



PRELIMINARY RECLAMATION AND CLOSURE PLAN
KENO DISTRICT MINE OPERATIONS
KENO HILL SILVER DISTRICT

REVISION 2

SEPTEMBER 2012



Table of Contents

1	BACKGROUND.....	1
2	INTRODUCTION.....	2
2.1	ALEXCO'S OTHER ACTIVITIES IN THE KHSD.....	4
3	ALEXCO'S RECLAMATION AND CLOSURE PLANNING AND IMPLEMENTATION	7
3.1	OVERALL RECLAMATION AND CLOSURE OBJECTIVES	7
3.2	INTEGRATION WITH DISTRICT-WIDE CLOSURE PLANNING	11
4	PROJECT OVERVIEW	12
5	ENVIRONMENTAL AND SOCIO-ECONOMIC SETTING	13
6	GENERAL RECLAMATION AND CLOSURE MEASURES	15
6.1	PROGRESSIVE RECLAMATION	15
6.2	REVEGETATION	15
6.2.1	Cover Engineering Design Parameters	15
6.2.2	Revegetation Design Characteristics	16
6.3	BORROW AND COVER SOURCES.....	17
6.4	RECLAMATION RESEARCH	17
6.5	DATA COLLECTION PROGRAMS AND DEVELOPMENT OF DESIGN PARAMETERS	17
7	MINE-COMPONENT RECLAMATION AND CLOSURE MEASURES	20
7.1	BELLEKENO PRODUCTION UNIT AREA	20
7.1.1	Bellekeno Waste Rock Storage Facilities/Disposal Areas	21
7.1.2	Bellekeno 625 Adit.....	24
7.1.3	Bellekeno East Adit.....	26
7.1.4	200 Level Vent Raise.....	26
7.1.5	Bellekeno Surface Infrastructure	33
7.2	ONEK PRODUCTION UNIT AREA	35
7.2.1	Onek Waste Rock Storage Facilities/Disposal Areas.....	36
7.2.2	Onek Surface Infrastructure	38



7.3	LUCKY QUEEN PRODUCTION UNIT AREA	38
7.3.1	Lucky Queen Waste Rock Storage/Disposal Areas	39
7.3.2	Lucky Queen Surface Infrastructure	39
7.4	LINEAR DISTURBANCES	42
7.4.1	Roads	42
7.4.2	Transmission Lines.....	42
7.5	FLAT CREEK CAMP	45
7.6	MILL AREA AND ANCILLARY FACILITIES	45
7.6.1	Mill Buildings and Infrastructure	46
7.6.2	Mill Building	49
7.6.3	Mill Office and Dry	50
7.6.4	Electrical Substation	50
7.6.5	Mill Process Pond	51
7.6.6	Crushing Plant.....	52
7.6.7	Fine Ore Stockpile.....	53
7.6.8	Crusher MCC.....	54
7.6.9	Assay Lab	55
7.6.10	Mill Motor Control Centre.....	56
7.6.11	Fresh Water Tank	56
7.6.12	Diesel Storage Tanks	57
7.6.13	Propane Tank	57
7.6.14	Mill Wastes.....	57
7.6.15	Buried Infrastructure.....	58
7.7	DRY STACK TAILINGS FACILITY	58
7.7.1	DSTF Geochemical Performance	59
7.7.2	DSTF Soil Cover	59
8	FINAL CLOSURE CRITERIA	63
8.1	SITE CONDITIONS FOR COMPLETION CRITERIA	63
8.1.1	Physical Stability	63
8.1.2	Chemical Stability	63



8.1.3	Biological Stability.....	64
8.2	COMPLETION CRITERIA FOR MINE AREA COMPONENTS.....	64
9	CLOSURE MANAGEMENT AND MONITORING.....	66
9.1	IMPLEMENTATION SCHEDULE.....	66
9.2	ADAPTIVE MANAGEMENT STRATEGY	67
9.3	CLOSURE MONITORING AND MAINTENANCE.....	67
9.4	SUPERVISION AND DOCUMENTATION OF WORK.....	71
9.5	SITE PRESENCE AND DISTRICT-WIDE CLOSURE	71
10	TEMPORARY CLOSURE.....	72
10.1	PHYSICAL STABILITY AND GEOCHEMICAL STABILITY	72
10.2	SECURITY AND MONITORING	74
10.3	REPORTING	74
11	RECLAMATION AND CLOSURE COSTING.....	75
12	REFERENCES	87



LIST OF TABLES

Table 2-1. Relevant KHDS Assessment and Regulatory Approvals	4
Table 3-1: EMR RCP Requirements Reference List	9
Table 3-2: Schedule 1 Requirements for Terrestrial Performance Standards	10
Table 4-1 Keno District Mine Operations Overview	12
Table 5-1. Keno Hill Silver District Environmental Setting Summary.....	14
Table 7-1: Bellekeno and Lucky Queen Mine Water Management Schedule	30
Table 8-1: Keno Hill Mining Operations Reclamation Units Completion Criteria	65
Table 9-1: Bellekeno, Onek and Lucky Queen Decommissioning and Reclamation Closure Schedule	68
Table 9-2: Bellekeno, Onek and Lucky Queen Production Unit Areas Surveillance Network Monitoring Schedule	70
Table 10-1: Summary of Care and Maintenance Activities and Surveillance during Temporary Cessation of Mining Activities	73
Table 11-1: Keno Hill Silver District Mining Operations Closure Liability Cost Estimate Summary - Unit Rate Cost Table	76
Table 11-2: Keno Hill Silver District Mining Operations Closure Liability Cost Estimate Summary – End of Mine Life	77
Table 11-3: Bellekeno Mine Estimated Closure Costs	78
Table 11-4: Onek Mine Estimated Closure Costs.....	79
Table 11-5: Lucky Queen Mine Estimated Closure Costs	80
Table 11-6: Waste Rock Storage Estimated Closure Costs – End of Mine Life	81
Table 11-7: Access and Haul Roads Estimated Closure Costs.....	82
Table 11-8: Camp Downsize Estimated Closure Costs.....	83
Table 11-9: Mill Estimated Closure Costs	84
Table 11-10: Dry Stack Tailings Facility Estimated Closure Costs	85
Table 11-11: Site Management Estimated Closure Costs – End of Mine Life.....	86



LIST OF FIGURES

Figure 2-1 General Location Map	3
Figure 2-2 Property Overview	5
Figure 2-3 Site Reclamation and Decommissioning Plan Components	6
Figure 6-1 Growth Media Stockpiles	19
Figure 7-1 Bellekeno Mine Site Layout, Showing Specific Mine Components for Closure.....	22
Figure 7-2 Location of Existing Waste Rock Storage Facility and Proposed Waste Rock Disposal Area.....	23
Figure 7-3 Waste Rock Dump Regrading and Details	27
Figure 7-4 Bellekeno Mine Site Layout 625 Adit Layout and Conceptual Bulkhead Design	28
Figure 7-5 Bellekeno 625 Bioreactor Preliminary Design	29
Figure 7-6 Bellekeno Mine Site Layout East Portal Closure Rock Pile	31
Figure 7-7 Preliminary Concrete Cap Design	32
Figure 7-8 Onek Site Layout.....	37
Figure 7-9 Lucky Queen Site Layout	41
Figure 7-10 Bellekeno, Onek and Lucky Queen Production Unit Area Roads Subject to Standard Decommissioning and Reclamation	44
Figure 7-11 Mill Site Layout.....	47
Figure 7-12 Dry Stack Tailings Facility Layout.....	61
Figure 7-13 DSTF Soil Cover Design	62



LIST OF PLATES

Plate 7-1: Bellekeno 625 Area Overview	26
Plate 7-2: Bellekeno East Surface Facilities	34
Plate 7-3: Bellekeno East Portal	35
Plate 7-4: Lightning Creek Bridge and Typical Haul Road Section	43
Plate 7-5: Arial View of Mill Site Infrastructure and Layout	48
Plate 7-6: Mill Building	49
Plate 7-7: Mill Office and Dry	50
Plate 7-8: Electrical Substation	51
Plate 7-9: Mill Process Pond	52
Plate 7-10: Crushing Plant	53
Plate 7-11: Fine Ore Stockpile	54
Plate 7-12: Crusher MCC	55
Plate 7-13: Assay Lab	56
Plate 7-14: Mill MCC	57
Plate 7-15: DSTF Interim Reclamation, June 2012.....	60

APPENDICES

Appendix 1	Supporting Environmental Data
Appendix 2	Typical Waste Containment Facility Design, EBA, 2008
Appendix 3	Platoro Project – Example Of In Mine Pool Treatment
Appendix 4	Galkeno 900 Bioreactor Performance
Appendix 5	Kinetic Testing Results for Bellekeno Tailings

1 BACKGROUND

Alexco Resource Corp. (Alexco), through its wholly owned subsidiary Alexco Keno Hill Mining Corp., owns and operates the Bellekeno Mine located in the Keno Hill Silver District (the District). The Bellekeno Mine and Keno District mill operation is licenced under Quartz Mining License QML-0009 and Water Use Licence QZ09-092. The Preliminary Bellekeno Mine Decommissioning & Reclamation Plan was submitted in July 2009 as part of the Bellekeno mine licensing process. Section 9.2 of QML-0009 requires that an updated Reclamation and Closure Plan (RCP) be submitted within 12 months of the issuance of that license. Pursuant to that requirement, an updated RCP was submitted to Yukon Government, Energy Mines & Resources, Mineral Resources Branch¹ in January 2011 and was titled: Reclamation and Closure Plan, Bellekeno Mine, Keno Hill Silver District, January 2011. This RCP was approved in August 2011 conditional on a further update to the RCP by November 2011. Alexco submitted a further update to the Reclamation and Closure Plan (November 2011) and this updated RCP was approved by Yukon EMR in January 2012 and is the most currently approved RCP for mine operations in the Keno Hill Silver District and includes the operations of the Bellekeno mine and Keno District Mill.

As part of the license amendment process to bring the Lucky Queen and Onek deposits into production, Alexco has updated the currently approved RCP to include these two new mines. Given the ongoing development of the District, the RCP has also been redressed as the Preliminary Reclamation and Closure Plan, Keno District Mine Operations. This Preliminary RCP thus includes the approved reclamation and closure measures for current Bellekeno operations and infrastructure, the Keno District Mill, DSTF as well as measures for closure of the new Lucky Queen and Onek mines.

Note that the Lucky Queen and Onek Production Unit Areas included in this RCP have not been fully delineated pursuant to the Subsidiary Agreement between Alexco and Aboriginal Affairs and Northern Development Canada (AANDC). The scope of reclamation and closure planning provided in this Preliminary RCP consequently may be modified. Determination of the final Production Unit Areas will be made during the licencing process. The Preliminary RCP will be updated accordingly.

Components of the Reclamation and Closure Plan that are relevant to the scope of the proposed Lucky Queen and Onek Deposit Production Unit Areas include:

- Section 7.2 Onek Production Unit Area
- Section 7.3 Lucky Queen Production Unit Area
- Section 8 Closure Management and Monitoring
- Section 9 Temporary Closure

¹ Available at

http://www.emr.gov.yk.ca/mining/pdf/mml_bellekeno_reclamation_and_closure_plan_january_2011.pdf

2 INTRODUCTION

Figure 2-1 shows the general project location within Yukon, while Figure 2-2 shows the location on a smaller scale proximate to Keno City. The footprint of the Bellekeno, Onek and Lucky Queen Production Unit Areas occupies previously impacted terrain and watersheds with the exception of the Lightning Creek Bypass road, Keno City Bypass Road and Onek 990 portal.

The Keno District Mine Operations Preliminary Reclamation and Closure Plan addresses the following mine area components:

- Underground mining activities at the Bellekeno, Onek and Lucky Queen deposits, surface support infrastructure and activities, miners' dry area, offices, trailers and portals;
- Conventional flotation mill & supporting infrastructure, coarse ore stockpile, plant services, fuel storage area, employee dry area, offices, trailers and pond;
- Dry-stack tailings facility (DSTF);
- Bellekeno, Onek and Lucky Queen N-AML waste rock disposal areas (WRDA);
- Bellekeno, Onek and Lucky Queen P-AML waste rock storage facilities (WRSF);
- Bellekeno 625
- Temporary coarse ore stock piles;
- Site access roads; Bellekeno Haul Road, Christal Lake Haul Road (from Duncan Creek road to the mill); Lightning Creek Bypass Road (including the Lightning Creek bridge) and the new Keno City Bypass Road;
- Power distribution system (power poles, transformers); and
- Camp accommodations.

Please refer to Figure 2-3 for the location and summary of reclamation components under this RCP.

The closure measures that are expressed herein are based on the general approach and best management practices used by the mining industry today, which has in recent years developed a great deal of experience in different climates and physical conditions.

2.1 ALEXCO'S OTHER ACTIVITIES IN THE KHSD

Alexco and its subsidiaries undertake a variety of activities within the Keno Hill Silver District, including care and maintenance and environmental monitoring, water treatment of historic adit drainages, site closure planning, mining exploration and development and production of ore deposits. These activities are authorized under a suite of project approvals. Table 2-1 lists the relevant existing approvals.

Ongoing development of additional ore deposits will require amendments of the existing mine production Water Use Licence QZ09-092 and Quartz Mining Licence QML-0009. Additional minor approvals will also be required (e.g. septic system installation permit to accommodate expansion of Flat Creek camp). Coordination of mining and care and maintenance activities will be determined through the Water Licencing and QML processes. The Water Board will determine under which Water Use Licence activities will be included.

Table 2-1. Relevant KHDS Assessment and Regulatory Approvals

Purpose	YESAA Approval	Quartz Mining Act Approval	Water Use Licence
Mine Production	Project # 2009-0030 Decision Document	Quartz Mining Licence (QML-0009, expires 2025) ^a	Type A Water Use Licence QZ09-092, expires 2020 ^b
Advanced Exploration	Project # 2008-0039 Decision Document	Class 4 Mining Land Use Approval (LQ00240, expires 2018)	Type B Water Use Licence QZ07-078/Amendment 1 QZ10-0606, expires 2018 ^c
Care & Maintenance	Project #2006-0293 Decision Document	N/A	Type B Water Use Licence QZ06-074/Amendment 1 QZ08-082 ^d

Notes: ^a www.emr.gov.yk.ca/mining/pdf/mml_bk_qml-0009.pdf

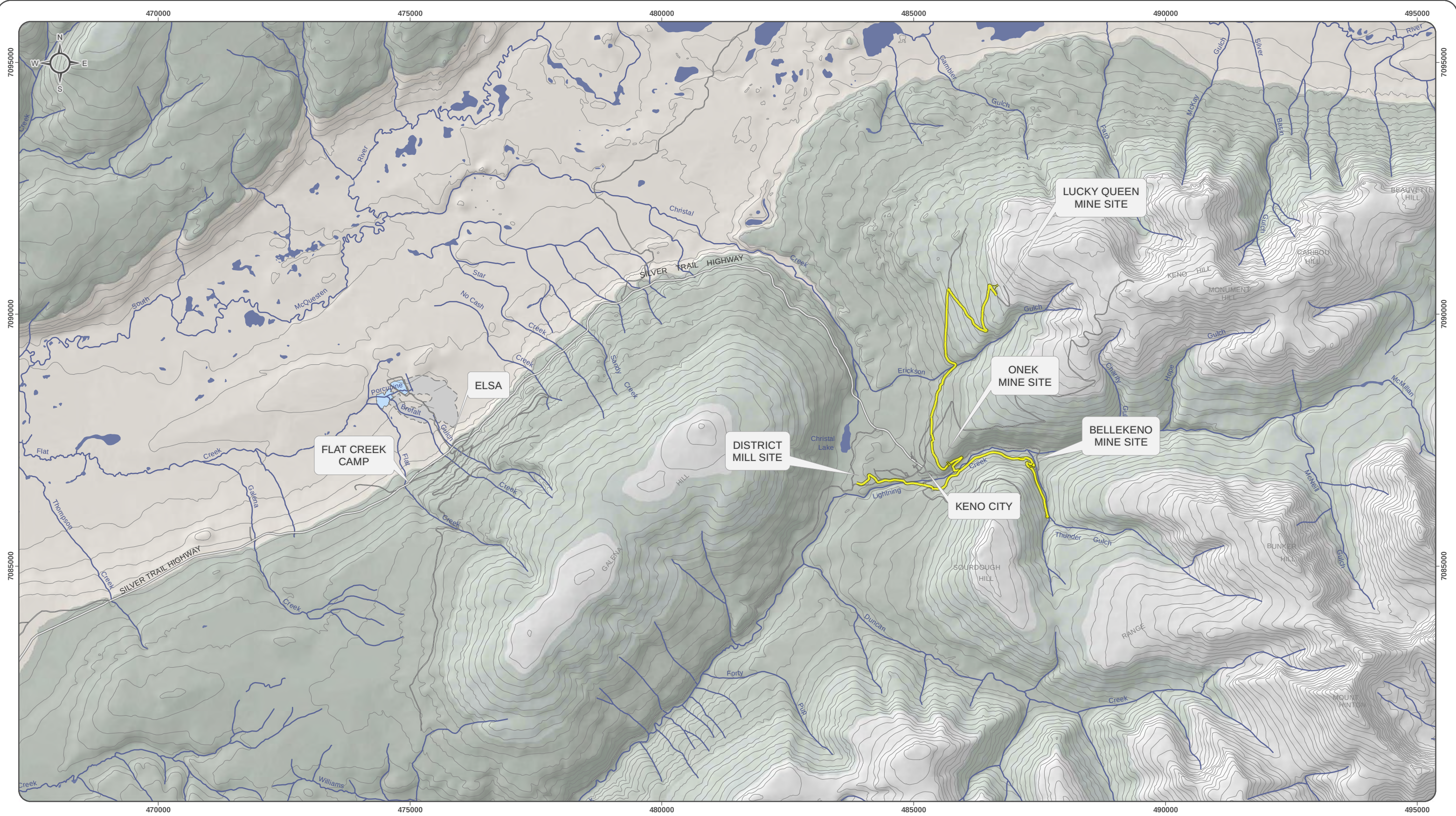
^b www.yukonwaterboard.ca/register/quartz/QZ09-092/Volume%204/10-1%20Water%20Use%20Licence.pdf

^c www.yukonwaterboard.ca/register/quartz/QZ10-060/Licence.pdf

^d www.yukonwaterboard.ca/register/quartz/qz08-082/amend_1.pdf

Closure and reclamation planning for the entire District (District Closure Plan) is currently being developed in accordance with the Subsidiary Agreement between Alexco and AANDC; once approved this plan will be implemented.

Certain procedures and environmental mitigative measures developed for the advanced exploration program have provided information to support the development of technically sound assumptions for inclusion into the Preliminary Keno District Mine Operations Reclamation and Closure Plan. Components of the advanced exploration program overlap with components comprising the RCP.



Site hydrography and contours provided by Aero Geometrics LTD, derived from aerial photograph.

Datum: NAD 83; Map Projection: UTM Zone 8N

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1:70,000 (when printed on 11 x17 inch paper)



- Portal/Adit
- Highway
- Secondary Road
- Existing or Proposed Haul/Bypass Road
- 100 meter contour
- Watercourse
- Waterbody

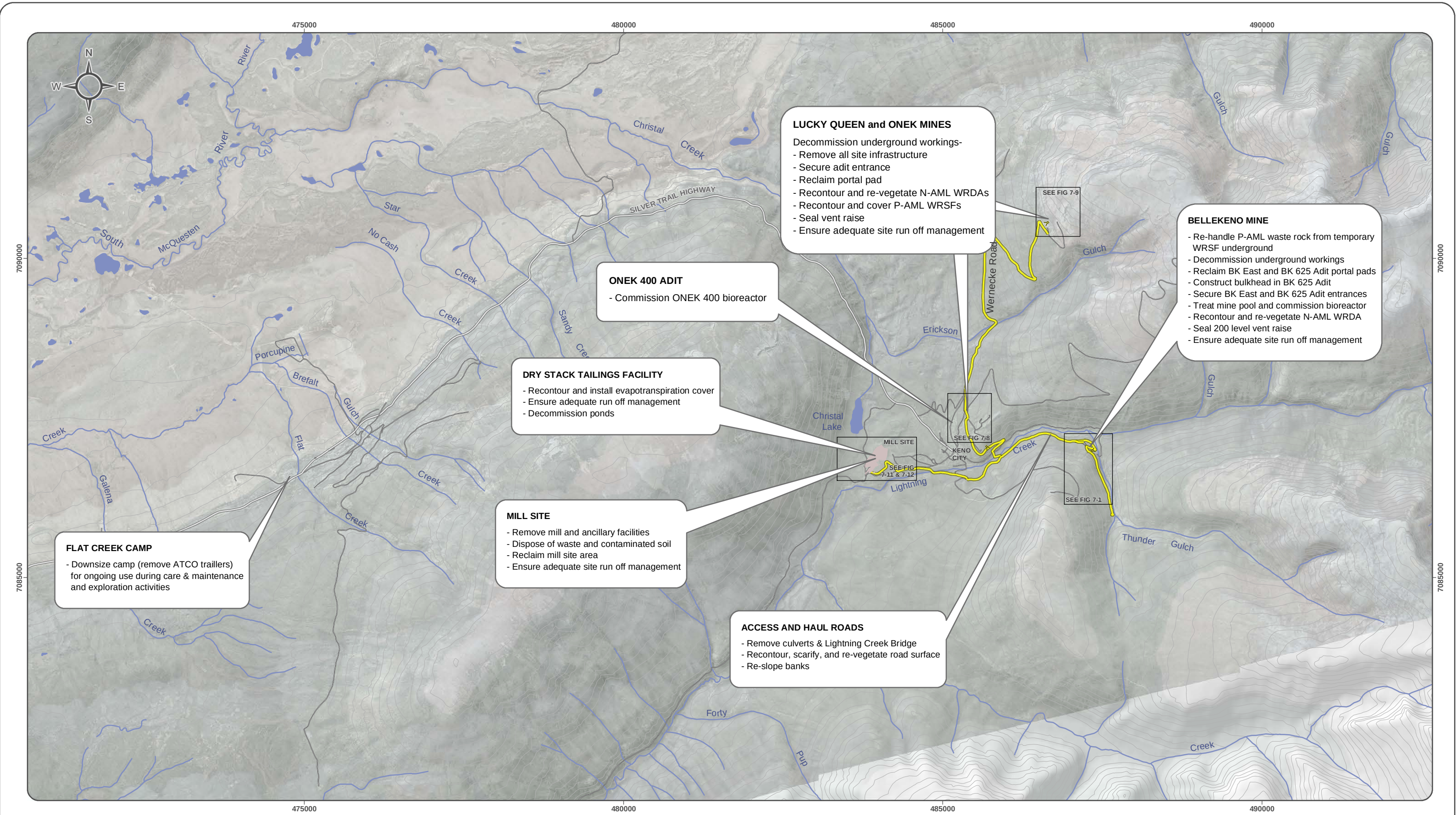


KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 2-2 PROPERTY OVERVIEW

AUGUST 2012

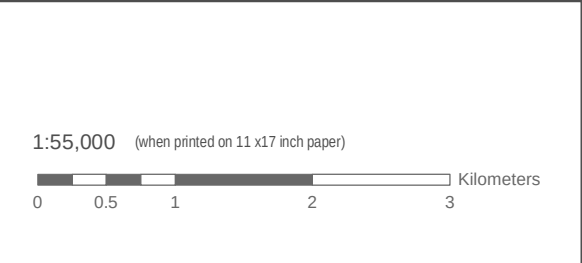
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(Last edited by: mducharme, 06/08/2012/10:41 AM)



Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13 and 14 2006. Site hydrography and contours provided by Aero Geometrics LTD, derived from aerial photograph.

Datum: NAD 83; Map Projection: UTM Zone 8N

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**KENO DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN**

**FIGURE 2-3
SITE RECLAMATION AND DECOMMISSIONING
PLAN COMPONENTS**

AUGUST 2012

I:\ALEX-05-01\Bellekeno\GIS\mxd\Closure\2012\03-Submitted July 2012\3_Site_Reclamation_Plan_20120806.mxd
(Last edited by: mducharme; 06/08/2012/10:44 AM)

LUCKY QUEEN and ONEK MINES

Decommission underground workings-

- Remove all site infrastructure
- Secure adit entrance
- Reclaim portal pad
- Recontour and re-vegetate N-AML WRDAs
- Recontour and cover P-AML WRSFs
- Seal vent raise
- Ensure adequate site run off management

ONEK 400 ADIT

- Commission ONEK 400 bioreactor

DRY STACK TAILINGS FACILITY

- Recontour and install evapotranspiration cover
- Ensure adequate run off management
- Decommission ponds

MILL SITE

- Remove mill and ancillary facilities
- Dispose of waste and contaminated soil
- Reclaim mill site area
- Ensure adequate site run off management

ACCESS AND HAUL ROADS

- Remove culverts & Lightning Creek Bridge
- Recontour, scarify, and re-vegetate road surface
- Re-slope banks

FLAT CREEK CAMP

- Downsize camp (remove ATCO trailers) for ongoing use during care & maintenance and exploration activities

BELLEKENO MINE

- Re-handle P-AML waste rock from temporary WRSF underground
- Decommission underground workings
- Reclaim BK East and BK 625 Adit portal pads
- Construct bulkhead in BK 625 Adit
- Secure BK East and BK 625 Adit entrances
- Treat mine pool and commission bioreactor
- Recontour and re-vegetate N-AML WRDA
- Seal 200 level vent raise
- Ensure adequate site run off management

3 ALEXCO'S RECLAMATION AND CLOSURE PLANNING AND IMPLEMENTATION

Alexco recognizes the importance of developing an RCP for the Keno District Mine Operations that is synchronized and integrated with the District Closure Plan that is currently being developed by the company in conjunction with AANDC, Yukon Government and First Nation of Nacho Nyak Dun (FNNND). Closure objectives, issues, and options are being developed by these four parties in a thorough process that involves field investigations, pilot studies and test work to identify appropriate closure options, supplemented by public/stakeholder consultation, in order to ensure that closure measures with the best potential for success, as viewed by all stakeholders, are selected for implementation.

3.1 OVERALL RECLAMATION AND CLOSURE OBJECTIVES

Alexco acknowledges Yukon Government's mandate and specifications for mine site closure and reclamation. As such, Alexco has developed this RCP to address regulatory and government policy for mine closure. In keeping with its high standards for environmental and social responsibility, Alexco intends to implement environmentally sound and technically feasible decommissioning and reclamation measures for the mining and milling operations included in this RCP. Closure planning and implementation will be undertaken with appropriate environmental care while respecting local laws, First Nations agreements, and the public interest and ensuring that the Company's high environmental standards are achieved. Necessary environmental protection measures have been adopted in the development of this RCP to ensure that a healthy environment exists after closure.

The Mineral Resources Branch outlined requirements to be included in the RCP in a letter to Alexco dated November 18th, 2009 (re: Bellekeno Mine Project QML-0009 – Plan Requirements), consistent with the *Yukon Mine Site and Reclamation Closure Policy* Technical Guidelines. These guidelines also provide direction on reclamation and closure objectives for key features of a mine. These requirements are referenced according to their location in this document in Table 3-1.

EMR has also included a Schedule as part of that letter which details specific objectives for the RCP to achieve in closure. The objectives of that schedule are reproduced here and referenced according to where in the RCP they are adhered to (Table 3-1).

Closure objectives can be considered in terms of the following key areas:

- a. (geo)chemical stability;
- b. water quality;
- c. physical stability; and,
- d. land use, aesthetics and public health and safety.

Closure principles and objectives work to ensure both physical stability and chemical stability of the site in the long term and are reflective of the guidelines derived from YG's Reclamation and Closure

Policy. The effectiveness of closure measures implemented from this RCP will be the subject of review by regulatory agencies and under the *Quartz Mining Act*, the company would be able to apply for a certificate of closure from the Yukon Government once there is agreement with their effectiveness. The following primary closure objectives were emphasized during the development of this plan.

1 Protect Public and Worker Health and Safety

2 Protect and Restore the Environment by:

- i. incorporating progressive reclamation where possible;
- ii. providing slope stabilization and erosion control on linear and non-linear disturbances;
- iii. ensuring long-term chemical stability of the N-AML waste rock disposal areas and components constructed from waste rock to minimize effects to downstream aquatic resources;
- iv. ensuring the long term chemical stability of materials placed into the dry stack tailings facility;
- v. ensuring the long-term physical stability of key structures such as the dry stack tailings facility, Bellekeno, 990 and Lucky Queen portals, P-AML waste rock storage facilities, and access roads; and
- vi. conducting post closure monitoring of the site and adaptive management to assess effectiveness of closure measures for the long term;

3 Ensure Land Use Commensurate with Surrounding Lands

4 Ensure Meaningful Participation of the FNNND

5 Ensure Cost Effectiveness

6 Realize a Walk-away Closure Scenario

Table 3-1: EMR RCP Requirements Reference List	
Closure Plan Requirement	Document Location
(a) A statement of the objectives to be achieved as a result of reclamation and closure of the site;	Section 3.1
(b) an analysis of the measures required to be implemented to ensure the ongoing physical and chemical stability of the site;	Bellekeno Mine (Section 7.1) Onek Mine (Section 7.2) Lucky Queen Mine (Section 7.3) Waste Rock (Section 6.2) Roads (Section 6.3) Camp (Section 6.4) Mill and Infrastructure (Section 6.5) Dry Stack Tailings Facility (Section 6.6)
(c) a description of how the Licensee will meet the performance standards set out in Schedule 1 (attached to this letter) unless other standards are agreed to in writing by the Chief in advance of submission of the plan;	Table 3-2
(d) target indicators to ensure that reclamation objectives have been met;	Section 13.0 of Monitoring and Surveillance Plan
(e) engineered (stamped or sealed) designs for the closure of all engineered structures, works, and installations associated with the Undertaking, including embankments and other containment structures, dry stack tailings facility, spillways, diversion ditches, waste rock and overburden dumps, the Lightning Creek bypass road and any other roads at the site, and ore stockpiles	Section 7
(f) a program and implementation schedule for the removal of all infrastructure at the site, including the mill and all infrastructure, camp and roads	Section 7.1
(g) a program and implementation schedule for ensuring the long term stability and closure of the dry stack tailings facility and waste rock storage facilities	Dry Stack Tailings Facility (Section 7.7) Waste Rock Storage Areas (Sections 7.1.1, 7.2.1 and 7.3.1)
(h) a program and implementation schedule for progressive reclamation to be carried out during development and production	Section 6.1
(i) a program for revegetation of disturbed areas, including a description of how soils will be tested for quality and quantity of nutrients and organic matter to support plant growth and a description of the seed mix to be utilized;	Section 6.2
(j) details of the covers (if any) to be placed over the non acid generating or metal leaching and the potentially acid generating or metal leaching waste rock storage facilities and dry stack tailings facility;	Section 6.3
(k) a monitoring and maintenance program and implementation schedule to obtain surface and hydrogeological information adequate to verify that the reclamation objectives and discharge requirements applicable for all engineered structures, works and installations are met at closure and post-closure;	Closure Monitoring and Maintenance (Section 8.3) Adaptive Management(Section 8.2)
(l) a cost estimate to implement the plan, including a cost estimate for post closure monitoring, inspections, interim care and maintenance;	Section 10
(m)details respecting maintenance of security at the site, including any requirements for continuous care by an on-site caretaker, during reclamation and closure and post-closure;	Section 8
(n) updates on the collection and interpretation of hydrogeological information, related geochemical effects and water discharge from the mine;	Section 7.1.2
(o) a program and implementation schedule for determining the effects on the receiving environment during closure and post-closure, including details of monitoring of geochemical and physical stability of all facilities at the Site and other matters as appropriate;	Section 7.2
(p) description of the quantity and quality of available organic material and borrow material stockpiles for use in reclamation;	Section 6.3
(q) list of equipment required to be on-site to ensure that the Licensee can provide an adequate response to an unexpected water flow or level, a spill or a release of a hazardous substance;	Section 8
(r) details of how technological developments and best management practices will be incorporated into the plan over time;	Section 6.4
(s) details respecting management of a temporary closure, including the following:	Section 9
(i) how the Licensee will secure the site during a temporary closure and ensure that all engineered structures, works and installations remain stable;	Section 9.1
(ii) how all engineered structures, works, and installations required to resume mining, milling, hauling and waste treatment will be maintained in good order on the site during a temporary closure;	Section 9.2
(iii) how the various roads under the control of the Licensee at the site will be monitored and controlled to prevent public use where appropriate and ensure public safety;	Section 9.1
(iv) a list equipment required to be on-site ensure that any unexpected water flows or levels or other contingencies are properly managed by the Licensee to protect the environment and human safety;	Section 7.1.2
(vi) monitoring and reporting schedules for ensuring the geochemical and physical stability of all engineered structures, works, and installations associated with the Undertaking, and	Sections 6.0; 7.0; 8.0 and 9.0
(vii) a cost estimate to implement (i) to (vi), as well as any other activities to be undertaken for a temporary closure of five years.	Section 10

Table 3-2: Schedule 1 Requirements for Terrestrial Performance Standards			
Technical Guideline #	Theme	Closure Objective	Document Reference
T-01	Water Retention and Sediment Control Structures	Ensure decommissioning of water retention and sediment control structures, and their appurtenances, in such a way that drainage at, and adjacent to the site, is stable in the long term.	Existing water treatment ponds will be decommissioned and reclaimed (see Section 7.1.3 for the Bellekeno Mine water treatment facility; Section 7.6.5 for the Mill Pond
T-02	Watercourses	Restore watercourses to meet current water management objectives (in accordance with the approved reclamation and closure plan).	Watercourses have not been physically altered by mining activities
T-03	Water Quality	Prevent contamination of receiving environments. Following decommissioning, water quality must consistently meet the requirements of applicable territorial and federal legislation. Recognition will be given to background levels of substances occurring prior to start of operations	A bioreactor will be installed in the current water treatment ponds at the Bellekeno Mine for treatment of mine discharge (see Section 7.1.2) and the Onek 400 adit (Section 7.2.2)
T-04	Site Contamination	Prevent exposure to and mobilization of substances that pose a risk to human health and the environment through physical and chemical stability	Section 7
T-05	Potential Acid Rock Drainage	Walk-away solution	P-AML and AML waste rock is being stored in a temporary lined facility during operations, and will be rehandled back to the underground below the long-term static water level of the mine at closure. Additional permanent P-AML storage facilities will be constructed according to approved engineering designs, if necessary (see Sections 7.1.1, 7.2.1 and 7.3.1)
T-06	Tailings Management	Ensure physical and chemical stability in the long term and eliminate the need for active treatment	The DSTF will be constructed in a manner that iss physically stable and covered with an evapotranspirative cover at closure to prevent infiltration and promote vegetation (see Section 7.7)
T-07	Underground Workings and Openings to Surface	Meet water quality objectives Except for authorized access, prevent inadvertent or intentional underground access that may be a hazard to humans and wildlife Prevent subsidence or changes in the topography that may result in a hazard to humans or wildlife	A rock pile will be constructed to close access to the Bellekeno East Adit (Section 7.1.2); an adit bulkhead will be installed at the Bellekeno 625 Adit to prevent access and provide the ability to manage water discharge (Section 7.1.2); an engineered cap will be placed at the 200 Level Vent Raise (Section 7.1.3)
T-08	Terrain Hazards	Terrain hazards at the site should be no more significant hazard to people and wildlife than is present in the surrounding vicinity	Section 7
T-09	Mine Rock Piles	Rock piles and dumps must be physically and chemically stable in the long term to prevent erosion, subsidence or collapse, and such that dump runoff and surface drainage meet legal requirements	Waste Rock will be stored in approved, engineered facilities and covered and revegetated at closure (see Section 7.1.1, 7.2.1 and 7.3.1)
T-10	Roads and Other Access	Protect public safety. In decommissioning linear infrastructure, enable pre-mining human and wildlife utilization of the area. If however, an alternative future land use is identified, alternative objectives may be identified	Road decommissioning will occur in a manner commensurate with EMR's Yukon Mine Site and Reclamation Closure Policy (see Section 7.4.1)
T-11	Erosion Control	Physical stability such that upon closure, slopes, excavations and other disturbed lands are in a condition that will limit the incidence of soil erosion, slumping and other instabilities that are likely to impede revegetation of a reclaimed site, pose a threat to public safety, lead to wildlife mortality or cause excessive sediment loads to enter nearby water bodies	Slopes will be regraded to at least 2.5H:1V or better, for physical stability
T-12	Re-vegetation	Ensure physical stability and prevent a temporary loss of wildlife habitat utilization from becoming permanent by re-establishing a vegetative mat (food source, hide, etc.) leading to self-sustaining natural revegetation	Revegetation will occur in a manner that meets or exceeds EMR's Yukon Mine Site and Reclamation Closure Policy (see Section 6.2)
T-13	Mine Infrastructure	Ensure physical stability and to remove potential threats to public heath and safety, including identification and removal of hazards and hazardous materials	All infrastructural buildings and equipment will be removed and transported offsite for salvage at the end of mine life (see Section 7.1.3,7.2.3 and 7.3.3 for Bellekeno, Onek and Lucky Queen Mine facilities; see Section 7.6 for the Mill area facilities)
T-15	Temporary Closure Site Conditions	Ensure public heath and safety and protection of the environment in the event of a temporary closure and to manage risks associated with potential abandonment of the site	Section 9
T-16	Geological Values and Heritage	Ensure post-closure access to geological information obtained both leading up to and during mineral development and production at a mine site	Not applicable

3.2 INTEGRATION WITH DISTRICT-WIDE CLOSURE PLANNING

Closure Objectives that were developed with and agreed to by Alexco/ERDC, Canada, FNNND, and Yukon to guide the development of the District Closure Plan are further presented in this section. These objectives will guide the selection of preferred closure options and the implementation of the final District Closure Plan. The intent of the Keno District Mine Operations RCP is to ensure that the site-specific objectives are aligned with district objectives. There are six primary objectives that have been finalized to guide the District Closure Plan, which have a number of sub-objectives that are intended to help define how the specific primary objective they relate to will be achieved.

1 Protect Public and Worker Health and Safety

- i. Prevent, minimize or mitigate any adverse effects on the health and safety of people using the land and water.
- ii. Prevent, minimize or mitigate any adverse effects on the health and safety of people working at the site.

2 Protect and Restore the Environment

- i. Prevent, minimize or mitigate adverse effects on the aquatic environment.
- ii. Prevent, minimize or mitigate adverse effects on the terrestrial environment.

3 Restore Mine Site to a State that Supports Community and Traditional Land Uses

- i. Minimize access restrictions.
- ii. Reclaim disturbed areas to support future community and traditional land use.
- iii. Preserve identified historical resources.

4 Maximize First Nation, Local, and Yukon Socio-economic Benefits

- i. Maximize training, capacity building, and employment and business opportunities for First Nation citizens.
- ii. Maximize training, capacity building, and employment and business opportunities for local residents and Yukoners.

5 Minimize Project Related Liability and Risk

- i. Minimize risks associated with project implementation.
- ii. Minimize post-closure residual liabilities.
- iii. Minimize post-closure risks.

6 Minimize Cost

- i. Minimize project implementation costs.
- ii. Minimize post-closure operations and maintenance costs.

4 PROJECT OVERVIEW

The Keno District Mine Operations principal mine activities and infrastructure include underground mining and development operations and a conventional flotation mill and dry stack tailings facility at the Keno District Mill site for the processing and production of minerals from the Bellekeno, Onek and Lucky Queen deposits. Table 4-1 presents an overview of the Bellekeno, Onek and Lucky Queen deposits currently included in the RCP.

Table 4-1 Keno District Mine Operations Overview

Location	0.5 to 4 km from Keno City, 45 km northeast of Mayo, 354 km north of Whitehorse, YT.
Land Position	Alexco Resource Corp. and its wholly owned subsidiary Elsa Reclamation and Development Corp. owns 1,563 claims and leases covering an area of approximately 24,262 ha within the Keno Hill Silver District including the Bellekeno, Onek and Lucky Queen deposit Production Unit Areas. Two Fee Simple lots within KHSD total 59 ha (Lot 960 and Lot 956)
Mines/Ore Deposits	Bellekeno, Lucky Queen, Onek
Mining Method	Year round underground narrow vein cut and fill/ shrinkage/ long hole mining
Current Mine Life	5 years
Current Total Project Life	15 years (0 – 5 years construction and mine operation; 6 – 15 years decommissioning and reclamation and closure monitoring).
Ore Production Rate	400 tonnes/day from all 3 deposits (annual average). Maximum of 613,000 tonnes of ore mined
Mine Waste Rock	500,000 tonnes of waste rock produced from underground development
Ore Mining and Placement Schedule	Ore mining for 365 days/year Mill Operation 365 day/year 100,000 tonnes of waste material placed on surface each year
Mill Recovery Process	Conventional flotation process producing separate lead/silver concentrate and zinc concentrate shipped off site for smelting. District Mill location at historic Flame and Moth pit area. Tailings placed in Dry Stack Tailings Facility or underground as paste backfill.
Effluent Testing	Metal Mining Effluent Regulations and as required by WUL QZ09-092
Work Force	~ 200 production and ongoing exploration supported by Flat Creek Camp
Airstrip	Mayo, YT
Power	Hydro grid power Yukon Energy, diesel power backup
Water Supply and Use	Water use and discharge within 2 drainages, Lightning Creek and Christal Creek. 245 m ³ /day water use, 385 m ³ /day water discharge Lightning Creek drainage for Bellekeno 68 m ³ /day fresh water use, 17 m ³ /day water discharge Christal Lake drainage Up to 90 m ³ /day for Onek and up to 45 m ³ /day for Lucky Queen Conventional lime precipitation water treatment
Environmental Baseline	Site Characterization Report 1996, ongoing data collection programs through current Type A Water Licence QZ09-092, Type B Water Licenses QZ06-074 and QZ07-078, Class IV Mining Land Use Approval LQ00240 and QML-0009.
First Nations	First Nation of Na-Cho Nyak Dun

5 ENVIRONMENTAL AND SOCIO-ECONOMIC SETTING

Table 5-1 summarizes existing environmental conditions in the Keno Hill project area. The Keno Hill Silver District lies within the Yukon Plateau – North Ecoregion, just south of the Wernecke Mountains. The terrain consists of concordant, rolling, upland areas separated by wide valleys. Alpine mountain peaks extend above the uplands locally. Many valleys include peatlands, palsas, fens and meadows of sedge tussocks. Upper slopes may be covered with scree material, with treeline occurring at 1,350 to 1,500 m. The area has been influenced by the latest glaciation but shows more subtle evidence of an earlier event as well.

Regional permafrost is irregularly distributed and its occurrence is dependent upon the elevation, hillside exposure, depth of overburden, soil types, amount of vegetative cover, and presence of flowing underground and surface water. At high elevations and on slopes with a northern exposure it is generally present.

The Keno Hill Silver District supports a variety of wildlife including ungulates, fur-bearers, small mammals, upland game birds and waterfowl. Moose are the most important subsistence animal in the area. Repeated survey work over the last 15 years indicates a healthy, stable moose population that has in recent years reached a maximum level of harvest. Woodland caribou are not presently found in the immediate study area with the exception of the appearance, in summer, of fewer than 10-12 caribou scattered in very small groups in the Mt. Hinton and Bunker Hill areas. Sheep are not known to inhabit the Keno Hill area.

The Keno Hill Silver District lies within the traditional territory of the FNNND and near the communities of Keno City and Mayo. The area has been shaped by mineral development over the past hundred years. Silver and lead ore deposits were discovered on Keno Hill in the early 1900s and the area has since seen fluctuating levels of ongoing quartz and placer mining and exploration. Today, the area supports not only mineral development, but also tourism, recreation, traditional pursuits, as well as the local people.

Keno City is a small community situated at the end of the Silver Trail Highway with a population of less than 20 permanent residents. The community was originally established to support mining operations in the area and the community's population has fluctuated over the last hundred years in response to local mineral development activity. Today, Keno City is a quiet community with residences, a few small businesses, the Keno City Mining Museum and the Keno City Alpine Interpretive Centre.

The community of Mayo is located approximately 50 km from the project site. Mayo has a population of roughly 450 people and serves as a distribution and service centre for the surrounding area, supporting mineral development, tourism and other activities. Mayo is also the administrative centre for the FNNND. In addition to being a tourist destination, the community is a base for wilderness and mining tourism, canoeing, hiking, big-game hunting and fly-in fishing.

Table 5-1. Keno Hill Silver District Environmental Setting Summary

Drainage Region	Stewart River drainage region
Significant Watersheds	McQuesten River, Lightning Creek and Stewart River Watershed, Mayo River
Ecoregion	Yukon Plateau (North)
Study Area Elevation	900-1350 m asl (Above Sea Level)
Vegetation Communities	Northern boreal forests occupy lower slopes and valley bottom; spruce, pine and alder; grasses and sedges, mosses occupy forest floor; heavy moss and lichen growth resident as ground cover understory of shrub willow; open and forest fringe areas of willow and scrub birch, and various flowering plant species.
Wildlife Species	Moose, grizzly and black bear, caribou, beaver, wolf, lynx, marten, wolverine, western tanager, magnolia warbler, white-throated sparrow, bald eagle, furbearers and small animals. Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed species include: Common Nighthawk (Threatened); Rusty Blackbird and Olive-Sided Flycatcher (Special Concern).
Fish Species	Bering and Beaufort Sea salmonids and freshwater species, including: Arctic grayling, Arctic char, lake trout, trout perch, lake whitefish, broad whitefish, burbot, inconnu, Arctic Cisco, Northern pike, slimy sculpin

6 GENERAL RECLAMATION AND CLOSURE MEASURES

6.1 PROGRESSIVE RECLAMATION

Progressive reclamation efforts will help reduce slope erosion through physical slope stabilization by means of revegetation efforts, enhancing ultimate reclamation success. Progressive reclamation will be undertaken in a manner to ensure that the amount of work required at the end of the mine life to achieve the closure objectives is minimized.

Progressive reclamation limits the environmental liability and thus reduces the on-going risk carried by the company through:

- providing remediation to reduce or eliminate chemically hazardous material and sources of chemical contamination and other wastes;
- stabilizing potential sources of erosion and sediment release;
- initiating slope stability measures to enable reclamation;
- replanting and reseedling of disturbed areas no longer required for mine operations;
- reducing the total area requiring reclamation at the end of mining; and
- reducing closure security requirements as closure liability is reduced progressively.

Progressive reclamation activities will take place at every possible opportunity. Initially these activities are limited to stockpiling surface overburden and soil materials for future use in stabilization and revegetation of disturbed areas resulting from mine construction.

Initial progressive reclamation associated with the development and operation of the Bellekeno mine and Keno District Mill has occurred in 2011-2012 and in previous years and consists of the following activities:

- Recontouring and revegetation of the slopes surrounding the Bellekeno mine portal;
- Recontouring the organic growth media stockpiles located at the mill area;
- Recontouring disturbed areas adjacent to the Dry Stack Tailing Facility (DSTF);
- Recontouring and revegetation of the west side slope of the DSTF

6.2 REVEGETATION

6.2.1 Cover Engineering Design Parameters

The use of growth media for revegetation will be prioritized in the following order:

1. Sufficient growth media will be identified from existing borrow stockpiles in the DSTF and Mill areas and left in place to construct a 0.25 meter storage and release cover over the DSTF.
2. Sufficient growth media will be identified and used to construct the soil/vegetative cover over the waste rock disposal areas containing N-AML material. The volume of material that

will be required is yet to be determined as this material will be used for road and other construction purposes insofar as possible over the life of the mine.

3. Sufficient growth media will be identified and used to construct the soil/vegetative cover over the waste rock storage facilities, in the case that additional facilities are required after the rehandling of P-AML to the underground. All P-AML WRSFs will be covered with growth media, the volume of which will be determined upon design and construction of the facilities.
4. Growth media will be spread in those recontoured slopes that do not contain the necessary fines content to promote successful revegetation.
5. The growth media if any that remains in stockpiles will be recontoured and revegetated.

It is important to note that not all the growth media placement requires a loader and truck mode of operation. Some of the growth media placement can be completed by dozer push alone.

6.2.2 Revegetation Design Characteristics

A revegetation research program will be carried out over the life of the mine to determine the seed mix characteristics to be used in seeding and revegetating the covered waste rock dumps and DSTF. This program will be commensurate with research investigations carried out for waste rock dumps under District closure, and will also be sensitive to the desired level of infiltration prevention into mine facilities. As a starting point, Alexco will use the seed mixture after the success demonstrated at the Brewery Creek Mine. The seed mixture recommended for the leach pad at Brewery Creek was tailored around the objective of limiting infiltration by using plant species that maximize water uptake through evapotranspiration and consisted of the following:

- 50% Violet Wheatgrass
- 20% Kentucky Bluegrass
- 20% Red Fescue
- 10% Alfalfa

This seed mix provides a denser growth and therefore results in a higher water uptake. It is likely that the DSTF and P-AML WRSFs will follow a similar design. However, this will be confirmed through additional site-specific studies including test plots already in progress at the DSTF. The final seed mix will be tailored specifically to the goals and objectives of the particular site, whether it is the DSTF, mine-area recontoured slopes, or waste rock disposal areas. The seed mix will be consistent with the objective of slope stabilization and prevention of soil erosion in the short-term, and returning the site in the longer-term to an environment that closely resembles pre-mining conditions.

Appropriate diversions will be in place to meet erosion prevention objectives. Alexco's revegetation program includes resloping to 3H:1V, providing growth media material where it is necessary and active fertilization and seeding.

Assessment of revegetation programs carried out as a part of the Keno Hill District closure will be carried out to ensure that Bellekeno, Onek and Lucky Queen Production Unit Areas closure is commensurate with the overall plan for the district.

6.3 BORROW AND COVER SOURCES

Borrow material will be required for cover systems. Any borrow areas used will be reclaimed through slope stabilization and revegetation.

There are four existing borrow storage sites located at the mill area (Figure 6-1) that are suitable for cover construction and reclamation purposes. There are also a number of known granular deposits on the hill slope above the Bellekeno Haul Road which have old access trails which could be sourced for the required borrow materials. The total volume of growth media stored in the piles shown in Figure 6-1 is approximately 4224.7m³.

6.4 RECLAMATION RESEARCH

Reclamation research programs are used to support the site specific refinement of closure measure designs implemented at sites during final closure. There are currently a number of reclamation research programs underway as part of the District Closure Plan. These current programs have direct application to the reclamation and closure of the Bellekeno, Onek and Lucky Queen Production Unit Areas and Alexco will continue to utilize the research programs underway within the District Closure Plan for planning and optimization of the *District Development RCP*. The following reclamation research programs are currently in progress and the results will be utilized for the Bellekeno, Onek and Lucky Queen Production Unit Areas:

- cover system design and field trials;
- site revegetation field trials;
- bioreactor trials; and
- natural attenuation studies.

Alexco will initiate additional reclamation research programs during the Bellekeno, Onek and Lucky Queen deposits production operations in order to infill any gaps in closure programs for the District Closure Plan. Details on any reclamation research programs will be included in subsequent revisions to this RCP.

6.5 DATA COLLECTION PROGRAMS AND DEVELOPMENT OF DESIGN PARAMETERS

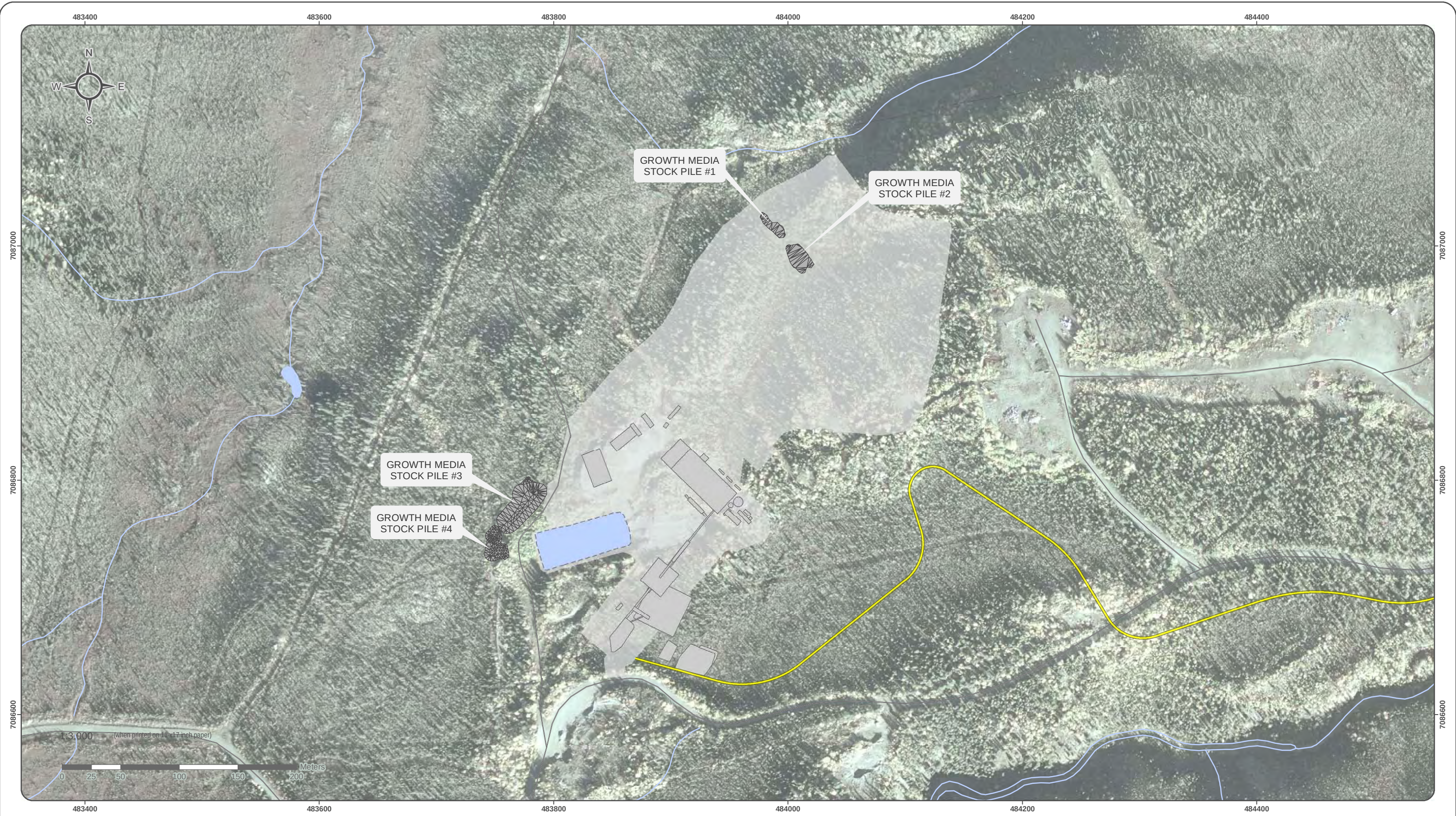
Data collection programs are currently underway at the Keno Hill District to assist in delineating site conditions and defining design parameters for closure measures. These data include:

- Surface water quality and hydrology,
- Groundwater quality and hydrology,
- Waste rock geochemistry,
- Tailings chemistry,
- Meteorology,
- Sediment quality; and
- Benthic community health



Numerous studies have been completed on the vast quantity of data that has been collected under the data collection programs. Of them, many have been carried out in an effort to support closure of the Keno Hill District (the former United Keno Hill Mines. Much of this work can be carried over to support operation and closure of the Bellekeno, Onek and Lucky Queen mines. Moreover, much of the data that has been collected will be reassessed separately to define design parameters.

Data collected to-date as a part of both baseline and production monitoring programs has been compiled and is presented in Appendix 1.



Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13 and 14 2006. Site hydrography and contours provided by Aero Geometrics LTD, derived from aerial photograph.

Datum: NAD 83; Map Projection: UTM Zone 8N

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-  Haul Road
-  Highway
-  Secondary Road

-  Growth Media Stockpiles
-  Building (As Built)
-  Pond (As Built)
-  Approximate Site Footprint



KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 6-1
GROWTH MEDIA STOCKPILES

AUGUST 2012

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7 MINE-COMPONENT RECLAMATION AND CLOSURE MEASURES

The approach to each subsection is to present a brief description of each component and related facilities with reclamation and closure objectives and measures. Refer to Figure 2-3 for an overall depiction of reclamation and closure measures.

The following components are addressed:

1. Bellekeno Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
2. Onek Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
3. Lucky Queen Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
4. Linear Disturbances
5. Flat Creek Camp
6. Mill and Ancillary Facilities
7. Dry Stack Tailings Facility

7.1 BELLEKENO PRODUCTION UNIT AREA

Closure Objectives: *The objectives for closing the Bellekeno Production Unit Area are to:*
(1) ensure physical and geochemical stability of the site;
(2) achieve passive management and treatment of the mine pool;
(3) minimize safety risks to people and wildlife, and
(4) reclaim the site to an aesthetically acceptable level.

The Bellekeno Mine consists of the underground workings, surface adit entrances, the current Bellekeno 625 treatment facility and associated buildings and infrastructure (Figure 7-1). The Bellekeno East portal is the primary ingress/egress point for the Bellekeno Mine. The Bellekeno 625 portal provides secondary escape and ventilation intake for the mine and discharges mining-impacted water which requires treatment for suspended solids, zinc and occasionally other metals and ammonia, on a continuous basis. The 200-level vent raise is not a component of the Bellekeno mine operations (it is a historic liability not used in Bellekeno operations) but is included in the RCP given its proximity to the Bellekeno mine.

Closure of the mine area will include restricting access and identifying and removing hazards and hazardous materials. The mine pool will be managed by transitioning from actively treating adit discharge to sealing the adit, implementing in situ mine pool treatment and installing a passive treatment system (bioreactor).

7.1.1 Bellekeno Waste Rock Storage Facilities/Disposal Areas

Closure Objectives: The objectives for closure of the Bellekeno waste rock storage facilities/disposal areas are to:

- (1) ensure geotechnical and geochemical stability of the site;*
- (2) minimize erosion;*
- (3) minimize safety risks to people and wildlife, and*
- (4) reclaim them to an aesthetically acceptable level.*

Waste rock extracted from the deposits is characterized and managed according to the Waste Rock Management Plan. Waste rock is identified as being one of the following types: potentially acid metal leaching (P-AML) or non acid metal leaching (N-AML).

7.1.1.1 P-AML Waste Rock Storage Facilities

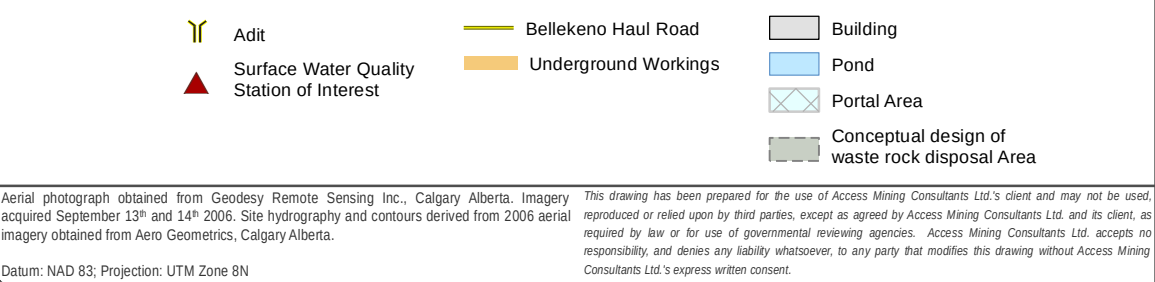
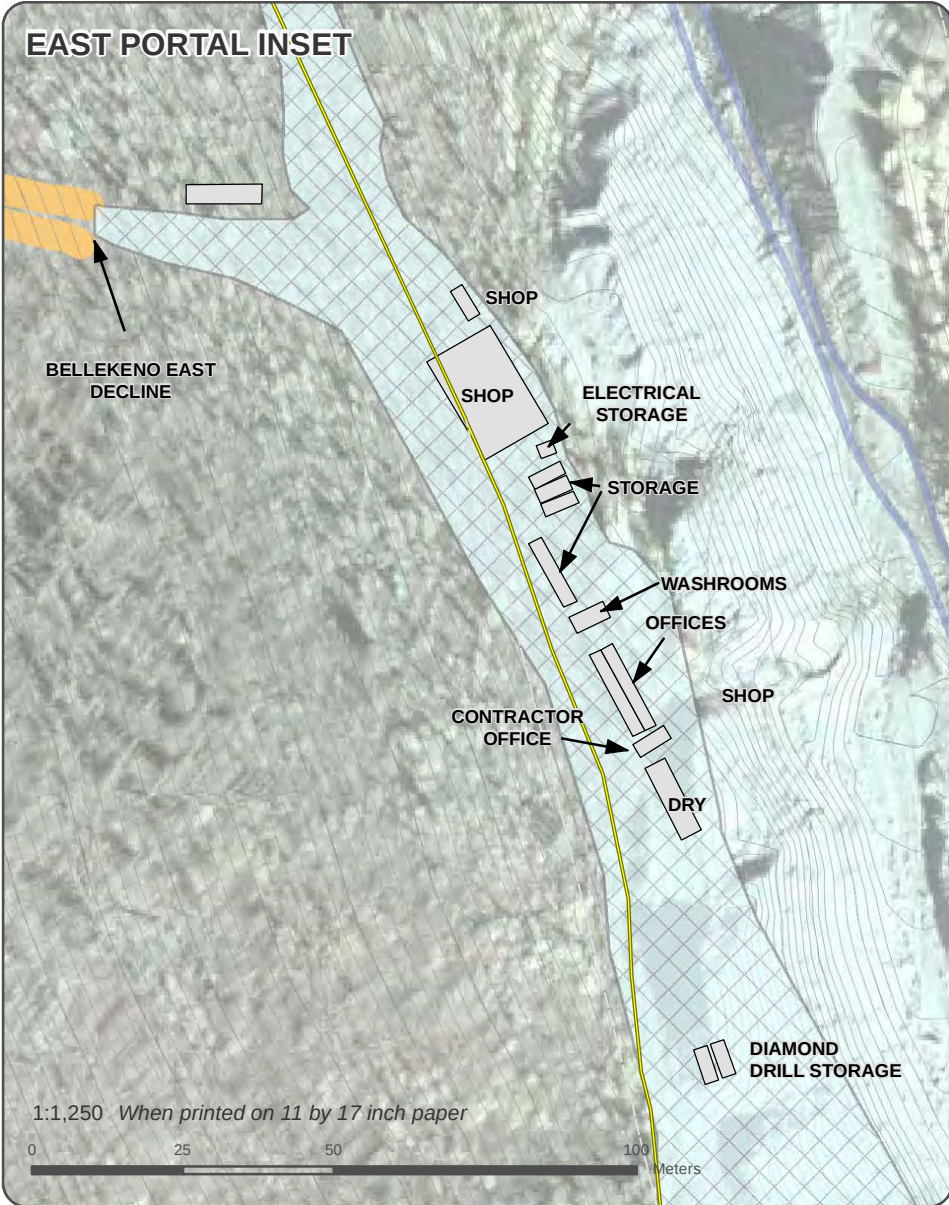
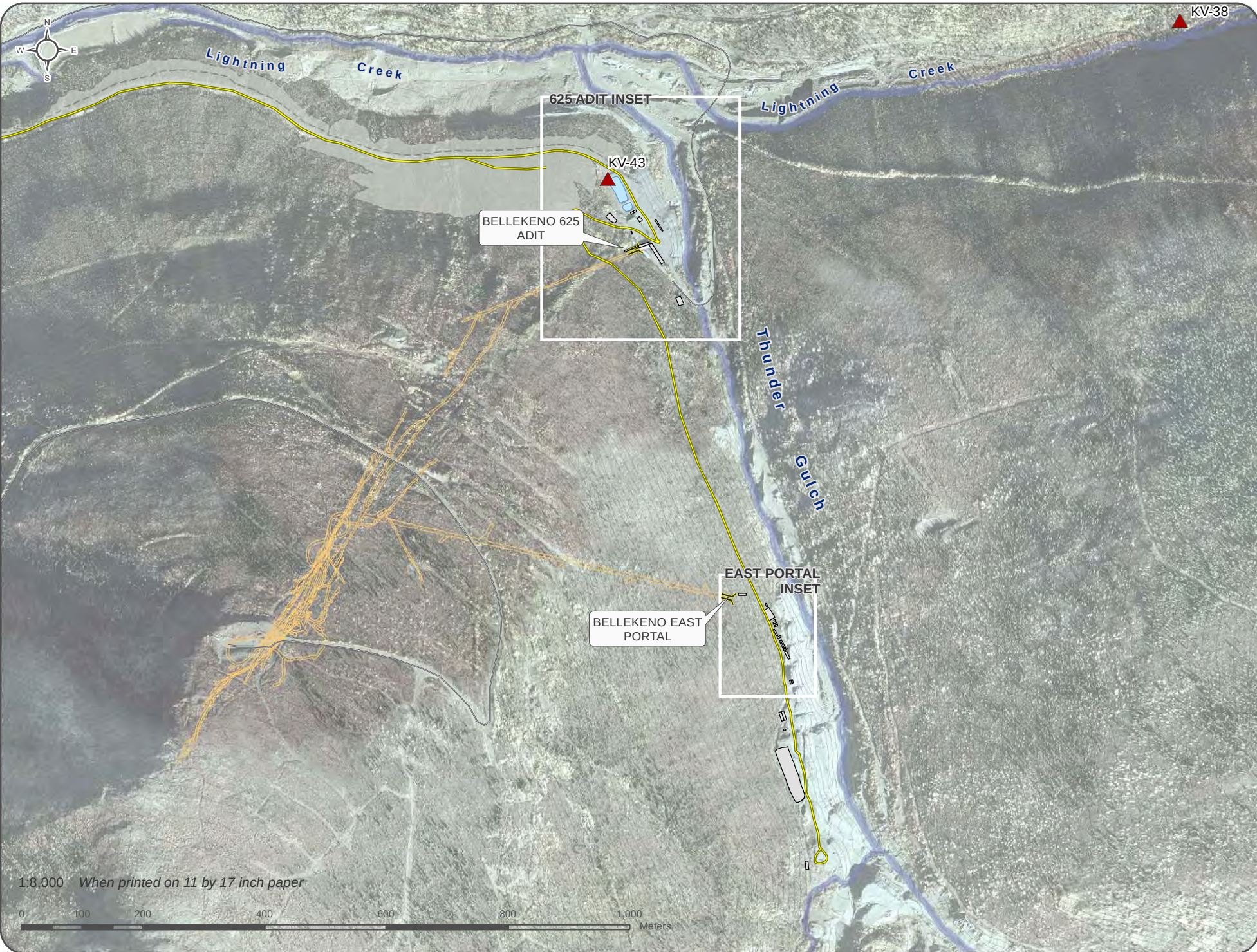
P-AML waste rock from the Bellekeno mine is currently being placed in a lined temporary Waste Rock Storage Facility (WRSF) located south of the Bellekeno East portal (Figure 7-1). The facility was designed according to the approved generic design (EBA, 2008)². At closure, P-AML waste rock stored in the temporary facility will be placed underground as mine backfill below the long-term static water level of the mine to limit oxygen contact with the P-AML waste rock. The temporary WRSF liner will be removed and the area recontoured and revegetated to be commensurate with the surrounding natural terrain. Revegetation will take place with appropriate growth media and seed mixes.

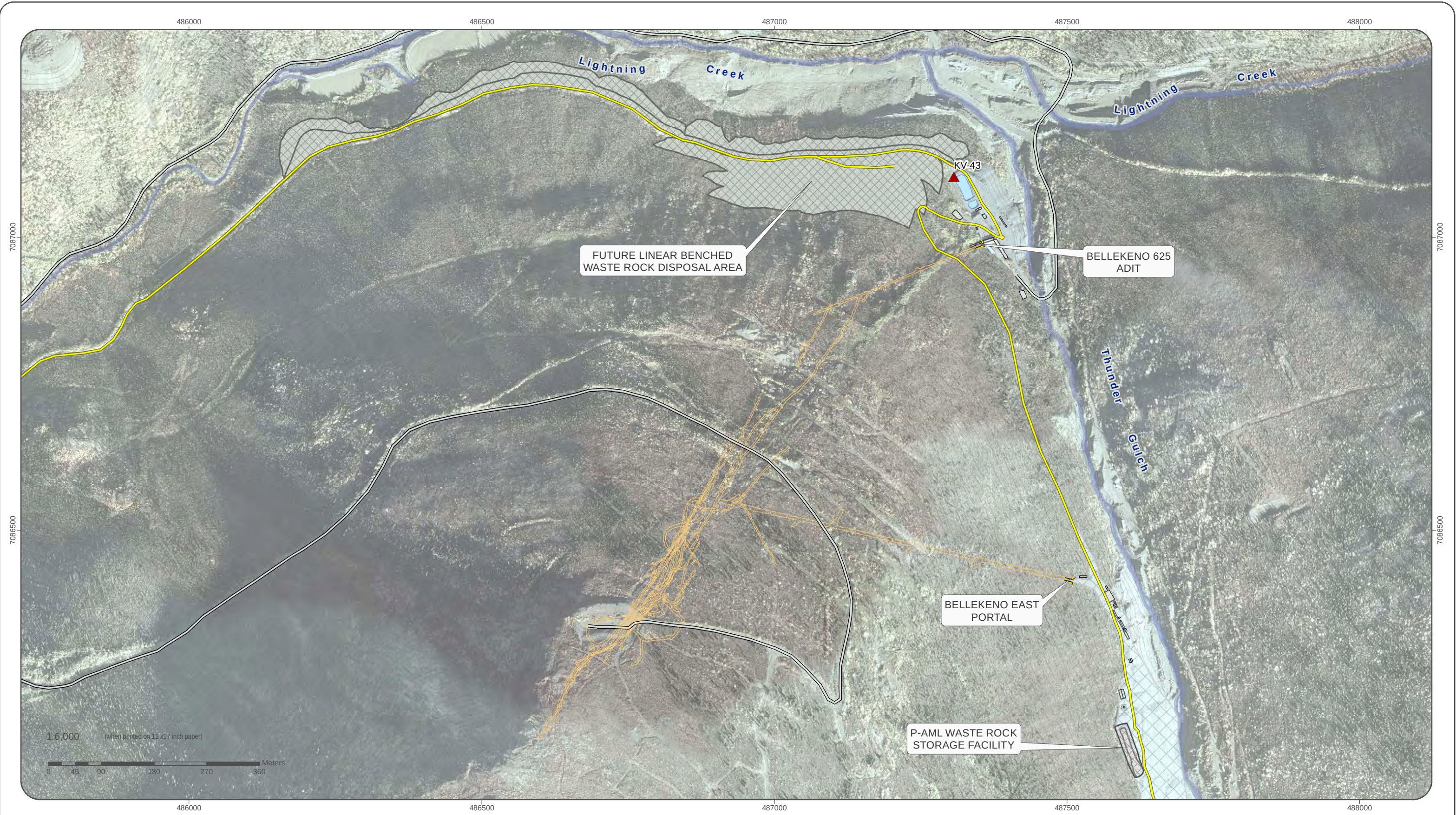
Additional permanent WRSFs for P-AML waste rock may be constructed at the Bellekeno site in accordance with the EBA approved generic facility design (Appendix 2). WRSFs will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRSF. The final overall (crest to crest) slope of the WRSF will be 3H:1V. If the P-AML waste in these facilities is not backfilled underground it will be covered with a total 0.5 m depth cover consisting of low-permeability borrow material in the bottom portion to minimize infiltration of meteoric water. The top portion of the cover shall consist of growth medium that will be seeded to promote vegetative growth. Appropriate stockpiled overburden material will be placed on the WRSF as part of the cover material.

7.1.1.2 N-AML Waste Rock Disposal Area

A Waste Rock Disposal Area (WRDA) was proposed to be constructed along the northeast flank of Sourdough Hill, northwest of the current Bellekeno 625 waste rock storage areas (Figure 7-2). The Bellekeno WRDA has not yet been constructed because the majority of the N-AML waste rock currently generated from the Bellekeno mine has been used for road construction material with a lesser amount as underground backfill.

² Available from the EMR website
http://www.emr.gov.yk.ca/mining/pdf/mml_bellekeno_mine_development_and_operations_plan_waste_rock_storage_facility.pdf





Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13 and 14 2006. Site hydrography and contours provided by Aero Geometrics LTD, derived from aerial photograph.

Datum: NAD 83; Map Projection: UTM Zone 8N

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	Adit		Bellekeno Haul Road		Underground Workings
	Surface Water Quality Station of Interest		Highway		Building
			Secondary Road		Pond
					Portal Area



KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-2

LOCATION OF EXISTING WASTE ROCK STORAGE FACILITY AND PROPOSED WASTE ROCK DISPOSAL

AUGUST 2012

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Preliminary engineering design by EBA of the proposed WRDA concluded that no additional contouring for stability is required upon closure. However, in order to further increase stability and improve aesthetics, Alexco will recontour the WRDA by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRDA. The final overall (crest to crest) slope of the WRDA will be 3H:1V. Based on the results of the reclamation research discussed, organics materials may be blended and scarified into the top surface of the WRDA to promote and enhance revegetation.

