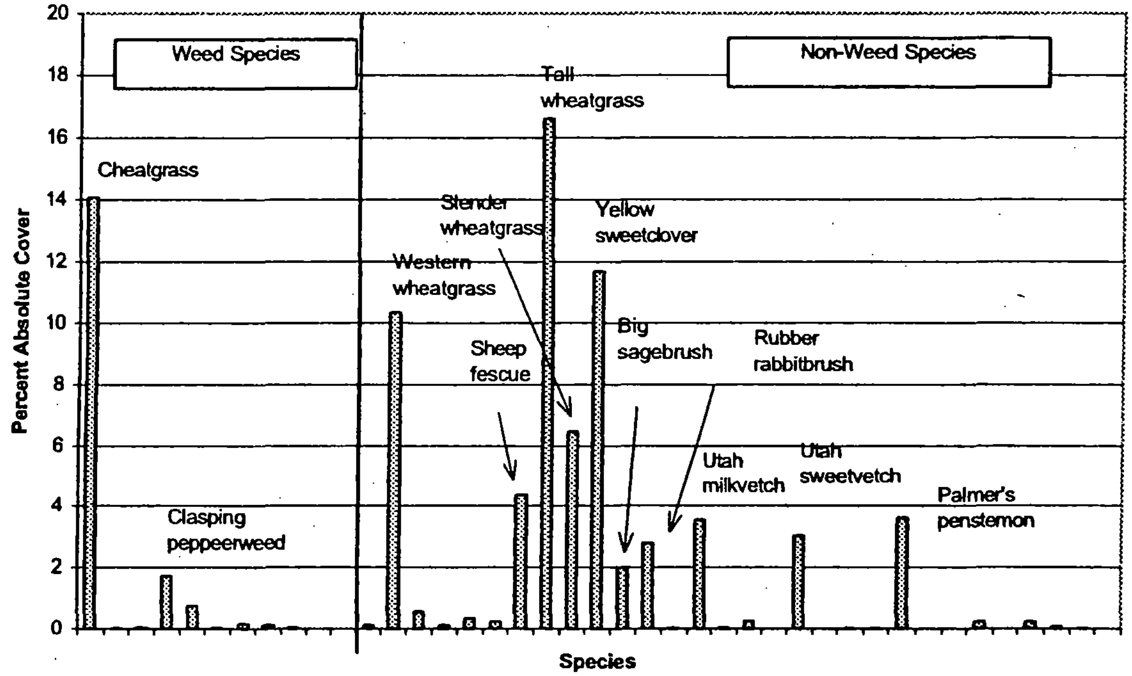

Figure 1. Average Absolute Cover by Species for Paired Plots with NO Biosolids Application

