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

REVISION 5.1

APRIL 2019

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1. INTRODUCTION

Alexco Resource Corp. (Alexco), through its wholly owned subsidiary Alexco Keno Hill Mining Corp., owns and operates the Keno Hill Mine Operations located in the Keno Hill Silver District (the KHSD). The Keno Hill Mine Operations include the Keno Hill District mill, district infrastructure and multiple underground silver/lead/zinc mines. The Bellekeno, Lucky Queen, Onek and Flame and Moth mines and the Keno Hill District mill are currently licenced for production under Quartz Mining License QML-0009 and Water Licence QZ09-092. The Bermingham deposit is licensed for advanced underground exploration under Mining Land Use Approval LQ00240. This Reclamation and Closure Plan (RCP) Revision 5 represents an update to the currently approved RCP Revision 4 and is a condition of QML-0009 and Water Licence QZ09-092 to be updated every two years.

This Keno Hill Mine Operations RCP Revision 5 includes the most recent envisioned mine plan outlined in the company's March 2017 Preliminary Economic Assessment and includes production from Bellekeno, Flame and Moth, Bermingham and Lucky Queen over an eight-year period. Although the Bermingham deposit is not permitted for production as of the date of this RCP Rev 5, it is included as it represents the most up to date plan of operations for the Keno Hill Mine Operations.

Note that the Bermingham, Lucky Queen, Onek and Flame and Moth Production Unit Areas included in this RCP have not been fully delineated pursuant to the Amended and Restated Subsidiary Agreement between Alexco and Indigenous and Northern Affairs Canada (INAC) as these deposits have not moved into production. The scope of reclamation and closure planning provided in this RCP Revision 5 consequently may be modified. Determination of the final Production Unit Areas will be made at the time of development and any changes to the RCP will be made during the next RCP update.

Figure 1-1 shows the general project location within Yukon, while Figure 1-2 shows the location on a smaller scale proximate to Keno City.

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

- Underground mining activities at the Bellekeno, Onek, Lucky Queen, Flame and Moth and Bermingham 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 mill ponds;
- Dry-stack tailings facility (DSTF), Phase I-II;
- Bellekeno, Onek, Lucky Queen, Flame and Moth and Bermingham N-AML waste rock disposal areas (WRDA) and P-AML waste rock storage facilities (WRSF);
- Temporary coarse ore stock piles;
- Site access roads; Bellekeno Haul Road from Mill to Bellekeno East (including the Lightning Creek bridge), Christal Lake Road (from Silver Trail Highway to the mill), Keno City Bypass Road from Bellekeno Haul Road to Wernecke Road (including the Lightning Creek bridge #2), Bermingham access road from Bermingham portal to Calumet Drive;

- Power distribution system (power poles, transformers);
- Water treatment plants and facilities; and
- Flat Creek Camp accommodations.

Please refer to Figure 1-3 for the location and summary of reclamation components under this RCP.

The closure measures that are expressed herein are consistent with the *Reclamation and Closure Planning for Quartz Mining Projects August 2013 Guidance Document (YG and YWB, 2013)*, 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. The overall outline and table of contents of this RCP differs slightly from the guidance document for purposes of report flow and site- specific mine area components but all the sections of the guidance document have been addressed.

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FIGURE 1-1
PROJECT LOCATION

JULY 2018

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1.1 ALEXCO'S ACTIVITIES IN THE KHSD

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

Ongoing development and production of the Flame and Moth deposit and additional future ore deposits will require amendments of the existing mine production Water Licence QZ09-092 and Quartz Mining License QML-0009. Additional minor approvals will also be required. Coordination of mining and care and maintenance activities will be determined through the Water Licencing and QML processes. The Yukon Water Board will determine under which Water Licence activities will be included.

Table 1-1 Relevant KHSD Assessment and Regulatory Approvals

Purpose	YESAA Approval	Quartz Mining Act Approval	Water Licence
Mine Production	Project # 2009-0030, 2011-0315, 2013-0161, Decision Documents	Quartz Mining Licence (QML-0009, expires 2031)[a]	Type A Water Licence QZ09-092 (amendment 2, QZ09-092-2), expires 2020[b]
Advanced Exploration	Project # 2008-0039, 2017-0086 Decision Documents	Class 4 Mining Land Use Approval (LQ00240, expires 2018)	Incorporated into QZ09-092[b]
Care & Maintenance	Project #2006-0293 and 2012-0141 Decision Documents	N/A	Type B Water Licence QZ17-084[b]

Notes: [a] http://www.emr.gov.yk.ca/mining/pdf/mml_keno_qml-0009_flamemoth_amendment.pdf
[b] http://www.yukonwaterboard.ca/WATERLINE/ [c]

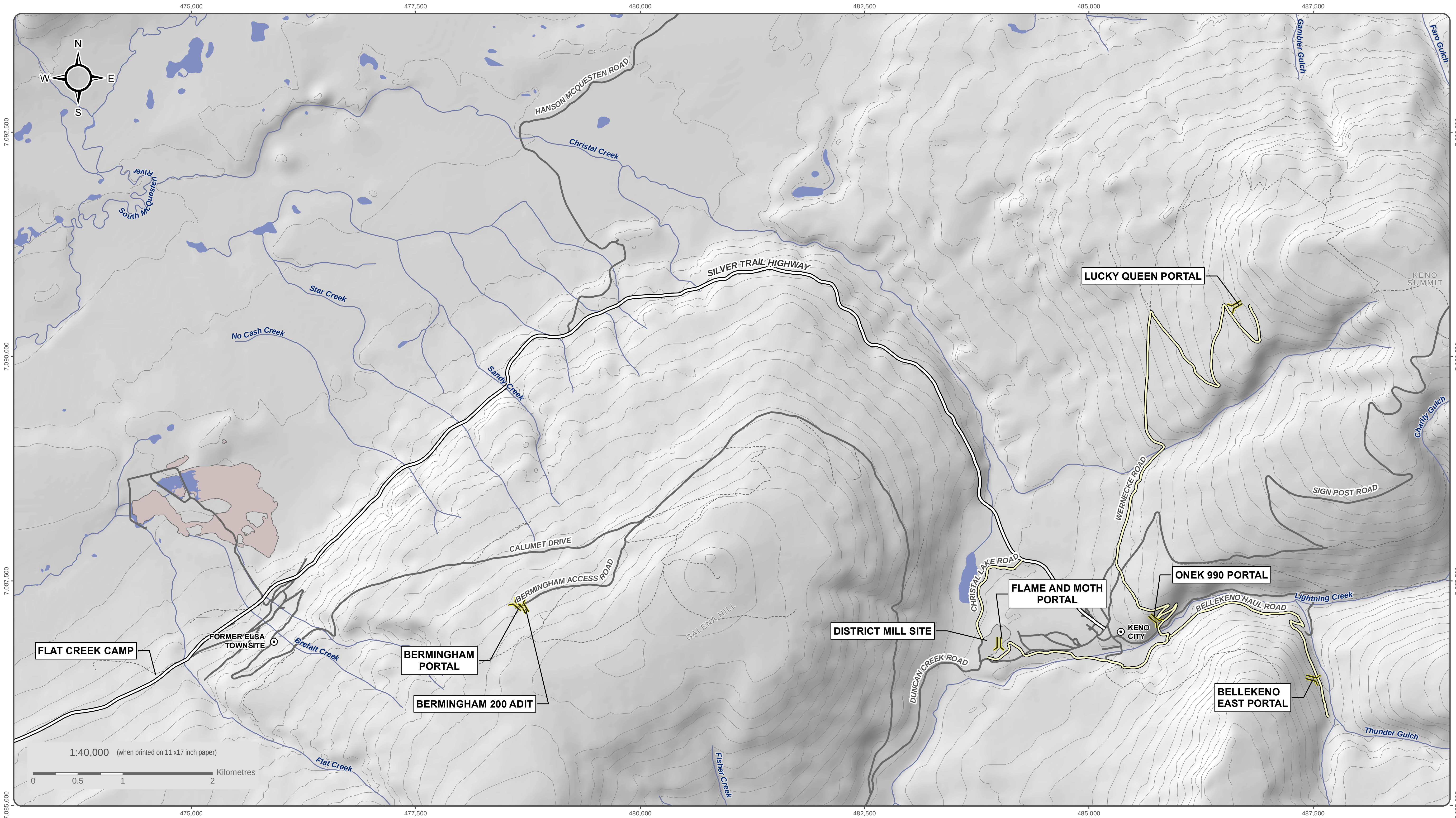
Closure and reclamation planning for the entire KHSD (District Closure Plan – Existing State of Mine (ESM) Reclamation Plan) is currently being developed in accordance with the Amended and Restated Subsidiary Agreement (ARSA) between Alexco and INAC; once approved and permits received this plan will be implemented.

1.2 PROJECT SCHEDULE

Active mining and milling operations are currently suspended at the Keno Hill Mine Operations. Table 1-2 summarizes the project schedule from its current status through the completion of the Life of Mine (LOM) plan. A more detailed project schedule is included as Table 5-3.

Table 1-2 Project Overview

Year	Summary of Main Project Activity
2013	• Suspension of mine/mill operations • District care and maintenance • QML-0009 and QZ12-053 amended for Lucky Queen and Onek Production
2014	• Flame and Moth YESAB assessment and decision document • Surface exploration • District care and maintenance
2015	• Surface exploration, Flame and Moth, Bermingham • District care and maintenance
2016	• QML-0009 amended for Flame and Moth development • Begin development of Flame and Moth underground portal, surface facilities construction • Surface exploration Bermingham • District care and maintenance
2017	• WL QZ12-053 amended for Flame and Moth production • Class IV amended for Bermingham advanced underground exploration • Commence Bermingham advanced underground exploration • District care and maintenance
2018	• Completed Bermingham underground exploration decline and underground exploration drilling • Commenced development of Flame and Moth decline, completed initial development in Q4 2018 • District care and maintenance



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Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on January 2018

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

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Place of Interest	Silver Trail Highway	Watercourse
Adit	Haul Road	Waterbody
Valley Tailings	Road	
	Limited-Use Road	

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RECLAMATION AND CLOSURE PLAN

FIGURE 1-2

PROPOERTY OVERVIEW

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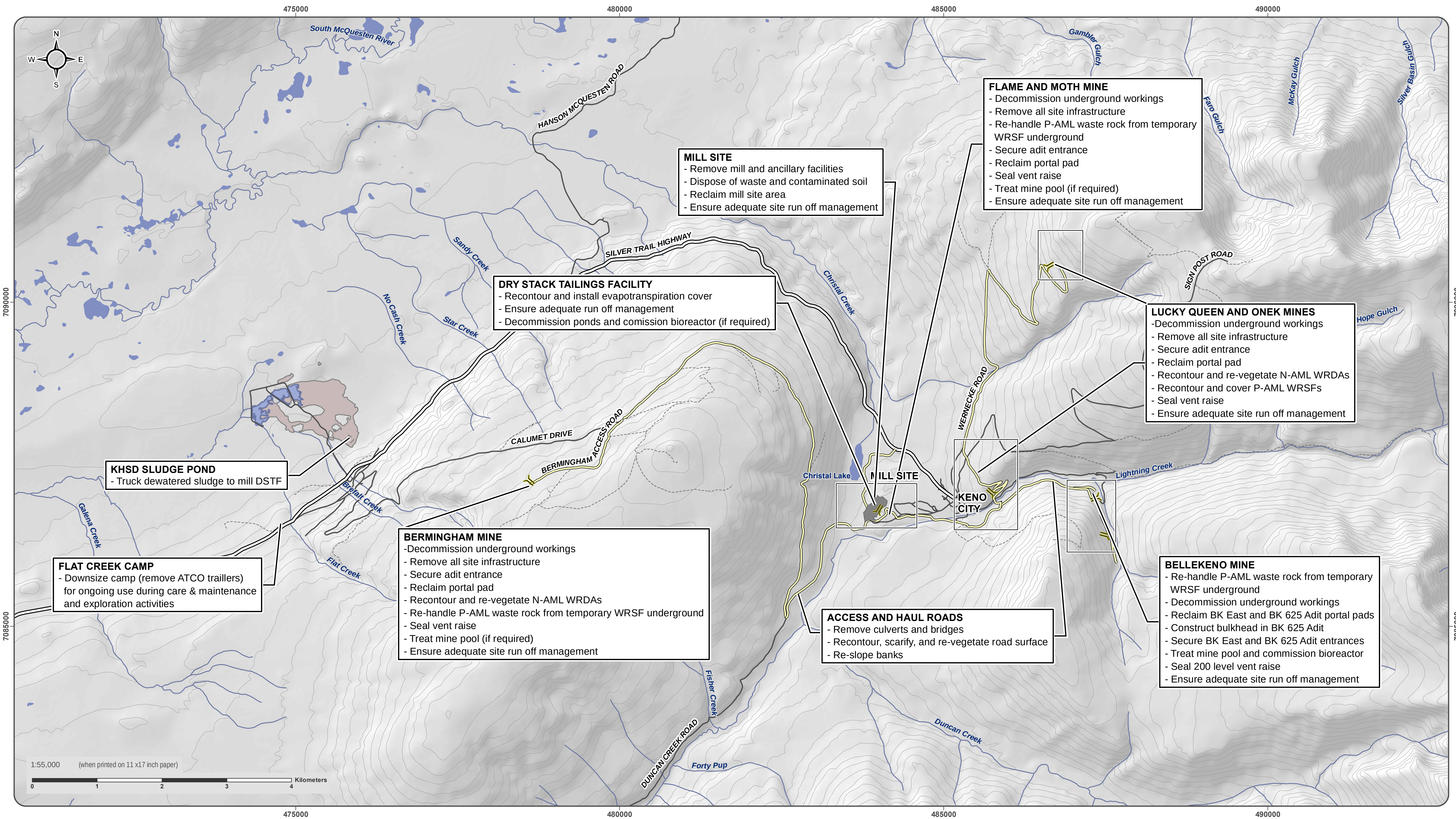

Datum: NAD 83; Map Projection: UTM Zone 8N

MineFeaturesPoint	Waterbody
Mill Site	Watercourse
KSSD Sludge Pond	Contours (100 ft intervals)
Silver Trail Highway	Other Road
Limited-Use Road	Haul Road

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KENO HILL SILVER DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 1-3

SITE RECLAMATION AND DECOMMISSIONING PLAN COMPONENTS

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2. RECLAMATION AND CLOSURE PLANNING

A significant responsibility of Alexco is to develop and implement a closure plan for the historic environmental liabilities (District Closure Plan) associated with past mining practices in the Keno Hill Silver District. This unique agreement and relationship between Alexco/INAC/First Nation of Nacho Nyak Dun (FNNND) provides for significant consultation and collaboration on closure objectives and final options for the development of the District Closure Plan. The knowledge, science and consultation gained from development of the District Closure Plan provides guidance for developing a Reclamation and Closure Plan for the activities associated with Alexco's modern Keno Hill Mine Operations.

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 INAC, Yukon Government and 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.

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.

In addition, principles and approaches for reclamation planning from the recently published *Reclamation and Closure Planning for Quartz Mining Projects Guidance Document* (YG and YWB, 2013) are incorporated into the RCP. To achieve its purpose, the guide has the following objectives:

- Describing the context for mine closure planning in the Yukon, and the rationale for requirements to submit RCPs and liability estimates;
- Describe the principles, philosophy and broad objectives for closure planning for Yukon mining projects;
- Describe the information expectations for RCPs and liability estimates; and
- Identify key sources of additional guidance for preparing RCPs and liability estimates.

The guidance document includes: methods for developing fundamental reclamation and closure objectives, methods for conducting community and regulatory engagement, reclamation and closure principles and principles for estimating liability.

2.1 COMPREHENSIVE COOPERATION AND BENEFITS AGREEMENT

Alexco and the FNNND have in place (signed June 2010, updated May 2016) a Comprehensive Cooperation and Benefits Agreement (CCBA).

The CCBA provides a modern, reasonable and fair platform upon which to maximize mutual benefits from our relationship. Importantly, the CCBA both acknowledges the FNNND aboriginal rights and title, and recognizes the legitimacy of our mining leases and grants and other property rights at Keno Hill. Equally important, the CCBA also provides significant social and financial components, including regular business liaison meetings, a full time FNNND Liaison Officer, scholarships, funding to hire consultants so they can participate in environmental permitting reviews such as the RCP and more.

As a result, FNNND is well informed about our applications, and their input is reflected in our project proposals. This is the hallmark of effective voluntary consultation in action, helping us achieve timely permitting of new projects; and through exposure to increasing opportunities brought about by our operations as well as other mining activities in their Traditional Territory.

2.2 CONSULTATION AND ENGAGEMENT

Alexco conducts on going consultation and stakeholder engagement with respect to all of our activities within the Keno Hill Silver District. Consultation and engagement is conducted in a variety of forms, including;

- Community meetings (Whitehorse, Mayo, Keno City);
- FNNND Chief and Council meetings;
- Technical meetings with multiple stakeholders and consultants;
- Site tours; and
- Meetings with regulators.

Often times, consultation and engagement will include a variety of topics and activities within the KHSD, including permitting of new mines, development of the Keno District Closure Plan or general updates.

2.3 RECLAMATION RESEARCH

Reclamation research and field validation of reclamation designs (hereafter collectively referred to as "research") are an important part of the closure planning process. The results 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 and field validation programs underway as part of the District Closure Plan that are co-funded and managed by Alexco as well as reclamation research and progressive reclamation directly related to the Keno Hill Mine Operations. These current programs have direct application to the reclamation and closure of the Keno Hill Mine Operations and Alexco will continue to utilize the research programs underway within the District Closure Plan for planning and optimization of the Keno Hill Mining

Operations RCP. The following reclamation research programs are currently in progress and the results will be utilized for reclamation and closure planning of the Keno Hill Mine Operations:

- Progressive reclamation on the DSTF;
- Cover system design and field trials;
- Site revegetation field trials;
- Bioreactor trials;
- Natural attenuation studies (Appendix 1.5); and
- In situ mine pool demonstration at Silver King.

Details and summary reports of the ongoing and completed reclamation research programs are included in Appendix 1. Alexco will continue to pursue both new research and field validation programs of reclamation during the ongoing update and optimization to the Keno Hill Mine Operations RCP. Details on any reclamation research programs will be included in subsequent revisions to this RCP.

2.4 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 quantity;
- Waste rock geochemistry;
- Tailings geochemistry;
- 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 Keno Hill Mine Operations. 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 2.

3. CLOSURE OBJECTIVES AND DESIGN CRITERIA

Yukon Government EMR has developed a schedule 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). A schedule outlining requirements for terrestrial performance standards has also been developed and is summarized in Table 3-2.

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, Bermingham, Flame and Moth, Onek 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**
(b) an analysis of the measures required to be implemented to ensure the ongoing physical and chemical stability of the site;	Bellekeno Mine (**Section 7.1.2**) Onek Mine (**Section 7.1.4**) Lucky Queen Mine (**Section 7.1.6**) Flame and Moth (**Section 7.1.8**) Bermingham (Section **(7.1.10)** Dry Stack Tailings Facility (**Section 7.2**) Waste Rock (**Section 7.3**) Mill and Infrastructure (**Section 7.5.5**) Camp (**Section 7.5.6**) Roads (**Section 7.7**)
(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;	**Table 3-3**
(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 Bellekeno Haul Road and any other roads at the site, and ore stockpiles	**Section 7 and appendices**
(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 7.5**
(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 7.2**) Waste Rock Storage Areas (**Sections 7.3**)
(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 7.9**
(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 7.9**
(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 7.10**) Adaptive Management (**Section 7.11.3**)
(l) a cost estimate to implement the plan, including a cost estimate for post closure monitoring, inspections, interim care and maintenance;	**Section 9**
(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 7.8**
(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 6**
(i) how the Licensee will secure the site during a temporary closure and ensure that all engineered structures, works and installations remain stable;	**Section 6.2**
(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 6.1**
(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 .10**
(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 9**

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 7.4 for the Bellekeno Mine water treatment facility; Section 7.5.5 for the Mill Pond; Section 7.5.1 for Bellekeno East water storage ponds; Section 7.5.2 for Onek water storage ponds; Section 7.5.3 for Lucky Queen water storage ponds. 7.5.4 Flame and Moth Treatment Pond and 7.5.5 for Bermingham water ponds
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 7.4.2). If monitoring indicates seepage from the DTSF requires treatment, a bioreactor will be installed.
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 PAML storage facilities will be constructed according to approved engineering designs, if necessary (see Section 7.3)
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 is physically stable and covered with a water shedding cover at closure to prevent infiltration and promote vegetation (see Section 7.2)
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), Onek 990 adit (Section 7.1.4), Bermingham (Section 7.1.10) and Flame & Moth adit (Section 7.1.8); an adit bulkhead will be installed at the Bellekeno 625 Adit and Lucky Queen Adit to prevent access and provide the ability to manage water discharge (Sections 7.1.5 and 7.1.6); 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 7.3)
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 7.7.1)
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 because 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 2.4)
T-13	Mine Infrastructure	Ensure physical stability and to remove potential threats to public health 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 7.5)
T-15	Temporary Closure Site Conditions	Ensure public health 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 6
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

3.1 INTEGRATION WITH DISTRICT-WIDE CLOSURE PLANNING

Closure Objectives that were developed with and agreed to by Alexco/ERDC, Canada (INAC), 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 ESM Reclamation Plan. The final version of the ESM Reclamation Plan has been submitted to INAC for approval and will enter the environmental assessment process in Q1 2018. The intent of the Keno District Mine Operations RCP is to ensure that the site-specific objectives are aligned with the ESM Reclamation Plan objectives. There are six primary objectives that have been finalized to guide the ESM Reclamation 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.

3.2 CLOSURE AND DESIGN 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 and maintained. 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 recontouring/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.

3.3 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.

3.4 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.

3.4.1 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.

3.4.2 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.

3.5 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 3-3 provides a general overview of each Mine Area Component and the site conditions associated with meeting completion criteria.

Table 3-3 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 Lucky Queen Flame and Moth Bermingham	Salvageable equipment removes. 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 and Disposal Areas			
Bellekeno Benched N-AML WRDA Bellekeno Temporary P-AML Facility Onek Permanent P-AML Facility Lucky Queen Permanent P -AML Facility Lucky Queen N-AML WRDA Flame and Moth Temporary P-AML Facility Bermingham Temporary P-AML Bermingham WRDA	Stable slopes WRSFs covered where applicable No significant wind or water erosion	No acid rock drainage 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

Reclamation Units		Completion Criteria Conditions		
		Physical Stability Requirements	Chemical Stability Requirements	Biological Stability Requirements
Water Diversion Structures				
	DSTF diversion berms	No significant erosion along channel banks and banks of dam structures	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 Tailing Facility				
	DSTF Phase I DSTF Phase II	DSTF covered with evapo-transpirative cover and vegetation No significant erosion or infiltration Tailings geotechnically stable	Any seepage reporting to Christal Creek watershed will not exhibit an adverse (measurable?) impact	Wildlife access

Reclamation Units		Completion Criteria Conditions		
		Physical Stability Requirements	Chemical Stability Requirements	Biological Stability Requirements
Bridges and Culverts				
	Lightning Creek Bridge (Keno City Bypass Road) Lightning Creek Bridge (Bellekeno Haul Road) 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 are stable with no significant wind or water erosion	All chemicals and contaminants remediated or removed	Sustainable vegetation cover
Linear Disturbances				
		No significant erosion along road banks and areas where culverts have been removed	All chemicals and contaminants remediated or removed	Sustainable vegetation cover

4. ENVIRONMENTAL AND SOCIO-ECONOMIC DESCRIPTION

The Keno Hill Mine Operations are within the traditional territory of the First Nation of Nacho Nyak Dun (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.

Table 4-1 summarizes existing environmental conditions in the Keno Hill Mine Operations 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 metres above sea level (masl). The area has been influenced by the latest glaciation but shows more subtle evidence of an earlier event as well.

Table 4-1 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 masl
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

4.1 CLIMATE

The Keno Hill Silver District and central Yukon climate is characterized by a subarctic continental climate with cold winters and warm summers. Average temperatures in the winter are between -15 and -20 degrees Celsius (°C) but can reach -60°C. The summers are moderately warm with average temperatures in July around 15°C. Mine and mill operations can be carried out year-round.

Because of its northern latitude, winter days are short with the sun low on the horizon such that north facing slopes can experience ten weeks without direct sunlight around the winter solstice. Conversely, summer days are very long, especially in early summer around the summer solstice. Annual precipitation averages 270 millimeters (mm); it is estimated that about 46% of this amount falls as snow, which starts to accumulate in October and remains into May or June.

Site meteorological data are collected at three meteorological stations: one located on Galena Hill above the Hector adit (elevation of 1,280 masl), one located adjacent to the District Mill and DSTF (at an elevation of 936 masl) and one located near the valley Tailings (elevation of 718 masl). Table 4-2 summarizes data collected to date at the Keno District Mill Campbell Scientific meteorological station, which is the station with the most complete data record at site. The sensors on this station include air temperature, relative humidity, total precipitation, pyranometer, and wind speed and direction.

Table 4-2 Monthly Statistics for the Keno District Mill Meteorological Station, 2011-2018

Month	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm) [10]	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
Jun - 11[2]	24.72	18.59	11.96	6.30	-2.56	n/a	n/a	1.35	9.14	n/a	n/a
Jul-11	25.67	18.50	12.91	8.00	5.09	n/a	n/a	1.15	8.02	n/a	n/a
Aug-11	22.32	15.58	9.78	5.37	1.93	n/a	n/a	1.18	9.15	n/a	n/a
Sep-11	17.97	11.29	6.07	1.85	-2.47	n/a	n/a	1.43	11.36	n/a	n/a
Oct-11	7.20	0.20	-2.74	-5.41	-9.84	n/a	*2.60*[3]	0.94	13.12	n/a	n/a
Nov-11	-4.23	-16.79	-19.54	-22.47	-34.99	n/a	0.00	0.58	12.05	n/a	n/a
Jan-12	-0.96	-19.10	-23.13	-26.79	-37.32	n/a	0.00	*0.59*	*9.51*	n/a	n/a
Feb-12	2.77	-6.77	-10.00	-13.07	-26.78	n/a	0.10 [4]	*1.38*	*15.62*	n/a	n/a
Mar-12	5.33	-7.69	-13.37	-18.00	-27.80	n/a	0.00	*0.97*	*9.24*	n/a	n/a
Apr-12	9.69	6.13	0.96	-3.87	-15.92	n/a	0.60 [4]	1.37	10.27	n/a	n/a
May-12	17.78	10.73	6.31	1.91	-3.47	*51.81* [5]	18.30	1.78	10.60	n/a	n/a
Jun-12	27.62	18.41	13.46	8.29	4.42	56.35	21.70	1.44	10.26	n/a	n/a
Jul-12	25.14	18.07	12.75	7.73	1.64	69.26	85.80	1.36	12.99	n/a	n/a
Aug-12	21.72	16.31	11.25	6.56	-0.89	67.79	47.00	1.62	9.41	n/a	n/a
Sep-12	20.24	10.33	5.90	2.08	-5.22	69.51	36.40	1.84	14.27	n/a	n/a
Oct-12	7.60	-3.95	-7.35	-10.32	-20.62	79.54	7.60	1.13	10.37	n/a	n/a
Nov-12	-8.98	-19.55	-21.90	-24.32	-33.36	81.43	0.00	0.94	9.36	n/a	n/a
Dec-12	-3.36	-21.30	-23.44	-25.58	-36.32	81.34	0.00	*0.26*	*5.93*	*1.01* [6]	*0.05* [7]
Jan-13	-1.59	-17.06	-20.01	-23.08	-41.48	82.92	0.00	*0.76*	*14.48*	1.06	0.81

Month	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm) [10]	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)[8]
Feb-13	1.54	-9.10	-12.52	-15.46	-23.74	88.36	0.30 [4]	*0.85*	*12.25*	10.26	1.27
Mar-13	3.26	-7.52	-13.16	-17.99	-29.96	64.08	3.90	1.59	12.47	95.82	6.33
Apr-13	6.07	-2.76	-7.94	-13.69	-25.07	54.50	8.20	2.44	12.93	190.02	14.48
May-13	23.31	10.20	5.27	0.23	-9.46	61.83	39.60	1.77	11.76	215.44	21.70
Jun-13	30.51	19.97	14.27	8.30	1.84	58.72	57.30	1.82	12.87	234.69	29.79
Jul-13	24.93	19.40	14.01	8.60	2.25	62.67	46.90	1.75	16.14	211.00	27.10
Aug-13	27.34	18.54	12.98	8.01	-0.38	66.30	51.90	1.49	11.05	156.25	21.38
Sep-13	16.11	9.69	5.81	2.26	-3.74	77.52	59.70	1.54	10.99	79.69	10.88
Oct-13	8.25	1.61	-1.32	-4.21	-10.10	86.75	44.60	1.11	11.62	35.75	4.26
Nov-13	0.18	-13.41	-16.68	-20.08	-37.96	84.26	10.60	*1.02*	*10.96*	4.93	*1.08*
Dec-13	-1.73	-21.23	-23.91	-26.70	-35.29	78.77	4.90	*0.75*	*9.47*	0.57	*0.62*
Jan-14	3.74	-9.33	-12.16	-15.10	-32.22	89.44	24.9	*0.72*	*10.03*	2.42	*0.641*
Feb-14	-1.93	-15.25	-19.40	-23.02	-33.55	75.20	2.9	0.87	10.85	31.34	1.988
Mar-14	4.57	-5.31	-11.29	-16.16	-26.79	54.77	0.7	1.57	11.98	115.54	9.174
Apr-14	10.93	4.09	-0.96	-5.78	-17.33	57.54	5.1	1.64	12.05	171.28	15.77
May-14	21.30	12.70	7.64	2.03	-3.03	52.18	12.8	2.09	19.21	217.91	29.81
Jun-14	24.93	16.21	11.39	5.95	-0.13	56.14	40.4	1.78	10.43	217.90	28.58
Jul-14	23.44	18.49	13.68	8.73	-0.04	65.01	31.0	1.63	13.38	187.31	23.84
Aug-14	22.09	15.57	10.87	6.93	0.06	74.59	67.7	1.44	11.85	139.84	15.72
Sep-14	17.70	8.76	4.28	0.49	-6.74	70.54	36.4	1.37	11.32	93.38	11.56
Oct-14	7.47	-0.91	-3.79	-6.33	-15.42	88.21	15.7	1.24	12.80	24.83	3.39

Month	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm) [10]	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)[8]
Nov-14	-2.21	-12.15	-14.34	-16.59	-30.16	88.64	1.40	*0.59*	*6.27*	3.12	*0.60*
Dec-14	-0.09	-11.05	-13.67	-16.31	-26.66	89.06	1.40 [9]	*0.51*	*8.87*	0.33	*0.40*
Jan-15	-0.34	-13.74	-16.50	-19.13	-34.86	85.85	1.9	*0.49*	*5.488*	1.30	*0.431*
Feb-15	2.87	-12.95	-15.93	-18.78	-39.39	84.95	12.7	0.75	10.36	9.06	0.859
Mar-15	5.54	-4.76	-9.83	-14.37	-28.70	70.52	4.1	1.45	12.6	86.48	6.292
Apr-15	10.90	5.36	0.56	-3.89	-10.48	61.71	4.2	1.75	12.37	163.45	16.03
May-15	26.51	16.95	10.96	4.60	-7.00	45.35	1.4	1.89	10.64	246.80	34.67
Jun-15	23.18	16.65	11.37	5.81	0.52	61.05	26.3	1.85	12.62	219.18	26.46
Jul-15	25.43	17.54	12.54	7.72	4.73	68.63	72.4	1.48	12.62	190.74	19.98
Aug-15	24.63	14.03	9.35	5.08	-3.09	75.14	54.9	*1.47*	*9.86*	146.76	*13.87*
Sep-15	13.57	7.07	2.77	-0.72	-7.72	79.33	32.6	1.71	15.64	83.01	10.12
Oct-15	7.32	0.88	-1.78	-4.16	-13.22	89.14	19.4	*1.08*	*10.07*	32.52	*2.92*
Nov-15	0.83	-11.17	-13.75	-17.16	-31.38	89.09	22.8	*0.71*	*12.15*	4.03	*0.60*
Dec-15	0.18	-12.38	-14.60	-16.93	-31.06	89.01	4.0	*4.59*	*14.24*	0.63	*0.13*
Jan-16	1.17	-8.96	-11.14	-13.58	-21.91	88.06	24.9	*0.83*	*15.35*	1.67	*1.45*
Feb-16	2.04	-7.63	-10.94	-14.27	-26.68	82.96	2.3	0.86	9.55	22.80	2.32
Mar-16	12.35	-0.55	-4.96	-8.72	-16.96	73.13	7.1	1.26	8.11	82.81	7.12
Apr-16	13.50	7.12	2.28	-2.23	-12.45	63.20	3.8	1.64	10.66	159.95	15.86
May-16	22.80	13.61	8.44	3.04	-1.59	54.73	14.7	1.89	11.89	210.96	25.97
Jun-16	25.98	18.36	12.88	7.17	2.27	56.52	40.0	1.76	13.37	234.99	29.78
Jul-16	23.73	17.71	13.37	9.07	1.71	73.05	63.4	1.46	12.54	173.59	17.36