7.1.1.3 Bellekeno Historic Waste Rock Dumps

Preliminary design for recontouring the historic Bellekeno 625 waste dump is shown in Figure 7-3 including re-sloping and construction of water diversion features. A toe buttress may be required along the alluvial terrace below the toe of the historic WRDA which was previously placer mined. This contingency may be necessary to improve the overall stability of the embankment in the event of an earthquake, or other seismic event. Adequate backfilling or re-contouring by the placer miner may alleviate this concern, but this should be re-examined at closure. A geotechnical inspection of the facility will be conducted to determine the need for a toe buttress.

7.1.2 Bellekeno 625 Adit

Closure Objective: The objectives for closure of the Bellekeno 625 adit are to:

- (1) achieve passive management and treatment of the mine pool; and*
- (2) minimize safety risks to people and wildlife.*

Without continued dewatering and pumping after closure, the static water elevation of the Bellekeno Mine will rise to and discharge from the Bellekeno 625 adit. A concrete adit bulkhead will be constructed to allow management of the mine pool long term. The bulkhead is not designed as a high head pressurized structure that will allow increased flooding above the 625 elevation, but rather as a water management tool and feature that will allow consistent flow to the secondary bioreactor treatment system. A conceptual design for the Bellekeno 625 adit bulkhead is shown in Figure 7-4. The size of this opening is approximately 2.5 m x 2.5 m.

A stainless steel grate will be installed at the adit entrance to restrict access by humans or wildlife. A padlocked door within the grate will allow for access to the bulkhead for closure monitoring and maintenance as needed.

The long-term water management and treatment approach for the Bellekeno mine is summarized as follows:

- A detailed hydrogeological study of the Bellekeno Mine is on-going during mine operations, and is required to determine the final flow rates to be expected from the Bellekeno mine. As noted above, based on the existing mine plan, the final elevation of the static water in the mine will be controlled by the Bellekeno 625 adit. This study will be based on information collected as part of the Bellekeno Hydrogeology Plan submitted in November 2010 as a requirement under Water Use Licence QZ09-092.
- Final detailed design engineering will be required to construct a bulkhead at Bellekeno 625. The bulkhead would be put in place as the mine pool is allowed to flood (estimated to take

- ~12 months if not longer). Instrumentation installed in the mine and bulkhead in the form of a pressure gauge will be installed to assist with monitoring of the mine pool elevation.
- In situ mine pool treatment to reduce soluble metals (zinc) loads using a carbon source such as molasses will be implemented immediately upon commencing Bellekeno mine pool flooding. Alexco has implemented this technology at several minesites throughout North and South America and it has proven highly successful in reducing soluble metal loading. The mine pool would be accessed through the Bellekeno East decline or secondary escapeways, which would not be blocked until Bellekeno 625 has been adequately decommissioned. In-situ treatment of the mine pool for at least 12 months prior to the mine pool discharging at 625 is expected to produce acceptable water quality discharge criteria. Evidentiary information to support the expected success of the in mine pool treatment of Bellekeno 625 is included in Appendix 3.
 - Once active treatment and pumping of the mine pool ceases and in situ treatment begins, conversion of the current water treatment ponds at Bellekeno 625 into bioreactors would take place. Water from the flooding mine pool would be pumped to the bioreactor constructed at 625 and commissioning and optimization of the bioreactor would take place. Once the treated mine pool reaches the static elevation of the 625 adit and begins to gravity flow out of the adit, pumping to the bioreactor for commissioning would cease and passive flow and treatment through the bioreactor would continue. This approach allows construction and commissioning of the bioreactor to have already been completed by the time the Bellekeno 625 mine pool floods and reaches static water elevation and discharges out the 625 adit. A bioreactor was constructed and operated from 2009-2011 at Galkeno 900 as part of the District closure planning process. The results of the Galkeno 900 bioreactor performance is included in Appendix 4 as support for this approach in closure of the Bellekeno mine.
 - The overall water management approach for Bellekeno is to have the bioreactor constructed and commissioned prior to when the mine pool is fully flooded and discharging out of the 625 adit. It is expected that the in situ mine pool treatment will obtain acceptable discharge water quality but in the event it does not then the bioreactor will already be fully commissioned by the time the mine pool reaches the elevation of the 625 level.

A preliminary design of the bioreactor at 625 is shown in Figure 7-5. A water treatment and management schedule for Bellekeno 625 is included in Table 7-1.

7.1.2.1 Bellekeno 625 Water Treatment Facility

The Bellekeno 625 Water Treatment Facility (WTF) includes a lime-addition circuit for metals removal, multi-media filtration system for TSS and an ion exchange system for ammonia removal. The system formerly consisted of a simple lime-addition circuit to deal with metal leaching from the exposed workings, but was upgraded to deal with an increase in TSS and ammonia levels associated with underground mining activities.

Sludge from the Bellekeno 625 WTF is currently disposed of into a cell on the surface of the Valley Tailings as per the current Sludge Management Plan and as authorized under QML-0009. Bellekeno water treatment sludge is also authorized for disposal in the DSTF. The sludge from Bellekeno 625 that is stored in the valley tailings cell is kept separate from the sludge generated at the other

treatment facilities. The sludge containment cells are not lined in order to allow water to exfiltrate from the cells.



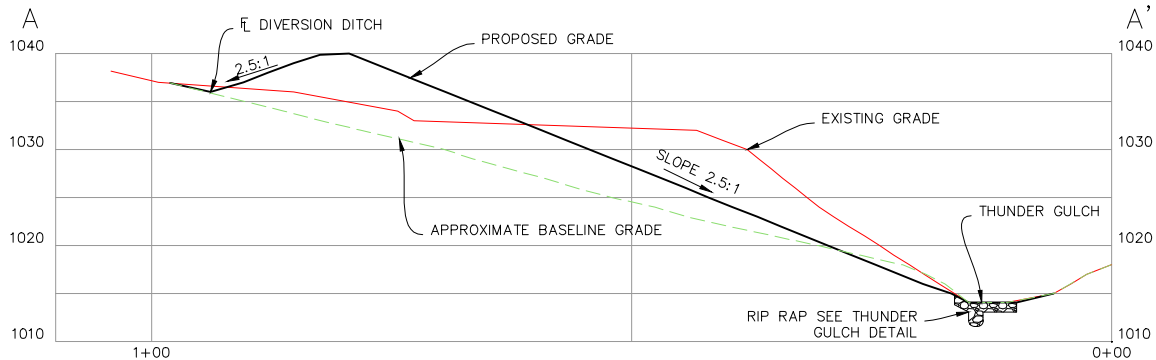
Plate 7-1: Bellekeno 625 Area Overview

7.1.3 Bellekeno East Adit

At closure, underground equipment will be removed from the underground mine through Bellekeno East (see Section 0). The portal will remain temporarily accessible at closure for the rehandling of P-AML waste rock back into the underground (see Section 7.2). The Bellekeno East adit opening will then be blocked by inserting rock fill to protect human health and safety and prevent wildlife access (Figure 7-6). This method, in use at other northern Canadian mines, allows for movement of water and air through the opening, as well as allowing for any movement of rock walls, to prevent failure as would occur with a concrete plug for example. An adit decant channel will not be constructed as any water leaving the mine workings will flow via the Bellekeno 625 adit which is connected to the Bellekeno East decline. Reclamation measures for the Bellekeno Mine are predicated on the fact that the static water elevation will not reach the elevation of the Bellekeno East portal and therefore this portal will not discharge water. As such the sediment ponds constructed at Bellekeno East for development of the decline will be progressively reclaimed prior to mine closure.

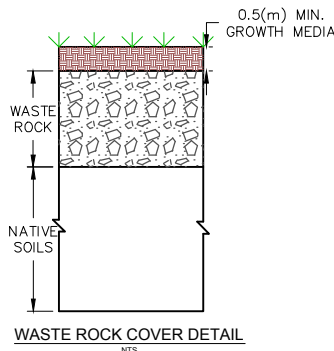
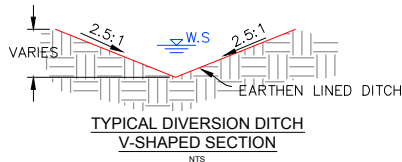
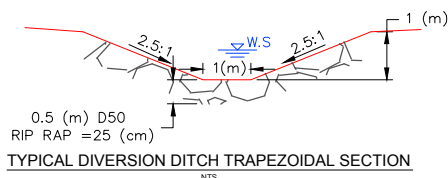
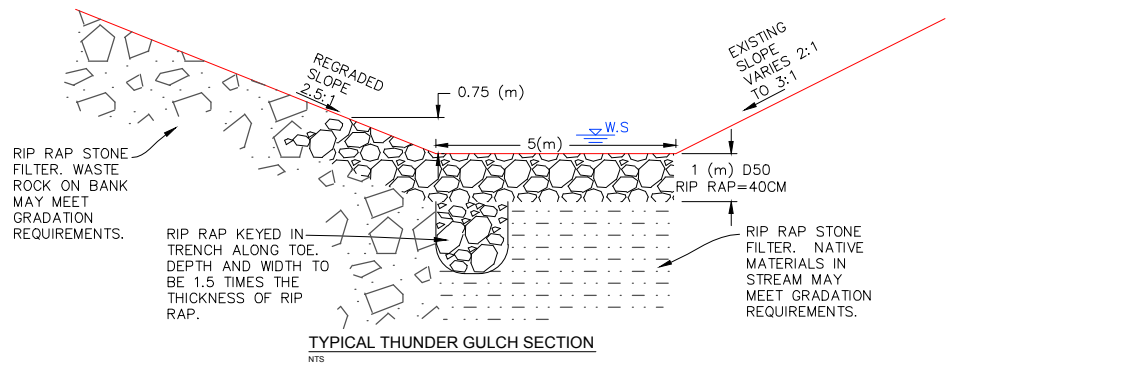
7.1.4 200 Level Vent Raise

The 200 level vent raise will be capped with an engineered concrete cap similar to what is used at mines elsewhere in Canada. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-7.

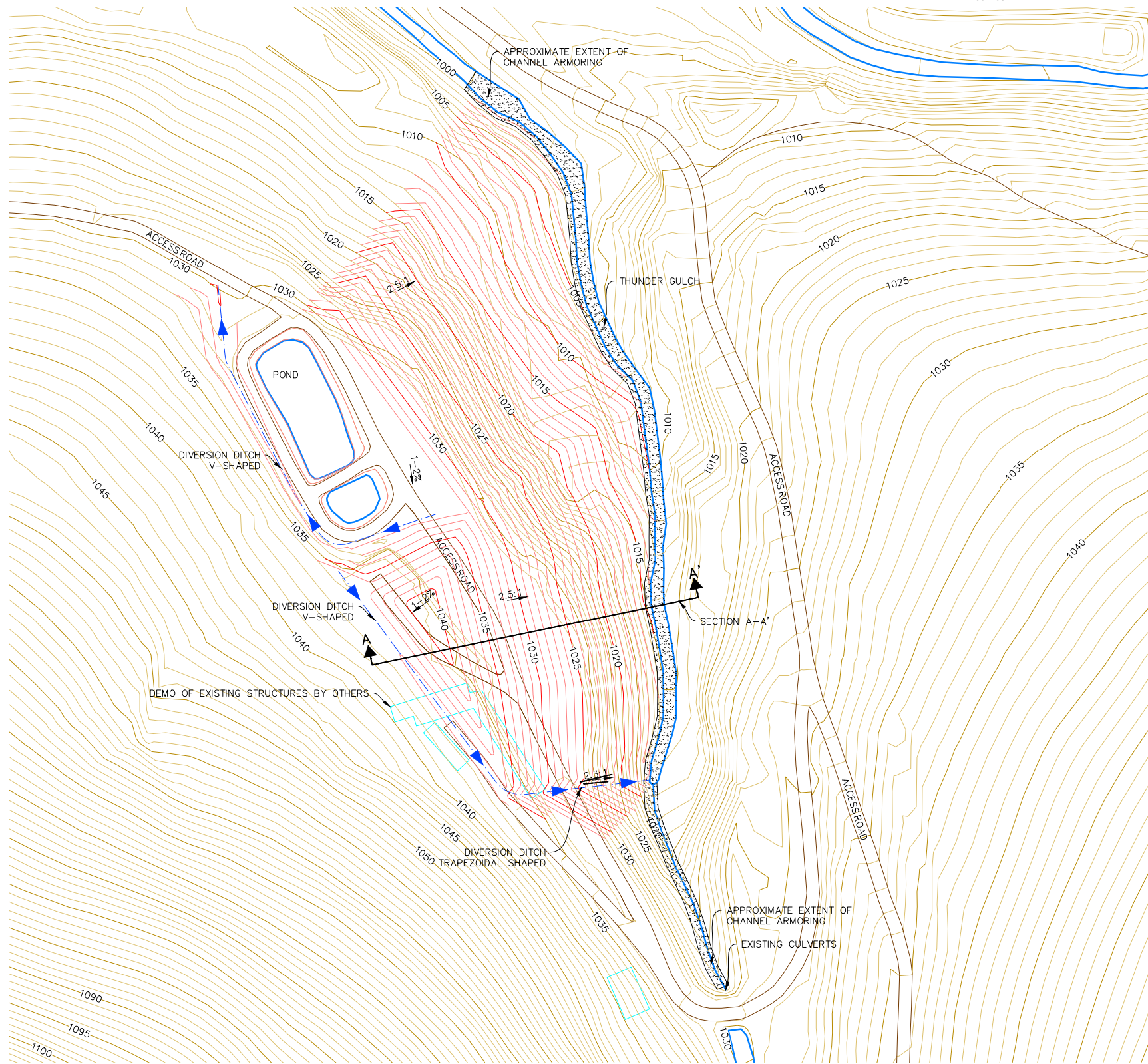


METRIC SCALE
0 10 20m
CONTOUR INTERVAL = N/A

SECTION A-A'



- NOTES:**
1. EXISTING CONTOURS PRESENTED MAY NOT REPRESENT CURRENT CONDITIONS. PLACER MINER CURRENTLY EXCAVATING AND MINING EAST OF THUNDER GULCH.
 2. CHANNEL SECTION MAY VARY DUE TO CURRENT PLACER MINING DISTURBANCE IN THUNDER GULCH.
 3. DIVERSION DITCHES SHALL BE EARTHEN WHEN SLOPES < 5% AND RIP RAP LINED WHEN SLOPES ARE GREATER.
 4. BELLEKENO EAST "HIGH ROAD" NOT PRESENTED ON THIS DRAWING.



J:\Projects\102001 - Keno - Alexco\102002 - Alexco Keno\Bellekeno Mine Closure\Bellekeno East\Grading (11-16-2011)

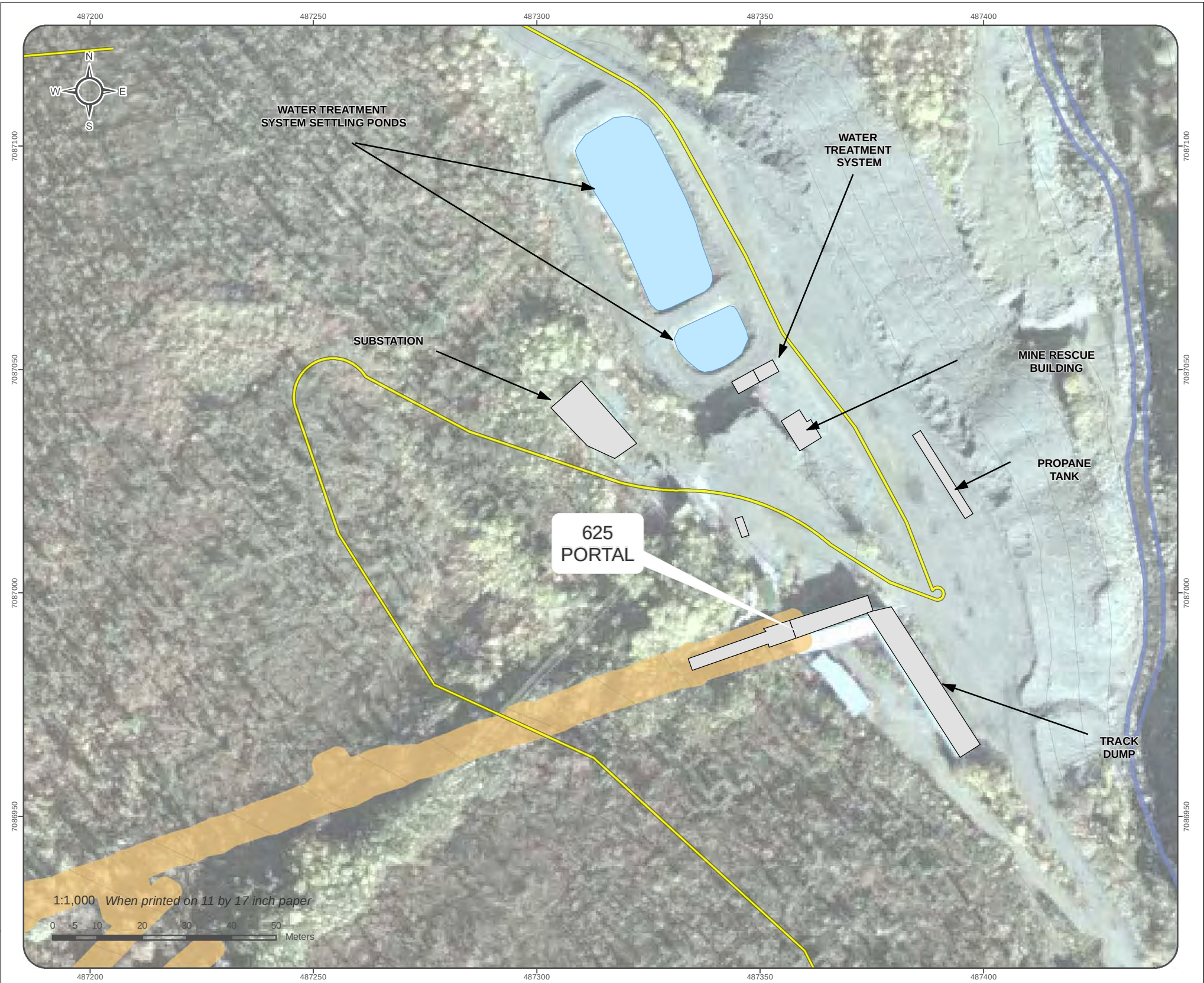
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4	---	---	---	---	---
3	---	---	---	---	---
2	---	---	---	---	---
1	---	---	---	---	---
0	---	---	---	---	---

DISCLAIMER: THIS DRAWING WAS DEVELOPED THROUGH THE APPLICATION OF PROFESSIONAL ENGINEERING SKILL AND PROPRIETARY METHODOLOGIES, PROCESSES AND KNOW HOW OF INTERALOGIC AS AUTHOR ALL PURSUANT TO THE TERMS OF A CONTRACTUAL SCOPE OF WORK GOVERNING ITS PREPARATION. THIS DRAWING MAY NOT BE USED OR MODIFIED OTHER THAN IN STRICT ACCORDANCE WITH THE TERMS OF THE GOVERNING CONTRACT AND SCOPE OF WORK OR OTHERWISE ASSENT THE INVOLVEMENT AND CONSENT OF THE AUTHOR ANY ALTERATION OR ADAPTATION OF THIS DRAWING SHALL BE CONSISTENT WITH THE AUTHOR'S CONTRACTUAL AND PROPRIETARY RIGHTS AND BE AT USER'S SOLE RISK AND WITHOUT ANY LIABILITY OR LEGAL RESPONSIBILITY OF INTERALOGIC.	
DRAWING REFERENCE(S): EXISTING TOPOGRAPHY PROVIDED BY _____, RECEIVED _____ 20__.	
DATUM: NAD83	SCALE: 1"=100'

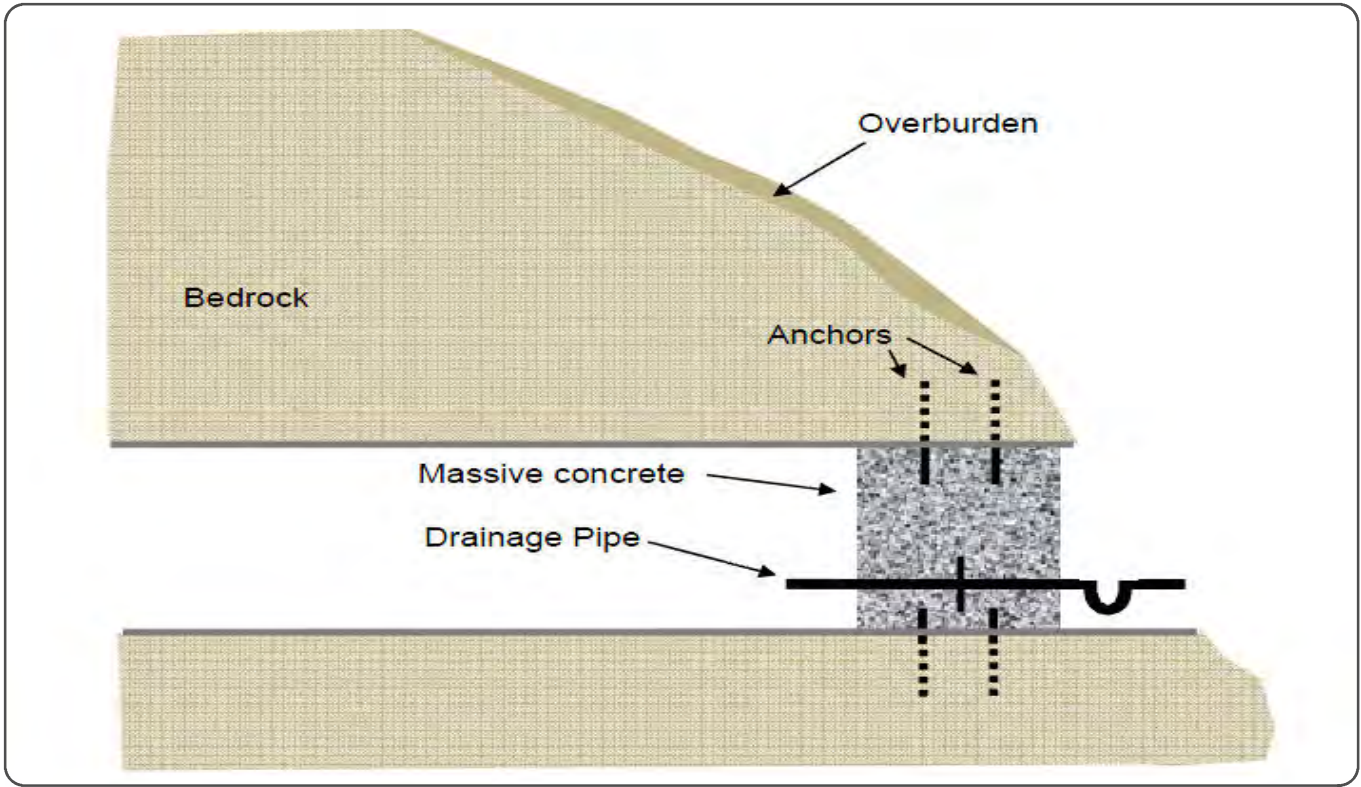
DESIGNED BY	CJG	11-16-2011
DRAWN BY	CJG	11-16-2011
CHECKED BY	B. JOHNSON	11-16-2011
APPROVED BY	B. JOHNSON	11-16-2011
PROJECT MANAGER	B. JOHNSON	11-16-2011
CLIENT APPROVAL	---	---
CLIENT REFERENCE NO.	---	---

PROJECT LOCATION	KENO CITY, YUKON, CANADA
PROJECT	BELLEKENO MINE CLOSURE
TITLE	FIGURE 7-3 WASTE ROCK DUMP REGRADING AND DETAILS

PROJECT LOCATION KENO CITY, YUKON, CANADA		 1603 Oakridge Dr., Suite 202 Fort Collins, Co. 80525 970.225.8222	
PROJECT BELLEKENO MINE CLOSURE			
TITLE FIGURE 7-3 WASTE ROCK DUMP REGRADING AND DETAILS		DRAWING FIGURE 7-3	REVISION
		FILE NAME Grading (11-16-2011)	



CONCEPTUAL 625 ADIT BULKHEAD DESIGN



- Underground Workings
- Building
- Pond

Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13th and 14th 2006. Site hydrography and contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.

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Datum: NAD 83; Projection: UTM Zone 8N

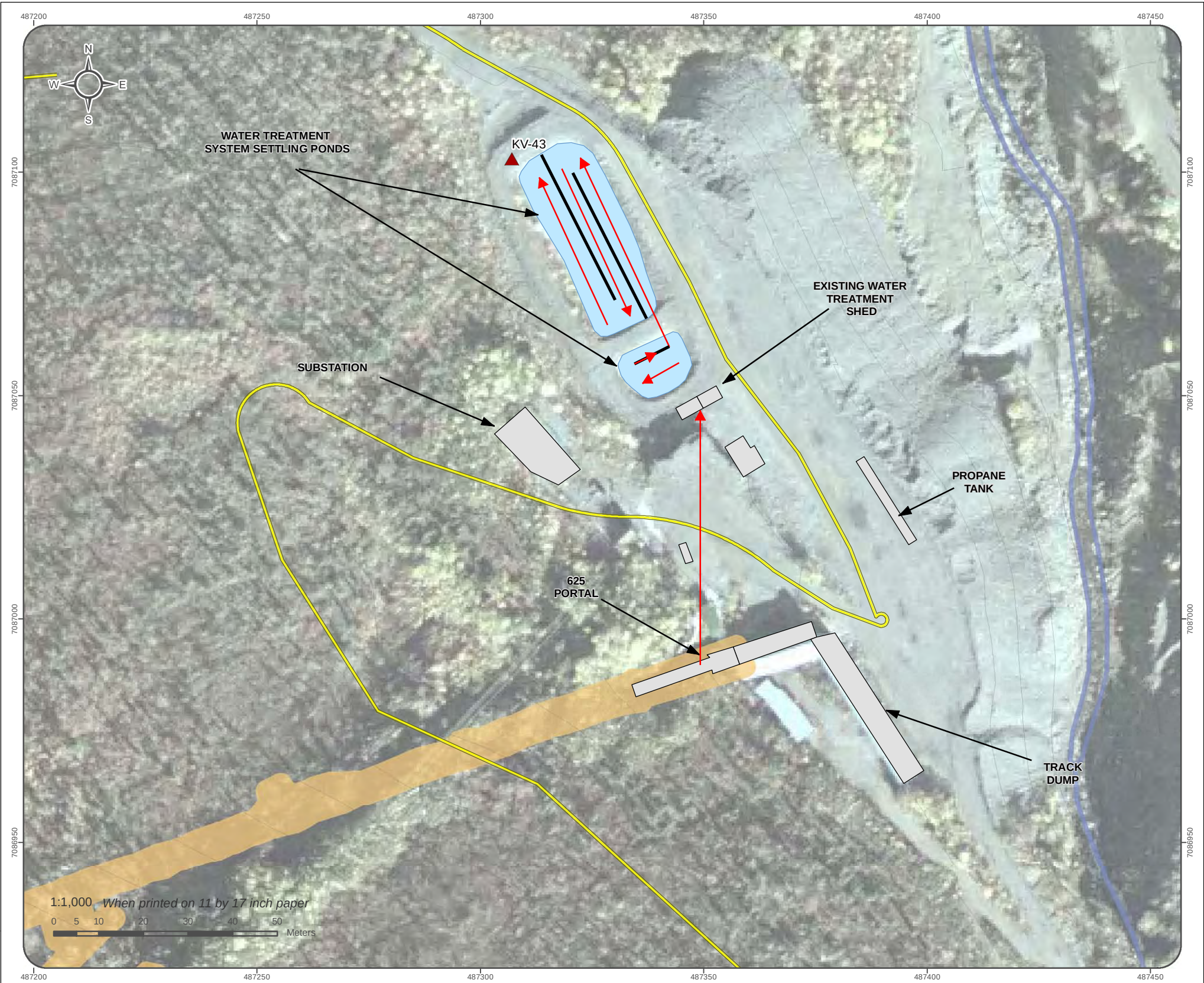


KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-4
BELLEKENO MINE SITE LAYOUT
625 ADIT BULKHEAD

AUGUST 2012

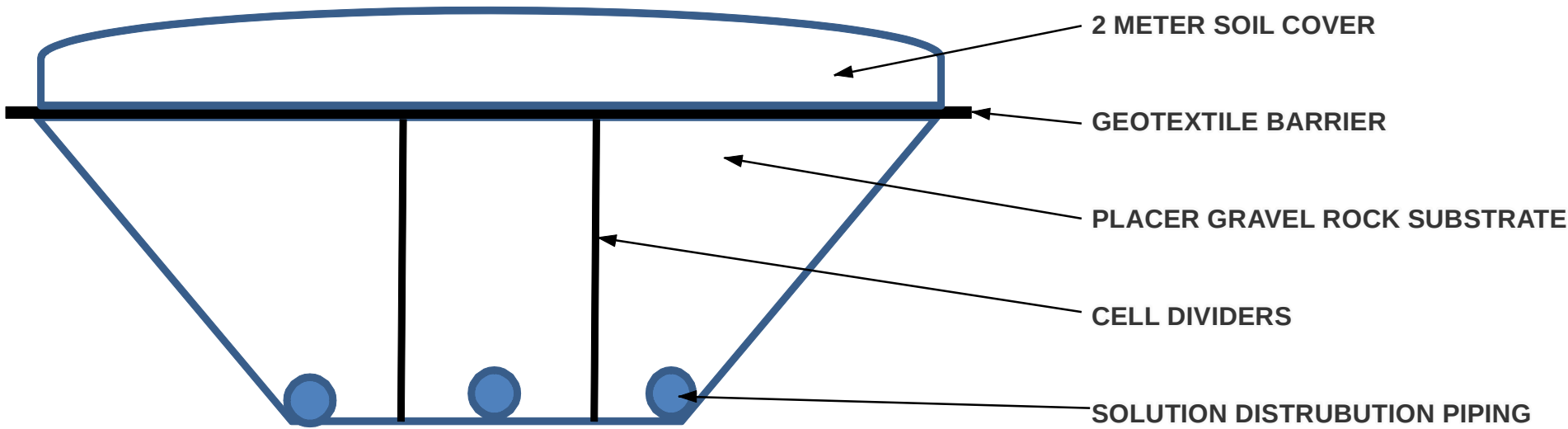
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(Last edited by: mduchame;06/08/2012/11:04 AM)



Conceptual Design Assumptions

Divide Pond 1 into 2 zones with a HDPE liner divider. 2 cells @ 6m x 15m	Porosity = 40%
Divide Poind 2 into 3 zones with a HDPE liner divider, 3 cells @ 5.3m x 42m	Flowrate = 4 lps
Total Volume = 2,700 m3	Retention Time = (2700 m3 x 0.40)/4 lps = 3.1 days

TYPICAL BIOREACTOR - CROSS SECTIONAL VIEW

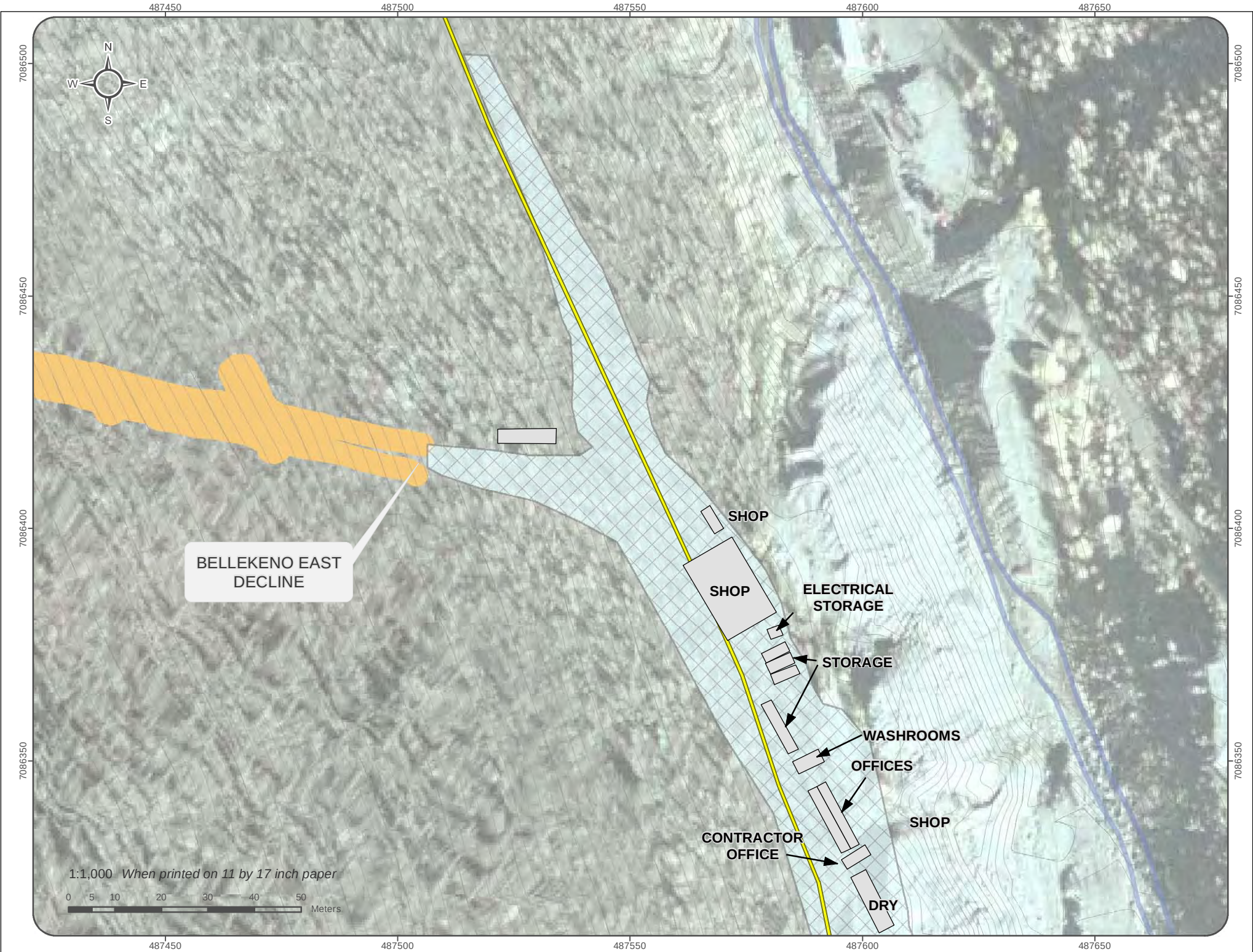


Building Pond Underground Workings		Flowpath of Adit Water Cell Divider	AKHM ACCESS	KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN		
Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13 th and 14 th 2006. Site hydrography and contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.		This drawing has been prepared for the use of Access Mining Consultants Ltd.'s client and may not be used, reproduced or relied upon by third parties, except as agreed by Access Mining Consultants Ltd. and its client, as required by law or for use of governmental reviewing agencies. Access Mining Consultants Ltd. accepts no responsibility, and denies any liability whatsoever, to any party that modifies this drawing without Access Mining Consultants Ltd.'s express written consent.		FIGURE 7-5 BELLEKENO 625 BIOREACTOR PRELIMINARY DESIGN		
Datum: NAD 83; Projection: UTM Zone 8N				DRAWN BY JP	AUGUST 2012	VERIFIED BY TL
				I:\ALEX-05-01\Bellekeno\GIS\mxd\Closure\2012\03-Submitted July 2012\9-BK625_Bioreactor_20120806.mxd (Last edited by: mduchame;06/08/2012/11:06 AM)		

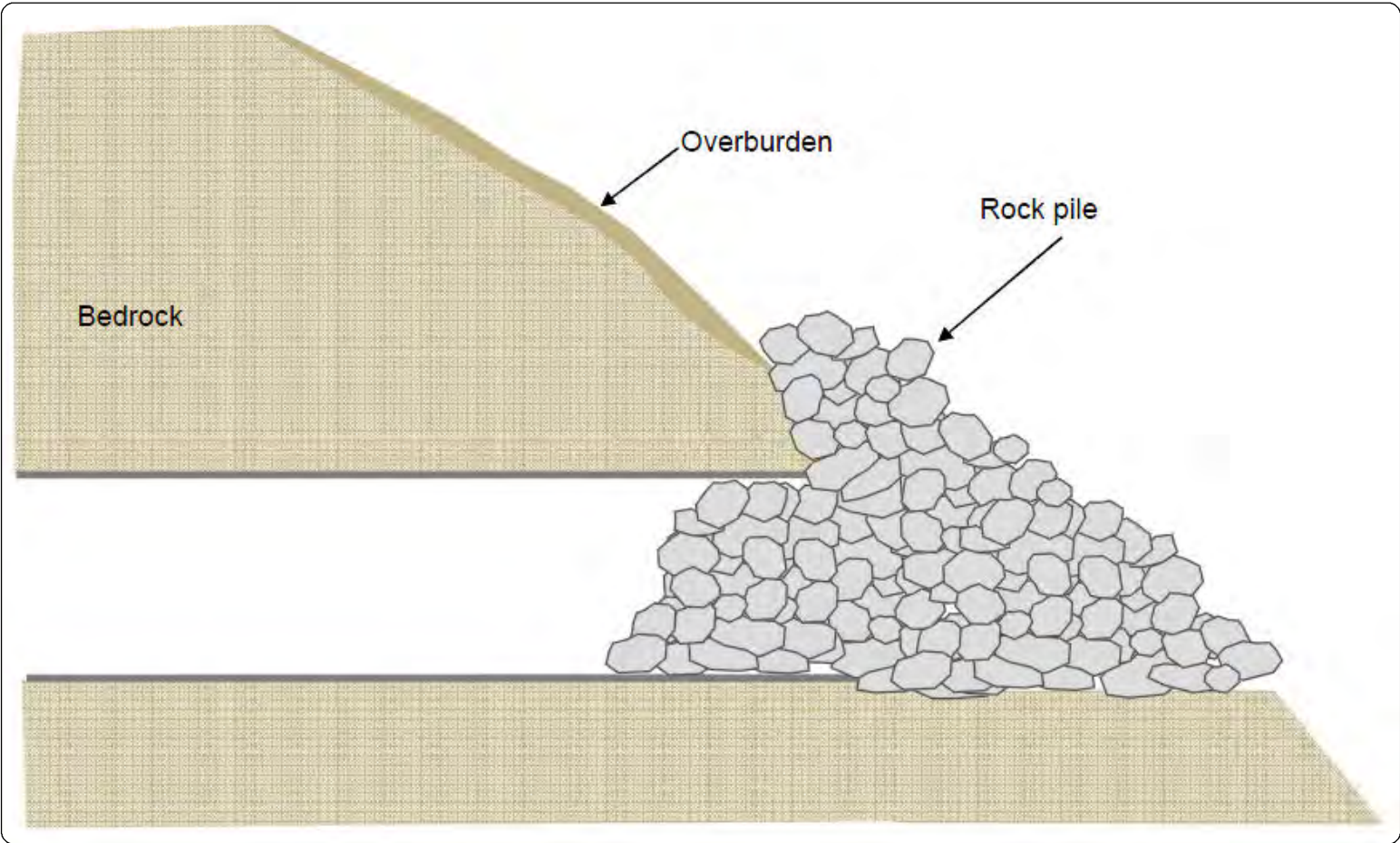
Table 7-1: Bellekeno and Lucky Queen Water Management Schedule

Months following cessation of mining activities												
Bellekeno Water Management Task	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Cessation of mining												
Pump shutdown and mine workings flooding												
Construct bioreactor												
Commission bioreactor with mine pool water												
Passive feed of bioreactor from mine pool												
Months following cessation of mining activities												
Lucky Queen Water Management Tasks	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Cessation of mining												
Construct bioreactor (if required)												
Commission bioreactor with adit discharge												
Passive feed of bioreactor from adit discharge												





CONCEPTUAL EAST PORTAL CLOSURE ROCK PILE



- Building; Unknown
- Bellekeno Haul Road
- Underground Workings
- Portal Area

Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13th and 14th 2006. Site hydrography and contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.

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Datum: NAD 83; Projection: UTM Zone 8N

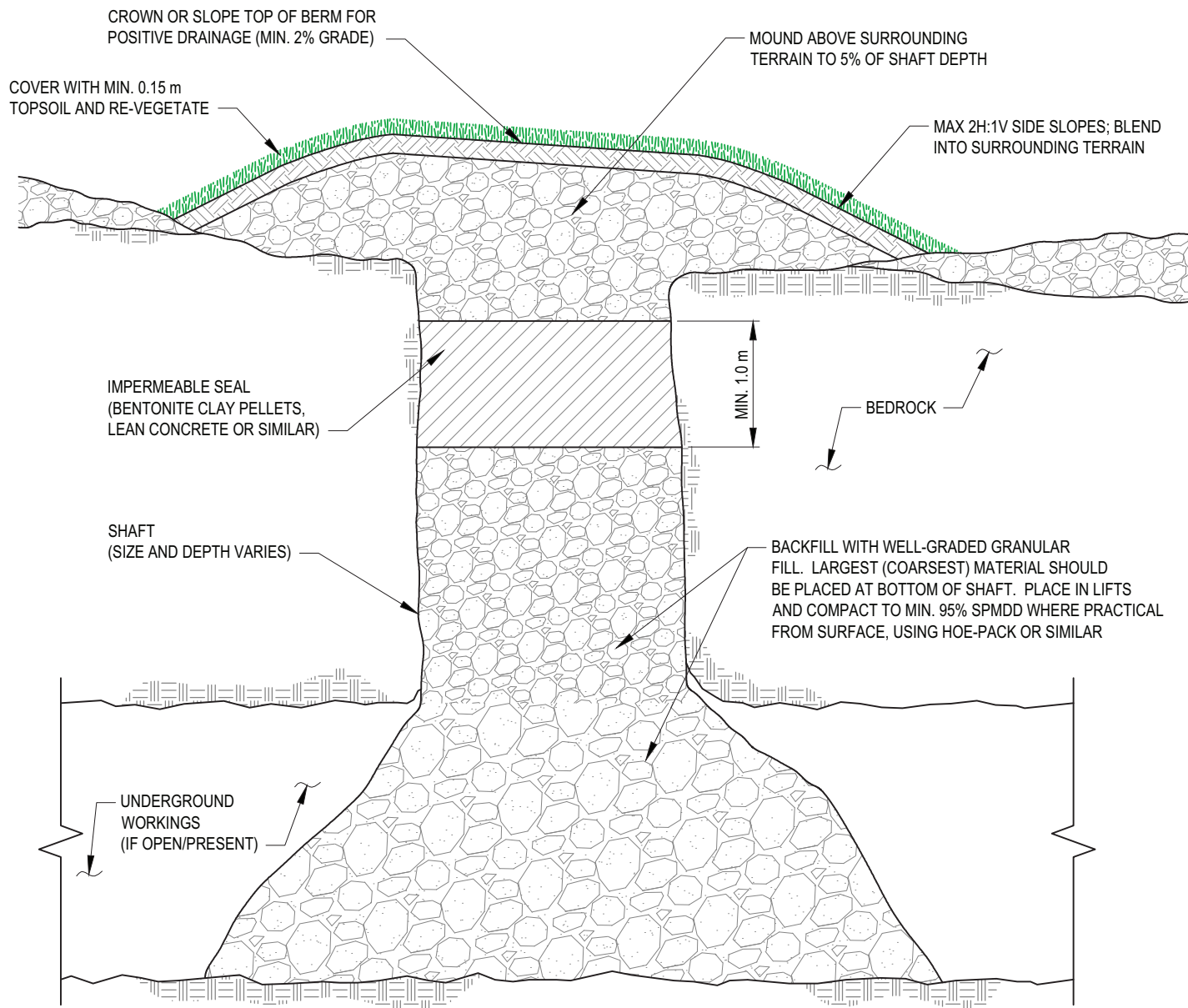


KENO DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 7-6
BELLEKENO MINE SITE LAYOUT
EAST PORTAL CLOSURE ROCK PILE

AUGUST 2012

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(Last edited by: mducharme;03/08/2012/16:57 PM)



NOTES:

1. Quantities will vary with shaft depth, connection to underground workings, and other conditions.
2. Remove and dispose of timber, trash, brush, topsoil and other debris in and around shaft area, prior to backfilling. Strip down to bedrock surface at collar where practical.
3. Dewater shaft and workings (if practical) prior to backfilling.
4. Existing steel pipe, concrete rubble (if present) should be removed or incorporated into backfill as directed by engineer.

CONCEPT DRAWING
NOT FOR CONSTRUCTION

STATUS
ISSUED FOR REVIEW

SCALE 1:50



CLIENT



KENO HILL SHAFT CLOSURES
KENO HILL, YT

CONCEPT A
DRY SEAL

PROJECT NO.
V15101043

DWN
SF

CKD
JP

REV
0

OFFICE
VANC

DATE
April 4, 2011

Figure7-7

7.1.5 Bellekeno Surface Infrastructure

Closure Objectives: The objectives for closure of Bellekeno surface infrastructure are to:

- (1) remove potential sources of environmental contamination;*
- (2) minimize erosion;*
- (3) minimize safety risks to people and wildlife, and*
- (4) reclaim the site to an aesthetically acceptable level.*

7.1.5.1 Bellekeno East Surface Facilities

Various surface support buildings and facilities (Plate 7-2) are in place near the entrance to the Bellekeno mine and include:

- Surface maintenance shop
- Sea container storage units
- Toiletries building
- Contractor offices
- Technical services offices

All of the surface buildings at Bellekeno East are portable structures that will be removed and transported offsite for salvage at the end of the mine life.

Plate 7-3 shows the current state of the Bellekeno East decline. The decline collar is a multi-plate culvert 4 meters in diameter extending from the surface into the competent bedrock.

At closure, underground equipment will be removed from the underground mine through the Bellekeno East portal. The portal will remain temporarily accessible at closure for the rehandling of P-AML waste rock back into the underground. The Bellekeno East adit opening will then be blocked by inserting rock fill to limit access by humans and wildlife (Figure 7-6). Reclamation measures for the Bellekeno Mine are predicated on the fact that the static water elevation will not reach the elevation of the Bellekeno East portal and therefore this portal will not discharge water. As such the sediment ponds constructed at Bellekeno East for development of the decline will be progressively reclaimed prior to mine closure.



Plate 7-2: Bellekeno East Surface Facilities

Reclamation of the Bellekeno East portal site will include removal of the shop and other buildings (e.g. explosives and cap magazine). Fuel tanks will be cleaned and removed along with liners for reuse or landfilling. Any additional debris will also be removed for reuse or proper disposal. All solid waste will be disposed of in accordance with the *Yukon Environment Act* Solid Waste Regulations. Alexco has a permitted commercial solid waste facility located in Elsa. All waste petroleum products and any other special waste, as defined in the Special Waste Regulations will be disposed of in accordance with the Regulations. Any soils contamination will be documented through a final site contamination assessment. Contaminated soil will be removed and/or remediated in an approved manner. A land treatment facility has been constructed near the Elsa Valley Tailings Facility for remediation of such soils for district closure, and can be used for remediation of any hydrocarbon contamination at the Bellekeno Mine. The portal site would then be recontoured and scarified to facilitate revegetation and establish drainage (revegetation at the Bellekeno East portal site has already been started). Signage will be installed to indicate the portal presence.

Surface water diversion infrastructure (berms, ditches) will be maintained to prevent surface runoff inflows into the adit and limit erosion. Water storage ponds will be filled in and contoured to match surrounding environmental features.

Compacted areas will be scarified to promote natural revegetation or selected areas will be reseeded with native vegetation.



Plate 7-3: Bellekeno East Portal

7.1.5.2 Bellekeno 625 Adit Surface Facilities

The primary facilities in place at the Bellekeno 625 location include:

- Historic loadout and snow shed facility
- Compressor shack
- Ventilation fan and propane tank
- Water treatment buildings
- Sea container storage units
- Electrical substation

An overview of the Bellekeno 625 area and facilities is shown in Plate 7-1. All of the surface buildings at Bellekeno East are portable structures that will be removed and transported offsite for salvage at the end of the mine life. Water treatment measures for closure are addressed in Section 7.1.2.

7.2 ONEK PRODUCTION UNIT AREA

Closure Objectives:

The objectives for closing the Onek Production Unit Area are to:

- (1) ensure physical and geochemical stability of the site;*
- (2) achieve passive management and treatment of the Onek 400 adit discharge;*
- (3) minimize safety risks to people and wildlife, and*
- (4) reclaim the site to an aesthetically acceptable level.*

The Onek Production Unit Area will consist of new underground workings, surface facilities and features at the 990 Portal (portal, surface buildings and infrastructure), P-AML WRSFs, N-AML

WRDAs, and the vent raise (Figure 7-8). The historic waste rock dumps associated with the new P-AML WRSFs and N-AML WRDAs are historic liabilities; however, they are included in the RCP because they are a component of the Onek Production Unit Area.

7.2.1 Onek Waste Rock Storage Facilities/Disposal Areas

Closure Objectives: The objectives for closure of the Onek waste rock storage facilities/disposal areas are to:

- (1) ensure geotechnical and geochemical stability of the site;*
- (2) minimize erosion;*
- (3) minimize safety risks to people and wildlife, and*
- (4) reclaim them to an aesthetically acceptable level.*

Waste rock extracted from the deposits is characterized and managed according to the Waste Rock Management Plan. Waste rock is identified as being one of the following types: potentially acid metal leaching (P-AML) or non acid metal leaching (N-AML).

7.2.1.1 P-AML Waste Rock Storage Facilities

P-AML waste rock will be stored either in the Onek P-AML WRSF to the north of the Onek historic open pit, which was previously licenced for Bellekeno advanced exploration and production, or in a new onsite P-AML WRSF. P-AML waste rock may also be placed underground as mine backfill. Additional WRSFs will be constructed as required as per EBA's generic facility design.

At closure, WRSFs will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRSF. The final overall (crest to crest) slope of the WRSF will be 3H:1V. The facilities will be covered with a cover 0.5 m in depth, consisting of low-permeability borrow material in the bottom portion to minimize infiltration of meteoric water. The top portion of the cover shall consist of growth medium that will be seeded to promote vegetative growth.

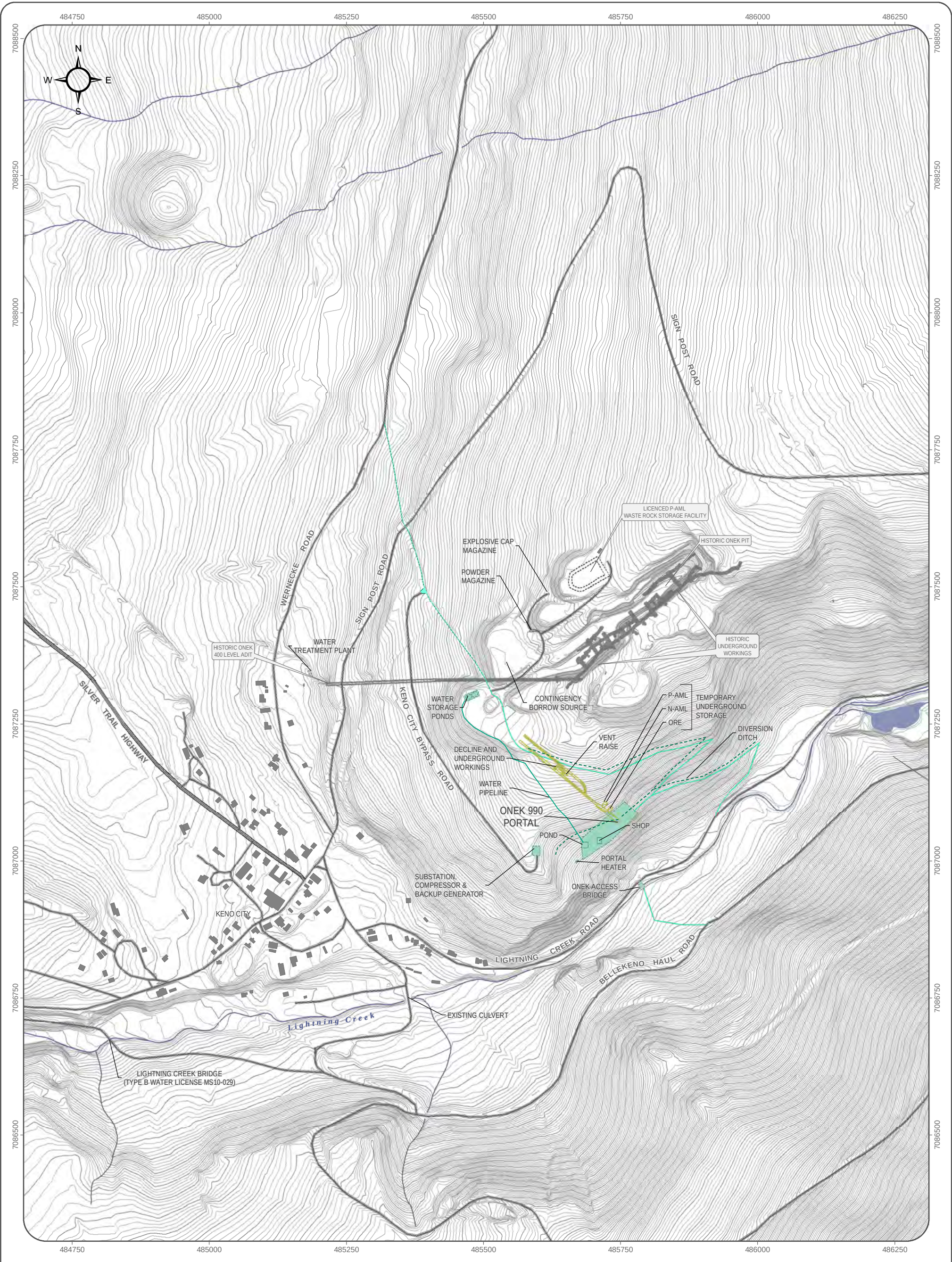
7.2.1.2 N-AML Waste Rock Disposal Area

N-AML will be used for general construction and access road repairs and surface capping, or placed into onsite N-AML WRDAs (Figure 7-8). N-AML material may also be placed underground as mine backfill as required.

The Onek N-AML WRDA will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRDA. The final overall (crest to crest) slope of the WRDA will be 3H:1V.

7.2.1.3 Onek Historic Waste Rock Dumps

Terrestrial reclamation of historic liabilities at Onek is currently under the scope of the District Closure Plan. At present, District Closure planning proposes pulling back crests, resloping dump slopes, and scarifying and revegetating the top surface to cover stained rock. The preliminary Onek historic waste rock dump recontouring design will be developed through final determination of the Production Unit Area and the mine licencing process.



Datum: NAD 83; Projection: UTM Zone 8N

1:6,500 When printed on 11 by 17 Inch paper

0

100

200

Meters

Existing Features

Proposed Feature

Proposed Underground Footprint

Building/Structure

Diversion Ditch

Proposed Bypass Road

Proposed Road

Highway

Secondary

Contour (5 m interval)

Contour (1 m interval)

ALEXCO KENO HILL MINING CORP.
PROPOSED DEVELOPMENT PLAN

FIGURE 7-8

ONEK DEPOSIT - 990 OPTION
PROJECT LAYOUT

Site hydrography and contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.

SEPTEMBER 2012

I:\Keno_Area_Mines\ONEK\Mapa1_Overview_Maps\Project_Overview\ONEK_990_ProjectLayout_20120907.mxd
(Last edited by: joan.9/7/2012 10:07 AM)

7.2.2 Onek Surface Infrastructure

Closure Objectives: *The objectives for closure of Onek surface infrastructure are to:*
(1) remove potential sources of environmental contamination;
(2) minimize erosion;
(3) minimize safety risks to people and wildlife, and
(4) reclaim the site to an aesthetically acceptable level.

At closure, underground equipment will be removed from the mine workings through the 990 Portal. The portal opening will be blocked by inserting rock fill to limit access by humans and wildlife (Figure 7-6).

Reclamation of the 990 Portal will include removal of the shop and other buildings. Fuel tanks will be cleaned and removed along with liners for reuse or landfilling. Any additional debris will also be removed for reuse or proper disposal. All solid waste will be disposed of in accordance with the *Yukon Environment Act* Solid Waste Regulations. Alexco has a permitted commercial solid waste facility located in Elsa. All waste petroleum products and any other special waste will be disposed of in accordance with the Special Waste Regulations. Any soils contamination will be documented through a final site contamination assessment. Contaminated soil will be removed and/or remediated in an approved manner. A land treatment facility has been constructed near the Elsa Valley Tailings Facility for remediation of such soils for district closure, and can be used for remediation of any hydrocarbon contamination at the 990 Portal. The portal site will be recontoured and scarified to facilitate revegetation and establish drainage. Signage will be installed to indicate the portal presence.

Surface water diversion infrastructure (berms, ditches) will be maintained as appropriate to manage surface runoff from entering the decline and limit erosion on site. Water storage ponds will be filled in and contoured to match surrounding environmental features. Compacted areas will be scarified to promote natural revegetation or selected areas will be reseeded with native vegetation.

The new Onek vent raise will be capped with an engineered concrete cap. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-7.

7.3 LUCKY QUEEN PRODUCTION UNIT AREA

Closure Objectives: *The objectives for closing the Lucky Queen Production Unit Area are to:*
(1) ensure physical and geochemical stability of the site;
(2) minimize safety risks to people and wildlife; and
(3) reclaim the site to an aesthetically acceptable level.

The Lucky Queen Production Unit Area will consist of the underground workings (rehabilitated historic 500 level adit and new workings), surface facilities and features at the Lucky Queen Portal Pad (portal, surface buildings and infrastructure), a new P-AML WRSF, a new N-AML WRDA, and the vent raise (Figure 7-9). The historic waste rock dumps associated with the new P-AML WRSF and N-

AML WRDA are historic liabilities; however, they are included in the RCP because they are a component of the Lucky Queen Production Unit Area.

7.3.1 Lucky Queen Waste Rock Storage/Disposal Areas

Closure Objectives: The objectives for closure of the Lucky Queen waste rock storage facilities/disposal areas are to:

- (1) ensure geotechnical and geochemical stability of the site;*
- (2) minimize erosion;*
- (3) minimize safety risks to people and wildlife; and*
- (4) reclaim them to an aesthetically acceptable level.*

Waste rock extracted from the deposits is characterized and managed according to the Waste Rock Management Plan. Waste rock is identified as being one of the following types: potentially acid metal leaching (P-AML) or non acid metal leaching (N-AML).

7.3.1.1 P-AML Waste Rock Storage Facilities

A new P-AML WRSF will be constructed at the Lucky Queen site as per EBA's generic facility designⁱⁱⁱ. P-AML waste rock will be placed in the WRSF or underground as mine backfill, as required.

At closure, the WRSF will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRSF. The final overall (crest to crest) slope of the WRSF will be 3H:1V. The WRSF will be covered with a total 0.5 m depth cover consisting of low-permeability borrow material in the bottom portion to minimize infiltration of meteoric water. The top portion of the cover shall consist of growth medium that will be seeded to promote vegetative growth.

7.3.1.2 N-AML Waste Rock Disposal Area

N-AML will be used for general construction and access road repairs and surface capping, or placed into the onsite N-AML WRDA (Figure 7-9). N-AML material may also be placed underground as mine backfill, as required.

The Lucky Queen N-AML WRDA will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the WRDA. The final overall (crest to crest) slope of the WRDA will be 3H:1V.

7.3.1.3 Lucky Queen Historic Waste Rock Dumps

Terrestrial reclamation of historic liabilities at Lucky Queen is currently under the scope of the District Closure Plan. At present, District Closure planning proposes pulling back crests, resloping dump slopes, and scarifying and revegetating the top surface. The preliminary Lucky Queen historic waste rock dump recontouring design will be developed through final determination of the Production Unit Area and the mine licencing process.

7.3.2 Lucky Queen Surface Infrastructure

Closure Objectives: *The objectives for closure of Lucky Queen surface infrastructure are to:*
(1) remove potential sources of environmental contamination;
(2) minimize erosion;
(3) minimize safety risks to people and wildlife, and
(4) reclaim the site to an aesthetically acceptable level.

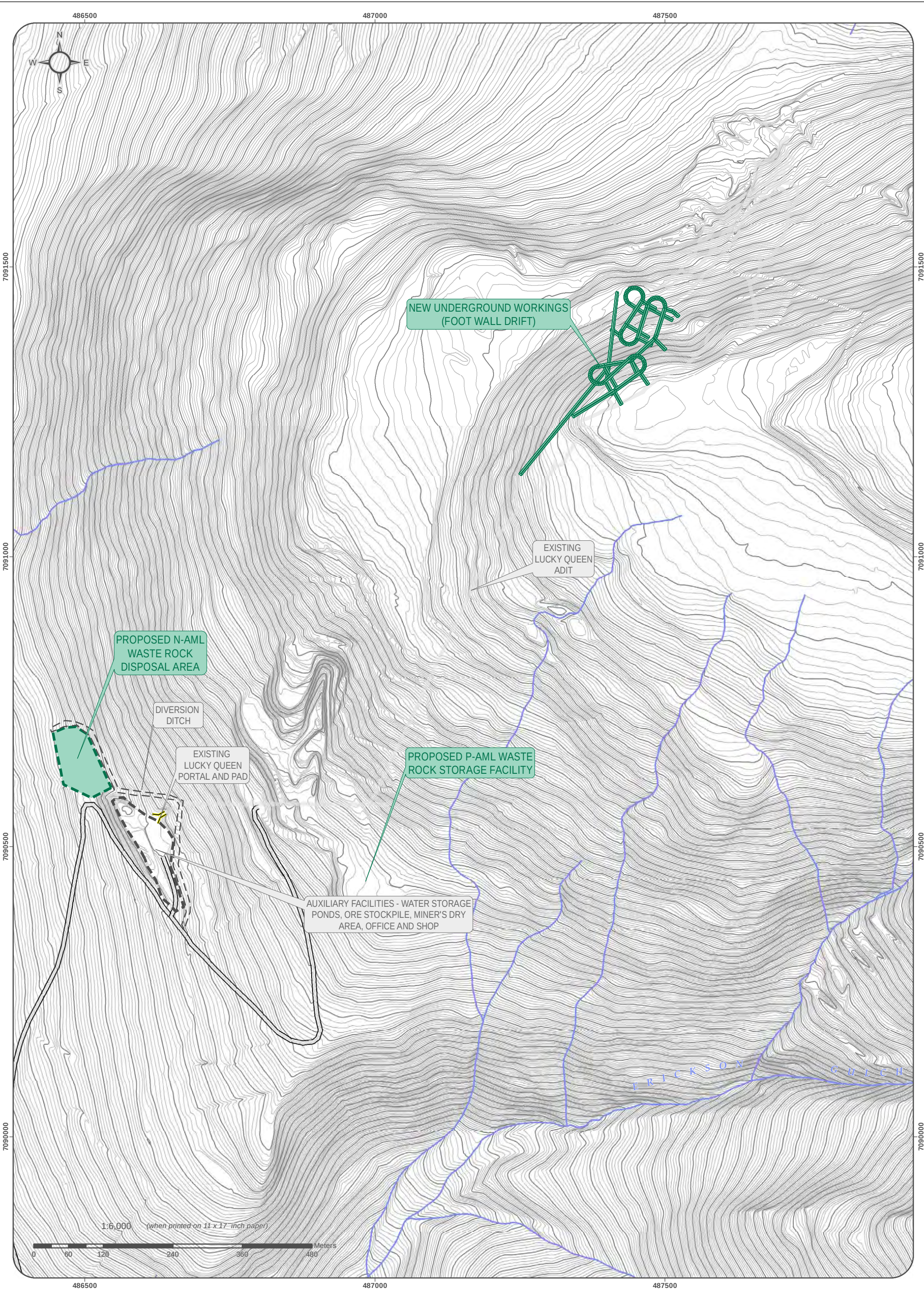
At closure, underground equipment will be removed from the mine workings through the Lucky Queen 500 level adit. The portal will be blocked by inserting rock fill to limit access by humans and wildlife (Figure 7-6).

Reclamation of the Lucky Queen Portal Pad will include removal of the shop and other buildings. Fuel tanks will be cleaned and removed along with liners for reuse or landfilling. Any additional debris will also be removed for reuse or proper disposal. All solid waste will be disposed of in accordance with the Yukon Environment Act Solid Waste Regulations. Alexco has a permitted commercial solid waste facility located in Elsa. All waste petroleum products and any other special waste will be disposed of in accordance with the Special Waste Regulations. Any soils contamination will be documented through a final site contamination assessment. Contaminated soil will be removed and/or remediated in an approved manner. A land treatment facility has been constructed near the Elsa Valley Tailings Facility for remediation of such soils for district closure, and can be used for remediation of any hydrocarbon contamination at the Lucky Queen site. The portal pad will be recontoured and scarified to facilitate revegetation and establish drainage. Signage will be installed to indicate the portal presence.

Surface water diversion infrastructure (berms, ditches) will be maintained as appropriate to manage runoff and limit erosion. Water storage ponds will be filled in and contoured to match surrounding environmental features.

Compacted areas will be scarified to promote natural revegetation or selected areas will be reseeded with native vegetation.

The new Lucky Queen vent raise will be capped with an engineered concrete cap. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-7.



Proposed Underground Workings

Existing Underground Workings

Contour (5 m intervals)

Contour (1 m interval)

EXISTING

Existing Features

PROPOSED

Proposed Features

Site hydrography and contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.

Datum: NAD 83; Projection: UTM Zone 8N

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AKHM

ACCESS

KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-9

LUCKY QUEEN SITE LAYOUT

AUGUST 2012

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7.4 LINEAR DISTURBANCES

Closure Objectives: The closure objectives for linear disturbances, including roads and transmission lines, are to:

- (1) achieve long term physical stability of the disturbed areas; and*
- (2) reclaim the areas such that it is aesthetically acceptable.*

7.4.1 Roads

All roads either newly developed or reconstructed/upgraded from existing roads will be subject to standard road decommissioning and reclamation measures at closure. Site roads include (Figure 7-10):

- haul road between BK East Portal and BK 625 Adit;
- Bellekeno Haul Road;
- Lightning Creek Bypass Road including the bridge at Lightning Creek;
- Christal Lake Road (from Silver Trail Highway to the mill); and
- Keno City Bypass Road.

Standard road decommissioning and reclamation measures at closure include: culvert removal, re-sloping banks and removal of the safety berm to reflect the natural topography as well as provide stability, and surface scarification to encourage natural revegetation (Figure 7-10). Re-grading/contouring the roads will ensure that runoff sheds off the road surface. Localized seeding with native vegetation will take place where erosion control is necessary. Compacted areas will be scarified to promote revegetation. Plate 7-4 illustrates a typical section of the haul road between the mine and mill, and shows the bridge crossing at Lightning Creek.

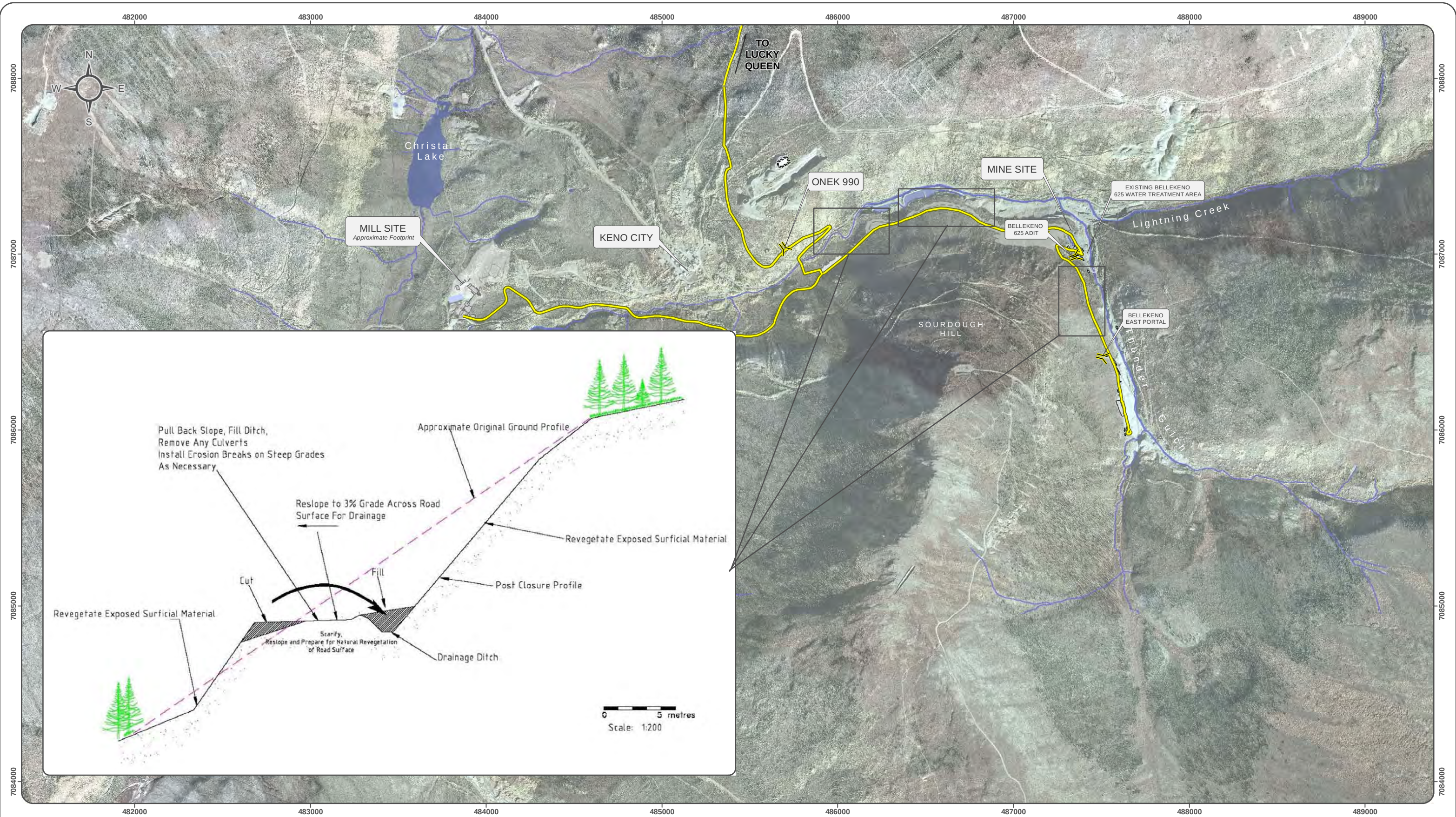
Alexco will consult EMR Client Services & Inspections and Highways & Public Works, Transportation Branch, to determine appropriate methods for limiting access to the sites.

7.4.2 Transmission Lines

Transmission lines constructed or to be constructed include the Bellekeno, Onek and Lucky Queen transmission lines. All transmission lines constructed will be subject to standard decommissioning and reclamation measures at closure, including removing power poles and lines, and undertaking measures to promote natural revegetation. Any compacted areas will be scarified.



Plate 7-4: Lightning Creek Bridge and Typical Haul Road Section



Aerial photograph obtained from Geodesy Remote Sensing Inc., Calgary Alberta. Imagery acquired September 13 and 14 2006. Site hydrography and contours provided by Aero Geometrics LTD, derived from aerial photograph.

Datum: NAD 83; Map Projection: UTM Zone 8N

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Y Adit
Bellekeno Haul Road



KENO HILL SILVER DISTRICT MINING OPERATIONS
PRELIMINARY RECLAMATION AND CLOSURE PLAN

FIGURE 7 - 10
BELLEKENO, ONEK AND LUCKY QUEEN
PRODUCTION UNIT AREA ROADS SUBJECT TO STANDARD
DECOMMISSIONING AND RECLAMATION

AUGUST 2012

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7.5 FLAT CREEK CAMP

Closure Objectives: To partially decommission/ downsize the Flat Creek camp facilities to accommodate on-going District closure, care & maintenance, and exploration activities at the KHSD.

Employees and contractors directly related to Bellekeno, Onek and Lucky Queen deposits production operations are housed in the Flat Creek camp as well as in 4 staff houses that are located in Elsa. Additional personnel and camp accommodation requirements are on-going beyond Bellekeno, Onek and Lucky Queen deposits production operations including exploration, care and maintenance and district closure planning and implementation. Given these ongoing activities, removal and closure of the entire camp facility is not envisioned as part of the Bellekeno, Onek and Lucky Queen deposits production closure plan and requirement.

Closure measures include dismantling and removal of the excess trailer units to Lot 960. The expanded septic system, along with the increased freshwater supply will remain in place for continued use by the downsized camp.

7.6 MILL AREA AND ANCILLARY FACILITIES

Closure Objectives: The objectives for decommissioning and closure of the mill and ancillary facilities are to:

- (1) remove potential sources of environmental contamination;*
- (2) minimize erosion;*
- (3) minimize safety risks to people and wildlife, and*
- (4) reclaim the site to an aesthetically acceptable level.*

The District Mill is located at the Flame and Moth mill site. An as-built layout of the mill facilities is shown in Figure 7-11. The Keno District Mill is a conventional differential flotation facility producing two separate metal concentrates that are shipped offsite for final processing.