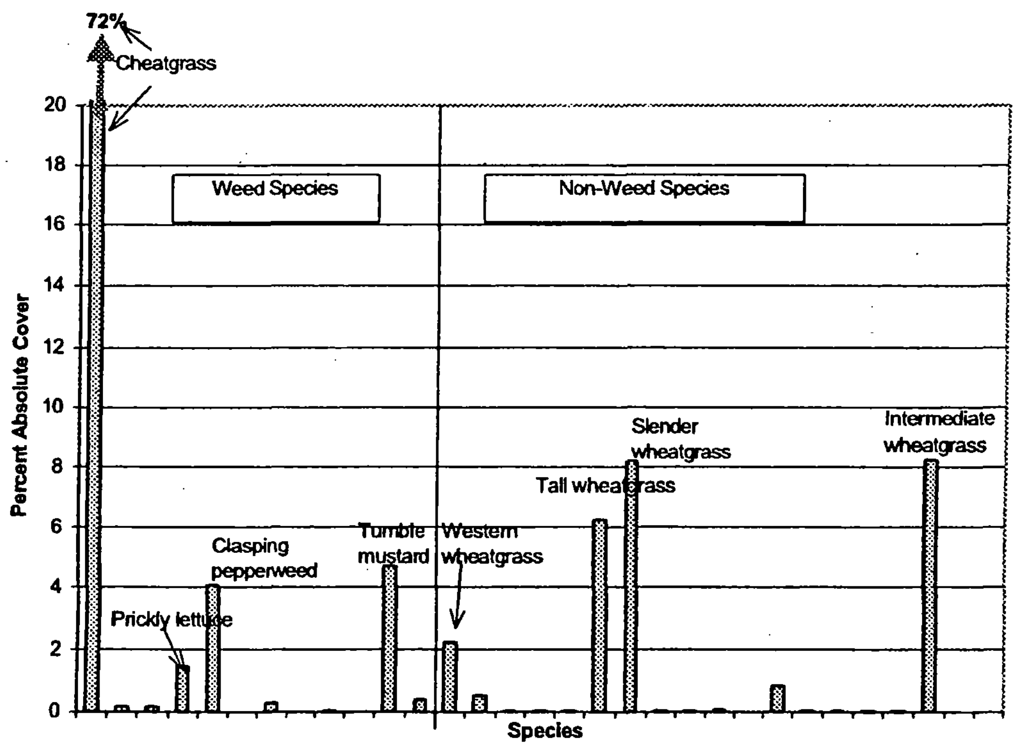

Figure 2. Average Absolute Cover by Species for Paired Plots with Biosolids Applied at 10 to 30 Dry Tons/Acre

During the 2001 field investigation, it was observed that the plots that were planted after biosolids were applied at rates of between 10 and 30 dry tons/acre had an average absolute cover of 107%. Non-weedy species provided 24% of this cover and weedy species provided 83%. A total of 19 non-weedy species and 12 weedy species were observed growing on the biosolids plots. On average, the absolute cover provided by Cheatgrass on the biosolids plots was 72%. No other species had an average absolute cover above 10%. Secondary species observed in order of decreasing abundance were: Slender Wheatgrass, Intermediate Wheatgrass, Tall Wheatgrass, Tumble Mustard, Clasping Pepperweed, Western Wheatgrass and Prickly Lettuce. Only the wheatgrass species were included in the original seed mixes that were applied to these sites.

In general the test plots that received biosolids had a higher total absolute cover than the control plots that received no biosolids. As shown on Figure 3, there is a weak positive correlation between the amount of biosolids applied to a plot and the absolute cover growing after five years ($R^2 = 0.20$). However, biosolids application appears to favor the establishment of weedy species on the test plots (Figure 4). There is a strong positive correlation between the biosolids application rate and the fraction of the total cover that is provided by weedy species ($R^2 = 0.85$). As shown on Figure 5, this results in a moderate negative correlation between the rate of biosolids application and the absolute cover provided by non-weed species ($R^2 = 0.40$). In most cases, the higher the biosolids application rate, the lower the absolute cover of the species that were intentionally seeded onto the site. On average, the control plots had more than twice as much cover provided by non-weed species than the plots that received 10 to 30 dry tons/acre biosolids. Species diversity, as measured by the number of species observed, was also higher on the control plots. An average of 9.2 species were observed on each of the biosolids test plots, but only 4.1 were non-weedy species. An average of 13.7 species were observed on each of the control plots, of which 9.6 were non-weed species.

An ANOVA analysis was performed on the seven paired plots for several of the measured parameters (Table 5). The differences in the absolute cover provided by non-weedy species was found to be statistically significant at a 0.05 significance level using an ANOVA analysis ($p=0.03$). The differences in total absolute cover provided by all species was also found to be statistically significant ($p=0.05$). However, total species diversity between plots that did and did not receive biosolids was not statistically significant at a 0.05 significance level ($p=0.24$).