Month	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm) [10]	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
Aug-16	24.42	16.67	11.92	7.82	1.22	70.86	42.2	1.50	10.69	152.32	17.72
Sep-16	17.42	10.00	5.01	0.90	-6.18	71.05	28.9	1.50	10.81	100.94	14.02
Oct-16	2.43	-3.20	-7.07	-9.99	-17.15	79.60	11.4	1.12	8.29	50.66	4.15
Nov-16	4.05	-8.20	-10.89	-13.45	-25.46	86.45	7.6	*0.80*	*9.57*	5.70	*1.99*
Dec-16	-4.20	-17.39	-19.62	-21.89	-32.16	83.76	1.3	*0.62*	*8.45*	0.56	*0.51*
Jan-17	-0.10	-13.10	-16.04	-18.97	-33.59	82.95	0.8	*1.06*	*11.03*	1.64	*1.76*
Feb-17	5.04	-11.47	-15.17	-18.42	-28.26	78.03	21.6	1.12	11.61	26.93	3.17
Mar-17	9.56	-9.61	-15.23	-19.49	-32.14	64.03	8.4	1.72	8.83	100.75	6.51
Apr-17	12.09	4.09	-1.17	-6.23	-16.26	57.70	7.1	1.81	10.50	173.66	15.44
May-17	19.93	12.98	8.06	2.94	-2.30	54.38	16.8	1.92	11.54	211.85	27.95
Jun-17	25.34	17.47	12.39	6.78	-0.90	54.93	20.2	1.73	13.32	225.93	28.61
Jul-17	28.09	20.67	14.99	9.44	4.21	64.01	39.4	1.57	13.65	212.94	25.50
Aug-17	28.31	18.20	12.83	8.12	1.95	64.85	16.7	1.46	11.01	156.87	21.67
Sep-17	19.06	11.19	6.94	3.36	-2.32	77.06	48.7	1.34	11.06	78.21	10.37
Oct-17	10.14	-0.31	-3.41	-6.38	-12.54	87.16	28.0	*1.05*	*8.65*	31.26	*3.40*
Nov-17	-5.89	-17.87	-20.14	-22.26	-33.90	83.46	0.0	*0.45*	*5.47*	5.37	*0.45*
Dec-17	*4.27*	-9.99	-12.29	-14.69	-31.16	86.62	19.8	*1.78*	*12.28*	0.74	*2.00*
Jan-18	6.71	-13.82	-17.19	-20.47	-34.3	82.19	9.6	0.34	12.84	n/a	1.68
Feb-18	-5.60	-16.65	-20.57	-23.82	-33.78	79.90	0.1	0.76	7.80	n/a	1.01
Mar-18	11.19	-4.43	-10.72	-15.56	-28.12	63.15	17.2	1.55	14.32	n/s	7.56
Apr-18	12.56	3.03	-3.89	-10.17	-21.68	50.97	0	1.77	9.28	n/a	15.92

Month	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm) [10]	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
May-18	21.13	12.34	6.27	0.75	-10.64	61.61	67.6	1.75	11.42	n/a	21.96
Jun-18	28.51	17.51	11.52	6.11	2.00	65.23	75.8	1.59	12.21	n/a	21.82
Jul-18	29.01	21.05	14.15	7.91	3.56	59.75	19.7	1.66	10.06	n/a	28.97
Aug-18	26.92	16.04	10.30	6.14	0.26	79.09	110.6	1.47	17.1	n/a	12.32
Sep-18	13.8	10.05	3.27	-1.94	-6.46	63.01	14	1.55	10.73	n/a	6.56
Oct-18	10.85	3.71	-0.94	-4.88	-12.41	72.22	4.23	1.32	10.79	n/a	4.56
Nov-18	2.83	-8.71	-11.52	-14.61	-25.79	89.76	0	0.56	10.49	n/a	0.78
Dec-18[10]	*2.22*	*-6.58*	*-9.49*	*-12.65*	*-19.83*	*85.58*	*0*	*1.22*	*13.45*	n/a	2.63

Notes: *Values in grey italics indicate a partial month*
[1]January 2012 has 25 days of complete wind data
February 2012 has 28 days of complete wind data
March 2012 has 30 days of complete wind data
December 2012 has 15 days of complete wind data
January 2013 has 21 days of complete wind data
February 2013 has 26 days of complete wind data
November 2013 has 24 days of complete wind data
December 2013 has 20 days of complete wind data
January 2014 has 9 days of complete wind data
November 2014 has 23 days of complete wind data
December 2014 has 6 days of complete wind data
January 2015 has 24 days of complete wind data
August 2015 has 28 days of complete wind data
October 2015 has 29 days of complete wind data
November 2015 has 9 days of complete wind data
December 2015 has 0 days of complete wind data
January 2016 has 16 days of complete wind data
November 2016 has 23 days of complete wind data
December 2016 has 22 days of complete wind data

January 2017 has 25 days of complete wind data
October 2017 has 28 days of complete wind data
November 2017 has 19 days of complete wind data
December 2017 has 9 days of complete wind date
[2] June 2011 has 29 days of complete data (station commissioned on June 2)
[3] 16 days of complete rain data
[4] Rainfall recorded at temperatures below zero may be due to snowmelt
[5] 25 days of complete RH data
[6] 18 days of complete solar radiation data
[7] 7 days of complete evapotranspiration data
[8] Evapotranspiration is invalid where wind is invalid
[9]Total precipitation likely underestimated due to partial freezing in snowfall conversion adaptor
[10] Only rainfall reported until October 2013 when a snowfall adaptor was installed

4.2 SURFACE WATER

Christal Creek and Lightning Creek are the two primary and important surface water drainages within the Keno Hill Silver District that have influence on reclamation and closure planning as well as active mine operations. Water quality, flow, aquatic and benthic resources have been extensively studied and documented for Christal and Lightning Creeks as part of the District closure planning and field investigations.

4.2.1 Christal Creek

Christal Creek flows northwest from Christal Lake for approximately 22 km before it flows into the South McQuesten River. Water chemistry and aquatic resources in the creek have been influenced by previous mine and milling operations including tailings deposition and adit discharge. Christal Creek receives treated input water from the Galkeno 900 adit and Galkeno 300 adit, in addition to seepages (surface and groundwater) from workings on the west face of Keno Hill. Although no discharge has occurred from the mill during operations, any treated discharge from the mill and the Flame and Moth mine would be directed to the upper reach of Christal Lake and eventually flow into Christal Creek. Historically, Christal Lake has been a receptor for effluent from various mines including Galkeno 900 and the Mackeno Mill area and Mackeno tailings, contributing to metal loading in Christal Creek.

Monitoring in this watershed begins at Christal Creek before its confluence with Hinton Creek (KV-50) and ends at the mouth of Christal Creek where it enters the South McQuesten River (KV-8). There are no significant tributaries to Christal Creek upstream of Hinton Creek; however, it is unknown to what degree mine-related discharges may have an influence on the drainage above KV-50 as there are known to be historical workings upstream of this sampling location. It is reasonable to assume that water quality at KV-50 reflects some degree of mine-related influence as a result of its proximity to mining areas, but could also reflect naturally mineralized seep areas. Table 4-3 summarizes the surface water monitoring stations on Christal Creek.

Table 4-3 Christal Creek Catchment Surface Water Monitoring Stations

SITE	SITE DESCRIPTION	MONITORING FREQUENCY
KV-6	Christal Creek at Keno Highway	Weekly when discharging/Monthly
KV-7	Christal Creek at Hanson Road	Monthly
KV-8	Christal Creek at mouth	Monthly
KV-48	Hinton Creek u/s Calumet Drive	Quarterly
KV-49	Hinton Creek u/s Christal Creek	Quarterly
KV-50	Christal Creek u/s Hinton Creek	Weekly when discharging/Monthly
KV-51	Christal Creek d/s Hinton Creek	Quarterly
KV-52	Natural spring to Christal Lake at Old Mackeno pumphouse	Monthly
KV-54	Erickson Gulch at Road to Lucky Queen	Quarterly
KV-79	Christal Creek d/s of Mackeno Tailings	Quarterly
KV-80	Christal Creek u/s of Mackeno Tailings	Quarterly

4.2.2 Lightning Creek

Lightning Creek is situated within a narrow valley with a steep gradient flowing from the north side of Sourdough Hill into Duncan Creek, which drains into the Mayo River. Hope and Thunder Gulches flow into Lightning Creek within the bounds of the KHSD. Lightning Creek has also been the site of extensive placer mining upstream of Keno City both historically and at the present time. Mine adit drainages from Bellekeno 625 (north side of Sourdough Hill) and Keno 700 (south side of Keno Hill) eventually report to the Lightning Creek drainage.

Lightning Creek is notable as it is the only large watershed in the KHSD not connected to the South McQuesten River. There are nine regularly monitored sites within the Lightning Creek drainage under Water Licence QZ09-092; eight sites between the background baseline station at KV-37, to the station at the Lightning Creek Bridge near Keno (KV-41), and a recently added site downstream, station KV-81, southwest of the Keno District mill site. Table 4-4 summarizes the surface water monitoring stations along Lightning Creek.

Table 4-4 Lightning Creek Catchment Surface Water Monitoring Stations

SITE	SITE DESCRIPTION	MONITORING FREQUENCY
KV-37	Lightning Creek upstream Hope Gulch	Quarterly
KV-38	Lightning Creek upstream Thunder Gulch	Quarterly
KV-39	Hope Gulch upstream Lightning Creek	Quarterly
KV-40	Charity Gulch upstream Lightning Creek	Quarterly
KV-41	Lightning Creek upstream bridge at Keno City	Monthly
KV-65	Thunder Gulch upstream of Bellekeno	Monthly
KV-76	Thunder Gulch downstream of Bellekeno 625 Adit	Quarterly
KV-77	Thunder Gulch upstream of Bellekeno East	Quarterly
KV-81	Lightning Creek Southwest of Mill Site	Weekly when discharging/Monthly

4.2.3 No Cash Creek

Surface water quality monitoring has been ongoing in the No Cash Creek catchment with regular monitoring occurring at the Bermingham 200 adit (KV-18), Ruby 400 (KV-19), No Cash 500 (KV-20), No Cash Creek at Silver Trail Highway (KV-21), No Cash Creek above the No Cash 500 adit (KV-111), No Cash Creek at Calumet Drive (KV-118) and Star Creek at Silver Trail Highway (KV-56). The water quality in No Cash Creek at KV-21 is dominated by the water quality discharge from the No Cash 500 adit and the natural attenuation processes occurring in this section of the Creek. No Cash Creek flows to the terminal bog and does not have a direct connection to the South McQuesten River.

Table 4-5 No Cash Monitoring Stations

SITE	SITE DESCRIPTION	MONITORING FREQUENCY
KV-18	Bermingham 200 Adit	Quarterly
KV-19	Ruby 400 Adit	Quarterly
KV-20	No Cash 500 Adit	Quarterly
KV-21	No Cash Creek u/s Silver Trail Highway	Monthly
KV-56	Star Creek at Silver Trail Highway	Monthly
KV-111	No Cash Creek above No Cash 500 adit	Monthly
KV-118	No Cash Creek at Calumet Drive	Monthly

Alexco provides regular monitoring data, analysis and discussion of trends in our monthly and annual reports submitted as a condition of WL QZ09-092 and QML-0009.

4.3 GROUNDWATER

Several groundwater monitoring studies have been conducted in the District, primarily around Keno City, and the Dry Stack Tailings and Flame & Moth areas. Groundwater in the Keno City area flows northwest towards Christal Lake. Adit discharge from the Onek 400 portal does not appear to impact groundwater supply wells in Keno City. The Flame & Moth area and Dry Stack Tailings Facility are downgradient of groundwater flow from Keno City, thus mining activities at these sites are not expected to affect groundwater quality beneath Keno City.

A district wide groundwater investigation was initiated in 2013, with single monitoring wells installed at a Keno 700, Sadie Ladue, Onek, Galkeno 900, Galkeno 300, Bermingham, Ruby 400, Husky, Husky SW, and Silver King. Groundwater quality data were collected from these wells which showed elevated concentrations of constituents related to mineralization (sulphate, cadmium, zinc, and arsenic).

4.4 VEGETATION AND WILDLIFE

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 (Lortie, 2009). 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.

4.5 SOIL AND BEDROCK

The Keno Hill Silver District is located in the northwestern part of the Selwyn Basin in an area where the northwest-trending Robert Service Thrust Sheet and the Tombstone Thrust Sheet overlap. The area is underlain by Upper Proterozoic to Mississippian rocks that were deposited in a shelf environment during the formation of the northern Cordilleran continental margin. The area underwent regional compressive tectonic stresses during the Jurassic and the Cretaceous, producing thrusts, folds and penetrative fabrics of various scales.

The Robert Service Thrust Sheet in the south is composed of Late Proterozoic to Devonian clastic sandstone, minor limestone, siltstone, argillite, chert, and conglomerate. The Tombstone Thrust Sheet to the north consists of Devonian phyllite, felsic meta-tuffs and metaclastic rocks, overlain by Carboniferous quartzite, which is the main host for the silver mineralization in the Keno Hill camp.

Except for a few localized areas, the soils are not strongly weathered or deeply leaching. They also exhibit a poor profile development, particularly those underlain by permafrost. The soils in the area can be conveniently classified into two general types: 1) residual and 2) muck peat/half bog. Residual soils were formed principally from the weathering of the various types of bedrocks, or as is evident in some places, from the decomposition of a till that predates the last glaciation.

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.

Soil and bedrock considerations in reclamation and closure planning are importantly linked to long-term geotechnical stability of the DSTF foundation. Design criteria for the DSTF considers the potential for permafrost degradation over time.

5. PROJECT DESCRIPTION

5.1 HISTORY

The Keno Hill Silver District is located in central Yukon (63° 54' 32" N, 135° 19’ 18” W; NTS 105M/14 & 105M/13), 354 km due north of Whitehorse. Access to the property is via the Alaska, Klondike and Silver Trail Highways from Whitehorse to Mayo (407 km) and an all-weather gravel road northeast from Mayo to Elsa (45 km); a total distance of 452 km. Figure 1-1 shows the location of the Keno Hill Silver District and Mine Operations.

The Keno Hill Silver District and mining operations has a rich history of exploration and mining with 21 deposits having documented silver production in excess of 3,110 kilograms (100,000 ounces). Silver was first found in 1901 but small-scale mining only began during 1913. High silver prices at the end of the First World War led to renewed and ultimately successful exploration activity in the area. Since then, at least 65 deposits and prospects have been identified within the area. Many small silver deposits were mined independently of each other, throughout the area between 1914 and 1925.

The Treadwell Yukon Company Limited (TYCL) in 1925 consolidated a number of small mines and properties in the area. TYCL continued to be the dominant company in the mining camp until it ceased operations in 1942 upon the untimely death of its founder, Livingston Wernecke.

Keno Hill Mining Company Limited (KHM) acquired the interests formerly controlled by TYCL in 1945. KHM was reorganized in November 1947 as United Keno Hill Mines Limited (UKHM) and by 1958 UKHM had acquiring several properties, interests in properties and other companies, including the assets of Galkeno Mines Limited and Canadian Northwest Mines and Oil.

Ventures Limited (later Falconbridge Nickel Mines Limited and Falconbridge Limited) acquired a controlling interest in the UKHM in 1960 when it merged with Frobisher Limited and acquired the Conwest interest. Falconbridge Nickel Mines Ltd. acquired 48.2% of UKHM in 1962 and assumed management control of UKHM.

UKHM ceased all production in the area in 1989 and placed the active mines on care and maintenance, but continued to conduct limited underground exploration and development at the Bellekeno and Silver King mines. On Feb 18, 2000, UKMH was granted bankruptcy protection with PricewaterhouseCoopers Inc. being court-appointed as the interim receiver and receiver-manager of UKMH in 2001.

In June 2005, Alexco was selected as the preferred purchaser of the assets of UKHM by PricewaterhouseCoopers Inc. In February 2006, Alexco's purchase of UKHM's assets through a wholly-owned subsidiary, Elsa Reclamation & Development Company Ltd. (ERDC), was approved. Under the Keno Hill Amended and Restated Subsidiary Agreement, Alexco and ERDC are indemnified against all historical liability, has property access for exploration and future development, and is not required to post security against pre-existing liabilities. ERDC received a water license from the Yukon government in November 2007, giving Alexco free and clear title to surface and subsurface claims, leases, free-hold land, buildings and equipment at Keno Hill. Since Alexco acquired the assets of the Keno Hill Silver District, the following major milestones have been achieved:

2006 - 2008: Alexco acquires KHSD and begins aggressive surface exploration programs, focus on expansion of Bellekeno resource;

2009: Underground development and construction at Bellekeno begins;

2010: Comprehensive Cooperation and Benefits Agreement (CCBA) signed with First Nation of Nacho Nyak Dun (FNNND). Construction of mill and surface facilities begins;

2011: Production at Bellekeno mine and Keno District Mill. Surface exploration at Flame and Moth begins;

2012: Development and rehab of Lucky Queen adit. Development of new Onek decline;

2013: Temporary suspension of Bellekeno mine operations and milling, district care and maintenance;

2014 – 2018: Permitting and development of Flame and Moth mine. Continued surface exploration, advanced underground exploration decline at Bermingham deposit. Decline development at Flame and Moth mine. Care and maintenance and water treatment.

The Keno Hill Silver District and Mine Operations are located on and around Galena Hill, Keno Hill and Sourdough Hill and are collectively known as the Keno Hill Silver District. The property lies along the broad McQuesten River valley with three prominent hills to the south of the valley. 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 (DSTF) located at the Keno District Mill site for the processing and production of minerals from the active, developed and future underground deposits including Bellekeno, Lucky Queen, Onek, Flame and Moth and Bermingham. The RCP incorporates underground mines and deposits that are in a variety of phases including active mines (Bellekeno), permitted and developed (Lucky Queen, Onek), permitted and under development (Flame and Moth) and future mines that are in the permitting and development phase (Bermingham). Table 5-1 presents an overview of the Keno Hill Mine Operations project that is subject to this RCP.

Table 5-1 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, Lucky Queen, Flame and Moth and Bermingham deposits. Two Fee Simple lots within KHSD total 59 ha (Lot 960 and Lot 956)
Mines/Ore Deposits	Bellekeno (Active 2010 – 2013, suspended 2013) Lucky Queen, Onek (permitted, developed, not active) Flame and Moth (permitted, under development) Bermingham (permitted for advanced exploration)
Mining Method	Year round underground narrow vein cut and fill/long hole mining

Current Mine(s) Plan Life	8 years including initial development
Current Total Project Life	8 years construction/development/operations/progressive reclamation 2 year final decommissioning and reclamation 10 years closure monitoring and maintenance.
Ore Production Rate	400 tonnes/day (annual average), across 4 mines/deposits (Bellekeno, Lucky Queen, Flame and Moth, Bermingham) ~1,300,000 tonnes of ore in LOM plan
Mine Waste Rock	786,000 tonnes of waste rock produced from underground development, 443,500 tonnes backfilled underground
Ore Mining Schedule	Ore mining for 365 days/year Milling operations 365 day/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 backfill.
Work Force	~ 175 employees and contractors during active mine operations
Airstrip	Mayo, YT
Power	Hydro grid power Yukon Energy, diesel power backup
Water Supply and Use	Water use and discharge within 3 drainages, No Cash Creek, Lightning Creek and Christal Creek. Conventional lime precipitation water treatment at Bellekeno 625, Flame and Moth, Bermingham
First Nations	First Nation of Na-Cho Nyak Dun

5.2 MINING AND MILLING OPERATIONS

5.2.1 Project Schedule

The Life of Mine (LOM) Plan that forms the basis of the RCP represents the current plan for development and production of the Keno Hill Mine Operations as per the March 2017 PEA. Mine operating plans are continuously reviewed and optimized depending on a variety of factors including metals prices, exchange rates, underlying operating costs (fixed and variable), ore grades, etc. As these and other factors change, both positively and negatively, ore production profiles from each of the mines will change. The Keno Hill Mine Operations are unique in terms of mine planning as they consist of a series of small underground mines. Depending on the various parameters, mines may come in and out of the LOM plan as factors change.

The historic mine operations that operated in the Keno Hill Silver District consisted of multiple smaller underground narrow vein mines that provided ore to a centralized mill. Alexco is operating in a similar approach whereby more than one underground mine is necessary to provide ample mill feed to a centralized mill (Keno District Mill). The Keno District Mill is designed for 400 tpd and the current LOM mine plan includes a combination of Bellekeno, Flame and Moth, Bermingham and Lucky Queen operating over an 8 year period. Table 5-2 presents the current LOM plan that is the basis for the RCP. The LOM plan assumes that recommencement of mine development and operations would begin in 2018.

Table 5-2 Keno Hill Mine Operations LOM Plan

Consolidated Mine Plan		2018	2019	2020	2021	2022	2023	2024	2025
Ore Tonnes	1,021,053	64,683	145,992	145,992	145,992	145,992	111,715	142,344	118,343
Development Meters (Ramp, Level Access, Vent Drive, Sump/pump)	9,305	3,264	1,729	844	1,294	311	1,466	397	-
Access Drift Meters (xcut)	9,070	741	1,768	1,666	1,507	985	922	740	741
Cut & Fill Meters	14,190	903	2,517	2,602	2,382	1,387	1,321	1,490	1,588
LH Meters	885	185	-	-	-	230	150	220	100
Raise Meters	984	272	316	76	113	-	208	-	-
Development Tonnes (Ramp, Level Access, Vent Drive, Sump/pump)	364,940	143,860	76,923	36,414	56,829	12,579	34,900	3,435	-
Access Drift Tonnes (xcut)	368,477	31,032	73,683	69,170	62,622	40,678	49,427	18,362	23,503
LH Tonnes	235,231	5,084	-	-	2,856	63,905	48,204	85,287	29,895
Cut & Fill Tonnes	724,741	59,600	146,082	146,082	143,136	82,087	60,741	20,403	66,610
Raise Tonnes (tonnes/m)	19,670	6,491	7,517	1,804	2,695	5	1,149	5	5
Waste Rock Broken (tonnes)	730,781	187,292	160,554	107,790	122,547	53,256	65,782	10,057	23,503
Backfill Required	649,916	37,148	90,242	93,612	90,859	96,124	98,375	80,744	62,810

Table 5-3 LOM Plans for Individual Mines

Bellekeno	Total	2018	2019	2020	2021	2022	2023	2024	2025
Ore Tonnes	37,144	37,144	-	-	-	-		-	-
Ag, gpt	747	747	-	-	-	-	-	-	-
Au, gpt		-	-	-	-	-	-	-	-
Pb, %	10.55	10.55	-	-	-	-	-	-	-
Zn, %	5.88	5.88	-	-	-	-	-	-	-
Development Meters (Ramp, Level Access, Vent Drive, Sump/pump)	-	-	-	-	-	-	-	-	-
Access Drift Meters (Xcut)	52	52	-	-	-	-	-	-	-
Cut & Fill Meters	396	396	-	-	-	-	-	-	-
LH Meters	185	185	-	-	-	-	-	-	-
Raise Meters	-	-	-	-	-	-	-	-	-
Development Tonnes (Ramp, Level Access, Vent Drive, Sump/pump)	-	-	-	-	-	-	-	-	-
Access Drift Tonnes (Xcut)	2,279	2,279	-	-	-	-	-	-	-
LH Tonnes	5,084	5,084	-	-	-	-	-	-	-
Cut & Fill Tonnes	32,061	32,061	-	-	-	-	-	-	-
Raise Tonnes (tonnes/m)	-	-	-	-	-	-	-	-	-
Waste Rock Broken (tonnes)	2,279	2,279	-	-	-	-	-	-	-
Backfill Required	21,904	21,904	-	-	-	-	-	-	-

Flame & Moth		2018	2019	2020	2021	2022	2023	2024	2025
Ore Tonnes	682,921	20,328	94,896	94,896	94,896	94,896	94,896	94,896	93,217
Ag, gpt	666	678	743	743	703	500	687	588	693
Au, gpt	0.50	0.31	0.44	0.56	0.59	0.39	0.47	0.54	0.54
Pb, %	2.75	2.58	2.86	2.70	3.00	2.09	3.76	1.88	2.98
Zn, %	5.78	6.71	5.62	6.21	6.45	6.90	5.12	4.30	5.63
Development Meters (Ramp, Level Access, Vent Drive, Sump/pump)	5,803	2,288	1,283	202	902	285	775	68	-
Access Drift Meters (X-cut)	4,554	536	1,007	691	635	464	498	159	564
Cut & Fill Meters	7,840	397	1,556	1,570	1,494	595	898	298	1,032
LH Meters	700	-	-	-	-	230	150	220	100
Raise Meters	433	88	222	26	50	-	48	-	-
Development Tonnes (Ramp, Level Access, Vent Drive, Sump/pump)	260,222	102,884	58,120	9,316	40,069	12,142	34,256	3,435	-
Access Drift Tonnes (Xcut)	189,816	22,420	42,121	28,765	26,381	19,234	20,770	6,622	23,503
LH Tonnes	210,458	-	-	-	2,856	63,905	42,597	74,493	26,607
Cut & Fill Tonnes	472,643	20,328	94,986	94,986	92,040	30,991	52,299	20,403	66,610
Raise Tonnes (tonnes/m)	10,322	2,105	5,279	613	1,181	-	1,144	-	-
Waste Rock Broken (tonnes)	469,576	132,567	107,956	39,099	68,037	31,375	56,981	10,057	23,503
Backfill Required	422,675	10,866	59,973	61,613	56,725	57,250	58,263	57,932	60,053

Bermingham		2018	2019	2020	2021	2022	2023	2024	2025
Ore Tonnes	220,037	7,211	51,096	51,096	51,096	51,096	8,442	-	-
Ag, gpt	1,276	2,591	1,732	1,245	945	1,019	1,142	-	-
Au, gpt	0.20	0.25	0.21	0.18	0.19	0.20	0.22	-	-
Pb, %	4.09	7.69	4.08	3.74	3.96	4.22	3.18	-	-
Zn, %	2.05	2.19	2.53	1.91	1.79	2.01	1.59	-	-
Development Meters (Ramp, Level Access, Vent Drive, Sump/pump)	2,513	976	446	642	392	26	31	-	-
Access Drift Meters (xcut)	3,404	153	761	975	872	521	122	-	-
Cut & Fill Meters	3,964	110	961	1,032	888	792	181	-	-
LH Meters	-	-	-	-	-	-	-	-	-
Raise Meters	391	184	94	50	63	-	-	-	-
Development Tonnes (Ramp, Level Access, Vent Drive, Sump/pump)	104,718	40,976	18,803	27,098	16,760	437	644	-	-
Access Drift Tonnes (xcut)	141,165	6,333	31,562	40,405	36,241	21,444	5,180	-	-
LH Tonnes	-	-	-	-	-	-	-	-	-
Cut & Fill Tonnes	220,037	7,211	51,096	51,096	51,096	51,096	8,442	-	-
Raise Tonnes (tonnes/m)	9,310	4,381	2,233	1,187	1,509	-	-		-
Waste Rock Broken (tonnes)	255,949	52,446	52,598	68,690	54,509	21,881	5,824		-
Backfill Required	147,115	4,378	30,270	31,999	34,134	38,874	7,461		-
Lucky Queen		2018	2019	2020	2021	2022	2023	2024	2025
Ore Tonnes	80,951	-	-	-	-	-	8,377	47,448	25,126
Ag, gpt	1,206	-	-	-	-	-	977	1,259	1,184
Au, gpt	0.12	-	-	-	-	-	0.13	0.13	0.11
Pb, %	2.63	-	-	-	-	-	1.85	2.72	2.72
Zn, %	1.32	-	-	-	-	-	2.53	1.21	1.13
Development Meters (Ramp, Level Access, Vent Drive, Sump/pump)	989	-	-	-	-	-	660	329	-
Access Drift Meters (Xcut)	1,060	-	-	-	-	-	302	581	177
Cut & Fill Meters	1,990	-	-	-	-	-	242	1,192	556
LH Meters	-	-	-	-	-	-	-	-	-
Raise Meters	160	-	-	-	-	-	160	-	-
Slashing Meters	-	-	-	-	-	-	-	-	-
Development Tonnes (Ramp, Level Access, Vent Drive, Sump/pump)	35,217	-	-	-	-	-	23,477	11,740	-
Access Drift Tonnes (Xcut)	19,689	-	-	-	-	-	5,607	10,794	3,288
LH Tonnes	-	-	-	-	-	-	-	-	-
Cut & Fill Tonnes	80,951	-	-	-	-	-	8,377	47,448	25,126
Raise Tonnes (tonnes/m)	2,977	-	-	-	-	-	2,977	-	-
Waste Rock Broken (tonnes)	58,221	-	-	-	-	-	32,652	22,812	2,757
Backfill Required	60,544	-	-	-	-	-	7,085	36,909	16,550

Table 5-4 Keno Hill Mine Operations LOM Plan Decommissioning and Reclamation Plan Closure Schedule															
Phase / Activity	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028 → 2037
	Suspension/CM				**Mine Development/Operations**								**Active Closure**		**Post Closure Monitoring and Maintenance**
Progressive Reclamation															
Closure and Reclamation Optimization/Research															
Bellekeno Production Unit Area															
- Underground Development/Operations	**Suspension/CM**														
- Reclaim Bellekeno East Portal Site															
- Reclaim Bellekeno 625 Adit Site															
- Bulkhead 625 Installation															
- Bellekeno Mine Flooding and Insitu Treatment															
- Bellekeno 625 Bioreactor Construction/Operation															
- 200 Level Vent Raise															
Flame and Moth Production Unit Area															
- Underground Development/Operations															
- Portal Closure															
- Mine Flooding/In Situ Treatment															
- Vent Raise															
Lucky Queen Production Unit Area															
- Underground Development Operations															
- Reclaim Lucky Queen 500 Level Portal Site															
- Vent Raise															
Onek Production Unit Area															
- Underground Development Operations															
- Reclaim Onek 990 Portal Area															
- Vent Raise															
Bermingham Production Unit Area															
- Underground Development/Operations															
- Portal Closure															
- Mine Flooding/In Situ Treatment															
- 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															
- Christal Lake Road															
- Bermingham Access Road															
- Other Roads and Trails															
Camp Downsize															
Mill & Facilities															
- Active Milling Operations	**Suspension/CM**														
- Mill and Ancillary Facilities															
- Mill Pad															
- Ore/Tailings Stockpile Pads															
- Runoff Collection Pond(s)															
- Diversion Ditches to Collection Pond															
Dry Stack Tailings Facility Cover															
- Progressive Reclamation															
- Final Cover Reclamation															
Closure Site Management (monitoring & maintenance)															

Active Operations
Reclamation and Closure
Water Treatment/Management

5.2.2 Mining Methods

The mining methods employed at the underground mines associated with the Keno Hill Mine Operations are common and well proven mining methods and are selected based on deposit geometries, geotechnical conditions, production rates and other constraints. The mining methods are predominantly longhole and cut and fill and a brief description of the mining methods used are further summarized.

Cut and Fill (CF) mining is a method of short hole mining used in a wide range of deposit geometries. There are two main methods of cut and fill (CF) mining; overhand cut and fill (OCF) and underhand cut and fill (UCF). In the case of Flame and Moth, only OCF is anticipated.