The following mill infrastructure and facilities comprise the main facilities constructed over the 2010/2011 mill construction and commissioning period and comprise the facilities that require removal under the closure plan (Plate 7-5):

- Mill building
- Mill office and dry
- Electrical substation
- Mill process pond
- Crusher plant
- Crusher MCC
- Fine ore stockpile
- Mill feed conveyor
- Mill MCC



- Assay lab
- Process water tank
- Diesel storage tank
- Propane tank
- DSTF
- Lightning Creek bridge

7.6.1 Mill Buildings and Infrastructure

The buildings at the Keno District Mill site can be broken into three categories for dismantling and salvage purposes:

- modular, prefabricated trailer style buildings, such as the offices and dry;
- rigid, steel frame construction buildings with steel wall sheeting, such as the mill building;
- non-rigid prefabricated steel frame "fold-away" or containerized buildings;

The modular prefabricated trailer style buildings will, wherever economically feasible, be removed from the site and sold for their salvage value. Generally disassembly involves removing the underlying wood skirting, water, electrical and septic piping and cabling and then breaking the units into their respective prefabricated units. The individual units are then placed on axle dollies and removed from the site to be reused elsewhere following refurbishing. The remaining service piping, cabling and skirting lumber is removed and disposed of as either scrap or as salvageable material. The gravel pad beneath the trailer units will be scarified with a grader to enhance the re-establishment of natural vegetation.

In the event that it is found at the time of decommissioning that any such unit(s) cannot be removed or sold for their salvage value, then the unit(s) will be inspected for hazardous materials, the hazardous materials removed and units demolished on site. The materials with salvage value will be removed and sold for their respective value. Non-hazardous materials that have no salvage value will be disposed of in an approved landfill site on the mine site. Combustible wastes such as lumber-based building materials will be burned and the residue buried in the landfill site.



Aerial photography flight date: July 13th 2006. Ortho-rectification produced by Challenger Geomatics Ltd. Data obtained from EBA: "As built" spatial data: Mill pond (Y.E.S.), Mill structure, and current DSTF footprints, Roads (In House survey December 11th 2011). Design spatial data: Conveyance and water collection, diversion ditches and berm.

Datum: NAD 83; Projection: UTM Zone 8N

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Main Map: 1:2,500 Inset Map: 1:50,000
(when printed on 11 x17 inch paper)

0 50 100 150 200 Meters



KENO DISTRICT MINING OPERATIONS RECLAMATION
AND CLOSURE PLAN

FIGURE 7-11
MILL SITE LAYOUT

AUGUST 2012

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The rigid steel frame buildings will be dismantled on site with the support steel being sold for salvage value wherever economically feasible. Prior to disassembly, the buildings will be stripped of all non-attached equipment and materials such as shelving units, office furniture, equipment, etc. Wherever feasible, materials with salvage value will be sold for its value. Non-hazardous materials that have no salvage value will be disposed of in the approved on-site landfill area. As indicated earlier, all buildings will be inspected for hazardous materials, such as hydrocarbons, reagents, etc. Any such material will be removed and disposed of in a manner approved by regulatory authorities for the Yukon Territory. Generally disassembly of these buildings involves removing all of the steel sheet roof and wall panels and internal insulation. The steel support structure is then disassembled and where feasible sold for its salvage value either as an intact building or as high quality steel scrap. Internal steel structures would then be removed and treated in a similar fashion.

Above grade concrete footings, foundations concrete floor slabs and below grade concrete foundations will be covered by a minimum thickness of 1 m of overburden and scarified. These covered slabs will be seeded with an appropriate vegetation mix to establish vegetative growth over these areas. The specific details of each of the mill area buildings are further described in the following sections and closure measures identified.



Plate 7-5: Aerial View of Mill Site Infrastructure and Layout

7.6.2 Mill Building

The mill building is a pre-engineered steel building containing all of the processing equipment used for the milling, flotation and recovery of Ag, Pb and Zn from the Bellekeno mine underground ore. The mill building is 22.5 meters 54 meters in dimension (Plate 7-6).

Closure measures for the mill building include salvage and removal of the process equipment, dismantling of the engineered building, breaking the concrete slab to allow percolation of water and covering of the footprint with growth media.



Plate 7-6: Mill Building

7.6.3 Mill Office and Dry

The mill office and dry facility is comprised of two skid mounted trailer units and one skid mounted wash car with a wooden truss constructed over the top of the 3 units. The two office units are 3.05 x 8.3 meters in dimension and the dry/shower facility is 3.35 x 11.58 meters (Plate 7-7).

Closure measures for the mill office include dismantling the roof truss structure and removing the building from site. Since the office is a portable structure there is no demolition required.



Plate 7-7: Mill Office and Dry

7.6.4 Electrical Substation

An electrical substation is located adjacent to the mill office/dry facility and houses a primary 69 KV – 600 V step down transformer and electrical distribution infrastructure. The substation is enclosed by a 28 m x 15.5 m fence (Plate 7-8). The step down transformer will be removed and salvaged and the remaining equipment will be removed and either salvaged or buried. The same decommissioning measures will be applied to the Onek substation.



Plate 7-8: Electrical Substation

7.6.5 Mill Process Pond

The mill process pond is located downgradient from the mill building and contains and manages the process water balance required for the milling operation (Plate 7-9). Thickener overflow water from inside the mill building gravity flows via a 6" yellow pipe into the mill process pond. Process makeup water is pumped from the pond to the process water tank for makeup and recycle in the milling process. The mill process pond is 32 x 79 meters in dimension with a total design capacity of 3,500 m³.

Since the mill process pond was not constructed with an engineered fill embankment there is no long term stability concern that needs to be addressed at closure. Closure of the pond consists of removing and burying the HDPE liner, scarification of the side slopes and revegetation. The pond will serve as a sedimentation pond during closure for capture of surface water if necessary until revegetation is stabilized. Although not a component of the closure for the mill area, the pond could also serve as a bioreactor facility if the DSTF produces seepage requiring treatment.



Plate 7-9: Mill Process Pond

7.6.6 Crushing Plant

Coarse ore from the Bellekeno, Onek and Lucky Queen underground mines is transported to a crushing plant (Plate 7-10) where the coarse ore is crushed and reduced in size to nominally 3/8". The crushing plant is a portable two-stage closed circuit plant containing a jaw crusher, single deck screen and cone crusher. The crushers, screen deck and conveyors are all portable tire mounted units that can be easily removed from site. Once the material is crushed it is transported to the adjacent fine ore stockpile via a radial stacker conveyor.

Since the crushing plant is a portable unit on wheels, closure consists of transporting the crusher offsite for salvage value. The crusher retaining wall is constructed of 6 stacked sea- containers that likewise can be removed and salvaged.



Plate 7-10: Crushing Plant

7.6.7 Fine Ore Stockpile

Fine ore produced from the crushing plant is stored on a fine ore stockpile covered by a fabric membrane structure to isolate the ore from snow, rain and windy conditions (Plate 7-11). The fabric membrane structure is 11.35 meters tall, 18.3 x 24.5 meters in dimension and is supported by an aluminium support structure sitting on 4 (ea) 40' steel containers that provide containment of the fine ore as well as storage units for the crushing plant and mill spare parts inventory.

Closure of the stockpile includes excavation and milling of any residual fine ore remaining on surface, removal and salvage of the sprung structure and sea-containers. The buried tunnel will be removed and salvaged for steel scrap value.



Plate 7-11: Fine Ore Stockpile

7.6.8 Crusher MCC

A Motor Control Centre (MCC) for the crusher (Plate 7-12) is located adjacent to the crushing plant and provides electrical distribution for the various motors located in the crushing plant. The main electrical substation distributes 600 V electrical power directly to the crusher MCC and then individual motor starters within the MCC distribute power to the motors. The crusher MCC is a portable skid mounted steel insulated building with dimensions of 2.4 x 6.1 meters.

Closure measures for the crusher MCC consist of transporting the unit offsite for salvage value.



Plate 7-12: Crusher MCC

7.6.9 Assay Lab

The assay lab is located immediately adjacent to the mill building and consists of 3 skid mounted trailer units separated by a wooden deck and winter roof truss (Plate 7-13). The sample prep trailer is a skid mounted trailer used for preparation of mill and underground samples. The trailer is 13.47 x 3.05 meters in dimension.

The assay lab trailers consist of 2 separate skid mounted units that are joined together with assay capability for AA digestion and fire assay. The two assay trailers are 2.4 x 6.1 meters in dimension.

Closure measures for the assay lab consist of transporting the units offsite for salvage.



Plate 7-13: Assay Lab

7.6.10 Mill Motor Control Centre

A Motor Control Centre (MCC) for the mill building (Plate 7-14) is located immediately adjacent to the mill and contains the motor control starters and distribution for the mill equipment. The main electrical substation distributes 600 V electrical power to the mill MCC. The mill MCC is a skid mounted unit mounted on a steel support structure and has a dimension of 15.24 x 3.04 meters.

Closure measures for the mill MCC consist of transporting the unit offsite for salvage.

7.6.11 Fresh Water Tank

A steel fresh water tank is located next to the mill building and sits on a compacted gravel pad. Fresh water is delivered to the fresh water tank via a water truck and the fresh water is used in eye wash stations located throughout the mill building, for reagent mixing and for pump gland water. The fresh water tank has a capacity of 50.26 m³ and is 4 meters tall and 4 meters in diameter.

Closure of the fresh water tank consists of dismantling and cutting up for salvage value.



Plate 7-14: Mill MCC

7.6.12 Diesel Storage Tanks

Two skid mounted double walled diesel storage tanks are located adjacent to the concentrate loadout area and are used for general fuelling of mobile equipment and vehicles. The tanks each have a storage capacity of 3.78 m³.

The diesel storage tanks are supplied by the diesel supply vendor and closure consists of returning the tanks to the supplier.

7.6.13 Propane Tank

A tire mounted portable propane storage tank sits near the mill building with a capacity of 45,425 litres of propane. Propane is used at the mill for heating the mill building during winter conditions.

The propane tank is supplied by the vendor and closure consists of returning the tanks to the supplier.

7.6.14 Mill Wastes

Extra reagents or chemicals will be loaded up and returned to the supplier where possible. Concrete footings will be demolished and buried in situ. Any additional debris will also be removed for reuse or proper disposal. All solid waste will be disposed of in accordance with the *Solid Waste Regulations*. All waste petroleum products and any other special waste, as defined in the *Special Waste Regulations* will be disposed of in accordance with the Regulations. Any soils contamination will be documented through a final site contamination assessment. Contaminated soil would be removed and/or remediated in an approved manner (i.e. land treatment facility in Mayo or Elsa if one is developed there or buried and covered). The pad area will have its embankment shoulders re-graded

to prevent water ponding, and the surface will be scarified and reseeded to promote vegetative cover.

It is expected that at closure the material beneath the ore stockpiles will be processed through the mill to remove any remaining economic values as well as eliminating any potential contaminant of concern from the material. The impermeable rehandling pads will be demolished and buried once cleaned of all metal contaminants.

7.6.15 Buried Infrastructure

All buried piping and electrical cabling will be de-energized, drained and truncated where they break surface with the buried portions left remaining in the ground. The ends of all buried piping and cable runs will be cut off at 1 m below grade with the resulting excavations backfilled. Prior to abandonment all possible piping will be drained and washed to remove its contents.

The location of all known buried piping and cabling to be left in the ground will be marked on a site plan to be submitted to regulatory authorities for future reference.

Where appropriate, surface piping will be decontaminated by flushing the respective section of pipe with water and then removing the pipe for disposal. Large diameter piping will be sold for salvage where feasible. Piping with no salvage value will be disposed of in the site landfill area.

All above ground electrical cabling will be de-energized and removed. In most cases the cable will be recovered for its salvage value. Cable with no salvage value will be disposed of in the site landfill area.

7.7 DRY STACK TAILINGS FACILITY

Closure Objectives: *The objectives for the DSTF are to:*

- (1) ensure physical and geochemical stability of the DSTF;*
- (2) minimize erosion;*
- (3) effectively manage run off;*
- (4) reduce water infiltration into the DSTF;*
- (5) minimize safety risks to people and wildlife; and*
- (6) reclaim the site to an aesthetically acceptable level.*

The dry stack tailings facility (DSTF) is located adjacent to the mill site and the most recent as-built of the facility is shown in Figure 7-12. Water Licence QZ09-092 authorizes 322,000 tonnes of tailings can be placed on surface. As of June 2012, approximately 95,000 tonnes of tailings have been placed on the DSTF representing approximately 30% of the overall permitted capacity. The placement of tailings on surface is currently being conducted under an approved Phase 1 design and DSTF Operations and Monitoring Plan. Additional detailed designs will be required to ultimately expand the DSTF to the currently authorized 322,000 tonne volume. The DSTF will be progressively constructed and reclaimed over the life of the facility as tailings are generated by the mill. A portion of the DSTF will be built on an on-going basis each year. In the summer of each year or as the

progression of the facility allows, progressive reclamation will occur through recontouring the side slopes to the final design slope angle (3:1) and placing granular/organic material as a cover.

7.7.1 DSTF Geochemical Performance

Geochemical characterization of the tailings is being conducted as part of the Bellekeno Mine Tailings Characterization Plan which was submitted in December 2010 as a requirement under Water Licence QZ09-092. A humidity cell test is in operations for a composite sample of Bellekeno tailings produced and stored on the DSTF. The results of the kinetic testing for tailings are presented in Appendix 5. The results of this program are also included in the Annual Reporting submitted for QZ09-092. Static geochemical characterization of the Onek and Lucky Queen tailings have been previously presented as part of the environmental assessment and water licence permitting stage for deposition of tailings from these deposits into the DSTF.

7.7.2 DSTF Soil Cover

Closure measures for the DSTF are included in the final design report for the facility. Although the DSTF will be built in compacted 0.3 – 0.6 m lifts to limit water penetration, closure measures will include covering the recontoured stack with an approximately 0.25 - 0.5m thick evapotranspiration cover consisting of growth media and granular material that is locally stored in stockpiles. The cover will limit water migration through the stack. The first phase of reclamation has been completed on the western slope of the DSTF and includes recontouring to a 3:1 slope, placement of a 0.25 meter cover and seeding/fertilization. Plate 7-15 shows the reclamation underway on the DSTF during June 2012. A similar evapotranspiration cover has been constructed at the company's Brewery Creek Mine both on the heap leach pad (0.25 m cover) and a waste rock storage dump (0.5 m cover). The actual performance results of the Brewery Creek covers indicate precipitation infiltration rates between 7% – 22% with the variation related to differences in cover thickness and topography. Given the performance of the Brewery Creek covers over a 7 year period, the similarities in soil properties and climate conditions and the highly compacted nature of the DSTF, the reclamation measures proposed for the DSTF are expected to result in <10% infiltration through the DSTF. The climate conditions at Brewery Creek are very similar to the Keno Hill Silver District and the actual performance results of the Brewery Creek cover are a supporting reference to the expected performance results on the DSTF.



Plate 7-15: DSTF Interim Reclamation, June 2012

Alexco has proposed a reclamation and revegetation program that meets the EMR technical guidelines for erosion control and revegetation. The Yukon Mine Site and Reclamation Closure Policy includes establishment of stable slopes that prevent surface erosion and are conducive to successful re-vegetation by native plant species or other species adaptable to that environment (EMR, 2008).

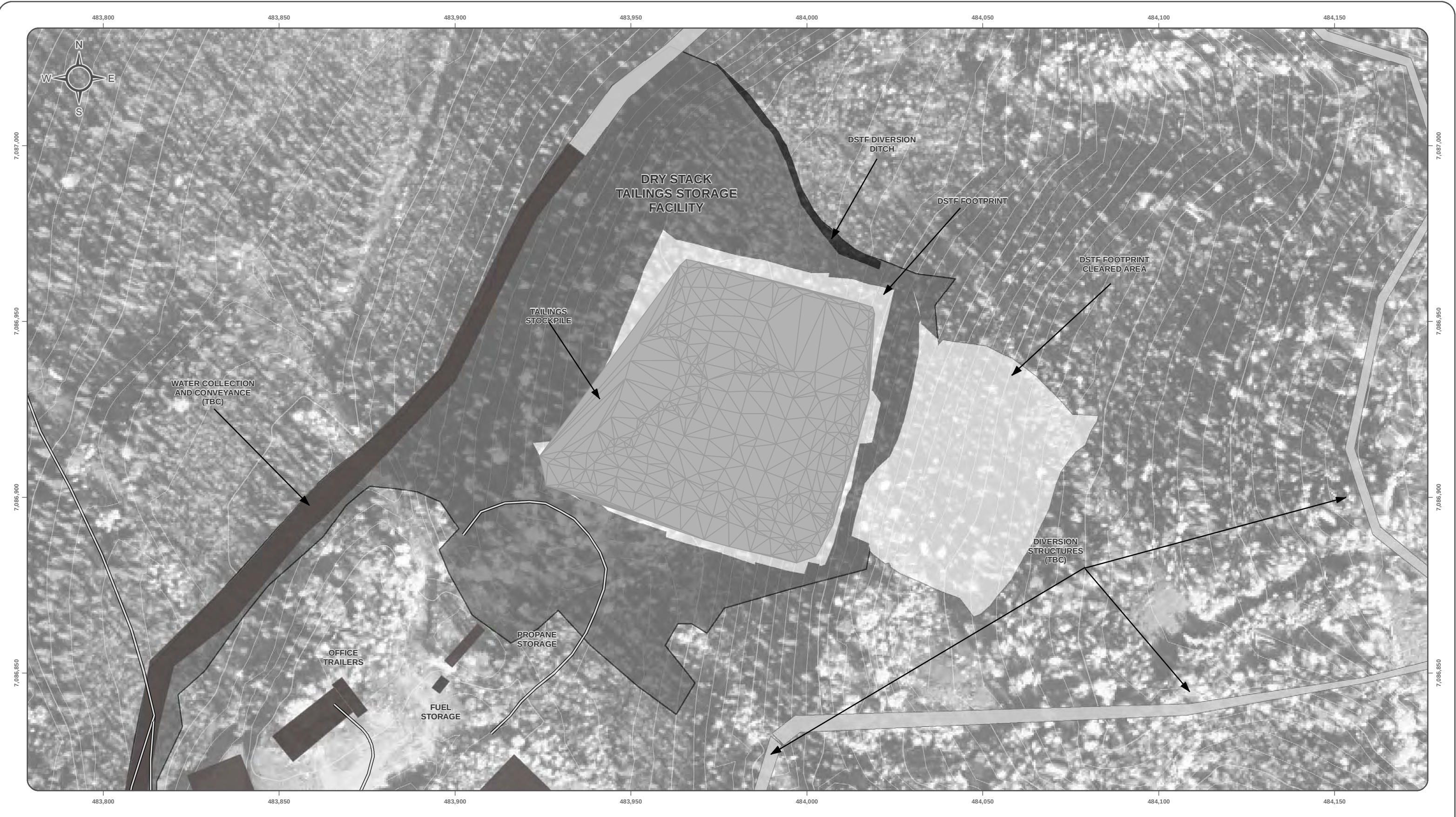
The soil cover design for the DSTF will include a hydrologic evaluation of the soil properties of both the tailings and the materials intended for use as cover so as to assess the hydraulic conductivity and indicate the level of expected infiltration to these facilities.

Currently, a program is in place to test the amount of pore water contained in the DSTF materials in an effort to determine the existing moisture content of the dry stack. This study will provide valuable information on both the amount of pore water contained within DSTF material, and to what degree there might be infiltration of additional meteoric waters to the stack.

To maximize the efficacy of the cover, an engineering evaluation of the proposed 0.25 m cover will be carried out using information collected at the site as a part of the environmental monitoring programs designed by Alexco and prescribed in Water Licence QZ09-092. This includes hydrologic information available for the site, as well as precipitation and snowpack data, together with laboratory soil properties and in-situ measurements of the hydraulic conductivity for the DSTF and identified cover material.

A conceptual evapotranspiration cover design is shown in Figure 7-13 and is based on the cover design constructed at Brewery Creek.

If monitoring during operations indicates that treatment will be required for meteoric water after final closure, a passive bioreactor treatment system will be constructed at the site immediately down slope from the DSTF. The area at the toe of the DSTF occupied by the runoff collection pond and polishing pond during operations can be reconstructed and used for the development of a gravel infiltration gallery, ethanol-based bioreactor cell (similar to the one currently in use at Galkeno 900 adit across Christal Lake and proposed for the Bellekeno, Lucky Queen and Onek mines if required).



Aerial photography flight date: July 13th 2006. Ortho-rectification produced by Challenger Geomatics Ltd. Data obtained from EBA: "As built" spatial data: Mill pond (Y.E.S.), Mill structure, and current DSTF footprints, Roads (In House survey December 11th 2011). Design spatial data: Conveyance and water collection, diversion ditches and berm.

Datum: NAD 83; Projection: UTM Zone 8N

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Main Map: 1:1,000 Inset Map: 1:50,000
(when printed on 11 x17 inch paper)

0 10 20 30 40 50 Meters

- As Built, Dry Stack Tailings Facility Footprint (phase 1)
- As Built, Dry Stack Tailings Facility Footprint Cleared area (phase 3)
- As Built, DSTF
- As Built, DSTF Diversion Ditch
- Design, DSTF Diversion Berm
- Tailings Stockpile Oct 2011



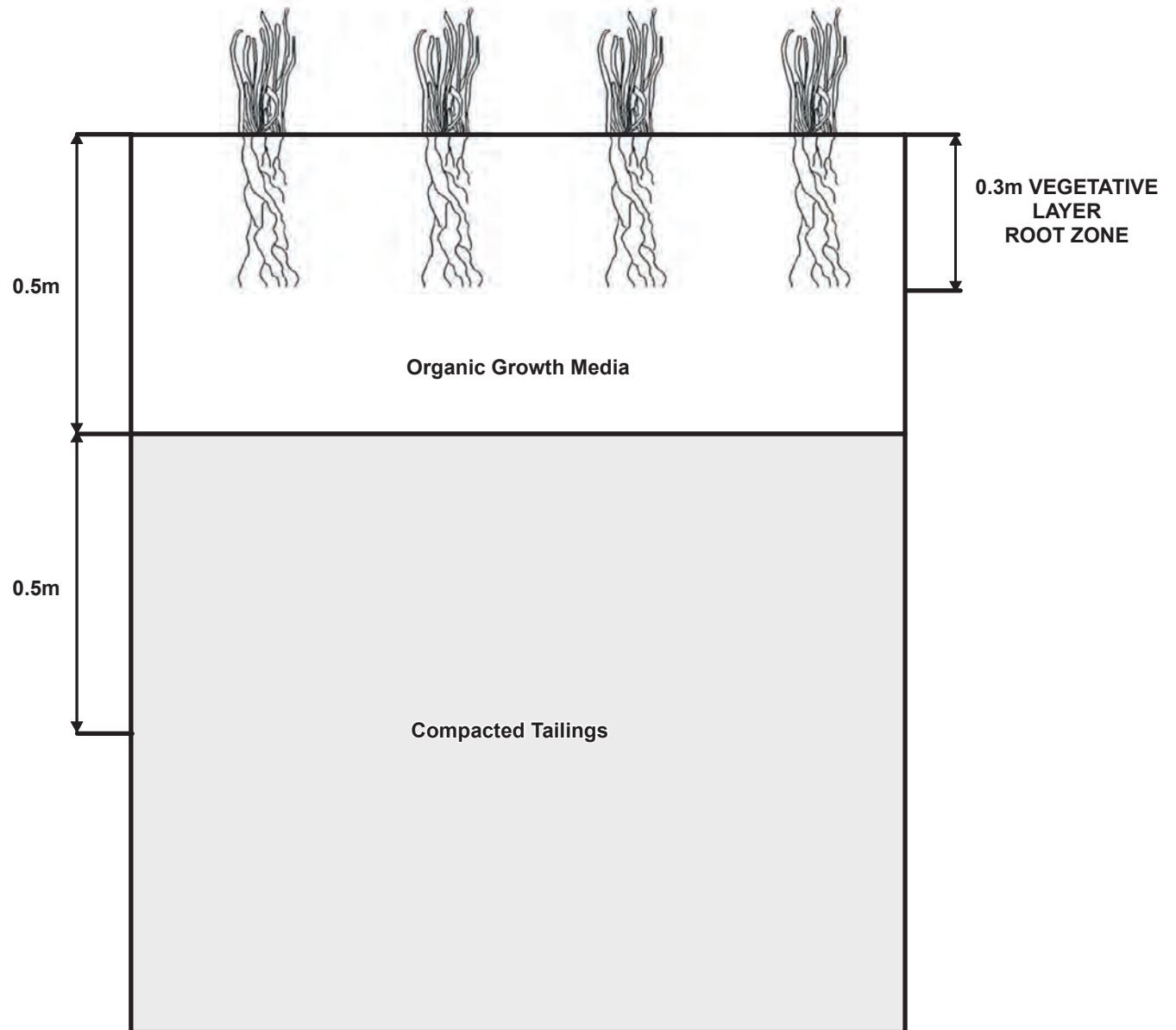
KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-12
DRY STACK TAILINGS FACILITY LAYOUT

AUGUST 2012

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SOIL COVER DESIGN



8 FINAL CLOSURE CRITERIA

Reclamation completion criteria will be used to assess the final reclamation obligations for the Keno District Mine Operations closure. These criteria will establish benchmarks to be used in determining when decommissioning, reclamation and monitoring programs have been completed and passive management has been implemented. The three stages of reclamation used to reach closure criteria are:

1. Decommissioning – removal of structures and creation of safe geotechnical structures, removal of contaminants, implementation of water management/treatment facilities and recountouring/revegetation.
2. Rehabilitation - the return of the disturbed site to a form and productivity level that is consistent with the closure objectives. Water management/treatment facilities are in place and operational, revegetation is complete and post closure maintenance and monitoring is underway.
3. Completion Criteria Conformance - monitoring and demonstration of establishment of sustainable reclamation features.

8.1 SITE CONDITIONS FOR COMPLETION CRITERIA

Completion criteria presented for the Keno District Mine Operations ensure that the closure measures meet overall objectives of mine site reclamation. The objectives of the completion criteria can be considered under the following three site conditions: physical stability, chemical stability, and biological stability.

8.1.1 Physical Stability

Physical stability is ensured by protecting the surface against wind and water erosion, providing for surface drainage, minimizing hazardous conditions, and contouring the surface to meet land capability objectives. Physical structures such as underground openings, sedimentation and treatment ponds, spillways, surface openings and waste rock storage areas will meet the following requirements:

- Be physically stable and designed in accordance with acceptable design criteria;
- Pose minimal hazard to the public and wildlife health and safety as a result of failure or physical deterioration;
- Continue to perform the function for which they were designed; and
- Have stable land surfaces with minimal surface erosion.

8.1.2 Chemical Stability

The reclaimed mine sites within the Keno Hill District will be chemically stable. This means surface waters and groundwater will be protected against significant adverse environmental effects resulting from discharges. In addition, discharges will not endanger public and wildlife health and safety, nor result in unacceptable deterioration of environmental resources.



Aspects to be monitored closely will include short-term and long-term changes in underground mine pool water quality seepage and runoff from the DSTF and waste rock storage areas and the chemistry of surface water draining from the site. Potential effects due to any acid rock drainage via surface or ground water will be mitigated. The success of physical reclamation will influence chemical and physical stability.

8.1.3 Biological Stability

The biological stability of the closed sites and potential effects on the surrounding environment are closely related to methods of reclamation, the end land use, and the physical and chemical characteristics of the site. Biological stability to vegetation and wildlife habitats is reached when these habitats are stable, self-sustaining, and productive, and meet the closure objectives.

8.2 COMPLETION CRITERIA FOR MINE AREA COMPONENTS

Each of the Mine Area Components will reach their completion criteria at varying times in the operations and post-mining period, but all will follow the same three stages of reclamation in systematic order. In addition, adjustments to the reclamation schedule will be expected due to modifications made from new innovations in reclamation practices, seasonal climate variability and/or geotechnical setbacks. Table 8-1 provides a general overview of each Mine Area Component and the site conditions associated with meeting completion criteria.

Table 8-1 Keno Hill Mining Operations Reclamation Units Completion Criteria

Reclamation Units	Completion Criteria Conditions		
	Physical Stability Requirements	Chemical Stability Requirements	Biological Stability Requirements
Underground Mines			
Bellekeno Onek Luck Queen	Salvageable equipment removed. All other equipment cleaned of hydrocarbons. Infilling of underground stopes with P-AML waste rock and tailings material Mine openings stabilized, barricaded and free-flowing with respect to water, where applicable	All chemicals and contaminants remediated or removed	N/A
Waste Rock Storage Facilities			
Bellekeno Benched N-AML WRSF	Stable slopes WRSFs covered where applicable No significant wind or water erosion	No ARD or metal leachate seepage concerns	Safe wildlife access
Water Management Structures			
Treatment Facility Settling Ponds Mill Process Pond	All impediments to normal hydrologic conditions broken down to re-establish hydrologic flow BK 625 ponds converted to geotechnically-stable bioreactors; mill pond liner removed and stable	All chemicals and contaminants remediated or removed	Safe ingress/egress for wildlife
Water Diversion Structures			
DSTF diversion berms	No significant erosion along channel banks and banks of dam structures Permanent, stable channel for Bellekeno 625 ongoing discharge from bioreactor decant pipe to Lightning Creek	All chemicals and contaminants removed	
Sedimentation Pond			
	No exposed sedimentation areas No significant wind erosion	Effluent quality requirements as required by the Water License	
Mill Site			
Mill Building Mill Office and Dry Electrical Substation Crushing Plant Fine Ore Stockpile Crusher MCC Assay Lab Mill Motor Control Centre Fresh Water Tank Diesel Storage Tanks Propane Tank Mill Wastes Buried Infrastructure	All infrastructure disassembled and removed Infrastructure supports and foundations removed or buried and berms broken down	All processing chemicals, contaminants and ore stockpiles removed	Sustainable vegetation cover
Dry Stack Tailings Facility			
	DSTF covered with an evapo-tranpirative cover and vegetation No significant erosion or infiltration Tailings geotechnically stable	Any seepage reporting to Christal Creek watershed will not exhibit an adverse (measureable?) impact	Wildlife access
Bridges and Culverts			
Lightning Creek Bridge Culverts	Stream and cut banks are stable and have no significant erosion Lightning Creek bridge is removed	All chemicals and contaminants remediated or removed	
Flat Creek Camp			
	Camp downsized to pre-production level Areas where camp buildings have been removed stable with no significant wind or water erosion	All chemical spills and contaminants remediated or removed	Sustainable vegetation cover
Linear Disturbances			
Roads Transmission Lines	No significant erosion along road banks and areas where culverts have been removed	All chemical spills and contaminants remediated or removed	Sustainable vegetation cover

9 CLOSURE MANAGEMENT AND MONITORING

The closure phase of the Bellekeno, Onek and Lucky Queen mines will commence with the cessation of economic mining at each respective operation. Closure management and monitoring of the site will be guided by licence requirements, the performance of physical structures remaining on site and the ability to achieve and demonstrate long-term compliance with effluent quality standards. Once overall closure performance has been demonstrated through the completion criteria for all aspects of decommissioning, the necessity of maintaining licences or permits would be examined. At this point, a Certificate of Closure, under the *Quartz Mining Act* would be requested. The following sections provide a general outline of the site management approach that will be taken at the Bellekeno, Onek and Lucky Queen mines during the closure phase.

Implementation of the RCP will be accomplished through Alexco site management and supervision, a combination of contractors and in-house employees and equipment and the integration of care & maintenance personnel on-site to implement decommissioning and reclamation tasks. Generally these tasks entail closure of mine components, salvage and removal of infrastructure, equipment and reagents, maintaining contingency water treatment facilities, decommissioning of roads and reclamation and revegetation of disturbed lands. A Site Contamination Assessment Plan will be prepared leading up to closure which:

- Locates through a site investigation program all contaminated material, if any, on the mine sites arising from any operation, transportation, storage, handling or processing;
- Characterizes the type, concentration, and horizontal and vertical extent of the contamination; and
- Proposes methods for dealing with the contamination.

These activities would be undertaken on a seasonal basis and directed by an on-site manager responsible for implementation of the Keno District Mine Operations RCP.

During site decommissioning, camp accommodations would be available to support site personnel. As other activities are currently scheduled to continue to be undertaken in the District a site caretaker or security personnel will not be required.

9.1 IMPLEMENTATION SCHEDULE

Progressive reclamation will begin during operations to promote slope stabilization and reduce erosion during the life of the mine. Disturbed slopes will be stabilized and revegetated as required. Construction areas not able to be progressively reclaimed due to the onset of winter will be targeted for the following snow-free period.

Progressive reclamation of the DSTF cover will occur for the most part during operations; however the installation of the final closure cover system will be conducted in the next snow-free period following the end of commercial milling unless there is additional milling of ore from other Production Units which may be permitted during the life of the currently active mine operations.

Mine decommissioning and reclamation including removal of equipment and infrastructure will mainly take place during the first year of mine closure. The Bellekeno 625 water treatment facilities

will be transitioned from active to passive treatment. The schedule for implementation of water management and treatment at Bellekeno, Onek 400 and Lucky Queen is shown in Table 7-1, and Table 8-1 shows the project decommissioning and reclamation schedule.

9.2 ADAPTIVE MANAGEMENT STRATEGY

Adaptive management planning is a recognized and effective tool to ensure that changing site conditions are subject to appropriately responsive reclamation actions, and that closure measures can be adapted to changing conditions to achieve desired performance.

In accordance with Clause 90 of Water Use Licence QZ09-092, an Adaptive Management Plan (AMP) was developed specifically for the Bellekeno Mine. This Plan was based on the framework established by the District Wide AMP but was customized for the specific activities and developments of the Bellekeno Undertaking. The District Wide AMP was developed for the entire KHSD under QZ06-074 to address historic liabilities during the development and implementation of the District Closure Plan. An updated Adaptive Management Plan that includes the Bellekeno, Onek and Lucky Queen Production Unit Areas has been prepared and will be refined as necessary.

9.3 CLOSURE MONITORING AND MAINTENANCE

Prior to mine commencement of operations in the Keno Hill Silver District by Alexco, a number of monitoring programs and a surveillance network were already in place for care and maintenance activities and for advanced exploration and preliminary development activities at the KHSD. These programs include physical inspections, effluent treatment systems and flow monitoring, a water quality surveillance network, old mine workings monitoring, aquatic effects monitoring for benthic invertebrate populations, sediment monitoring, waste rock and mine wall sampling and the Adaptive Management Plan.

When mining commenced at Bellekeno, several more monitoring programs came on line to assess the efficacy of the environmental measures implemented for mining and to determine environmental impacts of mining, if any. These programs will be tailored to assess closure measures and continue as necessary with cessation of mining. The scope of the required amendments to the existing monitoring programs would be determined at Closure. The following existing programs will continue in modified form after closure:

Table 9-1 Bellekeno, Onek and Lucky Queen Decommissioning and Reclamation Plan Closure Schedule													
Phase / Activity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	Operations			Closure									
Progressive Reclamation													
Closure and Reclamation Optimization/Research													
Bellekeno Production Unit Area													
- Bellekeno East Underground													
- Reclaim Bellekeno East Portal Site													
- Reclaim Bellekeno 625 Adit Site													
- Bulkhead 625 Installation													
- Bellekeno Mine Flooding and Insitu Pool Treatment													
- Bellekeno 625 Bioreactor and Commissioning													
- 200 Level Vent Raise													
Onek Production Unit Area													
- Onek Underground													
- Reclaim Sign Post Portal Pad Site													
- Reclaim Sign Post Adit Site													
- Vent Raise													
Lucky Queen Production Unit Area													
- Lucky Queen 500 Level Underground													
- Reclaim Lucky Queen 500 Level Portal Site													
- Reclaim Lucky Queen 500 Level Adit Site													
- Vent Raise													
Waste Rock Storage													
- Temporary P-AML WRSF - Bellekeno East													
- Permanent P-AML WRSFs													
- N-AML WRDAs													
- Reclaim Borrow Areas													
Roads													
- Access Road Extension Bellekeno East to Bellekeno 625													
- Bellekeno Haul Road													
- Keno City Bypass													
- Mill Site Access Including Christal Lake Road													
- Northside Bypass Road													
- Other Roads and Trails													
Camp Downsize													
Mill													
- Mill and Ancillary Facilities													
- Mill Pad													
- Ore/Tailings Stockpile Pads													
- Runoff Collection Pond(s)													
- Diversion Ditches to Collection Pond													
Dry Stack Tailings Facility Cover													
Closure Site Management (monitoring & maintenance)													

-
- (a) Surface water quality monitoring (as per Table 8-2)
 - (b) Hydrological monitoring
 - (c) Groundwater monitoring
 - (d) Physical and engineered structures monitoring (geotechnical assessment)
 - (e) Sediment, benthic and aquatic resources monitoring
 - (f) Climate monitoring (as required for assessment of other resources)

Monitoring activity will be required to determine the on-going and continued success of closure measures in meeting the closure objectives for a period of 10 years. The adaptive management approach will be used to determine thresholds identifying when remedial actions have been triggered, and then the success of the remedial measures will need to be incorporated into the monitoring and surveillance regime.

During closure, an Environmental Monitor will continue water quality sampling at some of the monitoring stations identified in the Type A Water Use Licence.

Table 8-1 shows the proposed closure monitoring schedule used as the basis for cost estimating. The schedule includes those sites that are relevant to post closure monitoring and monitored under other licences:

- Monitoring of road bank and drainage along access road;
- Physical inspection of dry stack tailings facility area;
- Physical inspection of the passive water treatment systems;
- Physical stability of all waste rock disposal areas;
- Success of revegetation measures (principally portal area and mill pad area, DSTF);
- Monitoring of cover system integrity (P-AML and DSTF); and
- Physical inspection of impacted earthen surfaces for evidence of erosion, gullyng, or sediment transport to watercourses.

The condition of permafrost beneath the WRDAs and DSTF will be monitored throughout operation and during the 10 year post closure monitoring period. The requirement for ground temperature monitoring will be reviewed 10 years after closure, depending on the status of the construction of the Bellekeno, Onek and Lucky Queen WRDAs. An annual geotechnical inspection should be conducted on the WRDA, DSTF and sedimentation/treatment ponds for at least 5 years after closure. The requirement for an annual geotechnical inspection will be reviewed 5 years after closure.

9.4 SUPERVISION AND DOCUMENTATION OF WORK

All decommissioning and reclamation works will be supervised to ensure that works are constructed according to their design and that this work is properly carried out and documented. The project manager or construction supervisor would supervise all closure works. Regular inspection procedures would be completed to document work progress, deficiencies and completion.

Upon completion of the decommissioning and reclamation works, a final site plan report will be prepared that will outline the facilities or works remaining on the site following closure including the locations of subsurface features. It is expected that this plan would be used to support an Application for a Certificate of Closure under the *Quartz Mining Act*.

9.5 SITE PRESENCE AND DISTRICT-WIDE CLOSURE

Currently, the Keno Hill Silver District is undergoing planning for full-scale district-wide closure to address the historic environmental liabilities. ERDC and AANDC are in partnership to reclaim the abandoned former United Keno Hill Mine (UKHM) mines. The tenure of this project is on the order of decades, and as such there will be a site presence for many years to come. Decommissioning and reclamation of the Bellekeno, Onek and Lucky Queen Production Unit Areas will occur in tandem with closure of the UKHM sites and therefore can be orchestrated together with district monitoring programs over the long term.

10 TEMPORARY CLOSURE

In the event of a premature closure, the following monitoring and care and maintenance activities (focused on a temporary closure scenario occurring after mine start-up) will be implemented. Alexco's priority during any temporary closure scenario will be to ensure that the site remains geochemically and physically stable, secure and safe, monitored and in compliance with applicable licences and legislation. This will include initial stabilization and on-going routine monitoring and maintenance of the site infrastructure and facilities until mining recommences or full closure is initiated.

Table 9-1 provides a summary of the various project components and associated inspection and maintenance activities during any temporary cessation of mining activities. Alexco's ongoing care and maintenance activities in the District are currently scheduled to continue beyond the next 5 years which means that there would be minimal additional costs related to a temporary closure at the Bellekeno, Onek and Lucky Queen Production Unit Areas.

10.1 PHYSICAL STABILITY AND GEOCHEMICAL STABILITY

Stabilization of site works during any temporary closure will be addressed initially well in advance of any closure scenario through the Company's commitment to progressive reclamation and stabilization measures. Progressive reclamation will be implemented on an ongoing basis (Section 6.1) to fulfil the Company's commitment to maintaining site stability and reclaiming areas as soon as operationally possible, therefore reducing both financial and operational liability.

Site infrastructure, including primarily buildings, equipment and machinery, will be emptied/drained of hazardous reagents and process fluids where appropriate and stabilized for temporary closure based on recommendations from mechanical and chemical suppliers, contractors and engineers. This includes the removal of all hazardous wastes, including waste hydrocarbons, coolants, lubricants, mill reagents and process chemicals. Depending on the anticipated length of a temporary closure, mill reagents and chemicals may remain on site in a secure condition for reuse once active operations recommence. The bulk explosives inventory will be removed from site and explosives storage containers and facilities will be inspected regularly. In the event of suspended operations, the onsite water treatment facilities will be maintained by the existing district care and maintenance crew.

This temporary closure will be conducted to a level whereby the infrastructure and mine components are ensured to be stable in the short term (less than 5 years) and whereby mining and milling operations can be resumed in a timely manner should the decision be made to transition back into operations. This will include:

- the retention of essential equipment/assets onsite to maintain infrastructure; and
- the storage of hazardous materials (not waste) in competent primary and secondary containment ensuring compliance with applicable legislation.

**Table 10-1: Summary of Care and Maintenance Activities and Surveillance
during Temporary Cessation of Mining Activities**

Project Component	Objectives	Care & Maintenance Activities	Monitoring	Monitoring Responsibility	Monitoring Timing/Frequency
Bellekeno Mine	Water Management	Maintain Bellekeno 625 water treatment facility and related water management infrastructure.	WUL Water Quality Surveillance Program	Care & Maintenance Crew	As per WUL
	Physical Stability	Restrict access to hazardous areas with physical barriers.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
Onek Mine	Water Management	Maintain Onek 400 water treatment facility and related water management infrastructure.	WUL Water Quality Surveillance Program	Care & Maintenance Crew	As per WUL
	Physical Stability	Restrict access to hazardous areas with physical barriers.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
Lucky Queen Mine	Water Management	Maintain Lucky Queen water management infrastructure.	WUL Water Quality Surveillance Program	Care & Maintenance Crew	As per WUL
	Physical Stability	Restrict access to hazardous areas with physical barriers.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
Waste Rock Storage	Physical stability	Runoff/Erosion/Sediment control. Progressive reclamation will occur during operations.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
			Geotechnical Inspection	Engineer	Annual
	Geochemical Stability	Cover P-AML WRSFs with HDPE Monitor WRSF & WRDA for seepage.	WUL Water Quality Surveillance Program	Care & Maintenance Crew	As per WUL
Roads	Physical Stability	Surface grading and granular amendments, ditch and culvert maintenance.	Visual inspection periodically for signs of instability/erosion	Care & Maintenance Crew	Weekly and after heavy precipitation events
Mill	Buildings, Equipment and Infrastructure	Secure buildings and retain necessary equipment for site maintenance.	Visual inspection for signs of instability.	Care & Maintenance Crew	Monthly
		Concentrate removed from site.			
	Physical Stability	Inspect for site stability.	Structural Inspection	Engineer	Twice Annually
		Reduce ore stockpile inventory.			
Dry Stack Tailings Facility	Physical stability	Surface water diversion structure repair/ maintenance.	Monitoring Program from DSTF Operating Plan; &	Care & Maintenance Crew	As per Monitoring Programs & QML
		Runoff/Erosion/Sediment control.	QML Physical Monitoring Program		
		Dust Control.			
	Geochemical Stability	Progressive reclamation will occur during operations.	Geotechnical Inspection from QML and DSTF Operating Plan	Engineer	Annual
Entire Site	Physical stability	Surface water diversion structure repair/ maintenance.	Monitoring Program from DSTF Operating Plan; &	Care & Maintenance Crew	As per Monitoring Programs & QML
		Runoff/Erosion/Sediment control.	QML Physical Monitoring Program		
		Dust Control.			
	Security	Progressive reclamation will occur during operations.	Geotechnical Inspection from QML and DSTF Operating Plan	Engineer	Annual
		Monitor for seepage and water quality.	WUL Water Quality Surveillance Program; & Monitoring Program from DSTF Operating Plan	Care & Maintenance Crew	As per WUL
	Miscellaneous Infrastructure	Full time site care & maintenance crew will check, repair and replace as required:	Care & Maintenance Monitoring of all infrastructure and site elements	Care & Maintenance Crew	Daily: Inspection Sheets included in Annual Reporting
		· precautionary signage			
	Reporting	· security gates – installed to restrict access to the mill			
		Minimize camp size.			
Entire Site	Reporting	Prepare and submit annual report to Yukon Water Board pursuant to	Care & Maintenance monitoring of all infrastructure and site elements	Care & Maintenance Crew	Daily: Inspection Sheets included in Annual Reporting
		Prepare and submit annual report to YG Mineral Resources Branch			
	Reporting	Prepare and submit quarterly monitoring reports to Environment Canada under MMER.		Alexco	Annually
					Quarterly, Online RISS Registry

10.2 SECURITY AND MONITORING

Uncontrolled access to the mine components and facilities could pose a risk to the public and to the site assets. As such, the full-time care and maintenance crew will conduct daily monitoring of all infrastructure and site elements. Equipment and vehicles will be available onsite for the staff should more intensive earthworks be required during the temporary closure period.

During temporary closure gates may be required and locked with warning signs erected at the gates and key locations around the site indicating the risks of entry. Site buildings will be locked and secured. Roads will be maintained as required.

The care and maintenance crew will be responsible for:

- Regular inspections of the site to observe and document the condition of, and any changes to: site security and public safety measures, infrastructure, mine components, etc., as well as to document potential emerging environmental or public health and safety objectives;
- Conducting routine physical monitoring activities;
- Regular water quality and flow monitoring;
- Submitting inspection and monitoring reports to managers on a regular basis;
- Responding to any security/safety objectives as required; and
- Conducting routine site maintenance and basic repairs to infrastructure and works as required (snow removal, culvert and road maintenance, building maintenance).

Site inspections and monitoring will be conducted by vehicle when seasonally possible. Some sites may be difficult to access in winter as snow removal would not be reasonable at all locations. Inspection results will be documented on a form and submitted to management on a regular basis. Reports of changes to physical status of any part of the site may warrant a follow-up investigation by managers and/or professional personnel.

The Company's Environmental Monitoring Program and detailed design reports further commit to structural monitoring, which will continue in the event of temporary closure.

Some elements of the monitoring program (geotechnical and structural inspections and non-routine water quality and biological monitoring) will be conducted by appropriate professional personnel, and results of these inspections will be included in annual reports and other required submissions.

10.3 REPORTING

Monitoring and inspection data collected will be compiled and submitted according to the required annual reporting timeframes for both the Quartz Mining and Water Use Licences.

11 RECLAMATION AND CLOSURE COSTING

Costing of the proposed decommissioning and reclamation measures is the basis for the provision of security held by Yukon Government (YG). YG currently holds a security bond (100% cash Letter of Credit) to cover the potential liabilities arising from the operation of the Bellekeno mine project. Alexco has completed a cost estimate to implement this RCP for the Keno Hill Silver District Mining Operations and the estimated cost to implement the reclamation and closure plan is **\$3,961,000**. The amount of security currently held by YG for reclamation and closure of the Bellekeno mine project is **\$3,678,100**. It is important to note that not all of the liabilities including in the cost estimate have yet been realized or created.

Closure liability cost estimate summary tables are provided below. Where possible, cost estimates were made using unit cost per volume. Where the use of unit costs proved difficult, then an estimation of equipment and labour hours were used. The unit costs and job hours were derived from Access Consulting Group's professional experience with other closure program costing estimates prepared for Yukon Government as well as Alexco's operational experiences. Unit costs are presented in Table 11-1.

As the mine continues to operate this Reclamation and Closure Plan will be reviewed every two years and closure costs updated based on more detailed engineering plans. Assumptions for the current closure liability cost estimates are based on current site conditions, as well as Alexco retaining the contract to perform site care and maintenance. Alexco maintains a constant presence on site fulfilling the care and maintenance contract and obligations, and this is reflected in closure costs for site management, the incremental costs of water treatment, as well as camp costs.

Certain pre-existing terrestrial liabilities are the responsibility of the Federal Government and have not been included. The need to reclaim these areas is still noted in the tables below as well as where further discussion is needed.

Table 11-2 summarizes closure liability cost estimates for the end of mine life. Cost estimates for the separate reclamation components including site management are provided in the remaining tables.

Table 11-1 Keno Hill Silver District Mining Operations Unit Rate Cost Table

EQUIPMENT RATES		
Bulldozer-small (Cat D6)	\$134	per hr
D8K Dozer	\$196	per hr
D9H Dozer	\$276	per hr
D250E Haul Truck	\$227	per hr
Tandem Haul Truck	\$113	per hr
A35 Haul Truck	\$196	per hr
Cat 325 Hoe	\$196	per hr
Cat 235 Excavator	\$247	per hr
235 Excavator w Hammer	\$283	per hr
Cat 16H grader	\$227	per hr
988B Loader	\$258	per hr
Tractor Trailer (lowbed)	\$134	per hr
30 ton Crane	\$165	per hr
Hiab Flatdeck truck	\$129	per hr
Cat 950 Loader	\$129	per hr
Underground LHD 4-6yd Placement	\$226	per hr
Underground Truck 20t	\$116	per hr
Misc Mine Infrastructure	\$103	per hr
Vacuum Truck	\$103	per hr
Gas Powered Pump	\$103	per day
Pickup Truck	\$2,575	per month
Support Equipment	variable	lump sum

PERSONNEL RATES		
Blaster	\$62	per hr
General Labourer	\$46	per hr
Underground Labourer	\$67	per hr
Trades Labourer	\$82	per hr
Underground / Site Supervisor	\$98	per hr
Medical Safety	\$52	per hr
Technician	\$77	per hr
Design Engineer	\$134	per hr
Environmental Scientist	\$129	per hr
Project Manager	\$9,991	per month
Camp Labourer	\$4,120	per month
Site Caretaker	\$6,283	per month
Environmental Monitor	\$108	per hr
Analytical Costs	\$400	Unit cost
Misc.	variable	lump sum

REVEGETATION RATES		
Revegetation Seed Mix	\$13	per kg
Revegetation Seed Mix - 50kg/ha	\$525	per ha
Fertilizer	\$1	per kg
Fertilizer - 250kg/ha	\$258	per ha
Tree Seedlings	\$1,803	per ha (1,000 seedlings per ha)
Seed/Fertilizer Application	\$1,545	per ha
Revegetation cost per ha. Including application cost	\$2,328	per ha

CONTRACTOR UNIT RATES & CAMP COST		
Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	\$4.64	cu.m
Custom Rate B (Load, haul and dump mineralized rock stockpile in BK East Decline)	\$4.77	cu.m
Compact and Contour Cover	\$2.12	cu.m
Excavation of Soil	\$5.30	cu.m
Supply and place Geotextile	\$7.42	sq m
Load, haul and place soil cover	\$8.48	cu.m
Haul & Place rock cover	\$8.48	cu.m
Drill, Blast and Screen Rip Rap	\$23.32	cu.m
Load and Haul and Place Rip Rap	\$13.78	cu.m
HDPE Liner Install	\$10.60	sq m
Erosion barriers	\$3.18	sq m
Freight run to Whitehorse	\$1,060	per load
Camp Cost	\$58	per day per person
Power and Heat	\$5,830	per month
Sundry equipment maintenance	\$5,300	yearly
General Administrative expenses	\$2,120	per month
Employee Transport Costs	\$3,180	per month

Note: Custom Unit Rates have been developed specifically for Keno Hill Silver District mining operations as of September 2012, taking into account such factors as haul distance, grade, machinery required, time required, etc.

Table 11-2 Keno Hill Silver District Mining Operations Closure Liability Cost Estimate Summary End of Mine Life

Item No.	Mine Component	Cost
1	BELLEKENO MINE	\$598,000
1.1	Bellekeno East Underground	\$33,000
1.2	Reclaim Bellekeno East Portal Site	\$91,000
1.3	Reclaim Bellekeno 625 Adit Site	\$35,000
1.4	<i>Bulkhead Installation*</i>	<i>\$239,000</i>
1.5	Bellekeno 625 Water Treatment Facility Transition	\$168,000
1.6	200 Level Vent Raise	\$32,000
2	ONEK MINE	\$198,000
2.1	Onek Underground	\$26,000
2.2	Onek Portal Site and local surface infrastructure	\$148,000
2.3	Vent Raise	\$24,000
3	LUCKY QUEEN MINE	\$187,000
3.1	Lucky Queen Underground	\$36,000
3.2	Lucky Queen Portal Site and local surface infrastructure	\$96,000
3.3	Vent Raise	\$55,000
4	WASTE ROCK STORAGE	\$303,000
4.1	Temporary P-AML WRSF - Bellekeno East	\$40,000
4.2	Onek and Lucky Queen P-AML WRSFs	\$134,000
4.3	Non-AML WRDA - Bellekeno 625	\$96,000
4.4	Non-AML WRDA - Lucky Queen 500	\$25,000
4.5	Reclaim Borrow Area	\$8,000
5	ROADS	\$143,000
5.1	Access Road Extension Bellekeno East to Bellekeno Temp P-AML WRSF (~1160 m)	\$17,000
5.2	<i>Powerline Haul Road (~3.15 km)*</i>	<i>\$38,000</i>
5.3	Keno City Bypass (~1200 m)	\$20,000
5.4	<i>Mill Site Access Including Christal Lake Road (1.9 km)*</i>	<i>\$26,000</i>
5.5	Other Roads and Trails (~5 km)	\$5,000
5.6	Onek Connector (2 km)	\$20,000
5.7	Lucky Queen Road (3.15 km)	\$17,000
6	CAMP DOWNSIZE	\$27,000
7	MILL	\$495,000
7.1	Mill and Ancillary Facilities	\$317,000
7.2	Mill Pad (~3 ha)	\$28,000
7.3	Ore/Tailings Stockpile Pads	\$13,000
7.4	Water Treatment Plant Operation (~2 yrs)	\$88,000
7.5	Runoff Collection Pond (4,700 m ³)	\$39,000
7.6	Diversion Ditches to Collection Pond	\$10,000
8	DRY STACK TAILINGS FACILITY	\$287,000
8.1	Mine Year 2 DSTF Cover	\$34,000
8.2	Mine Year 3 DSTF Cover	\$38,000
8.3	Mine Year 4 DSTF Cover	\$67,000
8.4	Mine Year 5 DSTF Cover	\$69,000
8.5	Mine Year 6 DSTF Cover	\$79,000
9	SITE MANAGEMENT	\$950,000
9.1	Onsite Management	\$296,000
9.2	Compliance Monitoring and Reporting	\$600,000
9.3	Contaminated Site Assessment Plan	\$14,000
9.4	Closure Maintenance	\$40,000
	TOTAL CLOSURE COSTS	\$3,188,000
	Contingency Costs (15%)	\$478,000
	Contingency Water Treatment (Mines & Mill 2 yrs) include Project Management of 7%	\$234,000
	Contingency Bellekeno N-AML WRDA Toe Buttress, includes project management of 7%	\$61,000
	GRAND TOTAL CLOSURE COSTS - END OF MINE LIFE	\$3,961,000

* for discussion with AANDC & YG re terrestrial liability (also components of item 1.3 & 1.4, see table for breakdown)

Table 11-3 Bellekeno Mine Estimated Closure Costs

Item No.	Reclamation Component	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
1.1	Bellekeno East Underground						
	Removal of underground equipment (e.g. paste plant; switch gear; electrical; hydraulic control)	Underground LHD 4-6yd Placement	per hr	60	\$226	\$13,534	
		A35 Haul Truck	per hr	60	\$196	\$11,742	
		General Labourer	per hr	120	\$46	\$5,562	\$30,838
	Project Management	7% of Total Cost	%		7.00%	\$2,159	\$2,159
	Sub-Total						\$33,000
1.2	Reclaim Bellekeno East Portal Site						
	Remove shop and other buildings (explosives and cap magazine)	Misc.	lump sum	1	\$25,000	\$25,000	
	Supply rockfill for portal barrier	Load and Haul and Place Rip Rap	cu.m	700	\$14	\$9,646	
	Labour for portal barrier	General Labourer	per hr	40	\$46	\$1,854	
	Characterize settling ponds sediments	Analytical Costs	Unit cost	1	\$400	\$400	
	Remove settling ponds liners to landfill	A35 Haul Truck	per hr	2	\$196	\$391	
		General Labourer	per hr	8	\$46	\$371	
	Clean out fuel tank residue	Misc.	lump sum	1	\$1,000	\$1,000	
	Haul fuel tank and liner for reuse or landfill	Cat 325 Hoe	per hr	6	\$196	\$1,174	
		A35 Haul Truck	per hr	6	\$196	\$1,174	
		General Labourer	per hr	16	\$46	\$742	
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$196	\$3,914	
		A35 Haul Truck	per hr	20	\$196	\$3,914	
		General Labourer	per hr	40	\$46	\$1,854	
	Test area soils for contamination	Environmental Monitor	per hr	8	\$108	\$865	
	Laboratory Analysis for soils testing	Analytical Costs	Unit cost	2	\$400	\$800	
	Haul any contaminated soils to nearest Land Treatment Facility	Cat 325 Hoe	per hr	16	\$196	\$3,131	
		A35 Haul Truck	per hr	16	\$196	\$3,131	
	Recontour and scarify area and slopes to establish drainage	D8K Dozer	per hr	24	\$196	\$4,697	
		Cat 16H grader	per hr	20	\$227	\$4,532	
	Install Signage	Misc.	lump sum	1	\$1,000	\$1,000	
	Mob/Demob (entire mine)	Misc.	lump sum	1	\$15,000	\$15,000	\$84,591
	Project Management	7% of Total Cost	%		7.00%	\$5,921	\$5,921
	Sub-Total						\$91,000
1.3	Reclaim Bellekeno 625 Adit Site						
	Remove lab	Misc.	lump sum	1	\$5,000	\$5,000	
	Remove electrical substation*	Misc.	lump sum			\$0	
	Remove electrical transmission line (Keno City to BK 625)*	Misc.	lump sum			\$0	
	Remove shop/loadout facility, compressor shack*	Misc.	lump sum			\$0	
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$196	\$3,914	
		A35 Haul Truck	per hr	20	\$196	\$3,914	
		General Labourer	per hr	40	\$46	\$1,854	
	Test area soils for contamination	Environmental Monitor	per hr	8	\$108	\$865	
	Laboratory Analysis for soils testing	Analytical Costs	Unit cost	2	\$400	\$800	
	Haul any contaminated soils to nearest Land Treatment Facility	Cat 325 Hoe	per hr	16	\$196	\$3,131	
		A35 Haul Truck	per hr	16	\$196	\$3,131	
	Recontour and scarify area and slopes to establish drainage	D8K Dozer	per hr	24	\$196	\$4,697	
		Cat 16H grader	per hr	20	\$227	\$4,532	
	Install Signage	Misc.	lump sum	1	\$1,000	\$1,000	\$32,838
	Project Management	7% of Total Cost	%		7.00%	\$2,299	\$2,299
	Sub-Total						\$35,000
1.4	Bulkhead Installation*						
	Hydrogeologic study & engineering for concrete bulkhead	Misc.	lump sum	1	\$45,000	\$45,000	
	Underground Rehab for bulkhead	Misc.	lump sum	1	\$50,000	\$50,000	
	Construct concrete plug	General Labourer	per hr	120	\$46	\$5,562	
		Underground Labourer	per hr	200	\$67	\$13,390	
		Underground Truck 20t	per hr	120	\$116	\$13,967	
	Concrete Batch	Misc.	lump sum	1	\$75,000	\$75,000	
		Cat 950 Loader	per hr	80	\$129	\$10,300	
	Install Instrumentation (e.g pressure gauge)	Misc.	lump sum	1	\$10,000	\$10,000	\$223,219
	Project Management	7% of Total Cost	%		7.00%	\$15,625	\$15,625
	Sub-Total						\$239,000
1.5	Bellekeno 625 Water Treatment Facility Transition						
	Contingency treatment operation (2 yrs after mine flooding)**	Misc.	lump sum	24	\$7,845	\$188,280	
	Remove salvageable equipment	General Labourer	per hr	16	\$46	\$742	
		Trades Labourer	per hr	16	\$82	\$1,318	
	Load & return extra reagents/chemicals	General Labourer	per hr	8	\$46	\$371	
		Misc.	lump sum	1	\$2,000	\$2,000	
	Dismantle building	Cat 235 Excavator	per hr	4	\$247	\$989	
		Cat 950 Loader	per hr	10	\$129	\$1,288	
		Tractor Trailer (lowbed)	per hr	30	\$134	\$4,017	
		General Labourer	per hr	40	\$46	\$1,854	
	In mine pool treatment	Misc.	lump sum	1	\$40,000	\$40,000	
	Characterize settling ponds sediments/sludge	Analytical Costs	Unit cost	2	\$400	\$800	
	Remove sludge from settling ponds	Vacuum Truck	per hr	40	\$103	\$4,120	
		General Labourer	per hr	40	\$46	\$1,854	
	Remove settling ponds liners to landfill	A35 Haul Truck	per hr	4	\$190	\$760	
		General Labourer	per hr	8	\$45	\$360	
	Construct infiltration gallery	A35 Haul Truck	per hr	80	\$196	\$15,656	
		Cat 950 Loader	per hr	60	\$129	\$7,725	
		General Labourer	per hr	60	\$46	\$2,781	
	Operate infiltration gallery (5 yrs)	Misc.	lump sum	5	\$10,000	\$50,000	
	Site levelling	D9H Dozer	per hr	20	\$276	\$5,521	
	Scrap hauled to solid waste facility	Cat 235 Excavator	per hr	8	\$247	\$1,978	
		D250E Haul Truck	per hr	12	\$227	\$2,719	
	Misc. Supplies & Tools	Misc.	lump sum	1	\$10,000	\$10,000	\$156,852
	Project Management	7% of Total Cost	%		7.00%	\$10,980	\$10,980
	Sub-Total						\$168,000
1.6	200 Level Vent Raise						
	Engineering for concrete cap	Misc.	lump sum	1	\$10,000	\$10,000	
	Concrete Batch	Misc.	lump sum	1	\$10,000	\$10,000	
		Cat 950 Loader	per hr	12	\$129	\$1,545	
		Hiab Flatdeck truck	per hr	48	\$129	\$6,180	
	Labour for cap	General Labourer	per hr	40	\$46	\$1,854	\$29,579
	Project Management	7% of Total Cost	%		7.00%	\$2,071	\$2,071
	Sub-Total						\$32,000
	Total Estimated Cost in Reclaiming Bellekeno Mine						\$598,000

* for discussion with AANDCC & YG re terrestrial liability

**contingency cost incorporated into summary table

Table 11-4 Onek Mine Estimated Closure Costs

Item No.	Reclamation Component	Equipment / Labour	Units	Quantity	Unit Cost	Cost
2.1	Onek Underground					
	Removal of underground equipment (e.g. paste plant; switch gear; electrical; hydraulic control structures)	Underground LHD 4-6yd	per hr	72	\$226	\$ 16,241
		A35 Haul Truck	per hr	20	\$196	\$ 3,914
		General Labourer	per hr	80	\$46	\$ 3,708
	Project Management	7% of Total Cost	%	7%		\$ 1,670
	Sub-total					\$ 26,000
2.2	Onek Portal Site and local surface infrastructure					
	Remove shop and other buildings (explosives and cap magazine)	Misc.	lump sum	1	\$5,000	\$ 5,000
	Supply rockfill for portal barrier	Load and Haul and Place Rip Rap	cu.m	700	\$14	\$ 9,646
	Labour for portal barrier	General Labourer	per hr	40	\$46	\$ 1,854
	Clean out fuel tank residue	Misc.	lump sum	1	\$1,000	\$ 1,000
	Haul fuel tank and liner for reuse or landfill	Cat 325 Hoe	per hr	6	\$196	\$ 1,174
		A35 Haul Truck	per hr	6	\$196	\$ 1,174
		General Labourer	per hr	16	\$46	\$ 742
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$196	\$ 3,914
		A35 Haul Truck	per hr	20	\$196	\$ 3,914
		General Labourer	per hr	40	\$46	\$ 1,854
	Sample and test area soils for contamination	Environmental Monitor	per hr	8	\$108	\$ 865
	Laboratory Analysis for soils testing	Analytical Costs	Unit cost	4	\$400	\$ 1,600
	Haul any contaminated soils to nearest Land Treatment Facility	Cat 325 Hoe	per hr	16	\$196	\$ 3,131
		A35 Haul Truck	per hr	16	\$196	\$ 3,131
	Recontour and scarify area and slopes to establish drainage	D8K Dozer	per hr	24	\$196	\$ 4,697
		Cat 16H grader	per hr	20	\$227	\$ 4,532
	Install Signage	Misc.	lump sum	1	\$1,000	\$ 1,000
	Mob/Demob (entire mine)	Misc.	lump sum	1	\$15,000	\$ 15,000
	Remove lab	Misc.	lump sum	1	\$5,000	\$ 5,000
	Remove electrical substation	Misc.	lump sum	1	\$2,500	\$ 2,500
	Remove electrical transmission line	Misc.	lump sum	1	\$5,000	\$ 5,000
	Remove shop/loadout facility, compressor shack	Misc.	lump sum	1	\$5,000	\$ 5,000
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$196	\$ 3,914
		A35 Haul Truck	per hr	20	\$196	\$ 3,914
		General Labourer	per hr	24	\$46	\$ 1,112
		A35 Haul Truck	per hr	16	\$196	\$ 3,131
		Cat 16H grader	per hr	20	\$227	\$ 4,532
	Install Signage	Misc.	lump sum	1	\$500	\$ 500
	Characterize settling pond sediments/sludge	Analytical Costs	Unit cost	2	\$400	\$ 800
	Remove sludge from settling pond	Vacuum Truck	per hr	40	\$103	\$ 4,120
		General Labourer	per hr	40	\$400	\$ 16,000
	Remove settling ponds liners to landfill	A35 Haul Truck	per hr	4	\$196	\$ 783
	Site levelling	D9H Dozer	per hr	20	\$276	\$ 5,521
	Scrap hauled to solid waste facility	Cat 235 Excavator	per hr	8	\$240	\$ 1,920
		D250E Haul Truck	per hr	12	\$227	\$ 2,719
	Misc. Supplies & Tools	Misc.	lump sum	1	\$7,500	\$ 7,500
	Project Management	7% of Total Cost	%	7%		\$ 9,674
	Sub-total					\$ 148,000
2.3	Vent Raise					
	Engineering for concrete cap	Misc.	lump sum	1	\$7,500	\$ 7,500
	Concrete Batch	Misc.	lump sum	1	\$5,000	\$ 5,000
		Cat 950 Loader	per hr	12	\$129	\$ 1,545
		Hiab Flatdeck truck	per hr	48	\$129	\$ 6,180
	Labour for cap	General Labourer	per hr	40	\$46	\$ 1,854
	Project Management	7% of Total Cost	%	7%		\$ 1,546
	Sub-total					\$ 24,000
	Total Estimated Cost for Reclaiming Onek Mine					\$ 198,000

Table 11-5. Lucky Queen Mine Estimated Closure Costs

Item No.	Reclamation Component	Equipment / Labour	Units	Quantity	Unit Cost	Total Cost
3.1	Lucky Queen Underground					
	Removal of underground equipment (e.g. paste plant; switch gear; electrical; hydraulic control structures)	Underground LHD 4-6yd	per hr	100	\$226	\$ 22,557
		A35 Haul Truck	per hr	20	\$196	\$ 3,914
		General Labourer	per hr	150	\$46	\$ 6,953
	Project Management	7% of total project	%	7%		\$ 2,340
	Sub-total					\$ 36,000
3.2	Lucky Queen Portal Site and local surface infrastructure					
	Remove shop and other buildings (explosives and cap magazine)	Misc.	lump sum	1	\$ 5,000	\$ 5,000
	Supply rockfill for portal barrier	Load and Haul and Place Rip Rap	cu.m	700	\$ 14	\$ 9,646
	Labour for portal barrier	General Labourer	per hr	40	\$ 45	\$ 1,800
		General Labourer	per hr	8	\$ 46	\$ 371
	Clean out fuel tank residue	Misc.	lump sum	1	\$ 1,000	\$ 1,000
	Haul fuel tank and liner for reuse or landfill	Cat 325 Hoe	per hr	6	\$ 196	\$ 1,174
		A35 Haul Truck	per hr	6	\$ 196	\$ 1,174
		General Labourer	per hr	16	\$ 46	\$ 742
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$ 196	\$ 3,914
		A35 Haul Truck	per hr	20	\$ 196	\$ 3,914
		General Labourer	per hr	40	\$ 46	\$ 1,854
	Sample and test area soils for contamination	Environmental Monitor	per hr	8	\$ 108	\$ 865
	Laboratory Analysis for soils testing	Analytical Costs	Unit cost	4	\$ 400	\$ 1,600
	Haul any contaminated soils to nearest Land Treatment Facility	Cat 325 Hoe	per hr	16	\$ 196	\$ 3,131
		A35 Haul Truck	per hr	16	\$ 196	\$ 3,131
	Recontour and scarify area and slopes to establish drainage	D8K Dozer	per hr	12	\$ 196	\$ 2,348
		Cat 16H grader	per hr	20	\$ 227	\$ 4,532
	Remove electrical transmission line	Misc.	lump sum	1	\$ 5,000	\$ 5,000
	Remove shop/loadout facility, compressor shack	Misc.	lump sum	1	\$ 5,000	\$ 5,000
	Area cleanup and haul debris to landfill	Cat 325 Hoe	per hr	20	\$ 196	\$ 3,914
		A35 Haul Truck	per hr	20	\$ 196	\$ 3,914
		General Labourer	per hr	24	\$ 46	\$ 1,112
		A35 Haul Truck	per hr	16	\$ 196	\$ 3,131
		Cat 16H grader	per hr	20	\$ 227	\$ 4,532
	Characterize settling pond sediments/sludge	Analytical Costs	Unit cost	2	\$ 400	\$ 800
		General Labourer	per hr	40	\$ 46	\$ 1,854
		Environmental Monitor	per hr	3	\$ 108	\$ 324
	Remove settling ponds liners to landfill	A35 Haul Truck	per hr	4	\$ 196	\$ 783
	Revegetation	Revegetation cost per ha. Including application cost	per ha	0.5	\$ 2,328	\$ 1,164
	Scrap hauled to solid waste facility	Cat 235 Excavator	per hr	8	\$ 247	\$ 1,978
		D250E Haul Truck	per hr	12	\$ 227	\$ 2,719
	Misc. Supplies & Tools	Misc.	lump sum	1	\$ 7,500	\$ 7,500
	Project Management	7% of total project	%	7%		\$ 6,295
	Sub-total					\$ 96,000
3.3	Vent Raise					
	Engineering for concrete cap	Misc.	lump sum	1	\$ 7,500	\$ 7,500
	Concrete Batch	Misc.	lump sum	1	\$ 5,000	\$ 5,000
		Cat 950 Loader	per hr	12	\$ 129	\$ 1,545
		Hiab Flatdeck truck	per hr	48	\$ 129	\$ 6,180
	Labour for cap	General Labourer	per hr	40	\$ 46	\$ 1,854
		Sub-total				\$ 22,079
	Project Management	7% of total project	%	7%		\$ 11,187
	Sub-total					\$ 55,000
	Total Lucky Queen Mine closure costs					\$187,000