Table 5.
Statistical Analysis of Differences between Treatments (Biosolids versus Non Biosolids) using an ANOVA analysis

Absolute Cover of Non-Weedy species Total Cover Identified for all Non-Weedy Species						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	24	23	22	5.71	12	0.03
Non Biosolid	62	35	35			

Species Diversity Total Number of Species Identified						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	9.2	5.7	5.3	1.53	12	0.24
Non Biosolid	13.7	8.0	7.4			

Total Absolute Cover Total Number of Species Identified						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	107	12	11	4.41	12	0.05
Non Biosolid	76	40	37			

The application of biosolids at rates of between 10 and 30 dry/tons acre appears to favor the growth of volunteer weedy species at the expense of non-weed species. In most cases the application of biosolids ultimately inhibited the establishment of species that were intentionally seeded onto the test plots at the Bingham Canyon Mine. These study results suggest that depending upon specific reclamation goals, biosolids application may not always be beneficial, and that application rates of less than 10 dry tons/acre may be optimal at reclamation sites. Unfortunately, these study results cannot be used to estimate the optimum biosolids application rate between 0 and 10 dry tons/acre that may aid in initial vegetation establishment without favoring the dominance of weedy species in the longer term.

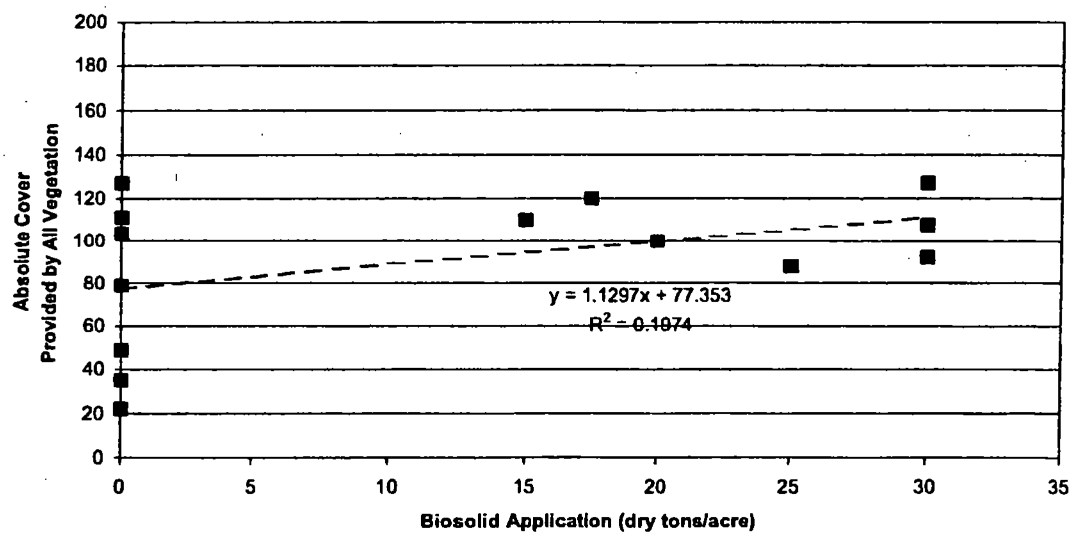

Figure 3. Absolute Cover Provided by All Species versus Tons of Biosolids Applied