OCF typically uses uncemented fill and mining begins at the bottom of a mining block and advances in "slices" of "lifts" upwards. Stoping begins from an access ramp driven off the main level to the bottom of the mineralized zone to be accessed. Using development mining techniques, a drift is driven through the mineralized zone to the defined limit of mining. Upon completion, the drift (or "cut") is filled with cemented back-fill, which would consist of tailings or waste rock. Once the stope is filled the ore access off the main haulage ramp is driven down to access the next lift on top of filled cut. This process continues until the top of the stope is reached. See Figure 5-1 for a typical CF schematic. The majority of ore mined from the Bellekeno mine to date has been through OCF and cemented rock fill mining methods and is well demonstrated.

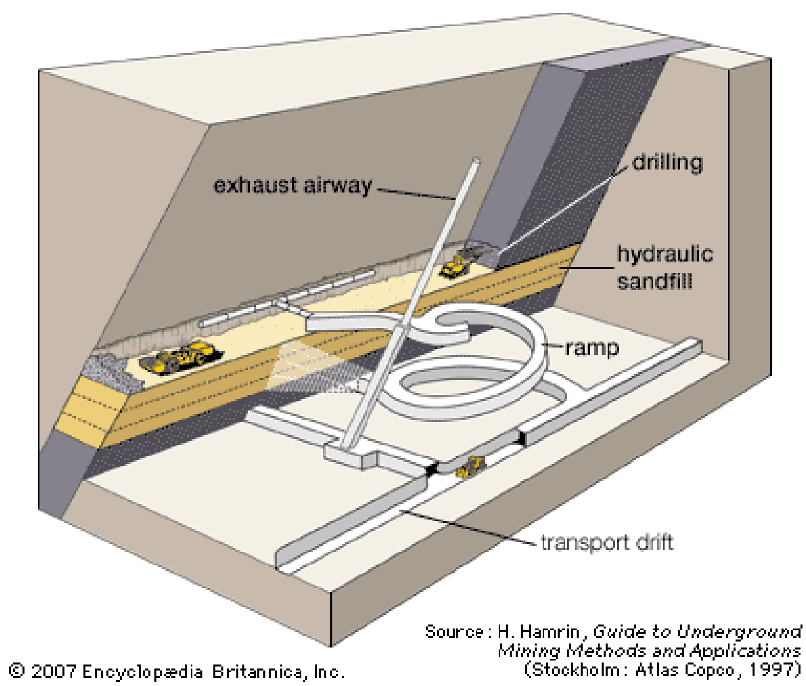


Figure 5-1 Overhand, Mechanized Cut & Fill Mining Methods (Source: Atlas Copco)

Long hole stoping ("LH") is normally used where large blocks of continuous mineralization can be identified and the surrounding rock is reasonably strong (Figure 5-2). Access to the top and bottom of the mineralized block is provided with drifts. A vertical opening (slot raise) is created within the stope block from the top of the block to the bottom. Long holes are drilled to blast vertical slabs off the mineralized block which is then scooped from a lower drawpoint by an LHD loader.

The depth on blast holes in the production sequence will be approximately 10-15 metres long. Blind raises or slot raises will be drilled with the LH drill unit, blasted and the stope block will be retreated out by drilling and blasting successive rings. Typically, LH blocks will be pulled last unless they are in an area that would not conflict with ongoing operations. They could also be filled if they are located too close to mine infrastructure.

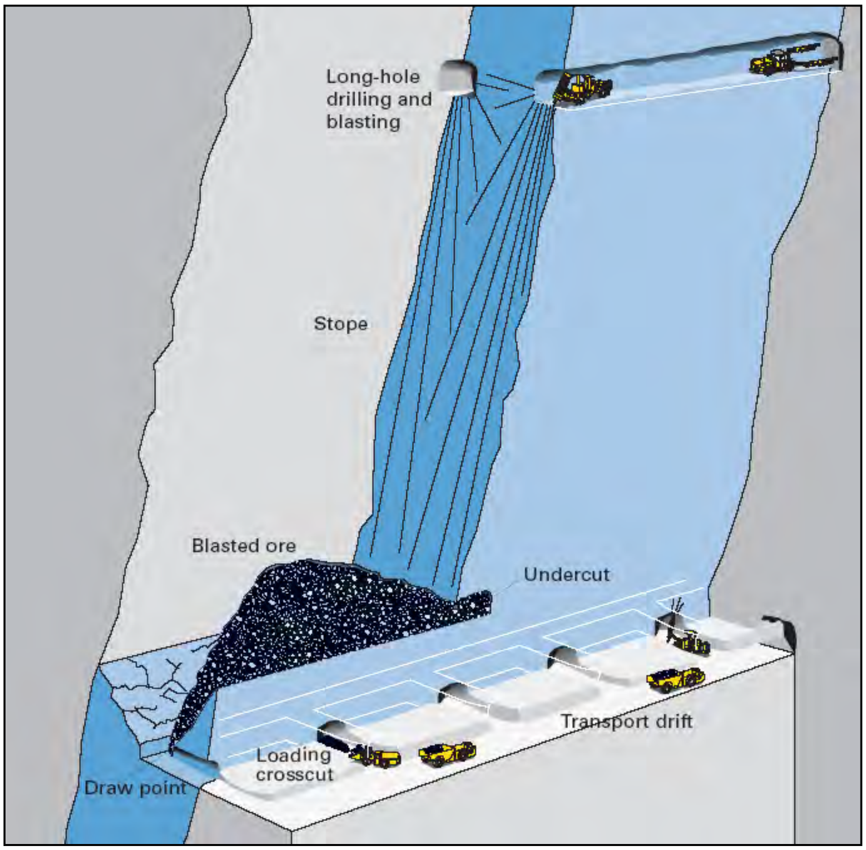


Figure 5-2 Long Hole Mining Method (Source: Atlas Copco)

5.2.3 Backfill

Backfill materials consisting of development waste rock (N-AML and P-AML) and dry filtered tailings are placed into empty stopes by Load Haul Dump (LHD) or 15-tonne trucks. The mix of these materials is flexible and vary be each mine to minimize the surface environmental impact while optimizing the most efficient and cost effective back filling sequence. For cut and fill stopes, the backfill will be pushed up tight to the back using an LHD equipped with a rammer jammer.

Cemented backfill at approximately 5% cement by weight will be used in longhole stopes. The cement, rock and water will be mixed by LHD bucket in a small sump-like cut out near the empty stope. Cement will be transported underground in bulk bags.

All waste rock will be inspected and tested as per the updated Waste Rock Management Plan, which segregates all waste rock as either potentially acidic/metal leaching (P-AML) or not (N-AML).

Cemented Tailings/Waste Rock Backfill

Cemented tails and waste rock back fill are the preferred backfill methods. Where sill pillars are required, a cemented fill will be used to provide a stable back to mine up to from beneath. Extraction of the vein from the final lift requires that the pillar is self-supporting and maintains integrity while the heading is active. The quality and the placement of the fill are both important factors in this application. An increased cement content of between four and five percent will be required to provide the required strength of the pillar. In areas where additional caution is required during final lift extraction, the lift will be mined using up-holes and remote mucking.

Careful preparation of the excavation where cemented fill is to be placed will be required, including blasting beyond the vein contacts to provide a clean, rough surface for the fill to hang on. The floor should be cleaned prior to placement to prevent material falling from the back following mining. An appropriate lead time should be provided to allow set-up and cure for the cemented fill. Standard quality control procedures (e.g. unconfined compressive strength and slump tests) should be completed during batching and following placement of cemented tailing fill materials. Table 5-2 summarizes the amount of backfill required during the LOM Plan schedule.

5.2.4 Ground Control

A third party geotechnical ground control management plan (GCMP) was developed for the Bellekeno mine (SRK 2009) and is updated to reflect site specific conditions at each new mine as necessary. The GCMP addresses underground geotechnical stability and the required ground control measures to be used to ensure safe working conditions and the long term stability of underground infrastructure. Crown pillar thicknesses have been assessed at each mine to address potential for surface subsidence and ground classes have been defined for the development headings. Mine infrastructure has been designed to avoid areas with potential poor ground conditions and the support is designed to provide long term stability.

In addition to the ground support designs in waste development headings, stopes are backfilled with cemented waste rock and/or filtered tailings. The combination of stope backfilling and the ground control management plan and measures addresses any concerns with long term underground stability and subsidence that needs to be considered in the RCP.

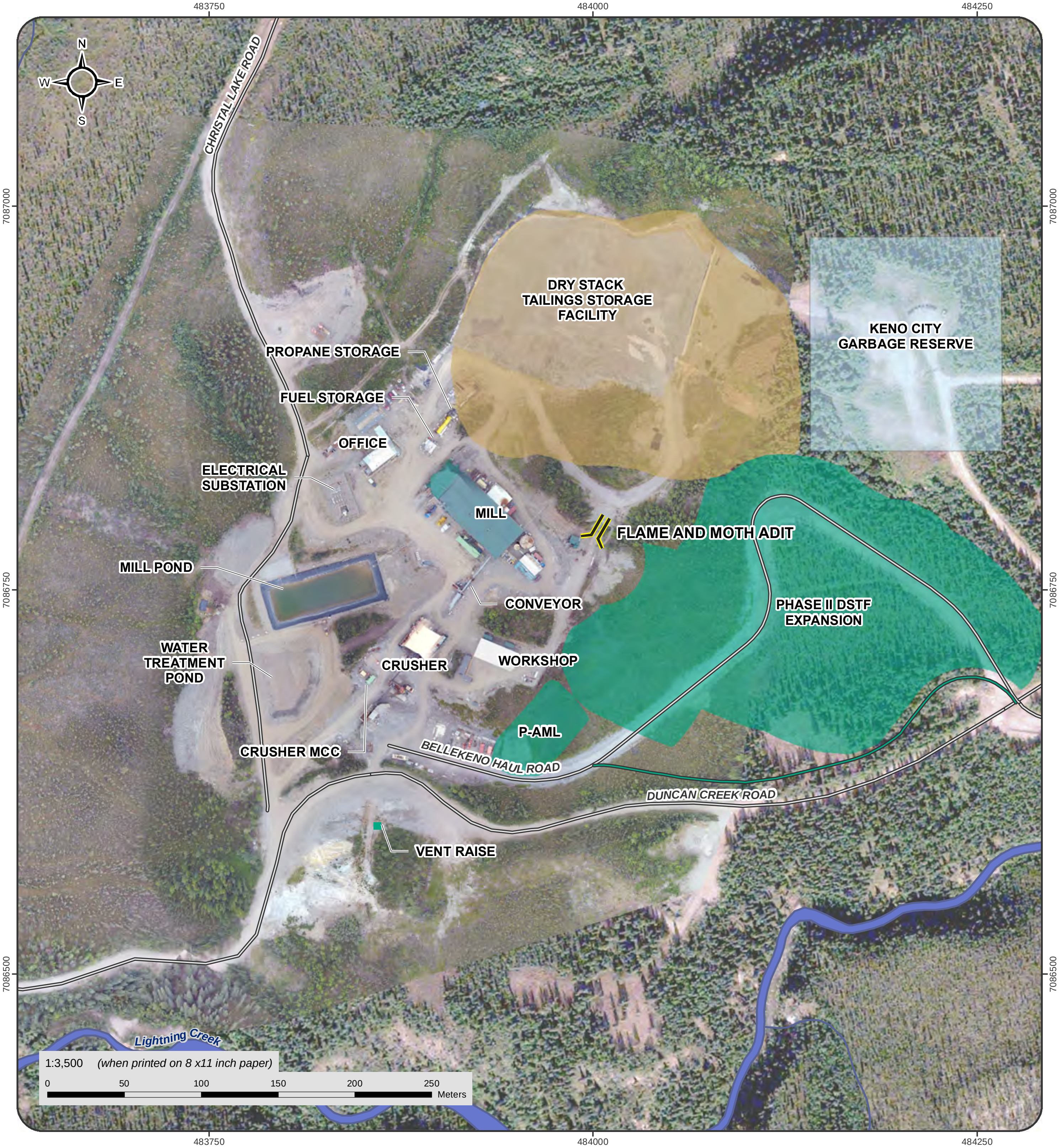
5.2.5 Milling Process Description

The Keno District Mill is a conventional differential flotation facility producing two separate metal concentrates that are shipped offsite for final processing. Preparatory construction including the mill concrete foundation began in September 2009 while full scale construction of the mill facilities began in earnest in April 2010 and initial mill commissioning commenced in December 2010. An overview of the District Mill and supporting infrastructure is shown in Figure 5-3.

Figure 5-3 District Mill Infrastructure Overview

Mill Design Criteria

The overall mill site layout is shown in Figure 5-4. Design criteria for the mill operations are summarized in Table 5-5.



Current DSTF
DSTF 322k Tonnes Design
To Be Constructed Features

Adit
Road
Proposed Road
Watercourse

AKHM

AEG

KENO DISTRICT MINE OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 5-4
DISTRICT MILL AND
FLAME AND MOTH LAYOUT

JULY 2018

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on February 2018

Datum: NAD 83; Projection: UTM Zone 8N

D:\Project\AllProjects\Keno_Area_Mines\ALL-SITES\02-Map\01_Overview\02-District Mill\F_M_letter_20180129.mxd
(*Last edited by: amatlashevska; 12/02/2018/15:02 PM*)

Table 5-5 District Mill Design Criteria

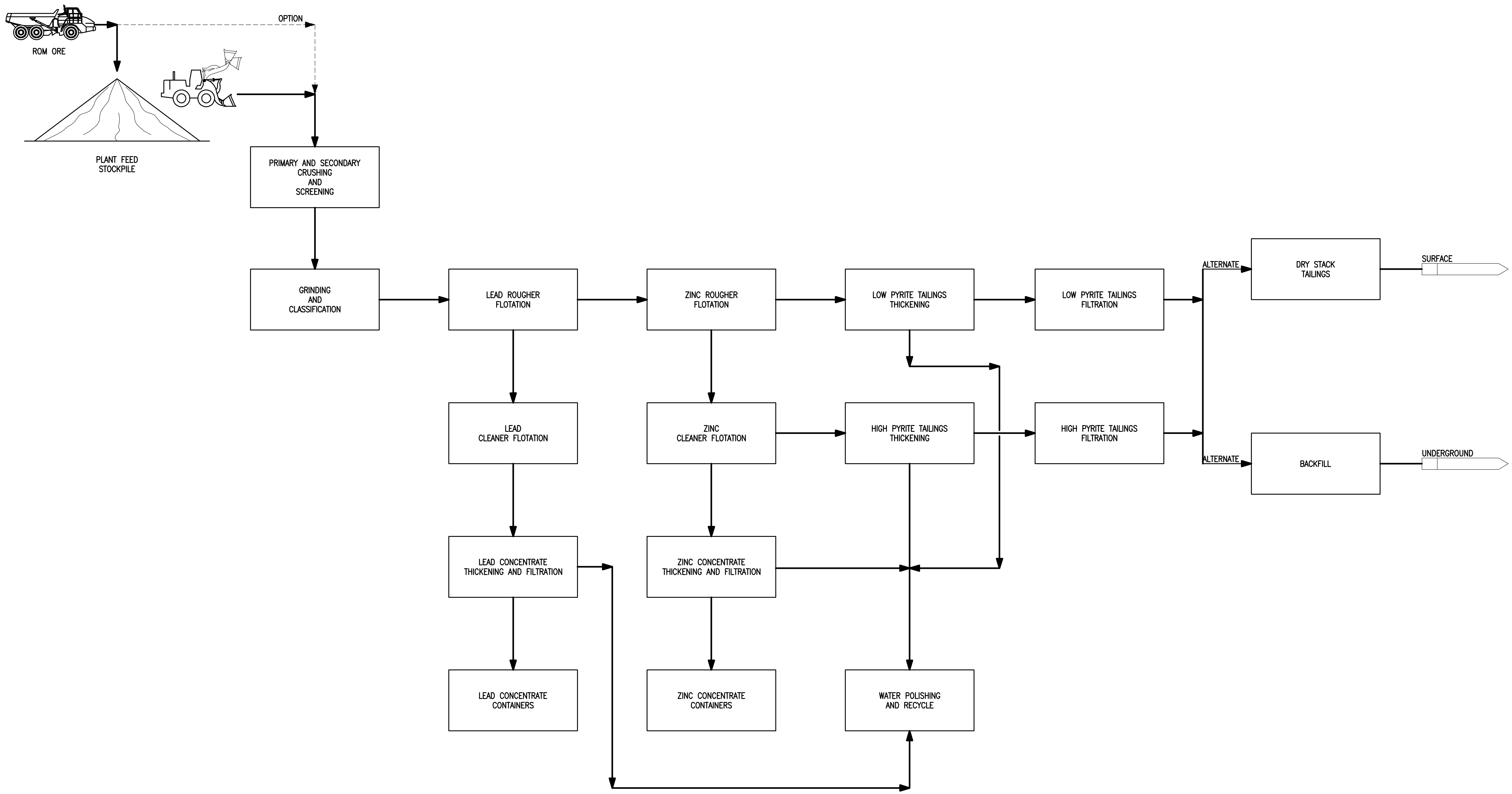
Description	Unit	Value
Type of Ore Processed		
Silver/Lead/Zinc sulphide mineralization Bellekeno/Lucky Queen/ Onek Mines		
Ore Characteristics		
Specific Gravity	g/cm³	3.46
Bulk Density	t/m³	2.1
Moisture Content	%	3-5
Operating Schedule		
Crusher Plant		
Shift/Day		1
Hours/Shift	h	12
Hours/Day	h	12
Grinding and Flotation Plant		
Shift/Day		2
Hours/Shift	h	12
Hours/Day	h	24
Days/Year	day	365
Plant Availability/Utilization		
Overall Plant Feed	mt/a	149,000
Overall Plant Feed	mt/d	250 - 400
Crusher Plant Availability	%	80.0
Grinding and Flotation Plant Availability	%	92.0
Crushing Process Rate	mt/h	63.8
Grinding/Flotation Process Rate	mt/h	18.5
Head Grades (LOM)	% Pb	2 - 10
	% Zn	3 -12
	g/t Au	0.25 – 0.5
	g/t Ag	500 – 1,250
Recovery (LOM)	Pb %	93
	Zn %	75
Recovery (LOM) including in Pb & Zn concentrates	Au %	70
Recovery (LOM) including in Pb & Zn concentrates	Ag %	92
Silver-Lead Concentrate Grade (LOM)	% Pb	65
	% Zn	2.3
	g/t Au	1.5
	g/t Ag	5,500
Zinc Concentrate Grade (LOM)	% Pb	0.5
	% Zn	45
	g/t Au	1.1
	g/t Ag	300
Silver-Lead Concentrate Mass Recovery (LOM)	%	13
Silver-Lead Concentrate Production (LOM)	t/a	12,000
Zinc Concentrate Mass Recovery (LOM)	%	9
Zinc Concentrate Production (LOM)	t/a	8,000

5.2.6 Process Overview

The Keno District Mill consists of the following process circuits;

- primary and secondary crushing circuits with a belt conveyor to transport the crushed ore to the covered fine ore stockpile;
- fine ore reclaim system feeding crushed ore from the covered fine ore stockpile;
- primary and secondary ball milling in a closed circuit with a high frequency screen and cyclone to produce a grinding product of 80% passing 174 µm;
- the ground high frequency screen underflow feeding to lead rougher scavenger flotation circuit to recover lead and silver minerals; the lead rougher flotation concentrate being upgraded in three stages of cleaner flotation;
- the zinc rougher flotation concentrate being upgraded in three stages of cleaner thickening and pressure filtration of the lead and zinc concentrates; and
- thickening and pressure filtration of tailings, disposed either at underground as backfill or at the surface dry stack tailings facility.

The mill process flowsheet is presented in Figure 5-5.



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DWG. NO.	REFERENCE DRAWINGS

REV. No.	ISSUE No.	DESCRIPTION	DATE	BY
D	1	ISSUED FOR INFORMATION	15JUN10	JPR
C	1	ISSUED FOR CLIENT APPROVAL	29JAN10	CC
B	1	ISSUED FOR INFORMATION	09JUL09	AKF
A	1	ISSUED FOR CLIENT REVIEW	21MAY09	CC

CLIENT | PRO.MAN. | PRO.ENG. | PROCESS | ELECTR. | INSTR. | PIPING | MECH. | STRUCT. | SERVICES | ARCH. | LAYOUT

		DATE
SECTION:	PROCESS	
SCALE:	NONE	
DESIGN. BY:	RA	25MAR09
DRAWN BY:	PH	25MAR09
CHECK. BY:		
APP. BY:		

YUKON TERRITORY

ALEXCO

WARDROP Engineering Inc.

TITLE

BELLEKENO PROJECT (EP)

SIMPLIFIED FLOWSHEET
PROCESS FLOWSHEET No.1

Figure 5-5

FILENAME	PROJECT NUMBER	DRAWING NUMBER	REV.
A0009001.DWG	09539602.00	A00-09-001	D

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A1

U:\A-G\ALEXCO RESOURCE CORP – 5396\09539602.00 – BELLEKENO PROJECT (EP)\09-PROCESS\PFD\A0009001.DWG

5.3 DRY STACK TAILINGS FACILITY

Alexco employs Dry Stack Tailings technology for management and longterm storage of tailings. Following dewatering through plate and frame filter presses located inside the mill building, the tailings (~10% M) are deposited onto a storage location outside the mill building via a conveyor belt. The tailings stockpile has a live capacity of approximately 4 – 6 hours and on a periodic basis the tailings are rehandled and loaded into a 30-tonne articulating haul truck and transported to the DSTF (or alternatively to the underground mines for use as underground paste backfill and cemented tailings). A photo of the placement of tailing lift on the DSTF is shown in Figure 5-6. The detailed design of the DSTF phase I is presented in Figure 5-7 and Figure 5-8.

The dewatered tailings are transported onto a liner system designed to capture any residual porewater that may leave the pile. The tailings are laid down in 0.5 meter lifts and compacted with a vibratory roller compactor.

Figure 5-6 Compacted DSTF Lift

The DSTF will be developed in phases. Phase 1 of the DSTF footprint has a current design capacity of 322,000 tonnes. Once Phase 1 is exhausted, the DSTF will be expanded in an adjacent area near the mill (Phase 2) and will accommodate the remaining tailings that are generated during the LOM plan. The design for Phase 2 (not yet constructed) is shown in Figure 5-9.

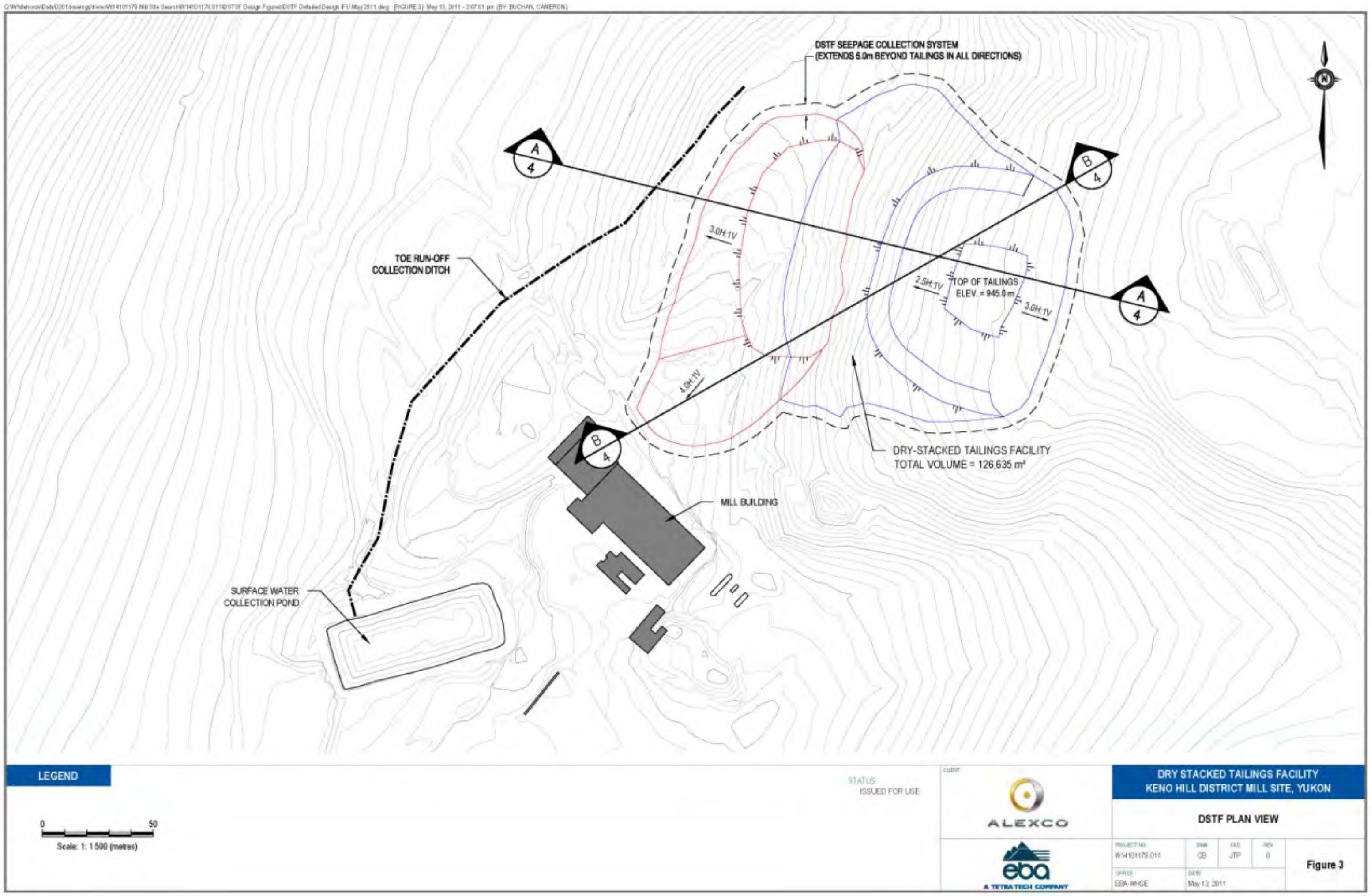


Figure 5-7 DSTF Phase I Plan View

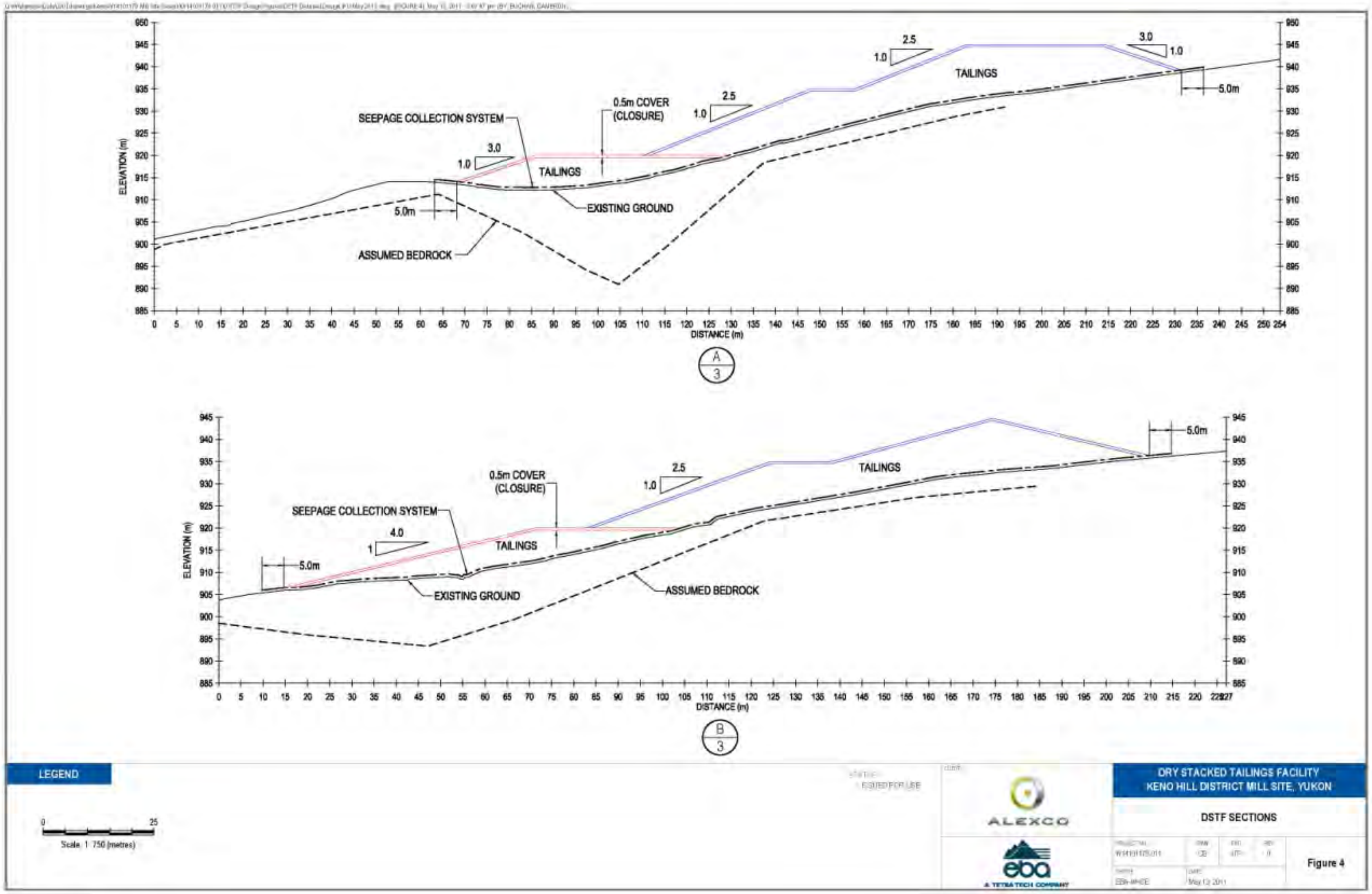
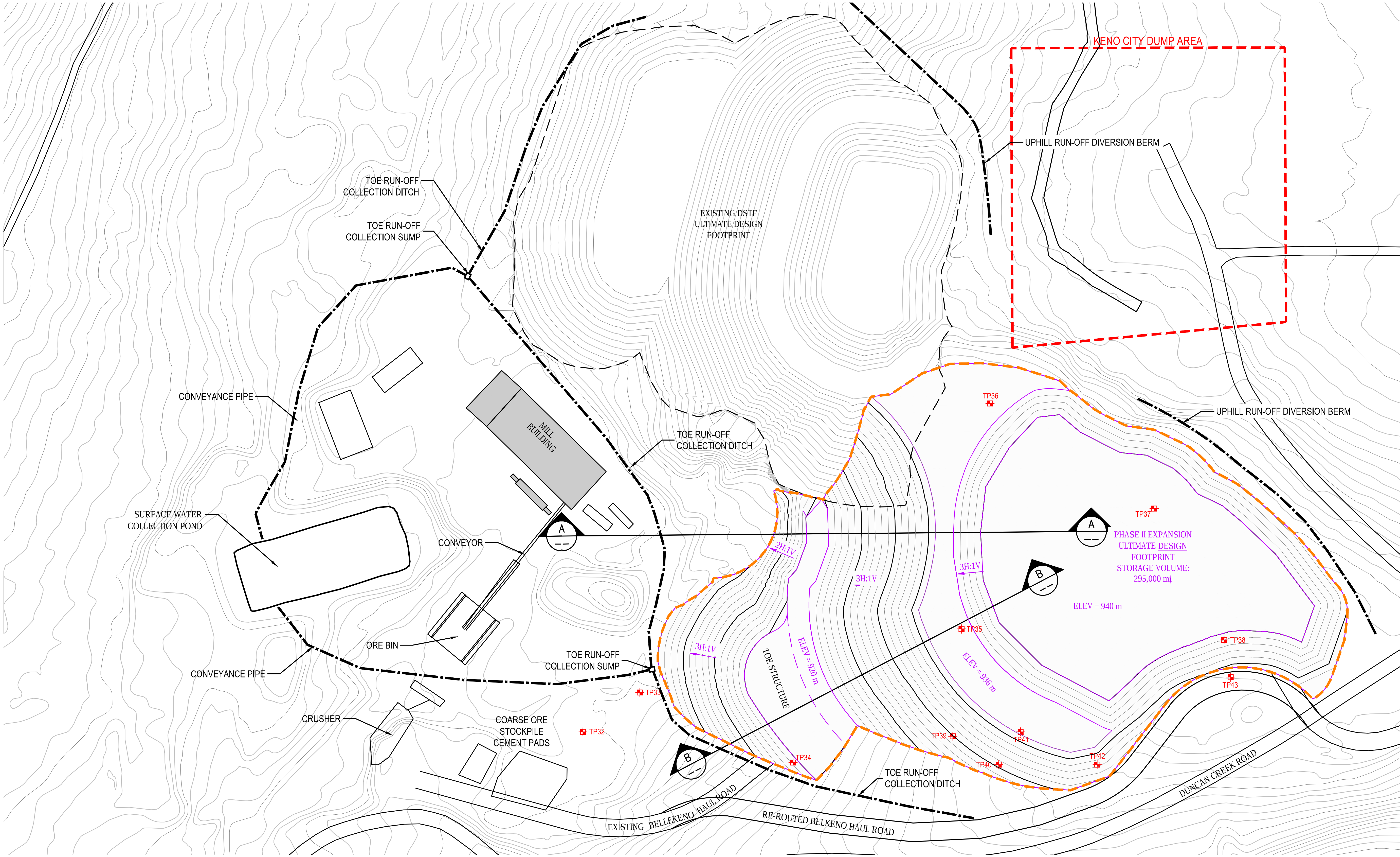


Figure 5-8 DSTF Phase I Sections



LEGEND:

- TESTPIT LOCATION (PHASE II EXPANSION)
- DSTF PHASE II EXPANSION FOOTPRINT

0 100

Scale: 1 : 1750 (metres)

Q:\Whitehorse\Data\0201\drawings\Keno\W14103548-01 DSTF Phase II Liner Stability\W14103548-01 Figs 1-3 R0.dwg [FIGURE 1] May 20, 2015 - 3:25:16 pm (BY: BUCHAN, CAMERON)

CLIENT

ALEXCO

TETRA TECH EBA

DRY-STACKED TAILINGS FACILITY E□ PANSION - PHASE II
KENO HILL DISTRICT MILL SITE, YUKON

DSTF PHASE II EXPANSION

PROJECT NO.	DWN	CKD	REV
W1410354□-01	CB	□TP	1
OFFICE	DATE		
EBA-WHSE	M□□ 15, 2015		

F□□r□ 5-9

5.4 OPERATIONS WATER MANAGEMENT

Water treatment and management during active operations includes a water treatment plant at Bellekeno 625 and a planned water treatment plant for the Flame and Moth and Bermingham mines. At Bellekeno 625, mine in-flow water is pumped to surface into a lime based metals precipitation water treatment plant located near the 625 adit. Bellekeno mine water treatment is primarily associated with zinc contamination. Lime slurry is mixed with underground mine water, mixed in a reactor tank and then flows through two lined settling ponds to allow precipitation of zinc hydroxide sludge along with other hydroxide based metal precipitates. The water treatment plant at Bellekeno has operated successfully for over 8 years and is well demonstrated and proven. The water encountered during the development and operation of the Flame and Moth underground workings will either be utilized in the milling process as makeup water or discharged. Discharged water will meet the effluent quality standards to achieve the water quality objectives presented within Water Licence QZ09-092. Treated and released water for Flame and Moth will be managed using new water management facilities located within the current Mill footprint including a water treatment plant and storage/settling pond. Tailings produced will be deposited on the permitted and existing DSTF, as well as in an expanded area of the DSTF, which will be lined.