Table 11-6 Waste Rock Storage Estimated Closure Costs - End of Mine Life

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
4.1	Temporary P-AML WRSF - Bellekeno East						
	Rehandle underground	Custom Rate B (Load, haul and dump mineralized rock stockpile in BK East Decline)	cu.m	6000	\$5	\$28,620	
	Remove liner and haul to solid waste facility	D250E Haul Truck	per hr	2	\$227	\$453	
		General Labourer	per hr	8	\$46	\$371	
	Site recontouring	D8K Dozer	per hr	20	\$196	\$3,914	
	Revegetation	Revegetation cost per ha. Including application cost	per ha	1.8	\$2,328	\$4,190	\$37,548
	Project Management	7% of Total Cost	%		7.00%	\$2,628	\$2,628
	Sub-Total						\$40,000
4.2	Onek and Lucky Queen P-AML WRSFs						
	Educt impounded water	General Labourer	per hr	16	\$46	\$742	
		Vacuum Truck	per hr	16	\$103	\$1,648	
	Recontour waste rock	Cat 235 Excavator	per hr	16	\$247	\$3,955	
	Cover (0.5 m cover for 5 WRSF at 50 m x 50 m)	Load, haul and place soil cover	cu.m	13,500	\$8	\$114,480	
	Revegetation	Revegetation cost per ha. Including application cost	per ha	2	\$2,328	\$4,656	\$125,480
	Project Management	7% of Total Cost	%		7.00%	\$8,784	\$8,784
	Sub-Total						\$134,000
4.3	Non-AML WRDA - Bellekeno 625						
	Recontour waste rock - pull back crests	Cat 235 Excavator	per hr	60	\$247	\$14,832	
	Scarification	Cat 16H grader	per hr	24	\$227	\$5,438	
	Revegetation	Revegetation cost per ha. Including application cost	per ha	30	\$2,328	\$69,834	
	<i>Toe buttress**</i>	Cat 235 Excavator	per hr	120	\$247	\$29,664	
		D250E Haul Truck	per hr	120	\$227	\$27,192	\$90,104
	Project Management	7% of Total Cost	%		7.00%	\$6,307	\$6,307
	Sub-Total						\$96,000
4.4	Non-AML WRDA - Lucky Queen 500						
	Recontour waste rock - pull back crests	Cat 235 Excavator	per hr	15	\$247	\$3,708	
	Scarification	Cat 16H grader	per hr	6	\$227	\$1,360	
	Revegetation	Revegetation cost per ha. Including application cost	per ha	8	\$2,328	\$18,622	
							\$23,690
	Project Management	7% of Total Cost	%		7.00%	\$1,658	\$1,658
	Sub-Total						\$25,000
4.5	Reclaim Borrow Area						
	Stabilize slopes	Cat 235 Excavator	per hr	12	\$240	\$2,880	
	Revegetation	Revegetation cost per ha. Including application cost	per ha	2	\$2,328	\$4,656	\$7,536
	Project Management	7% of Total Cost	%		7.00%	\$527	\$527
	Sub-Total						\$8,000
	Total Estimated Cost in Reclaiming Waste Rock Storage Areas						\$303,000

***contingency cost incorporated into summary table*

Table 11-7 Access and Haul Road Closure Estimated Costs

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
5.1	Access Road Extension Bellekeno East to Bellekeno Temp P-AML WRSF (~1160 m)						
	Culvert excavation (2 culverts)	Cat 235 Excavator	per hr	20	\$247	\$4,944	
	Culvert removal and install swales	General Labourer	per hr	20	\$46	\$927	
		D250E Haul Truck	per hr	2	\$227	\$453	
	Reslope banks/remove safety berm	D8K Dozer	per hr	16	\$196	\$3,131.20	
	Scarify road surface	Cat 16H grader	per hr	16	\$227	\$3,626	
	Erosion barriers (50% of length)	Erosion barriers	sq m	750	\$3	\$2,385	\$15,466
	Project Management	7% of Total Cost	%		7.00%	\$1,083	\$1,083
	Sub-Total						\$17,000
5.2	Powerline Haul Road (~3.15 km)*						
	Culvert excavation (20 culverts)	Cat 235 Excavator	per hr	60	\$247	\$14,832	
	Culvert removal and install swales	General Labourer	per hr	60	\$46	\$2,781	
		D250E Haul Truck	per hr	4	\$227	\$906	
	Reslope banks/remove safety berm	D8K Dozer	per hr	40	\$196	\$7,828	
	Scarify road surface	Cat 16H grader	per hr	40	\$227	\$9,064	\$35,411
	Project Management	7% of Total Cost	%		7.00%	\$2,479	\$2,479
	Sub-Total						\$38,000
5.3	Keno City Bypass (~1200 m)						
	Culvert excavation (4 culverts)	Cat 235 Excavator	per hr	12	\$247	\$2,966	
	Culvert removal and install swales	General Labourer	per hr	12	\$46	\$556	
		D250E Haul Truck	per hr	2	\$227	\$453	
	Reslope banks/remove safety berm	D8K Dozer	per hr	20	\$196	\$3,914	
	Scarify road surface	Cat 16H grader	per hr	12	\$227	\$2,719	
	Lightning Creek bridge removal	Cat 235 Excavator	per hr	20	\$247	\$4,944	
		Tractor Trailer (lowbed)	per hr	12	\$134	\$1,607	\$17,160
		Erosion barriers	sq m	120	\$3	\$382	
		General Labourer	per hr	20	\$46	\$927	
	Project Management	7% of Total Cost	%		7.00%	\$1,201	\$1,201
	Sub-Total						\$20,000
5.4	Mill Site Access Including Christal Lake Road (1.9 km)*						
	Culvert excavation (40 culverts)	Cat 235 Excavator	per hr	40	\$247	\$9,888	
	Culvert removal and install swales	General Labourer	per hr	40	\$46	\$1,854	
		D250E Haul Truck	per hr	5	\$227	\$1,133	
	Reslope banks/remove safety berm	D8K Dozer	per hr	12	\$196	\$2,348	
	Scarify road surface	Cat 16H grader	per hr	40	\$227	\$9,064	\$24,287
	Project Management	7% of Total Cost	%		7.00%	\$1,700	\$1,700
	Sub-Total						\$26,000
5.5	Other Roads and Trails (~5 km)						
	Scarify road surface	Cat 16H grader	per hr	20	\$227	\$4,532	\$4,532
	Project Management	7% of Total Cost	%		7.00%	\$317	\$317
	Sub-Total						\$5,000
5.6	Onek Connector (2 km)						
	Culvert Excavation (6 culverts)	Cat 235 Excavator	per hr	12	\$247	\$2,966	
	Culvert removal and install swales	General Labourer	per hr	12	\$46	\$556	
		D250E Haul Truck	per hr	2	\$227	\$453	
	Reslope banks/remove safety berm	D8K Dozer	per hr	12	\$196	\$2,348	
	Scarify road surface	Cat 16H grader	per hr	40	\$227	\$9,064	
	Bridge Removal	Cat 235 Excavator	per hr	16	\$240	\$3,840	
	Project Management	7% of Total Cost	%		7.00%	\$1,077	
	Sub-Total						\$20,000
5.7	Lucky Queen Road (3.15 km)						
	Culvert Excavation (6 culverts)	Cat 235 Excavator	per hr	12	\$247	\$2,966	
	Culvert removal and install swales	General Labourer	per hr	12	\$46	\$556	
		D250E Haul Truck	per hr	2	\$227	\$453	
	Reslope banks/remove safety berm	D8K Dozer	per hr	20	\$196	\$3,914	
	Scarify road surface	Cat 16H grader	per hr	34	\$227	\$7,704	
	Project Management	7% of Total Cost	%		7.00%	\$1,092	
	Sub-Total						\$17,000
	Total Estimated Cost in Reclaiming Roads						\$143,000

* for discussion with AANDC & YG re terrestrial liability

Table 11-8 Camp Downsize Estimated Closure Costs

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
6	Camp Downsize						
	Dismantle 5 trailer units and transport to Lot 960 private	Misc.	lump sum	1	\$25,000	\$25,000	\$25,000
	Project Management	7% of Total Cost	%		7.00%	\$1,750	\$1,750
	Sub-Total						\$27,000
	Total Estimated Camp Downsizing Costs						\$27,000

Table 11-9 Mill Estimated Closure Costs

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
7.1	Mill and Ancillary Facilities						
	Remove equipment (crushers, conveyors, mill equipment, trailer units, other ancillary facilities - fine ore bin)	General Labourer	per hr	600	\$46	\$27,810	
		Trades Labourer	per hr	400	\$82	\$32,960	
		Cat 950 Loader	per hr	150	\$129	\$19,313	
		Cat 235 Excavator	per hr	50	\$247	\$12,360	
		Tractor Trailer (lowbed)	per hr	120	\$134	\$16,068	
	Load and return extra reagents/chemicals	General Labourer	per hr	75	\$46	\$3,476	
		Misc.	lump sum	1	\$2,500	\$2,500	
	Dismantle Mill Building	Cat 950 Loader	per hr	70	\$129	\$9,013	
		Tractor Trailer (lowbed)	per hr	70	\$134	\$9,373	
		Trades Labourer	per hr	300	\$82	\$24,720	
		General Labourer	per hr	1,000	\$46	\$46,350	
	Concrete Demolition	235 Excavator w Hammer	per hr	60	\$283	\$16,995	
		D9H Dozer	per hr	20	\$276	\$5,521	
	Crane Support	30 ton Crane	per hr	200	\$165	\$32,960	
	Haul scrap to solid waste facility	Cat 235 Excavator	per hr	50	\$247	\$12,360	
		D250E Haul Truck	per hr	100	\$227	\$22,660	
	Misc. Supplies & Tools	Misc.	lump sum	1	\$2,000	\$2,000	\$296,438
	Project Management	7% of Total Cost	%		\$0	\$20,751	\$20,751
	Sub-Total						\$317,000
7.2	Mill Pad (~3 ha)						
	Test area soils for contamination	Environmental Monitor	per hr	16	\$108	\$1,730	
	Laboratory Analysis for soils testing	Analytical Costs	Unit cost	20	\$400	\$8,000	
	Haul any contaminated soils to nearest Land Treatment Facility	Cat 325 Hoe	per hr	16	\$196	\$3,131	
		A35 Haul Truck	per hr	16	\$196	\$3,131	
	Regrade embankment shoulders	D8K Dozer	per hr	8	\$196	\$1,566	
	Scarify pad area	Cat 16H grader	per hr	8	\$227	\$1,813	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	3	\$2,328	\$6,983	\$26,355
	Project Management	7% of Total Cost	%		7.00%	\$1,845	\$1,845
	Sub-Total						\$28,000
7.3	Ore/Tailings Stockpile Pads						
	Concrete Demolition & Burial	Cat 235 Excavator	per hr	20	\$247	\$4,944	
		D9H Dozer	per hr	20	\$276	\$5,521	\$10,465
	Haul any contaminated soils to DSTF or Mine for disposal	Cat 235 Excavator	per hr	4	\$190	\$760	
		A35 Haul Truck	per hr	4	\$190	\$760	
	Project Management	7% of Total Cost	%		7.00%	\$733	\$733
	Sub-Total						\$13,000
7.4	Water Treatment Plant Operation (~2 yrs)						
	Contingency treatment operation (2 yrs freshet)	Misc.	lump sum	2	\$15,000	\$30,000	
	Construct infiltration gallery	A35 Haul Truck	per hr	80	\$196	\$15,656	
		Cat 950 Loader	per hr	60	\$129	\$7,725	
		General Labourer	per hr	60	\$46	\$2,781	
	Operate infiltration gallery (5 yrs)	Misc.	lump sum	5	\$10,000	\$50,000	\$76,162
	625 Sludge Rehandle	Misc.	lump sum	1	\$6,000	\$6,000	
	Project Management	7% of Total Cost	%		7.00%	\$5,751	\$5,751
	Sub-Total						\$88,000
7.5	Runoff Collection Pond (4,700 m³)						
	Pump down impounded water	General Labourer	per hr	36	\$46	\$1,669	
		Gas Powered Pump	per day	2	\$103	\$206	
	Misc. Supplies & Tools	Misc.	lump sum	1	\$500	\$500	
	Characterize pond sediments/sludge	Analytical Costs	Unit cost	1	\$400	\$400	
	Remove sediment/sludge from settling pond	Vacuum Truck	per hr	16	\$103	\$1,648	
		General Labourer	per hr	16	\$46	\$742	
	Breach dyke, relocate and contour materials	Excavation of Soil	cu.m	3,000	\$5	\$15,900	
	Stabilize slopes with erosion barriers	Erosion barriers	sq m	3,000	\$3	\$9,540	
	Remove discharge pipeline	Misc.	lump sum	1	\$5,000	\$5,000	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	0.5	\$2,328	\$1,164	\$36,768
	Project Management	7% of Total Cost	%		7.00%	\$2,574	\$2,574
	Sub-Total						\$39,000
7.6	Diversion Ditches to Collection Pond						
	Recontour	D9H Dozer	per hr	24	\$276	\$6,625	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	1	\$2,328	\$2,328	\$8,953
	Project Management	7% of Total Cost	%		7.00%	\$627	\$627
	Sub-Total						\$10,000
	Total Estimated Mill Closure Cost						\$495,000

Table 11-10 Dry Stack Tailings Facility Estimated Closure Cost

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
8.1	Mine Year 2 DSTF Cover						
	Top with overburden and soil (0.5m)	Load, haul and place soil cover	cu.m	3,500	\$8	\$29,680	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	0.7	\$2,328	\$1,629	\$31,309
	Project Management	7% of Total Cost	%		7.00%	\$2,192	\$2,192
	Sub-Total						\$34,000
8.2	Mine Year 3 DSTF Cover						
	Top with overburden and soil (0.5m)	Load, haul and place soil cover	cu.m	4,000	\$8	\$33,920	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	0.8	\$2,328	\$1,862	\$35,782
	Project Management	7% of Total Cost	%		7.00%	\$2,505	\$2,505
	Sub-Total						\$38,000
8.3	Mine Year 4 DSTF Cover						
	Top with overburden and soil (0.5m)	Load, haul and place soil cover	cu.m	7,000	\$8	\$59,360	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	1.4	\$2,328	\$3,259	\$62,619
	Project Management	7% of Total Cost	%		7.00%	\$4,383	\$4,383
	Sub-Total						\$67,000
8.4	Mine Year 5 DSTF Cover						
	Top with overburden and soil (0.5m)	Load, haul and place soil cover	cu.m	7,000	\$8	\$59,360	
	Remediate sludge storage area	D8K Dozer	per hr	8	\$196	\$1,566	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	1.4	\$2,328	\$3,259	\$64,185
	Project Management	7% of Total Cost	%		7.00%	\$4,493	\$4,493
	Sub-Total						\$69,000
8.5	Mine Year 6 DSTF Cover						
	Top with overburden and soil (0.5m)	Load, haul and place soil cover	cu.m	8,000	\$8	\$67,840	
	Revegetate	Revegetation cost per ha. Including application cost	Revegetation cost per ha. Including application cost	2.5	\$2,328	\$5,820	\$73,660
	Project Management	7% of Total Cost	%		7.00%	\$5,156	\$5,156
	Sub-Total						\$79,000
	Total Estimated DSTF Closure Cost						\$287,000

Table 11-11 Site Management Estimated Closure Costs - End of Mine Life

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Cost	Cost	Total Cost
9.1	Onsite Management						
	Project Management and Engineering - Included in costs for each closure component						
	Pickup truck	Pickup Truck	per month	15	\$2,575	\$38,625	
	Sundry equipment maintenance	Sundry equipment maintenance	yearly	3	\$5,300	\$15,900	
	Power and heat (incremental additional costs)	Misc.	lump sum	15	\$5,830	\$87,450	
	General Administrative expenses	General Administrative expenses	per month	15	\$2,120	\$31,800	
	Camp Costs	Camp Cost	per day per person	2100	\$58	\$122,430	
	Sub-Total						\$296,000
9.2	Compliance Monitoring and Reporting						
	<i>Water Quality Monitoring</i>						
	Years 1-5 (monthly)	Incremental Cost*	monthly	60	\$5,000	\$300,000	
	Years 6-10 (quarterly - spring/summer/fall)	Incremental Cost*	quarterly	20	\$5,000	\$100,000	
	Disbursements (non-labour/non-analytical)	Misc.	lump sum	80	\$1,000	\$80,000	
	<i>Biological Monitoring - Closure implementation</i>						
	Years 1-5 (Every 2 Years)	Incremental Cost*	yearly	2	\$4,000	\$8,000	
	Years 6-10 (Every 2 Years)	Misc.	yearly	3	\$4,000	\$12,000	
	Bellekeno waste rock & DSTF permafrost monitoring (10 yrs)	Misc.	yearly	10	\$5,000	\$50,000	
	WRDA & DSTF Annual Geotechnical Inspection - 5 yrs after closure	Incremental Cost*	yearly	5	\$10,000	\$50,000	
	Sub-Total						\$600,000
9.3	Contaminated Site Assessment Plan						
	Develop Plan	Misc.	lump sum	1	\$7,000	\$7,000	
	Assessment Reporting	Misc.	lump sum	1	\$7,000	\$7,000	
	Sub-Total						\$14,000
9.4	Closure Maintenance						
	Manage Land Treatment Facility and Testing*	Misc.	per year	5	\$5,000	\$25,000	
	Misc. Maintenance work related to the site after closure (roads, covers, revegetation)	Misc.*	per year	5	\$3,000	\$15,000	
	Sub-Total						\$40,000
	Total Estimated Cost for Site Management at Closure						\$950,000

* incremental cost of conducting these programs given existing District Plan monitoring programs

12 REFERENCES

- Energy, Mines and Resources, Yukon, 2008. Yukon Mine Site and Reclamation Closure Policy Financial and Technical Guidelines
- BGC Engineering, 2002(a). Heap Leach Facility Soil Cover Design Report. Viceroy Minerals Corporation, Brewery Creek Mine. July 2002
- BGC Engineering, 2002(b). Blue Sediment Waste Rock Storage Area Soil Cover Design Report. Viceroy Minerals Corporation, Brewery Creek Mine. November 2002

Appendix 1 Suporting Environmental Data

Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

From: Anthony Bier, Access Consulting Group, Catherine Henry, Access Consulting Group

CC: Tiffany Lunday, Access Consulting Group

Date: March 28, 2012

Re: Data Summary for 2011 Flam and Moth Meteorological Station, Keno, YT

INTRODUCTION

This memo describes the data collected in 2011 at the Flame and Moth meteorological station located above the Alexco Flame and moth Mill and below the old Keno City dump near Keno, YT (UTM coordinates: 08 V 048409 7086872, elevation: 936m).

OBSERVATIONS AND EQUIPMENT CONDITIONS 2011:

- The Flame and Moth weather station was assembled in the spring of 2011 and was operational on June 2, 2011 at 10 am PDT.
- The station uses Campbell Scientific hardware which included sensors for the measurement of temperature, relative humidity, rainfall, wind speed and wind direction (see Appendix I for a list of components and photos)
- The station was downloaded September 25th 2011 and it was found that the tipping bucket rain gauge was not functioning. The site was visited and the rain gauge went online October 14th 2011.
- The station was visited and downloaded on December 17th 2011 and again on March 18th 2011.
- Upon analysis of the 2011 data C. Henry investigated a suspicious lack of variation in the relative humidity record and found an error in the program code.
- The Flame and Moth Meteorological station does not have a pyranometer at this time.

METHODS AND RESULTS:

Monthly averages for the 2011 period of record were calculated from hourly values recorded by the data logger for the following parameters: temperature, daily maximum temperature, daily minimum temperature, and wind speed (Table 1, Appendix II). Monthly extreme maximum temperature, extreme minimum temperature, maximum wind speed and total rainfall are also shown in Table 1 for 2011. Occasional freezing of the wind monitor occurred, as well as the above mentioned gauge issues. Those are that the tipping bucket was not functional until October 14th and there was an error in the program code which resulted in inaccurate relative humidity readings.

Evapotranspiration was estimated for 2011 using a model provided by the University of California. The model used both the Penman-Monteith equation and the Hargreaves and Samani equation (Snyder and Eching, 2002). Using a spreadsheet provided the various climate parameters were used to calculate values for total monthly evapotranspiration. Input parameters required include average daily max temperature, average daily min temperature, average daily wind speed and average dew point temperature. These values were taken from Flame and Moth where available and filled in with values from Galena hill secondly and lastly from the Environment Canada station at the Mayo airport. Therefore, these data provide only a rough approximation of evapotranspiration (Table 2, Appendix II). Furthermore, evapotranspiration is calculated for different theoretical average vegetation height and more detailed vegetation data is required to increase the degree of confidence in the model. It should be noted that negative condensation values correspond to sublimation (i.e. frost). Negative evapotranspiration during the winter months is expected.

CONCLUSIONS AND RECOMMENDATIONS:

- A pyranometer should be installed at the Flame and Moth meteorological station, to allow the incorporation to the datalogger program of an instruction calculating evapotranspiration. Additionally, an evaporation pan may also be considered to validate estimates of evaporation.
- A program revision has been written for the Campbell Scientific data logger which fixes the code for the relative humidity sensor and should be sent to the data logger at the next site visit.
- Hourly data for the period of recorded has been requested from Environment Canada for the MAYO A meteorological station and can be used to extend the record of rainfall and relative humidity at the Flame and Moth station.

REFERENCES:

Snyder, R.L. and Eching, S. 2002. Peman-Monteith daily (24-hour) and Hargreaves Samani Equations for Estimating Reference Evapotranspiration from Monthly Data. Regents of the University of California. Supplement provided by UofC, Davis, California.

Appendix I: Meteorological Station Components

Component	Model	Serial #
Air Temperature and Relative Humidity Sensor	HMP45C212	n/a
Tipping Bucket Rain Gauge	TE525M	45303-910
Wind Speed and Direction Sensor	05103AP-10-L	WM105907
Solar Panel	SX320J	T21008289B30EC8
Datalogger	CR800	16119
Battery	PS-12120 F2	06299-HC



Appendix II: Tables

Table 1: Monthly statistic for meteorological parameters collected at Flame and Moth Station

	Monthly Avg. Temp (°C)	Monthly Avg. Max Temp (°C)	Monthly Extreme Max Temp (°C)	Monthly Avg. Min Temp (°C)	Monthly Extreme Min Temp (°C)	Monthly Total Rain (mm)	Monthly Avg. Wind Speed (m/s)	Monthly Max Wind Speed (m/s)
Jun-11¹	11.96	18.59	24.72	6.3	-2.56		1.35	9.14
Jul-11	12.91	18.5	25.67	8	5.09		1.15	8.02
Aug-11	9.78	15.58	22.32	5.37	1.93		1.18	9.15
Sep-11	6.07	11.29	17.97	1.85	-2.47		1.43	11.36
Oct-11	-2.74	0.2	7.2	-5.41	-9.84	2.602	0.94	13.12
Nov-11	-19.54	-16.79	-4.23	-22.47	-34.99	0	0.58	12.05
Dec-11	-12.95	-9.37	-2.61	-16.47	-24.17	0	0.81	14.52

1. 29 complete days – station was commissioned on June 2

2. Partial month (16 complete days) - also some rainfall was recorded at temperatures below 0C and may be due to snowmelt

Table 2: Evapotranspiration estimates at Flame and Moth site

Month	PM ETr (mm d ⁻¹)	HS ETo (mm d ⁻¹)	PM ETo (mm d ⁻¹)	Rs (MJ m ⁻² d ⁻¹)	Tx (°C)	Tn (°C)	U2 (m s ⁻¹)	Td (°C)	Monthly Total (mm)		
									PM ETr	HS ETo	PM ETo
Jan	0.04	0.01	-0.07	0.85	-12.9	-17.2	1.4	-18.3	1.11	0.24	-2.06
Feb	0.25	-0.01	0.14	2.96	-15.8	-21.7	2.7	-21.9	7.05	-0.38	3.79
Mar	0.62	0.07	0.4	9.7	-13.1	-18.1	2.3	-22.1	19.24	2.15	12.42
Apr	1.11	0.63	0.85	16.48	-4.4	-10.2	2.9	-11.2	33.41	18.91	25.38
May¹	6.66	3.85	4.7	21.87	20.4	8.1	3.1	0.4	206.51	119.26	145.58
Jun	3.67	4.11	3.14	20.1	18.6	6.3	1.4	7.1	109.97	123.38	94.24
Jul	3.08	3.63	2.73	15.9	18.5	8	1.1	9.3	95.5	112.39	84.63
Aug	2.3	2.48	2	12.9	15.6	5.4	1.2	7.1	71.35	76.79	62.14
Sep	1.65	1.26	1.28	8.9	11.3	1.9	1.4	2.3	49.62	37.94	38.43
Oct	0.02	0.27	0.12	3.5	0.2	-5.4	0.9	-0.4	0.73	8.28	3.83
Nov	0	-0.01	-0.02	0.9	-16.8	-22.5	0.6	-19.1	-0.11	-0.28	-0.52
Dec	-0.17	0.01	-0.25	0.3	-9.4	-16.5	0.8	-12.7	-5.28	0.22	-7.86

¹ Likely over estimates ET at Flame and Moth due to MAYO A data

Legend:

Data from Galena Hill Met. Station

Date from MAYO A Met. Station

PM ETr Calculated reference evapotranspiration for 0.5 m tall reference surface using Penman-Monteith equation
 HS ETo Calculated reference evapotranspiration using Hargreaves-Samani (1985) equation
 PM ETo Calculated reference evapotranspiration for 0.12 m tall reference surface using Penman-Monteith equation
 Rs Solar Radiation (From Galena Hill Station)
 Tx Average Daily Maximum Temperature
 Tn Average Daily Minimum Temperature
 U2 Wind Speed
 Td Average Dew Point Temperature

Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

From: Anthony Bier, Access Consulting Group, Catherine Henry, Access Consulting Group

CC: Tiffany Lunday, Access Consulting Group

Date: March 28, 2012

Re: Data Summary for 2011 Flam and Moth Meteorological Station, Keno, YT

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Solar Panel	SX320J	T21008289B30EC8
Datalogger	CR800	16119
Battery	PS-12120 F2	06299-HC



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Oct-11	-2.74	0.2	7.2	-5.41	-9.84	2.602	0.94	13.12
Nov-11	-19.54	-16.79	-4.23	-22.47	-34.99	0	0.58	12.05
Dec-11	-12.95	-9.37	-2.61	-16.47	-24.17	0	0.81	14.52

1. 29 complete days – station was commissioned on June 2

2. Partial month (16 complete days) - also some rainfall was recorded at temperatures below 0C and may be due to snowmelt

Table 2: Evapotranspiration estimates at Flame and Moth site

Month	PM ETr (mm d ⁻¹)	HS ETo (mm d ⁻¹)	PM ETo (mm d ⁻¹)	Rs (MJ m ⁻² d ⁻¹)	Tx (°C)	Tn (°C)	U2 (m s ⁻¹)	Td (°C)	Monthly Total (mm)		
									PM ETr	HS ETo	PM ETo
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Mar	0.62	0.07	0.4	9.7	-13.1	-18.1	2.3	-22.1	19.24	2.15	12.42
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May¹	6.66	3.85	4.7	21.87	20.4	8.1	3.1	0.4	206.51	119.26	145.58
Jun	3.67	4.11	3.14	20.1	18.6	6.3	1.4	7.1	109.97	123.38	94.24
Jul	3.08	3.63	2.73	15.9	18.5	8	1.1	9.3	95.5	112.39	84.63
Aug	2.3	2.48	2	12.9	15.6	5.4	1.2	7.1	71.35	76.79	62.14
Sep	1.65	1.26	1.28	8.9	11.3	1.9	1.4	2.3	49.62	37.94	38.43
Oct	0.02	0.27	0.12	3.5	0.2	-5.4	0.9	-0.4	0.73	8.28	3.83
Nov	0	-0.01	-0.02	0.9	-16.8	-22.5	0.6	-19.1	-0.11	-0.28	-0.52
Dec	-0.17	0.01	-0.25	0.3	-9.4	-16.5	0.8	-12.7	-5.28	0.22	-7.86

¹ Likely over estimates ET at Flame and Moth due to MAYO A data

Legend:

Data from Galena Hill Met. Station

Date from MAYO A Met. Station

PM ETr Calculated reference evapotranspiration for 0.5 m tall reference surface using Penman-Monteith equation
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Rs Solar Radiation (From Galena Hill Station)
Tx Average Daily Maximum Temperature
Tn Average Daily Minimum Temperature
U2 Wind Speed
Td Average Dew Point Temperature

Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

From: Anthony Bier, Access Consulting Group

CC: Brad Thrall, Alexco Keno Hill Mining Corp, Tiffany Lunday, Access Consulting Group

Date: August 1, 2012

Re: Keno District Mine Operations Snow Survey Summary, 2011 and 2012 Winter Programs

1 INTRODUCTION

The following memo describes the snow survey undertaken in and around Keno City, the Bellekeno Mine and the District Mill during the 2012 winter season by Access Consulting Group (ACG). Results for the 2011 snow sampling program are also provided herein. The sampling program was initiated in 2011, and consists of ten regular sampling locations.

2 METHODS

One sample was taken at each of ten designated locations (Figure 1) once monthly from January to April 2012 (inclusive).

There are several different methods to observe snow. Among these are:

- Utilizing a catch gauge to measure volumetric snowfall as snow water equivalent
- Recording snow depth and density to manually calculate snow water equivalent (SWE)
- Utilizing a snow sampler or snow tube to take a snowpack core for which the weight and length (snow depth) are recorded.

ACG utilized a Federal (US) specification snow sampler which was on loan from EBA Engineering Consultants Ltd. The spring scale was carefully checked for to ensure proper calibration. The spring scales are calibrated to show weight in snow water equivalent (SWE) in either inches or cm. In March of 2012 ACG purchased a Federal type snow sampler from Geo Scientific Ltd. (Vancouver), which was used for the month of April. It is

recommended that in the future the snowpack also be sampled in May to better understand the rate at which the snowpack melts.

The basic action is to sample the snowpack in an open area to limit the impact of interception on the sample. The snow tube is equipped with a cutter and slowly rotated straight into the snowpack until the ground surface is felt. The snow depth is then noted. Using the cutter, the sampler will cut into the ground surface by twisting and pushing down. The tube is then leaned to the side and pulled out to avoid the core sliding out. The tube is then weighed together with the soil core, at which point the soil core is removed and weighed on its own. The tube must be weighed to find the tare weight prior to each sample.

In the winter of 2012 the soil core was weighed with the snow core but not weighed following the sample. As a result the assumption is made that 5cm moss core equals about 1 gram, every centimeter of mineral soil would equate to 1 gram and every 2.5 cm of organic soil would equate to 1gram. Since detailed descriptions of the soil core or moss plug were taken this was possible. One gram is equal to 2.65 mm of snow water equivalent in the snow tube.

3 RESULTS

Table 1 shows the SWE in cm for 2011 for each month at each site as well as the mean monthly SWE.

Table1: 2011 Snow survey results in cm of SWE

Station	Date 2011		
	Jan-12	Feb-10	Mar-22
BKS-1	7.6	7.6	5.1
BKS-2	7.6	7.6	7.6
BKS-3	7.6	10.2	7.6
BKS-4	7.6	7.6	7.6
BKS-5	5.1	7.6	5.1
BKS-6	2.5	2.5	0.0
BKS-7	7.6	10.2	7.6
BKS-8	7.6	7.6	5.1
BKS-9	7.6	10.2	10.2
BKS-10	10.2	7.6	5.1
Mean	7.1	7.9	6.1

Table 2 shoes the SWE in cm in 2012 for each month at each site as well and the mean monthly SWE. It should be noted that in January 2012 BKS-5 was sampled next to BKS-10 (figure 1). However, a discrepancy was noticed between the location co-ordinates and the location description and the sample site was move to a new location to reflect the description. It is not known whether BKS-5 samples were taken next to BKS-6 or BKS-10 in 2011.

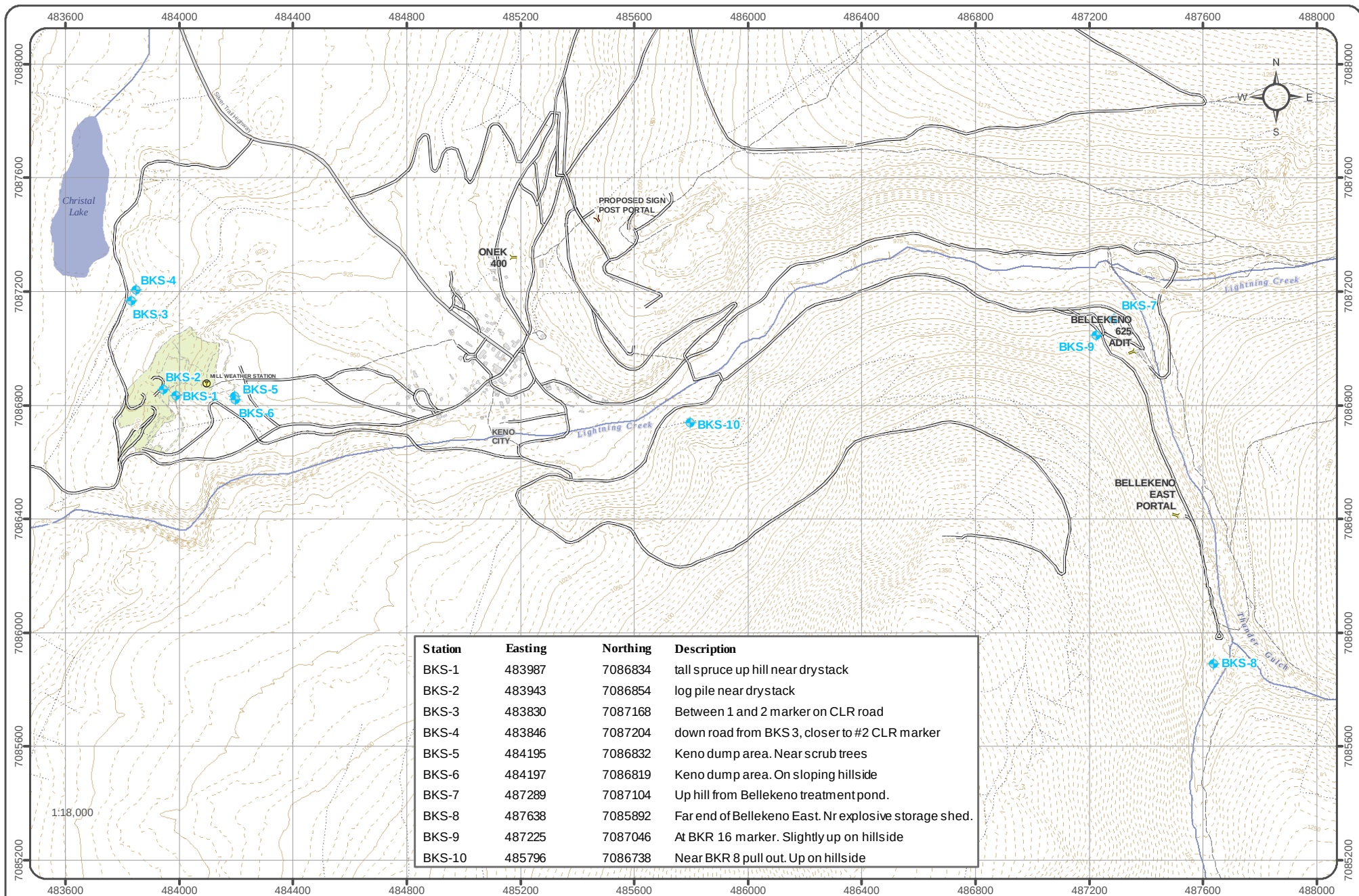
Table 2: 2012 Snow survey results in cm of SWE

Station	Date 2012			
	Jan-18	Feb-12	Mar-17	Apr-13
BKS-1	6.0	16.1	18.7	8.7
BKS-2	12.2	13.6	9.3	20.8
BKS-3	9.6	12.5	4.4	7.7
BKS-4	8.5	17.6	12.3	8.8
BKS-5.0	13.7			
BKS-5.1		11.3	12.2	9.6
BKS-6	11.2	12.6	14.8	19.8
BKS-7	12.5	13.7	4.8	8.5
BKS-8	9.9	13.8	17.4	19.5
BKS-9	12.4	13.3	17.1	0.0
BKS-10	13.3	16.5	27.7	10.7
Mean	10.9	14.1	13.9	11.4

The survey results show that the snowpack reached its peak in February. According to the Yukon Snow Survey Bulletin & Water Supply Forecast April 1, 2012, peak snowpack in the Stewart River Sub-Basin is usually the end of March/beginning of April, as was the case in 2012 (Government of Yukon, 2012). Two possible explanations have been found for the departure in results obtained in the Keno District from those obtained for the Stewart Basin by GY. It may be the case that there are an insufficient number of locations to represent the snowpack in the Keno District. This can be resolved by expanding the sampling network to include more locations and capture more aspects in 2013, which is the intent for 2013. Another potential cause of the apparent decrease from February to March could be due to snow drifting, as there was a marginal increase in accumulation from February to March in the Stewart River Basin (Government of Yukon, 2012). An expanded network may also resolve issues associated with snow drift.

REFERENCES

Government of Yukon, 2012. Yukon Snow Survey Bulletin and Water Supply Forecast April 1, 2012, Water Resources Branch, Department of Environment, Government of Yukon. Box 2703, Whitehorse, Yukon Y1A 2C6.



Station	Easting	Northing	Description
BKS-1	483987	7086834	tall spruce up hill near drystack
BKS-2	483943	7086854	log pile near drystack
BKS-3	483830	7087168	Between 1 and 2 marker on CLR road
BKS-4	483846	7087204	down road from BKS 3, closer to #2 CLR marker
BKS-5	484195	7086832	Keno dump area. Near scrub trees
BKS-6	484197	7086819	Keno dump area. On sloping hillside
BKS-7	487289	7087104	Up hill from Bellekeno treatment pond.
BKS-8	487638	7085892	Far end of Bellekeno East. Nr explosive storage shed.
BKS-9	487225	7087046	At BKR 16 marker. Slightly up on hillside
BKS-10	485796	7086738	Near BKR 8 pull out. Up on hillside

National Topographic Data Base (NTDB) compiled by Natural Resources Canada at a scale of 1:50,000. Cadastral data compiled by Natural Resources Canada. Reproduced under license from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

Site contours derived from 2006 aerial imagery obtained from Aero Geometrics, Calgary Alberta.

Datum: NAD 83; Map Projection: UTM Zone 8N

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	Snow Monitoring Station		Highway		5 Meter Contours
	Weather Station		Secondary Road		25 Meter Contours
	Proposed Adit		Track		Buildings
	Adit		Trail		Mill Site



WINTER 2011 & 2012 KENO SNOW SURVEY SUMMARY

**FIGURE 1:
AKHM SNOW SURVEY SAMPLE LOCATIONS**

AUGUST 2012

D:\Project\AI\Projects\AL\EX-05-03\Bellekeno\GIS\mxd\Overview_Maps\WQ_Stations\SnowSurvey\SnowMonitoring_20120801.mxd
(Last edited by: Jirdeban; 03/08/2012 15:15 PM)

Appendix 2 Typical Waste Containment Facility Design, EBA, 2008

Alexco Resource Canada Corp.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT
CONSTRUCTION SPECIFICATIONS
ISSUED FOR USE

W14101142

July 2008

TABLE OF CONTENTS

<u>Section</u>		<u>Number of Pages</u>
Section 1001	Definitions	1
Section 1002	General	2
Section 1003	Fill Materials	2
Section 1004	Fill Placement	2
Section 1005	Liner System	11
Section 1006	Quality Assurance	5
Section 1007	Design Alternatives	2
Section 1008	Operation and Maintenance	2

APPENDICES

Appendix A Construction Drawings



Section 1001

DEFINITIONS

DEFINITIONS

1.0 General

- .1 Definitions of terms used throughout the Construction Specifications are presented in this Section.

2.0 Definitions

Construction Drawings:	the drawings, as issued for construction, of the Typical Waste Containment Facility Design.
Construction Specifications:	this document.
Contract:	the legal and binding agreement between the Contractor and Alexco Resource Corp. regarding construction of the Waste Containment Facility.
Contractor:	the general contractor responsible for constructing the Waste Containment Facility.
Engineer:	the Professional Geotechnical Engineer registered in the Yukon who is associated with the construction process.
Owner:	Alexco Resource Corp.
Site:	the area in which construction of the Waste Containment Facility or related activity is occurring.
Unsuitable:	not meeting the requirements stated herein or not receiving the Engineer's approval.
Facility:	all components of the Waste Containment Facility.

END OF SECTION



Section 1002

GENERAL

GENERAL

1.0 General

- .1 Alexco Resource Canada Corp. intends to construct a containment facility to store waste rock from the Bellekeno advanced underground exploration and development program. As the company advances through the Keno Hill Silver District, it is anticipated further underground exploration and development programs will require similar containment facilities. Therefore, a typical design has been developed to account for the various potential site and construction material conditions.
- .2 The Facility is to be located within previously disturbed areas, all of which will be incorporated within a district wide closure plan. This district wide closure plan is required under the water license QZ06-074.
- .3 Site specific conditions and Facility location have not been provided or considered. Once Facility location and site specific conditions are known, they must be reviewed by the Engineer. Furthermore, the base of the Facility must be approved by the Engineer prior to fill placement.
- .4 The Facility will be lined with a suitable geomembrane. Water in the Facility will flow towards the vertical culvert and pond within the voids of the waste material.
- .5 Water in the Facility will be monitored and tested on a regular basis. Based on water quality analysis, the waste water will be extracted via pump truck and discharged to the environment or treated in a designated treatment facility.
- .6 Once the Facility reaches its ultimate capacity, the Facility will be capped and reclaimed.

2.0 Scope of Work

- .1 The scope of work for the construction of the Facility is as follows:
 - a. Construct the liner subgrade and berms with Zone B material at the specified grade. This could include cut/fill operations should the foundation material be satisfactory;
 - b. If required, install a geotextile layer to act as separator for Zone A and Zone B materials;
 - c. Construct the liner bedding with Zone A material;

- d. Install the liner system consisting of a suitable liner material and if required, protective geotextile layers above and below the liner, and a geocomposite reinforcing layer;
- e. Place and compact cover material, Zone A material, over the liner system;
- f. Install vertical culvert as specified on the Construction Drawings;
- g. Place and compact the waste material;
- h. Regrade the waste material and place and compact capping material;
- i. Install vegetative cover.

END OF SECTION



Section 1003

FILL MATERIALS

FILL MATERIALS

1.0 General

- .1 This section describes the construction material specifications for the Waste Containment Facility.

2.0 Reference Standards

- .1 The most recent copy of American Society for Testing Materials, ASTM C136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate.

3.0 Material Sources

- .1 No material of any type shall be borrowed or excavated without the Owner's prior approval.
- .2 Pits and quarries shall be maintained and managed in accordance with the requirements set out in the Owner's Land Use and Quarry Permits.
- .3 Zone A material shall be obtained from sources approved by the Owner, provided the final product meets the requirements specified herein. Processing may be required to achieve the specified gradation.
- .4 Zone B material shall be obtained from sources approved by the Owner, provided the final product meets the requirements specified herein. Processing may be required to achieve the specified gradation.
- .5 The parent rock from which all fill materials are derived shall consist of sound, hard, durable material free from soft, thin, elongated or laminated particles and shall contain no unsuitable substances. The potential quarry source shall be approved by the Engineer.
- .6 The quarry source for the Facility fill materials shall be inspected by the Engineer throughout material processing to ensure the product meets the requirements stated herein.

4.0 Material Specifications

.1 Zone A Material

The Zone A material shall consist of hard, durable particles, shall be free of roots, topsoil, and deleterious material and shall have a particle size distribution, as measured by ASTM C136, as presented in Table 1003.1.

TABLE 1003.1: ZONE A MATERIAL (10 MM MINUS) - PARTICLE SIZE DISTRIBUTION LIMITS

Sieve Size (mm)	% Passing Fine Limit	% Passing Coarse Limit
10	100	100
5	80	100
2	55	100
0.63	25	65
0.25	10	40
0.08	2	15

.2 Zone B Material

The Zone B material shall be free of roots, topsoil and other deleterious material and shall have a particle size distribution within the limits presented in Table 1003.2.

TABLE 1003.2: ZONE B MATERIAL (200 MM MINUS) - PARTICLE SIZE DISTRIBUTION LIMITS

Sieve Size (mm)	% Passing Fine Limit	% Passing Coarse Limit
200	100	100
100	85	100
50	65	100
25	40	100
5	20	55
2	0	20

END OF SECTION



Section 1004

FILL PLACEMENT

FILL PLACEMENT

1.0 General

- .1 The fill placement methods to be used during construction of the Waste Containment Facility are described in this Section.
- .2 Construction shall be performed in accordance with the best modern practice and with equipment best adapted to the work being performed. Embankment materials shall be placed so that each zone is homogeneous; free of stratifications; ice chunks, lenses or pockets; and layers of material with different texture grading not conforming to the requirements stated herein.
- .3 No fill material shall be placed on any part of the foundation until it has been prepared, as specified herein. Placement of fill material shall conform to the lines, grades and elevations shown on the Construction Drawings.
- .4 Embankment construction shall not proceed when the work cannot be performed in accordance with the requirements of the Construction Specifications. Any part of the embankment that has been damaged by the action of rain, snow or any other cause shall be removed and replaced with the appropriate material conforming to the requirements stated herein.
- .5 Stockpiling, loading, transporting, placing, and spreading of all materials shall be carried out in such a manner to avoid segregation. Segregated materials shall be removed and replaced with the materials meeting the requirements stated herein.
- .6 The Contractor shall remove all debris, vegetation or any other material not conforming to the requirements stated herein. The Contractor shall dispose of these materials in an area approved by the Owner.

2.0 Zone B Material Placement

- .1 The Zone B material shall be placed to the design elevation as specified in the Construction Drawings in lifts no greater than 500 mm in uncompacted thickness.
- .2 The design elevation for the top of the Zone B berm material shall be no less than 0.5 m above original ground.
- .3 Moisture condition and compact using the minimum number of passes established in accordance with section 1006.4.2.

3.0 Zone A Material Placement

- .1 The Zone A material shall be placed as bedding for the liner system (minimum 300 mm thick) to the design grade specified in the Construction Drawings.
- .2 Subsequent to the liner installation, the Zone A material shall be placed as liner system cover material. The liner system cover material shall be placed to the minimum thickness specified in Table 1004.1 dependent on the type of liner selected.

TABLE 1004.1: RECOMMENDED MINIMUM COVER THICKNESSES

Liner Material	Minimum Required Thickness
Enviro Liner® 4040 (Without Geocomposite)	1.3 m
Enviro Liner® 4040 (With Geocomposite)	0.3 m
HDPE 60	0.3 m
PVC 40 (With Geocomposite)	0.3 m

- .3 The Construction Drawings are based on the selection of Enviro Liner® 4040 with the installation of a geocomposite reinforcing material. Other design alternatives are detailed in Section 1007.
- .4 Zone A material shall be placed in lifts not exceeding 300 mm in uncompacted thickness. Vehicle traffic is prohibited from maneuvering within the Facility until the cover material has reached the minimum thickness required as specified in Table 1004.1.
- .5 Moisture condition and compact with using the minimum number of passes established in accordance with section 1006.4.1.
- .6 Equipment with ground pressures higher than 380 kPa should not be permitted inside the Facility once the liner system has been placed. Care is required to provide the appropriate thickness of fill beneath a vehicle when placing material above the liner system to ensure it is not damaged. Traffic in the area should be restricted to low ground pressure equipment.

END OF SECTION



Section 1005

LINER SYSTEM

LINER SYSTEM

1.0 General

- .1 The product and installation specifications for the non-woven geotextile, liner systems and geocomposite materials to be used in the Waste Containment Facility are presented in this section.
- .2 The liner system will be provided by the Owner and installed by the Contractor.

2.0 Reference Standards

- .1 The most recent copy of the following American Society for Testing Materials standards:
 - a. ASTM D638 Standard Methods for Tensile Properties of Plastics.
 - b. ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.
 - c. ASTM D1004 Standard Test Methods for Initial Tear Resistance of Plastic Film and Sheeting.
 - d. ASTM D1603 Standard Test Methods for Carbon Black in Olefin Plastics.
 - e. ASTM D1777 Standard Test Methods for Thickness of Textile Materials.
 - f. ASTM D4533 Standard Test Methods for Trapezoidal Tearing Strength of Geotextiles.
 - g. ASTM D4632 Standard Test Methods for Grab Breaking Load and Elongation of Geotextile.
 - h. ASTM D4751 Standard Test Methods for Determining Apparent Opening Size of a Geotextile.

- i. ASTM D4833 Standard Test Methods for Index Puncture Resistance for Geotextile, Geomembranes, and Related Products.
 - j. ASTM D5199 Standard Test Methods for Measuring the Nominal Thickness of Geosynthetics.
 - k. ASTM D5261 Standard Test Methods for Measuring Mass per Unit Area of Geotextiles.
 - l. ASTM D5994 Standard Test Methods for Measuring Core Thickness of textured Geomembranes
- .2 Federal Test Method
- a. FTM Standard 101.

3.0 Materials

.1 Geotextile

- a. The non-woven geotextile shall have a weight of 542 g/m². The manufacturer shall, prior to shipment of materials, provide to the Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.1.

TABLE 1005.1: RECOMMENDED MINIMUM GEOTEXTILE PROPERTIES

Physical Property	Minimum Average Roll Value (Weakest Principle Direction)
Thickness – Typical (ASTM D5199)	3.6 mm
Grab Tensile Strength (ASTM D4632)	1690 N
Elongation at Failure (ASTM D4632)	50 %
Trapezoidal Tear Strength (ASTM D4533)	645 N
Puncture (ASTM D4833)	1070 N
Apparent Opening Size (ASTM D4751)	150 microns
Weight – Typical (ASTM D5261)	542 g/m ²

- b. Any visible damage to the shipment of geotextile shall be noted on the freight receipt and project records.
- c. Storage of geotextile rolls on site shall be in a secure location that will minimize exposure to the elements, UV light and physical damage.

.2 Enviro Liner® 4040

- a. The Enviro Liner® shall be 1.0 mm (40 mil) thick geomembrane or equivalent. The manufacturer shall, prior to shipment of materials, provide to the Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.2.

TABLE 1005.2: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

Property	Enviro Liner® 4040
Minimum Average Thickness (ASTM D5994)	1.0 mm
Relative Density (ASTM D792)	0.939
Tensile Strength at Yield (ASTM D638)	26.6 N/mm
Elongation at Yield (ASTM D638)	800 %
Tear Resistance (ASTM D1004)	98 N
Puncture Resistance (FTMS 101)	271 N
Carbon Black Content (ASTM D1603)	2.0 – 3.0 %

- b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.
- c. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements and physical damage.
- d. Enviro Liner® geomembrane is suitable for secondary containment of hydrocarbons and other chemicals, and primary containment of water and water based effluents or as approved by manufacturer.

.3 HDPE Liner

- a. The HDPE geomembrane shall be 1.5 mm (60 mil) thick geomembrane or equivalent. The manufacturer shall, prior to shipment of materials, provide to the Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.3.

TABLE 1005.3: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

Property	Textured HDPE 60
Minimum Average Thickness (ASTM D5994)	1.5 mm
Relative Density (ASTM D792)	0.94
Tensile Strength at Yield (ASTM D638)	22.0 kN/m
Elongation at Yield (ASTM D638)	12 %
Tear Resistance (ASTM D1004)	187 N
Puncture Resistance (FTMS 101)	480 N
Carbon Black Content (ASTM D1603)	2.0 – 3.0 %

- b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using welding techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.
- c. Extrusion resin used for extrusion joining of sheets and for repairs should be HDPE from the same resin batch as the sheet resin. Physical properties must be the same as the liner sheets.
- d. HDPE liner is suitable for containment of hydrocarbons and chemicals as well as water and water based effluents or as approved by manufacturer.
- e. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements and physical damage.

.4 PVC Liner

- a. The PVC geomembrane shall be 0.95 mm (38 mil) thick geomembrane or equivalent. The manufacturer shall, prior to shipment of materials, provide to the

Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.4.

TABLE 1005.4: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

Property	PVC 40
Minimum Average Thickness (ASTM D5994)	0.95 mm
Tensile Strength at Yield (ASTM D638)	17 N/mm
Elongation at Yield (ASTM D638)	430 %
Tear Resistance (ASTM D1004)	44 N

- b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.
- c. PVC liner is suitable for containment of water and water based effluents or as approved by manufacturer. It is not suitable for containment of hydrocarbons.
- d. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements, UV light and physical damage.

.5 Geocomposite

- a. The geocomposite reinforcing material shall be 5 mm (200 mil) thick or equivalent. The manufacturer shall, prior to shipment of materials, provide to the Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.5.

TABLE 1005.5: RECOMMENDED MINIMUM GEOCOMPOSITE PROPERTIES

Property	Geo-Comp 5
Minimum Average Thickness (ASTM D5994)	5 mm
Relative Density (ASTM D792)	0.94
Tensile Strength at Yield (ASTM D638)	79 N/cm
Puncture Resistance (FTMS 101)	489 N
Carbon Black Content (ASTM D1603)	2.0 %

- b. The geocomposite material supplied under the specifications shall not have defects or any signs of contamination or inclusions of foreign matter. Excessive defects may be grounds for rejecting the entire roll of geocomposite.

4.0 Installation - Enviro Liner® 4040 Design (with Geocomposite)

- .1 The liner system consists of the following layers (starting from the top layer):
 - Geo-Comp 5 or equivalent geocomposite
 - Enviroliner 4040 or equivalent geomembrane
- .2 The liner should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor. The geocomposite material is only required on the floor and approach berm of the Facility.
- .3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.
- .4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.
- .5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.
- .6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

Enviro Liner® Installation

- .7 The Enviro Liner® should be deployed subsequent to the placement of Zone A bedding material.

- .8 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional piece of Enviro Liner® installed as per the manufacturer's specifications over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.
- .9 Low ground pressure equipment should be used to deploy the liner material. No equipment shall be allowed on the liner.

Geocomposite Reinforcing Installation

- .10 The geocomposite material should be deployed subsequent to the placement of the Liner.
- .11 No equipment is permitted on the liner material during the placing of the geocomposite reinforcing material. The geocomposite reinforcing material must rolled out by hand and the cover material placed in accordance with Section 1004.

Material Quantities

- .12 Estimated material quantities required for the lined pad are listed in Table 1005.6

TABLE 1005.6: MATERIAL QUANTITY ESTIMATES

Material	Total Area (m ²)
Enviro Liner® 4040	1900
Geo-Comp 5	905

5.0 Installation - HDPE 60 Design

- .1 The liner system consists of the following layers (starting from the top layer):
 - HDPE 60 mil or equivalent geomembrane
- .2 The liner should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor.
- .3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to

avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.

- .4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.
- .5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.
- .6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

HDPE Liner Installation

- .7 The HDPE liner should be deployed subsequent to the placement of Zone A bedding material. The liner should be placed with no horizontal seams on the slopes. Tie-in seams should be located on the floor at a minimum of 1.5 m from the toe of the slopes.
- .8 The liner panels shall be welded together along the full length of the seam to the top of the berm.
- .9 Both the wedge and the extrusion welding equipment should be qualified by conducting trial seam tests prior to start-up each day and at approximately 4-hour intervals during seaming operations. During the trial seam, the minimum peel and shear strength criteria set by the manufacturer for the 60 mil HDPE geomembrane should be met. The industry-accepted peel and shear strengths for 60 mil HDPE geomembrane are 78 ppi (pounds/inch) and 120 ppi, respectively.
- .10 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional

piece of HDPE liner extrusion welded over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.

- .11 Low ground pressure equipment should be used to deploy the liner material. No track-wheel equipment shall be allowed on the liner. Equipment travel on the liner material should be kept to a minimum.

Material Quantities

- .12 Estimated material quantities required for the lined pad are listed in Table 1005.7

TABLE 1005.7: MATERIAL QUANTITY ESTIMATES

Material	Total Area (m ²)
HDPE 60 Liner	1900

6.0 Installation - PVC 40 Design

- .1 The liner system consists of the following layers (starting from the top layer):
 - Geo-Comp 5 or equivalent geocomposite
 - PVC 40 mil or equivalent geomembrane
- .2 The liner system should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor. The geocomposite material is only required on the floor and approach berm of the Facility.
- .3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.
- .4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.

- .5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.
- .6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

PVC Liner Installation

- .7 The PVC liner should be deployed subsequent to the placement of Zone A bedding material.
- .8 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional piece of PVC liner installed as per the manufacturer's specifications over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.
- .9 Low ground pressure equipment should be used to deploy the liner material. No equipment shall be allowed on the liner.

Geocomposite Reinforcing Installation

- .10 The geocomposite material should be deployed subsequent to the placement of the Liner.
- .11 No equipment is permitted on the liner material during the placing of the geocomposite reinforcing material. The geocomposite reinforcing material must be rolled out by hand and the cover material placed in accordance with Section 1004.

Material Quantities

.12 Estimated material quantities required for the lined pad are listed in Table 1005.8

TABLE 1005.8: MATERIAL QUANTITY ESTIMATES

Material	Total Area (m ²)
PVC 40 Liner	1900
Geo-Comp 5	905

END OF SECTION



Section 1006

QUALITY ASSURANCE

QUALITY ASSURANCE

1.0 General

- .1 The quality assurance testing suggested is described in this section.

2.0 Reference Standards

- .1 The most recent edition of the following American Society for Testing Materials standards:
 - a. ASTM C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
 - b. ASTM D698 – Standard -Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))
 - d. ASTM D4437 – Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes.
- .2 Geosynthetic Research Institute
 - a. GRI Test Method GM6 – Pressurized Air Channel Test for Dual Seamed Geomembranes.

3.0 Fill Particle Size Testing Requirements

- .1 Zone A Material
 - a. Samples of the Zone A material should be evaluated from locations within the borrow source prior to construction. One sample will be evaluated every 500 m³ placed during construction to ensure the placed gradation meets the specification stated herein. The required tests and testing frequency for the Zone A material are presented in Table 1006.1.

TABLE 1006.1: TESTING AND FREQUENCY OF ZONE A MATERIAL

Test	Test Frequency
Particle Size Analysis	One (1) test every 500 m ³ during construction.

.2 Zone B Material

- a. Samples of the Zone B material will be evaluated from the foundation material within the Facility prior to construction and every 2000 m³ placed during construction to ensure the placed gradation meets the specification stated herein. The required tests and testing frequency for the Zone B material are presented in Table 1006.2.

TABLE 1006.2: TESTING AND FREQUENCY OF ZONE B MATERIAL

Test	Test Frequency
Particle Size Analysis	One (1) location within the Facility and One (1) test every 2000 m ³ during construction.

4.0 Fill Compaction Testing Requirements

.1 Zone A Material

- a. Compact each lift with a minimum of six passes using a large smooth-drum, vibratory compactor. The optimum vibratory frequency and number of passes should be determined during construction using proof-roll tests, which demonstrate optimum compaction. The Engineer should inspect the compaction effort to ensure that this effort results in a density equivalent to about 95% MDD.

.2 Zone B Material

- a. Compact each lift with a minimum of six passes using a large smooth-drum, vibratory compactor. The optimum vibratory frequency and number of passes should be determined during construction using proof-roll tests, which demonstrate optimum compaction. The Engineer should inspect the compaction effort to ensure that this effort results in a density equivalent to about 98% MDD.
- b. The foundation material (Zone B or subcut material) should also be compacted as specified in section 1006.4.1.

5.0 Geomembrane Testing Requirements

.1 General

- a. The Contractor is responsible for obtaining mill certificates from the manufacturer and forwarding them to the Engineer.
- b. If applicable, the Contractor shall record all seam parameters (i.e. time, date, operator, welding speed and temperature) on the liner.
- c. If applicable, the Contractor shall be responsible for completing the vacuum box testing and pressure testing for the appropriate seams. The Contractor shall mark the test number and parameters on the liner.
- d. If applicable, the Contractor shall supply and use a field tensiometer for testing liner seams for shear and peel strength.
- e. The Contractor is responsible for maintaining testing records.
- f. All coupons and test specimens remain the property of the Owner.

.2 Qualifying Welds

- a. Qualifying seams shall be conducted on fragmented pieces of material at the following times:
 - At the start of each shift of production seaming, and at 4 hour intervals during production seaming;
 - When a new operator or new machine starts welding;
 - When a machine is restarted after repairs;
 - When welding is stopped for sixty (60) minutes or more;
 - When there is a change in the ambient conditions; and
 - At the discretion of the Engineer.
- b. Qualifying seams shall be 1 m long, and shall be subject to shear and peel testing. The test seam shall meet the minimum requirements stated herein for seam strength, when tested on a field tensiometer. If a qualifying seam fails, the seaming procedure shall be reviewed and the test shall be repeated.

.3 Non-Destructive Testing

- a. Test all wedge-welded seams over their full length using a vacuum unit or air pressure test.
 - Seam intersections will also be subject to vacuum box testing, regardless of seaming method employed.
 - The Contractor shall supply all apparatus and personnel for this type of test.
 - The tests shall be witnessed and documented by the Engineer.
- b. Clean all seams to permit proper inspection.
- c. Repair any seams which fail non-destructive testing in accordance with this Specification. Repairs shall be fully documented by the Contractor.

.4 Vacuum Box Testing

- a. Extrusion welded seams should be tested using either vacuum box testing or pick-testing. Vacuum box testing involves placing the extrusion weld under a vacuum. The weld is first coated with a soapy water solution and any holes in a weld would be indicated by a stream of bubbles when vacuum is applied.
- b. No leaks shall be permitted while conducting vacuum box testing.
- c. Pick-testing is conducted on uneven surfaces where a vacuum cannot be maintained. During pick testing, attention should be paid to the following specific items:
 - The width of the weld;
 - Weld bond to the underlying geomembrane;
 - Joints between three panels (“T” joints);
 - Defects such as bubbles created within the weld due to moisture; and
 - Textured weld surfaces due to temperature fluctuation in the extrusion welder.

.5 Air Pressure Testing

- a. Wedge welded seams should be air-pressure tested over their full lengths using an air pressure test. Air pressure testing involves pressurizing the air channel located between the dual tracks of the seams to a minimum pressure of 40 psi for a period of five minutes.
- b. During the test, the air pressure is not allowed to drop more than 4 psi (10% allowance). Any leaks and bubbling in the seams found during the non-destructive tests must be repaired by extruding a patch of HDPE material over the defect.
- c. Air pressure testing shall be carried out according to GRI Test Method GM6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

.6 Destructive Testing for Production Seams

- a. Cut-out coupons shall be taken at a minimum frequency of one (1) per 150 m of seam, or once per seam. Coupons shall be cut by the contractor at the location directed by the Engineer. Coupons shall generally be taken from a location that does not affect the performance of the liner. All cut-outs shall have rounded corners. Care shall be taken to ensure that no slits penetrate the parent liner.
- b. All holes left by cut outs shall be patched immediately.

.7 Testing of Repairs

- a. All repairs shall be tested using the Vacuum Box in accordance with test method ASTM 4437.

END OF SECTION



Section 1007

DESIGN ALTERNATIVES

DESIGN ALTERNATIVES

1.0 General

- .1 This section provides design alternatives for the Facility should the fill materials available on or near site not adhere to the gradation specifications stated in Tables 1003.1 and 1003.2.
- .2 Should Zone A, Zone B or both materials not meet the gradation specifications stated in Tables 1003.1 and 1003.2 then the recommended design alternatives are available in Table 1007.1.

TABLE 1007.1: RECOMMENDED DESIGN ALTERNATIVES FOR GRADATION NON-COMPLIANCE				
		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	This section does not apply	This section does not apply	See Section 1007.2
	Gradation Below Fine Limit	See Section 1007.2	See Section 1007.2	See Section 1007.2
	Gradation Above Coarse Limit	See Section 1007.3	See Section 1007.3	See Section 1007.4

2.0 Detailed Design Alternatives – Non-Compliance Criteria I

- .1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required at the interface between Zone A and Zone B materials.
- .2 The geotextile material should be deployed prior to the placement of Zone A material.
- .3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.
- .4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

3.0 Detailed Design Alternatives – Non-Compliance Criteria II

- .1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required above and below the liner system.
- .2 The geotextile material should be deployed prior to the deployment of the liner system as well as subsequent to the deployment of the liner system.
- .3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.
- .4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

4.0 Detailed Design Alternatives – Non-Compliance Criteria III

- .1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required above and below the liner system as well as at the interface between Zone A and Zone B materials.
- .2 The geotextile material should be placed prior to the placing of Zone A material, prior to the deployment of the liner system as well as subsequent to the deployment of the liner system.
- .3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.
- .4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

END OF SECTION



Section 1008

OPERATION AND MAINTENANCE

OPERATION AND MAINTENANCE

5.0 General

- .1 This section provides a general guideline for the operation and maintenance of the Waste Containment Facility.

6.0 Geomembrane Lined Pad

- .1 Structure Maintenance
 - a. This section refers to the structure as the berm, side slopes, and floor of the Facility.
 - b. The structure shall be inspected regularly. Attention shall be concentrated on the following:
 - Eroded and/or damaged granular slope and floor surfaces and
 - Exposed liner material
 - c. Any identified problems should be repaired immediately. The repair can be conducted by reconstructing the damaged or eroded slopes with a material of similar gradation to Zone A material. Any exposed liner material can be recovered with Zone A material; however, if the liner material is damaged, liner installation personnel shall be retained to repair the liner.
- .2 Surface Water Management
 - a. The Facility is designed to drain all surface water to the installed vertical culvert. Each month, the water level must be inspected, pumped and disposed of appropriately.
 - b. The frequency of monitoring must be increased during times of high precipitation or snow melt within the Facility.

7.0 Filling Procedure

- .1 The filling procedure for the Facility is as follows:
 - a. Waste material is not to exceed a height of 3.0 m above the level of the top of the berm unless approved by the Engineer;
 - b. Waste material is not to be placed higher than relative elevation 0.5 m below the crest of the liner unless approved by the Engineer.

8.0 Closure

- .1 Upon reaching capacity the Facility will be capped with material meeting the specifications outlined in Table 1008.1 or as approved by the Engineer.

TABLE 1008.1: CAPPING MATERIAL- PARTICLE SIZE DISTRIBUTION LIMITS

Sieve Size (mm)	% Passing Fine Limit	% Passing Coarse Limit
100	100	100
50	95	100
25	90	100
20	85	100
5	65	90
0.63	35	60
0.08	5	20

- .2 The capping material shall have a minimum thickness of 0.5 m.
- .3 The vegetative cover must be capable of self-regeneration without continuous dependence on fertilizer or re-seeding.
- .4 The vegetative cover must have sufficient density and species diversity to stabilize the surface against the effects of long term erosion.
- .5 Closure monitoring should include inspection for any ponding water. If ponded water is present capping material should be added or re-graded.