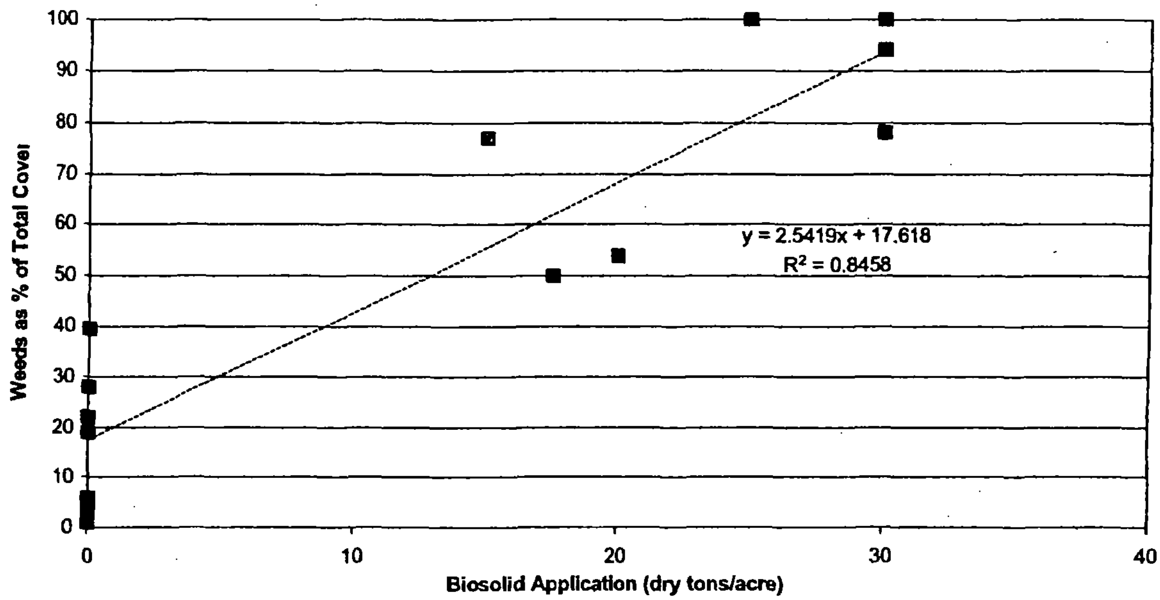

Figure 4. Percent of the Total Cover Provided by Weedy Species versus Tons of Biosolids Applied

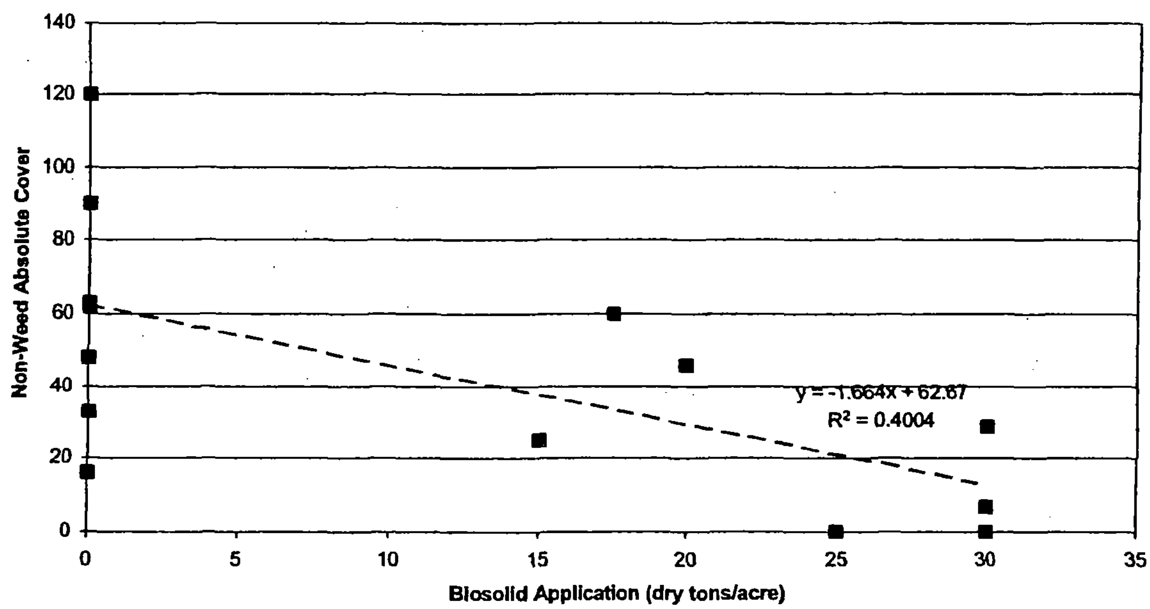

Figure 5. Absolute Cover Provided by Non-Weedy Species versus Tons of Biosolids Applied