Given the close proximity of the Flame and Moth deposit and portal to the existing infrastructure at the Keno District Mill, a number of common facilities and infrastructure will be used which will improve the overall efficiency of the operation and reduce any potential environmental and socio-economic effects. Figure 5-4 shows the Flame and Moth project site.

The Flame and Moth mine will require common surface support facilities including a dedicated mine office, dry/lunch room, maintenance shop, fuel storage tanks and laydown yard. A water management settling pond will also be constructed adjacent to the Mill pond. The portal location is shown in Figure 5-10.

Figure 5-10 Flame and Moth Portal Location

The Waste Rock Management Plan has been updated to incorporate waste rock generated from the Flame and Moth development (AEG, 2018a). An increase in the licenced total tonnage of waste rock stored on surface will not be required. Waste rock generated from the Flame and Moth Mine will be used for underground backfill, construction of laydown pads, access roads to the crusher, a toe abutment for the DSTF expansion, base layer for the DSTF expansion and for general construction purposes.

A comprehensive hydrogeological investigation was completed at the Flame and Moth deposit to assess the hydrological conditions associated with development of the deposit. The hydrogeological investigation estimates that up to 35 lps of groundwater inflow could be expected and encountered during the operation of the Flame and Moth mine. Management of mine inflows at Flame and Moth is planned to be via underground sumps and pumps, similar to the water management program at the Bellekeno Mine.

A main dirty water sump is planned for the 660 m elevation near the fresh air raise and main ramp. A dirty water centrifugal pump(s) are planned in two parallel banks of three pumps each in series, capable of up to 70 lps or twice the anticipated mine inflows. Two steel cased 150 mm diameter boreholes are planned to deliver dirty water from the main sump to a sump near the portal for additional settling prior to be pumped to water treatment plant.

Area sumps are planned as follows: two sumps at the lowest areas of Lightning and one at the lowest area of Christal. These sumps will be equipped with 45 kW dirty water submersible pumps to pump to the main sump at the 660 m elevation. Figure 5-11 presents the issued for construction Engineering design drawing for the Flame and Moth Water Treatment Pond. The pond has been designed to have a capacity of 6,500 m^3.

In terms of contingency water storage, the contingency plan is the same as is currently in place and successfully used at Bellekeno which is to temporarily store water underground during any water treatment upset conditions. Since the Bellekeno water treatment plant has been upgraded and in operation, the longest period of an upset condition requiring temporary cessation of underground pumping and intentionally holding back water underground is approximately 24 hours. In the event there were a temporary upset of the Flame and Moth water treatment plant, a similar contingency plan would be initiated. Operational freeboard is also maintained in the water treatment pond to allow for treatment upset conditions and temporarily suspend discharge.

Static and kinetic testing was conducted on Flame and Moth drill core samples, spanning all the major lithologies expected to encounter during excavation. The results and interpretation of this testing are summarised in Appendix 3.3. Briefly, ABA, ICP aqua regia digested metals, and shake flask extraction testing indicated that the samples are non-acid generating and the majority have low metal leaching capacity. Similar results were obtained from testing of waste rock from Bellekeno, Lucky Queen, and Onek deposits.

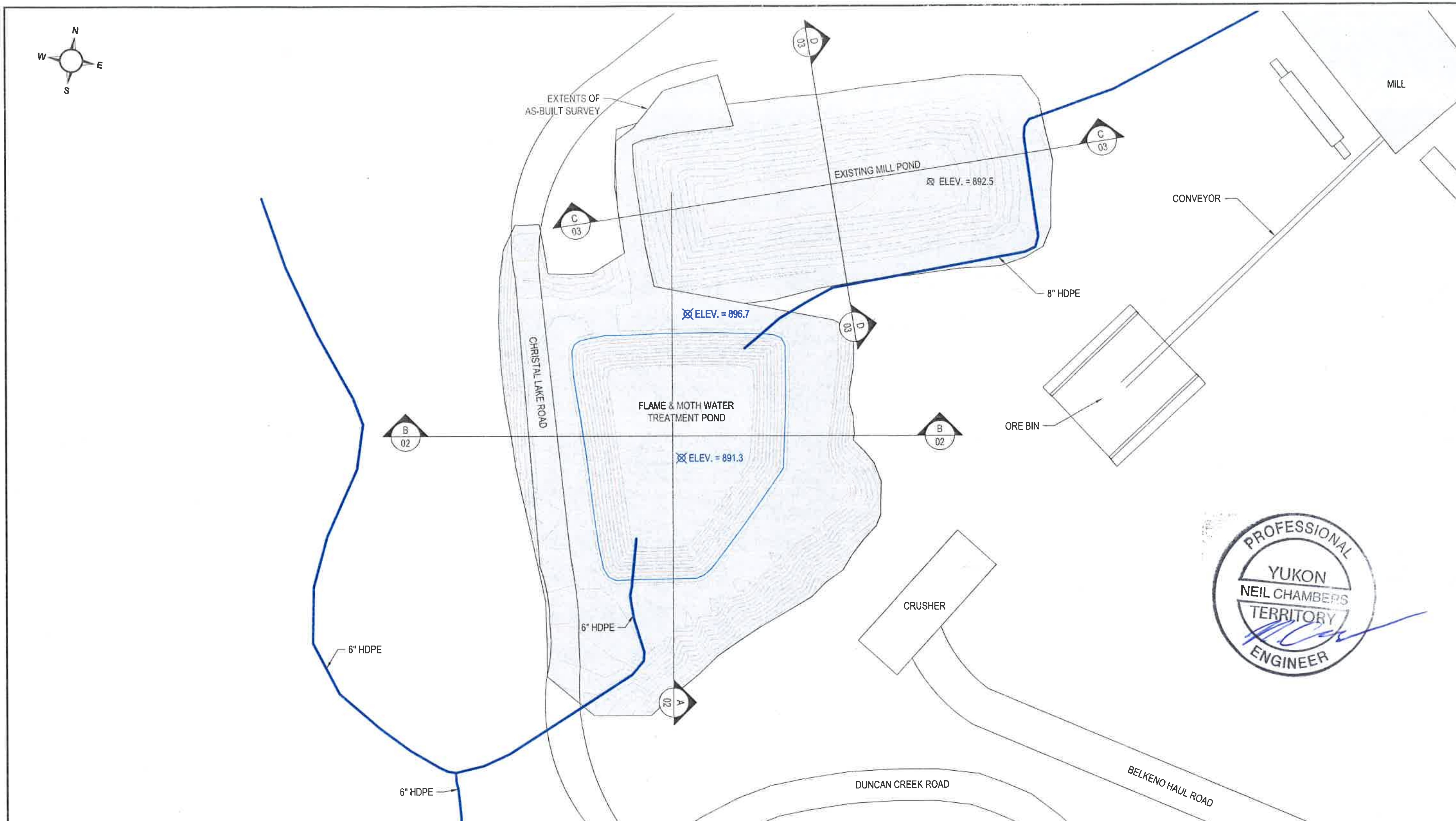
A 30 m waterbody setback has been established for deposition of N-AML waste rock in consideration of its zinc content (1100 ppm Zn threshold), in accordance with the WRMP.

Water management structures, including berms, ditches and temporary water storage ponds, will be established to convey water around N-AML and P-AML waste rock dumps and direct water to appropriate locations to be discharged to ground.

The AMP includes an "event" for monitoring N-AML waste rock piles and their seepages, and stipulates adaptive management measures to be undertaken if an increasing trend in acid generation or metal leaching is detected.

As observed in actively discharging adits throughout the KHSD, the pH of Flame and Moth adit water is expected to be circumneutral to slightly alkaline. Based on the Bellekeno adit water, elevated total concentrations of zinc (BK625 median 1.8 mg/L), lead (BK625 median 1.61 mg/L), cadmium (BK625 median 0.017 mg/L), and silver (BK625 median 0.012 mg/L) are anticipated, with freshet extremes generally an order of magnitude higher.

The Bellekeno water treatment plant (WTP) uses basic metal hydroxide precipitation technology and particulate removal technology including coagulation, settling, and filtration. In general, lime solution is added to the underground mine collected waters and a zinc hydroxide precipitate (sludge) is formed and settles to the bottom of two lined ponds. The suspended solids in the mine discharge and the zinc hydroxide particulates are removed by coagulation with lime, settling in ponds, and filtration in a multimedia filtration process.



DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2019-04-18	Stamped	0	KB	NC
2019-04-18	Draft for review	C	KB	KW
2019-04-18	Draft for review	B	KB	KW
2019-04-18	Draft for review	A	KB	KW

0 25m

Scale: 1:750 @ 11"x17"

APPROXIMATE AS-BUILT CONSTRUCTION VOLUMES FOR FLAME & MOTH POND(m^3)

CUT = 4685 m^3

FILL = 2265 m^3

NOTE

ORIGINAL GROUND CONTOURS FROM LIDAR DATA (DATED NOVEMBER 2014)

ALEXCO

Flame & Moth
Water Use License

Drawing No: ALEX-13-NMP-02-0C102.01

Figure 5-11

Flame & Moth and Mill Ponds As-Built
Site Plan

REVISION: 0	2019-04-18	PROJECT No.: ALEX-13-NMP-02
DRAWN BY: KAB	DESIGNED BY: JP (EBA)	REVIEWED BY: NC

5.4.1 Flame and Moth Water Treatment Plant

The Flame & Moth treatment plant design builds on Alexco's experience of successfully treating water over the past eight years in the Keno Hill Silver District as part of care and maintenance of the Silver King, Galkeno 300, and Galkeno 900 sites and mining operations at the Bellekeno mine. The new Flame & Moth treatment facility is located adjacent to and within the Keno District Mill, and the processes used in the treatment plant are comprised of the following general processes:

1) Particle removal via a hydrocyclone, multimedia filter, clarifier/thickener, and/or settling pond;

2) Metals removal as needed with the addition of air, pH adjustment, a polymer, and settling in a clarifier/thickener;

3) Ammonia removal via biological oxidation/degradation processes (with the addition of air and organic carbon) and an optional ion exchange (IX) system for final polishing.

Mass load model for Christal Creek and Lightning Creek were developed by Interralogic, Inc./ Hatch using Goldsim simulation framework. The models were initially prepared for simulating metal loads in Christal Creek and Lightning Creek, and to evaluate the reclamation options (currently being developed) for the Keno Hill Silver District Type 2 Abandoned Mines. Hatch's revised draft reports, Chemical Mass Load Model for Christal Creek: Description and results: 2016 update (Hatch, 2016a) and Chemical Mass Load Model for Lightning Creek: Description and results: 2016 update (Hatch, 2016b), provide a detailed description of the development of the models, including the loading sources, key assumptions, stochastic parameters and model calibration. The model has been recalibrated up to September 2015. The GoldSim model has also been updated to include potential loadings from the proposed Flame and Moth Mine including N-AML waste rock, expanded dry stack tailings facility, mine discharge and groundwater flow from the mine pool or bioreactor at closure for cadmium and zinc, the contaminants of concern, plus the additional parameters with effluent quality standards in Water Licence QZ09-092-2, which are ammonia (NH_3), arsenic (As), copper (Cu), lead, (Pb), nickel (Ni) and silver (Ag). Additional parameters for the model were not included as the N-AML waste rock humidity cell leaching rates and the deep ground water sampled from the three deep wells (FM-MW-1, FM-MW-2, FM-MW-3) did not identify any additional parameters of potential concern.

The load models calculated metal loadings for three phases of the project: pre-mining development, operations, and reclamation and post-closure. The load model calculates metal loading results for Christal Creek and Lightning Creek from 2008 to December 31, 2014 without any potential loading from the proposed mining activities from the Flame and Moth Mine. The models then accounts for operating the Flame and Moth Mine from January 1 to March 31, 2021 at the maximum mining rate of 400 tonnes per day (tpd). The loading models incorporate potential loadings for the reclamation and post closure phase (2021 to 2031).

The largest proposed loading source, Flame and Moth Mine discharge, is only of short duration and will cease at the end of the mine life. The model results present the predicted concentrations for the Flame and Moth discharge at both the average anticipated concentrations and the proposed effluent quality standards for the complete life of mine. The comparison of the results using the EQS discharge for the complete life of the mine is overly conservative based on Alexco's track record for operating five water treatment plants in the Keno District and the scenario presented for average expected discharge concentrations is more representative of anticipated monthly concentrations. The modelling results also show that the long term concentrations in

Christal Creek and Lightning Creek ameliorated by the District Closure Plan currently under development will not be impacted by the Flame and Moth project.

5.4.2 Bermingham Water Treatment

As part of mine operations at Bermingham, a water treatment plant similar to Flame and Moth will be constructed. The Bermingham mine will require continual dewatering, with discharge flows dependent on mine depth. It is estimated that flow rates may reach a maximum of 13.9 litres per second (lps) with incoming water quality generally compliant except for some metals and potentially with elevated levels of ammonia and total suspended solids from underground mining activities. The new treatment facility would be located near the Bermingham portal, and the processes used in the treatment plant will be comprised of the following general processes:

a) Metals removal as needed with the addition of air, pH adjustment, a polymer, and settling in a clarifier/thickener;

b) Particle removal via a hydrocyclone, clarifier/thickener, and settling pond;

c) Ammonia removal via optional ion exchange (IX) system for final polishing.

Elements of the Proposed System

Figure 5-12 shows the layout of the proposed Bermingham Water Treatment Plant (WTP). All of the systems and technology proposed for the Bermingham WTP are proven technologies operating at Keno Hill or elsewhere in the industry. The system operates as follows:

- Water is collected underground and pumped to surface where it passes through one, or several, hydrocyclone(s). At the hydrocyclone, water enters tangentially and spins at the cylindrical entrance. The spinning action causes heavier particles to be thrown toward the wall of the chamber and drift downward, thereby removing total suspended solids. Water, which is less dense than the solids, continues spinning and moves vertically up and out of the unit.

- Water then flows into a rapid mix tank where it is mechanically agitated and reagents are added to adjust the pH. By raising the pH, a small portion of the ammonia is transformed into a dissolved gas, and some treatment of ammonia occurs in the rapid mix tank and subsequent settling. A polymer is added to densify the sludge and in the future, additional reagents such as coagulant aids may be added into the reactor to remove other metals if determined necessary during plant commissioning.

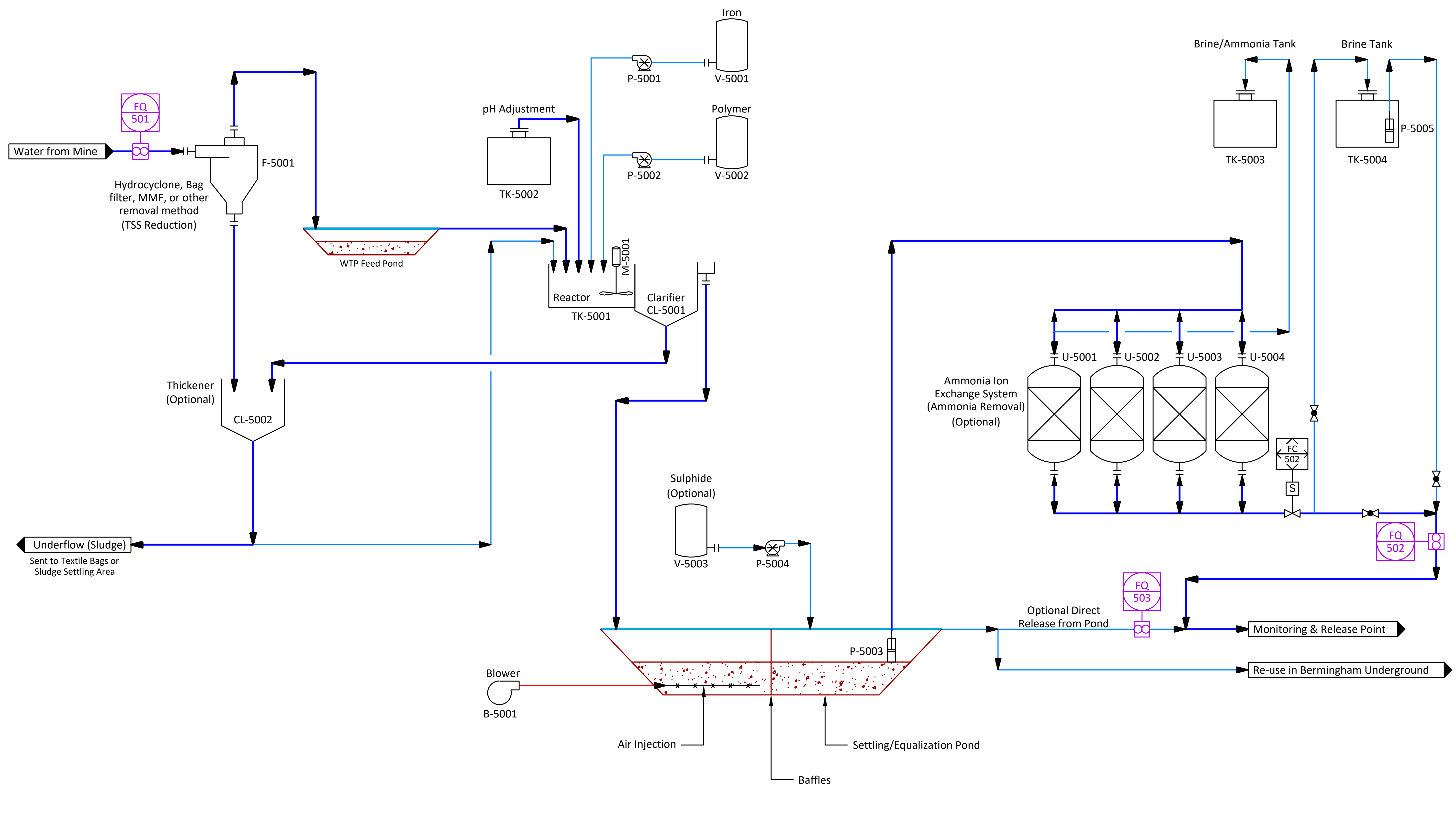
- Water flows from the rapid mix tank into the clarifier settling body where heavier particles accumulate at the bottom of the cone as sludge. This sludge is pulled from the clarifier by a sludge blow-down system and sent to a thickener.

- Sludge and heavier particles from both the clarifier and hydrocyclone enter an optional thickener which increases the percent solids of this combined slurry before sending the sludge to either textile dewatering bags or sludge settling pond for final disposal in the Bermingham SW pit. At closure the sludge in the pit will be covered with waste rock and till material.

- Water from the clarifier travels vertically up and out of the settling body where it enters the aeration and treatment portion of a lined pond.

- Once water enters the settling and equalization area, residence time will allow for final particle removal and polishing of the treated water.

- Water can then be decanted from the pond for discharge or reused within the Bermingham underground activities, or pumped to an optional ion exchange ammonia removal system for final treatment.



DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-07-25	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

Bermingham WTP
Bermingham Water Treatment Plant
Drawing No.: ALEX-16-NMP-03-5DI602

Piping and Instrumentation Diagram

Figure 5-12

REVISION A	2018-07-25	PROJECT No.: ALEX-16-NMP-03
DRAWN BY: KB	DESIGNED BY: EL	REVIEWED BY: BT

5.5 MONITORING

The Monitoring, Surveillance and Reporting Plan (AEG, 2018b) describes the framework used to manage mining operations in the KHSD. The plan includes monitoring and reporting of:

- The local and receiving environment through scheduled inspections and sample programs;
- Effluent discharge points and treatment system performance;
- Site facilities and incorporated design measures to ensure structural stability and prevention of accidents and malfunctions;
- Remediation success; and
- Adaptive management responses.

If monitoring indicates that physical structures, treatment systems or mitigative measures are not performing then maintenance or contingency plans can be implemented following an adaptive management approach.

Prior to mine development in the KHSD, a number of monitoring programs and a surveillance networks were already in place as per care and maintenance activities (Water Licence QZ06-074), advanced exploration and preliminary development activities at the Bellekeno mine (Water Licence QZ07-078) as well as district-wide closure and new mine permitting studies. These programs include but are not limited to physical inspections, a water quality surveillance network, old mine workings monitoring, aquatic resources monitoring for benthic invertebrate and fisheries populations, sediment monitoring, waste rock and mine wall sampling and the Adaptive Management Plan. Monitoring, surveillance and reporting applicable to Bellekeno, Flame and Moth, Onek 990 and Lucky Queen Mines are presented in the Monitoring, Surveillance and Reporting Plan (AEG, 2018b).

Alexco provides regular monitoring data, analysis and discussion of trends in our monthly and annual reports submitted as a condition of QZ09-092 and QML-0009.

6. 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 6-1 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 6 years which means that there would be minimal additional costs related to a temporary closure of the Keno Hill Mine Operations.

6.1 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 2.3) 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 6-1 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.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
	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.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
	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.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
	Physical Stability	Restrict access to hazardous areas with physical barriers.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
Flame and Moth Mine	Water Management	Maintain Flame and Moth water management infrastructure.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
	Physical Stability	Restrict access to hazardous areas with physical barriers.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
Bermingham Mine	Water Management	Maintain Bermingham water management infrastructure.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
	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.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
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.			
	Water Management	Maintain water treatment system and related water management infrastructure.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
Dry Stack Tailings Facility	Physical stability	Surface water diversion structure repair/ maintenance.	Monitoring Program from DSTF Operating Plan; & QML Physical Monitoring Program	Care & Maintenance Crew	As per Monitoring Programs & QML
		Runoff/Erosion/Sediment control.			
		Dust Control.			
		Progressive reclamation will occur during operations.	Geotechnical Inspection from QML and DSTF Operating Plan	Engineer	Annual
	Geochemical Stability	Monitor for seepage and water quality.	WL Water Quality Surveillance Program; & Monitoring Program from DSTF Operating Plan	Care & Maintenance Crew	As per WL
Entire Site	Physical stability	Runoff/Erosion/Sediment control.	QML Physical Monitoring Program	Care & Maintenance Crew	As per QML
		Road/culvert maintenance.			
		Progressive reclamation will occur during operations.			
	Security	Full time site care & maintenance crew will check, repair and replace as required: · precautionary signage · security gates – installed to restrict access to the mill	Care & Maintenance Monitoring of all infrastructure and site elements	Care & Maintenance Crew	Daily: Inspection Sheets included in Annual Reporting
	Miscellaneous Infrastructure	Minimize camp size.			
		Inspect power line	Care & Maintenance monitoring of all infrastructure and site elements	Care & Maintenance Crew	Daily: Inspection Sheets included in Annual Reporting
	Reporting	Prepare and submit annual report to Yukon Water Board pursuant to WL, including details of temporary closure activities and monitoring.		Alexco	Annually
		Prepare and submit annual report to YG Mineral Resources Branch pursuant to the QML, including details of temporary closure activities and monitoring.			
		Prepare and submit quarterly monitoring reports to Environment Canada under MMER.			Quarterly, Online RISS Registry

6.2 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.

6.3 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 Licences.

7. FINAL RECLAMATION AND CLOSURE MEASURES

This section of the Reclamation and Closure Plan provides the details on the proposed reclamation and closure measures for each mine component in the Keno Hill Mine Operations. The approach to each subsection is to present a brief description of each component and related facilities with reclamation and closure objectives and measures.

The following mine components specific to the Keno Hill Mine Operations are addressed:

1. Underground Workings and Opening to Surface
    - Bellekeno Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawings: C-2401, C-2402, B-2101, B-2102, D-2102, D-2301, D-2601)
    - Onek Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawings: C-4401, B-4101, B-4301)
    - Lucky Queen Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawings: C-3401, B-3101, B-3301)
    - Flame and Moth Deposit – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawing: C-1401)
    - Bermingham Deposit - including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawings: C-5401, B-5101, B-5301)
2. Dry Stack Tailings Facility – Phases I – II
   (Appendix 3.1, Drawings: C-7401)
3. District Mill, Ancillary Facilities, Flat Creek Camp
   (Appendix 3.1, Drawings: C-6401, B-6101, B-6301, C-9401, B-9101, B-9301)
4. Roads and Linear Disturbances
   (Appendix 3.1, Drawings: B-0301)

Development of the mines in the Keno District Mine Operations progress through the life cycle of the LOM Plan. The RCP addresses reclamation and closure cost liabilities at the different times, including current disturbance, end of Year 2 and End of Mine life. Table 7-1 summarizes the disturbance by Mine Area Component at these different stages in the LOM Plan.

Table 7-1 Summary of Disturbance Area by Mine Component

Mine Component	Units	Current (February 2018)	Year 2 LOM Plan	End of LOM Plan
Mill Facilities				
Ore Mined/Milled	tonnes	248,644	440,824	907,715
Dry Stack Tailings Facility	tonnes	180,722	282,112	553,692
Dry Stack Tailings Facility Area (unreclaimed)	ha	0.6	2.5	5.5
Mill Pad area	ha	4.79	4.79	4.79
Bellekeno				
BK East Yards/Portal/Laydown Areas	ha	2.04	2.04	2.04
BK 625 Yards/Portal/Laydown Areas	ha	1.29	1.29	1.29
N-AML WRDA	tonnes	0	0	0
N-AML WRDA	ha	0	0	0
Temporary P-AML WRSF	ha	0.20	0.20	0.20
Temporary P-AML WRSF	tonnes	425	1,105	1,105
Temporary P-AML WRSF	m^3	250	650	650
Onek				
Yards/Portal/Laydown Areas	ha	0.35	0.35	0.35
N-AML WRDA	tonnes	0	0	0
N-AML WRDA	ha	0	0	0
P-AML WRSF	ha	0.48	0.48	0.48
P-AML WRSF	tonnes	0	0	0
P-AML WRSF	m^3	0	0	0
Lucky Queen				
Yards/Portal/Laydown Areas	ha	0.63	0.63	0.63
N-AML WRDA	tonnes	0	0	80,000
N-AML WRDA	ha	0	0	0.4
P-AML WRSF	tonnes	0	0	44,000
P-AML WRSF	ha	0	0	0.43
P-AML WRSF	m^3	0	0	25,882
Flame and Moth				
Yards/Portal/Laydown Areas	ha	0	0.1	0.1
N-AML WRDA	tonnes	0	75,000	125,193
N-AML WRDA	ha	0	4.1	6.9
P-AML WRSF	tonnes	0	6,000	12,000
P-AML WRSF	ha	0	0.12	0.23
P-AML WRSF	m^3	0	2000	4000
Bermingham				
Yards/Portal/Laydown Areas	ha	0.66	0.66	0.66
N-AML WRDA	tonnes	11,175	70,000	195,000

Mine Component		Current	Year 2 LOM Plan	End of LOM Plan
	Units	(February 2018)		
N-AML WRDA	ha	0	0.68	1.86
P-AML WRSF	tonnes	0	2,500	10,000
P-AML WRSF	ha	0	0.4	0.13
P-AML WRSF	m^3	0	800	3,000
Roads and Other				
Camp Accommodations	ha	2.2	2.2	2.2
Sludge Volume	m^3	150	225	350
BK Haul Road length	metres	5,661	5,661	5,661
Christal Lake Road	metres	1,299	1,299	1,299
Keno City Bypass Road	metres	2,060	2,060	2,060
Bermingham Access Road	metres	0	1,979	1,979

7.1 UNDERGROUND WORKINGS AND OPENINGS TO SURFACE

The underground workings and openings to surface that are addressed in the RCP include the following:

- Bellekeno Mine
    - Bellekeno East Portal
    - Bellekeno Mine Decline and Underground Workings
    - Bellekeno 625 Adit/Secondary Escape
    - Bellekeno 200 Vent Raise
- Lucky Queen Mine
    - Lucky Queen Portal
    - Lucky Queen Underground Adit and Workings
    - Lucky Queen Vent Raise/Secondary Escape
- Onek Mine
    - Onek Portal
    - Onek Decline and Underground Workings
    - Onek Vent Raise/Secondary Escape
- Flame and Moth Mine
    - Flame and Moth Portal
    - Flame and Moth Decline and Underground Workings
    - Flame and Moth Vent Raise/Secondary Escape
- Bermingham Deposit
    - Bermingham Portal
    - Bermingham Decline and Underground Workings
    - Bermingham Vent Raise/Secondary Escape

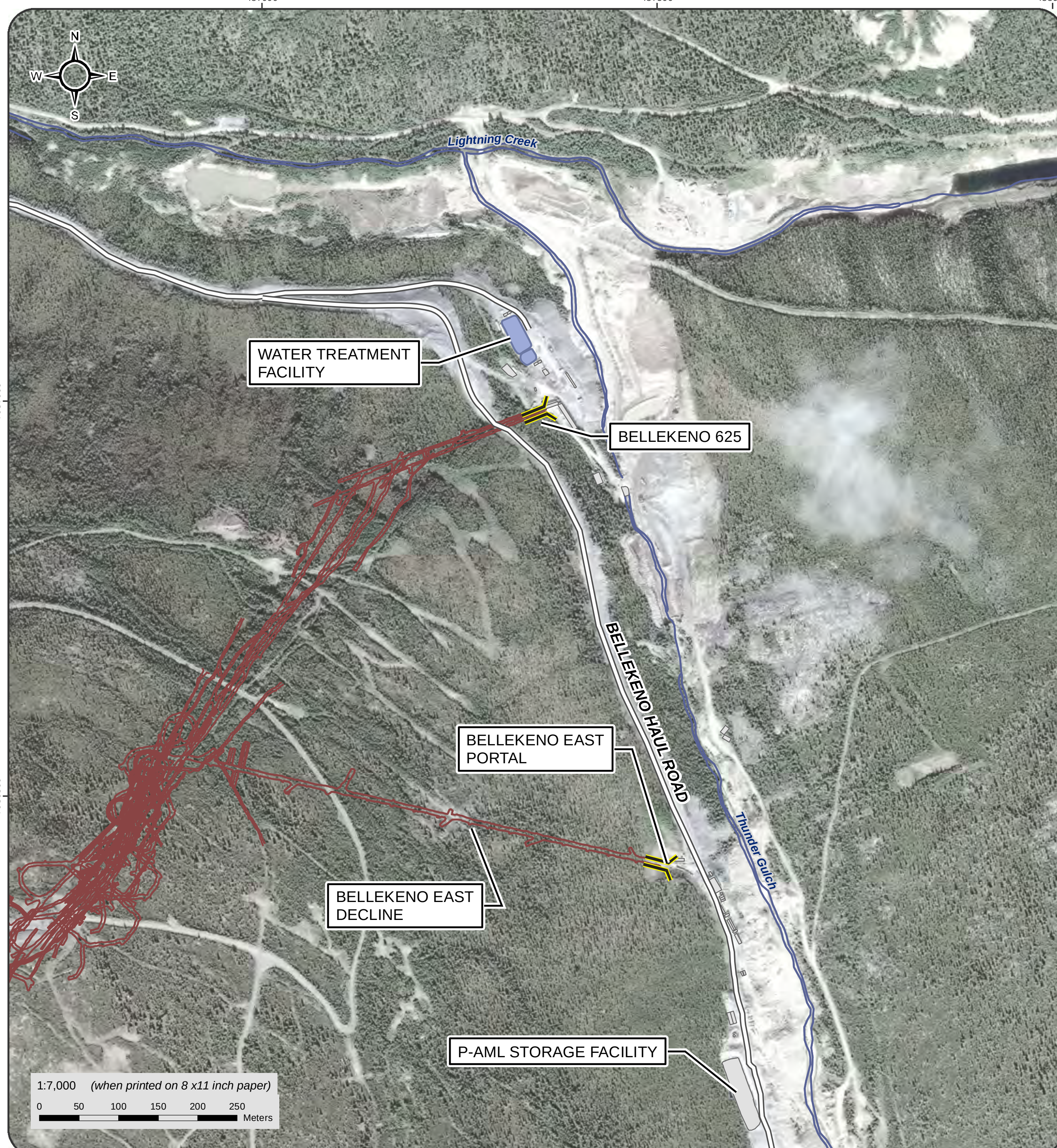
7.1.1 Closure Objectives

The objectives for closing the underground workings and openings to surface 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.