END OF SECTION

APPENDIX

APPENDIX A CONSTRUCTION DRAWINGS

Appendix 3 Platoro Project – Example Of In Mine Pool Treatment

Treatment Sludge Use in Mine Pools

- Overview of Platoro Site History
- Water treatment & discussion of sludge alternatives
- Presentation of the in-mine pool treatment technology including results to-date
- Presentation of the expected benefits of in-mine sludge injection on the pool chemistry
 - comparison of sludge use in anaerobic mine pool vs. a hypothetical aerobic mine pool
- Transferability of the carbon-loaded sludge injection strategy to other sites

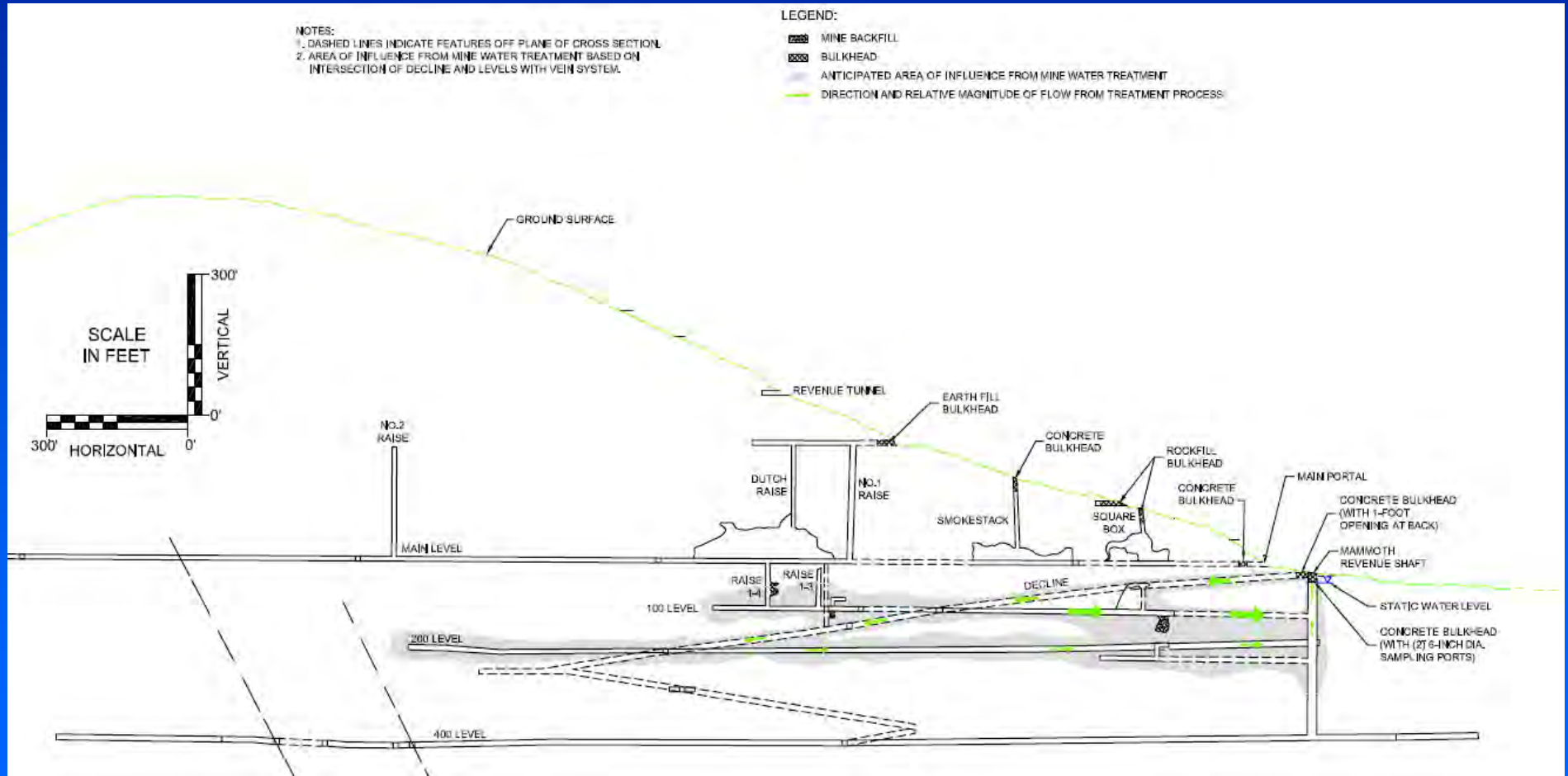
Site History

- First mining in late 1800s
- Most recent mining in 1960s
- UGI began exploration in 1980
 - Above ground water table until 1985
 - Below ground water table; mine dewatered until 1991
- Surface reclamation completed 1993
- Active water treatment pursuant to CDPS permits since 1985

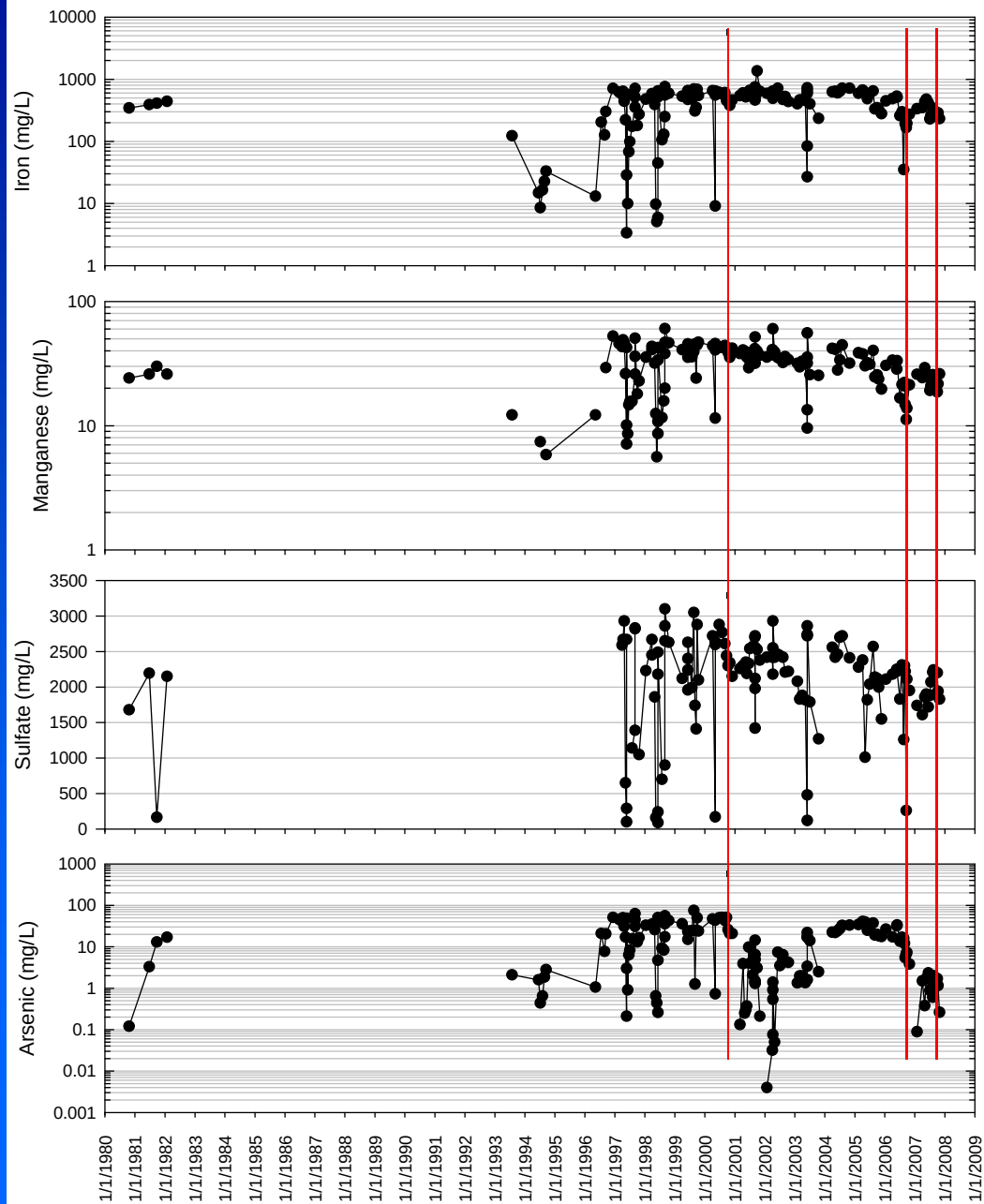
Aerial view of site



Mine Workings



Mine Water Chemistry



Treatment Solids Management

- Sludge management alternatives currently being evaluated
 - Above ground as is currently employed
 - Currently approximately 15,000 to 20,000 cubic yards at 10 to 20 percent solids by weight
 - Hauling offsite
 - Solids pass TCLP
 - Placement in mine with carbon pre-treatment
 - Mine water quality benefits
 - Class V rule authorization injection

Benefits of sludge use in mine pool

- Site-wide reduction of toxicity, mobility and volume
- Iron from treatment plant sludge
 - improves geochemical stability of in pool treatment precipitates
 - improves treatment plant efficiency by enhancing iron | arsenic ratio

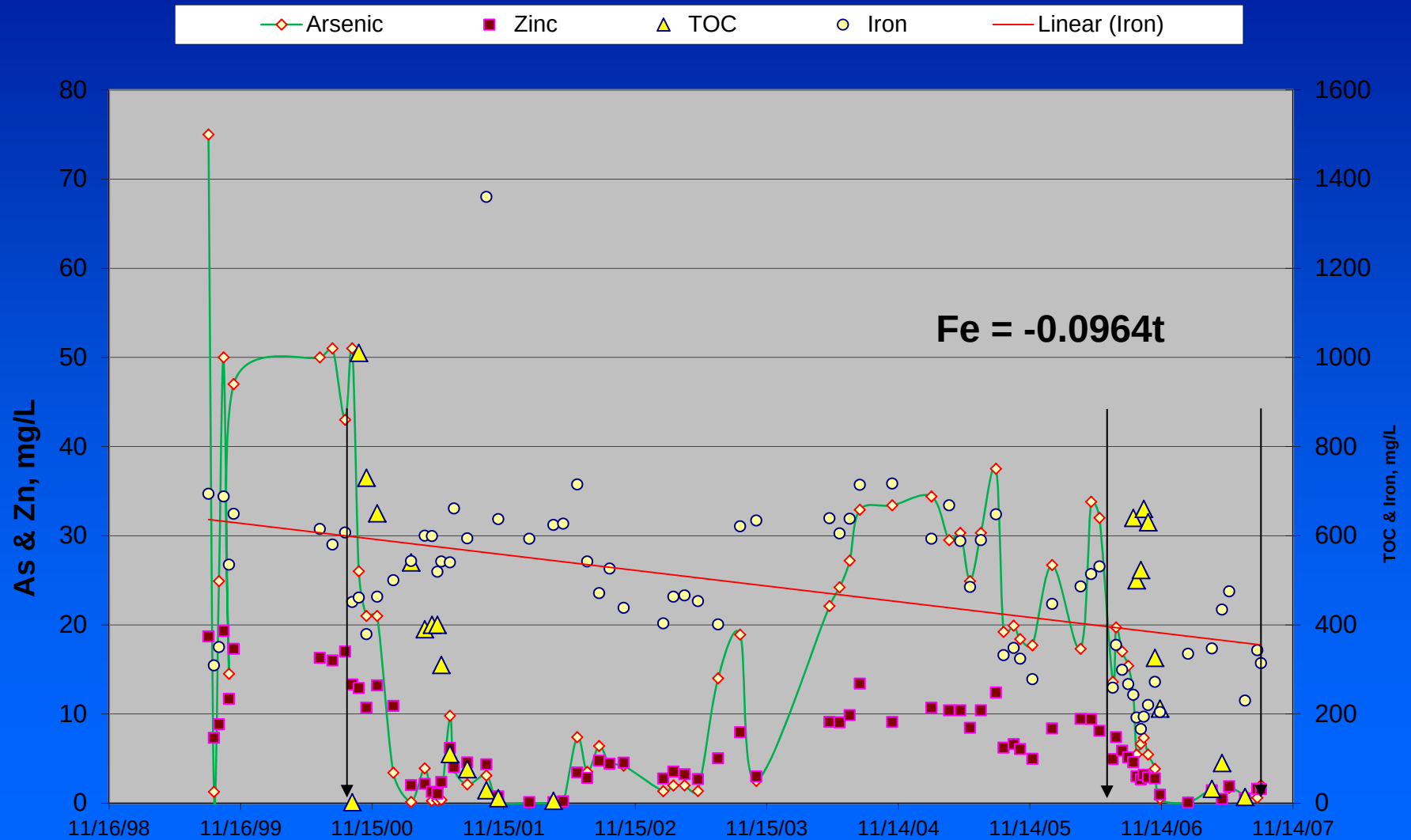
Platoro Mine Pool Treatments

- September 2000, August 2006 and October 2007
- Additions of ethanol, methanol, molasses with minor additives (cheese whey byproducts, fats, CSB)
- Mine pool has become progressively more anaerobic, reducing the generation rate of iron, sulfate and other leaching byproducts
- Solubility of arsenic is reduced through biotreatment (~ 50 mg/L before; <1 mg/L after)

Methanol injection into mine pool



Mine pool injection results



Carbon-Amended Sludge Use

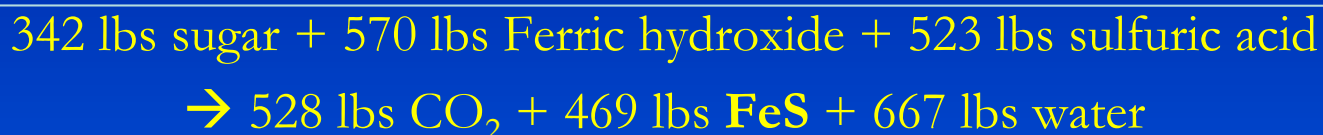
- Net consumption of acidity; or net generator of bicarbonate alkalinity if free acidity is unavailable
- Addition of sugars and other carbon sources (including polysaccharides as needed for long-term redox management) at a stoichiometric amount linked to the amount of metal hydroxides
- Conversion of metal hydroxides to metal sulfide

Advantages of carbon-amended sludge use

- Bicarbonate alkalinity buffering
- Ferric iron consumption—redox buffering
- Reduced volume of sludge
- Improved precipitate stability in lower pH conditions

Fate of contaminants	Ex-situ storage	In-Mine pool treatment
Arsenic	FeOOH arsenate	As ₂ S ₃ :FeAsS ₂
Zinc	Zn(OH) ₂	ZnS
Al, Mn	Al/Mn oxides	Reduced gangue leaching of Al, Mn
Iron	Iron oxyhydroxides	Iron sulfide

Stoichiometry of reactive carbon amendments



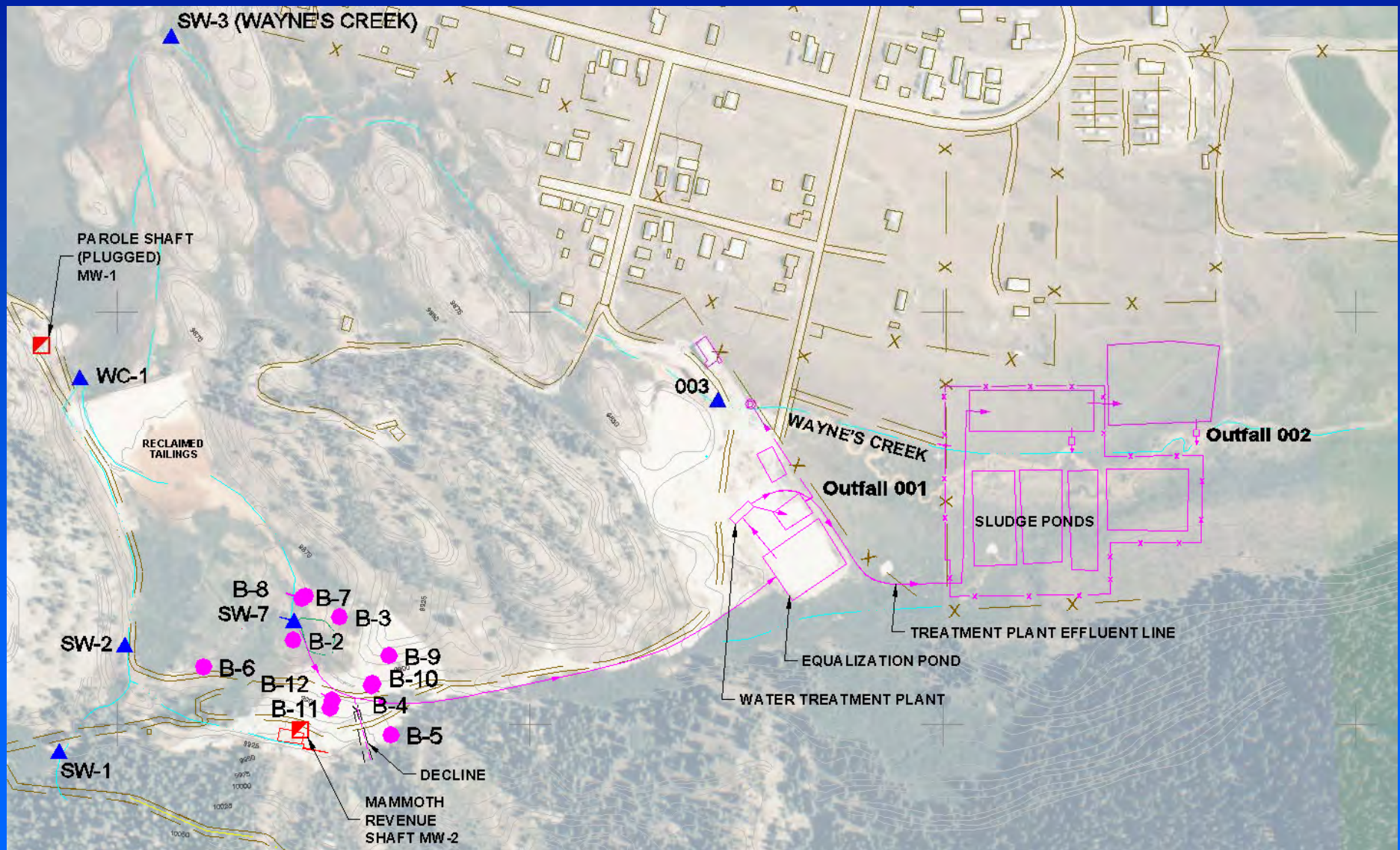
- 1 mole of table sugar reduces 5.3 moles each of iron hydroxide and sulfuric acid; forming iron monosulfide and water
- Net consumption of acidity and large reduction in contaminant volume; re-storing contaminants as insoluble and stable minerals
- Volume of iron hydroxide sludge is more than 17 x greater than for iron monosulfide; ~ 15,000 CY of iron hydroxide sludge should compact to 1,000 CY of mineral sulfide sediment ; other constituent volumes will be somewhat reduced as well

Sludge Stability Effects

- Biogenic minerals tend to be compact in volume and generally out of the flow pathways
- Bacteria reshape precipitates that “stick out”; excess sulfhydryl ion activity (HS^-) temporally dissolves metal as bisulfides which re-precipitate in more stable environs
- Iron sulfide (mackinawite) forms in-place at density higher than 170 lbs/cubic foot
- Present sludge density is less than 11 lbs/cubic foot



Site Overview



Treatment Solids Transfer at the Mammoth-Revenue Mine: Chemistry and Conceptual Engineering Design

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TABLE OF CONTENTS

1.0	INTRODUCTION.....	1
2.0	MINE AREA HYDROGEOLOGY	2
3.0	CHEMISTRY OF TREATMENT PLANT SOLID RESIDUALS.....	5
3.1	Chemical Characteristic of Solids	5
3.2	Alkalinity Potential of Solids.....	5
3.3	Solids Interaction and Steady-State Solution Chemistry	8
3.4	Long-Term Chemical Stability of Solid Residuals	12
4.0	CONCEPTUAL ENGINEERING DESIGN.....	16
4.1	Characterization of Solids.....	16
4.2	Transfer System	18
4.3	Water and Solids Mass Balance.....	19
4.4	Transfer Period	22
4.5	System Configuration	23
4.6	Monitoring and Contingency Plan.....	24

LIST OF TABLES

Table 2-1	Hydraulic Conductivity Of Geologic Materials In The Platoro Valley
Table 3-1	Solid Alkalinity Potential in Depth Samples for Multiple Ponds
Table 3-2	Solution Chemistry for Various Mixtures of Solids and MRS Solution
Table 3-3	Second Phase Batch Mixtures and Solution pH Measurements
Table 3-4	Metals Analyses in Select Second Phase Test Batch Mixtures
Table 4-1	Solids Content in Depth Samples – Ponds 1, 3, and 4
Table 4-2	Material Volumes in Ponds 1, 3, and 4 (units of cubic yards)

LIST OF FIGURES

Figure 1-1	Site Location
Figure 3-1	MRS Solution pH Response to Treatment Plant Residual Additions
Figure 3-2	Alkalinity Titration Curves at Various Depths in the Platoro Solids Collection Ponds
Figure 4-1	Solids Collection Ponds Profile Sampling Locations
Figure 4-2	Slurry Transfer System Layout-Schematic Diagram
Figure 4-3	Dynamic Systems Model of Slurry System
Figure 4-4	Simulated Flows in the Slurry Transfer System
Figure 4-5	Selected Metrics of the Slurry Transfer System
Figure 4-6	Additional Metrics of the Slurry Transfer System

1.0 INTRODUCTION

Union Gold, Inc. (UGI) has operated a water treatment facility in conjunction with exploration activities at the Mammoth-Revenue mine since the mid-1980s and since the mid-1990s has operated the water treatment plant in support of reclamation activities. Over the period of operation, residual solids from the water treatment operation have accumulated in four solids collection ponds that are located to the east of the water treatment plant. In 1999 a fifth solids collection pond was constructed, which has provided volume relief for the remaining ponds. Figure 1-1 shows the site with the layout of the water treatment facility and associated solids collection ponds. In an effort to continue the site reclamation effort, UGI contracted with Telesto Solutions, Inc. (Telesto) to evaluate the geochemical and conceptual engineering implications of transferring residual solids from the ponds into the Mammoth-Revenue mine workings. Such a transfer would accomplish the following multiple, beneficial objectives:

- Placement of chemical mass that originated in the mine workings/mineralized vein back to the point of origin
- Re-establish the capacity of the water treatment ponds with the potential to reclaim one or more of the solids collection ponds
- Utilize un-reacted neutralization capacity of the residual solids as a means of completing in situ treatment of the Mammoth-Revenue mine water

An evaluation of the residual solids transfer option has been completed including a detailed geochemical testing program to assess the potential for metals leaching from contact of the residual solids with mine water both near- and long-term. This document presents results of the residual solids transfer evaluation and is organized in the following manner:

- Section 2 – presents a summary of the mine area hydrology for purposes of establishing hydrologic control over flows affected by the mining and exploration-related conditions in the vicinity of the Mammoth-Revenue mine
- Section 3 – provides detailed discussion of testing procedures and results obtained in assessing the geochemical effect of transferring residual solids to the Mammoth-Revenue mine workings
- Section 4 – describes the conceptual engineering design for completing the residual solids transfer and outlines a monitoring program to evaluate the residual transfer progress and related mine-water chemistry.

2.0 MINE AREA HYDROGEOLOGY

The Platoro area has a long history of mining and exploration dating from the late 1800s. The target of historical mining was the mineralized vein referred to as the Mammoth-Revenue vein, which trends to the northwest and dips steeply (approximately 75 degrees) to the southwest. The Mammoth-Revenue vein averages approximately 8 feet in width and is characterized as vuggy quartz with associated gold and silver mineralization. Additionally, the Mammoth-Revenue vein contains marcasite (FeS_2). The Mammoth-Revenue vein cross-cuts the 1,800 foot thick La Jara Formation. The La Jara Formation is a dense latite porphyry deposited during the long time period of volcanic activity associated with the development of the Platoro caldera complex (Bohn, 1983).

In the time period from 1979 through 1991, UGI and others conducted the most recent phase of exploration. The majority of the primary access routes to the Mammoth-Revenue vein were constructed in the latite bedrock because the latite is very competent in regards to geotechnical stability. Drifts were completed in the Mammoth-Revenue vein at the 0, -200, and -400 Levels as measured from the collar elevation of the Mammoth-Revenue shaft.

The major geologic features in the vicinity of the Mammoth-Revenue mine are the latite bedrock and fluvioglacial deposits. The latite bedrock generally forms the topographic highs in the vicinity of the Mammoth-Revenue mine, rising steeply to the south of the Mammoth-Revenue shaft and as isolated bedrock outcrops to the northeast and northwest of the Mammoth-Revenue shaft (Figure 2-1). A northwest trending shallow valley (hereafter “the bog”) heads at the Mammoth-Revenue mine and extends for approximately 1,800 feet to the northwest (Figure 2-1). The bog is filled with fluvioglacial deposits that range in composition from organic-rich, fine-grained sediments to well-sorted gravels. The fluvioglacial sediments are bounded on three sides by latite bedrock.

The town of Platoro is located to the north and east of the Mammoth-Revenue mine and is separated from the bog by a latite bedrock outcrop (Figure 2-1). Sediments in the vicinity of Platoro are probably associated with the historical evolution of the Conejos

River resulting in a thick sequence of fluvioglacial sediments (up to 100 feet) overlying the latite bedrock.

Hydrologic testing of the primary geologic formations in the vicinity of the Mammoth-Revenue mine provides the basis for interpreting the relative degree of interconnectivity of the water-bearing geologic units. A summary of calculated hydraulic conductivity for each of the water-bearing geologic units is shown in Table 2-1 (SRK, 1981).

Table 2-1 Hydraulic Conductivity Of Geologic Materials In The Platoro Valley¹

Location	Geologic Formation	Hydraulic Conductivity (K) (cm/s)
Mammoth-Revenue Area	Quartz Latite	1×10^{-5}
Bog	Organic Layer	$<1 \times 10^{-5}$
Bog	Glacial Deposits	4×10^{-4}
Mine Area	Mineralized Vein	10^{-3} to 3×10^{-2}
Town of Platoro	Alluvial Sediments	3×10^{-2}

notes: 1. Range of values from SRK (1981)

In addition to the hydraulic testing reported in Table 2-1, historical water level measurements were taken as part of the initial investigation work completed by UGI (SRK, 1981). The water levels indicate that the ground water system in the bog is not hydraulically connected with the ground water system in the alluvial aquifer because the water levels in the bog are different than the water levels in the alluvial aquifer. An interpretation of the general hydrology in the vicinity of the Mammoth-Revenue mine is contained in a recent detailed analysis of the mine area hydrology (Telesto, 2003).

The fluvioglacial deposits in the bog fill a depression in the latite bedrock, which acts as a local ground water discharge zone for the shallow, fractured latite bedrock aquifer. In addition, there may be some flow of ground water along the surface expression of the Mammoth-Revenue vein into the surrounding fluvioglacial sediments of the bog (Figure 2-1). Although some ground water probably flows through the latite bedrock surrounding the fluvioglacial deposits, the relative magnitude is likely small compared to the volume of ground water flowing to the surface in the bog. Surface water in the

vicinity of the Mammoth-Revenue mine derives primarily from snowmelt, and the runoff from snowmelt is directed into the bog. Surface and ground water in the bog exits the through a topographic low in the latite bedrock located near the northwest end of the bog (sampling station SW-3; Figure 2-1). Thus, the primary mechanism for communication between the ground water in the vicinity of the Mammoth-Revenue mine and groundwater in the alluvial aquifer underlying the town of Platoro is the flow of water from the bog at SW-3.

Throughout recent exploration activity in the Mammoth-Revenue mine by UGI, a sump at the toe of the waste rock deposit below the Mammoth-Revenue shaft has acted to capture ground water flow in the immediate mine vicinity. The sump, referred to as SW-7 (Figure 2-1), operates year-round with discharge to the water treatment plant from April through October, and to the Mammoth-Revenue mine workings from November through March. Thus, hydrologic capture of ground water flow associated with the mine workings is maintained throughout the year. Capacity for the over-winter pump back from SW-7 (less than 5 gpm) is provided by over pumping from the Mammoth-Revenue mine late in the year with drawdown in the Mammoth-Revenue shaft (MRS) approximately 30 feet below the collar on the concrete pad that covers the shaft

The flow of ground water in the vicinity of the Mammoth-Revenue Mine is governed in part by the relative magnitude of the hydraulic properties of the water-bearing geologic formations in the area. Topographic conditions also impose a control on the migration of ground water in the mine area. In general, ground water flow in the vicinity of the Mammoth-Revenue Mine is restricted by the low hydraulic conductivity of the latite bedrock in the area. Ground water flow does occur in the shallow, fractured latite, but the magnitude is less than the flow rate in the Mammoth-Revenue vein or in the fluvio-glacial sediments. Extensive hydrologic characterization and monitoring data has reasonably demonstrated that there is minimal potential for a direct hydrologic connection between the mine workings and the alluvial aquifer underlying the town of Platoro.

3.0 CHEMISTRY OF TREATMENT PLANT SOLID RESIDUALS

The neutralization potential of the treatment residuals, and resulting water quality, influences the location and method of placement in the mine workings. The potential for dissolution of the treatment solid residuals in the low-pH water in the MRS, under several representative conditions, has been evaluated in laboratory-scale tests. These laboratory tests evaluated the alkalinity potential, steady-state solution chemistry, and chemical stability of treatment solid residuals in Ponds 1 to 4 (Figure 2-1). Material used in these tests was obtained from Pond 4 (aged residual) and from the treatment plant clarifier underflow (fresh residual).

3.1 Chemical Characteristic of Solids

The wet solid residuals that are located in the four collection ponds are the result of gravity dewatering of clarifier underflow from the water treatment plant. Based on typical mine water and plant discharge water chemistries, the treatment process solid residuals possess a substantial quantity of hydrolyzed metal solids (e.g., iron hydroxide) that predominantly consist of iron (approximately 80 percent) and lesser quantities of aluminum (5 percent), arsenic (6 percent), manganese (6 percent), and zinc (2 percent). These solids have undergone an aging process that has been influenced by variable moisture, temperature, and time.

3.2 Alkalinity Potential of Solids

A preliminary evaluation of treatment residuals alkalinity potential was determined by titrating a known volume of acidic MRS solution with both aged and fresh solid residual in two separate tests. These tests involved incremental additions of wet solids to neutralize both the free acidity and relatively larger amount of mineral acidity associated with dissolved metals concentrations (principally iron) in the MRS solution. Due to the distinct physical characteristics of the two test residuals, fresh material was added in volume increments, whereas aged material was added in mass increments. The curves generated by the potential alkalinity determinations are shown in Figure 3-1. The test solutions were not aerated to induce oxidation of ferrous iron, but were conducted in

conditions equivalent to an open system by allowing exposure of the continuously mixed solutions to atmospheric oxygen.

From a starting pH of 4.34, aged residual was added in small increments (0.2 to 2 grams) to a pH of 6, larger increments (2 to 10 grams) to a pH of 7, and then major increments (100 grams) to a final pH of 8.2. Varying the addition amounts allowed for better resolution of pH changes in the critical range between pH 5 and 7, where a substantial portion of iron is precipitated and mineral acidity is released. The release of mineral acidity inhibits complete neutralization and limits chemical stabilization of the added solids.

For the aged residual, approximately 230 grams was required to reach a neutral solution pH of 7, and another 570 grams to reach a pH of 8. The sharp inflection in the aged residual titration curve (at pH 6.3; Figure 3-1) is indicative of the elevated iron concentrations and release of acidity that occurs when iron begins to oxidize and precipitate from solution. Approximately 95 percent of the residual solids alkalinity is consumed between pH 6.3 and the final pH of 8.2. The calculated acidity for the MRS control sample of 32 meq/L and the mass of residual added to reach a final titration pH yields potential alkalinity values of 0.032 meq/wet gram and 0.52 meq/dry gram of aged residual.

In the potential alkalinity determination of fresh residuals, gradually increasing amounts of sample were added in varying mixtures to a total volume of 1,000 mL per liter of MRS solution. The initial solution pH of 4.35 increased to a final value of 5.85 (Figure 3-1) after addition of 1,000 mL fresh residual, which is too low of a pH to make a total alkalinity calculation. An estimate of the fresh residual alkalinity content can be made, however, by comparing the change in pH to that observed in the aged residual test. In the aged residual test, a change in pH to 5.85 was observed after the addition of 25 grams of sample, or 23.8 mL when an adjustment for specific gravity is made (SG measured at 1.05). The 23.8 mL addition of aged residual is equivalent to an alkalinity contribution of 1.5 meq per liter of fresh residual, after adjusting for sample dilution (1,000 mL fresh residual added to 1.0 L of MRS solution).

An additional potential alkalinity measurement of a filtered sample of fresh residual, to partition alkalinity attributable to soluble and solid phases, yielded a solution alkalinity concentration of 0.14 meq/L (28 mg/L as CaCO₃). The preceding calculations of total fresh residual alkalinity and soluble alkalinity measurement suggest that greater than 90 percent of fresh residual alkalinity is related to the solid content of the solution. Comparison of the solids content for the two residual types (42 times higher for the aged residual) and the respective observed rates of pH change, also suggest that alkalinity is primarily attributable to the solid content of the treatment residuals (both fresh and aged).

3.2.1 Distribution of Solids Alkalinity Potential

To understand if the Pond 4 sample is typical of materials in all four solids collection ponds, additional samples were obtained from Ponds 1, 3, and 4 and analyzed. Pond 2 was not sampled because it was operated during the same period as Pond 1 and is considered to be accurately represented by Pond 1. This additional level of detailed analysis is important in the overall evaluation of treatment solids characteristics because solid residuals from the treatment plant have been generated and stored for more than 15 years.

Potential alkalinity was measured in the solid residual samples collected from several depths in Ponds 1, 3, and 4. The alkalinity titration curves for each of the samples are provided on Figure 3-2. The method that was used for the Platoro treatment residuals is different than a standard alkalinity determination of an aqueous solution because it does not involve measurement of the relative carbonate system alkalinity. For the solid residual, alkalinity was determined by mixing wet solid residual into a 0.50-liter solution of 0.005N HCl then taking pH measurements after each incremental addition.

The measured water content of each sample was factored into the calculation to normalize the equivalent solids potential alkalinity. A solution pH of 7.0 was used as the titration endpoint because the measurement of the HCl acid solution consisted only of free acidity (H⁺ activity). The described method is essentially equivalent to the first phase testing except that a higher pH was used for the titration endpoint. In the first phase testing, MRS solution (containing iron, aluminum, and manganese) was used to

estimate the treatment solid residual equivalent alkalinity. Results of the second phase depth alkalinity determinations are provided in Table 3-1.

Table 3-1 Solid Alkalinity Potential in Depth Samples for Multiple Ponds

Pond 1			Pond 3			Pond 4		
Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
0.64	0.93	1.7	0.86	1.0	0.25	1.16	1.16	1.0

Alkalinity is presented as meq/dry gram of solid.

Overall, the second phase alkalinity determinations indicate that a greater amount of potential alkalinity is available in the bulk of the solid treatment residuals than was estimated in the first phase testing (0.52 meq/dry gram). This is true for all measurements except for the Pond 3 bottom sample, which appears to be an anomalous sample, in terms of both alkalinity and water content. Including the Pond 3 bottom sample, the average alkalinity of material in the three ponds sampled is 0.97 meq/dry gram of solid.

3.3 Solids Interaction and Steady-State Solution Chemistry

Laboratory-scale tests were conducted in support of an evaluation of steady-state solution chemistry and neutralization potential of treatment process residuals. These tests were supported by information generated in previous test work: (1) determination of solids content and (2) a titration of MRS water with wet solids. Several leaching tests were performed to simulate a range of conditions under which solids residuals might be injected into the mine workings:

- Acidic leaching with minimal mixing
- Mildly-acidic leaching with continuous mixing
- Neutral leaching with continuous mixing.

Individual test results, and potential implications, are discussed in this section.

The design of the three leaching tests was intended to simulate conditions representative of the possible treatment residual injection methods, encompassing the following scenarios: (1) deep injection into the mine workings under acidic-leaching, (2) shallow injection under mildly-acidic, well-mixed conditions, and (3) complete mine solution

‘treatment’ in neutralized, well-mixed conditions. Individual test conditions were controlled by varying the degree of mixing as well as the mass concentration of added residual. Using the information obtained in the titration tests, the following mass quantities of aged residual were used in each test condition: (1) 10 grams per liter of MRS, (2) 100 g/L, and (3) 1,000 g/L. A fourth test condition using only MRS solution served as the test control.

Each of the three leaching tests was performed over a period of 14 days to allow solutions to reach a representative state of chemical equilibrium. At the end of this contact period, samples were drawn from each test solution, filtered, and preserved for laboratory analyses. The analytical suite included dissolved measurements for RCRA metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver) in addition to metals commonly found in the MRS solutions (aluminum, copper, iron, manganese, and zinc). The remaining test solutions were archived for future potential analysis to evaluate longer-term chemical effects of each condition. Analytical results for the four test conditions, as well as a field sample taken at the same time (September 4, 2001) as the test solution, are provided in Table 3-2.

The September 4, 2001 MRS sample represents total concentrations, whereas test control and leach samples are dissolved concentrations. Differences in concentration between MRS and test control samples may be attributed to sample filtering (control), change in temperature conditions (testing conducted at about 25°C), a residual organic carbon and bacterial content related to the 2000/2001 in situ biological treatment of the mine workings, and the time between when the sample was taken and when the testing was completed. The test control sample, consisting of MRS solution, contained a suspended solid content. Continued anaerobic bacterial activity in the test control (containing the suspended solids) would be expected to further reduce arsenic (in acidic conditions) and increase manganese concentrations, relative to the September 4, 2001 field sample. For purposes of comparison, the control would usually be the sample used to evaluate changes related to the testing. Because of the previously identified factors that could affect the chemistry of the control, the more appropriate comparison is to look both at the original sample (September 4, 2001) and at the control.

Table 3-2 Solution Chemistry for Various Mixtures of Solids and MRS Solution

Constituent	Sept. 4, 2001 MRS – 50 foot	Test Control	10-gram Leach	100-gram Leach	1,000-gram Leach
pH	4.04	4.54	5.02	6.68	8.76
Aluminum	-	3.09	22.8	<0.03	0.09
Arsenic (5) ¹	1.5	0.162	0.88	0.024	0.0103
Barium (100)	-	0.011	0.009	0.0078	0.0011
Cadmium (1)	0.0006	<0.001	<0.001	<0.0005	0.0001
Chromium (5)	-	<0.001	0.051	<0.0005	0.0025
Copper	-	0.011	0.011	0.007	0.0081
Iron	596	589	641	226	0.08
Lead (5)	-	<0.001	<0.001	<0.0005	<0.0001
Manganese	37.2	52.2	41	104	4.56
Mercury (0.2)	-	<0.0002	<0.001	<0.0002	<0.0002
Selenium (1)	-	<0.001	<0.005	<0.001	<0.001
Silver (5)	-	<0.0005	<0.0005	<0.0005	<0.00005
Zinc	3.65	1.83	3.43	<0.01	<0.01

Notes: 1. Numbers in parentheses for RCRA metals indicate toxicity limit in mg/L.

The dissolved metal concentrations for each test condition primarily reflect a balance of residual solid mass added, metal solubility at a particular pH, and relative degree of solid and solution contact. In the deep-injection, acidic test condition (10-gram leach), increased concentrations of aluminum, arsenic, chromium, iron, and zinc were observed (relative to the test control). The increase in metals concentrations is explained by the lower solution pH (5.02) where the solubility of amorphous metal compounds is higher. Although a much greater mass of metals was added in the form of solid residual (approximately 610 mg, based on 6.1 percent solids), the lack of mixing in this test undoubtedly attenuated the rate of metals release. Comparing the relative amount of metals in the control sample to percentage increases in the 10-gram leach test indicates that aluminum and chromium have the highest potential to leach under acidic conditions. Arsenic, zinc, and iron also show an increase in concentration as compared to the control, but a comparison against concentrations measured in the original field sample indicate

that the concentration changes observed may be due in part to secondary chemical processes unrelated to the chemical reaction of treatment residuals and low-pH mine water. These test results suggest that water quality in the mine would be affected by a deep injection scenario in which low-pH mine solutions would be in contact with treatment residual solids.

Under slightly-acidic, well-mixed conditions, dissolved concentrations of all metals tested remained the same or improved, except for manganese, which doubled (relative to the test control). In the slightly acidic to neutral pH range, manganese is predominantly present in its chemically-reduced form (Mn[II]), and is highly soluble. For this test (100-gram leach), an increase in concentration of this metal would be expected given the mass of manganese added in the residual solids, its high solubility at the solution pH (6.68), and biologically-altered solution state as a result of the recent in-situ microbial treatment conducted in 2000/2001. The in-situ microbial treatment generated electrochemically-reduced conditions and produced organic material capable of forming metal complexes that decrease oxidation potential, and increases net solubility. This is particularly evident for manganese and iron, two metals that were measured at high levels in the final test solution. Given the overall reduction in iron (from 589 to 226 mg/L), the level of residual dissolved arsenic indicates that this metalloid is also in its chemically-reduced state (As[III]), which is a form that does not efficiently co-precipitate with iron hydroxide, but will react with dissolved sulfide in acidic solutions.

A completely neutralized, well-mixed condition (1,000-gram leach) is most representative of a scenario in which the entire mass of stored treatment residual would be transferred to the mine workings. The calculated volume of residual in the treatment ponds (20,000 cubic yards) and estimated solution volume in the upper mine workings (4 million gallons) compares closely with the 1,000-gram per liter test condition. In this test, metals concentrations were reduced by the greatest amount, in particular, the primary metals in the MRS (iron, manganese, zinc, aluminum, and arsenic). The high pH (8.76) of the mixed solution explains this degree of reduction in concentrations because iron and manganese are more easily oxidized and less soluble in this pH range. Aluminum concentration increased slightly (relative to the 100-gram leach) because this

metal is least soluble between pH 6.5 and 7, with increasing solubility as pH rises above this range. Overall, only chromium increased in concentration relative to the control sample, from <0.001 to 0.0025 mg/L. When compared to RCRA concentration limits, only arsenic, barium, and chromium were detected in the 1,000-gram leach test, at levels that are far below the limit (0.2 percent of the limit and less).

3.4 Long-Term Chemical Stability of Solid Residuals

Long-term chemical stability batch tests have been conducted by combining Test Solids from the first phase testing with MRS water collected in April 2002. Test Solids were generated in the batch neutralization work (from the 'treatment' condition) and consisted of aged treatment plant residuals and metals precipitated from the MRS mine water. The batch mixtures, which were completely mixed at the beginning of the test then undisturbed until sampling, should be considered a worst-case representation of low-pH mine water leaching of injected solids. This is especially true since analytical samples were taken of the free solution above the solids as well as interstitial solution in direct contact with solids.

A total of ten batch mixtures were set up with relative solid residual quantities ranging from 2.5 to 486 percent (relative to MRS water volume). After a 14-day contact period, the solution pH of each of the batch mixtures was measured (Table 3-3). The pH measurements served as the principal criteria for selecting samples for additional metals analysis.

Several observations can be made from an initial analysis of the batch mixtures: (1) a small amount of Test Solids (~10 percent) causes a pH change of 3 units, (2) a neutral pH is achieved when the relative amount of solids is 25 percent, and (3) only small pH changes occur above pH 8 even with substantially large increases in solids content. The batch mixture results are important because they provide a strong indication of the Test Solids residual buffering potential against future contact with the low-pH, mineralized vein or MRS water. These second phase test results, which are supported by first phase measurements that indicate a large alkalinity potential in the aged solid residuals, verify

Table 3-3 Second Phase Batch Mixtures and Solution pH Measurements

Batch Mixture No.	MRS (grams)	Wet Solids (grams)	Relative Percent (solids:MRS)	Final pH	Metals Analyses
0 (control)	100	0	0.0	3.38	N
1	100.1	2.5	2.5	3.10	Y
2	100.6	5.3	5.3	5.44	Y
3	100.1	10.6	10.6	6.34	N
4	100.2	25.2	25.1	7.06	Y
5	70.1	40.5	57.8	7.82	N
6	50.0	50.1	100.2	8.15	Y
7	50.2	75.3	150.0	8.25	N
8	41.3	80.1	193.9	8.30	N
9	30.3	90.2	297.7	8.38	Y
10	20.6	100.1	485.9	8.42	N

the ability of the Test Solids to establish and maintain neutral pH conditions in the mine workings with an adequate solids concentration.

The second phase of testing also included an evaluation of batch mixture water quality. Five of the batch mixtures were selected, based on the screening pH measurements, for further analysis to evaluate the leaching (and treatment) potential of the solid residuals. This additional analysis of the batch solutions consisted of measuring dissolved metals concentrations for aluminum, arsenic, iron, manganese, and zinc (after 14 days of contact). The metals measurements provide information regarding the balance of metals leaching and metals removal in the mixtures, allowing an assessment to be made of probable future water quality after solids injection into the mine workings. The results of these analyses are provided in Table 3-4.

Table 3-4 Metals Analyses in Select Second Phase Test Batch Mixtures

Batch Mixture No.	pH	Aluminum	Arsenic	Iron	Manganese	Zinc
MRS (100')	3.38	NA	0.54	644	40.5	1.68
1	3.10	27.6	<0.08	289	67.7	4.8
2	5.44	1.0	<0.08	285	88	2.32
4	7.06	<2	<2	66.2	198	0.5
6	8.15	<0.03	<0.04	0.08	25.2	<0.01
9	8.38	0.07	<0.04	0.04	10.4	<0.01

The MRS sample was obtained from the 100-foot depth interval (below shaft collar) in April 2002.

The metals analyses reveal significant information relevant to understanding the long-term stability of injected solids. The most important information relates to the ability of the injected solids to maintain improved water quality after initial injection and mixing, when contact with low-pH mine water occurs. Most notable are aluminum, arsenic, and zinc, which are undetectable in mixtures that contain equal amounts of solids and mine water; iron is also significantly reduced, from 644 to 0.04 mg/L. Additional observations include:

1. Maintaining neutral pH conditions (attained with equal volumes of mine water and injected solids) provides nearly complete control of metals concentrations (except manganese)
2. Leaching of iron and zinc from the Test Solids occurs when conditions are acidic (below pH 6)
3. Leaching of manganese from the Test Solids occurs when the pH does not exceed 8
4. The most improved water quality occurs when the Test Solids concentration substantially exceeds the MRS concentration
5. The results for batch mixture number 6, which are similar to first phase 1,000-gram leach test results, suggest that solids precipitated from the MRS water (from contact with treatment residuals) are highly stable and will not leach if pH conditions are maintained above 8.

The most important conclusion from the second phase leaching tests is that the injected and secondary (precipitated from the mine water) solids will be stable as long as solutions in the mine are maintained in an alkaline condition. Also significant is the substantial

reductions in metals concentrations (aluminum, arsenic, iron, and zinc) that can be achieved and maintained when the injected solid residuals content (by wet mass) reaches a level equivalent to the mine water.

4.0 CONCEPTUAL ENGINEERING DESIGN

4.1 Characterization of Solids

One aspect of transferring residual solids is the physical properties of the material. For example, identifying the appropriate slurry composition (water:rock ratio by weight) will dictate the water demand for accomplishing the solids transfer. The appropriate water:rock ratio would then need to work within the water management capabilities of the existing infrastructure and the ability of the system to meet the water demand. The following sections describe the measurements and analysis associated with considerations of solids and slurry properties.

4.1.1 Solids Content

Each of the three ponds sampled were divided into three distinct vertical zones, based on observable water content. A top zone was identified by desiccation cracks, a middle zone that has a water content greater than the top zone (and not exposed to the atmosphere), and a bottom saturation zone. Samples were obtained from each of these zones in Ponds 1, 3, and 4, and evaluated for solids content and alkalinity (sample locations shown on Figure 4-1; Table 4-1).

Table 4-1 Solids Content in Depth Samples – Ponds 1, 3, and 4

Pond 1			Pond 3			Pond 4		
Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
18.6	17.4	10.4	13.8	13.6	23.1	19.4	10.3	13.7

Solids contents are presented as percentages (by weight).

The solids contents measured in the second phase testing indicate higher values than in the initial testing (6.1 percent). The higher solids content are interpreted to mean that more water will be required to slurry transfer the solids into the mine workings. Except for Pond 3, the solids content typically decrease from top to bottom, as would be expected since the bottom layers were saturated. In Pond 3, the highest solids content measured in the bottom sample is attributed to a heterogeneous layer of presumed high-calcium material (evidenced by an overall lighter color and striations of white material).

The apparent anomalous value in Pond 3 indicates that pockets of non-uniform material are probably present, although sparingly, at various depths and locations in the solids collection ponds.

4.1.2 Volume

During the sampling activity, depth cross-section measurements were made across the width of each pond. From the depth measurements, material thickness was extrapolated along the length of each pond and total volumes calculated.

Table 4-2 Material Volumes in Ponds 1, 3, and 4 (units of cubic yards)

Pond 1	Pond 2	Pond 3	Pond 4
3,510	3,670	2,630	7,150

The total solids volume in the four storage ponds is estimated to be 17,000 cubic yards. This is a 24 percent higher total volume of treatment solid residuals than the 1993 estimated amount of 13,700 cubic yards (Water Waste and Land, Inc., 1993). A current best estimate volume of 3.6 million gallons in the active portion of the Platoro mine workings calculates to approximately 17,800 cubic yards of potential storage.

Estimating the total solids volume and solids content are important pieces of information to understand the volume of water required to slurry transfer treatment solids to the mine workings. Further analysis of the slurry water requirements will be completed as part of the final engineering design that would consist principally of additional physical testing and water balance modeling. This additional analysis will also likely provide the necessary information to calculate the total available alkalinity in Ponds 1 through 4.

4.1.3 Physical Characteristics

In general, the treatment residuals contain a significant amount of water that gives the material a thixotropic characteristic (i.e., behaves like a fluid when agitated). Furthermore, the absence of a significant calcium component in the treatment solids (usually calcite or gypsum) prevents the solid material from forming a ‘cake’ without some form of mechanical dewatering. Although the calcium concentration in the treated

solution is elevated from the addition of lime, the conditions are not conducive to the formation of calcium-based solids because of low concentrations of carbonate and sulfate in particular. The treatment solid residual is best described as a hydrous, gelatinous material. This characteristic enhances the potential for ‘fluidizing’ the solids and controlling the location of deposition in the mine workings.

The described physical characteristic is important when considering the following transfer issues that will be addressed in the full engineering design: (1) dilution with treated water to enhance fluid characteristics, (2) particle density and settling rate as pertaining to transmission line velocity, and (3) bulk solids characteristics for injection into the mine workings. Results from the test work described in this report, and professional judgment, will serve as the basis for final selection and configuration of physical components that address each of the listed transfer issues. The conceptual transfer system presented herein is based on the available information and will be modified according to the development of new data from modeling as well as additional testing of the solid residuals.

4.2 Transfer System

Operation of the described solids transfer system will be dependent on the production of treated water from the WTP because dilution water will be supplied from the clarified zone in Pond 5 (Figure 1-1). The primary system component, a displacement and mixing unit, will be located at the present solids collection ponds (Ponds 1 to 4). The objective of the displacement and mixing component will be to fluidize the solids into a relatively uniform concentration (2 to 4 percent solids by weight). Two methods will be employed for the operation: (1) a hydraulic operation to dilute and remove the solids from the ponds and (2) a mechanical operation to uniformly mix the diluted solids in preparation for pumping.

The hydraulic operation will consist of a high-pressure water jet (hydraulic monitor) to deliver dilution water and displace the solids. A submersible pump placed at a lower elevation in the pond will transfer the diluted slurry to an enclosed mixing tank (mechanical operation) fitted with a top-mounted, propeller-type mixer. The mixing tank

is essential to the system for producing feed slurry consistent in solids concentration and particle size. A pump suction line will be located near the mixing tank bottom, whereas an overflow port located near the tank top will convey excess slurry back to the source pond, providing containment within the displacement and mixing unit.

Diluted slurry pumping will deliver solid treatment residuals directly to the mine workings. The primary delivery pump will be portable, located adjacent to the mixing tank. If necessary, secondary or booster pumping will be provided to assist with making the approximate lift of 150 feet to the Decline portal entrance. The planned pipeline alignment, shown on Figure 4-2, will follow the present Pond 5 residual solids discharge line route and continue along the south side of the primary access road to the mine area. If necessary, secondary spill containment will be provided for the pipeline in locations where potential contact with spillage may occur.

Solids will be initially injected into the mine workings via the Decline portal entrance. A determination will be made in the engineering design phase for placement of the discharge location in the Decline. One of the objectives for the solids transfer is to distribute the solids throughout the active mine working volume. Achieving this goal will require that transferred solids reach the lowest end of the Decline (-200 Level) and disperse through this drift. Pumping from the MRS and discharging solids into the Decline will introduce a flow path that maximizes this distribution within the active mine workings.

A secondary injection location for the solids will be the lower levels of the MRS. The potential use of this location is discussed further in Section 4.5.

4.3 Water and Solids Mass Balance

As noted previously, there is a need to iterate in the conceptual engineering design the balance between the water demand for slurry formation and transfer and the ability of the combined mine workings system to generate sufficient water to support the slurry transfer system. Given the typical hydrologic cycle in the vicinity of the Mammoth-Revenue mine, the period in early spring through June usually generates more than enough water because of snowmelt contributions to the mine area. Following snowmelt, the water

supply derives principally from the Mammoth-Revenue mine workings. In 2002, the water production of every major river basin in Colorado was one of the lowest on record, and the snowmelt at Platoro was finished by the end of April. The current snowpack is not showing much improvement over last year, and the runoff could be even less. Thus, there is a need to understand the water and solids mass balance of a slurry transfer system incorporating not only the natural constraints imposed by variable water production rates (via climate), but also constraints imposed by the current infrastructure (e.g., pumps) that would be used as part of the slurry transfer system.

4.3.1 DSM Development

A dynamic systems model (DSM) was developed of the conceptual solids transfer system as shown in Figure 4-3. The DSM simulates time-dependent processes by explicitly recognizing the inherent complexity of linked reservoir systems. The basic system metrics evaluated in the DSM for the solids transfer system were flows, pond volumes, and solids transfer quantity. All components of the DSM can be tracked if desired.

4.3.2 Flows

System flows were developed using the large amount of information gathered during the past several field seasons. Water treatment plant operation was described and quantified by UGI personnel. One major component of the system is the Mammoth-Revenue mine workings. Water from the mine workings is pumped from the MRS and the current pumping schedule is usually dictated by the water level in the equalization basin that feeds the water treatment plant. The water treatment plant is operated on a 24-hours per day, 5 to 7-day per week basis from plant start-up in April to plant shutdown in October of each year.

Ground water inflow to the mine workings was evaluated using the pumping a water level response curves developed each year by UGI. The resulting inflow function was input to the DSM as shown in Figure 4-3. Water demand in the slurry transfer system was calculated based on the specified water content of the slurry and an initial water content of the solids.

Response of the system is shown in Figures 4-4, 4-5, and 4-6. The x-axis is time in Julian days with the time zero date set equal to January 1. In Figure 4-4, pertinent flow rates are shown as a function of time. Two flows are shown for the slurry transfer system. The first corresponds to the water flow and the second flow corresponds to the solids flow. The sum of the two transfer flows is shown in Figure 4-4 as the total flow. Flows associated with Pond 5 are also shown on Figure 4-4.

In Figure 4-5, total quantities in the Mammoth-Revenue mine, total solids transferred to the mine workings, total solids in the solids collection ponds, and percentage of solids transferred are shown. The DSM simulation employed a stage-capacity relationship derived from analysis of the pumping data for the MRS. The range of volume spanned during the course of a typical pumping season is limited as reflected in the small drawdown measured in the MRS (15 to 20 feet). Thus, the stage-capacity relationship can be represented by a linear function and the value used in the DSM was set equal to approximately 104,000 gallons per foot of drawdown. The response of the Mammoth-Revenue mine workings shown in Figure 4-5 may not hold during a drought, but the effect would be to over-predict the amount of drawdown for a given period of pumping. Approximately 48 percent of the total solids volume would be transferred during the first season of transfer. Pumping from the MRS would be required almost continuously (24 hours/day at 90 gpm) except for a brief period of time during snowmelt when substantial water reports to SW-7.

Figure 4-6 shows additional system metrics including the amount of drawdown in the MRS, the projected ground water inflow rate to the mine workings, the volume of water in the equalization basin, and the steady flow rate from the equalization basin to the water treatment plant. Because the DSM is a time-dependent tracking model, changes in the timing of pumping and flow rates will generate different system responses, each different result may achieve the overall objectives of the slurry transfer program.

4.3.3 System Limitations

Two important system limitations were identified during system simulation with the DSM: (1) the available pond volume in Pond 5 and (2) the availability of water over the

course of the slurry transfer season to ensure maximum transfer of slurry in the first year. As shown, the steady flow to Pond 5 from the water treatment plant will be approximately 100 gpm. The slurry transfer system will only be operated approximately 10 hours per day, 7-days per week, but the water treatment facility will be operated 24 hours/day, 7-days per week. Thus, the discharge from Pond 5 will vary during the period of slurry system operation but will never exceed the water treatment plan through flow rate of 100 gpm.

The second potential limitation identified in the conceptual engineering design was the availability of water from the mine area to satisfy the combined water demands of the water treatment plant and the slurry make-up system. If the low snowpack continues in the southeastern San Juan Mountains, there may be some limitation to pumping hard from the MRS because of low water levels.

4.4 Transfer Period

An important goal of the treatment solids transfer program is to complete transfer of at least 50 percent of the total solids volume initially present in Ponds 1 to 4. As a contingency, in the event that at least 50 percent of the total solids volume cannot be transferred, UGI would propose to add hydrated lime slurry into the mine workings by injecting into the Decline and pumping from the MRS. Supplemental addition of hydrated lime slurry to the mine workings would also be implemented if the metals concentration in the mine workings indicated that sufficient neutralization had not occurred. The addition of hydrated lime slurry would be used only to make up any deficit in pH control based on variations in alkalinity of the solids residuals or as a consequence of not achieving the target transfer percentage. Other methods of hydrated lime addition will be considered if direct injection is not feasible, including an undiluted application to the Decline from batched volumes of hydrated lime slurry.

Because the injection flow rate and operating hours will be held relatively constant, the total solids volume that will be transferred in a given time period will be highly dependent on the slurried solids concentration. As discussed in Section 4.3, it is conservatively assumed that a nominal slurry concentration of 2 percent will be achieved.

Given the initial condition of solids in Ponds 1 to 4, and the planned method for displacement and mixing, a solids concentration of 4 percent is considered to be a maximum value.

In estimating the time for completing the solids transfer, and associated percentage of solids volume transferred, a start date of June 1 and end date of October 31 are assumed. At an average 2 percent solids concentration, approximately 48 percent of the initial solids volume in Ponds 1 to 4 can be transferred in the first year of operation.

4.5 System Configuration

Certain operational details of the planned transfer system are provided in Section 4.2. Additional details of the transfer process include the location of major system components and approximate sizing of units (final sizing would be determined in the engineering phase). Figure 4-2 provides a conceptual layout of the system, showing the planned locations and alignments of these major system components.

A general description of the transfer system layout is provided in the following discussion. Treated, dilution water will be drawn from Pond 5 at a temporary overflow structure placed near the eastern border of the pond. The location of this structure will be carefully selected to minimize disturbance of solution that is decanted at the discharge structure. A submersible pump at the overflow structure will deliver water from the pond to the hydraulic monitor system location at Ponds 1 to 4. A combination of fixed piping and flexible hoses will connect the portable hydraulic monitor unit to the dilution water pressure line. In-pond solids slurry pumping components will be placed at the lowest respective bottom location in each of Ponds 1 to 4. Positioning of the hydraulic monitor unit will be variable over the period of transfer.

The mechanical mixing unit will be located along the northern edge of the solids collection ponds (Figure 4-2). In contrast to the hydraulic monitor unit, positioning of this unit will be relatively fixed, changing only a couple of times during the entire transfer period. The slurry transfer line will initially follow the same alignment as the present residual solids discharge line (to Pond 5), and will then be routed along the southern edge of the primary access road to the mine workings and decline. Exact

placement of the line will be determined during the engineering phase of the project, and will be based on several criteria: (1) minimize surface disturbance during construction and (2) to maximize accessibility for monitoring. Possible modifications to the transfer line alignment may be necessary in the mine workings area to allow a change in the point of discharge (as discussed in Section 4.6.2).

4.6 Monitoring and Contingency Plan

The solids transfer operation will encompass a number of units, located over a relatively large area, that are interdependently operated. Successful operation will therefore require adequate monitoring of the individual components. To assist in the operational monitoring, specific control measures will be incorporated into the design to ensure that the solid residual slurry is safely transferred and that spill potential is minimized. An example of this type of control measure would be an integrated power switch that automatically powers off dependent units if a failure occurs in a supporting component.

Certain contingencies will also be incorporated into the operation to provide assurances that regulatory and project objectives are met. These are identified and discussed in the following sections.

4.6.1 Transfer System Monitoring

System monitoring will be implemented to include frequent daily inspections. Primary monitoring locations will involve the Pond 5 (treated dilution water source), the displacement and mixing unit, the slurry transmission line, and the discharge location. Prior to implementing the solids transfer program, a formal monitoring and inspection plan will be developed and submitted.

4.6.2 Mine Workings Discharge System

The current plan for discharge at the Decline portal entrance is to route the transmission pipe through the small opening at the top of the bulkhead. A potential issue of this discharge method is that solids will accumulate over time at a location above the mine water level and restrict the opening that allows solids to flow down the Decline to the lower level drifts. Further evaluation of this potential will be completed to determine the

likelihood that this method will require modification. Possible modifications include breaching the bulkhead to gain better access and placement of the discharge pipe, or installation of a borehole that extends into a flooded location of the Decline.

4.6.3 Secondary Containment for the Transmission Line

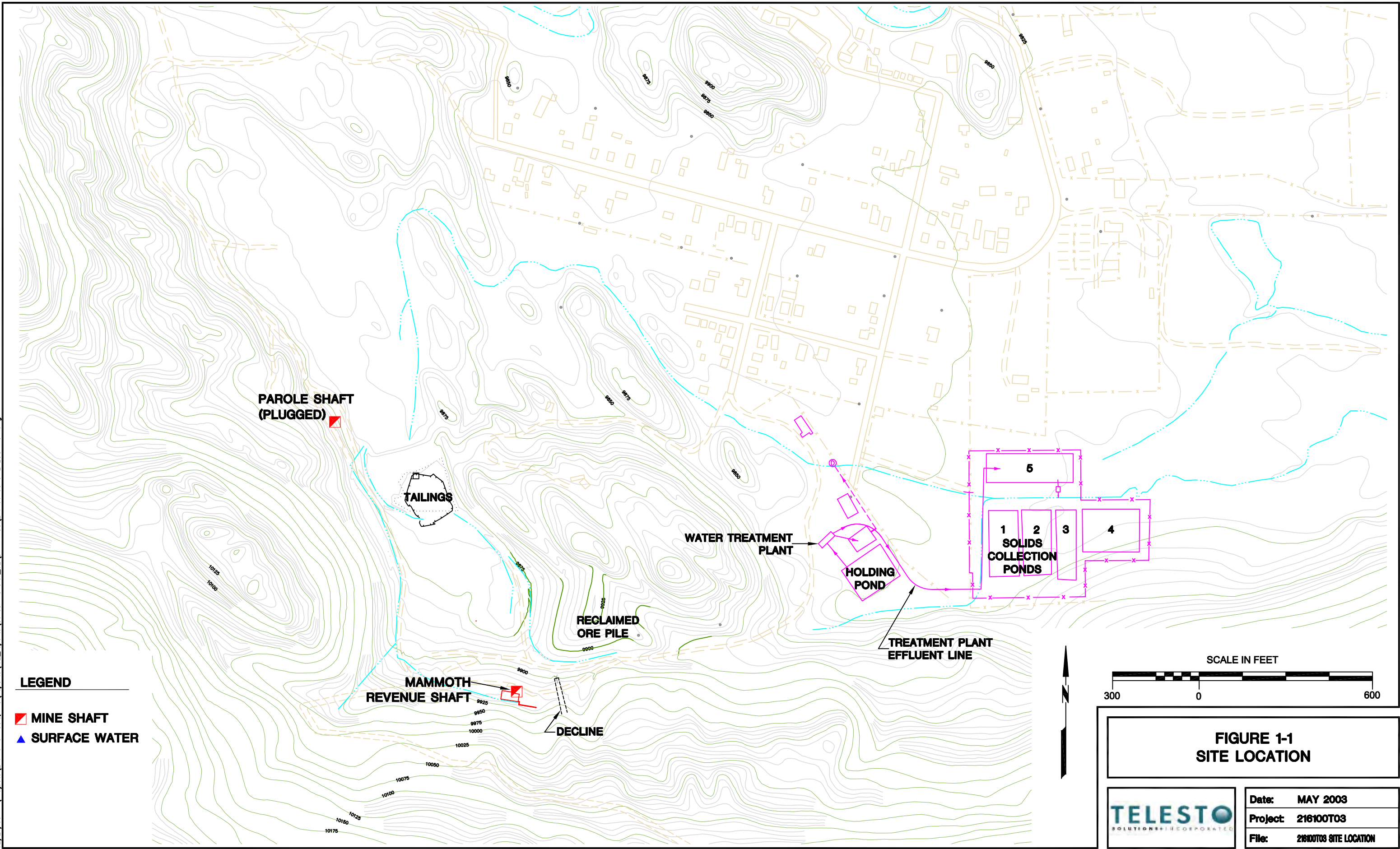
Due to the temporary nature of the solids transfer program and the non-hazardous characteristic of the solids, secondary containment of the solid residual slurry transfer is not planned. By routing the transmission pipeline through areas where contact with a potential spill is minimized, possible safety issues will be averted. In addition, operational practices and controls will be utilized to further minimize potential spill of solid residual, including pipe rinsing with treated water at the end of each day and pressure signals that trigger power-off features in the unlikely event that a pipe bursts. Frequent daily monitoring of the pipeline during operation will allow for a rapid response and repair of small leaks.

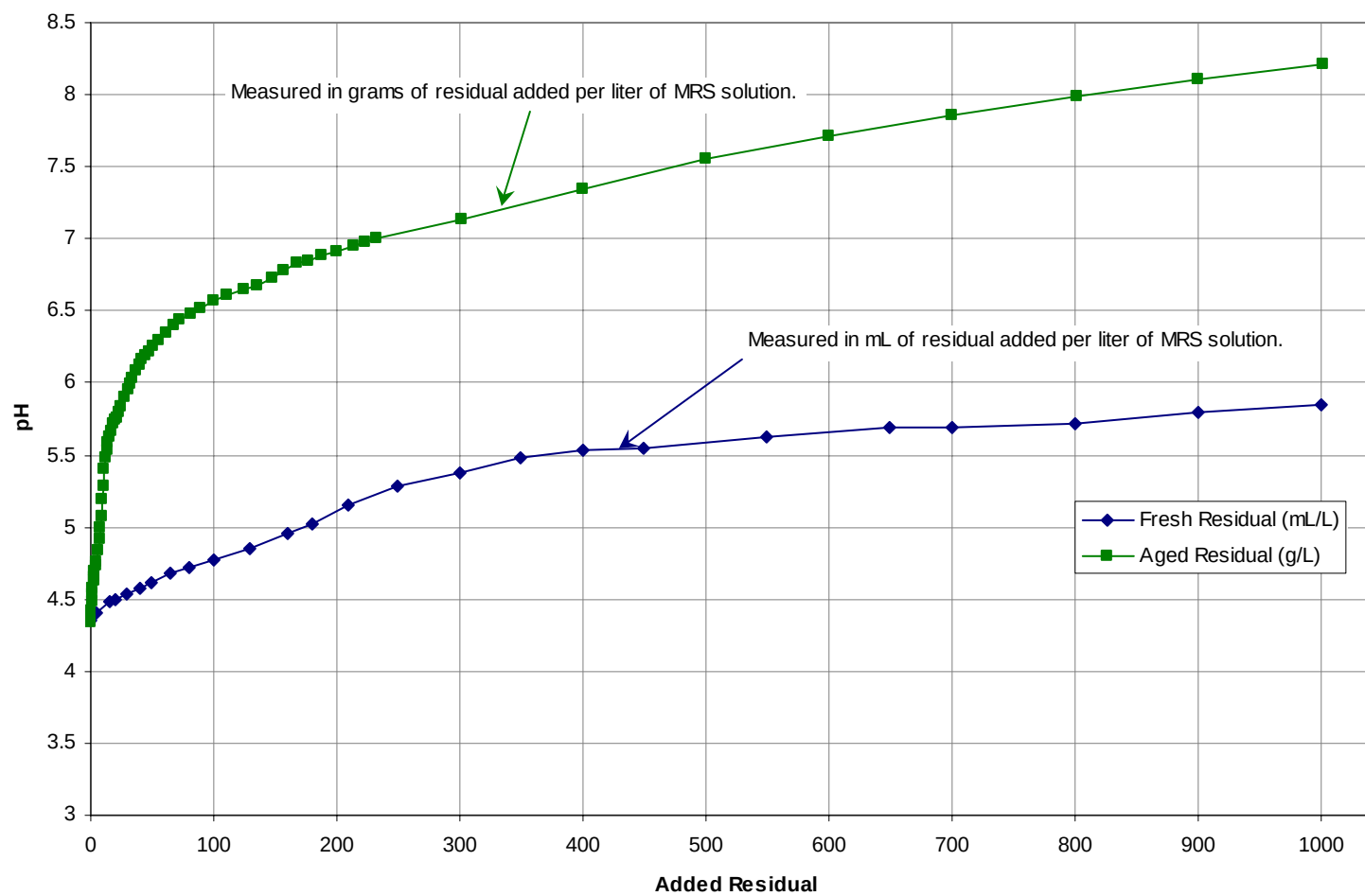
4.6.4 Mine Workings Response Monitoring

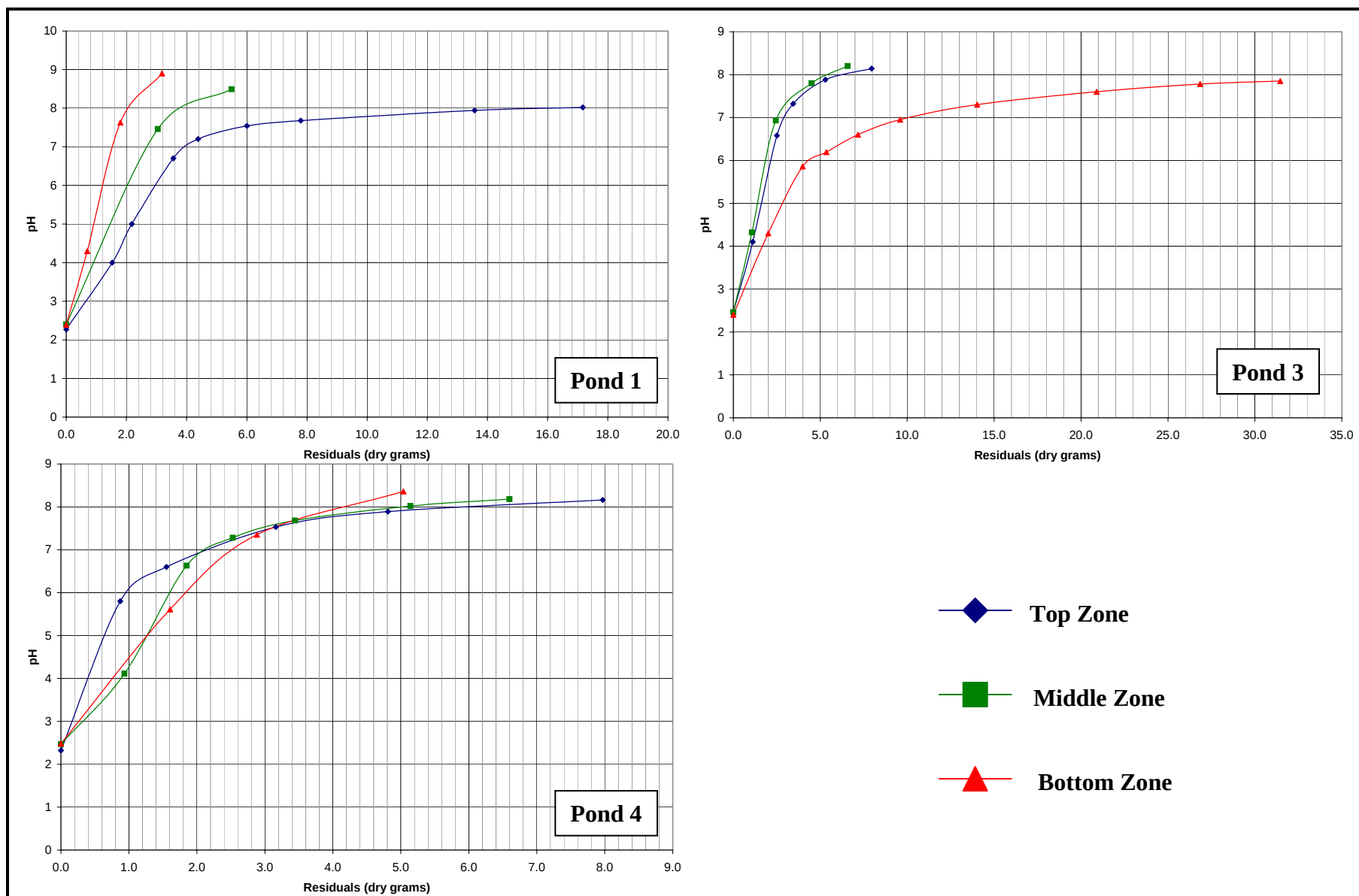
Monitoring the water chemistry changes that accompany the transfer of treatment solids to the mine workings will provide the necessary information to judge the effect of the slurry transfer on water quality in the mine workings and surrounding area. UGI will continue the current monitoring program in the mine area as part of the slurry transfer program. Sampling locations include the MRS, SW-7, B-series ground water monitoring wells, and other location farther down gradient (e.g., SW-3 and selected ground water wells in Platoro). Water chemistry samples will be collected on a monthly basis. Samples will be filtered in the field using a 0.45 µm membrane filter to remove suspended, fine-grained solids prior to acidifying samples for metals analysis. Field filtering will be necessary because of the inherent nature of the mine workings solution following injection of the treatment solids slurry. The constituents analyzed during the transfer process will be the same as have been monitored in the past (arsenic, iron, manganese, zinc, sulfate, TDS, and sodium). Alkalinity will be measured when the pH of the mine workings solution is greater than 5. Two samples will be collected to characterize the initial chemical conditions in the mine workings before the addition of

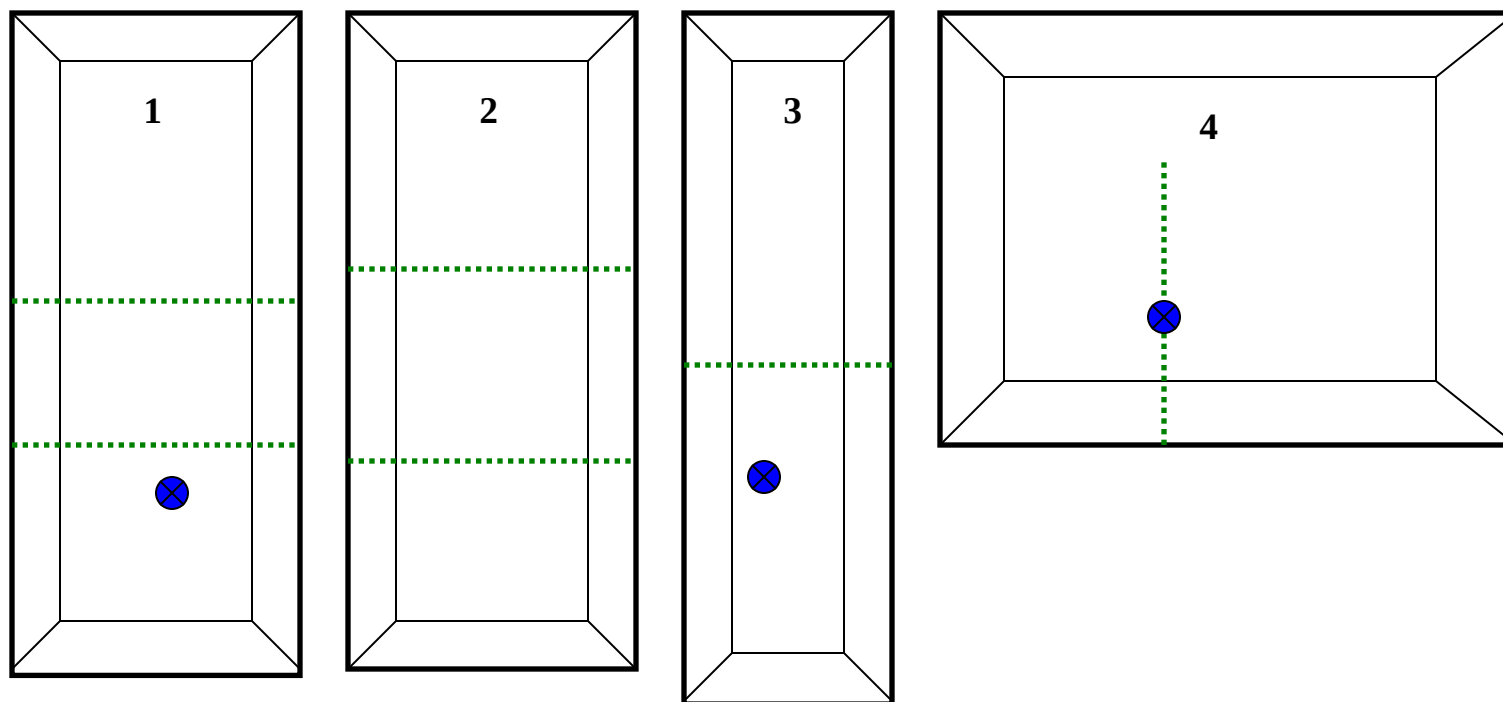
treatment solids (roughly in June) and one at the end of the first year of treatment solids transfer (November). The beginning and ending samples will be analyzed for a full suite of metals, major cations and anions, alkalinity, and TDS.