7.1.2 Bellekeno Mine

The Bellekeno Mine consists of the underground workings and surface adit entrances (Bellekeno East portal and decline and the Bellekeno 625 adit), water treatment facility and associated buildings and infrastructure (Figure 7-1). The Bellekeno East portal is the primary ingress/egress point for the Bellekeno Mine (Figure 7-2 and Figure 7-3). An as built of the Bellekeno Mine underground workings as of September 2013 when operations were suspended is shown in Figure 7-4. The Bellekeno Life for Mine Plan is provided in Figure 7-5. The Bellekeno 625 adit provides secondary escape and ventilation intake for the mine and discharges mining-impacted water requiring 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. Figure 7-2 shows the remaining surface buildings at Bellekeno East that will require removal.



Adit

Mine Feature Footprint

Pond

Underground Workings

Haul Road

Watercourse

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on February 2018

Datum: NAD 83; Projection: UTM Zone 8N

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KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-1

BELLEKENO MINE OVERVIEW

JULY 2018

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(Last edited by: amatlashevska; 12/02/2018/15:04 PM)

Figure 7-2 Bellekeno East Portal and Site Facilities

Figure 7-3 Bellekeno East Portal

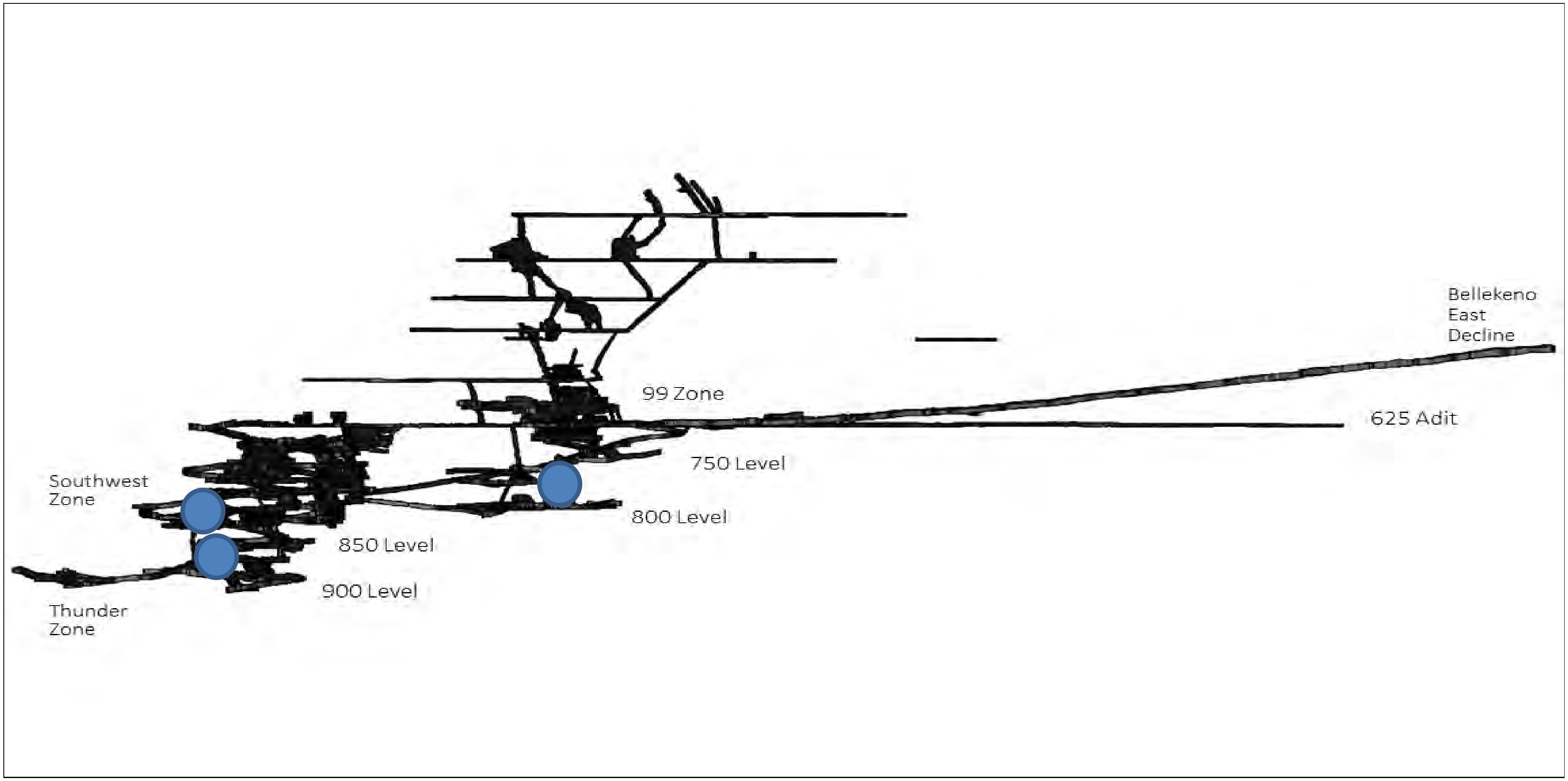


Figure 7-4 Bellekeno Mine As-Built Current Conditions January 2018

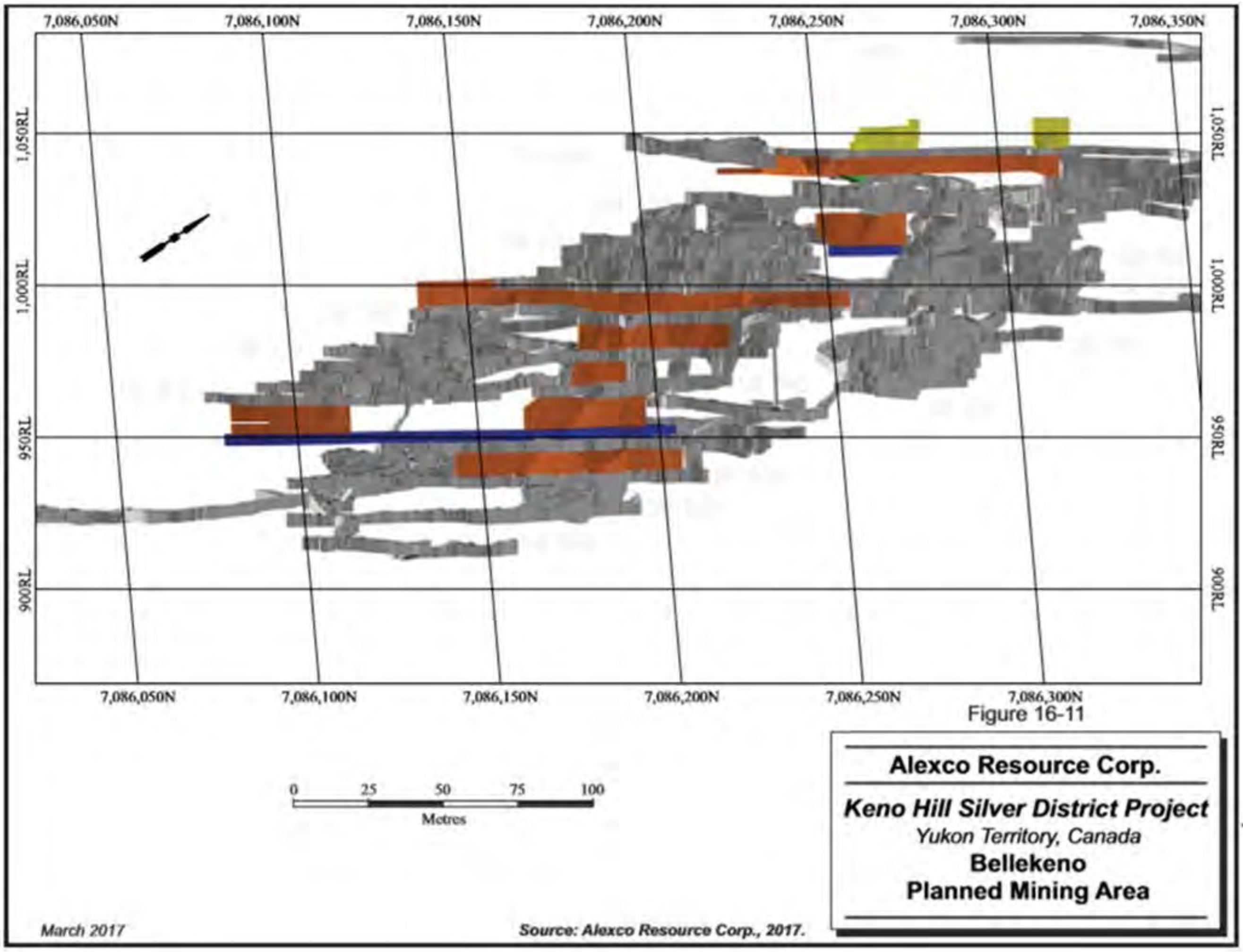


Figure 7-5 Bellekeno LOM Plan

7.1.3 Bellekeno Mine Closure Measures

The steps and measures required for closure of the Bellekeno Mine include:

1. Stabilize or backfill any remaining stopes as necessary to ensure long-term geotechnical stability underground;
2. Backfill any remaining P-AML waste rock on surface to underground. *Note – 250 m³ of P-AML waste rock remained in the lined facility adjacent to Bellekeno East upon temporary suspension of operations.*
3. Remove/salvage underground assets and equipment;
4. Remove/salvage surface facilities and infrastructure;
5. Remove any hazardous materials;
6. Install mine pool treatment infrastructure; and
7. Install rock pile portal cover at Bellekeno East.

Removal of underground equipment upon closure includes mining equipment such as trucks, LHD's, drills, etc. Mining fleet equipment will be brought to surface and either transported offsite or salvaged. There will be some equipment left underground that has either minimal salvage value or the cost to remove exceeds any salvage value. The following equipment may be left underground at each mine:

- Electrical cable;
- Electrical junction boxes;
- Steel piping;
- Hoses; and
- Vent tubing.

No hazardous material such as explosives, oils, lubes will be left underground at closure. The equipment left underground is not expected to have any hazardous material associated with it that would require any decontamination.

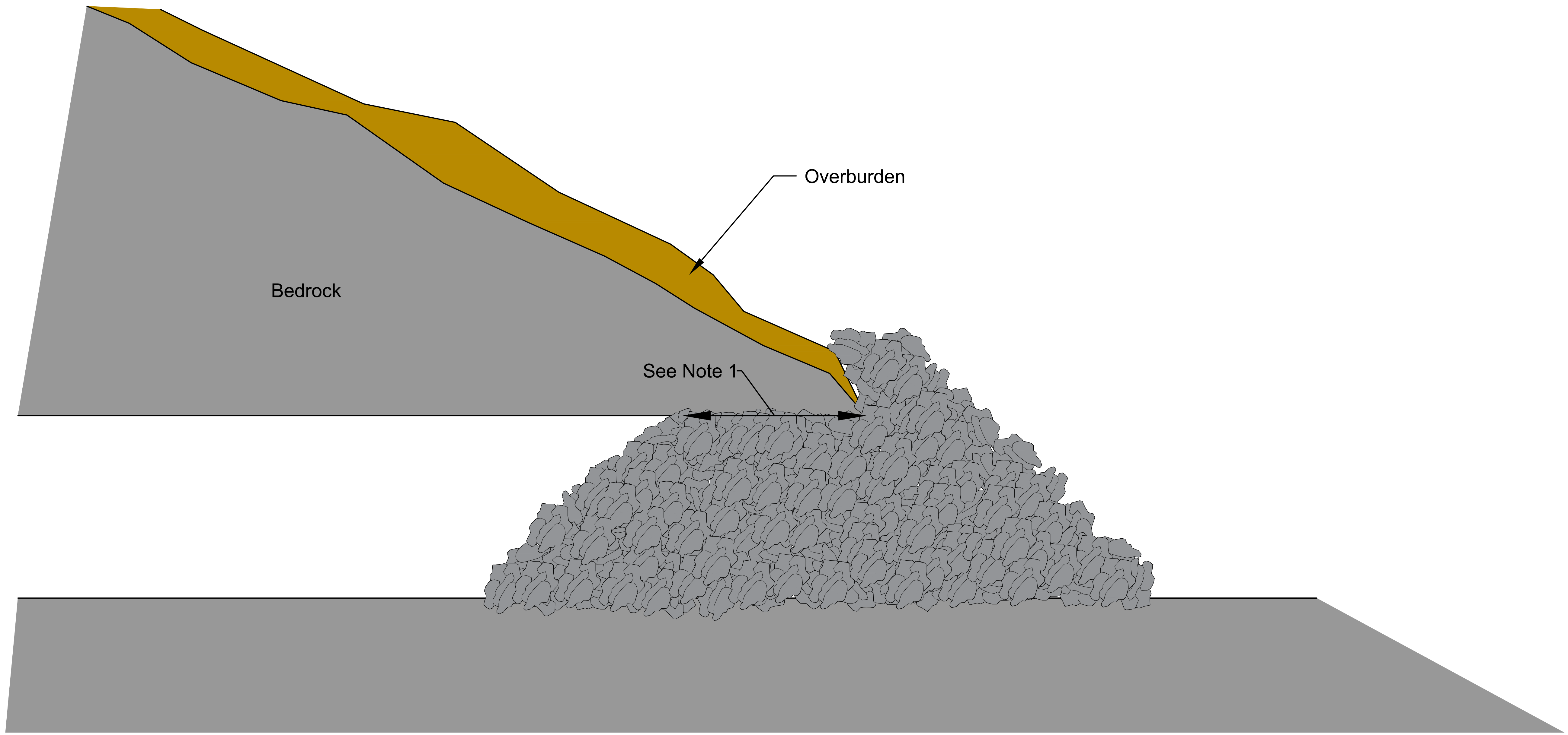
The mine pool will be managed by transitioning from actively treating adit discharge to sealing the 625 adit with a hydraulic bulkhead, implementing in situ mine pool treatment and installing a passive treatment system (bioreactor). Further discussion on the closure measures associated with long-term water management at Bellekeno is presented in Section 7.4.2.

At closure, underground equipment will be removed from the underground mine through Bellekeno East. The portal will remain temporarily accessible at closure for the rehandling of P-AML waste rock back into the underground (see Section 7.4). 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.

Reclamation measures for the Bellekeno East, and Bellekeno 625 adit areas are described on Drawings C-2401 and C-2402 respectively located in Appendix 3.1.

200 Level Vent Raise

The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 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.



Notes:
1. Backfill should extend to a minimum length equal to the largest opening dimension.
2. Backfill material should consist of well graded, durable rock fill and coarse rip-rap.
3. The use of well graded rock intermixed with large boulders will discourage people from digging into the backfill.
4. Backfill should be inert, or material that poses no additional threat to mine water quality.
5. Backfill should extend past the opening and mound over the top of the entrance to completely seal the opening and compensate for settlement.
6. Backfill outside the entrance should be covered with either coarse rip-rap to reduce erosion, or a native till, to permit vegetation.

Not to scale

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-02	Draft for review	A	KAB	--

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Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-S-0301

Figure 7-6

Portal Closure
Typical Rock Pile Closure Design

REVISION: A	2018-01-02	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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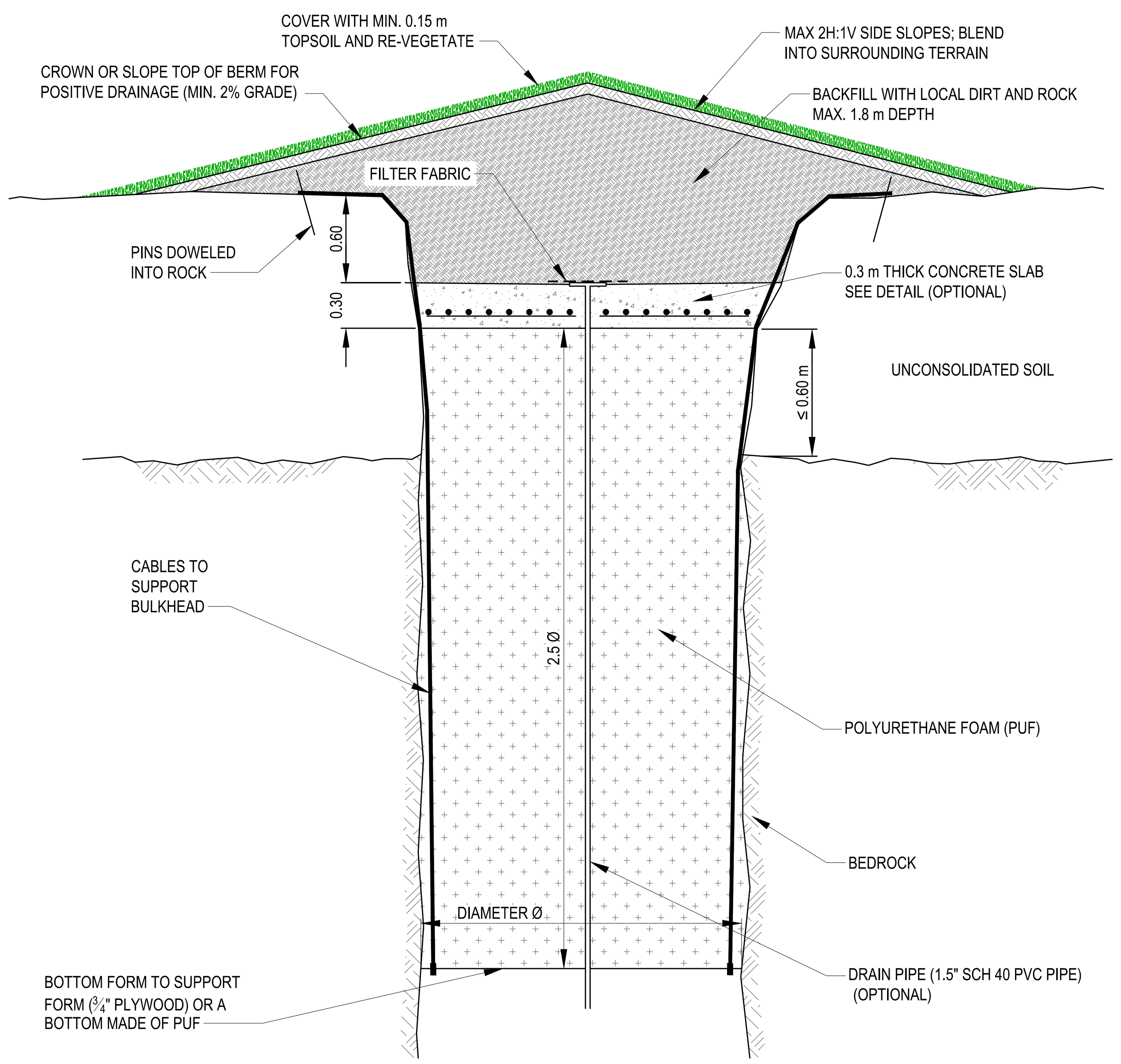
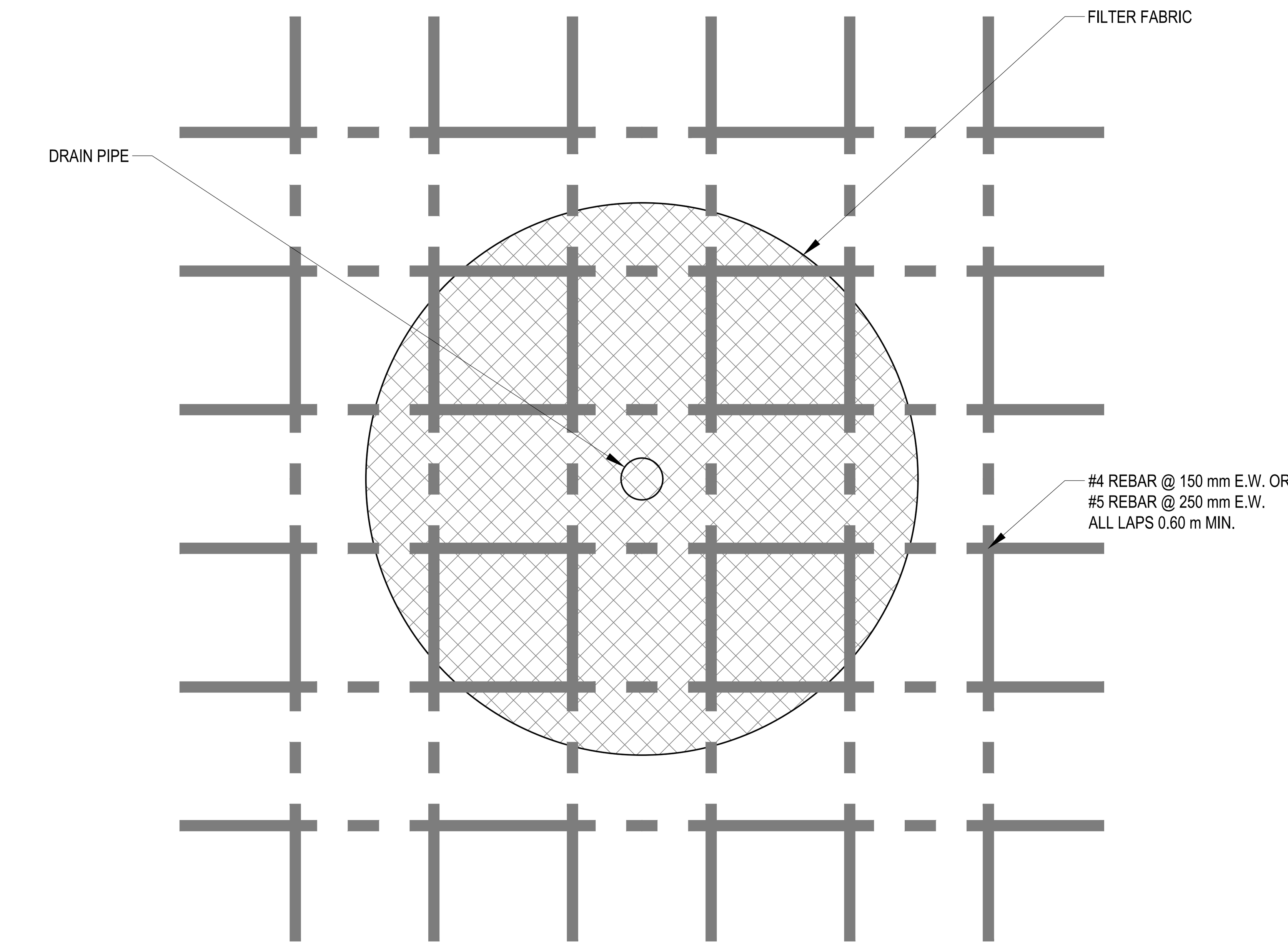
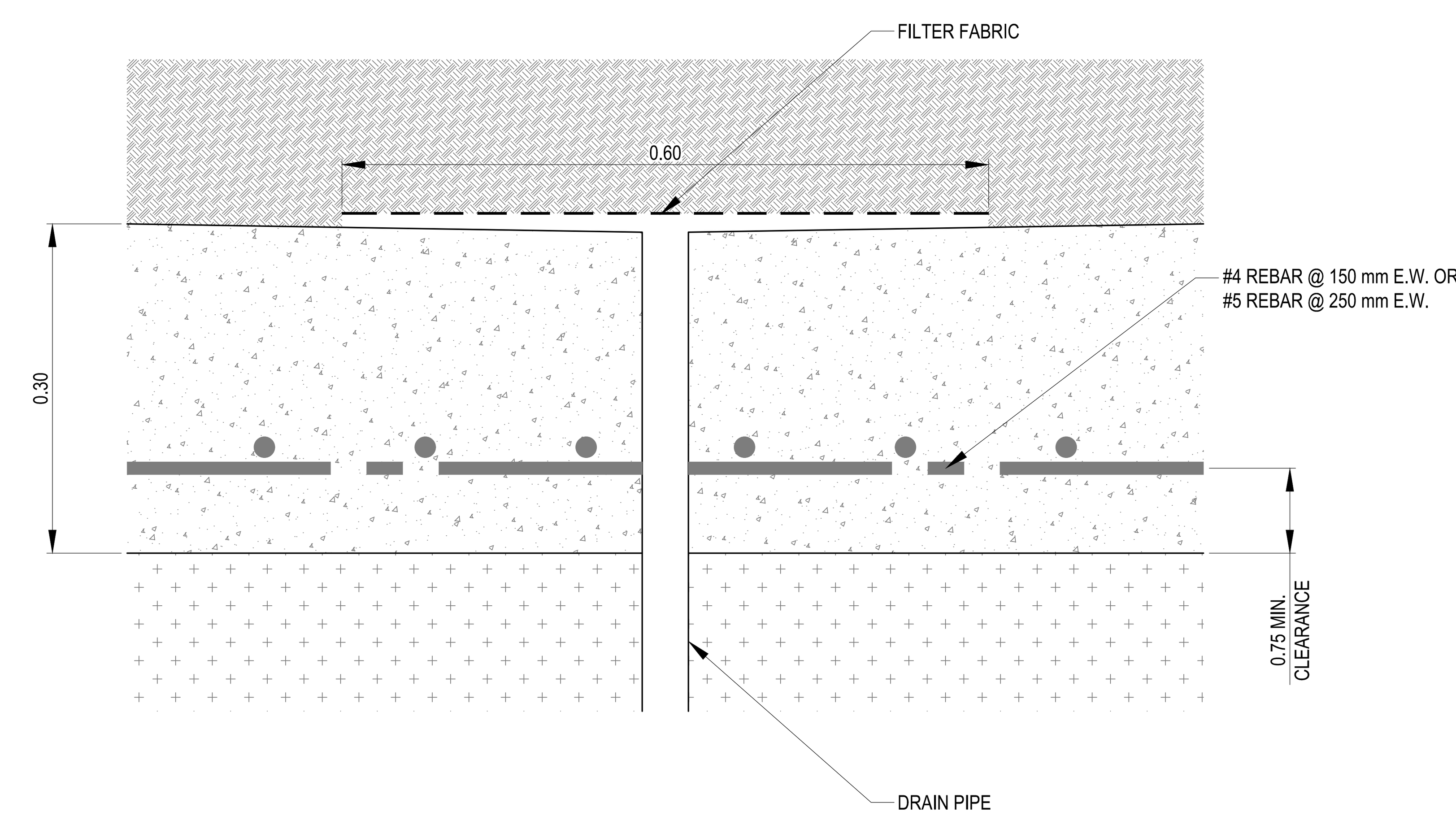


SHAFT PUF WITH CONCRETE SLAB CLOSURE

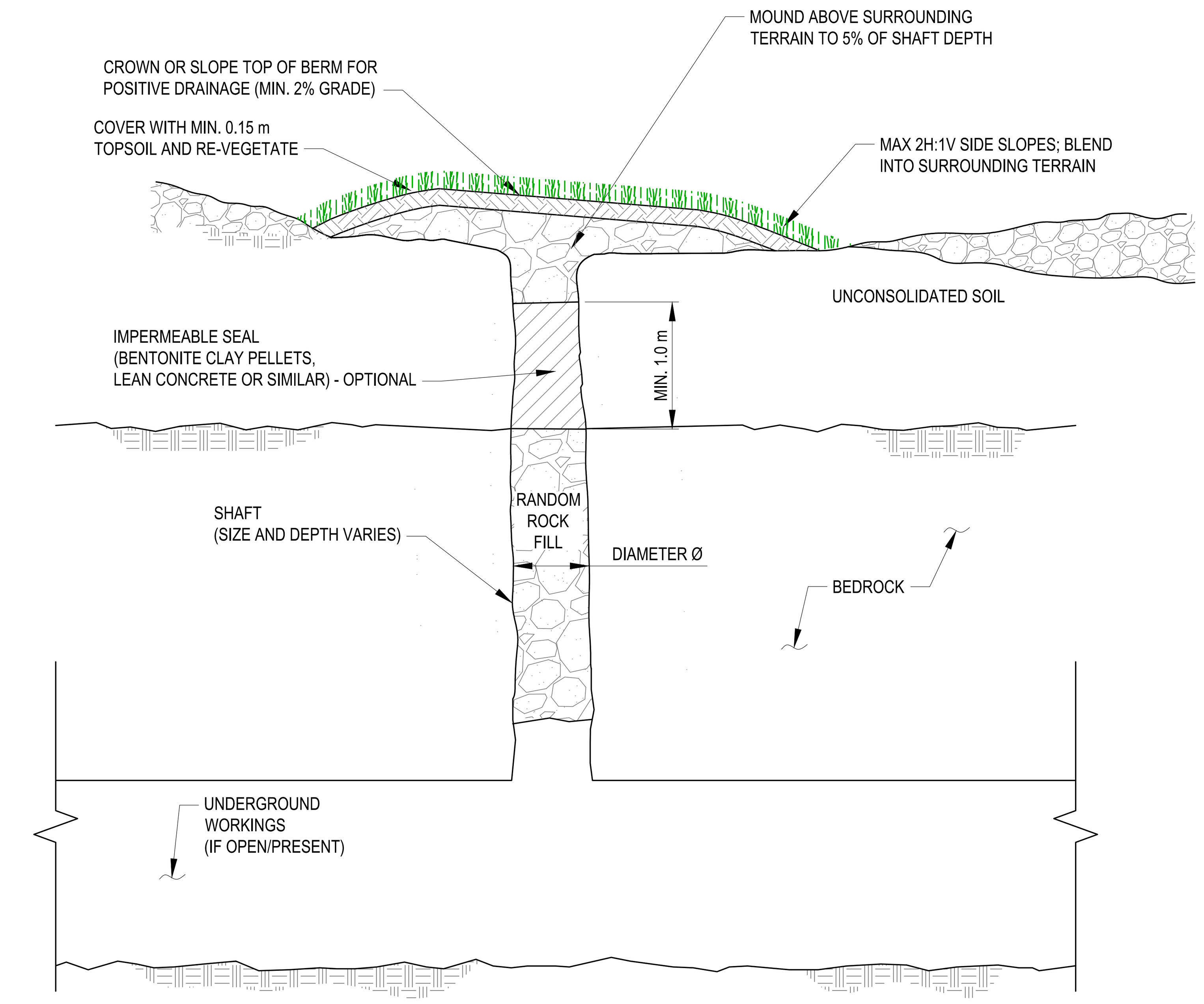
NOT TO SCALE





CONCRETE SLAB DETAILS

NOT TO SCALE



SHAFT BACKFILL (DRY SEAL) CLOSURE

NOT TO SCALE

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Lower the bottom form into the shaft to the final depth of the Polyurethane foam (PUF)
3. Install drain pipe (1.5 " SC 40 PVC) extending from below the bottom form to planned top of concrete cap.
4. Place seals into the cracks between the edges of the bottom form to prevent foam from falling down the shaft.
5. Pour the mixed PUF foam onto the bottom form to form the plug.
6. Construct the 0.3 m concrete slab. Concrete slab sloped outwards to drain (2%)
7. Back fill on top of the concrete slab with local dirt and rock.
8. Concrete shall have a minimum 20 MPa compressive strength at 28 days
9. The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of concrete to establish that minimum strength required for concrete slab has been obtained.