02/21/03 P:\Projects\216-Union Gold, Inc\Reports\02_reports\Solids Transfer_02\DRAWINGS\216100T03 SITE LOCATION.dwg





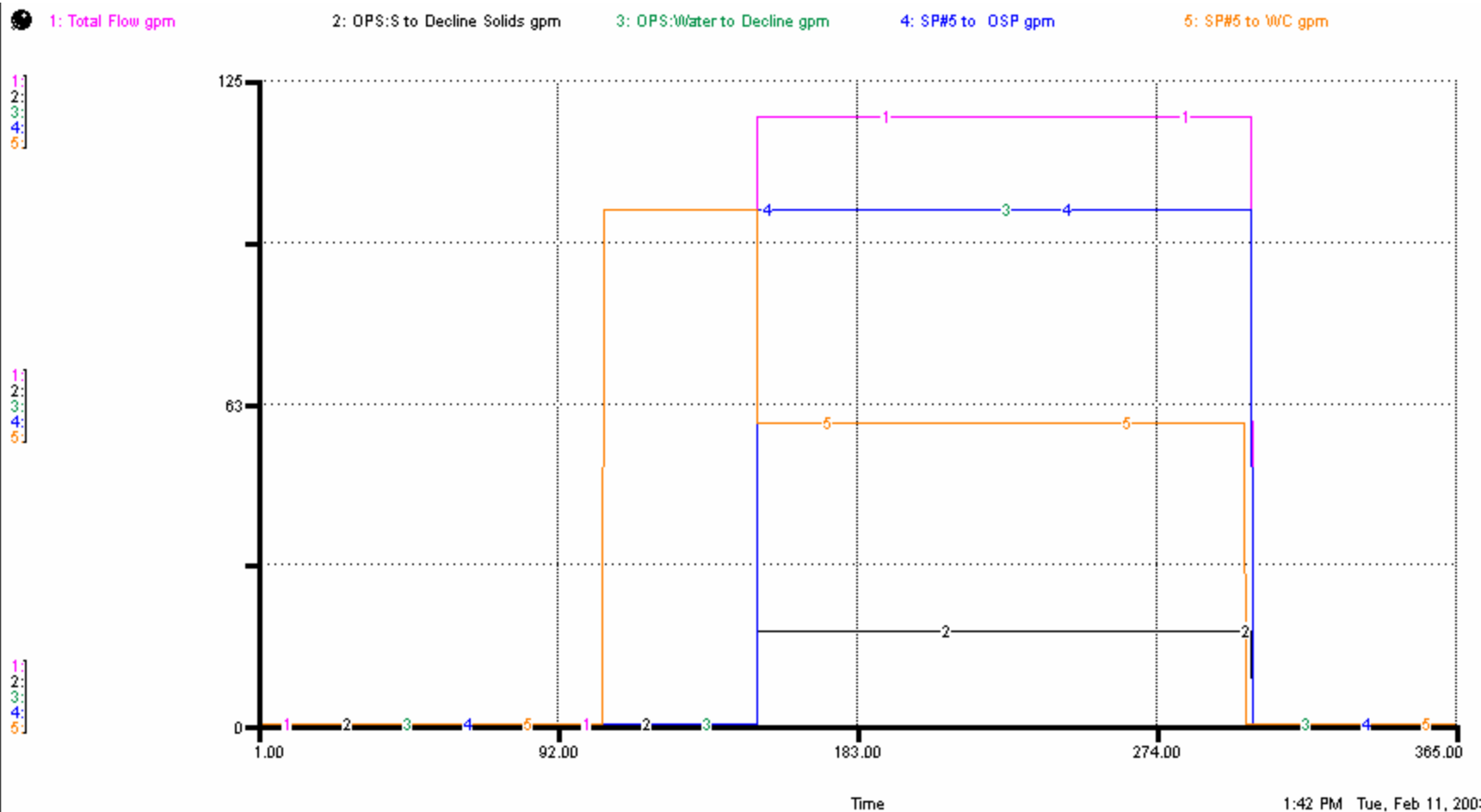




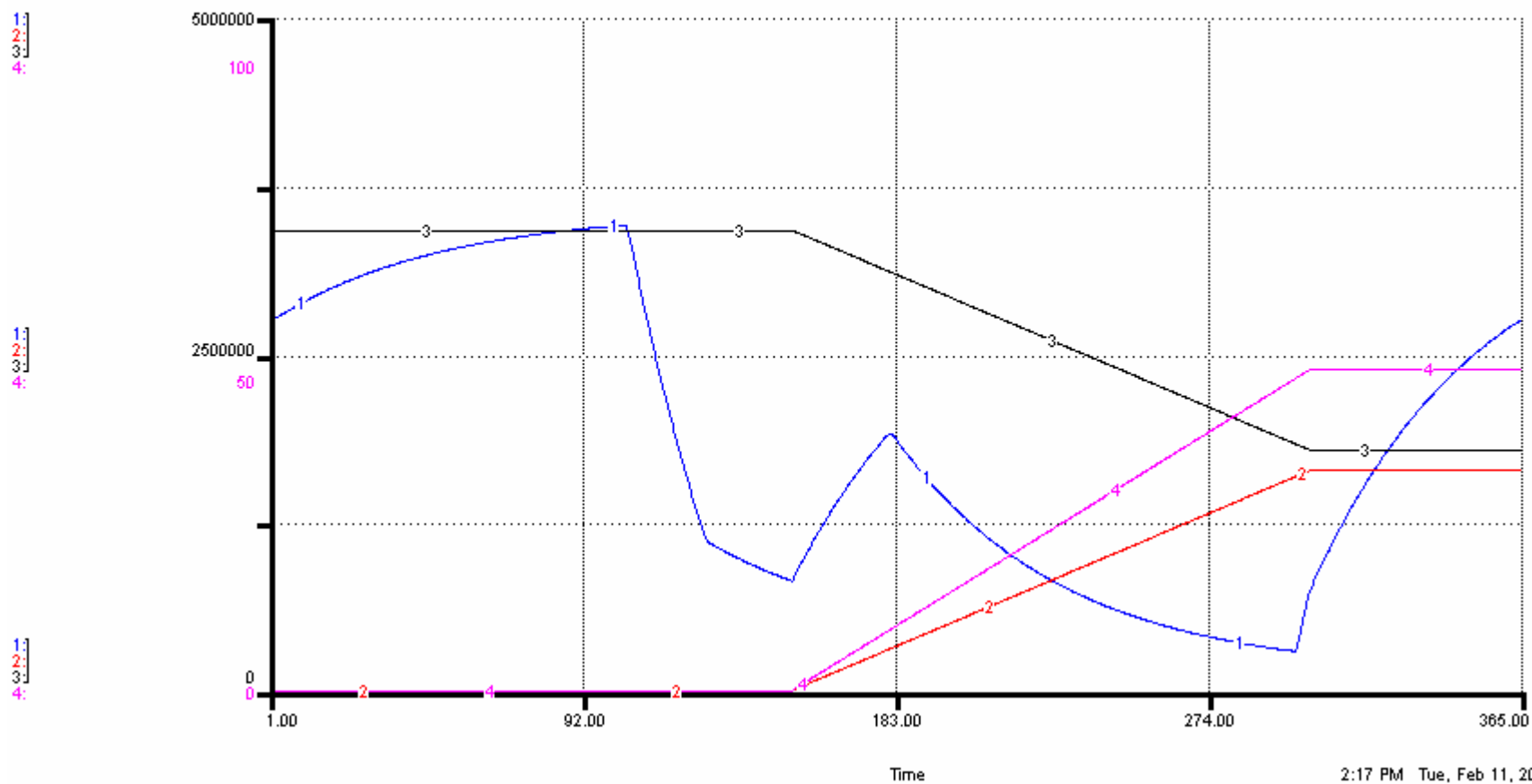
⊗ Solids Sampling Locations

..... Depth Profile Locations

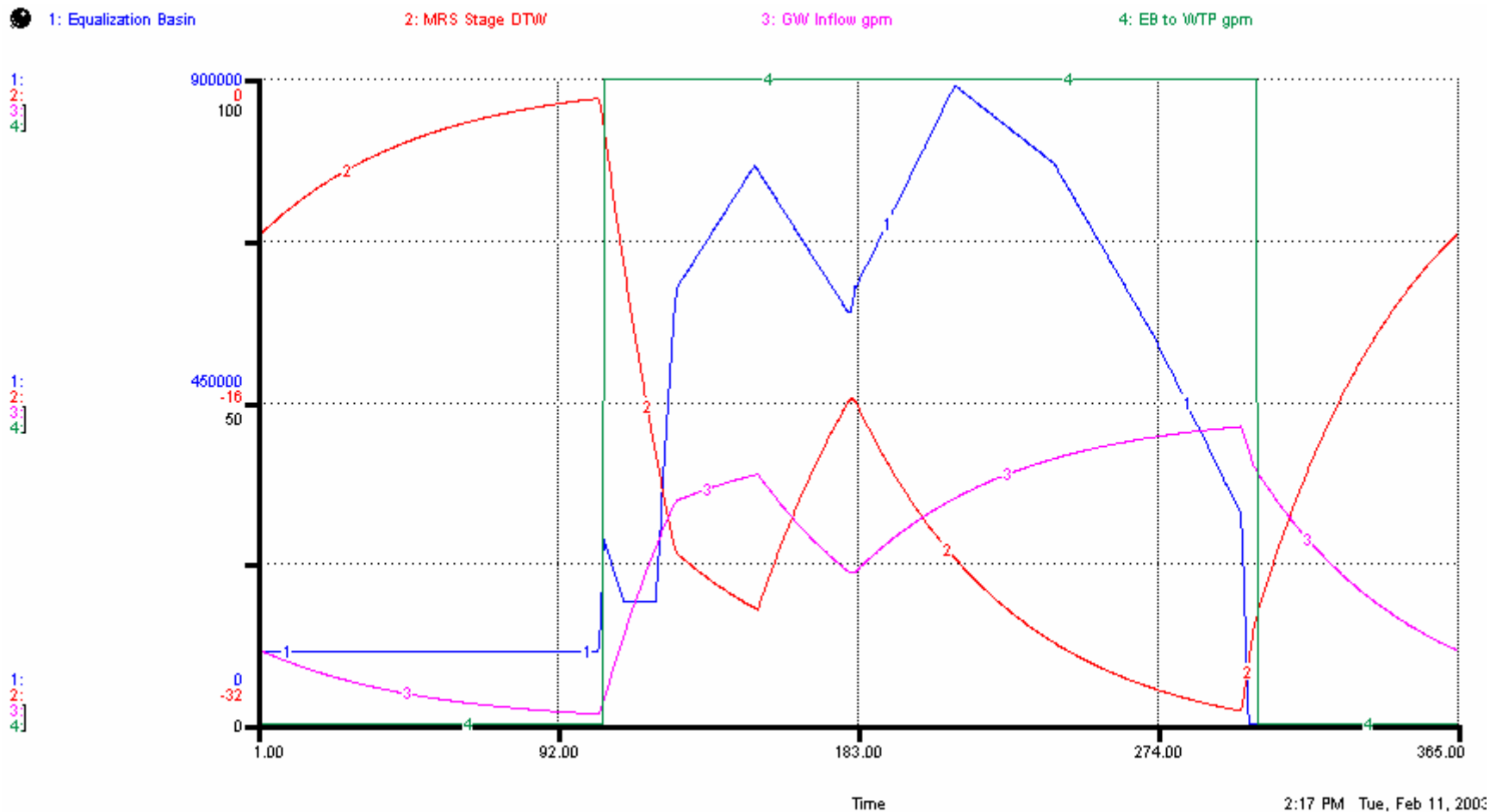
Scale is approximated.



1: Mammoth Revenue Mine 2: Total Solids to Mine Workings 3: Other Sludge Ponds Solids 4: Percentage Solids Transfer



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ATTACHMENT 1

SUMMARY OF PROPOSED SOLIDS TRANSFER AT THE PLATORO MINE, PLATORO, COLORADO

INTRODUCTION

Union Gold, Inc. (UGI) has operated a water treatment facility in conjunction with exploration activities at the Mammoth-Revenue mine since the mid-1980s and since the mid-1990s has operated the water treatment plant in support of reclamation activities. Over the period of operation, residual solids from the water treatment operation have accumulated in four solids collection ponds that are located to the east of the water treatment plant. In 1999 a fifth solids collection pond was constructed, which has provided volume capacity relief for the remaining ponds. Figure 1 shows the site with the layout of the water treatment facility and associated solids collection ponds. In an effort to continue the site reclamation effort, UGI contracted with Telesto Solutions, Inc. (Telesto) to evaluate the geochemical and conceptual engineering implications of transferring residual solids from the ponds into the Mammoth-Revenue mine workings. Such a transfer would accomplish the following multiple, beneficial objectives:

- Placement of chemical mass that originated in the mine workings/mineralized vein back to the point of origin
- Re-establish the capacity of the water treatment ponds with the potential to reclaim one or more of the solids collection ponds
- Utilize un-reacted neutralization capacity of the residual solids as a means of raising the pH of the Mammoth-Revenue mine water
- Re-establish original oxidation-reduction conditions in the mine workings with the water anaerobic and dissolved metals would be precipitated as stable sulfide minerals by addition/mixing of organic compounds (e.g., methanol) with treatment solids.

An evaluation of the residual solids transfer option has been completed including a detailed geochemical testing program to assess the potential for metals leaching from contact of the residual solids with mine water both near- and long-term and under the

conservative conditions of well-mixed and oxygenated. Direct field results are available regarding the effects of organic carbon addition to the mine workings.

SOLIDS INTERACTION AND STEADY-STATE SOLUTION CHEMISTRY – MINE WATER NEUTRALIZATION

Historical Bench-Scale Evaluation

Laboratory-scale tests were conducted in support of an evaluation of steady-state solution chemistry and neutralization potential of treatment process residuals. These tests were supported by information generated in previous test work: (1) determination of solids content and (2) a titration of Mammoth-Revenue Shaft water (MRS) with wet solids. Several leaching tests were performed to simulate a range of conditions under which solids residuals might be injected into the mine workings:

- Acidic leaching with minimal mixing
- Mildly-acidic leaching with continuous mixing
- Neutral leaching with continuous mixing.

Individual test results, and potential implications, are presented herein.

The design of the three leaching tests was intended to simulate conditions representative of the possible treatment residual injection methods, encompassing the following scenarios: (1) deep injection into the mine workings under acidic-leaching, (2) shallow injection under mildly-acidic, well-mixed conditions, and (3) complete mine solution ‘treatment’ in neutralized, well-mixed conditions. Individual test conditions were controlled by varying the degree of mixing as well as the mass concentration of added residual. Using the information obtained in the titration tests, the following mass quantities of aged treatment residual were used in each test condition: (1) 10 grams per liter of MRS, (2) 100 g/L, and (3) 1,000 g/L. A fourth test condition using only MRS solution served as the test control.

Each of the three leaching tests was performed over a period of 14 days to allow solutions to reach a comparable state of chemical equilibrium. At the end of this contact period, samples were drawn from each test solution, filtered, and preserved for laboratory analyses. The analytical suite included dissolved measurements for drinking water

constituents in ground water as specified in Table 1 of the Colorado Department of Public Health and Environment Regulation 41 “*The Basic Standards for Ground Water.*” The remaining test solutions were archived for future potential analysis to evaluate longer-term chemical effects of each condition. Analytical results for the four test conditions, as well as a field sample taken at the same time (September 4, 2001) as the test solution, are provided in Table 1.

The September 4, 2001 MRS sample represents total concentrations, whereas test control and leach samples are dissolved concentrations. Differences in concentration between MRS and test control samples may be attributed to sample filtering (control), change in temperature conditions (testing conducted at about 25°C), a residual organic carbon and bacterial content related to the 2000/2001 in situ biological treatment of the mine workings, and the time between when the sample was taken and when the testing was completed. The test control sample, consisting of MRS solution, contained a suspended solid content. Continued anaerobic bacterial activity in the test control (containing the suspended solids) would be expected to further reduce arsenic (in acidic conditions) and increase manganese concentrations, relative to the September 4, 2001 field sample. For purposes of comparison, the control would usually be the sample used to evaluate changes related to the testing. Because of the previously identified factors that could affect the chemistry of the control, the more appropriate comparison is to look both at the original sample (September 4, 2001) and at the control.

The dissolved metal concentrations for each test condition primarily reflect a balance of residual solid mass added, metal solubility at a particular pH, and relative degree of solid and solution contact. In the deep-injection, acidic test condition (10-gram leach), increased concentrations of aluminum, arsenic, chromium, iron, and zinc were observed (relative to the test control). The increase in metals concentrations is explained by the lower solution pH (5.02) where the solubility of amorphous metal compounds is higher. Although a much greater mass of metals was added in the form of solid residual (approximately 610 mg, based on 6.1 percent solids), incomplete mixing in this test undoubtedly attenuated the rate of metals release. Comparing the relative amount of metals in the control sample to percentage increases in the 10-gram leach test indicates

that aluminum and chromium have the highest potential to leach under acidic aerobic conditions. Arsenic, zinc, and iron also show an increase in concentration as compared to the control, but a comparison against concentrations measured in the original field sample indicate that the concentration changes observed may be due in part to secondary chemical processes unrelated to the chemical reaction of treatment residuals and low-pH mine water. These test results suggest that water quality in the mine would be degraded by a deep injection scenario in which low-pH mine solutions would be in contact with treatment residual solids.

Table 1 Solution Chemistry for Various Mixtures of Solids and MRS Solution (in units of mg/L except pH in s.u.)

Constituent	Sept. 4, 2001 MRS – 50 foot	Test Control	10-gram Leach	100-gram Leach	1,000-gram Leach
pH	4.04	4.54	5.02	6.68	8.76
Aluminum	-	3.09	22.8	<0.03	0.09
Arsenic (0.01) ¹	1.5	0.162	0.88	0.024	0.0103
Barium (2)	-	0.011	0.009	0.0078	0.0011
Cadmium (0.005)	0.0006	<0.001	<0.001	<0.0005	0.0001
Chromium (0.10)	-	<0.001	0.051	<0.0005	0.0025
Copper	-	0.011	0.011	0.007	0.0081
Iron	596	589	641	226	0.08
Lead (0.05)	-	<0.001	<0.001	<0.0005	<0.0001
Manganese	37.2	52.2	41	104	4.56
Mercury (0.002)	-	<0.0002	<0.001	<0.0002	<0.0002
Selenium (0.05)	-	<0.001	<0.005	<0.001	<0.001
Silver (0.05)	-	<0.0005	<0.0005	<0.0005	<0.00005
Zinc	3.65	1.83	3.43	<0.01	<0.01

Notes: 1. Numbers in parentheses are human health standards for ground water as presented in Regulation 41 “*The Basic Standards for Ground Water*” of the Colorado Department of Public Health and Environment (all units in mg/L).

Under slightly-acidic, well-mixed conditions, dissolved concentrations of all metals tested remained the same or decreased, except for manganese, which doubled (relative to

the test control). In the slightly acidic to neutral pH range, manganese is predominantly present in its chemically-reduced form (Mn[II]), and is highly soluble. For this test (100-gram leach), an increase in concentration of this metal would be expected given the mass of manganese added in the residual solids, its high solubility at the solution pH (6.68), and biologically-altered solution state as would occur under the current plan. The in-situ microbial treatments in the MR have generated electrochemically-reduced conditions and produced organic material capable of forming metal complexes that decrease oxidation potential, and increases net solubility. This is particularly evident for manganese and iron, two metals that were measured at high levels in the final test solution. Given the overall reduction in iron (from 589 to 226 mg/L), the level of residual dissolved arsenic indicates that this metalloid is also in its chemically-reduced state (As[III]), which is a form that does not efficiently co-precipitate with iron hydroxide, but will react with dissolved sulfide in acidic solutions.

A completely neutralized, well-mixed condition (1,000-gram leach) is most representative of a scenario in which the entire mass of stored treatment residual would be transferred to the mine workings. The calculated volume of residual in the treatment ponds (20,000 cubic yards) and estimated solution volume in the upper mine workings (4 million gallons) compares closely with the 1,000-gram per liter test condition. In this test, metals concentrations were reduced by the greatest amount, in particular, the primary metals in the MRS (iron, manganese, zinc, aluminum, and arsenic). The high pH (8.76) of the mixed solution explains this degree of reduction in concentrations because iron and manganese are more easily oxidized and less soluble in this pH range. Aluminum concentration increased slightly (relative to the 100-gram leach) because this metal is least soluble between pH 6.5 and 7, with increasing solubility as pH rises above this range. Overall, only chromium increased in concentration relative to the control sample, from <0.001 to 0.0025 mg/L.

Long-Term Chemical Stability of Solid Residuals

Long-term chemical stability batch tests have been conducted by combining Test Solids from the first phase testing with MRS water collected in April 2002. Test Solids were generated in the batch neutralization work (from the ‘treatment’ condition) and consisted

of aged treatment plant residuals and metals precipitated from the MRS mine water. The batch mixtures, which were completely mixed at the beginning of the test then undisturbed until sampling, should be considered a worst-case representation of low-pH mine water leaching of injected solids. This is especially true since analytical samples were taken of the free solution above the solids as well as interstitial solution in direct contact with solids.

A total of ten batch mixtures were set up with relative solid residual quantities ranging from 2.5 to 486 percent (relative to MRS water volume). After a 14-day contact period, the solution pH of each of the batch mixtures was measured (Table 2). The pH measurements served as the principal criteria for selecting samples for additional metals analysis.

Several observations can be made from an initial analysis of the batch mixtures: (1) a small amount of Test Solids (~10 percent) causes a pH change of three standard units, (2) a neutral pH is achieved when the relative amount of solids is 25 percent, and (3) only small pH changes occur above pH 8 even with substantially large increases in solids content. The batch mixture results are important because they provide a strong indication of the Test Solids residual buffering potential against future contact with the low-pH, mineralized vein or MRS water. These second phase test results, which are supported by first phase measurements that indicate a large alkalinity potential in the aged solid residuals, verify the ability of the Test Solids to establish and maintain neutral pH conditions in the mine workings with an adequate solids concentration.

The second phase of testing also included an evaluation of batch mixture water quality. Five of the batch mixtures were selected, based on the screening pH measurements, for further analysis to evaluate the leaching (and treatment) potential of the solid residuals. This additional analysis of the batch solutions consisted of measuring dissolved metals concentrations for aluminum, arsenic, iron, manganese, and zinc (after 14 days of contact). The metals measurements provide information regarding the balance of metals leaching and metals removal in the mixtures, allowing an assessment to be made of probable future water quality after solids injection into the mine workings. The results of these analyses are provided in Table 3.

Table 2 Second Phase Batch Mixtures and Solution pH Measurements

Batch Mixture No.	MRS (grams)	Wet Solids (grams)	Relative Percent (solids:MRS)	Final pH	Metals Analyses
0 (control)	100	0	0.0	3.38	N
1	100.1	2.5	2.5	3.10	Y
2	100.6	5.3	5.3	5.44	Y
3	100.1	10.6	10.6	6.34	N
4	100.2	25.2	25.1	7.06	Y
5	70.1	40.5	57.8	7.82	N
6	50.0	50.1	100.2	8.15	Y
7	50.2	75.3	150.0	8.25	N
8	41.3	80.1	193.9	8.30	N
9	30.3	90.2	297.7	8.38	Y
10	20.6	100.1	485.9	8.42	N

Table 3 Metals Analyses in Select Second Phase Test Batch Mixtures

Batch Mixture No.	pH	Aluminum	Arsenic	Iron	Manganese	Zinc
MRS (100')	3.38	NA	0.54	644	40.5	1.68
1	3.10	27.6	<0.08	289	67.7	4.8
2	5.44	1.0	<0.08	285	88	2.32
4	7.06	<2	<2	66.2	198	0.5
6	8.15	<0.03	<0.04	0.08	25.2	<0.01
9	8.38	0.07	<0.04	0.04	10.4	<0.01

The MRS sample was obtained from the 100-foot depth interval (below shaft collar) in April 2002.

The metals analyses reveal significant information relevant to understanding the long-term stability of injected solids. The most important information relates to the ability of the injected solids to maintain improved water quality after initial injection and mixing, when contact with low-pH mine water occurs. Most notable are aluminum, arsenic, and zinc, which are undetectable in mixtures that contain equal amounts of solids and mine water; iron is also significantly reduced, from 644 to 0.04 mg/L. Additional observations include:

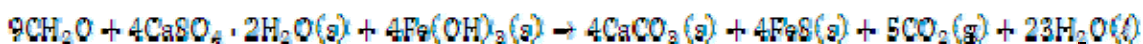
1. Maintaining neutral pH conditions (attained with equal volumes of mine water and injected solids) provides nearly complete control of metals concentrations (except manganese)
2. Leaching of iron and zinc from the Test Solids occurs when conditions are acidic (below pH 6)
3. Leaching of manganese from the Test Solids occurs when the pH does not exceed 8
4. The most improved water quality occurs when the Test Solids concentration substantially exceeds the MRS concentration
5. The results for batch mixture number 6, which are similar to first phase 1,000-gram leach test results, suggest that solids precipitated from the MRS water (from contact with treatment residuals) are highly stable and will not leach if pH conditions are maintained above 8.

The most important conclusion from the second phase leaching tests is that the injected and secondary (precipitated from the mine water) solids will be stable as long as solutions in the mine are maintained in an alkaline condition. In the event that the solids added do not increase pH in the mine workings, or that pH remains low during the initial stages of the solids transfer, UGI will monitor the condition and provide infrastructure to add neutralizing agent (e.g., lime or caustic soda) to properly adjust the pH of the mine workings. Also significant is the substantial reductions in metals concentrations (aluminum, arsenic, iron, and zinc) that can be achieved and maintained when the injected solid residuals content (by wet mass) reaches an amount equivalent to the mine water.

SOLIDS INTERACTION AND STEADY-STATE SOLUTION CHEMISTRY –NEUTRALIZATION & ORGANIC CARBON ADDITION

Biogeochemical processes/effects of the proposed mine pool treatment using a combination of water treatment plant solids and organic carbon will act to re-establish original chemical and geochemical conditions in the mine workings. That is, prior to lowering of the ground water table and exposure of sulfide minerals to atmospheric conditions, both the ground water and the mineral phases were consistent with a low oxidation-reduction state, which is due to limited oxygen solubility in water and consumption of oxygen in the shallow soils zone during infiltration. Under such anaerobic conditions, the ground water was probably slightly acidic to neutral and dissolved metals concentrations consistent with pH conditions and low solubility of metal-bearing sulfide minerals associated with the mineralized vein (i.e., Mammoth-Revenue vein). The proposed in situ treatment program would consist of transfer of water treatment solids (containing excess neutralization potential) mixed with organic carbon such that conditions close to original can be re-established in the mine workings. Achieving such conditions in the mine workings would enhance long-term stability of solids formed by neutralization alone.

The following equation presents the net stoichiometric reaction from the addition of carbohydrate-based carbon (general formula of CH₂O) sources to sulfate-saturated iron hydroxide-rich water treatment solids:

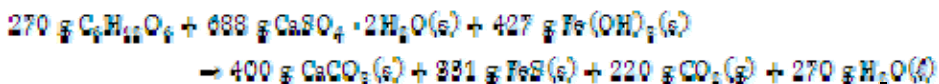


Excess sulfate from gypsum and from the mine pool water will be used to make iron sulfide, while excess calcium precipitates with biogenically formed carbonates as calcium carbonate.

This stoichiometric ratio is critically important to the overall mine pool stabilization process. Treatment of the mine pool under present conditions will become limited in available iron as sulfate continues to leave in the discharge and iron accumulates in the treatment pond solids. The biological in-mine pool pretreatment process that is critical to

maintaining the appropriate iron/arsenic ratio for performance of the water treatment plant requires iron as a scavenger for formed sulfide ions. Without recovery of iron from the treatment ponds the ability of the pretreatment process to continue will eventually be impaired.

On a weight basis, the preceding equation can be written as:



While chemically accurate, this equation does not fully present the associated physical changes (i.e., densification and volumetric reduction) that will occur during the process of converting hydroxides to sulfides in the mine workings. The approximate density of the water treatment pond solids is presently 1.07 grams per cubic centimeter (g/cm³) with about 15% dry matter by weight. Solids conversion via the above listed chemical reaction with added carbon sources and in time will reduce the anticipated volume of the inputs of newly formed in-place minerals by approximately 96 percent with a solids density of 3.41 g/cm³. The volume of solids formed in the mine after treatment and removal of the entire pond inventory of 17,500 CY will therefore be condensed and converted to around 640 CY.

CONCEPTUAL MINE WORKINGS CHEMICAL RESPONSE

The chemistry in the mine workings during placement of the treatment solids will be dynamic with all of the mixtures described in Tables 1 and 3 represented in different portions of the reaction zone. Thus, there will be a reactive zone within the overall chemical reaction front of the treatment solids placement where the concentrations of some constituents will potentially rise to levels shown in Table 3. The extent of a potential reaction zone with elevated concentrations of constituents is not projected to constitute a sufficiently large percentage of the total treated mine workings volume to result in excessive concentrations reporting to the sump at SW-7. As indicated in Table 1, the majority of the dissolved metals in the mine workings water will ultimately settle and consolidate in the mine workings such that further chemical reaction as related

to the addition of organic carbon is expected to govern the ultimate character of the solids.

All seepage from the mine workings during the period of treatment will be captured and treated at the water treatment plant. In addition, the water treatment facility is adequately designed to effectively treat mine water with elevated concentrations. Therefore, UGI has the appropriate infrastructure in place to manage mine water chemistry during the dynamic period of chemical reaction following treatment solids placement in the mine workings.

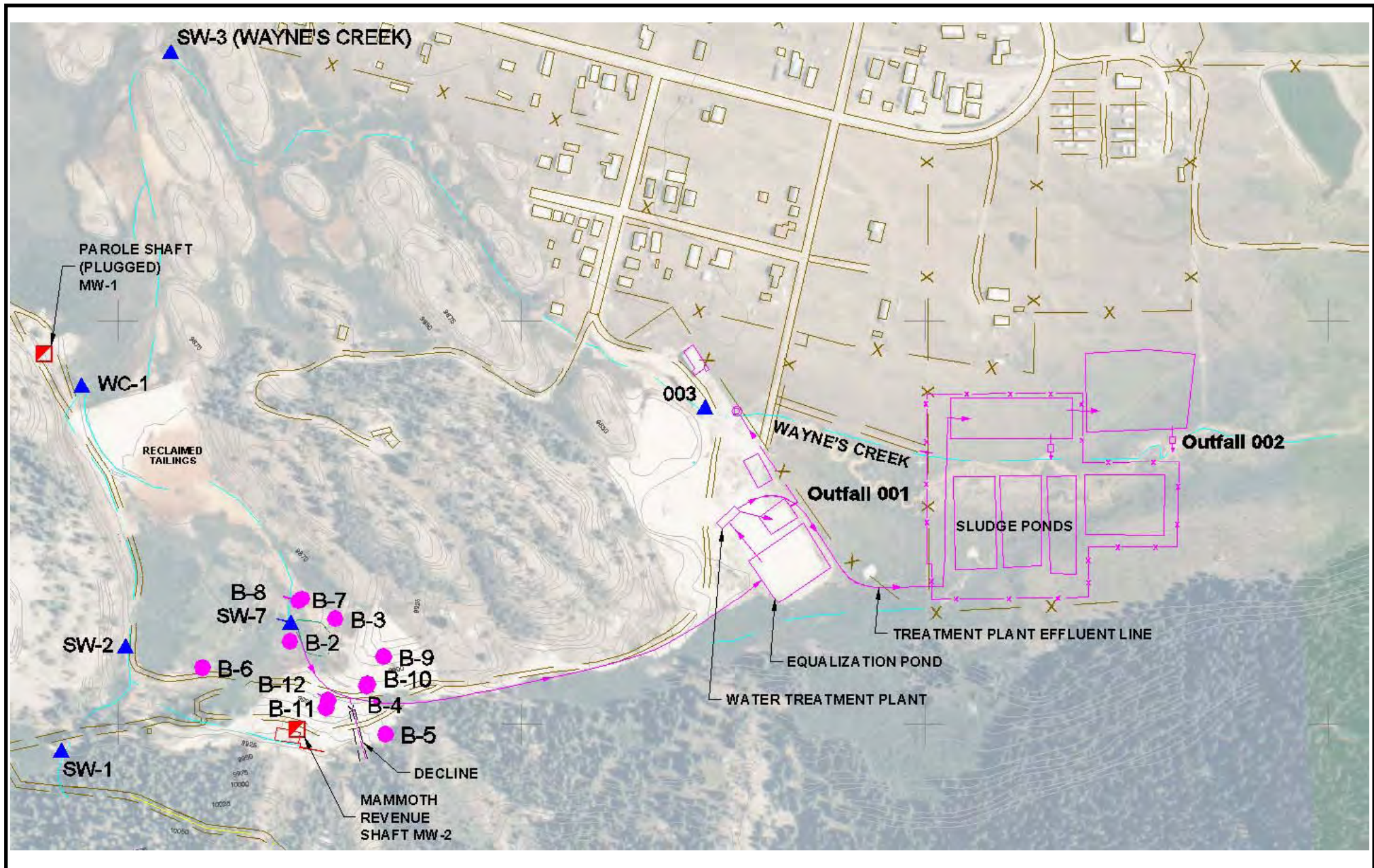


FIGURE 1 GENERAL SITE LAYOUT

ATTACHMENT 2

SUMMARY OF THE GEOLOGY AND HYDROLOGY IN THE VICINITY OF THE MAMMOTH-REVENUE SHAFT, PLATORO, CO

MINE AREA HYDROGEOLOGY

The Platoro area has a long history of mining and exploration dating from the late 1800s. The target of historical mining was the mineralized vein referred to as the Mammoth-Revenue vein, which trends to the northwest and dips steeply (approximately 75 degrees) to the southwest. The Mammoth-Revenue vein averages approximately 8 feet in width and is characterized as vuggy quartz with associated gold and silver mineralization. Additionally, the Mammoth-Revenue vein contains marcasite (FeS_2). The Mammoth-Revenue vein cross-cuts the 1,800 foot thick La Jara Formation. The La Jara Formation is a dense latite porphyry deposited during the long time period of volcanic activity associated with the development of the Platoro caldera complex (Bohn, 1983).

In the time period from 1979 through 1991, UGI and others conducted the most recent phase of exploration. The majority of the primary access routes to the Mammoth-Revenue vein were constructed in the latite bedrock because the latite is very competent in regards to geotechnical stability. Drifts were completed in the Mammoth-Revenue vein at the 0, -200, and -400 Levels as measured from the collar elevation of the Mammoth-Revenue shaft.

The major geologic features in the vicinity of the Mammoth-Revenue mine are the latite bedrock and fluvialglacial deposits. The latite bedrock generally forms the topographic highs in the vicinity of the Mammoth-Revenue mine, rising steeply to the south of the Mammoth-Revenue shaft and as isolated bedrock outcrops to the northeast and northwest of the Mammoth-Revenue shaft (Figure 1). A northwest trending shallow valley (hereafter “the bog”) begins at the Mammoth-Revenue mine and extends for approximately 1,800 feet to the northwest (Figure 1). The bog is filled with fluvialglacial deposits that range in composition from organic-rich, fine-grained sediments to well-sorted gravels. The fluvialglacial sediments are bounded on three sides by latite bedrock.

The town of Platoro is located to the north and east of the Mammoth-Revenue mine and is separated from the bog by a latite bedrock outcrop (Figure 1). Sediments in the immediate vicinity of Platoro are probably associated with the historical evolution of the Conejos River resulting in a thick sequence of fluvioglacial sediments (up to 100 feet) overlying the latite bedrock.

Hydrologic testing of the primary geologic formations in the vicinity of the Mammoth-Revenue mine provides the basis for interpreting the relative degree of interconnectivity of the water-bearing geologic units. A summary of calculated hydraulic conductivity for each of the water-bearing geologic units is shown in Table 1 (SRK, 1981).

Table 1 Hydraulic Conductivities of Geologic Materials in the Platoro Valley¹

Location	Geologic Formation	Hydraulic Conductivity (K) (cm/s)
Mammoth-Revenue Area	Quartz Latite	1×10^{-5}
Bog	Organic Layer	$<1 \times 10^{-5}$
Bog	Glacial Deposits	4×10^{-4}
Mine Area	Mineralized Vein	10^{-3} to 3×10^{-2}
Town of Platoro	Alluvial Sediments	3×10^{-2}

notes: 1. Range of values from SRK (1981)

In addition to the hydraulic testing reported in Table 1, historical water level measurements were taken as part of the initial investigation work completed by UGI (SRK, 1981). The water levels indicate that the ground water system in the bog is not in direct hydraulic connection with the ground water system in the alluvial aquifer because the water levels in the bog are different than the water levels in the alluvial aquifer.

The fluvioglacial deposits in the bog fill a depression in the latite bedrock, which acts as a local ground water discharge zone for the shallow, fractured latite bedrock aquifer. In addition, there may be some flow of ground water along the surface expression of the Mammoth-Revenue vein into the surrounding fluvioglacial sediments of the bog (Figure 1). Although some ground water probably flows through the latite bedrock surrounding the fluvioglacial deposits, the relative magnitude is likely small compared to

the volume of ground water flowing to the surface in the bog. Surface water in the vicinity of the Mammoth-Revenue mine derives primarily from snowmelt, and the runoff from snowmelt is directed into the bog. Surface and ground water in the bog exits through a topographic low in the latite bedrock located near the northwest end of the bog (sampling station SW-3; Figure 1). Thus, the primary mechanism for communication between the ground water in the vicinity of the Mammoth-Revenue mine and groundwater in the alluvial aquifer underlying the town of Platoro is the flow of water from the bog at SW-3.

Throughout recent exploration activity by UGI in the Mammoth-Revenue mine, mine-related seepage has been captured at a sump located at the toe of the waste rock deposit below the Mammoth-Revenue shaft. The sump, referred to as SW-7 (Figure 1), operates year-round with discharge to the water treatment plant from April through October, and to the Mammoth-Revenue mine workings from November through March. Thus, hydrologic capture of ground water flow associated with the mine workings is maintained throughout the year. Capacity for the over-winter pump back from SW-7 (less than 5 gpm) is provided by over pumping from the Mammoth-Revenue mine late in the year with drawdown in the Mammoth-Revenue shaft (MRS) approximately 30 feet below the collar on the concrete pad that covers the shaft.

CONCLUSION

The flow of ground water in the vicinity of the Mammoth-Revenue Mine is governed in part by the relative magnitude of the hydraulic properties of the water-bearing geologic formations in the area. Topographic conditions also impose a control on the migration of ground water in the mine area. In general, ground water flow in the vicinity of the Mammoth-Revenue Mine is restricted by the low hydraulic conductivity of the latite bedrock in the area. Ground water flow does occur in the shallow, fractured latite, but the magnitude is less than the flow rate in the Mammoth-Revenue vein or in the fluvio-glacial sediments. Extensive hydrologic characterization and monitoring data has reasonably demonstrated that there is not a direct hydrologic connection between the mine workings and the alluvial aquifer underlying the town of Platoro. Thus, any changes in mine water chemistry that might occur during intermediate stages of

additional reclamation activities in the mine area (e.g., treatment solids transfer) would be captured within the mine area at the SW-7 sump and then treated in the water treatment plant prior to discharge.

REFERENCES

- Bohn, E.E. 1983. "Geology and precious metal deposits within the Platoro Caldera, Colorado: A high level epithermal system." *in 89th Annual Northwest Mining Association Convention*, Spokane, WA.
- Steffen, Robertson, and Kirsten. (SRK) 1981. *Site Selection Investigation for the Platoro Project*. Prepared for Union Gold, Inc.

ATTACHMENT 3

Application of pH Neutralization and Organic Carbon Addition at the Barite Hill Mine, South Carolina – Supporting Documents

**Document 1: September 10, 2008 – Barite Hill Pit Lake and Mineral Springs Seep
Update**

**Document 2: Low Cost Treatment of a Highly Contaminated Pit Lake Using
Innovative Technology Barite Hill Mine, McCormick, SC; Alexco Inc,
U.S. Bureau of Reclamation, U.S. Environmental Protection Agency**

(full documentation at [www. http://epaosc.net/doc_list.asp?site_id=2768](http://epaosc.net/doc_list.asp?site_id=2768))

September 10th, 2008

Barite Hill Pit Lake and Mineral Springs Seep Updates

Water Quality Improvements for Barite Hill Pit Lake

Comparison of untreated lake water (October 2007) and interim treated lake water (August 22, 2008) to Priority Pollutant Criteria provided under Regulation 61-68 (adopted June 2004) and adjusted for a water hardness of 400 mg/L.

	Human Health	WQC under R 61-68			
	MCL	CMC	CCC	October 07	August 08
Potentially Applicable Standards (priority pollutants)				Pit water untreated	Pit water treated
Antimony	0.006	NSA	NSA	0.02	0.006 ND
Arsenic	0.01	0.34	0.15	0.968	0.010 ND
Cadmium	0.005	0.008	0.0026	1.57	0.005 ND
Chromium	0.1	0.57	0.074	0.141	0.010 ND
Copper	1	0.057	0.039	287	0.010 ND
Lead	0.015	0.32	0.005	0.161	0.010 ND
Nickel	0.61	1.071	0.167	0.404	0.020 ND
Selenium	0.05	NSA	0.005	0.23	0.010
Zinc	5	0.339	0.339	40.2	0.020 ND

As a necessary residual effect of the treatment process, iron and manganese exceed one or more secondary water quality criteria. Iron is observably precipitating as large deposits of iron monosulfide (FeS) throughout the lake, surrounding and encapsulating other heavy metal sulfides. Iron and manganese are anticipated to continue to drop out to ultimately achieve low concentrations (through geochemical precipitation) when the previously added soluble organic carbon is depleted through redox reactions with sediments containing iron hydroxides and other metal hydroxides. Since the July 2008 sampling event iron has decreased from 322 mg/L to 287 mg/L. Total organic carbon (TOC) content is now at 127 mg/L.

	Secondary MCL (mg/L)	Pit Water Untreated October 2007	Pit Water Treated August 2008
Aluminum	0.2	244	0.20
Iron	0.3	1150	287
Manganese	0.05 – 0.1	13.6	11.7

Reduction in environmental impact and off-site contaminant loading as measured via seep quality update.

Assessment of the site by the REAC team (Lockheed Martin 2007) determined that the flow rate from the seeps to the Hawes Creek tributary was, during an historic drought in May 2007, about 5 gallons per minute.

Reassessment of the same stream segment in July and August 2008, indicated that the stream seepage was about 0.8 gallons per minute. Observation of the pit lake shows a similar coating throughout the lake sediments as was observed on the anchor ropes shown above, and it is possible that this precipitation process is plugging the fractures and reducing the seepage flow rate. The lake level is as high or higher than during the assessment conducted in May 2007, while the flow rates have decreased more than 80%, so we can be confident in asserting that the actual transmissibility of seepage along these fractures has been reduced, similar to what might be achieved by physical grouting or plugging of the seepage zones.

While numerous points along the creek indicate iron – staining and evident seepage, one particular seepage location closest to the pit contained notable sulfide odor on July 30 2008. This seepage location was outfitted with a covered one-gallon plastic bucket perforated on the bottom and on the side wall away from the creek toward the location of seepage, and was re-sampled on August 22nd 2008. The quality of the seepage from this location has markedly improved while still containing much of the ionic strength consistent with previous seepage.

Analyte	July 30 seep (Bucket #2)	Aug 22 seep (Bucket #2)	% of previous seepage
Ca	400	456	114.0%
Na	80.6	122	151.4%
K	10.1	65.6	649.5%
Cu	84.3	0.138	0.2%
Zn	45.6	0.157	0.3%
Cd	5.05	0.005	0.1%
TDS	7940	4250	53.5%
Fe	1070	493	46.1%
Mn	23.6	6.93	29.4%

It can be expected that the TDS of a treated seepage flow would drop, without the drop being attributable to dilution. The reason for this is that heavy metal sulfates such as iron and copper sulfate would be replaced in solution by a lighter alkali or alkali earth carbonate, formed by microbial metabolism of the added soluble organic carbon. While the total ions in solution are likely to be similar, the atomic masses are lower, and the TDS will be lower. An example of this TDS reduction can be given in that copper sulfate has a formula weight of 159.5 g/mole, while sodium bicarbonate to replace it in solution has a formula weight of 84 g/mole.

It is evident from this data that the removal actions taken in the pit lake have resulted in both substantial reductions in flow to the seeps entering the creek and have also resulted in improvements to the quality of the seepage waters particularly for the most toxic parameters copper, zinc and cadmium.

Low Cost Treatment of a Highly Contaminated Pit Lake Using Innovative Technology Barite Hill Mine McCormick, SC

Joe Harrington Alexco Inc, Mike Gobla US Bureau of Reclamation, Leo Francendese, and Ed Bates, USEPA

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In the United States alone there are hundreds of mineral mine pit lakes, most in the West, but some, like Barite Hill are from mineral mining in the Eastern US. Although some have good water quality, many have acidic water with elevated concentrations of toxic metals. Developing effective low cost solutions for treatment of such pit lakes is essential for restoring the environment and protecting human health. The effective, low cost, innovative technology and approach described in this paper offers a solution for at least some of these sites.

The Environmental Protection Agency (EPA) Region 4, Emergency Response and Removal Branch (ERRB) worked in cooperation with the US Department of the Interior, Bureau of Reclamation and the private companies CMC Environmental Services Inc, Alexco Resource US Corp and TNA Inc. to develop and implement an innovative, formulated remedy for the acidic pit lake at the abandoned Barite Hill Mine in South Carolina.. The selected remedy included a patented technology provided by Alexco Resources US Corp, (involving addition of liquid carbon), and has resulted in low cost, effective acid pit lake mitigation with a superior end result compared to conventional neutralization treatment schemes. The resulting pit lake has excellent water quality and minimal risk of remobilization of the deposited metals. The achievements were made at an approximate cost savings of 79 to 88 % compared to traditional remedies for acid pit lakes.

The Problem

The Barite Hill Mine located near McCormick, South Carolina, was a cyanide heap-leaching operation that produced approximately 1,835,000 grams (58,996 troy ounces) of gold and 3,390,280 grams (109,000 troy ounces) of silver (Clark, 1999). Mining operations took place from 1990 thru 1994 followed by a period of reclamation. Bankruptcy of Nevada Goldfields Inc. in 1997 resulted in abandonment of the partly reclaimed site. The site is located in a wet climate (average 48 inches/year of rainfall); so the long term evolution is that the pit would become a flow through lake. Although the mining company had neutralized the half-full pit lake with lime and coated the adjacent waste-rock backfills with gunite, the pit re-acidified upon further filling. Two extensions on the west side of the pit were partially backfilled with 250,000 tons of pyrite-rich (more than 50% pyrite) waste-rock which was left with angle of repose slopes extending down to the water's edge. The gunite coating failed to provide an effective isolation of the pyritic waste-rock backfills.

When EPA was asked to respond in early 2007, the pit lake was filled with approximately 60 million gallons of acid water (pH range 1.5 to 2.2) which had very high heavy metals concentrations (aluminum, arsenic, cadmium, copper, iron, manganese, nickel, selenium, zinc) 100s to 1000s of times over levels that would be protective of the environment (Table1). An adjacent creek had been sterilized for approximately a mile of the 2 mile distance to nearby Strom Thurmond Lake which is used both as a drinking water reservoir and recreational fishing resource. During investigations, a potential for catastrophic release was identified in which the pit lake would fill and overtop along a low wall rim where the upper layers of topsoil would give way and release 40 acre-feet of contaminated acid water as a flood wave that would carry contaminants into the environmentally sensitive lake. On July 3rd 2007, the South Carolina Department of Health and Environmental Control (SCDHEC, 2007) recorded a pH of -3.9 in the creek after an evening rainstorm and morning atmospheric warming event. During a September 2007 sampling event, the pit lake also generated a fog covering the entire surface area. Sulfur dioxide measurements at the pit lake rim (a full 100 plus meters away) were measured at 13 mg/m³ equaling the National Institute of Occupational Safety and Health Short Term Exposure Limit (NIOSH STEL) of 5 ppm. Based upon available data, the USEPA identified the pit lake as a primary hazard to human health and the environment. EPA determined that removal of the hazardous conditions were required. The USEPA requested assistance from the US Department of Interior, Bureau of Reclamation to help identify potential options to reduce the risks posed by the pit lake to acceptable levels.



Figure 1 Image of the Barite Hill Mine. The Pit Lake is located in the upper right corner. Approximately 250,000 CYS of gray pyritic rock sit on its SW borders.

Evaluation of Potential Solutions

In cooperation with the USEPA, the Bureau of Reclamation (BOR) identified six potential options for mitigation of the acidic Barite Hill Pit Lake (Reclamation, 2007). These options were identified and evaluated consistent with USEPA Superfund policy guidance. The options were:

- Option 1. No Action, Accept the Consequences of the Acid Pit Lake
- Option 2. Construct Spillway and Fencing
- Option 3. Perpetual Water Treatment
- Option 4. Neutralize, Backfill, and Reclaim
- Option 5. Blast Pit Rim, Partially Backfill and Reclaim as a Dry Basin
- Option 6. Minimal Waste Backfill, Lime Neutralization, and Carbon Addition

The costs for each remedy option are presented in Table 1. The findings of the remedy evaluation were that options 1, 2, and 3 were not sufficient to mitigate the problem

because a hazardous acid and heavy metals bearing pit lake would remain at the site. Option 1, the no action alternative, is also not acceptable because the danger of a catastrophic release of acid water would remain if the pit rim were to fail. Option 2 would prevent a catastrophic release of acid water, but there would still be significant impacts to downstream receptors. A one inch rainfall would cause an estimated 500,000 gallons of acid water to flow out of the pit and into the downstream environment. Option 3 for perpetual water treatment would eliminate the risk of offsite discharge (provided a large enough plant was built and kept operational) but there are implementation problems related to technology for treating such low pH water, available space for long term sludge storage, and the significant recurring costs to operate and maintain a sophisticated water treatment plant in perpetuity.

Remedy options 4, 5, and 6 were judged likely to provide a reclaimed pit which would have neutral drainage and were expected to be sufficient to mitigate the problem. Each of these options required neutralization/treatment of the existing acid water in the pit, involve some degree of lime amending and backfilling of mine waste rock, covering/capping of pyritic bedrock and mine waste exposures, and revegetation. The water in the pit would be neutralized and then discharged to the creek under Options 4 and 5. Under Option 6 the water would be neutralized but not discharged, a neutral pit lake would remain.

Option 4 has the advantage that in addition to eliminating the pit lake, all of the pyritic highwall exposures would be covered with fill. This option, which would completely backfill the pit, is a very high cost remedy because of the large volume of costly backfill that would be required. There is no clean backfill source of sufficient quantity available at the mine site. The backfill would either be acidic waste rock from the site, much of which would need to be neutralized, or clean backfill imported to the site.

Although feasible, Option 5 would require a significant level of site investigation and engineering design, and is expected to be costly to implement. To establish a free draining pit with minimal backfill requirements, part of the north highwall between the pit and the creek would be blasted and removed. The water table in the pit would be lowered to be similar to that of the adjacent creek. As a result of eliminating the pit lake, the hydraulic gradient in the remaining pyritic highwalls would increase and much of these highwalls may remain uncovered. Extensive grouting to prevent a network of acid seeps from establishing within the remaining fractured highwalls would be required. Like Option 4, a significant portion of the backfill would either need to be neutralized acid waste rock or imported clean fill. The part of the pit below creek level would be filled with sludge from neutralization and it may be difficult to backfill into or over this sludge to establish a free draining surface that can be stabilized and reclaimed. Options 4 and 5 also share a risk that lime neutralized waste fills may result in seepage that is neutral but metal laden thus requiring further treatment or polishing.

Option 6 (minimal waste backfill, lime neutralization, and carbon addition) was selected for implementation. This option had a moderate cost (almost an order of magnitude less than conventional backfill approaches), and was of medium complexity to implement.

Under this option, the pit lake would be neutralized but the lake would remain. A spillway would be constructed to allow neutral water to overflow to the creek. About 50,000 cubic yards of the pyritic angle of repose mine waste on the west side of the pit would be placed in the lake bottoms where negative redox conditions would prohibit leaching of acid and metals, and the remaining waste-rock backfill would be capped and reclaimed. Some of the pyritic highwalls would be capped while others, which are too steep to cover, would remain exposed to the environment. Because the pit may continue to generate small amounts of acid from remaining highwall exposures and from seepage and interaction of the water table with the capped waste-rock mass, carbon loading was included to establish a sulfate reducing bacteria (SRB) system in the pit lake. (SRB systems have often been used to treat acid metal discharges on mining sites, mostly in the Western US.). The water quality would be controlled by the infrequent addition of lime and or carbon to maintain the SRB culture. SRB cultures are known for producing substantial amounts of alkalinity and for precipitating metals as sulfides. Thus the pit lake would be maintained at near neutral pH conditions and be free of most metal contaminants. Because of the fear that the initial lime addition would generate large amounts of sludge and which could occupy 1/3 of the available lake volume, Alexco suggested that simultaneous carbon loading with the lime neutralization could result in a pit lake with minimal sludge. Based upon effectiveness, implementability, low long term operation and maintenance costs, and lower capital costs, the USEPA decided to implement option 6.

Alexco Inc was identified as the technically qualified and best value subcontractor to execute the required carbon loading technology. They operated as a subcontractor to the prequalified emergency response and removal services prime contractor, CMC Environmental Services Inc. CMC Inc. was responsible for providing the requested pit lake lime neutralization and carbon loading technology, construction of the flow through pit lake and waste rock cap design concept. TNA Inc. provided technical services support such as surveying, field sampling, analytical services, report compilation and bench scale treatabilities. BOR continued to provide engineered design plans and played an active role in continued site management with the USEPA On Scene Coordinator (OSC).

Table 1 Summary of Barite Hill Pit Remedy Options and Costs

Remedy Option	Cost *
No action	Risk of catastrophic failure would remain.
Construct spillway and fencing	\$300,000. A 1" rain would cause 500,000 gallons of acid water to flow out of the pit.
Perpetual water treatment	\$5,700,000. Plus \$1 million/year for operation. Acid would be contained but an acid lake would still be present at the site.
Neutralize, backfill, and reclaim	\$21,710,000. 1.15 million cubic yards of waste would be hauled in to fill the pit. The fill would cover the sulfide bedrock exposures, but some seepage could remain.
Blast the pit rim, partially backfill, and reclaim as a dry basin	\$12,390,000. Difficult to implement, a dry basin would remain, some acid seepage likely.
Minimal waste backfill, lime neutralization, carbon loading	\$2,600,000. The acid pit lake would be transformed to a clean lake requiring minimal long term maintenance. Waste fills would be graded and capped. This is the selected remedy.

* The costs are based upon conceptual level designs estimates for the purpose of comparing one option to another. They do not include final design, construction management, or contractor overhead and profit. The selected option had a total cost of \$4 million.

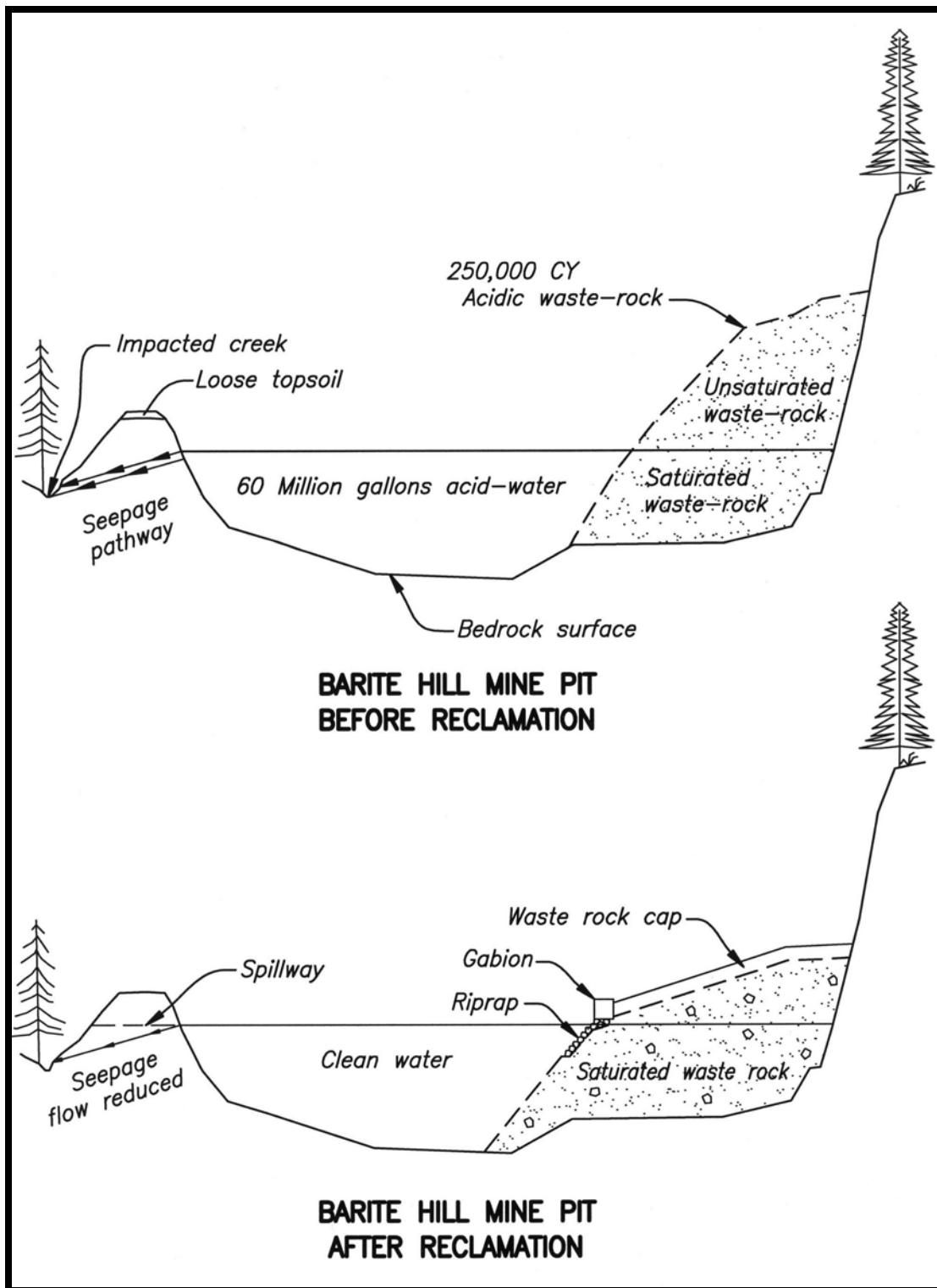


Figure 2 Cross section of the Barite Hill Mine Pit selected option.

Implementation of the Chosen Removal Action



Figure 3 Pit Lake before and after implementation of the chosen remedy (pre toe and topsoil construction)

Implementation of the Removal Action began in the fall of 2007 when construction equipment was mobilized to the site. Initial actions were to establish road access to the low pit rim and remove the unstable topsoil and loose rock. An impact hammer was used to carve out a 20-foot-wide temporary spillway in the bedrock, thus eliminating the possibility that a large flood event would cause a dam-break type erosion failure of the pit wall. Some acid could be released in a flood, but it would be a small volume compared to the catastrophic 40 acre-foot flood wave that could have occurred if there was an erosional failure of the upper pit rim.

The next action was grading the waste-rock to eliminate the angle-of-repose slopes by pushing about 50,000 yd³ of waste-rock into the pit. A small stockpile of spent carbide lime, a waste product from acetylene manufacturing, was on site. Carbide lime was chosen as the preferred neutralizing agent because it was determined to be more cost effective than other classic lime alternatives. The carbide lime purchased and used on site had 1/2 the reactivity of processed lime while being approximately 1/3 the cost. In addition, it provided a use for an otherwise wasted byproduct of nearby acetylene

manufacturing plants. Because the waste-rock gave off SO₂ fumes after rain events, a thin layer of lime was periodically spread onto the waste surface during grading operations to reduce the rate of acid generation. This action protected the workers and lowered the amount of additional stored acidity being released into the pit lake as the waste rock was submerged.

Neutralization of the pit and carbon loading began shortly after grading commenced. A principal concern about the remedy option was the potential for re-acidification of the pit after reclamation was complete. Prior to reclamation, acid inputs to the pit lake came principally from the waste-rock backfill and to a lesser degree from runoff and seepage from exposed pyritic high walls. Submergence of some of the waste-rock and capping of what remained above the lake level was chosen as the principal means of reducing acid input to the pit. The pyrite-rich high wall on the north side of the pit was graded and capped with soil and seeded. The east high wall was too tall to reclaim, it would remain as an acid source.

There would also be acid input from the waste-rock fill due to infiltration through the cap, and by fluctuations in the pit lake water level interacting with the backfill mass. Measures to minimize changes in the pit lake surface elevation were implemented. The spillway was designed as the principle outlet for water from the pit. Under normal conditions the pit lake water surface would be at or just below the spillway elevation. Spillway capacity was sized to limit lake level rises during a flood to a maximum of 2 feet of temporary rise during the 100-year flood event.

Periods of drought are more problematic to mitigate against decreases in the lake elevation. The upstream watershed was increased by excavating through the south pit wall to drain an adjacent area. Storm-water runoff into the pit would increase for a given storm event by enlarging the watershed. For drought, a ground water well and pump was installed to allow for water addition. Even this measure has limits, the bedrock at the site is tight and wells have a low yield. Finally, excess neutralization potential is provided by the pit treatment. A monitoring system will detect adverse changes in the pit lake, but it is expected that excellent water quality will be maintained for a long time.

Stoichiometric calculations coupled with empirical analytical evidence support the expectation of sustainable, excellent water quality. Current water quality compared to October 2007 pretreatment can be seen in Table 2.

Table 2 Pit Lake Water Quality Before and After Treatment (mg/l)

	Human Health ¹	WQC under R 61-68 ²			
	MCL	CMC	CCC	October 07	August 08
Potentially Applicable Standards (Priority Pollutants)				Pit water untreated	Pit water treated
Antimony	0.006	NSA	NSA	0.02	0.006 ND
Arsenic	0.01	0.34	0.15	0.968	0.010 ND
Cadmium	0.005	0.008	0.0026	1.57	0.005 ND
Chromium	0.1	0.57	0.074	0.141	0.010 ND
Copper	1	0.057	0.039	287	0.010 ND
Lead	0.015	0.32	0.005	0.161	0.010 ND
Nickel	0.61	1.071	0.167	0.404	0.020 ND
Selenium	0.05	NSA	0.005	0.23	0.010
Zinc	5	0.339	0.339	40.2	0.020 ND

1. USEPA drinking water criteria

2. Priority Pollutant Criteria provided under Regulation 61-68 (adopted June 2004) and adjusted for a water hardness of 400 mg/L.

ND not detected at the reporting limit shown

Acid loading potential from waste rock fills to the pit lake

Contaminant loading to the pit lake occurred during the mining period from 1990 – 1994 and then to May 2008 when rock addition to the pit lake ceased. The soluble load of sulfate is estimated to be comprised of that amount of salts accumulating in the pit lake itself, and the amount of sulfate that has seeped out of the pit lake to Hawes Creek. Seepage to the creek has only been a recent phenomenon since 2003. Around that time the pit levels are estimated to have risen to an elevation greater than the adjacent creek. At a worst case assumed loading, the seepage rates could have averaged 12 L/min since January 2003; for a total sulfate load of 8.5 g/L x 12 l/min x 526,000 minutes/year x 5 years (Jan 2008 – Jan 2003), or 242 mega grams (267 tons) of sulfate. Accumulated in the pit lake and the saturated volume of the fills is a volume of about 60 MM gallons containing about 2,146 tons of sulfate. Taken together, the amount of sulfate likely generated from the waste fills and high walls since 1994 is 2,413 tons. This mass of sulfate was generated from the oxidation of pyrite; therefore we can calculate from stoichiometry the amount of iron likely residing in the lake waters or in the sediment layers. The reaction of pyrite with oxygen proceeds as follows:



Total iron arising from this reaction to form the observed 2,413 tons of sulfate is 702 tons iron. The kinetic rate of loading can be grossly estimated by dividing the mass load (2,413 tons sulfate + 702 tons iron) by the duration of leaching (18 years) for a rate of 173 tons/year. This equates to 0.47 tons (948 lbs) of metal sulfate contained in leachate every day.

The total area of fills is about 4 acres and wastes were stacked to a depth of about 60 feet comprising highly pyritic materials. It is estimated that more than 20 times more pyrite waste-rock fill remains above the water table than what has been oxidized. Because the remaining amount of pyrite is negligibly different from the beginning amount (more than 95% of the pyrite has not oxidized), the assumption of linear zero order kinetics is valid ($dF/dt = -R_{py}$). ZHeng et al showed that the rate of pyrite oxidation can be approximated by the equation:

$$R_{py} = -6k_1[\text{Fe}^{3+}]^{0.15} / d_{py} \rho_{py}$$

Given the known ferric iron concentrations, and the density and estimated particle size of pyrite, we can calculate the specific rate constant for pyrite oxidation in g/cc-day at the Barite Hill Mine Site:

$$\text{Fe}^{3+}; 3 \times 10^{-4} \text{ g/cc}$$

$$d_{py} \text{ in cm; } 100 \text{ micron or } 0.01 \text{ cm}$$

$$\rho_{py} \text{ is about } 4.8 \text{ g/cc}$$

$$R_{py} [\text{g/cc-day}] =$$

$$6 \times k_1 \times (3 \times 10^{-4})^p / (0.01 \times 4.8); = 5.9 \text{ (18 yrs) or } 7.6(14 \text{ yrs}) \times 10^{-7} \text{ g pyrite oxidized/cc-day.}$$

$$k_1 = (R_{py} d_{py} \rho_{py}) / (6[\text{Fe}^{3+}]^p); \text{ g/cm}^2\text{-days } k_1 = 2.1 \times 10^{-8} \text{ for high ferric ion concentrations, calculated in centimeters, grams, days or cgd units.}$$

At lowered concentrations, below 0.01 molar Fe^{3+} , the reaction order approaches first order with respect to ferric ion (from 0.15), and the reaction rate equation becomes:

$$R_{py} = -6k_1[\text{Fe}^{3+}] / d_{py} \rho_{py}$$

Logic associated with subaqueous capping of approximately 50,000 CYS of waste rock



Figure 4 Grading of the South Waste Rock Pile

Using the previously derived values and assuming that Fe^{3+} concentrations in the lake would be kept below 5 mg/L, the rate of subaqueous oxidation would be reduced to 3.8×10^{-12} g pyrite oxidized/cc-day. Maintenance of sufficiently reducing conditions, such as through provision of excess organic carbon to maintain the SRB culture and assure reducing conditions (negative redox), will keep ferric ion below 5 mg/L and therefore ensure that the rate of subaqueous pyrite oxidation is reduced by as much as 200,000-times from the previously calculated oxidation rate of 5.9×10^{-7} g pyrite oxidized/cc-day that the wastes were subjected to prior to carbon loading and prior to placement under water. In effect, the submerged rock becomes a negligible source of acid loading.

In addition, the placement of the 50,000 CYS towards the pit lake allowed for the creation of sufficient slope to construct an in place cap for the remaining waste rock.

Benefits of capping wastes surrounding the pit lake

Capping of above-water fills with a fine-grained water retaining, organic rich soil and maintaining vegetation would both reduce available ferric ion concentration in the fills, and increase the distance and reduce the porosity for diffusion of oxygen to the pyrite

grains, significantly slowing oxidation rates.

Once capped, the leaching kinetics are no longer solely limited by mineral reaction constraints, but become additionally limited by water and air flow rates. These limitations are exerted by both distance of diffusion (thickness of the cover), and by a decreased area through which diffusion can occur (decreased gas-filled porosity) through the selection of the appropriate water retaining soils.

Ficks first law (steady state diffusion) can be used to estimate flux of oxygen through inert non-oxygen consuming soils. With the gas-pair diffusivity (O_2/N_2) D , the diffusion distance x and the concentration of oxygen c , the vector flux of oxygen through the plane normal to x is given as:

$$J = -D \, dC/dx$$

Mass loading is then estimated by the product of flux J and the area A .

Gas pair diffusivity has been estimated at $0.2 \, \text{cm}^2/\text{s}$ or, once adjusted by tortuosity (~ 2), about $9,000 \, \text{cm}^2/\text{day}$.

Gradient of oxygen dC can be estimated across the cover thickness dx . dC is the differential between 21 vol % oxygen decreasing to about 3% oxygen, where bacterial oxidation is observed to cease, which converted to mass of oxygen per unit volume in consistent units is $0.000257 \, \text{g oxygen/cc}$. Dx is approximately 110 cm to the base of the cover, where pyrite would be first encountered. Flux J is therefore limited by diffusion through the thickness of the cover (assumed for this calculation to be inert / non-oxygen consuming) to a maximum flux of 366 lb/day or $10 \, \text{g/m}^2\text{-day}$.

Placement of an inert (non-oxygen consuming) clay cover will therefore reduce the mass loading to the pit lake from around 950 lbs/day, to about 366 lbs/day.

Benefits of vegetated oxygen consuming cover

The foregoing is a conservative estimate of the reduction of loading as a result of placement of a diffusion-reducing clay cover. The clay cap is further covered with a foot of organic-amended growth medium to establish a vegetated cap. This manufactured topsoil cover will consume oxygen, and thereby provide additional reduction in potential loading from these covered wastes.

Analysis indicates that the soil cover being placed contains about 6% total organic carbon (AES Atlanta, GA), and it will be maintained in a vegetated state. The amount of oxygen that could penetrate into this cover and be consumed within the cover materials due to reactive consumption that can arise from this load of carbon stored in the cover is 780,000 pounds. This amount of carbon is sufficient to consume 16 years of diffusion loading – or enough to initially withstand a 16 year drought.

Additionally, vegetation seed mixes that are being specified by Clemson University reclamation specialists are being placed on the cover during the autumn of 2008, and these cover grasses in the South Carolina climate typically produce more than 10 tons of organic matter per acre per year, adding more than 400 lbs/day of oxygen consuming carbon sources to the soil cover.

The rate of ingress of oxygen to the pyritic fills through the cover, as designed and constructed, will be minimal. Oxygen ingress will be attenuated by the cover thickness, consumed by plant cover photosynthetic fixation of carbon in the root zone, and backstopped by the high concentration of carbon provided within the cover soils.

High wall oxidation rate estimate

The pyrite veins exposed by the mining process are partially submerged by the water level of the pit lake. The portion of the veins that remain exposed to air will continue to oxidize and release acidity and metals to the lake. The oxidation rate of the high wall is limited by the classical fire triangle: oxidation of pyrite requires oxygen, water and pyrite. For some exposed pyrite faces, oxidation rates will be minimal because water does not stay on the exposed face, it quickly runs off. For those fractures that can hold water, either due to their proximity to the water line, or due to fine particles that retain water through soil-like properties, the oxidation of pyrite can proceed rapidly until either the water becomes acid-saturated (entailing too great of an osmotic pressure for the bacterial metabolism to proceed), or the heat of the reaction causes drying out of the water-binding soil particles. Lastly, when the pyrite is consumed we can either have adherent coatings of ferric hydroxide, or if the iron is solubilized shrinkage cracks and voids can be created which may compromise the structural integrity of the wall. The result could be sloughing of the oxidized particles and the exposure of a new face of pyrite with a new set of fractures some of which may be susceptible to acidification.

To estimate the worst case oxidation rate from this high-wall oxidation scenario, we assumed that the pyritic sections of the high wall can oxidize at the same rate proportional to the amount of pyrite exposed as was previously exposed in the rubble waste piles adjacent to and partially submerged in the pit lake margins.

Reactive volume of the high wall is assumed to be 50% of the area of the eastern highwall to a depth of 3 feet. This wall is 600 feet long by 60 feet high above the water, and taken to a depth of 3 feet yields 4,000 yd³ of volume; so at 50% reactive material there is 2,000 cubic yards of reactive rock volume.

As previously noted, the total volume of the pyritic wastes in the pit backfills is around 250,000 – 300,000 cubic yards, and this uncovered waste, without any run-on controls or covers, generated 1000 - 1200 pounds per day of contamination as observed over the past 18 years since mining began. The amount of waste in the high walls is less than 0.8% of the amount that was in the rubblized waste fills, and therefore a worst case calculation is that the high walls could generate about 10 pounds of metal sulfate per day.

Of course, the high walls are not rubblized broken rock, and except for fracture zones do not have the moisture holding capacity or fine grain size to provide habitat for bacterial oxidation, so we can expect that this is a maximum rate of oxidant waste entering the lake.

Pit Lake neutralization and carbon amendment process



Figure 5 Simultaneous waste rock grading and carbon loading/carbide lime in situ neutralization at the pit lake

Stoichiometry: Estimate of liquid and solid phase contaminants

The pit lake has been estimated to contain 60MM gallons of acid rock drainage water in 7.4 acres of water surface generally in three depth zones. From the start of treatment the treatment team understood the potential chemical mass load in the lake requiring treatment to be (Alexco, 2007):

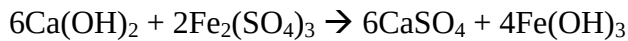
- 1,600-2,400 tons mineral acidity
- 150 – 410 tons of dissolved ferric iron
- 56 - 110 tons of dissolved copper
- 20 - 35 tons of other heavy metals (As, Cd, Pb, Ni, Se and Zn) TDS

In addition to this known metals load in the water, the sulfate levels indicated that there had to be an additional unseen mass load of metal contaminants sorbed to the sediments

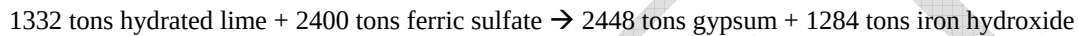
in the lake bed. If on average 2,000 tons of sulfates are in the lake, it had to arise from the oxidation of pyrite (FeS_2) and therefore about 580 tons of iron “should” be in the lake system (either in the water column, or in the lake bed as sorbed / precipitated mineral sediment).

Based on variable analyses for iron ranging from 420 mg/L up to 1,150 mg/L, there was a considerable unknown component of hidden metals mass load that would require both pH adjustment and redox amendment.

Lime neutralization alone proceeds according to the following equation:



On a lake-wide basis, this equation can be rewritten as:



Chemical acid neutralization adjustment was conducted by CMC Environmental Services Inc using carbide lime (a byproduct of the acetylene manufacture process) blended directly into the pit lake via a custom designed, aerated batch delivery system from January – May 2008. This process required the addition of about 1,860 tons of hydrated and water saturated lime, or about 1,300 tons of hydrated (but dry) lime (estimated due to the variable moisture content). It should be noted that it is difficult to know with certainty that neutralization had been fully achieved. The reason for this uncertainty is that when the pH of the surrounding lake water adjusts from 2.0 up to about 7.0 and the soluble chemical mass decreases through chemical precipitation, the sorbed chemical mass begins to desorb from the rock / sediment layers and to enter the lake water. This desorption and dissolution process began the day lime began to be added in late January, and has continued to the present time. Waste-rock placed into the lake during the later stages of neutralization will desorb over a similar (but offset or shifted by several months) time period.

At some point however, other processes become more dominant in the lake. The most important of these is the biological conversion of about 400 tons of organic carbon compounds simultaneously added to the lake with the lime. These organic compounds can be represented in their simplest form as CH_2O .

Addition of carbon sources while simultaneously conducting acid neutralization results in a uniquely stable end point. A graphical depiction of the thermodynamic conversion process is shown in the Pourbaix diagram for iron (Figure 6).