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Quantities will vary with shaft depth, connection to underground workings, and other conditions.
3. Mobile equipment must never operate on ground that shows signs of subsidence without taking adequate precautions.
4. Remove as practical, if present, 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.
5. Existing steel pipe, concrete rubble (if present) should be removed or incorporated into backfill as directed by engineer.
6. Random rock fill must be:
   a. Non-acid generating rock fill
   b. Sized to contain no rocks greater than 1/4 the diameter of the shaft.
7. Every effort should be made to keep all debris other than rock fill from going underground.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	TT	--

ALEXCO ENVIRONMENTAL GROUP

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TETRA TECH EBA

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No:
AKHM-13-01-S-0303-ShaftCap

Figure 7-7

Shaft/Raise to Surface Typical Concrete Cap Design

REVISION: A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW

7.1.4 Onek Mine

The Onek mine was developed in 2012 and currently consists of 220 meters of a primary decline and surface facilities (office building, storage containers, and ventilation fan). P-AML WRSFs, N-AML WRDAs, and the vent raise have not yet been constructed. The Onek mine is not currently included in the Keno Hill Mine Operations LOM plan and these additional facilities would not be constructed until Onek becomes part of the LOM plan. An overview of the Onek mine is shown in Figure 7-8 and Figure 7-9. An as built of the Onek mine underground workings is shown in Figure 7-10.

Figure 7-8 Onek Mine Surface Overview

Adit

Existing Mine Feature Footprint

To Be Completed Mine Feature Footprint

Underground Workings Footprint

Secondary Road

Limited-Use Road

Watercourse

Aerial Imagery aquired on August 2017

Datum: NAD 83; Projection: UTM Zone 8N

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KENO DISTRICT MINE OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 7-9

ONEK 990 MINE LAYOUT

JULY 2018

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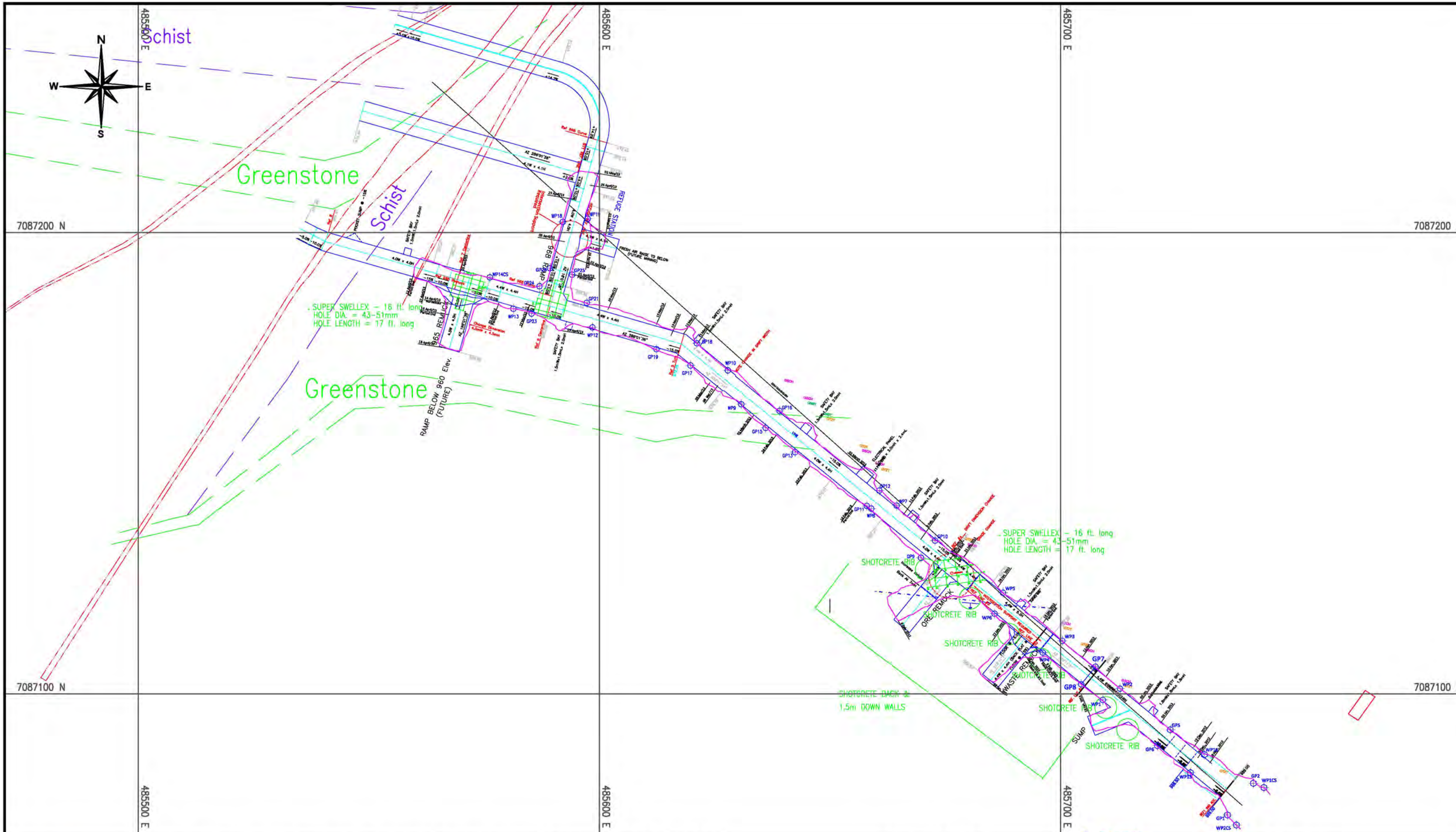


ALEXCO RESOURCE CORP BELLEKENO MINE	DEPT.	APPROVED BY	DATE	COMMENTS
	SURVEY			
	ENGINEERING			
	GEOLOGY			
	ALEXCO MANAGER			
	PROCON SUPER			

ALEXCO

TITLE: **ONEK**

ASBUILT 30 May 2013

Figure 7-10

Drawn by: DARIN BAKER	Scale: 1:750
Date: 05/30/2013	Approval: Date:
File: H:\Bellekeno Underground\Development-Planning\Promine\promine dra...	

7.1.5 Onek Mine Closure Measures

The closure measures associated with the Onek mine include the following steps:

1. Remove/salvage underground assets and equipment;
2. Remove any hazardous materials;
3. Remove/salvage surface facilities and infrastructure; and
4. Install rock pile portal cover at the Onek 990 portal.

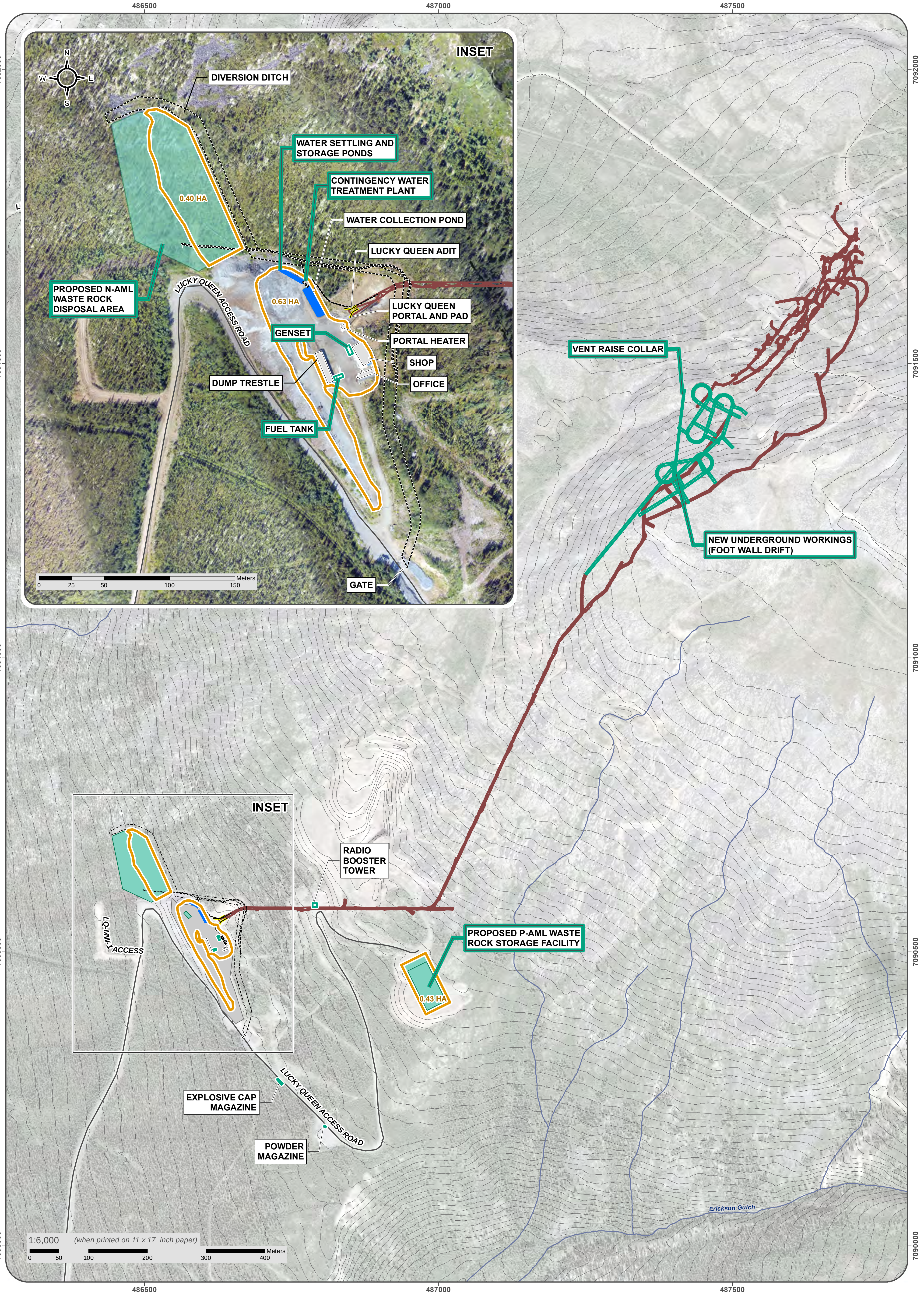
The Onek mine is not expected to produce any water during operations or closure. This is evidenced by groundwater modelling presented during the environmental assessment and licensing process as well as the Onek decline development project that demonstrated no water was encountered or produced underground at Onek. Since the Onek decline was developed in September 2012 and suspended, no water has pooled at the bottom of the decline after nearly 3 years, again supporting the closure design for Onek that no long term water management features are required for the Onek mine for closure since no water is expected to flood the underground workings and exit the Onek 990 portal.

A rock pile cover similar to Bellekeno East (Figure 7-6) will be constructed to close the Onek 990 portal face and prevent inadvertent access from wildlife or people.

The grading plan and the reclamation measures for the Onek mine are described and presented on Drawings B-4101, B-4301 and C-4401 located in Appendix 3.1.

7.1.6 Lucky Queen Mine

The Lucky Queen mine adit was rehabilitated in 2011/2012 including installation of new ground support over the 1,200 metres of historic adit. This adit will provide primary ingress/egress to the Lucky Queen mine (Figure 7-11). The Lucky Queen mine 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. The current status of the Lucky Queen mine includes the portal, a portable office trailer, shop maintenance building and a storage building (Figure 7-12). An unlined settling pond is in place to manage water flowing from the Lucky Queen mine. 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 once it is declared. A P-AML WRSF has not been constructed yet for the Lucky Queen mine. An as built of the Lucky Queen underground workings is shown in Figure 7-13. The Lucky Queen life of Mine plan is presented in Figure 7-14.



Adit	Ditch/Pipeline
As Built Mine Features	Existing Underground Workings
Proposed Mine Features	Proposed Underground Workings
Pond	Other Road
Revegetation Area	Limited-Use Road
	Watercourse
	Contour (5 m interval)

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on February 2018

Datum: NAD 83; Projection: UTM Zone 8N

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FIGURE 7-11
LUCKY QUEEN MINE LAYOUT

JULY 2018

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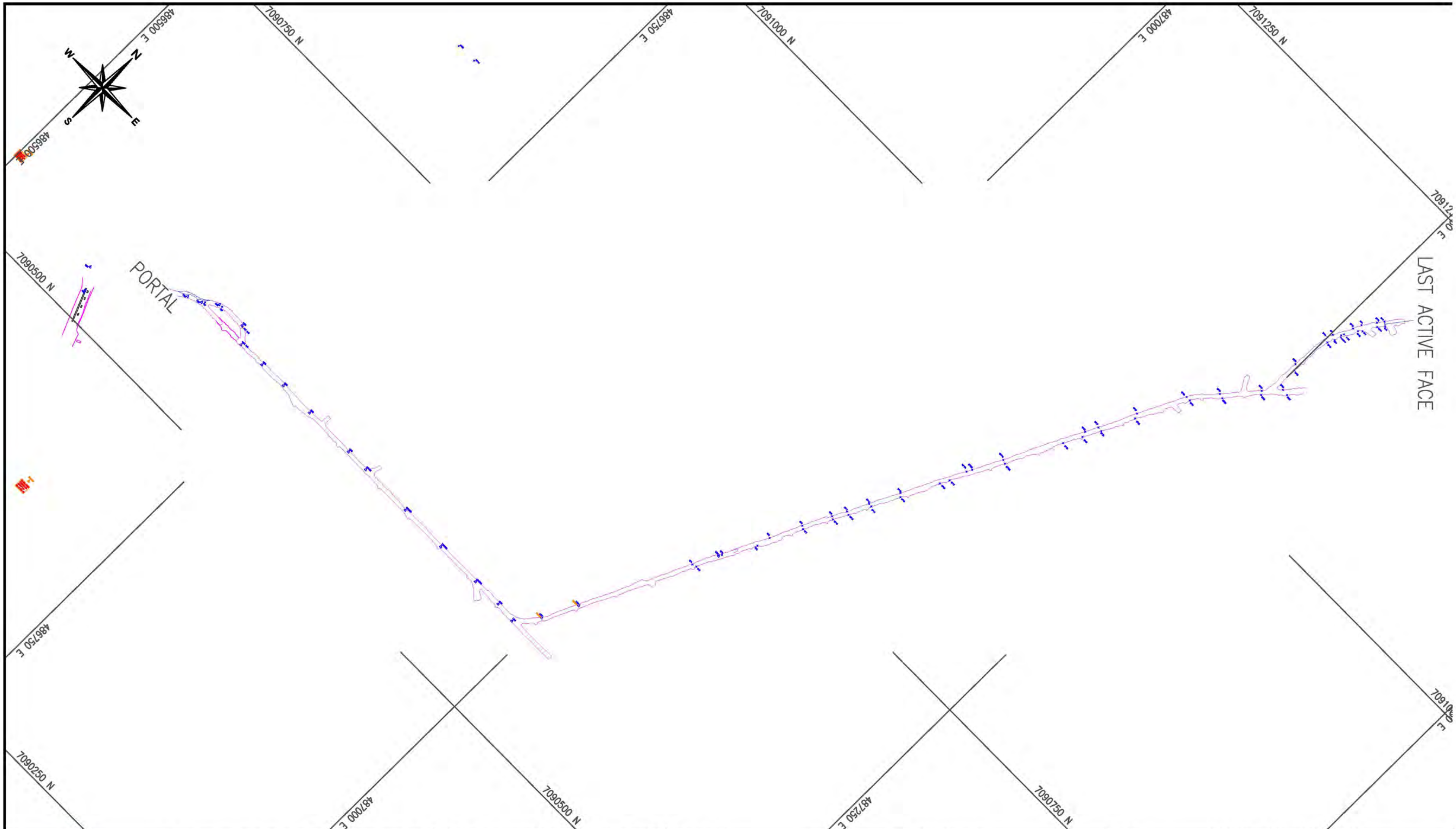
Figure 7-12 Lucky Queen Portal



ALEXCO RESOURCE CORP
BELLKENO MINE

DEPT.	APPROVED BY	DATE	COMMENTS
SURVEY			
ENGINEERING			
GEOLOGY			
ALEXCO MANAGER			
PROCON SUPER			

TITLE: LUCK QUEEN MINE
Asbuilt March 8, 2013
Figure 7-13

Drawn by: DARIN BAKER	Scale: 1:2500
Date: 03/08/2013	Approval: Date:
File: C:\Users\Darin Baker\Documents\Drawing1.dwg	

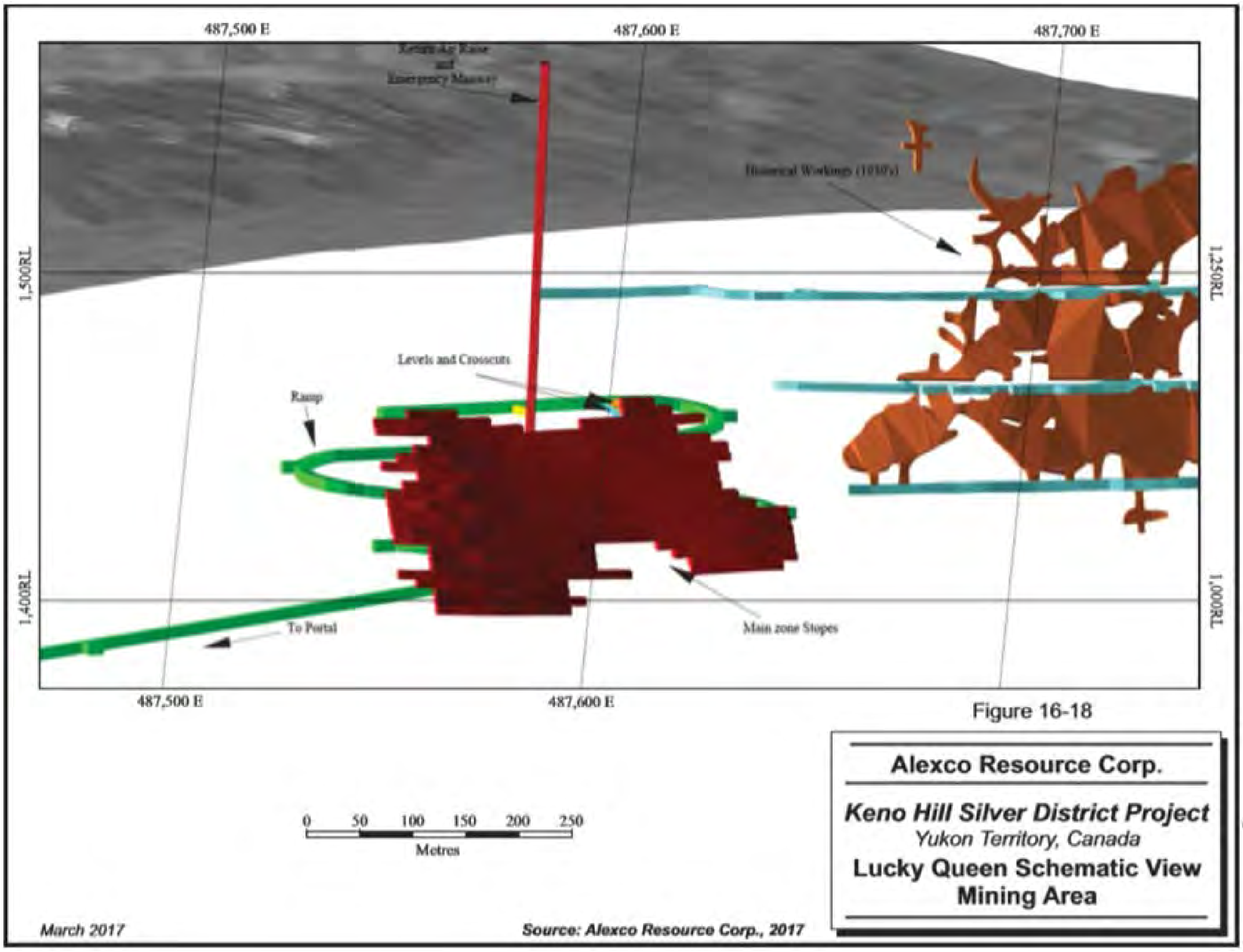


Figure 7-14 Lucky Queen Mine LOM Plan

7.1.7 Lucky Queen Mine Closure Measures

The steps and measures required for closure of the Lucky Queen Mine include:

1. Stabilize or backfill any remaining stopes as necessary to ensure long-term geotechnical stability underground;
2. Backfill any remaining P-AML waste rock on surface to underground;
3. Remove/salvage underground assets and equipment;
4. Remove/salvage surface facilities and infrastructure;
5. Remove any hazardous materials; and
6. Construct concrete adit bulkhead

The Lucky Queen mine drift is currently draining groundwater at a rate of approximately 1 lps. This water is predominantly clean groundwater that does not require treatment and meets direct effluent quality standards. The water from Lucky Queen is managed through an insulated bulkhead that collects water into a pipe and directs it to an unlined settling pond located outside the portal.

A concrete bulkhead will be constructed at Lucky Queen, similar to the design proposed for the Bellekeno 625 adit (Figure 7-31). The bulkhead is not designed for high pressure but will serve to collect water draining from the adit, prevent air movement and potential for ice formation inside the adit and prevent inadvertent access.

The grading plan and the reclamation measures for the Lucky Queen mine are described and presented on Drawings B-3101, B-3301 and C-3401 located in Appendix 3.1.

7.1.8 Flame and Moth Mine

The Flame and Moth deposit was outlined by surface exploration drilling in 2010 through 2013 with ongoing surface exploration. The Flame and Moth mine portal location is approximately 50 metres from the District Mill and will utilize common infrastructure (offices, power, water, compressed air, etc) associated with the mill. The location of the Flame and Moth mine in relation to the District mill is shown in Figure 7-15 and in Figure 5-4. The as-built of the Flame and Moth portal is shown in Figure 7-16. The Flame and Moth underground workings design is shown in Figure 7-17.

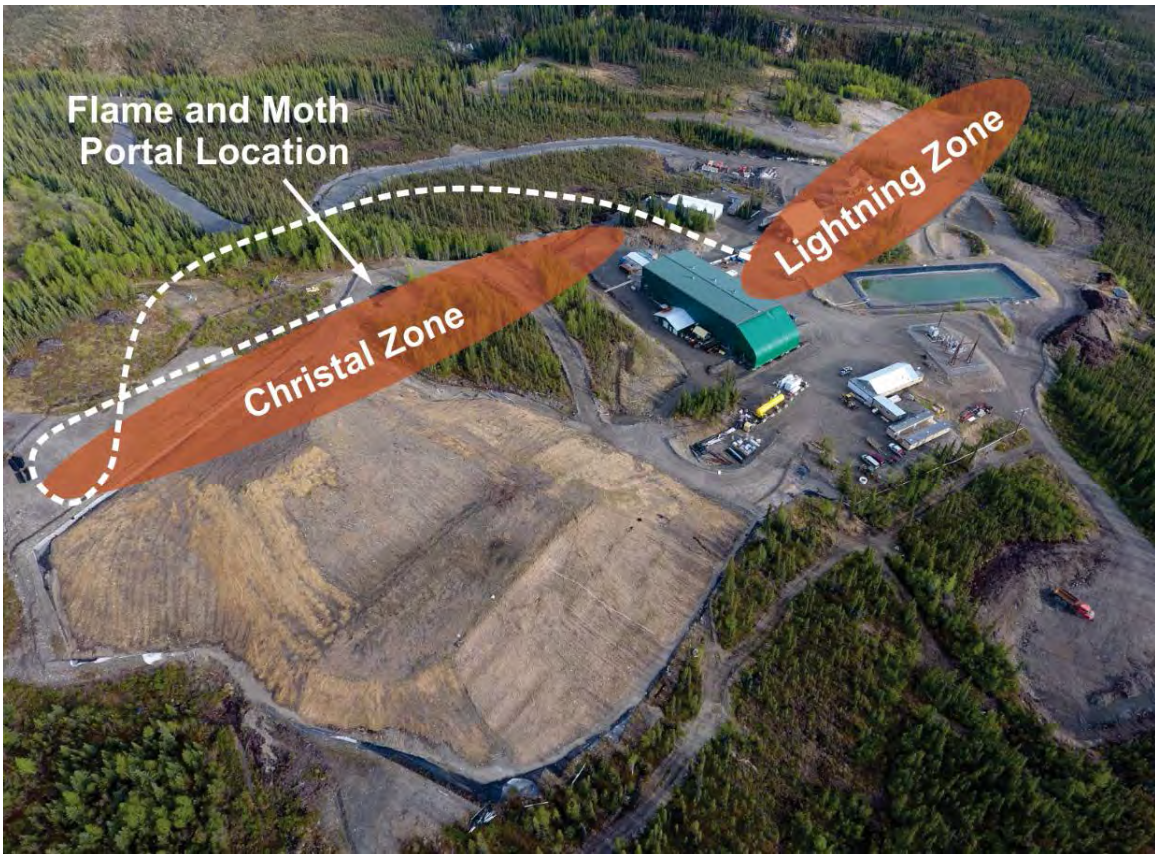


Figure 7-15 Flame and Moth Portal and Decline Layout

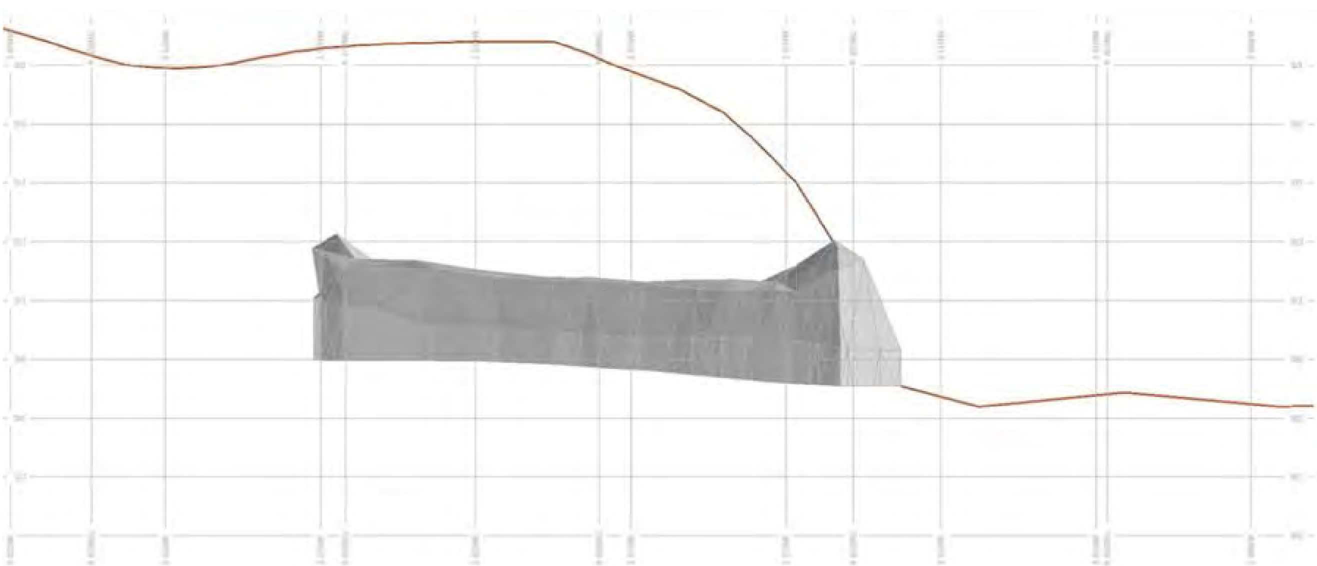


Figure 7-16 Flame and Moth As Built Conditions

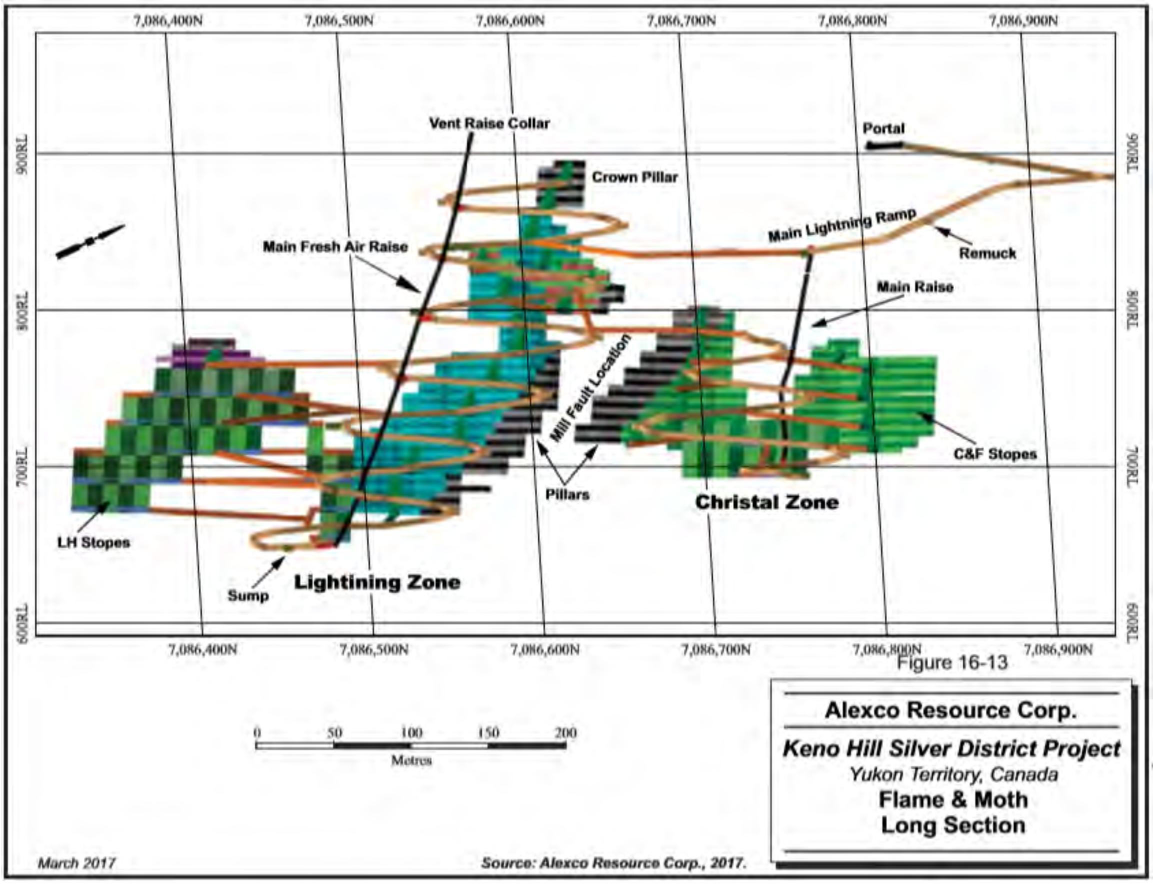


Figure 7-17 Flame and Moth LOM Plan

7.1.9 Flame and Moth Mine Closure Measures

The steps and measures required for closure of the Flame and Moth include:

1. Stabilize or backfill any remaining stopes as necessary to ensure long-term geotechnical stability underground; Backfill any remaining P-AML waste rock on surface to underground;
2. Remove/salvage underground assets and equipment;
3. Remove/salvage surface facilities and infrastructure not included in the mill area mine area component;
4. Remove any hazardous materials; and
5. Install rock pile portal cover.