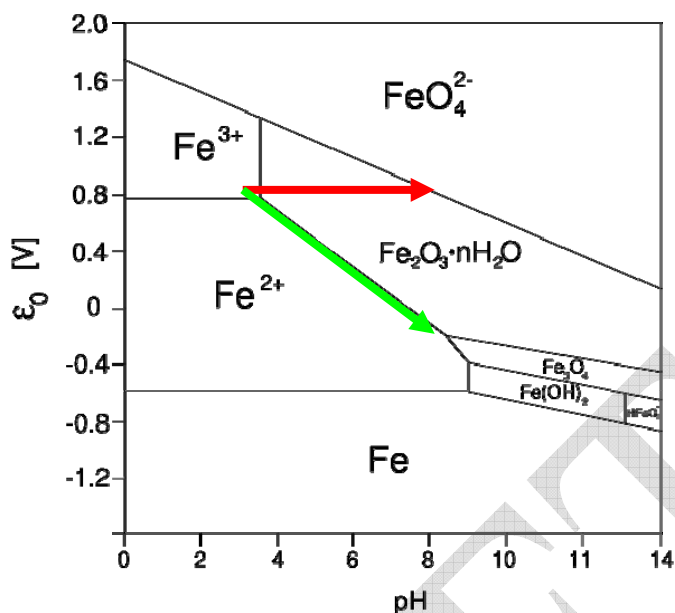


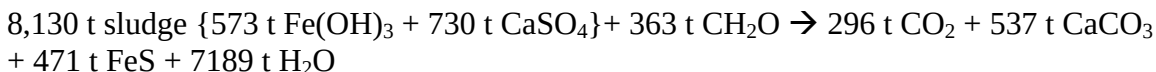
Figure 6 Pourbaix diagram of the thermodynamic conversion process for iron

In Figure 6, the horizontal (left to right) red arrow depicts the pH adjustment process only, while the (diagonally down and to the right) green arrow depicts Alexco's process for simultaneous neutralization and redox amendment. Lime neutralization with simultaneous carbon addition enabled the formation of iron monosulfide and minor amounts of gypsum precipitates rather than the massive amounts of iron hydroxide sludge typically formed during lime neutralization. Considering that titration tests showed that approximately 30 feet of sludge would be generated by conventional lime neutralization, the resulting less than 6-inches of precipitates formed by Alexco's carbon addition during lime neutralization is a remarkable result.

The following equation presents the overall stoichiometric reaction from the addition of carbohydrate-based carbon sources to sulfate-saturated iron hydroxide treatment solids:



On a weight basis for conversion of a portion of the sludge in the lake to form equimolar carbonates and sulfides from the neutralization sludge, the preceding sediment equation can be rewritten as (t = tons):



The formation of 296 tons of carbon dioxide within the lake waters was noted to exert an effect on the pH neutralization process. Addition of lime tends to react with the dissolved carbon dioxide, forming additional calcium carbonate. While formation of calcium carbonate is an intrinsic part of the treatment process, it is possible to consume several hundred tons of lime without increasing the pH due to the biological growth bloom that

occurs upon addition of lime. The release of carbon dioxide from bacterial metabolism will temporarily be trapped in solution and is then available to immediately react with and consume the new lime that is continually being added, somewhat prior to and during its reaction with the surrounding mineral acidity. Undoubtedly some of this lime/carbon dioxide reaction cycle occurred at the later stages of pit lake neutralization and somewhat increased the lime demand. This is not negative to the overall stability of the lake, as it would be creating a microbially formed and highly reactive calcium carbonate that would provide neutralization potential that will resist future acidification of the lake.

Geochemical end-states

The treatment provides several benefits including:

- Density benefits (Reduction in Volume) – toxic metals are 28 times denser as sulfides.
- Chemical transformation (Reduction in Toxicity) – dissolved metals are treated to form sulfides.
- Location benefits (Reduction in Mobility) – metals are on average precipitated far below the water line.

While accurate, the equation for conversion of sludge to carbonates and sulfides previously presented in this paper does not fully present the densification and volumetric reduction that will occur during this process of converting hydroxides to sulfides in the sediment layers. The approximate density of the sediments and lime treatment residuals prior to carbon loading would be about 1.07 g/cc with about 15% dry matter (after settling and compression under its own weight). After treatment with added carbon sources, the anticipated volume of the sediments, around 10,000 cubic yards of wet hydroxide solids can be reduced to about 350 cubic yards of newly formed in-place minerals with an estimated density of 3.4 g/cc. This works out to be a twenty eight-fold (28x) reduction in the volume of the sediments. This process is observable and ongoing within the lake. Black amorphous iron sulfide is observable at depths of several inches thick or greater throughout the lake bed at many locations that have been sampled.

While the conversion of toxic contaminants (such as copper) from a dissolved state to a solid mineralized state in the pit lake with subsequent sedimentation is rapid and has mostly happened concurrent with lime addition, the kinetics of the conversion of the sediments that are already in-place cannot happen as rapidly. The limitation on the solid conversion rate (from iron hydroxides to iron monosulfide) is jointly based on the rate of diffusion of soluble carbon and the rate of dissolution of the iron hydroxide particles.



Figure 7 Iron monosulfide sludges

Reduction in Environmental Impact and Off-site Contaminant Loading

Assessment of the site by the REAC team (Lockheed Martin, 2007) determined that the flow rate from the seeps to the Hawes Creek tributary was, during an historic drought in May 2007, about 5 gallons per minute.

Reassessment of the same stream segment in July and August 2008 indicated that the pit lake seepage to the stream was about 0.8 gallons per minute. Observation of the pit lake shows a similar coating throughout the lake sediments as was observed on the anchor ropes shown above, and it is possible that this precipitation process is plugging the fractures and reducing the seepage flow rate. The lake level is as high or higher than during the assessment conducted in May 2007, while the flow rates have decreased more than 80%, so we can be confident in asserting that the actual transmissibility of seepage along these fractures has been reduced, similar to what might be achieved by physical grouting or plugging of the seepage zones.

While numerous points along the creek indicate iron – staining and evident seepage, one particular seepage location closest to the pit contained notable sulfide odor on July 30 2008. This seepage location was outfitted with a covered one-gallon plastic bucket perforated on the bottom and on the side wall away from the creek toward the location of seepage, and was re-sampled on August 22nd 2008. The quality of the seepage from this location has markedly improved while still containing much of the ionic strength consistent with previous seepage.

It can be expected that the TDS of a treated seepage flow would drop, without the drop being attributable to dilution. The reason for this is that heavy metal sulfates such as iron and copper sulfate would be replaced in solution by a lighter alkali or alkali earth carbonate, formed by microbial metabolism of the added soluble organic carbon. While the total ions in solution are likely to be similar, the atomic masses are lower, and the TDS will be lower. An example of this TDS reduction can be given in that copper sulfate has a formula weight of 159.5 g/mole, while sodium bicarbonate to replace it in solution has a formula weight of 84 g/mole.

Removal actions taken in the pit lake have resulted in both substantial reductions in flow to the seeps entering the creek and have also resulted in improvements to the quality of the seepage waters particularly for the most toxic parameters copper, zinc and cadmium.

Table 3 Chemistry of Pit Lake Seepage to the Stream

Analyte	July 30 seep (Bucket #2)	Aug 22 seep (Bucket #2)	% of previous seepage
Ca	400	456	114.0%
Na	80.6	122	151.4%
K	10.1	65.6	649.5%
Cu	84.3	0.138	0.2%
Zn	45.6	0.157	0.3%
Cd	5.05	0.005	0.1%
TDS	7940	4250	53.5%
Fe	1070	493	46.1%
Mn	23.6	6.93	29.4%

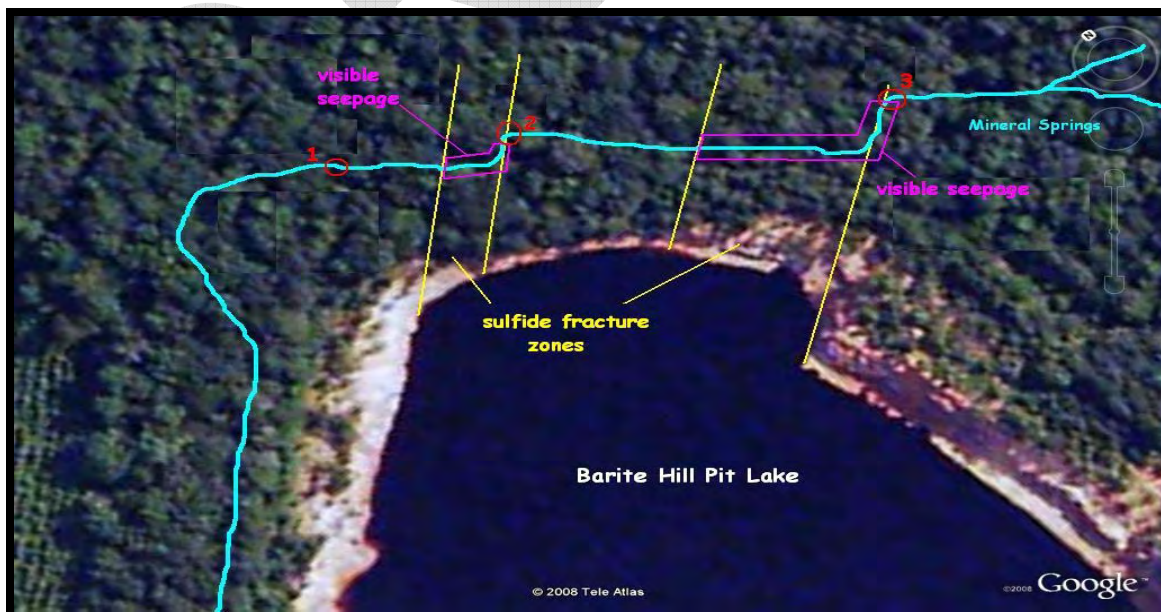


Figure 8 Aerial illustration of Pit Lake seeps and fracture zones

Measuring Expectations for the Future: Comparison of Acid/Metals Loading Potential vs. Acid/Metals Treatment Potential

Oxidation from the highwall areas may contribute as much as 10 pounds per day of metal sulfates. If contaminated water is accumulating within the saturated portion of the waste fill areas, a sustained decrease in lake levels, such as might occur in a severe drought, could draw the top five feet of water from within the saturated fill areas, containing as much as 1 million gallons of water and, at previous contaminant loading rates (4 g/L metal sulfates), contribute 33,000 pounds of metal sulfate contaminants over the course of the drought. Stooksbury (State Climatologist for Georgia) wrote that the frequency of 2 year droughts has been about every 25 years since the 1700s. At this return interval the average load from drought would be 3.6 lbs/day. Combined the high wall and waste-rock fill sources could contribute 14 lbs of acid metal sulfates (such as copper sulfate, aluminum sulfate and ferric iron sulfate) each day to the lake waters.

While several inches of strongly reducing sediments have been observed throughout the lake, with only 1.0 inch of metal sulfide / metal carbonate mixture covering the 7 acres of lake bed, we have at least 5.4 million pounds of solid redox and pH buffer available to resist acidification and oxidation. If we limit this to only the soluble TOC present in the lake today (127 mg/L C), there is presently about 60,000 pounds of organic carbon soluble in the lake. Additionally over 1000 tons of organic carbon was added in the form of wood chips to the lake bed.

Therefore the maximum daily loading of acid metal sulfates, that at a worst case could be formed from the high walls and unsaturated waste-rock fill and enter the lake during drought conditions, can be neutralized for the next 12 years by the soluble organic carbon presently in the lake waters, or can be neutralized for the next 1060 years by the amount of iron sulfide (FeS) and carbonates precipitated in the lake bed.

If the site experienced catastrophic loss of vegetative cover and organic cover, so that the deeper clay cover was the only benefit reducing the loading from unsaturated fills, the loading rates might increase (until the cover was fixed) to be several hundred pounds of metal sulfate per day. This condition would be stabilized by the lake bed sediments (which would dissolve iron and precipitate copper by galvanic displacement reactions) for 700 days for each millimeter of bed sediments, or for 50 years through the first 1 inch of sediments.

Conclusion

The USEPA, working in cooperation with the US Dept of Interior and the private companies, CMC Environmental Inc, Alexco Resources US Corp and TNA Inc., developed and implemented a low cost effective innovative approach employing neutralization, control of iron oxidation, carbon addition, capping, and sulfate reducing bacteria to remediate the acid pit lake contaminated with toxic metals at the Barite Hill Mine in South Carolina. The cooperative venture employed a patented technology of Alexco in combination with sound mine remediation strategies to resolve the imminent

risk to public health and environment at a cost savings of 79-88 % compared to more conventional approaches. The complete set of site documents can be found on the following website: <http://www.epaosc.net/baritehillnevadagoldfieldsremoval>.

DRAFT

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Appendix 4 Galkeno 900 Bioreactor Performance



PRELIMINARY RECLAMATION AND CLOSURE PLAN
KENO DISTRICT MINE OPERATIONS
KENO HILL SILVER DISTRICT

REVISION 1

APPENDICES

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Appendix 4 Galkeno 900 Bioreactor Performance



GALKENO 900 SULPHATE-REDUCING BIOREACTOR 2008-2011 OPERAITONS

FINAL REPORT

March 2012

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT CORP.

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY.....	1
2 BACKGROUND	2
3 GALKENO 900 TREATMENT LAYOUT	4
4 BIOREACTOR OPERATIONAL SUMMARY	10
5 METALS REMOVAL MECHANISMS IN BIOREACTOR TREATMENT	12
5.1 LITERATURE REVIEW AND BACKGROUND DISCUSSION	13
5.2 DETERMINATION OF THE SULPHATE REDUCTION RATE	15
5.3 RECIRCULATION DYE TEST	16
6 BIOREACTOR PERFORMANCE	18
6.1 GENERAL PARAMETERS	18
6.2 DISSOLVED METALS	19
6.2.1 ZINC 20	
6.2.1.1 MINERALOGICAL ANALYSIS OF ZINC PRECIPITATES.....	22
6.2.2 ANTIMONY	23
6.2.3 ARSENIC	24
6.2.4 CADMIUM	25
6.2.5 IRON 26	
6.2.6 MANGANESE	27
6.2.7 NICKEL.....	28
7 BIOREACTOR ENGINEERING DISCUSSION	29
7.1 GENERAL BIOREACTOR DESIGN IMPROVEMENTS.....	29
8 DISCUSSION AND CONCLUSIONS.....	32
9 REFERENCES	34

LIST OF TABLES

Table 1 – Residence Time within the Bioreactor per Flow Rate	17
Table 2 - Effluent Quality Standards per Water Licence.....	18
Table 3 - Total vs. Dissolved Zinc per Operation Phase	20

LIST OF FIGURES

Figure 1 - Galkeno 900 Layout	4
Figure 2 - Inlet Valve	4
Figure 3 - Bioreactor Influent Sump	5
Figure 4 - Bioreactor Inlet.....	5
Figure 5 - Bioreactor Construction	6
Figure 6 - Bioreactor Standpipe	7
Figure 7 - Bioreactor Layout.....	7
Figure 8 - Bioreactor Discharge Valves	8
Figure 9 - Conceptualization of Flow Path in the Bioreactor.....	17
Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp.....	19
Figure 11 - Zinc removal by the Galkeno 900 Bioreactor	21
Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor.....	23
Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor.....	24
Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor	25
Figure 15 - Iron Removal by the Galkeno 900 Bioreactor	26
Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor.....	27
Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor.....	28

LIST OF APPENDICES

APPENDIX A SUMMARY REPORT ON OPTICAL AND ELECTRON MICROPROBE ANALYSIS OF GALKENO 900 BIOREACTOR AT KENO HILLS

1 EXECUTIVE SUMMARY

Alexco Environmental Group has operated a test bioreactor at the Galkeno 900 mine site since October 2008. Bioreactor technology is considered a closure option for some adit drainage sites in the Keno Hill Silver District (KHSD) and this closure pilot study has been performed to validate the effectiveness of this treatment technology with special consideration of engineering a stable bioreactor for the KHSD climate. In general, once sulphate reduction onset occurred after a commissioning period, effective treatment (significant mass reduction averaging over 90% during operational periods, and achieving discharge criteria at lower flow rates) was accomplished with a test flow rate range of 0.5-1.0 litres per second (lps). The configuration of the bioreactor was suboptimal due to the very limited footprint available near the Galkeno 900 adit, and the regulatory requirement to operate the bioreactor upstream of the lime treatment system. However, the key objectives of the study were accomplished; specifically sulphate reducing rates were determined across year-round operation, and it was demonstrated that the sulphate bioreactor technology could achieve under some operational flow rates discharge water quality standards as set under the existing water licence QZ06-074. The primary failure mode of the bioreactor was failure of the pumping systems due to power outages, which happened several times during the study, which led to freezing of the antisiphon valves and loss of water by siphoning from the bioreactor.

During the operational treatment phase at 0.5 lps, results showed removal of close to 99.8% zinc was achieved (5-6 mg/L reduced to 0.011 mg/L). During the operational treatment phase at 1.0 lps a maximum of 97.8% removal was occasionally achieved. Section 6, Bioreactor Performance, provides additional information concerning other metals that have also been substantially removed in the bioreactor at flow rates between 0.5 lps and 1.0 lps respectively. While zinc is the primary Constituent Of Concern (COC), the reduction of these other constituents will have beneficial effects in the reduction of toxicity where elevated metals have a combined toxicity more than any one metal alone. Iron and manganese, which had good removal during the recirculation phase (99% for both metals) showed a dissolution and production from the bioreactor during the reduction onset and initial through flow phases. Manganese currently passes through the reactor unchanged, while iron is still slowly releasing from the reactor. Conservative elements show less than 10% change during passage through the bioreactor, including calcium, magnesium, silica, sodium and strontium, demonstrating that dilution is not a significant factor causing metal removal in the reactor.

Mineralogical analysis was performed on materials removed from the bioreactor to identify minerals and mineral phases that had been formed in the bioreactor. The purpose of this work was to strengthen the conclusions about the ultimate fate of metals removed in the bioreactor, and to determine if the inferences about removal mechanisms are confirmed when examining the solid phases formed. The results showed that micron sized grains of ZnS were precipitated with a molar ratio of 1:1 indicating bacteriological sphalerite (ZnS) was being formed. The sphalerite formed bands which were indicative of biofilm deposition in successive layers. Some of the ZnS layers were immediately adjacent to or surrounding layers of Fe and Mn oxide or hydroxide, which is consistent with the operational phases of the bioreactor which initially had zinc removal coinciding with manganese and iron removal. When the bioreactor became anaerobic the Mn and later Fe was partially mobilized but the Zn which was removed with Mn and Fe became bacterially sequestered as ZnS. These results show that Zn removal in carbon source-fed bioreactors is predominantly performed by microbial sulfate reduction, producing predominantly a biofilm-enclosed ZnS phase.

2 BACKGROUND

A bioreactor was constructed and operated in the Keno Hill Silver District (KHSD) at the Galkeno 900 adit beginning in May 2008. The bioreactor ceased operations in late Spring 2011. These results demonstrate the viability of sulphate reduction technology for the removal of metals, especially zinc and other metals that react with aqueous sulphide, in the KHSD.

The bioreactor solid phase substrate utilized to construct the bioreactor was coarse rock from a nearby placer mining operation. Solid organic carbon forms were not utilized to allow for the simplest assessment of metals removal due to sulphate reduction only. The organic substrate supplied to the bioreactor included dissolved organic carbon forms, with sugars, alcohols and complex carbohydrates and proteins from milk used during the growth phase of the bioreactor operation, and sugars and alcohols used during the maintenance phase. The purpose of the organic substrate was initially to support microbial growth until sulphate reduction became the predominant microbial activity in the reactor, and during the treatment phase to support microbial sulphate reduction. Sulphate reduction is a chemical transformation performed by microbes that transfers electrons from organic carbon to sulphate, causing sulphate to be reduced to sulphide. Sulphide then reacts with many dissolved metals, forming very insoluble metal precipitates. The reactor also had the potential for other reactions to occur as a result of alkalinity being generated from the oxidation of organic carbon, and such as carbonate mineral formation within the bioreactor.

The bioreactor demonstration is part of a multipurpose program to assess the potential of adding an organic substrate to mine adit water to support metals removal, whether within a constructed bioreactor, within a mine pool, or in a naturally permeable zone outside a mine such as in a naturally occurring bog or gravel bed. Conceptually, the sulphide- and carbonate-based mineral precipitation that occurs in a bioreactor is similar to what would occur in a mine pool or natural sulphate reduction zone outside of a mine pool. The sulfate reduction rate observed in the bioreactor is similar to what would be achieved in these other settings.

Alexco has extensive experience with these types of in situ sulphate reduction systems, and owns six patents and has additional patents allowed and pending for the in-situ use of organic substrates and nutrients in earthen materials to stabilize metals. Alexco's technologies and patents provide in-situ encapsulation technologies, whereby soluble toxic metals including arsenic, cadmium, nickel, selenium, and zinc are geochemically encapsulated by more benign minerals within the groundwater aquifer or within and downgradient of sources of contamination such as within a pit lake, tailings impoundment, heap leach pad, or waste storage area. One patent that is applicable to this treatment approach is US patent #5,710,361, which describes amendment of metals-containing water with a carbon source to cause precipitation of metals during flow through rock or earthen materials via sulphate reduction.

Several adit discharge locations are being considered in the Closure Option assessment process for treatment in a bioreactor (Alexco Environmental Group, 2011). At this time, Silver King 100, Birmingham 200, Ruby 400, No Cash 500, Galkeno 900, Onek 400, Sadie Ladue 600 and Keno 700 are all considered as possible locations where bioreactor technology could be employed. Galkeno 900 has water chemistry and flow characteristics that are typical of these other adits in the KHSD. This test was of sufficient scale and operated long enough to provide design information that allows for the design of either a large scale bioreactor or an in-situ reduction field at several other adit drainage locations in the KHSD. The test was operated in a lined bioreactor allowing for the performance of the technology to be assessed while still in containment, but the



results of the tests (reaction rates and stoichiometry) can be extended in the design of either a lined or an unlined system. The operation of the reactor continued through the winter season to demonstrate durability of metals removal mechanisms. During the course of the bioreactor demonstration, the conventional lime treatment system was maintained to ensure water license discharge compliance criteria were met.

3 GALKENO 900 TREATMENT LAYOUT

Figure 1 shows the piping and instrumentation setup of the bioreactor and treatment facility at Galkeno 900.

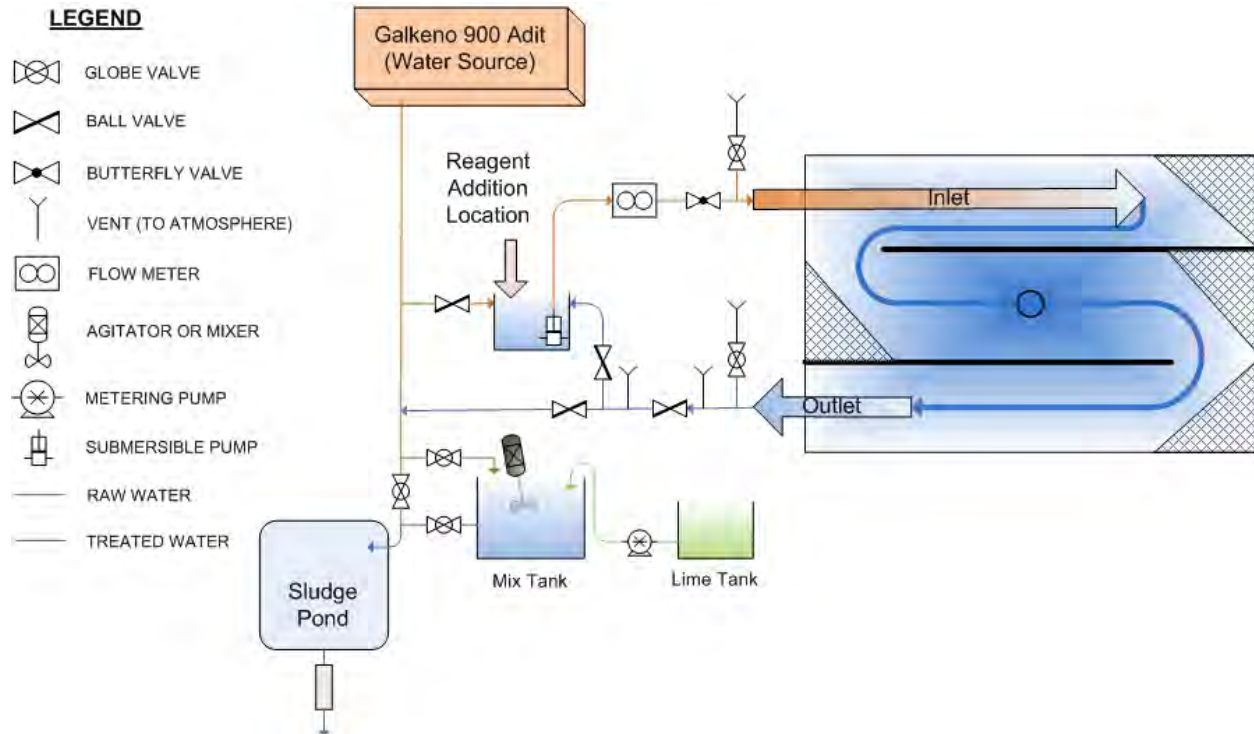


Figure 1 - Galkeno 900 Layout

Water drains from the Galkeno 900 adit at an average annual rate of 4 lps. This water is collected in a pipe and gravity flows away from the adit. Before the bioreactor system was installed, the water traveled directly to the treatment facility where it was mechanically agitated in a mix tank and dosed with lime slurry through a metering pump. Then the water was discharged to a sludge pond where the heavier particles were allowed to settle at the bottom in the form of sludge, and clean water was decanted and released. When the bioreactor treatment system was installed, additional valves and piping were added upstream of the lime treatment system so that a portion of the untreated adit water could pass through the bioreactor system for the purposes of this study.

Water is supplied to the bioreactor through an initial valve that when opened allows water to travel to the bioreactor's influent sump. Because of the harsh conditions in the Yukon, this valve, and all piping used in this setup was buried over 1 meter below surface, thereby reducing the possibility of freezing. Figure 2 shows the buried vertical pipe that contains this initial valve. In this figure, water travels downward from



Figure 2 - Inlet Valve

the adit to the lime treatment area. Opening this valve allows water to flow into the bioreactor's inlet sump.

The bioreactor inlet sump, shown in Figure 3, has a 48 inch diameter and is also located below surface. It is accessed through a cover that allows for reagent addition and water sampling as needed. Normal operation of the bioreactor requires the frequent dosing (constant dosing up to as infrequently as every two weeks, depending on flow rates) of a carbon source such as sugar, ethanol, or methanol. These reagents are slowly added to this sump via a metering pump for the liquids, or as dry powder for the sugar. During initial start-up, and on a few other occasions, an addition of milk sugars/protein as dry milk powder was required to aid the growth of microbes in the bioreactor. These reagents were also added at this location.



Figure 3 - Bioreactor Influent Sump

From the bottom of Figure 4 moving toward the top is a blue datalogger attached to the black Magnetic Flowmeter (Magmeter), a throttling globe valve, and finally a vertical anti-siphon standpipe. The datalogger records and stores the flow rates from the magmeter, allowing the system's operation rate to be tracked and analyzed. The globe valve is used to adjust the flow rate into the bioreactor. The vertical anti-siphon standpipe is exposed to the atmosphere. The system is designed so that in the event of pump failure, air will be pulled into the pipe and breaks the siphon. This series of instruments and valves is also located below grade in an insulated box and can be accessed through a cover.

The bioreactor is roughly 90 feet by 100 feet and has a liquid-filled portion that is 10 feet deep. It was dug partially into the native ground with an excavator, and the remaining depth was created by forming a berm around the excavated area. The bermed/excavated area was lined with 0.060 inch thick HDPE liner to form a pond, and then filled with waste rock recovered from a local placer mine. Figures 5 and 6 were taken during construction

Within in the bioreactor inlet sump is a 1-horsepower submersible pump. The cable seen in Figure 3, stretching from lower left to upper right, attaches to a chain allowing the pump to be removed from the mix tank for servicing and/or replacement. The discharge from this pump is shown in Figure 4.



Figure 4 - Bioreactor Inlet

of the bioreactor and Figure 7 shows the overall design.

After the pond was filled with placer oversize rock, a geofabric was laid across the bioreactor, and soil from the excavated area and hillside was used to provide a 4 foot soil cover over the bioreactor. This soil cover layer acted as an insulating layer, minimizing the amount of ice formation in the top layer of the bioreactor. When the bioreactor solids were sampled in March 2011, the ice layer was approximately 18 inches to 2 feet thick.

Water enters the bioreactor through an inlet pipe that transports water to the far side of the bioreactor (see Figure 7 for an overall view of the layout). The last half of the pipe is perforated with $\frac{3}{4}$ " holes, allowing water to fill the bioreactor and flow back and forth before final release.



Figure 5 - Bioreactor Construction



Figure 6 - Bioreactor Standpipe

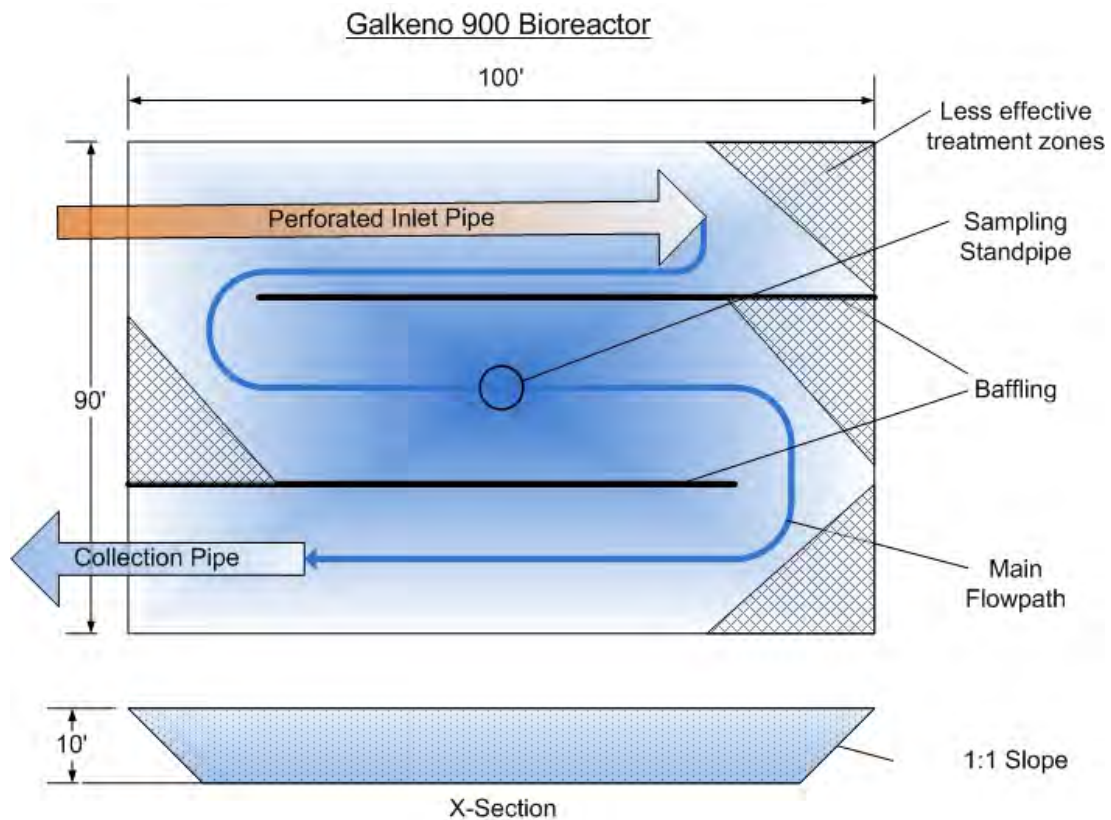


Figure 7 - Bioreactor Layout

Baffling was installed in two locations to create a torturous flow path and increase the contact time of the water with the media within the bioreactor,. This forces the water to travel a greater distance within the bioreactor before final release and to contact a greater fraction of the media. Also present at the center of the bioreactor is a sampling standpipe that can be seen in Figure 6. This allows samples to be collected and analyzed once water has passed midway through the bioreactor.

The discharge from the bioreactor is collected in a pipe and can then be either sent back to the bioreactor influent sump for recirculation or mixed with untreated adit water from the Galkeno 900 adit. This comingled water then passes through the lime treatment system mentioned earlier and is released into a sludge pond where heavy particulate settles and clean water is decanted and released. Figure 8 is the bioreactor discharge valve set-up. Water travels from the bioreactor on the right (not shown) and can either be sent up (as shown in the photo) to the bioreactor influent sump or to the left (as shown in the photo) to be comingled with adit water from the Galkeno adit. This setup is below surface grade and is accessible through a cover.



Figure 8 - Bioreactor Discharge Valves

Overall, the system was constructed to provide the operator with the maximum amount of flexibility to study the performance of a bioreactor without introducing the risk of releasing untreated water from the adit. Based on the positions of several valves, the system could be run in one of the following operation modes:

- 1) Bioreactor influent valve closed – collected adit water bypasses the bioreactor and is treated at the lime treatment facility.

- 2) Bioreactor influent valve and discharge valve closed – water pumped from the bioreactor influent sump fills the bioreactor and once filled, this mode allowed the water in the bioreactor to be continuously re-circulated. This was important to allow for the initial growth phase of the bioreactor, allowing the carbon source to be consumed in the bioreactor rather than being released from the discharge.
- 3) Bioreactor influent valve open and discharge valve open – untreated adit water was pumped into the bioreactor, sampled along several key locations, then discharged from the bioreactor and co-mingled with the untreated adit water where it was transferred to the lime treatment facility.

The water from the adit was a significant heat source for the bioreactor; therefore some amount of influent water from the adit was desired even during the initial growth phase of the bioreactor. In a full scale installation without the requirement of the downstream secondary treatment plant, these valving systems would not be required other than to provide a bypass from the adit if desired, and a temporary recirculation loop to allow discharged water to be sent back to the influent sump.

4 BIOREACTOR OPERATIONAL SUMMARY

Operational notes are included in this report to capture a few of the issues experienced during construction and operation of the bioreactor. The bioreactor construction began in the summer of 2008 with operation starting soon after. The following timeline outlines milestones, as well as issues, that were noted during operation:

- July-August 2008: Pond constructed and lined (see Figures 5 & 6).
- September 2008: Pond filled with oversize rock from a local placer mining operation (some small amounts of fines were present).
- October 4th, 2008: Start filling the bioreactor with untreated adit water.
- October 10th & 11th, 2008: Started recirculation of bioreactor water, added 182 kg sucrose to support microbial sulfate reduction.
- October 16th, 2008: 110 gal methanol and 1.8 kg dried milk solids added.
- October 2008: Bioreactor covered with geofabric and several feet of topsoil.
- October 2008 through May 2009: Occasional “top up” of untreated mine water to maintain full conditions in bioreactor. Make-up water averages ~ 1 m³/day or approximately 1 liter per minute average.
- January 23rd, 2009: 110 gal methanol added.
- January 2009: Determination of slow leakage rate from bioreactor ~ 1.09 m³/day.
- February 19th, 2009: Anti-siphon valve on the return recirculation line iced over, draining the bioreactor and flooding covers/box. Estimated ~135 m³ water was lost from the bioreactor through overflow of the tank.
- April 8th, 2009: Bioreactor standpipe blocked with ice – unable to sample.
- May 17th, 2009: Began adding methanol at the bioreactor influent sump at a rate of 1.0 litre per day.
- July 11th & 12th, 2009: Added 10 kg sucrose each day to jumpstart reduction, continued methanol addition at 1.0 litre per day.
- August 25th, 2009: Installed totalizer and flowmeter on the inlet to the bioreactor.

Once methanol was added at a constant rate, the bioreactor began through-flow operation. During that time, the following events occurred:

- October 8th, 2009: Initiated flow-through at a rate of 0.5 litre per second.
- December 18th, 2009: Initiated flow-through at a rate of 1.0 litre per second.
- January 7th-20th, 2010: Valve box flooded and frozen, thawed and repaired on January 20.
- February 15th, 2010: Power loss to submersible and metering pump.

- February 16th - 18th, 2010: Power loss while anti-siphon frozen which resulted in the loss of approximately half the bioreactor water volume through the sump; power restoration and line thawed; refilled bioreactor.
- August 6th, 2010: Reduced flow rate to 0.75 l/s to improve treatment.
- March 17th & 18th, 2011: Return line frozen.
- May 11, 2011: cessation of active operations; bioreactor sampled for solids mineralogical analysis.

A review of the operator's log provides some important details that will guide future design. On February 19th 2009 and February 16th 2010, loss of power and a lack of continued pumping of water, which maintained heat in the bioreactor lines, resulted in ice formation in the anti-siphon valve. With the transfer pump stopped, the bioreactor siphoned water into the sump, which overflowed on the ground around the sump.

5 METALS REMOVAL MECHANISMS IN BIOREACTOR TREATMENT

The removal of metals from mine waters by bioreactors is done around the world, utilizing a variety of approaches. Doshi (2006) summarizes the many different types of bioreactors that are in operation, and discusses the relative advantages and disadvantages of these different bioreactor systems. The bioreactor utilized at Galkeno 900 is one type of reactor, where the only carbon source added to the bioreactor was added in a dissolved form semi-continuously during the operation of the bioreactor. Bioreactors are often constructed utilizing a mixture of substrates which either act as a carbon source for microbial reactions, or these substrates can act as sorptive surface for metals precipitation. However, bioreactors with solid phase carbon sources are often limited in their sulphate reduction rates by the availability of soluble organic carbon (Buccambuso et al, 2007) indicating that the constant supply of a carbon source as was done in Galkeno 900 bioreactor will tend to prevent microbial limitations on treatment.

For context of this discussion, the operation of the Galkeno 900 bioreactor can be divided into three distinct time periods. They are:

- **Recirculation Phase – Operation Mode 2 (October 2009 - July 2009):** During this period, the bioreactor was placed into service with water from the adit entering at an average rate of one litre per minute (1 lpm), which provided makeup water to replace slow leakage, and also to provide some heat from the adit water during the cold season. An initial carbon source addition consisting of (1.8 kg) milk powder and (182 kg) table sugar (sucrose) and (110 gal) methanol was added to provide an energy and nutrient source for an initial microbial growth phase. No source of microbes other than what was present on the placer rock and what is carried in the mine water was added to the bioreactor. However, researchers studying mine water and sediment at the Penn Mine Church et al (2007) showed that mine water even in an pH 4 mine drainage with high concentrations of heavy metals contained sulphate reducing bacteria and accounted for metals removal processes. The water in the bioreactor was re-circulated at a rate of one to two liters per second to mix and distribute water in the bioreactor. The water was periodically sampled to evaluate microbial growth and activity indirectly by evaluating water quality changes that could be inferred to be caused by microbial action. During this period there was incomplete formation of reducing conditions and the bioreactor likely had both aerobic and anaerobic zones. During the recirculation phase, metal concentrations were decreased over several months (discussed more below) and the removal mechanisms during this time may have included oxidative mechanisms (iron and manganese oxide formation) with metal co-precipitation on the iron and manganese oxides, carbonate mineral formation, and microbial sulphate reduction and metal sulphide precipitation.
- **Reduction Onset Phase – Operation Mode 2 (July 2009 – September 2009):** During this period, water within the bioreactor continued to be re-circulated while additional carbon sources were added at the bioreactor influent sump. This resulted in elevated carbon concentrations and the onset of more strongly sulphate-reducing conditions. During this time, the development of stronger reducing conditions were observed, characterized by greater sulphate reduction, the dissolution of manganese and iron from the reactor solid phase (likely manganese and iron oxides formed during initial bioreactor operations, as well

as structural iron and manganese minerals in the placer rocks), and greater metals removal as sulphides.

- **Operational Treatment Phase – Operation Mode 3 (October 2009 – May 2011):** An initial flow rate of 0.5 lps was established into the reactor, and after stable metal removal conditions were observed this flow rate was maintained for several consecutive bimonthly samples. Soon after, the flow rate was increased to 1.0 lps in December 2009. In August 2010, the flow rate of the bioreactor was reduced to 0.75 lps, or approximately 19% of the adit flow. This flow rate was then maintained for the remaining operation of the bioreactor.

The results displayed in this report focus primarily within the operational treatment phase. The other phases, while important, are reflective of treatment performance during the transition of the bioreactor from construction to operation.

5.1 LITERATURE REVIEW AND BACKGROUND DISCUSSION

The formation of metal precipitates in a bioreactor that has carbon sources added to or present in the solid phase of the bioreactor has been extensively studied for 30+ years. There are several different styles of bioreactors, both in terms of carbon sources and flow dynamics. Some very large bioreactors have been created to treat flows as large as 20 lps or greater, and some bioreactors are designed to treat very acidic or concentrated metal-containing mine drainage. Each bioreactor must be designed to reflect the environmental conditions, the water chemistry of the mine water being treated, and other relevant variables as discussed in this report.

To understand the processes that occur in bioreactors many studies have attempted to identify directly by examination of mineral formation or by inference from water chemistry signatures what primary mechanisms are responsible for metals removal. When complex carbon sources are added as a solid phase in the bioreactor construction (i.e., peat, straw, compost, wood chips, etc.), a broad range of mechanisms has been documented (Gusek, 2002; Doshi, 2007; Gusek et al, 2008), that include:

- Sorption of metals on organic matter.
- Precipitation of iron hydrous oxides including ferric and mixed valence minerals, which then provide mineral surfaces for sorptive removal of metals, or metals can also be co-precipitated within the iron mineral matrix.
- Precipitation of manganese oxides including manganese (IV) oxides and mixed valence (III/IV) oxides and manganese carbonates, which then provide mineral surfaces sorptive removal of metals, or metals can also be co-precipitated within the manganese mineral matrix.
- Precipitation of metal sulphides, including primary metal sulphides such as ZnS or CdS, as well as precipitation of iron sulphides such as amorphous FeS and co-precipitation of metals within the FeS matrix. Depending on the pH of the bioreactor and the availability of structural iron, a very large amount of FeS minerals can be formed by aqueous sulphide formed by microbes reductively dissolving iron from the rock matrix, creating a “bank” of amorphous sulphide which has reactivity toward dissolved metals.

- Precipitation of some metals in their reduced forms, for example selenium reduction from a Se(VI or IV) anion to elemental selenium precipitates Se.
- Precipitation of metals as carbonate minerals. Some of the relevant metals have somewhat soluble carbonate minerals (e.g., zinc carbonate minerals including smithsonite, and hydrozincite) which are relatively more soluble than sulphides. When sulphide is not present, these minerals may provide a precipitation-removal mechanism.

Sorption of metals on organic matter is not a relevant metals removal mechanism by design in the Galkeno 900 bioreactor because only coarse rock was used as a solid substrate. The metal removal mechanisms in this reactor appear to initially relate to removal of iron and manganese during the recirculation phase, and then over time the removal mechanism transitioned to a metal sulphide removal mechanism (inferred because metals removal continued to occur when iron and manganese ceased being removed and actually increased in concentration during flow through the reactor). The precipitation and removal of metals in their reduced forms is not a significant potential mechanism for most of the metals present in Galkeno 900 adit water, with the potential exception of uranium which was only present in very low concentrations in the influent water. Consequently, the formation of sulphide from sulphate, which is a chemical reaction that is catalyzed by microbes and relies on the availability of organic carbon, is the primary performance variable that is relevant in the Galkeno 900 bioreactor performance evaluation. In typical evaluation of bioreactors where sulphate reduction/sulphide precipitation is a dominant mechanism, the Sulphate Reduction Rate (SRR) is determined as a primary design variable.

In a bioreactor with available sulphate and a soluble carbon source added, Dar et al (2007) showed that sulphate reducing bacteria (SRB) are the dominant microbe that accumulates in the bioreactor, and by inference the vast majority of the carbon consumption is performed by SRB. In their study, only a few different strains accounted for the majority of the cells present, indicating that microbes capable of utilizing the carbon source and reduce sulphate will become dominant in the bioreactor.

After the bioreactor entered stable operation, metals removal mechanisms appear to have shifted from the mixed reaction that were discussed in the prior report (Alexco Resource US Corp, 2009) to primarily a sulphide-based precipitation process. The stability of metals removed as sulphides are consequently an important consideration for the performance of the bioreactor. Jong and Perry (2004) studied the form of metals that were precipitated from solution as a result of the sulphate reduction process, and determined that arsenic, copper, iron, nickel, and zinc were primarily bound up in a sulphide phase that was also associated with residual organics, and that carbonate or hydroxide phases were relatively minor phases that held the metals removed from solution. The United States Environmental Protection Agency SITE program studied the stability of these sulphate-reducing bioreactor precipitates at the Leviathan Mine, in California. Using a series of different tests, the EPA determined that the metals in the bioreactor precipitates were below regulated total metals thresholds (California standards), the WET extraction test showed that the metals in the bioreactor did not leach above regulated soluble threshold standards, and that as defined by TCLP extraction testing the bioreactor solid materials were not hazardous.

The effectiveness of this sulphate reduction bioreactor process is sensitive to important variables including the hydraulic residence time in the bioreactor, the sulphate reduction rate, and the filtration capacity of the media.

Because the products of the sulphate reduction reaction include both sulphide and bicarbonate alkalinity, it is possible that carbonate precipitation is also an important mode of precipitation for some of the metals removed in the reactor. However, for most of the metals being removed in the bioreactor, including antimony, arsenic, cadmium, cobalt, iron, nickel, and zinc, a sulphide precipitation mechanism appears more likely because sulphide precipitates are less soluble than the carbonate precipitates of these elements. The mineralogical analysis discussed in Section 6.2.1.1 confirms that sulphide is the solid phase form of zinc precipitates formed in the bioreactor. Thus the sulphate reduction reaction is the primary reaction that we will focus on optimizing in the bioreactor operations.

5.2 DETERMINATION OF THE SULPHATE REDUCTION RATE

Microbial production of sulphide from sulphate is dependent on the presence of sufficient numbers of sulphate-reducing bacterial (SRB) cells, and the availability of organic carbon, according to the following reaction:

4 moles methanol + 3 moles sulphate $\rightarrow$ 3 moles sulphide + 4 moles bicarbonate

The rate of the reaction is nearly the same at temperatures in natural environments where the long-term temperature is around freezing (-2°C to 2°C) as it is in natural environments where the long-term temperature is around 20°C when the abundance of SRB is the same (Knoblauch, Jorgensen, and Harder, 1999). This is due to the development of psychrophilic (i.e., ‘cold loving’) SRB. The growth rate of psychrophilic SRB is typically far slower than temperate SRB, which is reflected in the long growth period (October 2008 to August 2009) required for the Galkeno 900 bioreactor to reach maturity so that it could sufficiently treat mine water. However, once the bioreactor was competent to perform sulphate reduction (as evidenced by net sulphide concentrations leaving the reactor in the 1 to $10\text{ }\mu\text{M}$ range, indicating that there is excess aqueous sulphide created above what was required to react with the soluble and solid phase metals) then the bioreactor SRR could be assessed. (Note: it was possible to add more organic carbon to the reactor and support additional sulphate reduction, however it would result in higher dissolved sulphide which would not be required for metals precipitation, and could result in reduction of oxygen in the surface receiving streams. At the amount of sulphide precipitation that was achieved (1 to $10\text{ }\mu\text{M}$ range) dissolved oxygen consumption would be less than 1 mg/L , or less than 10% of what is normally in surface water.)

The SRR is measured in terms of mM sulphate reduced per m^3 of bioreactor substrate per day. The influent sulphate compared to the effluent sulphate is compared to determine the amount of sulphate removal. The average sulphate removal amount during the treatment phase was 128 mg/L , or 1.33 mM . With a known bioreactor volume of approximately $2,550\text{ m}^3$, and a flow rate of 1 lps, the total sulphate removal per day was $115,200\text{ mM}$, which yields a SRR of $45\text{ mM/m}^3/\text{day}$. For comparison, arctic ocean sediments have SRRs in the range of $5\text{--}40\text{ mM/m}^3/\text{day}$ (Knoblauch, Jorgensen, and Harder, 1999), showing that the bioreactor has a similar rate as natural systems that have long term adaptation to cold environments.

The SRR calculated for the Galkeno 900 bioreactor is conservatively calculated based on dividing the amount of sulphate reduced by the volume of the entire bioreactor. However, less effective treatment zones or “dead zones” are identified in Figure 7 and were expected based on the sub-optimal configuration that was available at Galkeno 900. These areas can limit the exchange of organic carbon and therefore it is likely that minimization or elimination of these dead zones will improve the performance of the bioreactor.

5.3 RECIRCULATION DYE TEST

The volume of the bioreactor voids needed to be determined independently to assess residence time and other performance characteristics of the bioreactor. The dimensions of the reactor were measured to be approximately 100 feet by 90 feet and 10 feet in depth. Assuming an estimated porosity of 0.35, the volume was calculated to be roughly 890 m³ or approximately 235,000 gallons. Starting on August 25th, 2009, a dye test was completed to independently assess the volume in the reactor.

Roughly eight ounces of rhodamineWT dye was added to the bioreactor on August 25 2009, and water was re-circulated in the bioreactor at a rate of two litres per second. After equilibrium conditions were reached in six days, a final dye concentration of 0.25 ppm dye was measured. The volume of the bioreactor was determined by the following formula:

$$\text{Volume of reactor} = \text{mass of dye added} \div \text{concentration measured}$$

Using this formula, the volume of the bioreactor was calculated to be approximately 909 m³, or approximately 240,000 gallons, which is consistent with the estimated volume based on the dimensions of the bioreactor and the estimated porosity of the rock.

Understanding the volume of the bioreactor is necessary to understand the potential hydraulic residence time for water passing through the reactor. At 0.5 lps, assuming the total porosity of the bioreactor is utilized, approximately 21 days of residence time is available, and at 1.0 lps, approximately 10.5 days of residence time is available. A 2 lps flow rate should result in a residence time of approximately 5.25 days.

The dye test was run under re-circulating conditions at a relatively fast rate (2 l/s). By definition, when the peak concentration of dye is measured in the effluent, 50% of the dye has passed through the reactor. The time for the peak dye to exit the bioreactor at 2 lps recirculation was determined to be approximately 1.03 days into the bioreactor operation. This much faster flow rate indicates breakthrough of the dye along flow paths that "short circuit" i.e., do not interact with the entire porosity of the bioreactor. Figure 9 shows conceptualization of flow in the bioreactor.

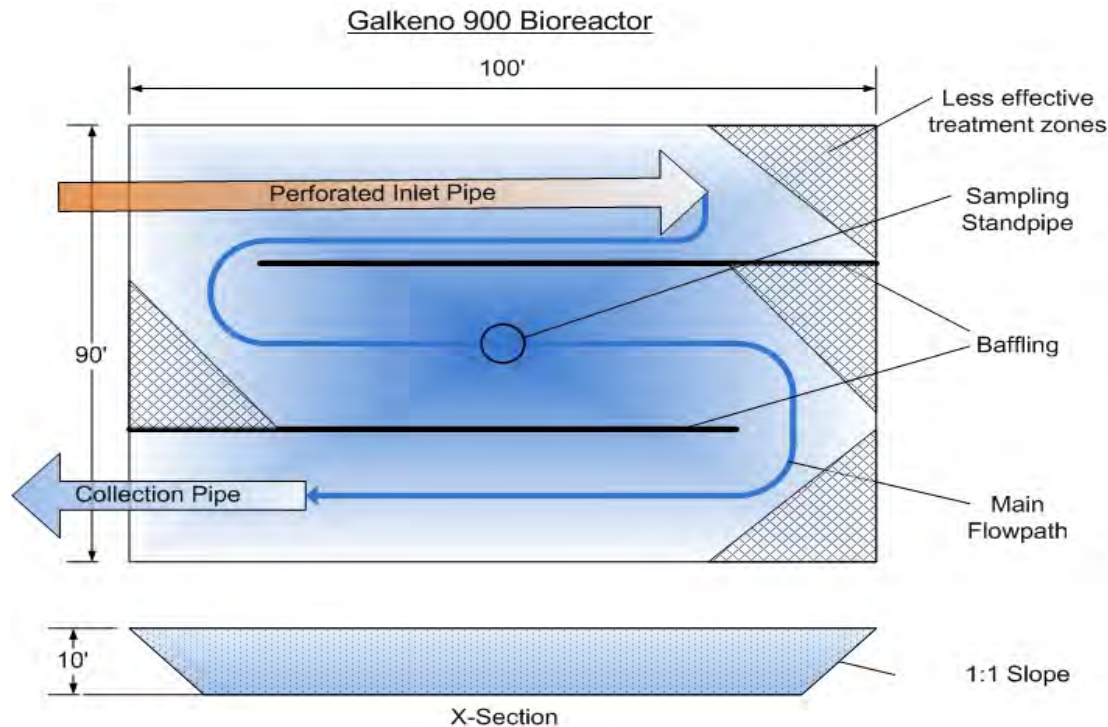


Figure 9 - Conceptualization of Flow Path in the Bioreactor

The “less effective treatment zones” are where water entering the bioreactor does not interact as much with the media and hence these zones are likely to only minimally contribute to the treatment performance. The activity in these areas is dependent on the availability of carbon sources diffusing from the actively flowing areas to support sulphate reduction. The practical residence time in the bioreactor can be estimated as two times the breakthrough time of the dye peak. This residence time corresponds to the volume of the reactor that participates in rapid exchange of influent water to the bioreactor discharge (this will be termed the “effective residence time”). (Note, in most porous media, there is a tailing phenomenon, where dye concentrations do not behave “normally” in a bell shape curve, but the second half of the curve “tails”, i.e., there is a slow bleed out of dye from slower flowing zones in the reactor which increases the time required for the washout of the dye. For the design of bioreactors these less effective zones cannot be relied upon for treatment and hence the 2X dye peak is used for design purposes.)

Table 1 – Residence Time within the Bioreactor per Flow Rate

Flow Rate	Residence time (total porosity)	Residence Time (active porosity)
0.5 lps	21.0 days	9.00
1.0 lps	10.5 days	4.50
2.0 lps	5.25 days	2.25

6 BIOREACTOR PERFORMANCE

The performance of the bioreactor with respect to water chemistry is summarized in the following tables, graphs, and discussion. To better understand the treatment goals, Table 2 provides the Galkeno 900 effluent quality standards per the Conditions of Water Licence QZ06-074. In order to release water from any adit in the KHSD that is currently under the Care and Maintenance of ERDC, the water discharge must meet these standards. It is important to note that some sites such as Keno 700 do not need to meet discharge standards in order to attain aquatic standards in the receiving environment (Lightning Creek). Targeting a mass reduction goal of 90% may be more relevant for some sites of this nature.

Table 2 - Effluent Quality Standards per Water Licence

Parameter	Maximum Concentration in a Grab Sample Measured in mg/L
pH	6.5 – 9.5 pH units
Suspended Solids	25.0 mg/L
Arsenic (total)	0.50 mg/L
Cadmium (total)	0.05 mg/L
Copper (total)	0.30 mg/L
Lead (total)	0.20 mg/L
Nickel (total)	0.50 mg/L
Silver	0.10 mg/L
Zinc (total)	0.50 mg/L

6.1 GENERAL PARAMETERS

The pH of the reactor did not substantially change through the operational period, with the inflow and outflow from the reactor in the same range as the pH of the adit drainage. Figure 10 illustrates the pH of the influent and effluent from the reactor.

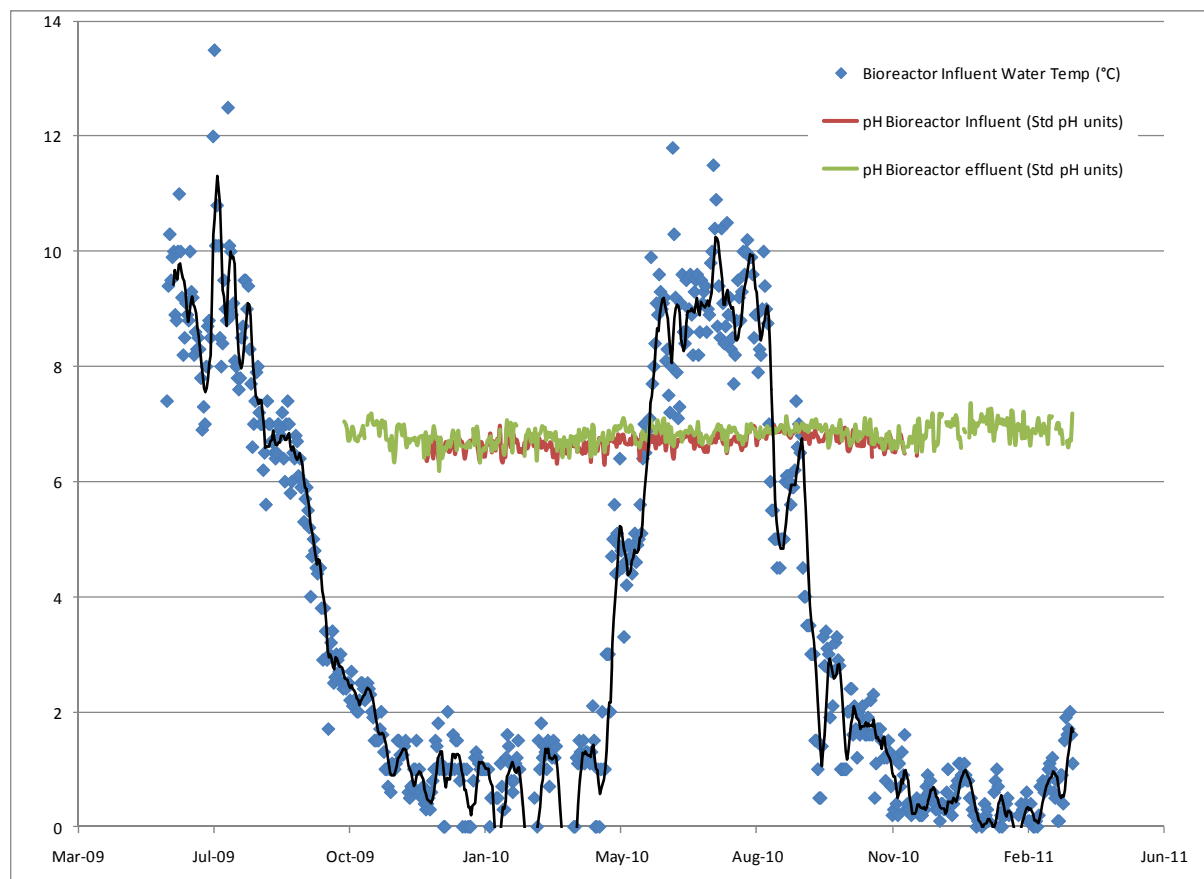


Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp

In addition to pH, Figure 10 also displays water temperatures of the bioreactor influent water recorded during operation. Notice how the influent water temperature decreases to less than 2°C from October through April each year. This emphasizes how important it is to keep water moving through both the bioreactor and the piping systems at all times to avoid freezing.

6.2 DISSOLVED METALS

The primary metal that exceeds discharge criteria at the Galkeno 900 adit is zinc, which is true of most of the adit discharge locations in the KHSD. There are other metals that potentially contribute to the toxicity of water and this and other discharge locations, and hence the water chemistry of all dissolved metals present in the Galkeno 900 water has been evaluated.

To better understand the performance of the bioreactor during operation, several graphs have been generated that plot each constituent of concern. These graphs display the results of samples taken at the adit, midway through the bioreactor, and at the discharge from the bioreactor. Within each graph, a blue and green transparent box was added to signify flow rates during operation. Within the blue box, the average

flow rate through the bioreactor was 0.5 lps. Within the green box, the flow rate was increased to 1.0 lps and then subsequently to 0.75 lps.

6.2.1 Zinc

The concentrations of zinc in the bioreactor were approximately 90% reduced during the recirculation phase where only minor additions of water (approximately one litre per minute) was being added to the reactor. During the onset of more strongly reducing conditions in the summer of 2009, dissolved zinc concentrations were decreased to below detection limits (0.01 mg/L). After this removal was confirmed for several consecutive sampling periods, the bioreactor treatment phase was initiated at 0.5 lps in October 2009. Figure 11 illustrates the removal efficiency of the bioreactor during both treatment periods, including the 0.5 lps flow rate (blue rectangle), and the 1.0 lps flow rate (green rectangle). During the 0.5 lps time period approximately three pore volumes were exchanged (calculated on a total porosity basis) and when calculated on a reactive volume estimated by 2X the dye peak, nearly eight pore volumes would have been exchanged during this period. This shows that the treatment cannot be attributed to dilution by previously treated water.

During the 1.0 lps treatment phase, approximately six pore volumes (calculated on a total porosity basis) passed through the bioreactor prior to the loss of power and pump failure that led to the bioreactor being back-siphoned out. The loss of complete treatment that occurred after the refilling of the bioreactor is attributed to the refilling of the bioreactor with approximately half of the volume of the reactor in February 2010. However, even with this refilling, the bioreactor still removed over 95% of the zinc in the sample taken immediately after refilling. (Note: data from the period after refilling the bioreactor indicates that the removal efficiency dropped to closer to 60-80% in the period immediately after the bioreactor siphoned out and was refilled, indicating that the pipe freeze-up and refilling of the reactor has temporary negative effects for a period of a few weeks after an upset.) This rapid reactivity of the bioreactor to recover from upset conditions indicates a residual treatment phase, most likely an amorphous FeS phase, has been formed in the bioreactor, which provides for rapid reaction with soluble zinc.

The conclusions that can be reached from the bioreactor's operation, before the pump failure, are that dissolved zinc can be effectively removed at 0.5 lps flow rate with an effective residence time of nine days, or a total residence of 21 days, and the first two months of operation at 1.0 lps also effectively removed dissolved zinc. However, there was a difference between dissolved zinc removal and total zinc removal within the bioreactor at the faster flow rate. Table 3 outlines the difference between dissolved and total zinc removal during the different operational phases.

Table 3 - Total vs. Dissolved Zinc per Operation Phase

	Average total zinc concentration (mg/L)	Average dissolved zinc concentration (mg/L)	% total zinc that is dissolved
Recirculation phase	0.64	0.65	100%
Reduction onset phase	0.32	0.27	86%
0.5 lps treatment phase	0.28	0.012	4%
1.0 lps treatment phase	0.74	0.13	17%
0.75 lps treatment phase	0.29	0.018	6%

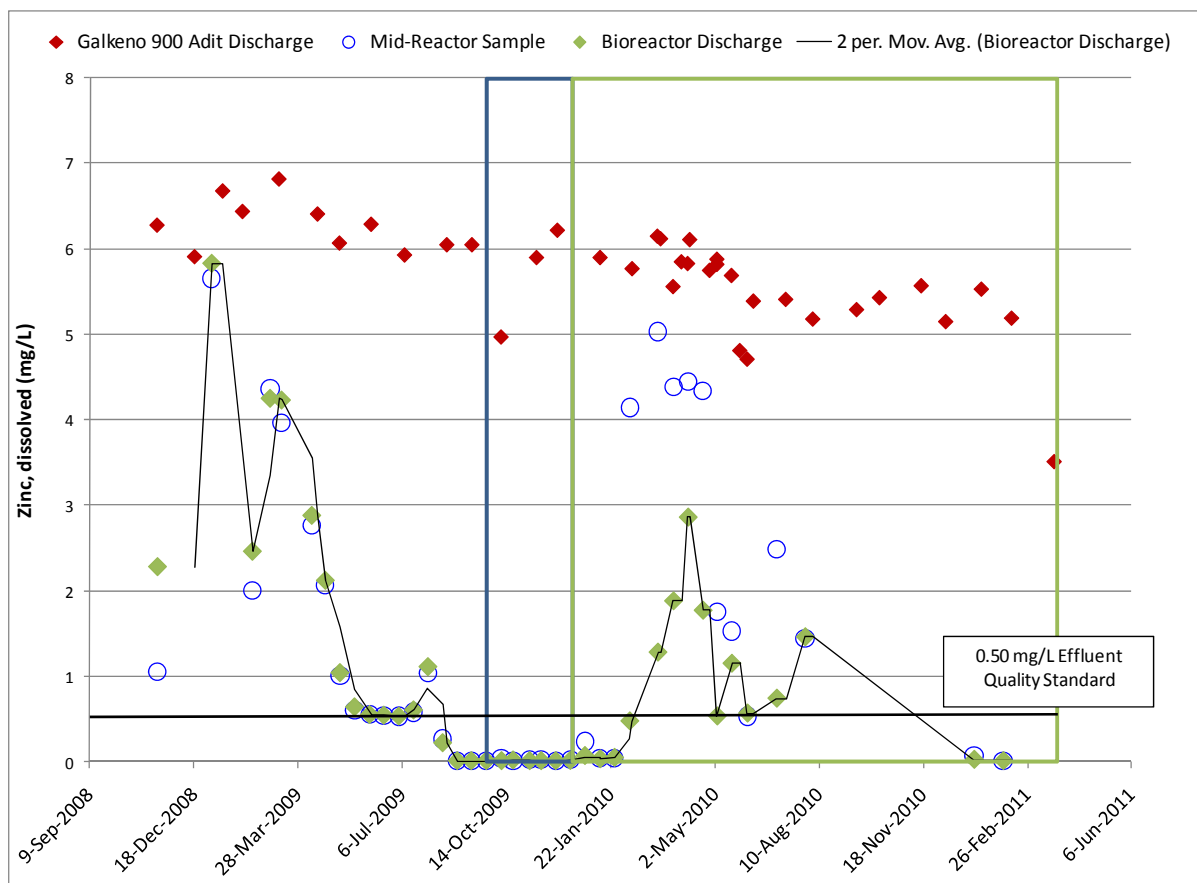


Figure 11 - Zinc removal by the Galkeno 900 Bioreactor

The difference between total and dissolved zinc is that total zinc can be filtered out, i.e., it is the particulate zinc in the bioreactor samples that has been reduced from the soluble phase and become a solid zinc phase. Because of the coarseness of the bioreactor rock (see Figure 5) the media does not act as a very good filter. This is consistent with what was observed at a bioreactor in Montana (Gammons and Frandsen, 2001), where fine ZnS particulates passed as colloids through the reactor but could be filtered out with a 0.45 μm filter. As discussed later, design of future bioreactors would include finer grained rock than coarse oversize placer rock to encourage some filtration. In addition, freshly formed sulphides are very fine particulates. In rapidly flowing systems, small or colloidal particles can remain suspended and exit the bioreactor without being agglomerated into larger particles that would drop out via gravity or by being caught in bioreactor media pore throats. Dissolved zinc averaged below the discharge treatment objective of 0.5 mg/L during both the 0.5 and 1.0 lps treatment regimes. However, the treatment objective was not achieved for total zinc for the higher flow rate (1.0 lps) regime (0.74 mg/L) except for the final two data points collected in January and February 2011. This indicates that additional residence time may be required in the bioreactor to filter the particulate materials, or a subsequent filtration treatment step could be taken in the discharge if the higher flow rate were to be used. An example of natural filtration is a wetlands or bog system, or infiltration into an underground porous aquifer. Active semi-passive or passive filtration systems such as sand filters, multimedia filters, or sedimentation ponds are other alternatives that could improve filtration.

6.2.1.1 Mineralogical Analysis of Zinc Precipitates

After decommissioning the bioreactor in the spring of 2011, samples were removed of the solids formed in the bioreactor utilizing a backhoe to dig through the cover layers into the bioreactor media. Bioreactor solids were preserved in epoxy to keep sulphide minerals stable which might be affected by exposure to oxygen. Preserved samples were evaluated with electron microprobe analysis using backscattered electrons and mapped for Mn, Fe, S, and Zn to examine elemental associations. Quantitative analysis of areas with elevated levels of zinc was further performed to determine elemental ratios, which allowed for mineralogical determination.

Micron-sized ZnS particles were found extensively within a biofilm layer on the bioreactor media. Appendix A "Summary Report on optical and electron microprobe analysis of Galkeno 900 Bioreactor at Keno Hills" shows the visual evidence of the biofilm containing the zinc sulphide materials. Consistent with the inference of the formation of iron sulphides, iron was observed coincident with the ZnS phases within the biofilms, as well as more broadly spread throughout the bioreactor materials. The atomic proportions of Zn:S of 1:1 was at a very high level of correlation (R^2 0.98) which verified the identification of sphalerite as the mineral into which zinc was being sequestered in the bioreactor.

The significance of ZnS as the storage phase for zinc in the bioreactor is that in a saturated setting it will remain stable and at a very low solubility. A buried, lined bioreactor is a feature that can readily be closed in place if desired, with no route for metals remobilization due to the physical encased (by liner and capping) structure of the reactor, and further certainty about the long term stability is provided by the very low solubility geochemical phases that the metals are stored in.

6.2.2 Antimony

Antimony concentrations declined approximately 80% during the test (0.0025 mg/L reduced to below the detection limit (0.0005 mg/L) for most of the phases of the test (See Figure 12). Antimony removal in an organic carbon-rich reducing system is typically attributed to an antimony sulphide phase, or by sorption to iron or manganese oxides, carbonates, or sulphides that are stable in reducing conditions.

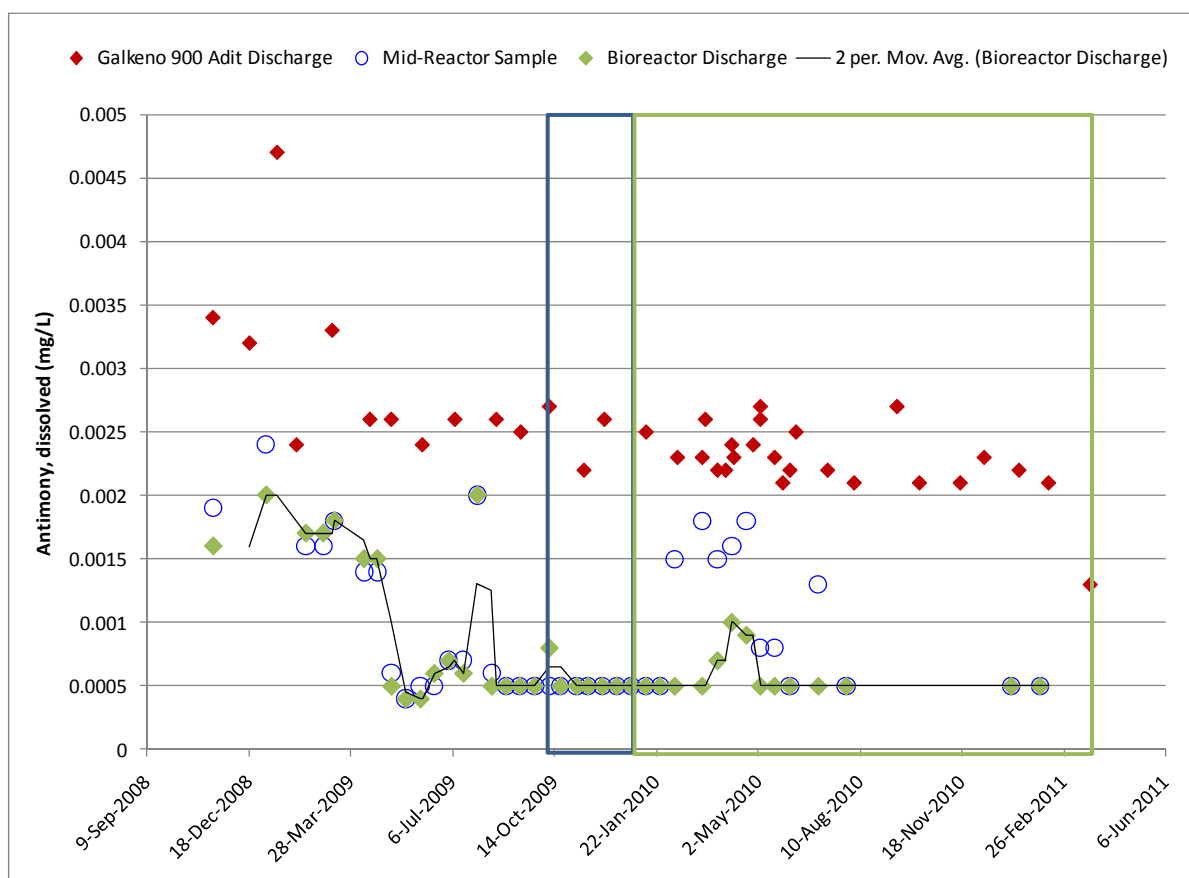


Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor

6.2.3 Arsenic

Arsenic concentrations declined approximately 97% (0.068 mg/L reduced to 0.0015 mg/L average of last two months) during the recirculation phase (See Figure 13). Arsenic concentrations increased during the reduction onset phase, indicating a temporary dissolution of arsenic-bearing mineral phases during this transition period. During both treatment phases, arsenic removal increased again as sulphate reducing conditions were established. During the treatment phases, arsenic removal averaged 58% for the 0.5 lps period, and 80% during the 1.0 lps. The performance during the 0.5 lps period was likely affected by the residual washout of dissolved arsenic released during the reduction onset period, so a long term average removal would more likely be similar to the 1.0 lps performance.