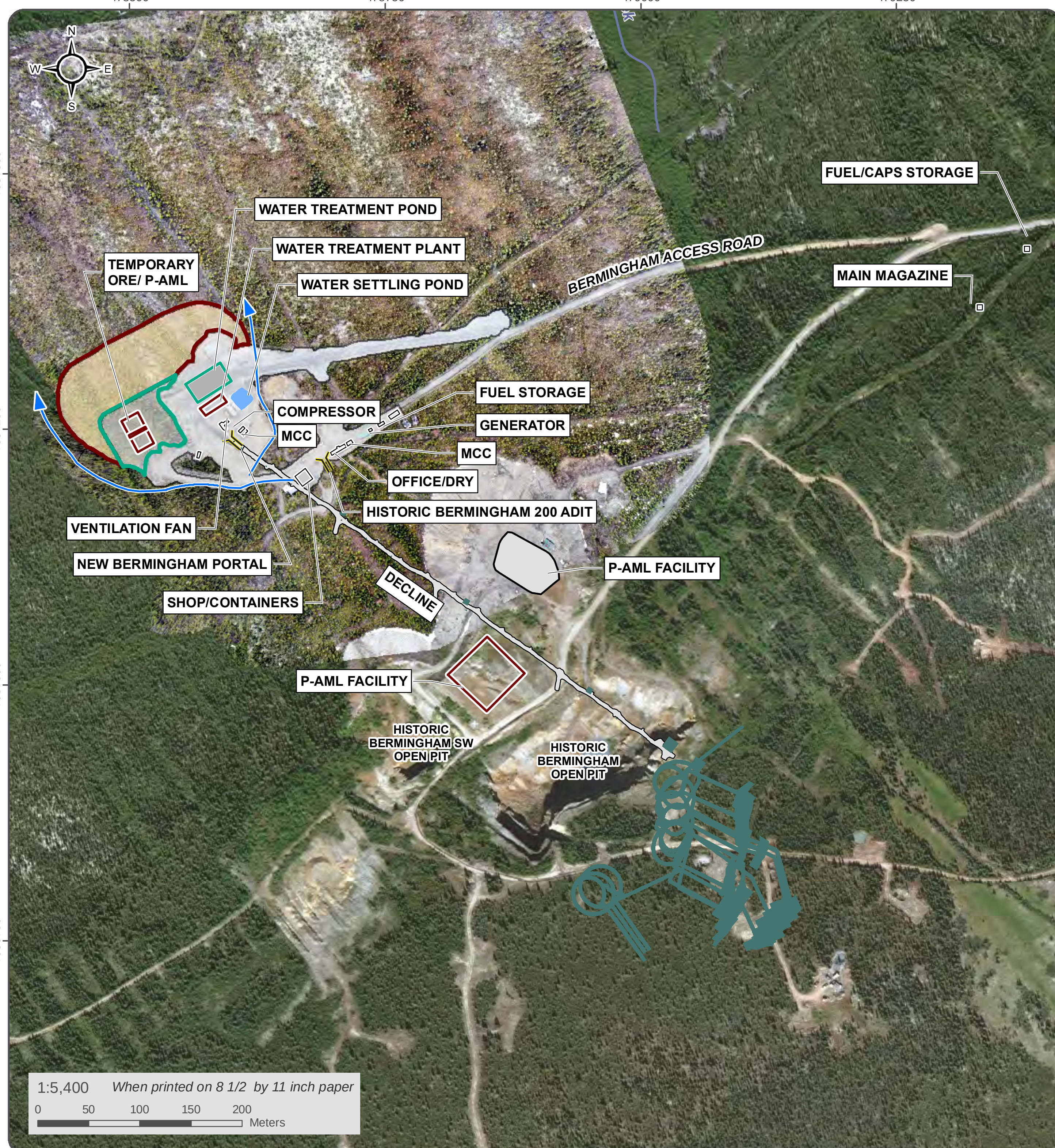
During operations, the Flame and Moth mine is expected to produce up to 35 lps at the deepest level of the mine. The current static water elevation of groundwater table within the Flame and Moth deposit is ~20 metres below surface. Once active mining operations cease, it is expected that the underground workings will flood overtime from groundwater infiltration. The elevation of groundwater is expected to return to current static elevations which is below the elevation of the Flame and Moth portal (906 masl) and therefore no water is expected to discharge the Flame and Moth mine requiring any ongoing water management at closure.

Reclamation measures for the Flame and Moth mine are described on Drawing C-1401 located in Appendix 3.1.

7.1.10 Bermingham Deposit

The Bermingham deposit was outlined by surface exploration drilling in 2010 through 2017. The Bermingham deposit is currently in an advanced underground exploration phase to better define the deposit for mine planning and engineering requirements (Figure 7-18). A total of ~ 9,400 m^3 of rock (670 meters @ 3.75m x 3.75m, ~25,300 tonnes) of waste rock will be brought to surface during the Bermingham underground exploration program. The Bermingham portal location is approximately 150 metres from the historic Bermingham 200 adit and infrastructure (offices, power, water, compressed air, etc) has been established for the advanced exploration program. The location of the Bermingham Portal is shown in Figure 7-18 and in Figure 7-19. The Bermingham advanced exploration surface layout is presented in Figure 7-20 and the advanced exploration decline as of December 31, 2017 is presented in Figure 7-21. The Bermingham underground workings life of mine design is shown in Figure 7-22.

Figure 7-18 Bermingham Advanced Exploration Decline and Surface Layout



Adit/Portal

Diversion Ditch

Proposed Underground Workings

As Built Pond

Permitted To Be Construced Mine Features

Proposed Mine Feature

As Built Mine Feature

ALEXCO KENO HILL MINING CORP.

FIGURE 7-19
BERMINGHAM MINE
PROJECT LAYOUT

APRIL 2019

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Datum: NAD 83; Projection: UTM Zone 8N

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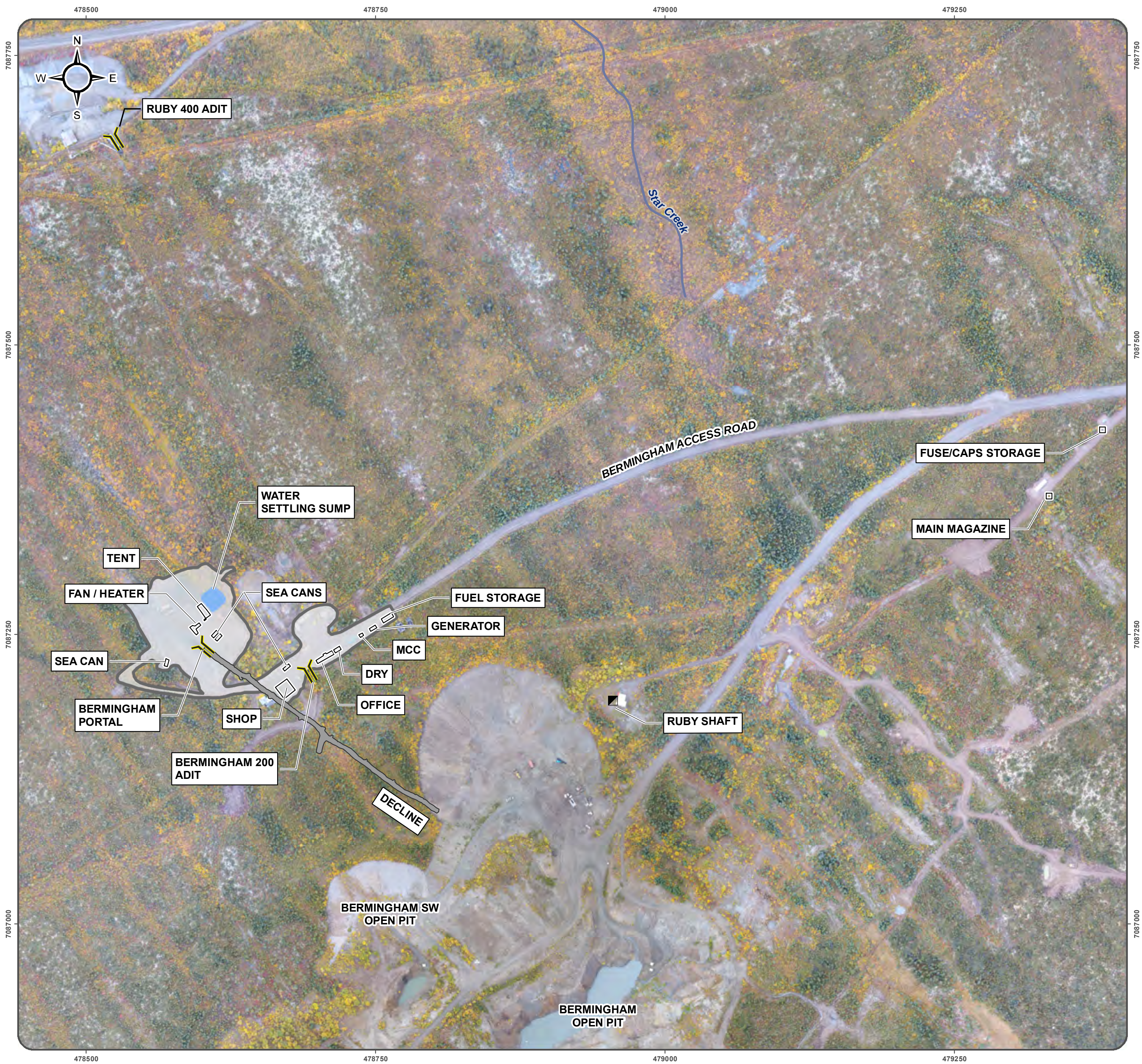
FIGURE 7-20
BERMINGHAM SURFACE LAYOUT AS-BUILT

JULY 2018



Adit/Portal
Shaft
Site Buildings
Decline
As Built Mine Footprint
Pond

0 50 100 150 Meters

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

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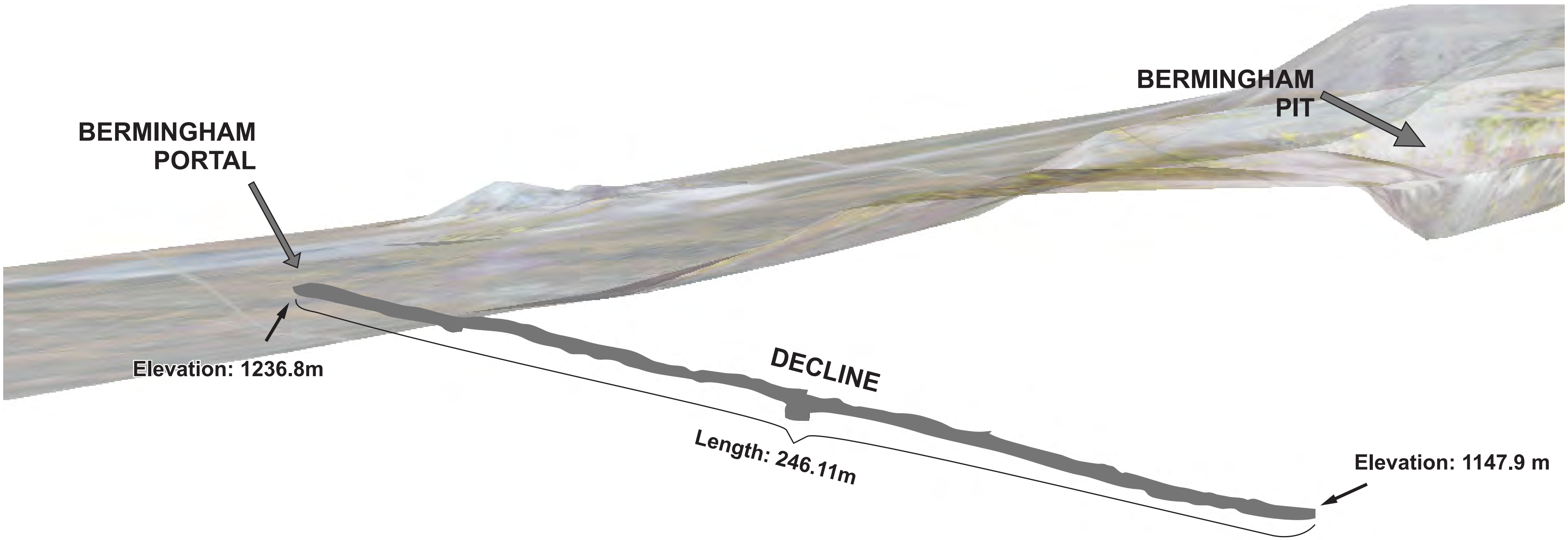
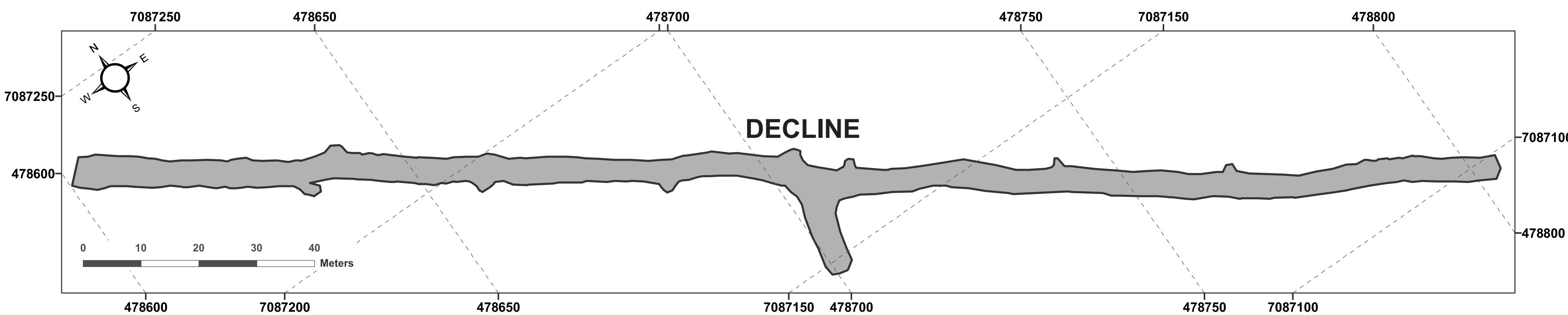
(*Last edited by: amatlashevska;23/01/2018/09:09 AM*)

VERTICAL SECTION VIEW



PLANAR VIEW



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CONCEPTUAL DRAWING; FEATURES ARE NOT TO SCALE

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KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-21
BERMINGHAM DECLINE AS BUILT

JULY 2018

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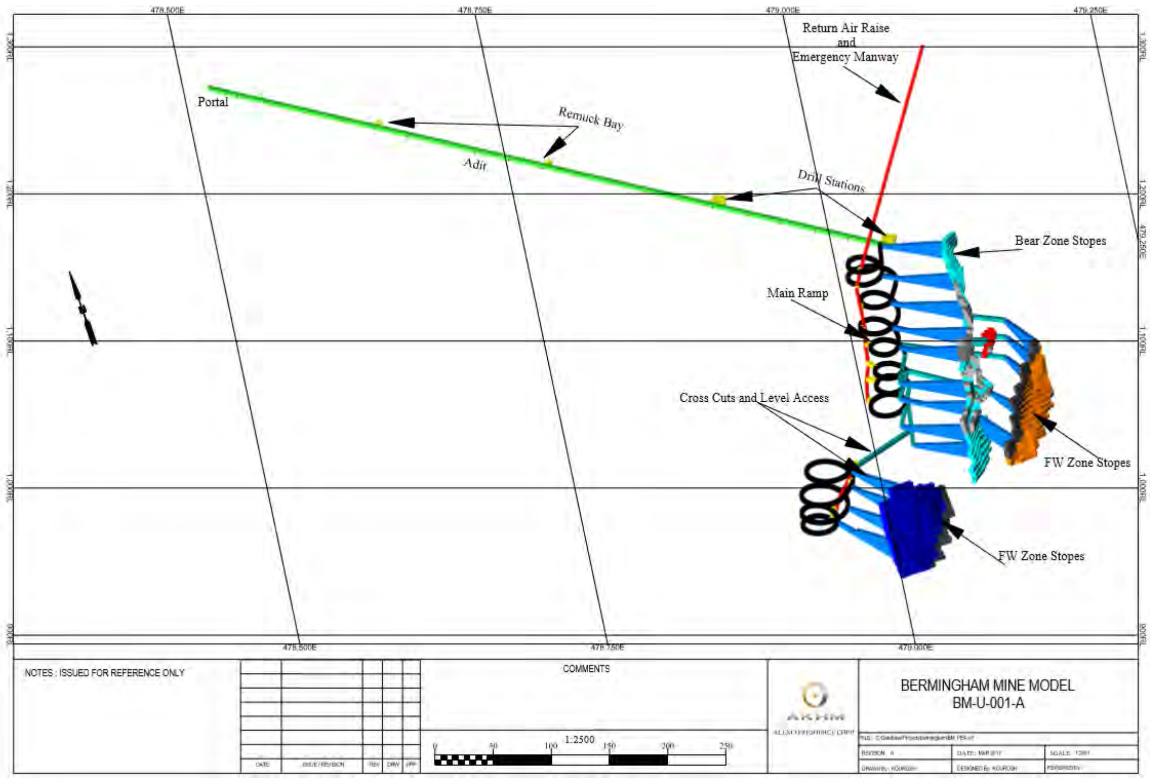


Figure 7-22 Bermingham LOM Plan

7.1.11 Bermingham Mine Closure Measures

The steps and measures required for closure of the Bermingham deposit and mine include:

1. Stabilize or backfill any remaining stopes as necessary to ensure long-term geotechnical stability underground; Backfill any remaining P-AML waste rock on surface to underground;
2. Remove/salvage underground assets and equipment;
3. Remove/salvage surface facilities and infrastructure;
4. Remove any hazardous materials;
5. Recontour N-AML WRSA, scarify and revegetate;
6. Install and implement mine pool treatment; and,
7. Install rock pile portal cover.

During operations, the Bermingham mine is expected to produce up to 13 lps at the deepest level of the mine. Once active mining operations cease, it is expected that the underground workings will flood overtime from groundwater infiltration. For the basis of long-term water management designs, it is assumed that the flooded Bermingham mine will discharge out of the portal and then infiltrate into the ground. Because of this assumption, mine pool treatment is included in the water management design for the closure of the Bermingham mine. The grading plan and the reclamation measures for the Bermingham mine are described and presented on Drawings B-5101, B-5301 and C-5401 located in Appendix 3.1.

Closure of the Bermingham mine will include restricting access and identifying and removing hazards and hazardous materials. Concern regarding physical stability of infrastructure at closure will be mitigated for the most part through disassembly and removal from the site, and by eliminating underground access. Additional chemical stability objectives will be associated with any soil contamination by fuel, chemicals or other wastes in the areas around the portal and treatment system. The Bermingham portal is expected to produce long term discharge therefore mine pool treatment is proposed.

At closure, underground equipment will be removed from the underground mine through the portal. The portal entrances will be blocked by inserting rock fill to protect human health and safety and prevent wildlife access. 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.

Reclamation of the portal site will include removal of the surface facilities 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 Environmental 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 soil 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 will be 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 Bermingham mine. The portal site would then be recontoured and scarified to facilitate revegetation and establish drainage. Signage will be installed to indicate the portal presence.

7.2 DRY STACK TAILINGS FACILITY

The dry stack tailings facility (DSTF) is located adjacent to the District mill site and the most recent as-built of the facility is shown in Figure 7-23 Dry Stack Tailings Facility Layout Current Conditions.

The closure objectives for the DSTF are to:

1. Ensure physical and geochemical stability of the DSTF;
2. Minimize erosion;
3. Effectively manage runoff;
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.

Water Licence QZ09-092 and QML-0009 authorizes 907,000 tonnes of tailings can be placed on surface in both the phase 1 and phase 2 expansion area. As of September 2013, approximately 179,811 tonnes of tailings have been placed on the DSTF representing approximately 20% 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 907,000 tonne volume. The DSTF will be progressively constructed and has been progressively 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.

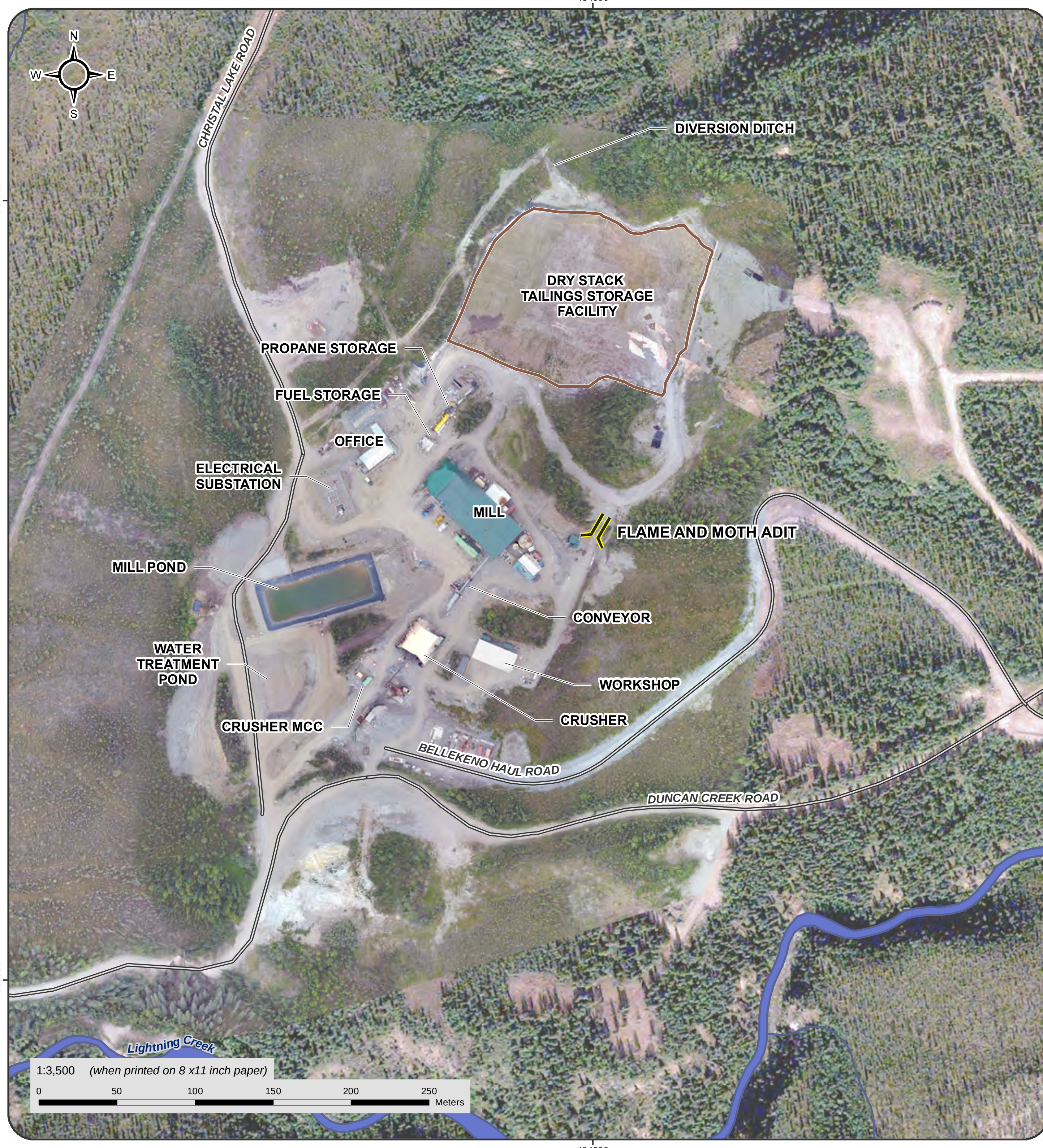
7.2.1 DSTF Geochemical Performance

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 was completed (212 week duration) for a composite sample of Bellekeno tailings produced and stored on the DSTF. The results of the kinetic testing for Bellekeno tailings are presented in Appendix 3.3. 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. Static and kinetic testing data from Flame and Moth waste rock and tailings are presented in Appendix 3.3.

7.2.2 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 a 0.25 m thick soil cover consisting of sandy loam growth media and granular material that is locally stored in stockpiles. The cover will limit water migration through the stack. The DSTF has been progressively reclaimed in 2 phases. The first phase of reclamation was completed in June 2012 and included the western slope of the DSTF with recontouring to a 3:1 slope, placement of a 0.25 – 0.5 m cover and seeding/fertilization. Figure 7-24 shows the reclamation underway on the DSTF during June 2012. The second phase of progressive reclamation was completed in August 2013 (Figure 7-25) and included recontouring the western slope of the upper bench and north and south slopes, placement of a 0.25 m cover and seeding/fertilization. A photo from the DSTF from September 2016 is presented in Figure 7-26. A summary report on the progressive reclamation on the DSTF completed in 2012 is included in Appendix 1.1. A similar evapotranspiration cover was constructed at the 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 seven-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.

The DSTF cover performance to date has shown no seepage from the toe of the dry stack facilities. Additional, groundwater well BH39 located in the dry stack tailings facility remains dry since installation. Runoff during snow melt and runoff from large rain events is captured and conveyed to the mill pond showing the cover is shedding water.



Adit

Current Dry Stack Storage Facility Liner

Road

Watercourse

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on January 2018

Datum: NAD 83; Projection: UTM Zone 8N

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FIGURE 7-23
DRY STACK TAILINGS FACILITY LAYOUT
CURRENT CONDITIONS

JULY 2018

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(*Last edited by: amatlashevska; 29/01/2018/09:07 AM*)

Figure 7-24 DSTF Progressive Reclamation, June 2012

Figure 7-25 DSTF Progressive Reclamation, August 2013

Figure 7-26 DSTF Progressive Reclamation, September 2016

The primary objective of the soil cover for the DSTF is to minimize erosion of the compacted tailings. Physical inspections from 2013 – 2017 demonstrate that the soil cover has been effective in doing so and has established vegetative cover as shown in Figure 7-26.

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).

Appendix 1.1 provides soil properties and nutrient analysis for the DSTF cover material. To maximize the efficacy of the cover, an engineering evaluation of the constructed 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.

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 that piloted at the Galkeno 900 adit across Christal Lake and proposed for the Bellekeno mine).

Reclamation measures for the DSTF are described on Drawing C-7401 located in Appendix 3.1.

7.3 WASTE ROCK STORAGE AND OVERBURDEN AREAS

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).

The closure objectives for the 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.

7.3.1 Bellekeno Waste Rock Storage Facilities/Disposal Areas

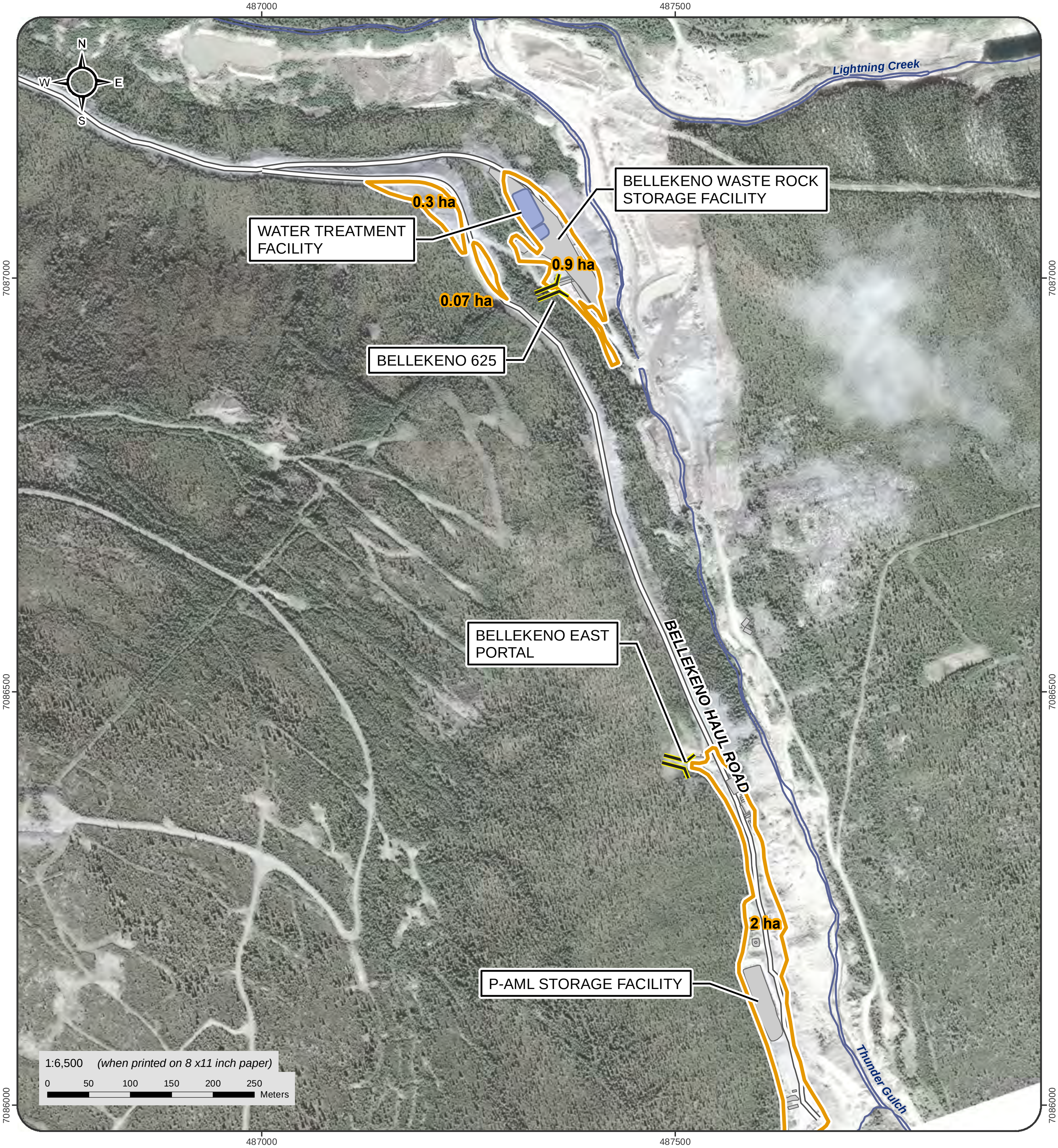
P-AML Waste Rock Storage Facilities

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 7-27). The facility was designed according to the approved generic design (EBA, 2008) Appendix 3.2. At closure, any remaining 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.

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. 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. With the current LOM plan for Bellekeno, there is no scheduled requirement for construction of a Bellekeno WRDA.

If, however a WRDA is constructed for Bellekeno, reclamation and closure will include 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.