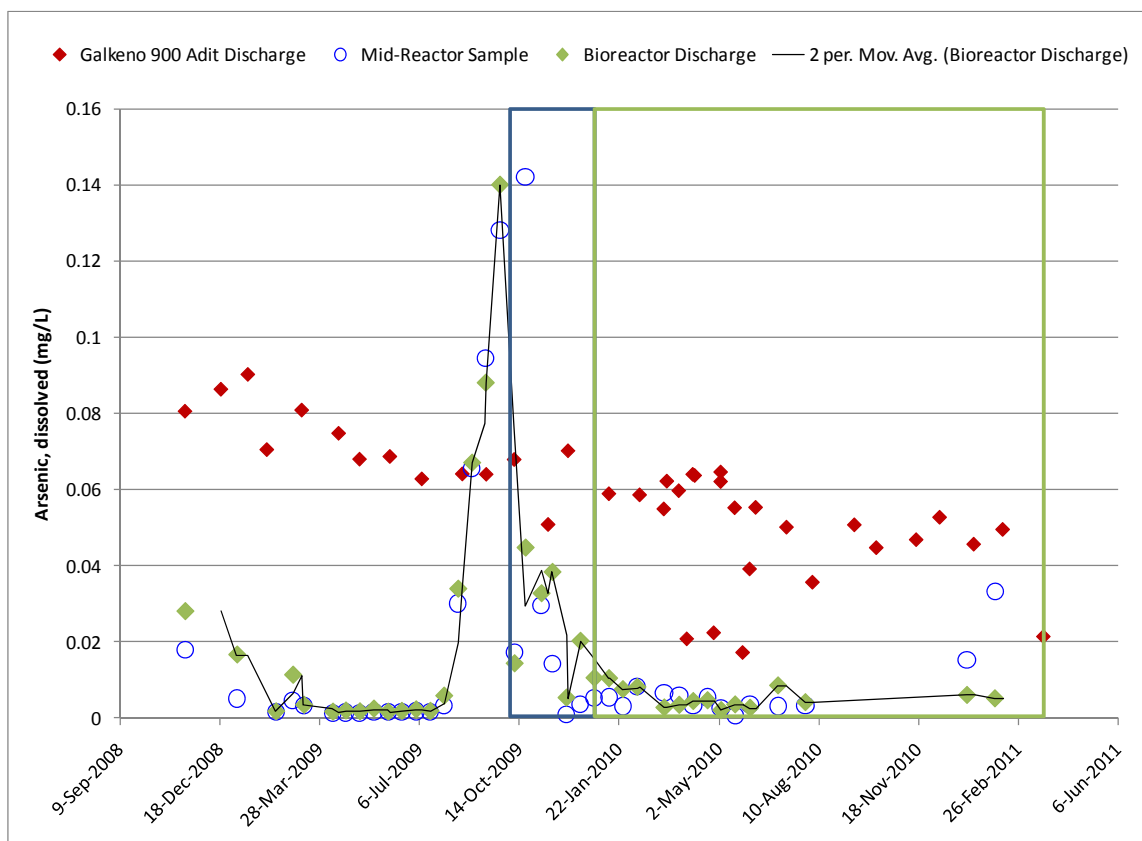


Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor

6.2.4 Cadmium

Cadmium concentrations declined approximately 60% (0.0015 mg/L reduced to 0.0005 mg/L average of last two months) during the recirculation phase (See Figure 14). After the beginning of the reduction onset phase, cadmium has been removed to below the detection limit and has remained at those levels during all the recirculation phases.

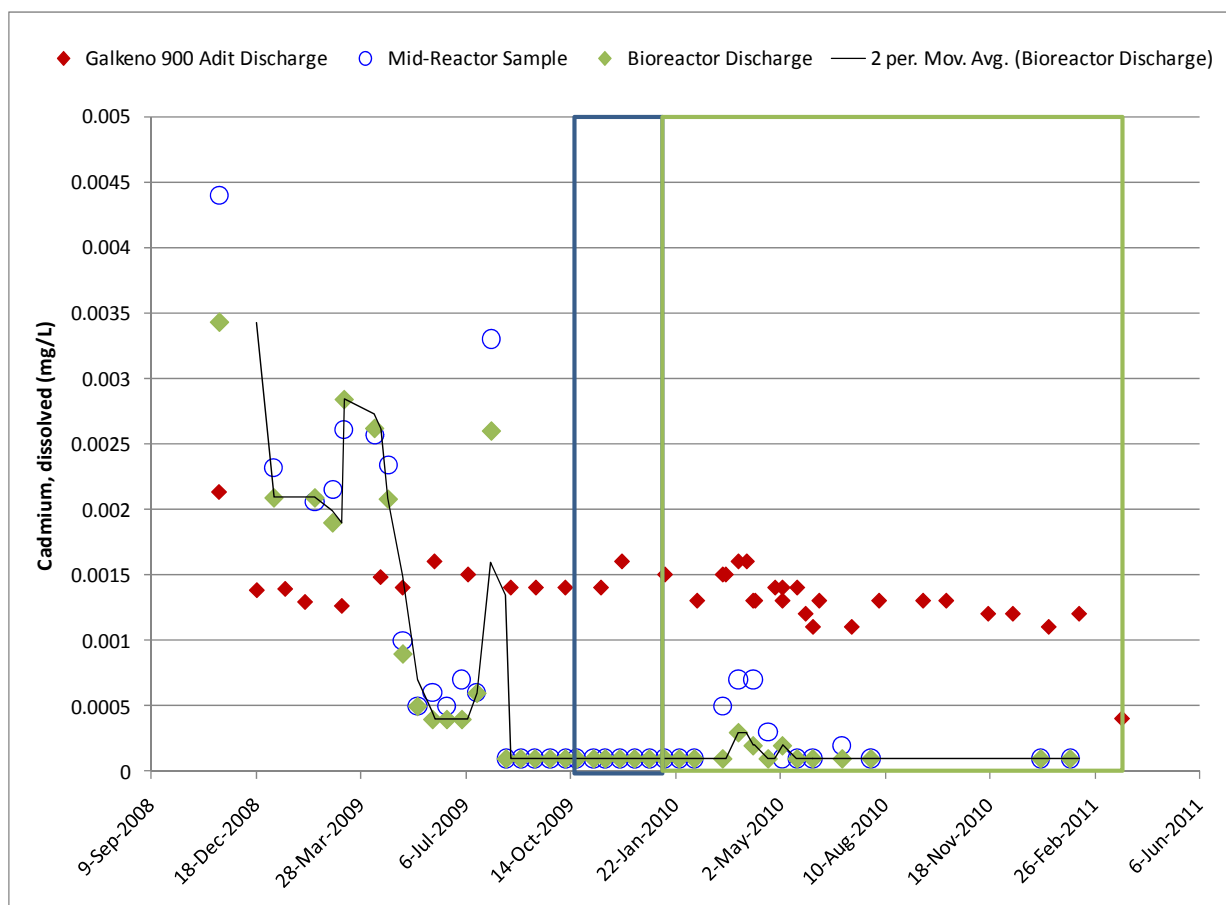


Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor

6.2.5 Iron

Iron concentrations declined approximately 97% reduction (1.75 mg/L reduced to 0.032 mg/L average of last two months) during the recirculation phase (See Figure 15). During this phase, iron appears to have been removed primarily by precipitation as an oxide. During the reduction onset phase, iron dissolved from the reactor and has been released at a rate higher than the amount entering the reactor through the recent operations.

Iron removal in the bioreactor provided sorption and co-precipitation phases for other trace metals removal during the recirculation phase. Some of the iron was likely also removed as sulphides in their initial amorphous precipitate form (operationally called Acid Volatile Sulphides or AVS). The rate of formation of this phase may be limited by the residence time provided in the bioreactor. An operational objective could include operating the reactor to create AVS.

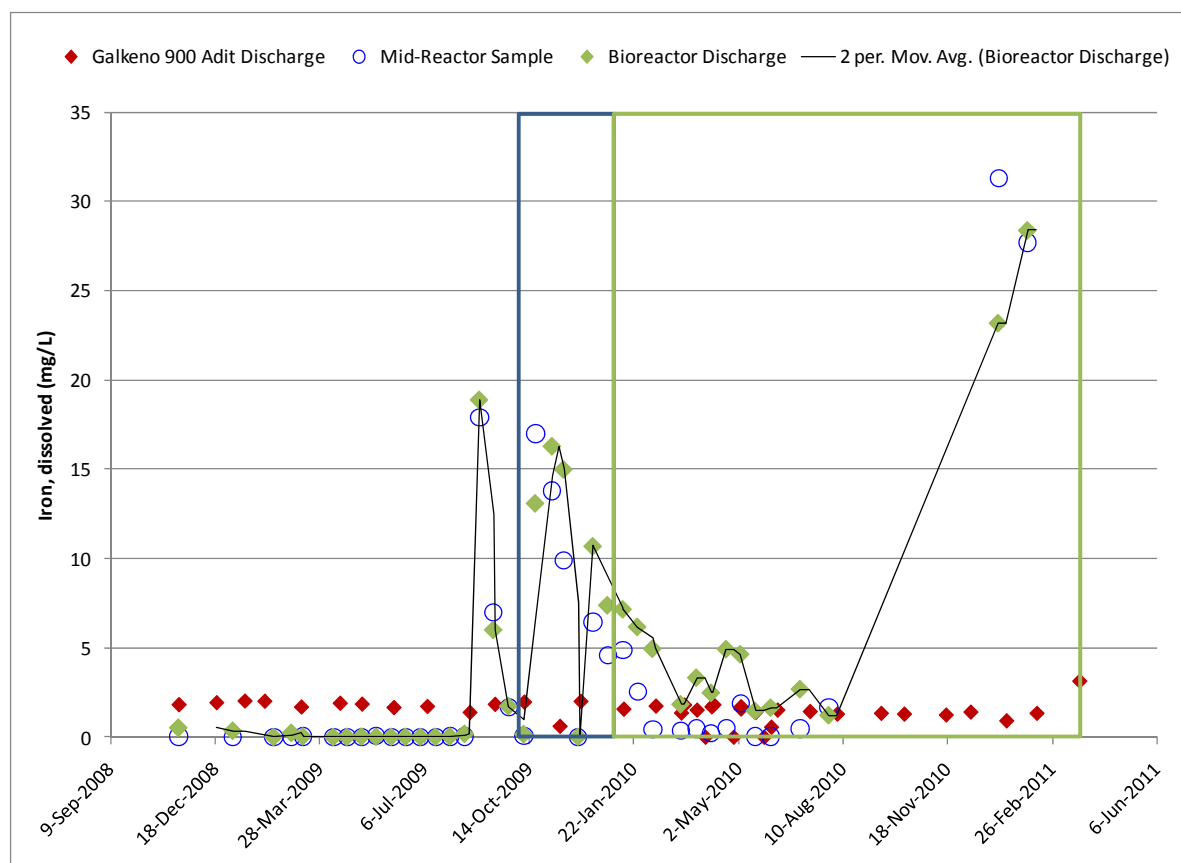


Figure 15 - Iron Removal by the Galkeno 900 Bioreactor

6.2.6 Manganese

Manganese concentrations declined approximately 98% (18 mg/L reduced to 0.25 mg/L) during the recirculation phase (See Figure 16). During the reduction onset phase, some manganese was released from the bioreactor, indicating that some of the manganese removal in the recirculation phase was as a manganese oxide. In through flow treatment phases the manganese concentrations entering the bioreactor and exiting the bioreactor were nearly the same, indicating manganese is not being removed from the reaction in the bioreactor under the more strongly reducing conditions and at the hydraulic residence times provided under the current flow regime.

Similar to iron, manganese removal in the bioreactor has important effects for other metals. Manganese carbonates and oxides that may have formed during the initial bioreactor operation phase have good sorption capacity for trace metals. Manganese precipitates may play a significant role in the removal of metals in the bioreactor.

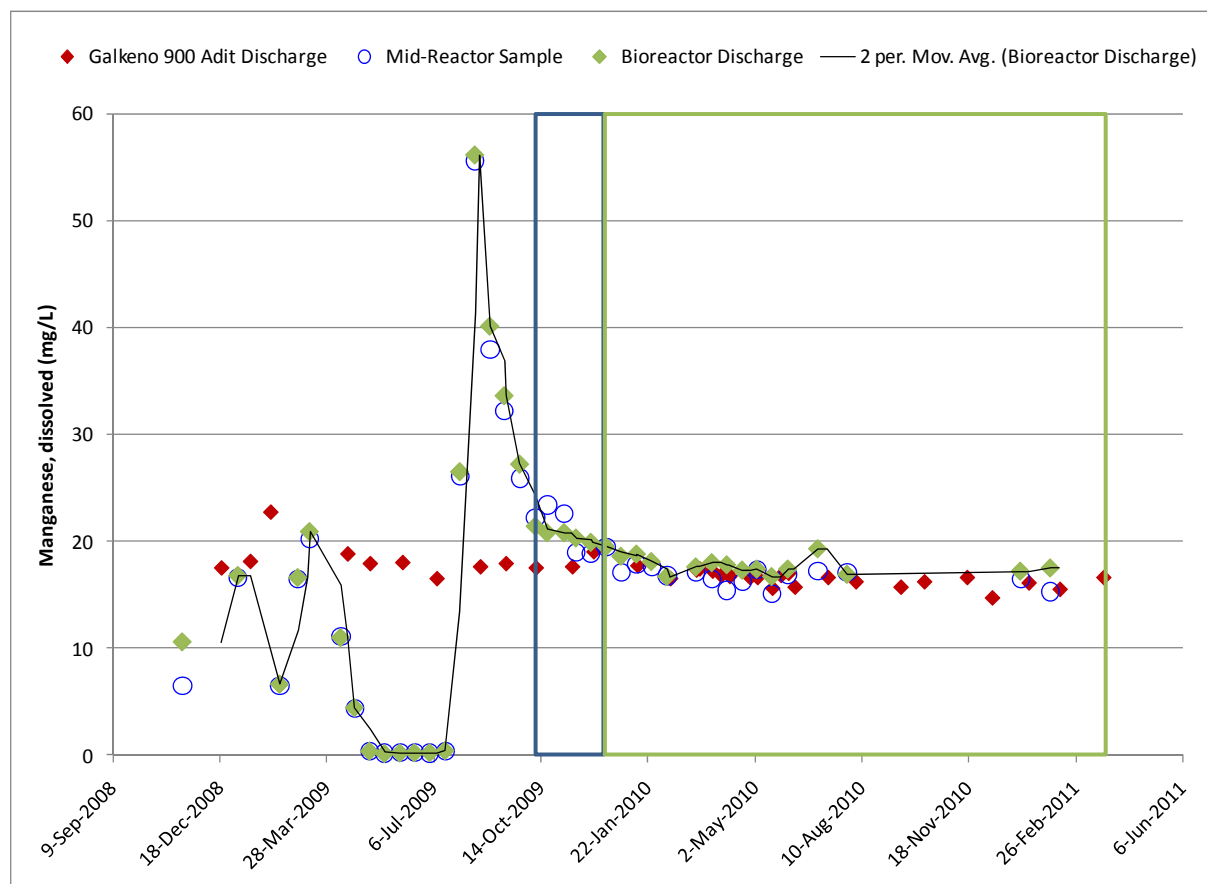


Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor

6.2.7 Nickel

Nickel concentrations declined approximately 80% (0.2 mg/L reduced to 0.04 mg/L average of last two months) during the recirculation phase (See Figure 17). During the reduction onset, a portion of the nickel was returned to solution, but during the slower flow periods, the nickel concentrations decreased to detection limits. Nickel removal during the 0.5 lps was 97.5%, but declined during the 1.0 lps flow rate. The treatment capacity of the reactor appears to be more sensitive for nickel than some other metals, as the mid-reactor sample increased during the switch to the higher flow rate. If nickel removal were an objective, operation of the bioreactor at a slower flow rate appears to be beneficial. However, the transition back to 0.75 lps improved the nickel removal.

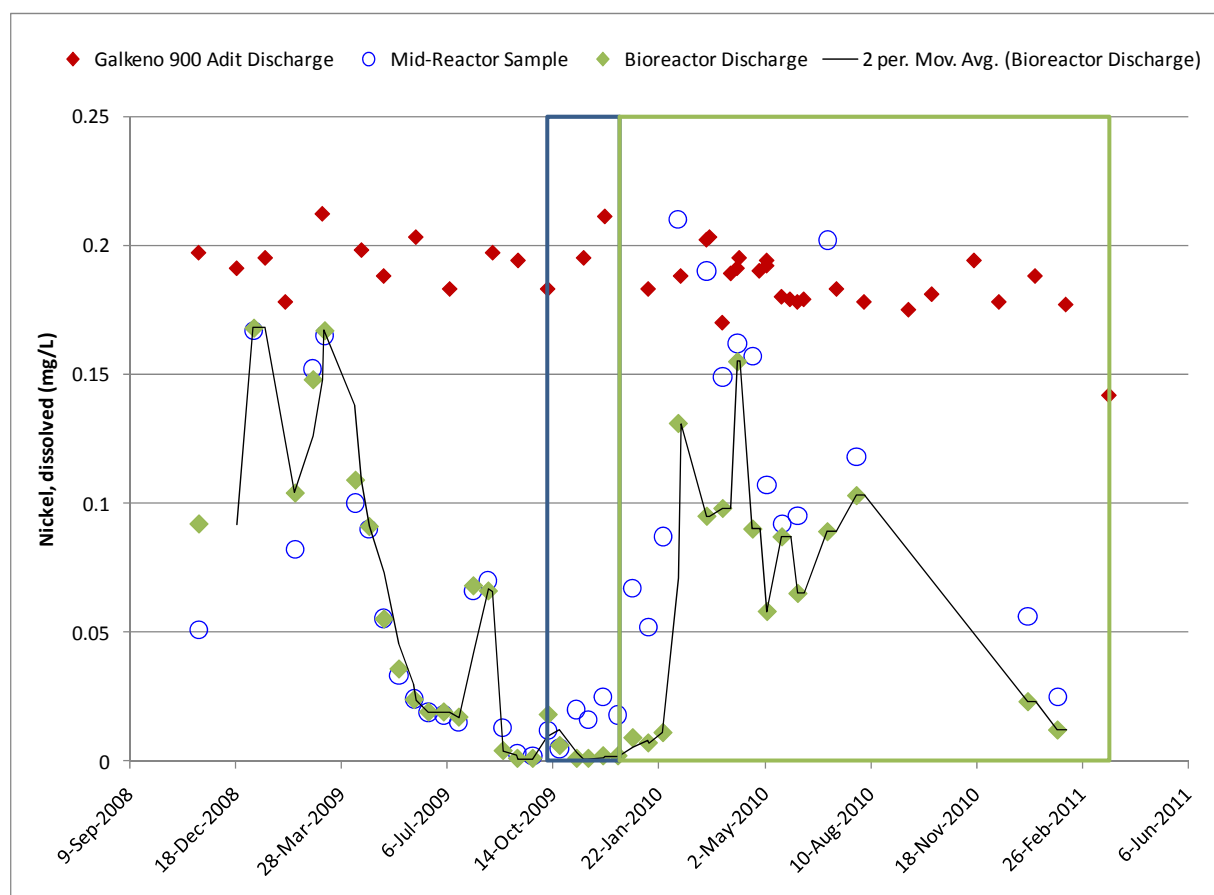


Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor

7 BIOREACTOR ENGINEERING DISCUSSION

Evaluation of the metals removal obtained in the bioreactor and determination of the SRR that can be achieved in the wintertime at the 0.5 and 1.0 lps flow rates enables an evaluation of the potential scaling factor for the size of the bioreactor that could treat the entire flow from the Galkeno 900 adit. Design improvements would focus on increasing contact with all of the bioreactor, and decreasing 'dead zones'. Experience at other sites has shown an elongated rather than square bioreactor has better contact parameters and fewer dead zones. In rough parameters, the flow from the Galkeno 900 adit is approximately 4 lps and remains consistent throughout the year and with the improvements and balancing the appropriate conservatism in design an approximate scale factor of four times the volume of bioreactor media would be used to design and cost a bioreactor for a full scale at Galkeno 900.

The minimum goal of 0.5 mg/L zinc was consistently achievable during normal operation of the bioreactor as long as the system remained in operation without interruptions. As shown in the data, a pump failure and/or pipe freezing can have a detrimental effect on the water quality results. This experience has shown the improvements to the design must focus on ensuring flow at all times, not dependent on power availability, and further improvements to insulation could also be achieved.

The removal of other metals was also consistently achieved with the exception of a short period when reduction onset occurred, when some metals were released with the reductive dissolution of iron and manganese.

7.1 GENERAL BIOREACTOR DESIGN IMPROVEMENTS

The following is an assessment of the Galkeno 900 design components that worked well and design components that did not work well. This information will provide the basis of design and inform the construction of future bioreactors within the district.

The following components worked well and should be repeated in future designs:

- 1.) **Torturous Path** - Creating a torturous path within the bioreactor using liner for baffling was needed with the Galkeno 900 design to minimize short-circuiting and increase residence time. However, the use of baffling created zones that did not provide effective treatment and these zones should be minimized or eliminated in future designs if possible. One way to do this is to create a bioreactor that is laid out as a long, gently sloping trench sections. Finding land where trenches could be constructed near adits in the Keno Hill area may be difficult in some areas.
- 2.) **Bioreactor Dead Zones** - As discussed earlier, approximately 60% of the media appears to be actively participating in treating the water as it passes through the bioreactor. The remaining volume is for practical purposes considered as dead zones. These dead zones can be minimized by creating longer and narrower flow paths. This design improvement should be considered for future bioreactors.

- 3.) **Flowing Water** - Water must be kept flowing - This is critical during the winter months in the Keno Hills district. Mine drainage and groundwater is above freezing, and the water temperature must be maintained while passing through the bioreactor. As long as the pump was working and water was continuously flowing through the bioreactor, freezing was avoided. Every freezing failure of the bioreactor was caused by power failures which lead to cessation of pumping and a loss of the heat capacity of the adit influent water. In future bioreactor designs, allowing adit water to flow via gravity through a bioreactor will eliminate the potential for pump failure and maintain flow through the bioreactor. The exact design for each bioreactor will be carefully considered to minimize power usage and prevent the potential for power interruptions to cause treatment failures.
- 4.) **Back-up Treatment System** - During this study, the discharge from the Galkeno 900 bioreactor was co-mingled with the untreated raw water from the adit. This combined water was then treated with a lime slurry and allowed to decant from a settling pond. It is possible to have a mobile system to treat water while the bioreactor until the discharged water meets the applicable standards or performance objectives. Once the bioreactor can demonstrate effective treatment with discharged water meeting standards, the treatment system could be removed or placed on stand-by.

The following components were sources of problems and should be eliminated or redesigned for future bioreactors in the district:

- 1) **Fill Material** - The fill material used in the Galkeno 900 bioreactor was too coarse. As seen in Figure 5, the material was a mixture of larger, broken rocks mixed with smaller pebbles and sand. By using a consistent fill material that is a smaller, crushed rock (between 3/8" to 2" diameters) additional surface areas will be available for bio-growth and will help avoid short circuiting.
- 2) **Metering Pump** - If the metering pump that provided a carbon source to the bioreactor stopped working, there was at best a limited stored carbon source available within the media. For future bioreactor designs, a limited amount of solid phase carbon source such as coarse sawdust or wood chips, and/or peat should be mixed with the media to provide a secondary source of carbon to sustain the bioreactor if the soluble/primary carbon source is interrupted.
- 3) **Pumps and Heat Trace** - As mentioned earlier, power failures were not planned for in the existing design. Inclusion of heat trace lines and backup power to pumps could have avoided the problems experienced in the Galkeno 900 bioreactor. In most cases, the location of the bioreactors could be placed in a downgradient location where power would only be required for the addition of a soluble carbon source. The carbon source could be designed to not require power by using an educator system where flow from the adit would draw in the carbon substrate by a venturi force. If utilized for backup power, a generator would be a very minimal size. The design would also consider placing the valves and controls inside the adit to minimize freezing.

Neither iron nor manganese were removed by the reactor during through flow operational phase. The natural attenuation studies in the district shows that these are readily removed in a very short distance by turbulent flow creating a natural oxidation system. This could be designed as a cascading discharge or could be performed in a natural setting such as an existing stream.

8 DISCUSSION AND CONCLUSIONS

When continuous flow was maintained to the bioreactor at acceptable flow rates, effective treatment was maintained. At higher flow rates the transformation of metals from their dissolved forms to an insoluble form was accomplished, but the filtration efficiency of the coarse rock in the bioreactor did not filter the insoluble precipitates effectively. Full scale application of the sulphate reduction bioreactor technology appears feasible if slight design modifications are made to ensure gravity flow from the adit, avoidance of siphoning due to freezing, and improved sizing of the bioreactor media.

Evaluation of longer term bioreactor studies have been conducted at the Leviathan mine since 1997 by the US EPA. The US EPA SITE program (2006) ranked the bioreactor technology for metals treatment at the Leviathan mine using the criteria shown below. The Discussion of the Galkeno 900 bioreactor in terms of how it performed is presented relative to the same evaluation criteria.

- For Overall Protection of Human Health and the Environment, it was determined that the sulphate reducing bioreactor was effective for reducing metals concentration, and produced non-toxic and stable precipitates. A similar conclusion can be reached for the Galkeno 900 bioreactor; confirmation of stable non-toxic precipitates is underway in addition was confirmed with the mineralogical studies. , but with lower influent metals concentration in the Galkeno 900 bioreactor it is reasonable to believe similar results will be determined.
- For Compliance with Applicable or Relevant and Appropriate Requirements (ARAR), it was determined that the bioreactor generally produced compliant discharge, and with minor adjustments compliance was improved further. Similar conclusions can be stated for the Galkeno 900 bioreactor.
- For Long Term Effectiveness and Performance, it was determined that the bioreactor consistently met the applicable standards over many years, and suggested that with additional engineering a more passive (wind and/or solar powered) system appeared to be feasible. The strength of this conclusion for Galkeno 900 reactor is weakened primarily due to power and freezing issues, but these issues can be engineered in future applications to be less significant and thereby increase the long term effectiveness and performance.
- For Reduction in Toxicity, Mobility, or Volume through Treatment, it was determined that the bioreactor concentrated the metals in a stable form. Similar conclusions can be reached for the Galkeno 900 bioreactor: on average over 90% of the metals were removed from solution and filtered out of the bioreactor during operational times. Confirmation that zinc was removed in a ZnS precipitate also shows that the bioreactor created a dense, low volume precipitate; compared to zinc precipitated as metal hydroxides, ZnS is multiple times denser and therefore lower volume.
- For Short Term Effectiveness, it was determined that the bioreactor effluent was protective of human health, and that the chemicals required for bioreactor operation could be handled safely with the appropriate engineering controls. Conclusions for the Galkeno 900 bioreactor are that it had short term effectiveness when operating at lower flow rates, and

consequently that by appropriate sizing and cold weather engineering a bioreactor can have high short term effectiveness in the KHSD.

- For Implementability, it was determined that the technology is simple, could be operated with limited operator involvement, and that it was stable over a long time. For the Galkeno 900 bioreactor, the technology is very simple and required little operator involvement, and if pumping and siphoning the bioreactor could be avoided through gravity feed, the Galkeno 900 bioreactor process has a high implementability ranking.
- For Cost, it was determined that it cost approximately \$15 per 1000 gallons to operate the Leviathan bioreactor. By way of comparison, the Galkeno 900 bioreactor costs are in the range of \$5 per 1000 gallons. The main difference is the lower level of reagent requirements due to lower metals concentration and neutral pH at the Galkeno 900 bioreactor.
- For Community Acceptance, it was determined that the operation of the bioreactor presented minimal risk to the community, with diesel generation and transportation of chemicals to the bioreactor being the main risks. With the lower chemical usage required for a bioreactor in the neutral drainages in the KHSD, and the availability of line power the Community Acceptance criteria should be even better in the KHSD.
- For State Acceptance, it was noted that California has allowed it to be the only water treatment technology used year-round at the Leviathan Mine site. The Galkeno 900 bioreactor is currently approved for pilot scale trials on the Keno Closure program and was approved as part of the environmental assessment and water licensing of the Bellekeno Mine.

The bioreactor testing program is now considered complete. If desired, a subsequent study utilizing a buried trench design without the use of power could be considered for a next phase of testing to demonstrate the effectiveness of this approach for sites where power is available only by generator.

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APPENDIX A

SUMMARY REPORT ON OPTICAL AND ELECTRON MICROPROBE ANALYSIS OF GALKENO 900 BIOREACTOR AT KENO HILLS

Summary Report on optical and electron
microprobe analysis of Galkeno 900
Bioreactor at Keno Hills

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Table of Contents

	Page Number
Table of Contents	2
List of Figures	2
Executive Summary	3
1. Introduction	4
2. Methodology	4
3. Results	4
3.1 Column Test	4
3.2 Galkeno Bioreactor	5
4. Discussion	8
5. References	8

List of Figures

Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain	5
Figure 2: 1B G900 BIO BSE images and element maps	5
Figure 3 GK900 Bioreactor sample. (A) Low magnification BSE image showing extensive bright bands of ZnS and Fe,(B) BSE image and element scans of area in red box in (A), (C) BSE image and element scans of area yellow box in (A)	6
Figure 4: GK900.BSE image and element scans of area in yellow box in Figure 3C Element scans along the yellow line in BSE image (A)	7
Figure 5: BioR sediment: BSE image and element maps showing the relationship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.	8

Executive Summary

Samples of sediment from the Galkeno Bioreactor and also from a column experiment were analyzed using optical microscopy and an electron microprobe at the University of Manitoba. The first samples from the column experiment and from the Galkeno Bioreactor were oven dried in an aerobic environment prior to making polished thin sections. The second set of Galkeno Bioreactor sediments were kept in a wet anaerobic state before being sealed in epoxy resin.

Column samples contained Mn and Zn coatings on lithic grain.

The results showed that micron sized grains of ZnS were precipitated with a molar ratio of 1:1 indicating bacteriological sphalerite was being formed. The samples preserved anaerobically contained significantly more sphalerite than the first set of samples. The sphalerite formed bands indicative of biofilm deposition. Some of the ZnS layers were immediately adjacent to or surrounding layers of Fe and Mn oxide or hydroxide. This result fits with the water data from the Bioreactor. During the initiation the reactor was in an aerobic state and Mn and Fe oxides and hydroxides were deposited sequestering some Zn. When the Bioreactor became anaerobic the Mn and later Fe was mobilized but the Zn was now bacterially sequestered as ZnS. Some of this was formed on the remaining FeOOH biofilm layers.

1. Introduction

This study was initiated to investigate the form of Zn that was attenuated in column tests and in the Galkeno 900 Bioreactor. The initial set of samples had been oven dried prior to making the polished thin sections. This set consisted of duplicate thin sections (A and B) from 6 samples from the upper, middle, and lower section of four column tests (samples #3-8) and of two other samples from the bioreactor sediments (Sherriff 2011a) .

A second set of samples were obtained during the decommissioning of the Bioreactor (BioR Sed., and GK900 Sed.) These samples were sent to Vancouver Petrographics in jars as slurries. They were air dried and immediately sealed in eposxy resin to preserve minerals that might be unstable in an oxidizing environment. Two thin sections were made of sample BioR (A and B) (Sherriff 2011b).

2. Methodology

Polished thin sections were made by Vancouver Petrographics. The thin sections were examined optically to determine overall composition and delineate areas of interest. Selected areas were imaged on the electron microprobe (EMP) at the University of Manitoba using back scattered electrons (BSE) and mapped for Mn, Fe, S, and Zn. Points of further interest were the quantitatively analyzed.

The microprobe was operated at an acceleration potential of 15 kV and a beam current of 3 nA measured on the Faraday cup, with a 1 μm diameter beam. The standards for the quantitative analysis were albite (Na), olivine (Mg), andalusite (Al), diopside (Si, Ca), pyrite (S, Fe), orthopyroxene (K), sphene (Ti), spessartine (Mn), pentlandite(Ni), chalcopyrite (Cu), Gahnite (Zn), cobaltite (As), barite (Ba), chromite (Cr), and galena (Pb). The results of quantitative point analyses are given in wt. % elements with oxygen added to the Mn coating analyses to balance the cations.

3. Results

3.1 FM Column Tests

Only samples #5A FM Peat Bottom and #8A FM Silt and Clay Bottom were analyzed using the electron microprobe. Under optical microscopy thin section #5A FM Peat Bottom showed just plant fragments in a red mud whereas thin sections 8A FM Silt and Clay Bottom had lithic grains in fine grained matrix. The results from the column samples were rather ambiguous. Small areas ($\sim 1\mu\text{m}$) in sample 5A had high Zn and S with Zn:S molar ratio of about 1:1 indicating possible precipitation of sphalerite. Sample 8A had a thin black coating of Mn and Zn around lithic grains with an average concentration is 8.1 wt. % Mn and 1.2 wt. % Zn giving an average Mn:Zn molar ratio of 3.4 (Figure 1)

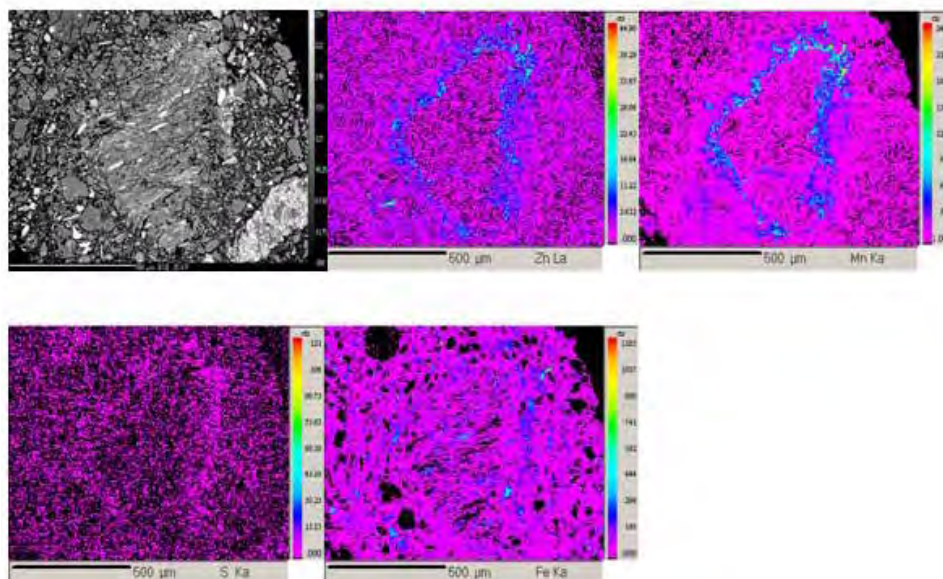


Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain

3.2 Galkeno Bioreactor

The first set of Galkeno Bioreactor samples showed a few small areas that contained micron sized areas of Zn and S in a ratio of about 1:1 indicating the presence of ZnS (Figure 2).

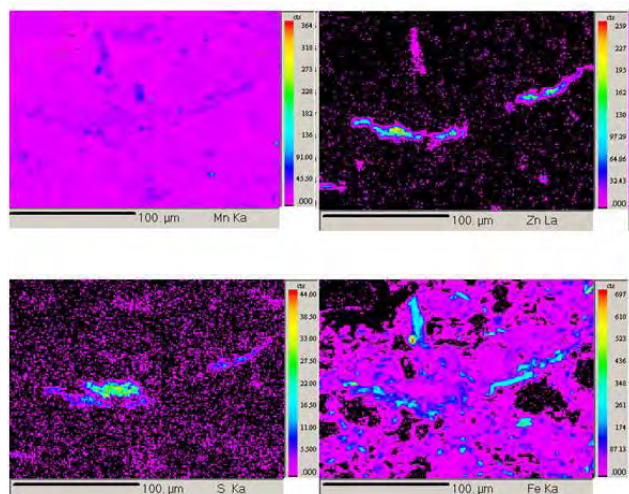


Figure 2: 1B G900 BIO BSE images and element maps

The second set of Galkena 900 samples (BioR Sediment and GK900 sediment) were kept under water and hence in an anaerobic environment until analyzed. These have a much higher concentration of micron sized ZnS grains, many of which formed bands indicating bacterial precipitation of sphalerite within a biofilm layer (Figure 3).

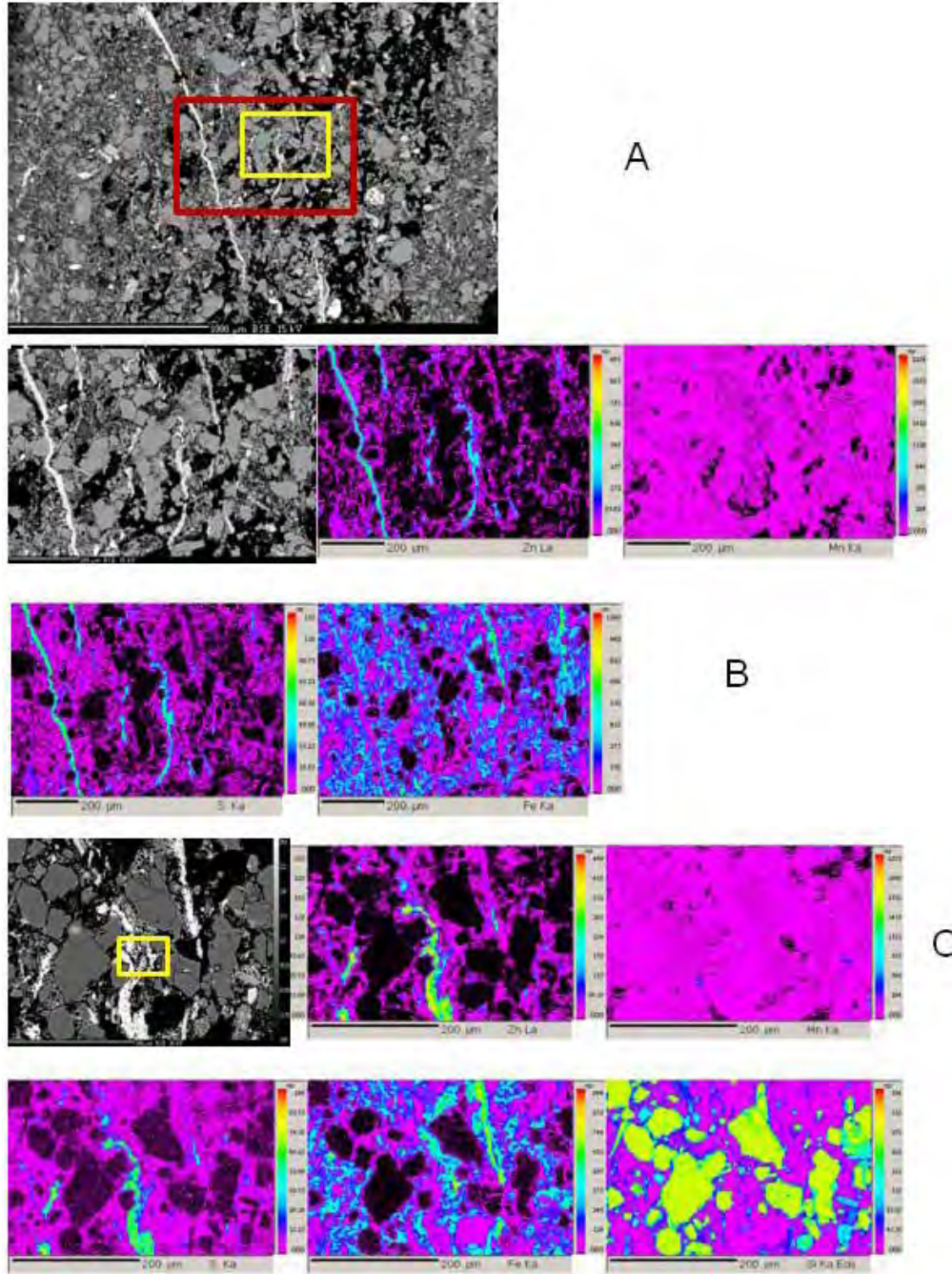


Figure 3 GK900 Bioreactor sample. (A) BSE image showing extensive bright bands of ZnS and Fe(B) BSE image and element scans of area in red box in (A) (C) BSE image and element scans of area yellow box in (A)

There were also areas containing Fe and Mn but not Zn or S (Figure 4). An elemental line scan across this area indicates regions rich in Zn and S adjacent to areas rich in Fe and Mn. Scatter plots of the quantitative analyses along the same line show that firstly Zn and S are related in atomic proportions of 1:1 (R^2 0.98) verifying the presence of sphalerite (ZnS) and secondly that Fe and Mn are precipitated together in a separate band (R^2 0.83). The concentrations of Mn are very low and there is no correlation between Fe and Zn or between Mn and Zn.

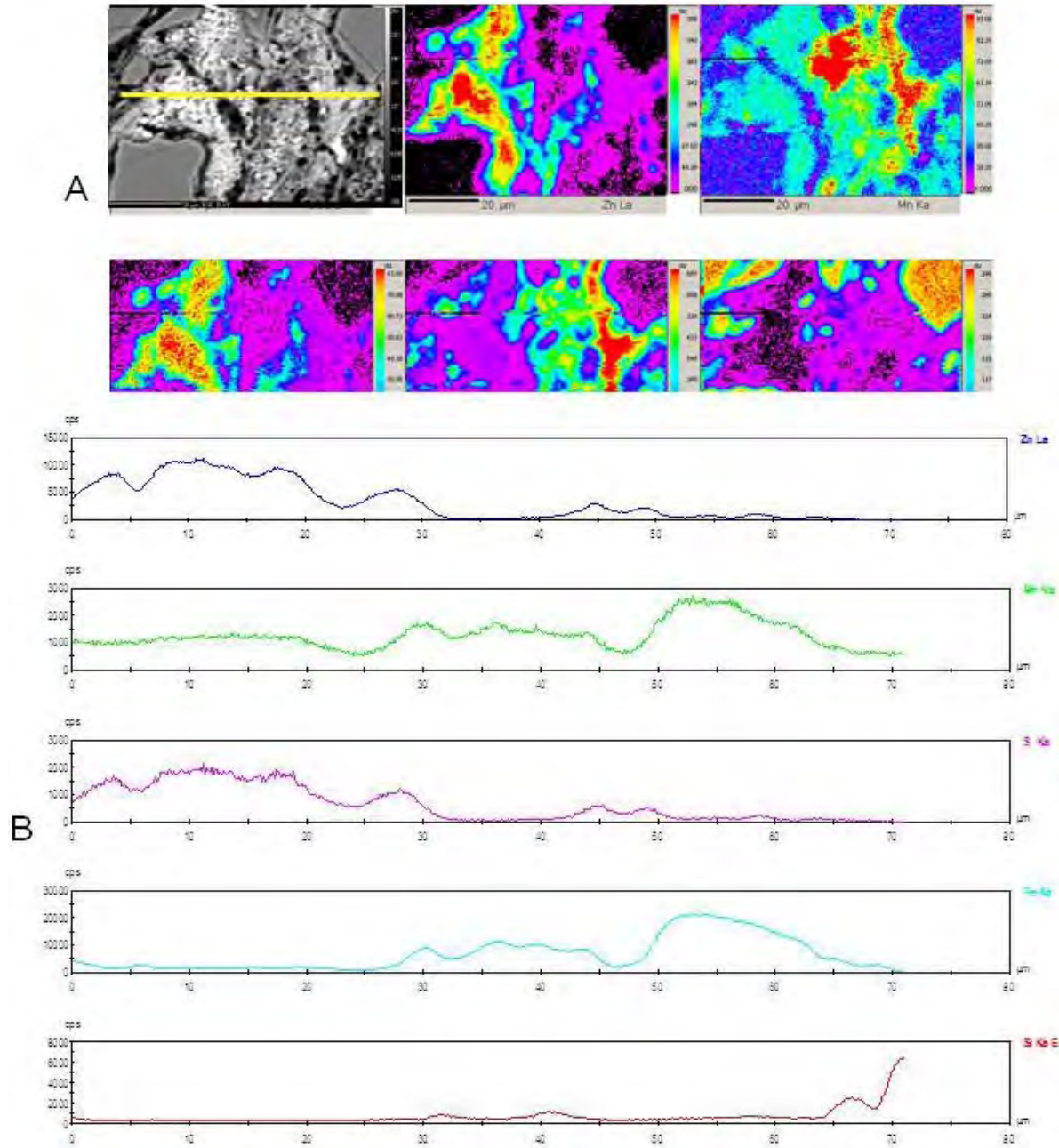


Figure 4: GK900. BSE image and element scans of area in yellow box in Figure 3 Element scans along the yellow line in BSE image (A)

In thin section BioR sediment A, a number of areas were imaged and mapped. A total of 160 points were selected within areas rich in Zn and S for quantitative analysis. In one area, two ZnS regions in the image have a thin band of Fe through the centre (Figure 5). The ZnS and Fe-rich bands were analyzed separately. A scatter plot of the concentrations of the ZnS band gives a 1:1 molar ratio of Zn to S indicating the presence of sphalerite. The Fe-rich bands have much lower concentrations of Zn and S and higher Fe and Mn. A plot of molar proportions of Zn and S indicates that there are still some grains of sphalerite in this region (Figure 5). In the Fe-rich band, there is a weak positive trend between the values of wt. % Fe and Mn (Figure 5).

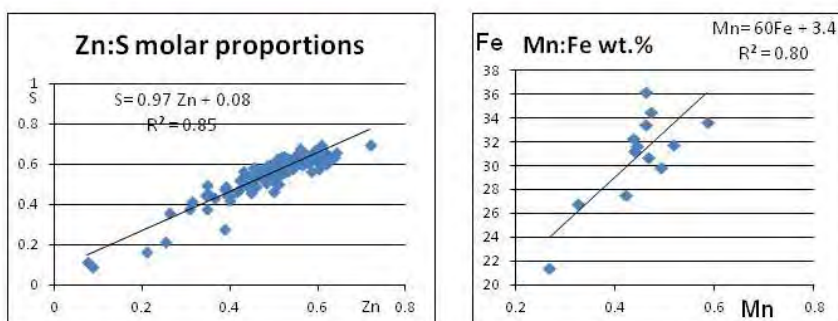
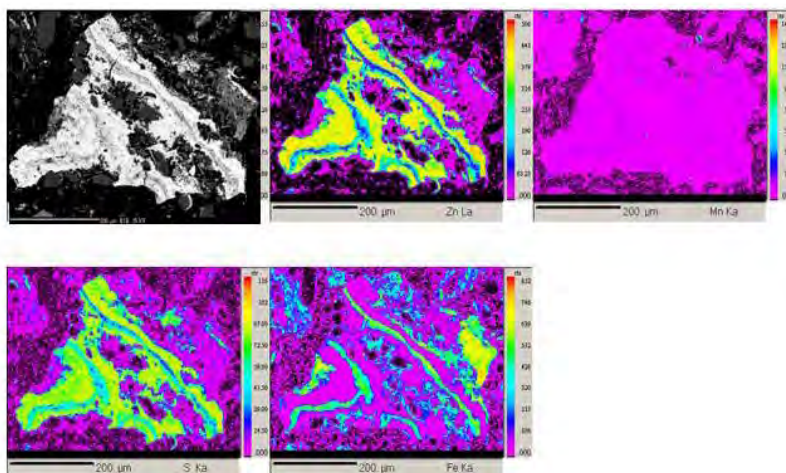


Figure 5: BioR sediment: BSE image and element maps showing the relation ship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.

4. Discussion

The chemical analytical data from the samples GK900 and BioR Sediment can be interpreted in light of the composition of water exiting the Bioreactor (Alexco Resource US Corp. 2011). When the reactor was initially established, from September 2008 to October 2009, the environment was aerobic, Mn, Zn and Fe were removed from the adit water probably as Zn absorbed on Mn oxide and FeOOH. In October 2009 the reactor became anaerobic and there was an immediate increase in the Mn concentration in the water. This would have been due to the dissolution of the Mn oxide. For the rest of the operation of the bioreactor, Mn was not removed from the mine water. Zn was then precipitated as ZnS by sulphate reducing bacteria with residual FeOOH acting as a template for the formation of a ZnS biofilm.

5 References

Alexco Resource US Corp (2011) Galkeno 900 Sulphate reducing Bioreactor 2008-2011 Operations Final Report.

Sherriff, B.L. (2011a) Interim Report on optical and electron microprobe analysis of Keno Hills samples set 3

Sherriff, B.L. (2011b) Interim Report on optical and electron microprobe analysis of Keno Hills samples set 4

Appendix 5 Kinetic Testing Results for Bellekeno Tailings

012345
Table 4- 4. Bellekeno Humidity Cell Results up to Week 44

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-0	MILL TAILS COMPOSITE-JAN- JUN2011-1	MILL TAILS COMPOSITE-JAN- JUN2011-2	MILL TAILS COMPOSITE-JAN- JUN2011-3	MILL TAILS COMPOSITE-JAN- JUN2011-4	MILL TAILS COMPOSITE-JAN- JUN2011-5
Date Sampled	17-AUG-11	24-AUG-11	31-AUG-11	07-SEP-11	14-SEP-11	21-SEP-11
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1045358-1	L1049390-1	L1051834-1	L1054437-1	L1057740-1	L1060984-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	750	500	500	500	500	500
Total Volume Out	550	460	460	450	450	475
Physical Tests						
Conductivity	1950	1050	1050	822	648	553
pH	7.89	7.7	7.86	7.81	7.91	7.81
Anions and Nutrients						
Acidity (as CaCO3)	5	4.8	5.8	10.9	5	3.4
Alkalinity, Total (as CaCO3)	43	45	68.3	64.5	49.6	62.7
Bromide (Br)	<0.050	<0.50	<0.5	<0.50	<0.050	<0.050
Chloride (Cl)	15.6	7.4	<5.0	<5.0	<0.50	<0.50
Fluoride (F)	0.354	0.37	0.34	0.34	0.288	0.27
Nitrate (as N)	10.1	3.36	<0.050	<0.050	0.0148	0.0065
Nitrite (as N)	0.0845	0.089	0.011	<0.010	0.0064	<0.0010
Sulfate (SO4)	1150	513	595	455	320	248
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.010	<0.010	<0.010	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	0.023	0.0241	0.0222	0.0178	0.0159	0.0166
Arsenic (As)-Dissolved	0.00081	0.00195	0.00248	0.0015	0.00139	0.00104
Barium (Ba)-Dissolved	0.0985	0.056	0.0372	0.0359	0.0387	0.0347
Beryllium (Be)-Dissolved	<0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.0010	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.166	0.157	0.185	0.117	0.075	0.076
Cadmium (Cd)-Dissolved	0.0264	0.0216	0.0339	0.0292	0.0228	0.0263
Calcium (Ca)-Dissolved	439	217	240	192	150	119
Chromium (Cr)-Dissolved	<0.0010	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00155	0.00089	0.00289	0.00318	0.00179	0.00198
Copper (Cu)-Dissolved	0.0049	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Iron (Fe)-Dissolved	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Lead (Pb)-Dissolved	0.192	0.161	0.137	0.104	0.111	0.128
Lithium (Li)-Dissolved	0.0608	0.0495	0.0488	0.0269	0.0196	0.0162
Magnesium (Mg)-Dissolved	17.3	10.6	10.3	6.94	4.64	3.7
Manganese (Mn)-Dissolved	3.69	1.81	4.07	3.71	2.11	2.13
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00463	0.00467	0.00422	0.00327	0.00376	0.00393
Nickel (Ni)-Dissolved	0.0037	0.0015	0.0042	0.00415	0.00193	0.00223
Phosphorus (P)-Dissolved	0.61	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	27.1	13	8.75	4.78	3.74	2.88
Selenium (Se)-Dissolved	0.00176	0.00109	0.00076	0.00075	0.00054	0.00044
Silicon (Si)-Dissolved	2.48	2.82	4.61	3.76	4.07	4.28
Silver (Ag)-Dissolved	0.00801	0.000588	<0.000020	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	67.5	23.3	10.4	3.64	2.14	1.35
Strontium (Sr)-Dissolved	1.33	0.623	0.565	0.382	0.276	0.249
Sulfur (S)-Dissolved	459	249	198	147	111	86.1
Thallium (Tl)-Dissolved	0.000564	0.000455	0.000381	0.000248	0.000147	0.000189
Tin (Sn)-Dissolved	<0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	<0.010	<0.010	0.016	0.014
Uranium (U)-Dissolved	0.000725	0.000413	0.000698	0.000526	0.000315	0.000276
Vanadium (V)-Dissolved	<0.0020	<0.0020	<0.0020	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	0.478	0.587	1.97	2.16	1.16	1.77

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-6	MILL TAILS COMPOSITE-JAN- JUN2011-7	MILL TAILS COMPOSITE-JAN- JUN2011-8	MILL TAILS COMPOSITE-JAN- JUN2011-9	MILL TAILS COMPOSITE-JAN- JUN2011-10	MILL TAILS COMPOSITE-JAN- JUN2011-11
Date Sampled	28-SEP-11	05-OCT-11	12-OCT-11	19-OCT-11	26-OCT-11	02-NOV-11
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1064228-1	L1067341-1	L1070094-1	L1073037-1	L1076479-1	L1079310-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	435	485	475	450	500	460
Physical Tests						
Conductivity	523	415	463	435	438	428
pH	7.91	7.86	7.84	7.79	7.91	7.83
Anions and Nutrients						
Acidity (as CaCO3)	5.6	7.1	7.2	6.3	10.4	5.1
Alkalinity, Total (as CaCO3)	68.4	78.3	73.7	73.9	72.1	75.6
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.254	0.208	0.183	0.164	0.161	0.179
Nitrate (as N)	0.0096	0.0052	<0.0050	<0.0050	0.007	0.0066
Nitrite (as N)	0.0036	0.0046	<0.0010	0.0016	0.0012	0.0043
Sulfate (SO4)	230	158	189	172	181	184
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	0.0219	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	0.0159	0.016	0.0164	0.0154	0.0155	0.0152
Arsenic (As)-Dissolved	0.00079	0.00091	0.0008	0.0008	0.00083	0.00078
Barium (Ba)-Dissolved	0.0371	0.0381	0.0395	0.0368	0.0389	0.0371
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.054	0.037	0.134	0.029	0.025	0.024
Cadmium (Cd)-Dissolved	0.0249	0.0205	0.0294	0.0292	0.0333	0.0328
Calcium (Ca)-Dissolved	121	90.3	101	94.3	100	94.2
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.002	0.0015	0.00223	0.002	0.00223	0.00219
Copper (Cu)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Iron (Fe)-Dissolved	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Lead (Pb)-Dissolved	0.123	0.0971	0.0956	0.107	0.104	0.0985
Lithium (Li)-Dissolved	0.0113	0.00832	0.0074	0.00656	0.00592	0.00589
Magnesium (Mg)-Dissolved	2.89	1.89	2.05	1.71	1.67	1.46
Manganese (Mn)-Dissolved	2.08	1.53	1.81	1.59	1.72	1.6
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00387	0.00361	0.00333	0.00314	0.00299	0.00319
Nickel (Ni)-Dissolved	0.00209	0.00154	0.00264	0.00217	0.00238	0.00209
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	2.23	1.57	1.58	1.3	1.29	1.17
Selenium (Se)-Dissolved	0.00042	0.00028	0.00031	0.00029	0.00028	0.00026
Silicon (Si)-Dissolved	4.42	4.11	3.97	3.98	4.07	4.17
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.853	0.562	0.746	0.46	0.477	0.426
Strontium (Sr)-Dissolved	0.245	0.179	0.185	0.166	0.168	0.187
Sulfur (S)-Dissolved	78.8	53.1	63.5	58.5	60.9	57.7
Thallium (Tl)-Dissolved	0.000218	0.000232	0.000105	0.000097	0.000099	0.000263
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.000261	0.000179	0.000243	0.000193	0.000212	0.000188
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	1.82	1.56	2.34	2.23	2.71	2.87

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-12	MILL TAILS COMPOSITE-JAN- JUN2011-13	MILL TAILS COMPOSITE-JAN- JUN2011-14	MILL TAILS COMPOSITE-JAN- JUN2011-15	MILL TAILS COMPOSITE-JAN- JUN2011-16	MILL TAILS COMPOSITE-JAN- JUN2011-17
Date Sampled	09-NOV-11	16-NOV-11	23-NOV-11	30-NOV-11	07-DEC-11	14-DEC-11
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1082246-1	L1084760-1	L1087901-1	L1090459-1	L1092275-1	L1095037-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	460	480	450	475	470	450
Physical Tests						
Conductivity	359	408	362	374	362	341
pH	7.85	7.91	7.87	7.95	7.90	7.8
Anions and Nutrients						
Acidity (as CaCO3)	6.2	7.5	5.8	7.7	4.8	5.7
Alkalinity, Total (as CaCO3)	71.3	71.7	72.3	72.4	72.7	71.2
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.138	0.125	0.124	0.113	0.111	0.174
Nitrate (as N)	0.0064	0.0062	0.0141	0.0061	<0.0050	0.0101
Nitrite (as N)	0.0046	0.0052	0.0056	0.0046	0.004	0.0069
Sulfate (SO4)	128	159	129	138	130	119
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	0.0141	0.0146	0.0145	0.0142	0.013	0.0129
Arsenic (As)-Dissolved	0.00075	0.00087	0.00076	0.00084	0.00083	0.00082
Barium (Ba)-Dissolved	0.0397	0.0441	0.0397	0.0417	0.0415	0.04
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.019	0.018	0.015	0.017	0.015	0.012
Cadmium (Cd)-Dissolved	0.0272	0.0329	0.0318	0.0342	0.0351	0.0343
Calcium (Ca)-Dissolved	79.2	94.6	79.7	80.6	80.6	79.5
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00164	0.00213	0.00183	0.00194	0.00188	0.00173
Copper (Cu)-Dissolved	<0.00050	0.0005	0.00062	0.00074	0.00078	0.00056
Iron (Fe)-Dissolved	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Lead (Pb)-Dissolved	0.0893	0.0894	0.0927	0.0918	0.0886	0.0852
Lithium (Li)-Dissolved	0.00417	0.00426	0.00365	0.00339	0.00291	0.00
Magnesium (Mg)-Dissolved	1.09	1.28	1.04	1.09	1	0.904
Manganese (Mn)-Dissolved	1.18	1.5	1.22	1.47	1.27	1.15
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00295	0.00277	0.00268	0.00265	0.00259	0.00248
Nickel (Ni)-Dissolved	0.00158	0.002	0.00161	0.00175	0.00163	0.0014
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	0.846	0.923	0.807	0.794	0.727	0.642
Selenium (Se)-Dissolved	0.0002	0.00022	0.00017	0.0002	0.00019	0.00017
Silicon (Si)-Dissolved	3.67	3.71	3.73	3.51	3.62	3.36
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.35	0.352	0.295	0.305	0.289	0.26
Strontium (Sr)-Dissolved	0.129	0.148	0.147	0.144	0.134	0.119
Sulfur (S)-Dissolved	43.4	54.1	44.3	46.7	43.5	40.5
Thallium (Tl)-Dissolved	0.000076	0.000079	0.000243	0.000267	0.000222	0.000176
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	0.01	0.011	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.000127	0.000184	0.000124	0.000147	0.00	0.0
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	2.14	2.69	2.55	2.71	2.76	2.64

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-18	MILL TAILS COMPOSITE-JAN- JUN2011-19	MILL TAILS COMPOSITE-JAN- JUN2011-20	MILL TAILS COMPOSITE-JAN- JUN2011-21	MILL TAILS COMPOSITE-JAN- JUN2011-22	MILL TAILS COMPOSITE-JAN- JUN2011-23
Date Sampled	21-DEC-11	28-DEC-11	04-JAN-12	11-JAN-12	18-JAN-12	25-JAN-12
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1097547-1	L1099484-1	L1100871-1	L1102685-1	L1104828-1	L1106888-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	460	410	445	425	420	490
Physical Tests						
Conductivity	397	512	525	505	472	435
pH	7.9	7.95	7.88	7.84	7.8	7.9
Anions and Nutrients						
Acidity (as CaCO3)	7.8	6.2	7.1	6.2	6.2	8.8
Alkalinity, Total (as CaCO3)	64.9	58.2	48.7	62.8	66.3	66.1
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.097	0.106	0.111	0.108	0.098	0.101
Nitrate (as N)	0.0137	<0.0050	0.0061	0.01	0.0096	0.0076
Nitrite (as N)	0.0054	0.0049	0.0026	0.0056	0.0045	0.0025
Sulfate (SO4)	129	194	206	193	175	148
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	0.013	0.0124	0.0107	0.0099	0.00986	0.0103
Arsenic (As)-Dissolved	0.00089	0.00092	0.00076	0.00084	0.00098	0.00145
Barium (Ba)-Dissolved	0.04	0.0465	0.045	0.0431	0.04	0.05
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.014	0.013	0.011	0.01	0.011	<0.010
Cadmium (Cd)-Dissolved	0.0372	0.0391	0.0465	0.0485	0.0479	0.0528
Calcium (Ca)-Dissolved	76.7	102	103	104	97.4	85.3
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00175	0.00184	0.00188	0.00201	0.00209	0.00241
Copper (Cu)-Dissolved	0.00073	<0.00050	<0.00050	0.00059	0.00099	0.00101
Iron (Fe)-Dissolved	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Lead (Pb)-Dissolved	0.083	0.0794	0.0943	0.0898	0.0966	0.0898
Lithium (Li)-Dissolved	0.00	0.00297	0.00282	0.00284	0.00	0.00
Magnesium (Mg)-Dissolved	0.974	1.28	1.39	1.45	1.28	1.28
Manganese (Mn)-Dissolved	1.15	1.13	1.2	1.23	1.3	1.36
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00226	0.00268	0.00266	0.00231	0.00233	0.00219
Nickel (Ni)-Dissolved	0.00148	0.00157	0.00125	0.00143	0.00141	0.0018
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	0.652	0.715	0.702	0.618	0.583	0.627
Selenium (Se)-Dissolved	0.00018	0.00022	0.0002	0.00017	0.00017	0.00016
Silicon (Si)-Dissolved	3.21	3.01	2.95	2.98	2.94	3.25
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.29	0.338	0.322	0.315	0.28	0.31
Strontium (Sr)-Dissolved	0.111	0.147	0.174	0.146	0.143	0.12
Sulfur (S)-Dissolved	44.4	65.8	70.6	65.8	59.3	50.5
Thallium (Tl)-Dissolved	0.000074	0.000078	0.000238	0.000091	0.000287	0.000098
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	0.011	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.0	0.0002	0.000178	0.00	0.0	0.0
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	2.72	2.18	2.69	2.98	2.91	3.47

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-24	MILL TAILS COMPOSITE-JAN- JUN2011-29	MILL TAILS COMPOSITE-JAN- JUN2011-30	MILL TAILS COMPOSITE-JAN- JUN2011-31	MILL TAILS COMPOSITE-JAN- JUN2011-32	MILL TAILS COMPOSITE-JAN- JUN2011-33
Date Sampled	01-FEB-12	07-MAR-12	14-MAR-12	21-MAR-12	28-MAR-12	04-APR-12
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1109203-1	L1121471-1	L1123018-1	L1125306-1	L1127559-1	L1130834-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	425	460	475	500	470	425
Physical Tests						
Conductivity	409	382	344	351	369	383
pH	7.97	7.91	7.85	7.9	7.9	7.93
Anions and Nutrients						
Acidity (as CaCO3)	4.1	5.4	7.4	8.3	9	11.5
Alkalinity, Total (as CaCO3)	58.2	65.5	64.8	59.8	54.9	57.1
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.092	0.08	0.08	0.073	0.071	0.071
Nitrate (as N)	0.0104	0.0063	0.0074	0.0085	0.0095	0.0056
Nitrite (as N)	0.0052	0.0015	0.0019	0.0014	0.0017	0.0019
Sulfate (SO4)	141	124	109	112	122	131
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	0.00943		0.00812		0.00817	
Arsenic (As)-Dissolved	0.0011		0.00155		0.00129	
Barium (Ba)-Dissolved	0.0407		0.0393		0.04	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0433		0.0491		0.0486	0.0498
Calcium (Ca)-Dissolved	83.5		62.1		67	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.00195		0.00256		0.00268	
Copper (Cu)-Dissolved	0.00082		0.00192		0.0024	
Iron (Fe)-Dissolved	<0.030		<0.030		<0.030	
Lead (Pb)-Dissolved	0.0809		0.0779		0.0847	
Lithium (Li)-Dissolved	0.00238		0.00172		0.00	
Magnesium (Mg)-Dissolved	1.07		0.862		0.987	
Manganese (Mn)-Dissolved	1.04		1.09		0.958	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00223		0.00178		0.00175	
Nickel (Ni)-Dissolved	0.00145		0.00188		0.00189	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.497		0.385		0.374	
Selenium (Se)-Dissolved	0.00017		0.00014		0.00015	
Silicon (Si)-Dissolved	2.87		2.72		2.43	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.241		0.209		0.20	
Strontium (Sr)-Dissolved	0.119		0.104		0.112	
Sulfur (S)-Dissolved	50.7		36.7		39.4	
Thallium (Tl)-Dissolved	0.000058		0.000038		0.000059	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.000099		0.00		0.0	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	2.76	4.25	3.72	3.14	3.11	3.35

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-34	MILL TAILS COMPOSITE-JAN- JUN2011-35	MILL TAILS COMPOSITE-JAN- JUN2011-36	MILL TAILS COMPOSITE-JAN- JUN2011-37	MILL TAILS COMPOSITE-JAN- JUN2011-38	MILL TAILS COMPOSITE-JAN- JUN2011-39
Date Sampled	11-APR-12	18-APR-12	25-APR-12	02-MAY-12	09-MAY-12	16-MAY-12
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1133140-1	L1135454-1	L1138358-1	L1141290-1	L1143994-1	L1147310-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	480	455	475	475	500	455
Physical Tests						
Conductivity	322	341	332	309	294	330
pH	7.79	7.92	7.9	7.9	7.85	7.88
Anions and Nutrients						
Acidity (as CaCO3)	6.9	10.3	15	12.8	8	6.2
Alkalinity, Total (as CaCO3)	49	61.2	58.8	49.2	55.3	49.3
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.059	0.068	0.067	0.059	0.05	0.058
Nitrate (as N)	0.0057	<0.0050	0.0069	<0.0050	0.0194	0.0061
Nitrite (as N)	0.0018	0.001	0.0014	0.0012	<0.0010	<0.0010
Sulfate (SO4)	102	112	106	94.3	88.7	108
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	0.00804		0.00749		0.00858	
Arsenic (As)-Dissolved	0.00168		0.00145		0.00154	
Barium (Ba)-Dissolved	0.0388		0.04		0.0408	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0538	0.0604	0.0485	0.0564	0.0525	0.0505
Calcium (Ca)-Dissolved	58.2		67.9		55.3	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.00277		0.00299		0.00307	
Copper (Cu)-Dissolved	0.00225		0.00315		0.00261	
Iron (Fe)-Dissolved	<0.030		<0.030		<0.030	
Lead (Pb)-Dissolved	0.0834		0.085		0.0926	
Lithium (Li)-Dissolved	0.00099		0.00		0.00148	
Magnesium (Mg)-Dissolved	0.939		1.12		1.02	
Manganese (Mn)-Dissolved	1.03		0.978		1.01	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00158		0.00165		0.00162	
Nickel (Ni)-Dissolved	0.00204		0.00221		0.00234	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.331		0.349		0.317	
Selenium (Se)-Dissolved	0.00012		0.00014		0.00013	
Silicon (Si)-Dissolved	2.41		2.58		2.45	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.184		0.20		0.172	
Strontium (Sr)-Dissolved	0.101		0.103		0.103	
Sulfur (S)-Dissolved	34.7		36.7		29.6	
Thallium (Tl)-Dissolved	0.000039		0.000042		0.000041	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.000042		0.0		0.000037	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	3.48	4.28	3.01	3.87	3.29	2.6

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-40	MILL TAILS COMPOSITE-JAN- JUN2011-41	MILL TAILS COMPOSITE-JAN- JUN2011-42	MILL TAILS COMPOSITE-JAN- JUN2011-43	MILL TAILS COMPOSITE-JAN- JUN2011-44	MILL TAILS COMPOSITE-JAN- JUN2011-45
Date Sampled	23-MAY-12	30-MAY-12	06-JUN-12	13-JUN-12	20-JUN-12	27-JUN-12
Time Sampled	00:00	00:00	00:00	00:00	00:00	00:00
ALS Sample ID	L1150106-1	L1153466-1	L1156963-1	L1160875-1	L1164482-1	L1167961-1
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	485	495	490	475	475	475
Physical Tests						
Conductivity	299	299	292	281	277	274
pH	7.80	7.9	7.8	7.91	7.9	7.93
Anions and Nutrients						
Acidity (as CaCO3)	8.8	14.9	14.3	8.7	7.7	12.9
Alkalinity, Total (as CaCO3)	57.9	55.5	62.8	58.8	48.5	47.4
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.052	0.05	0.048	0.044	0.041	0.037
Nitrate (as N)	0.0054	0.0067	<0.0050	<0.0050	<0.0050	<0.0050
Nitrite (as N)	<0.0010	<0.0010	0.0019	0.0018	<0.0010	0.0013
Sulfate (SO4)	92.9	90.9	87.4	81.8	82.7	82.3
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	0.0077		0.008		0.00729	
Arsenic (As)-Dissolved	0.0016		0.00168		0.00137	
Barium (Ba)-Dissolved	0.0446		0.05		0.0468	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0596	0.0614	0.0611	0.0614	0.0481	0.0493
Calcium (Ca)-Dissolved	53.9		56.6		52.8	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.0035		0.00402		0.0036	
Copper (Cu)-Dissolved	0.00241		0.00315		0.00261	
Iron (Fe)-Dissolved	<0.030		<0.030		<0.030	
Lead (Pb)-Dissolved	0.0831		0.0867		0.0875	
Lithium (Li)-Dissolved	0.00207		0.00		0.00165	
Magnesium (Mg)-Dissolved	1.32		1.43		1.46	
Manganese (Mn)-Dissolved	1.14		1.2		1.06	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00139		0.00133		0.00138	
Nickel (Ni)-Dissolved	0.00278		0.00313		0.00282	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.329		0.318		0.311	
Selenium (Se)-Dissolved	0.00015		0.00015		0.00015	
Silicon (Si)-Dissolved	2.57		2.62		2.48	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.183		0.18		0.159	
Strontium (Sr)-Dissolved	0.0966		0.0928		0.0919	
Sulfur (S)-Dissolved	31.1		29.3		27.4	
Thallium (Tl)-Dissolved	0.000039		0.000042		0.000037	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.00		0.0		0.00003	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	3.86	3.65	3.61	4.07	2.63	2.89

Sample ID	MILL TAILS COMPOSITE-JAN- JUN2011-46	MILL TAILS COMPOSITE-JAN- JUN2011-47
Date Sampled	04-JUL-12	11-JUL-12
Time Sampled	00:00	00:00
ALS Sample ID	L1171477-1	L1174745-1
Matrix	Water	Water
Sample Preparation		
Total Volume In	500	500
Total Volume Out	470	475
Physical Tests		
Conductivity	271	270
pH	7.9	7.9
Anions and Nutrients		
Acidity (as CaCO3)	5.3	6.8
Alkalinity, Total (as CaCO3)	49.1	56.2
Bromide (Br)	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50
Fluoride (F)	0.038	0.04
Nitrate (as N)	<0.0050	0.015
Nitrite (as N)	0.0019	0.0012
Sulfate (SO4)	79.9	78
Dissolved Metals		
Aluminum (Al)-Dissolved	<0.0050	FIELD
Antimony (Sb)-Dissolved	0.00719	
Arsenic (As)-Dissolved	0.00141	
Barium (Ba)-Dissolved	0.05	
Beryllium (Be)-Dissolved	<0.00010	
Bismuth (Bi)-Dissolved	<0.00050	
Boron (B)-Dissolved	<0.010	
Cadmium (Cd)-Dissolved	0.0513	0.0596
Calcium (Ca)-Dissolved	51.2	
Chromium (Cr)-Dissolved	<0.00050	
Cobalt (Co)-Dissolved	0.00407	
Copper (Cu)-Dissolved	0.00311	
Iron (Fe)-Dissolved	<0.030	
Lead (Pb)-Dissolved	0.0901	
Lithium (Li)-Dissolved	0.00	
Magnesium (Mg)-Dissolved	1.54	
Manganese (Mn)-Dissolved	1.2	
Mercury (Hg)-Dissolved	<0.000010	
Molybdenum (Mo)-Dissolved	0.00131	
Nickel (Ni)-Dissolved	0.00332	
Phosphorus (P)-Dissolved	<0.30	
Potassium (K)-Dissolved	0.311	
Selenium (Se)-Dissolved	0.00013	
Silicon (Si)-Dissolved	2.49	
Silver (Ag)-Dissolved	<0.000010	
Sodium (Na)-Dissolved	0.16	
Strontium (Sr)-Dissolved	0.0854	
Sulfur (S)-Dissolved	27	
Thallium (Tl)-Dissolved	0.00004	
Tin (Sn)-Dissolved	<0.00010	
Titanium (Ti)-Dissolved	<0.010	
Uranium (U)-Dissolved	0.0	
Vanadium (V)-Dissolved	<0.0010	
Zinc (Zn)-Dissolved	2.96	3.96