Adit

Mine Feature Footprint

Pond

Revegetation Area

Haul Road

Watercourse

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on February 2018

Datum: NAD 83; Projection: UTM Zone 8N

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RECLAMATION AND CLOSURE PLAN

FIGURE 7-27
LOCATION OF EXISTING BELLEKENO WASTE ROCK STORAGE FACILITY

JULY 2018

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(Last edited by: amatlashevska; 06/02/2018/09:02 AM)

Bellekeno 625 Waste Rock Dump

The Bellekeno 625 waste rock dump (Figure 7-27) is a historic facility that is included in this RCP under the designation of the Bellekeno Production Unit. Reclamation and closure of the Bellekeno 625 WRDA will include cleanup of equipment on the top surface of the WRDA, pulling back the crests with an excavator followed by scarification and revegetation of the flat surface of the WRDA. Long term road access will remain for pickup traffic to the Bellekeno 625 adit given it will drain and inspections will be required during the post closure monitoring and maintenance period.

Bellekeno East and Bellekeno 625 area regrading plans are described in Drawings B-2101 and B-2102 respectively, located in Appendix 3.1.

7.3.2 Onek Waste Rock Storage Facilities/Disposal Areas

P-AML Waste Rock Storage Facilities

The Onek mine is not currently in the Keno Mine Operations LOM plan so no Onek P-AML or N-AML waste facilities are included in the RCP. A P-AML WRSF was constructed on the historic Onek waste rock dump to the north of the Onek historic open pit for the purposes of advanced exploration and production at Bellekeno. Although constructed, no P-AML rock has been brought to surface and stored from development of the Onek decline. Closure of the Onek P-AML WRSF therefore includes removal of the liner and recontouring the outside containment berms followed by scarification of the surface and seeding/fertilization.

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 7-9). N-AML material may also be placed underground as mine backfill as required. No N-AML WRDA has been constructed and development rock from Onek was used for construction of the portal area laydown yard and haul road switch backs.

If the Onek N-AML WRDA is built, it 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.

Onek area regrading plan is described in Drawings B-4101 and B-4301, located in Appendix 3.1.

Onek Historic Waste Rock Dumps

Terrestrial reclamation of historic liabilities at Onek is currently under the scope of the District Closure Plan and is not included in the RCP.

7.3.3 Lucky Queen Waste Rock Storage/Disposal Areas

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 design. P-AML waste rock will be placed in the WRSF or underground as mine backfill, as required.

At closure, the P-AML 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 potion of the cover shall consist of growth medium that will be seeded to promote vegetative growth.

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 7-11). 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.

Lucky Queen area regrading plan is described in Drawings B-3101 and B-3301, located in Appendix 3.1.

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.

7.3.4 Flame and Moth Waste Rock Storage/Disposal Areas

Flame and Moth P-AML Waste Rock Storage Facilities

A lined temporary P-AML storage facility will be constructed as per EBA's generic facility design near the portal entrance (up to 12,000 tonnes) (Figure 5-4 and Appendix 3.5). This will be used during the initial development (137,000 tonnes) after which the development schedule will enable all P-AML development rock to remain underground, and the P-AML rock stored within the temporary facility will be moved back underground as backfill. All P-AML waste rock will be rehandled back underground prior to closure.

Flame and Moth N-AML Waste Rock Storage Facilities

A N-AML waste rock disposal area will not be built for Flame and Moth Mine as the rock will either be used for construction or used as backfill. N-AML materials may be used for construction of portal pad and laydown area, expanded coarse ore stockpile, mill yard expansion, new haul road to crusher and construction of the toe berm and base layer for DSTF expansion.

7.3.5 Bermingham Waste Rock Storage/Disposal Areas

Bermingham P-AML Waste Rock Storage Facilities

A temporary P-AML storage facility will be constructed as per EBA's generic facility design near the portal entrance (up to 10,000 tonnes). This will be used during the initial development (165,000 tonnes) after which the development schedule will enable all P-AML development rock to remain underground, and the P-AML rock stored within the temporary facility will be moved back underground as backfill. All P-AML waste rock will be rehandled back underground prior to closure.

Bermingham N-AML Waste Rock Storage Facilities

A N-AML waste rock disposal area will be built for the Bermingham Mine (Figure 7-19) or rock will either be used for construction or used as backfill. N-AML materials may be used for construction of portal pad and laydown area, and roads.

Bermingham area regrading plan is described in Drawings B-5101 and B-5301, located in Appendix 3.1.

7.4 WATER MANAGEMENT STRUCTURES AND SYSTEMS

7.4.1 Closure Objectives and Design Criteria

The primary closure objectives for the water management and treatment sites are in regards to chemical stability and environmental protection, including:

1. Prevent, minimize or mitigate adverse effects on the aquatic environment by removing constituents of concern prior to discharge to the aquatic or terrestrial environment.

2. Minimize effects on the terrestrial environment by reducing sources of metals that could affect soil quality.

3. Prevent the discharge of water to the environment that could cause human health effects.

A summary of the water management and treatment plan for each of the four mines and adits associated with the RCP is shown in Table 7-2.

Table 7-2 Mine Water Management Summary

Mine	Units
Bellekeno East	• No water discharges from Bellekeno East • Rock fill in front of adit
Bellekeno 625	• Mine floods and discharges from the 625 adit • Concrete hydraulic bulkhead (non-pressurized) • In situ treatment of Bellekeno mine pool as primary treatment • Convert lined WTP ponds to bioreactor as contingency
Lucky Queen	• Groundwater infiltration exits the Lucky Queen mine/portal • No treatment required • Concrete hydraulic bulkhead (non-pressurized)
Onek	• No water discharges from Onek 990 portal • Rock fill in front of adit
Flame and Moth	• Mine floods and reaches pre-mining static groundwater elevation (20 metres below surface and portal elevation, no portal discharge) • Rock fill in front of adit
Bermingham	• Mine floods and assumed to discharge out of Bermingham portal • In situ treatment of Bermingham mine pool as primary treatment • Active water treatment plant will remain in place and ready for operations as a contingency measure for a period of time for the Bermingham in situ treatment to demonstrate stability • Rock fill in front of adit

7.4.2 Bellekeno 625 Adit

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 contingency treatment system if it is required for treatment. As part of the District Wide Closure Planning process, preliminary and indicative designs for concrete bulkheads for numerous mines in the district have been developed. Appendix 3.5 provides preliminary design information excerpted from the ESM Reclamation Plan for the Keno Hill District (Keno Hill Adit and Shaft Closure, Tetra Tech EBA March 2015). A preliminary design for the Bellekeno 625 adit concrete bulkhead is shown in Figure 7-31. The size of the Bellekeno 625 adit 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 and flooding rates to be expected from the Bellekeno mine. The information to date supports a long-term mine inflow rate of ~2.85 lps. 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.
- Final detailed design engineering will be required to construct a concrete bulkhead at Bellekeno 625. A preliminary design is shown in Figure 7-31 (Appendix 3.1, Drawing S-0302). The bulkhead would be put in place as the mine pool is allowed to flood (currently estimated to take 6-8 months).
- 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 mine sites throughout North and South America and it has proven highly successful in reducing soluble metal loading. This technology is also undergoing a full-scale demonstration at Silver King as part of the District Closure project. The mine pool would be accessed through the Bellekeno East decline 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 1.2.
- Once active treatment and pumping of the mine pool ceases, the mine workings are allowed to flood and *in situ* treatment begins, conversion of the current water treatment ponds at Bellekeno 625 into bioreactors would take place. Bioreactor conceptual design described in Drawings D-2102 and D-2301, located in Appendix 3.1.
- 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 and can serve as a polishing step to the mine pool primary treatment if necessary. Bioreactor commissioning will be performed by recirculating water in the

bioreactor so as water begins to come from the mine the bioreactor will transition from recirculated water to adit discharge, if further treatment is required.

Bellekeno Mine In Situ Treatment Design

Design information required for in situ treatment at Bellekeno includes retention time, mine in flow volumes and mine water chemistry. The estimated volume of openings in the Bellekeno mine versus the mine elevation is shown in Table 7-3. Mine inflow is measured on a daily basis and the litres per second of pumping is shown in Figure 7-28. The average water inflow since mine operations were suspended in January 2015 – January 2017 is less than 2 lps. The measured mine inflow is used for water treatment and management design purposes and represents the long-term expected inflow to the Bellekeno mine. This is a conservative estimate since dewatered mines typically have a greater groundwater capture efficiency than a flooded mine because a dewatering cone develops around a dewatered mine, while when flooded the mine dewatering cone is minimized, essentially becoming a preferential flow path for localized groundwater seepage to surface.

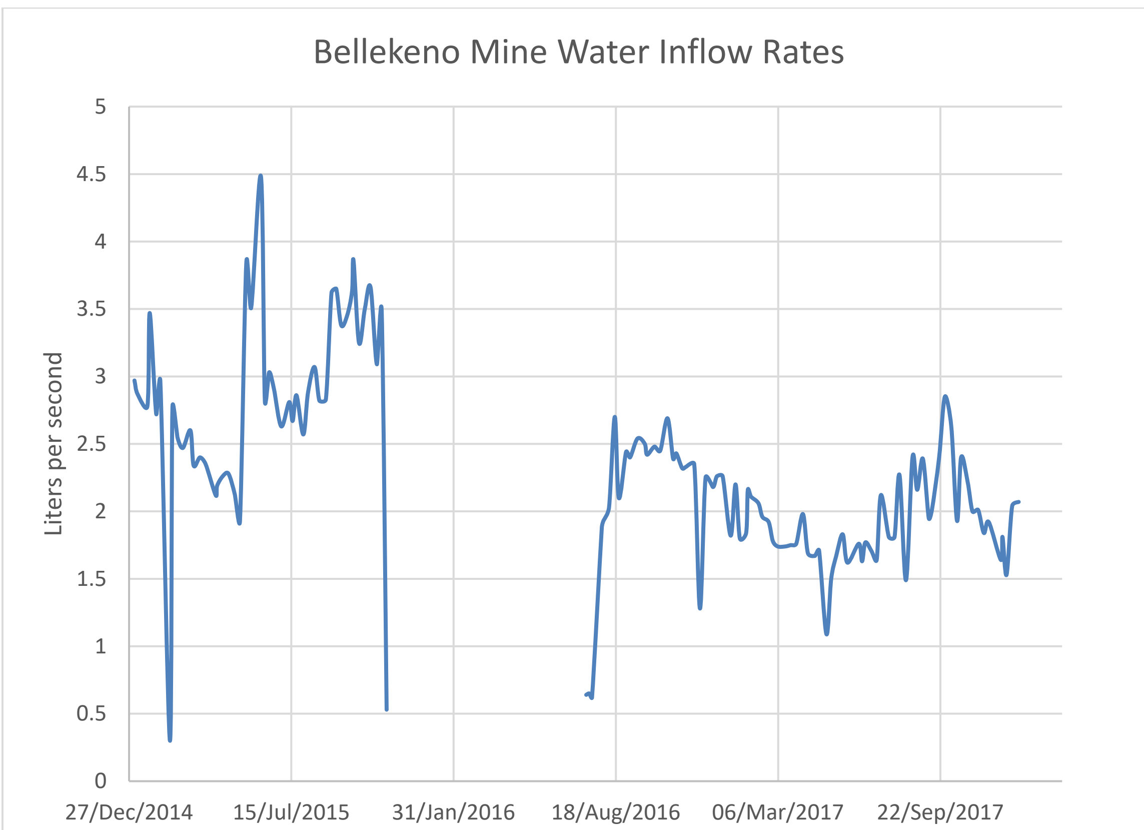


Figure 7-28. Bellekeno Mine Adit Discharge 2015 – Apr 2017

Zn concentrations in the Bellekeno mine water have remained relatively constant over the period August 2013 – January 2018 and represent the long term expected chemistry of the Bellekeno mine under closure conditions. Figure 7-29 shows the Zn concentration at Bellekeno since the mine has been in suspension and has had no mining related impacts (i.e. material movement, blasting, mucking, etc.). This is also a conservative design basis, as flooded mines typically have reduced metals leaching compared to dewatered mines because oxygen transfer is minimized where air is excluded. If anything, in the long term metals leaching, specifically zinc, should be expected to decrease as the mine is flooded and many of the voids become saturated. Some metals leaching is still expected for the mine voids that are above the flooded level (Bellekeno 625).

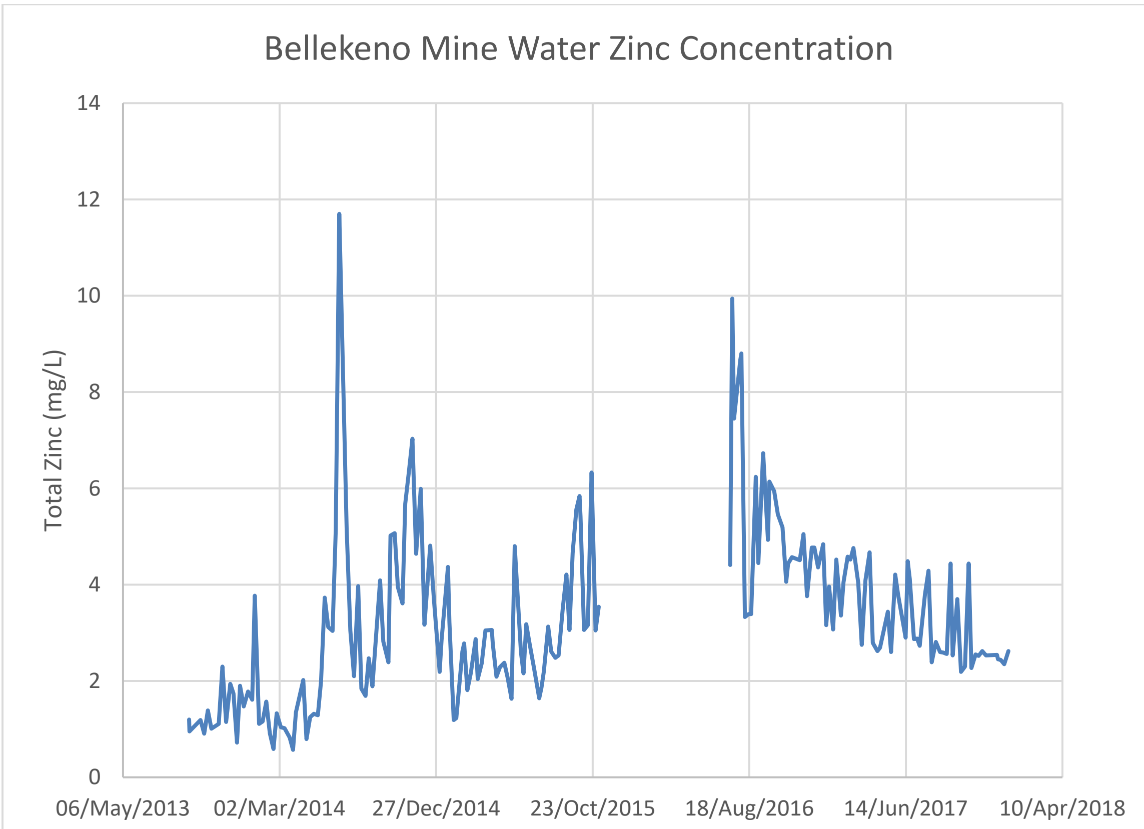


Figure 7-29 Total Zinc Concentration Bellekeno Mine Discharge

Table 7-3 Cumulative Mine Volume vs Elevation

Bellekeno Mine Elevations	Cumulative Mine Voids – m^3
625-650	67,633
650-700	50,685
700-750	38,556
750-800	36,994
800-850	21,467
850-900	4,290
900-950	2,730

A comparison of mine inflow and retention time is shown in Figure 7-30.

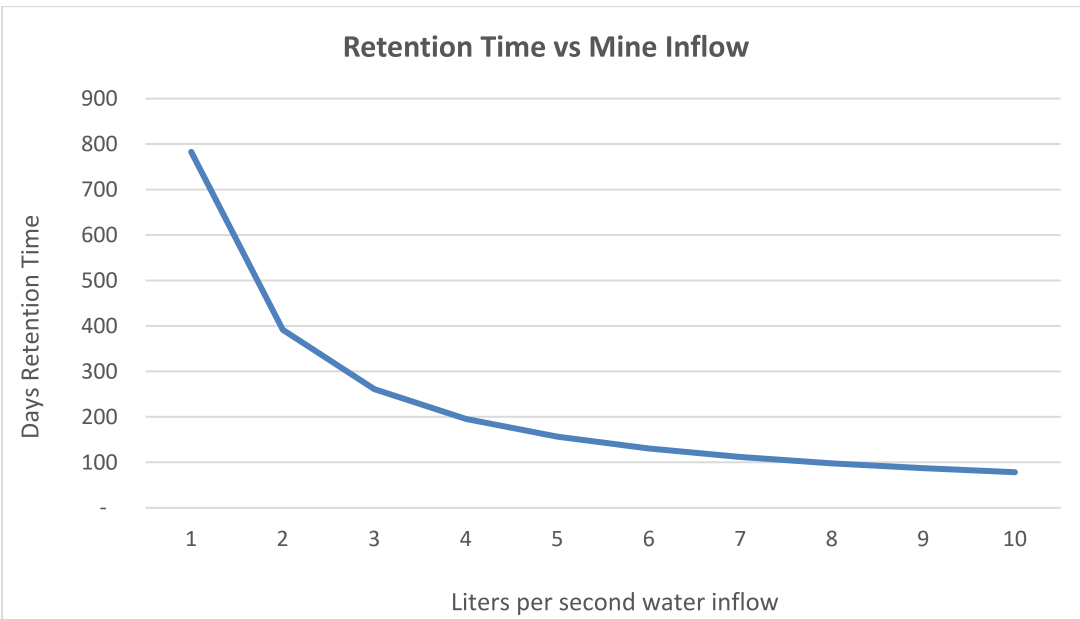


Figure 7-30 Bellekeno Retention Time vs Mine Water Inflow

The design parameters for in situ treatment of Bellekeno mine water is presented in Table 7-4.

Table 7-4 Bellekeno In Situ Treatment Design Parameters

Design Parameter	Unit	
Mine Inflow	Base Flow: 4 lps	Max Flow: 6 lps
Zn Untreated	Average: 4 mg/l	Max: 8 mg/l
Zn Treated	Discharge Criteria: 0.5 mg/l	
Mine Volume	67,600 m^3	

Retention Time	Average Retention: 200 days	Minimum Retention: 130 days

Based on the design flow of 4 lps and void openings of 67,600 m^3, it is calculated that there is approximately 200 days of retention time in the Bellekeno mine pool which is more than ample for effective in situ treatment.

The following summarizes the main design features of the Bellekeno in situ treatment system. The process flow and instrumentation diagram for the Bellekeno is situ treatment system is shown in Figure 7-35.

An adit concrete bulkhead at 625 will collect and manage water stored in the mine and provide hydraulic retention time (HRT), as well as providing access control. Figures 7-31 present a preliminary design for a concrete bulkhead applicable to Bellekeno 625. The bulkhead will consist of pressure monitoring instrumentation, clean out conduit (4") for removal of built up sediments behind the bulkhead and upper and lower discharge lines to gravity drain water from behind the bulkhead to the bioreactor.

A pipeline and recirculation pump to inject reagents and water recirculation to various levels of the mine. The Bellekeno mine is equipped with both air and water lines from surface to all levels throughout the mine and will be used as the recirculation and reagent addition pipeline upon closure. The discharge location of the injection pipe is planned to be in the stopes on the 850 level of the Southwest Zone (see blue dots in Figure 7-4). Water from the 625 level will be collected, amended with the design dose of reagents, and injected in the discharge location as illustrated, using the existing water lines.

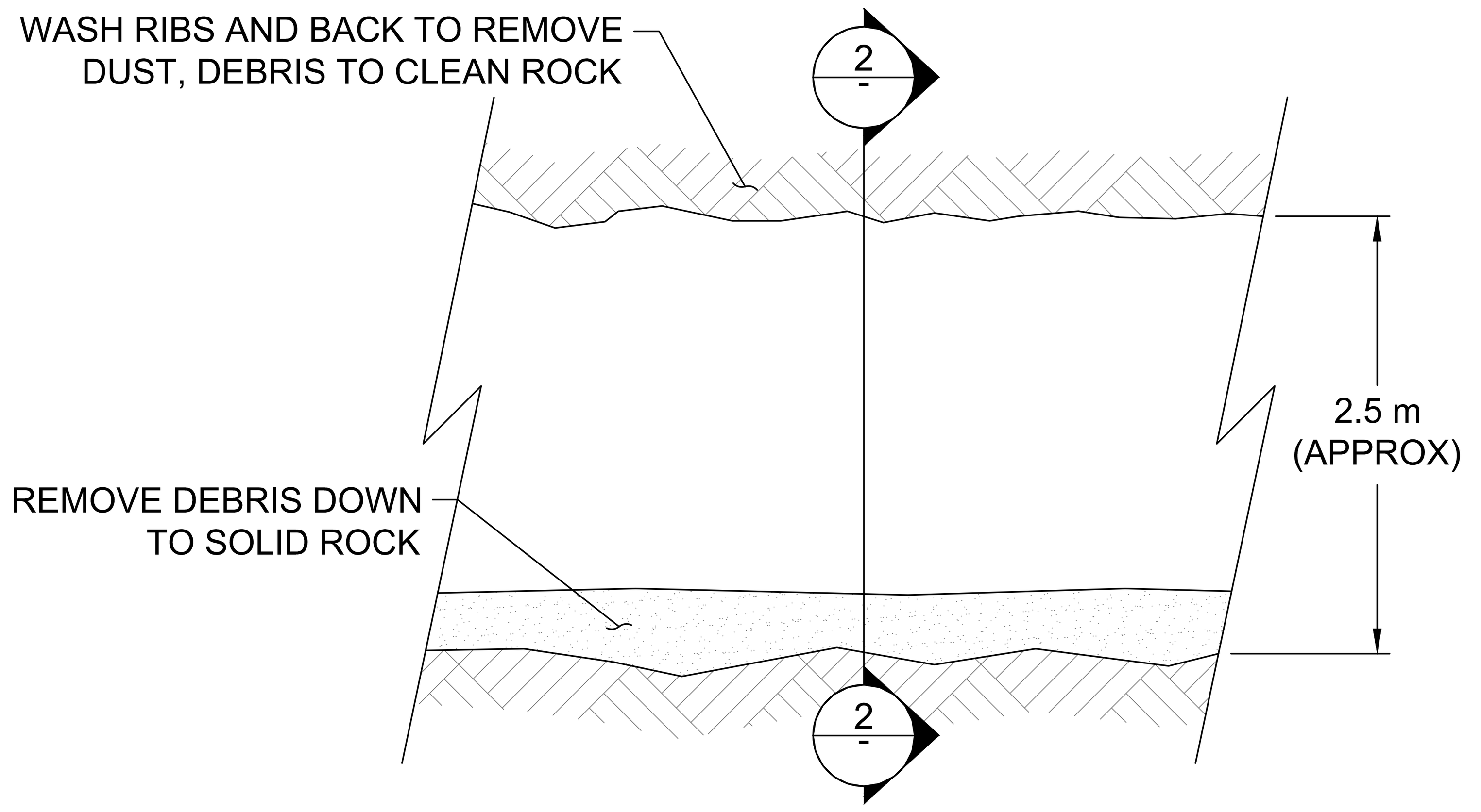
Site power will be supplied by current grid power connected at the Bellekeno 625 substation.

A process control and monitoring shed will be used to house the controls and monitoring systems for each site. This system will allow for the observation of the mine pool levels, in situ water chemistry parameters (pH, ORP, specific conductivity, and water temperature), flow rates, bulkhead pressures, and reagent tank levels. The collected information will be data logged, which allows for the review of the collected data over time. A sampling port will also be available to sample each site for lab water chemistry parameters. The current water treatment shed at 625 will be repurposed for this requirement.

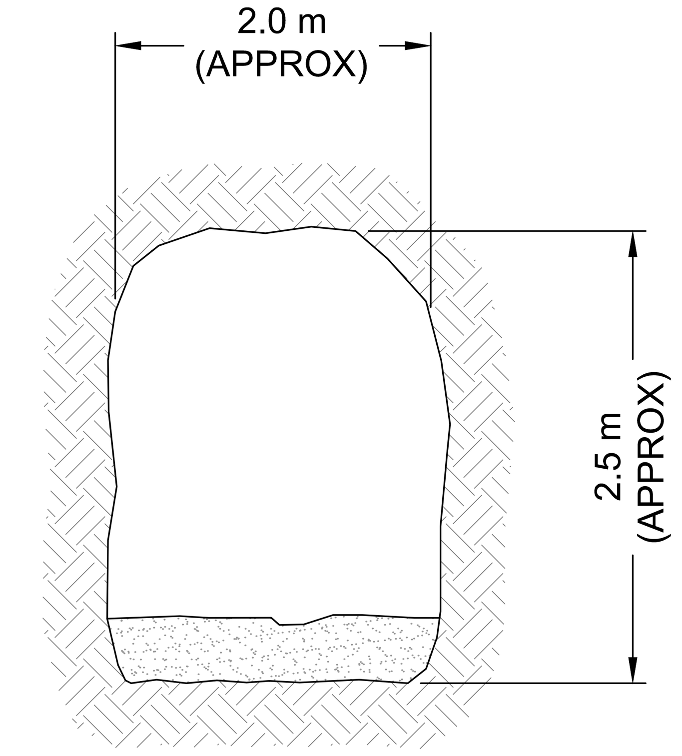
A reagent storage tank will be used to store site reagents. In most cases, an alcohol-based reagent will be utilized and stored in a tank sized to hold up to 12 months of reagent demand. The current lime tank inside the treatment shed at Bellekeno 625 will serve this purpose.

A reagent dosing pump with variable speed controls will be used to transfer reagents from the storage tank to the system pipeline for static mixing and conveyance for injection. The reagent dosing pump will be controlled by a Programmable Logic Controller located within the process control and monitoring shed, which allows reagent additions to be proportional to system flow rates.

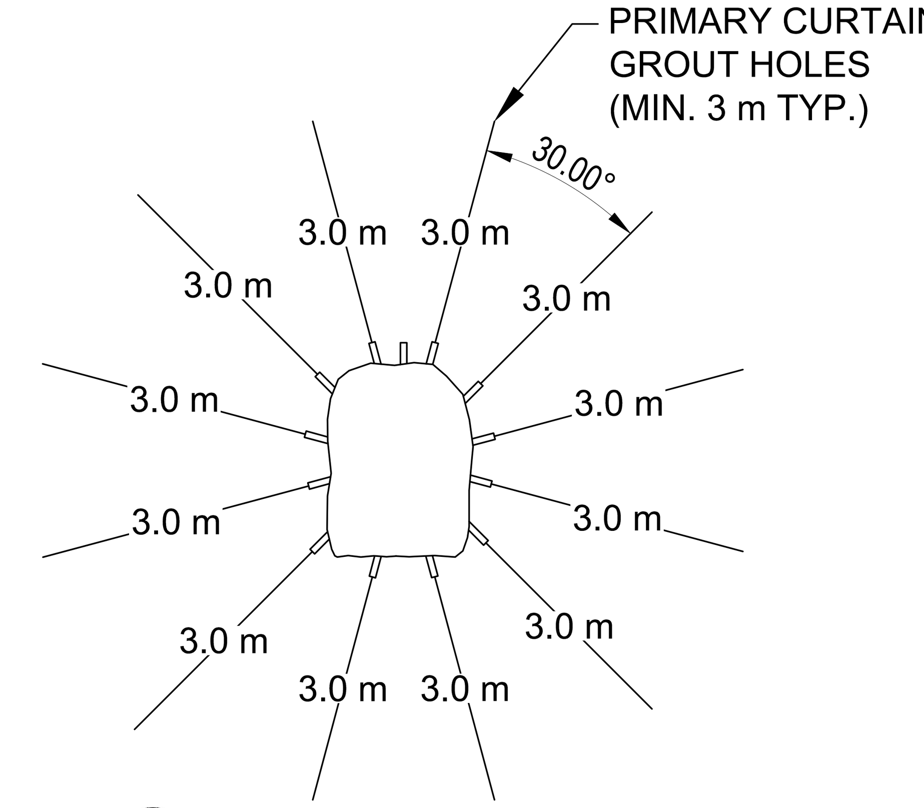
A Programmable Logic Controller (PLC) will be located in the process control and monitoring shed. This system is capable of monitoring up to eight 4-20 mA inputs from pressure gauges, flow meters, level sensors, and other monitoring equipment. In addition, it includes up to four 4-20 mA outputs that can control metering pumps, proportional flow valves, and other control equipment. The PLC system currently designed for each site will be connected to the internet allowing for real-time process monitoring and remote alarm notifications. This will also allow for in situ treatment experts to evaluate treatment data in real time and make adjustments.



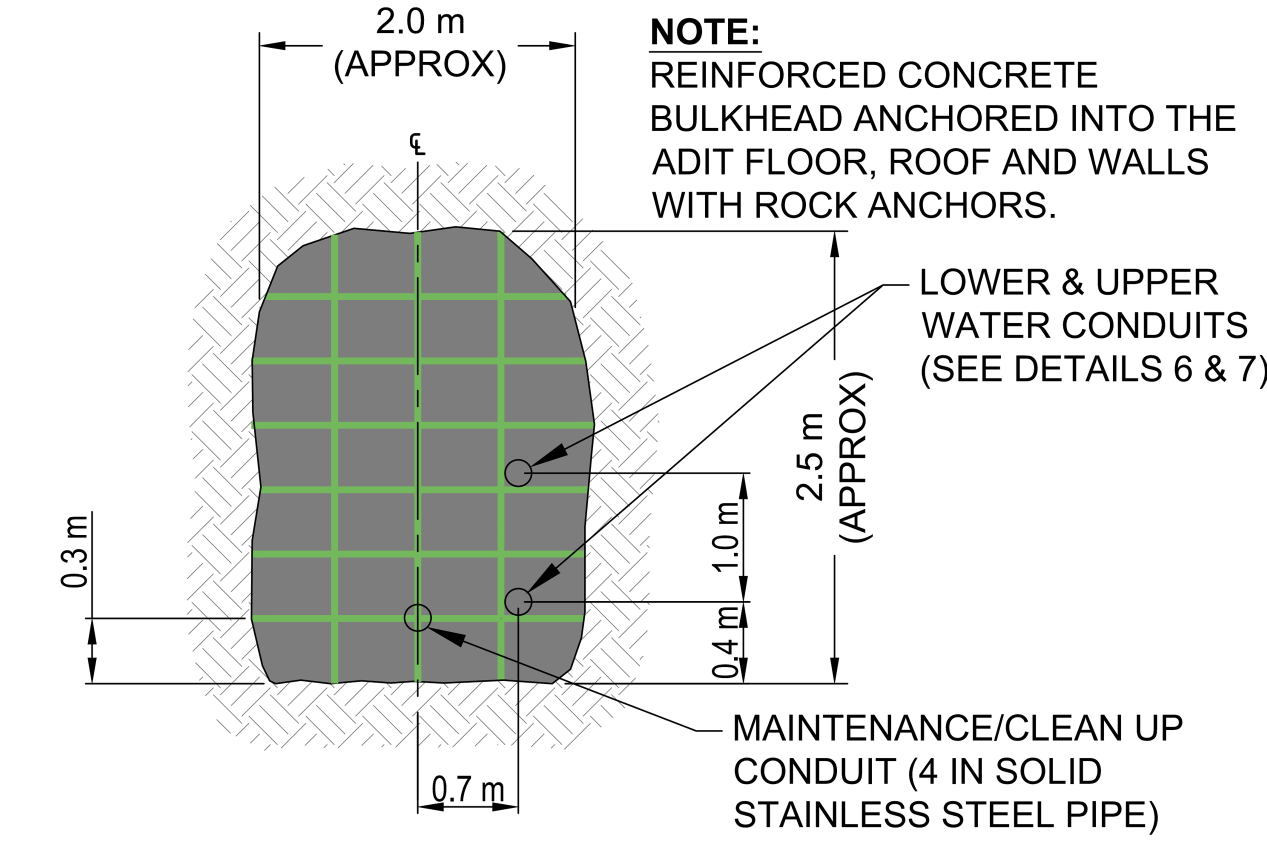
1 - PREPARE PLUG LOCATION - LONGITUDINAL SECTION VIEW
NOT TO SCALE



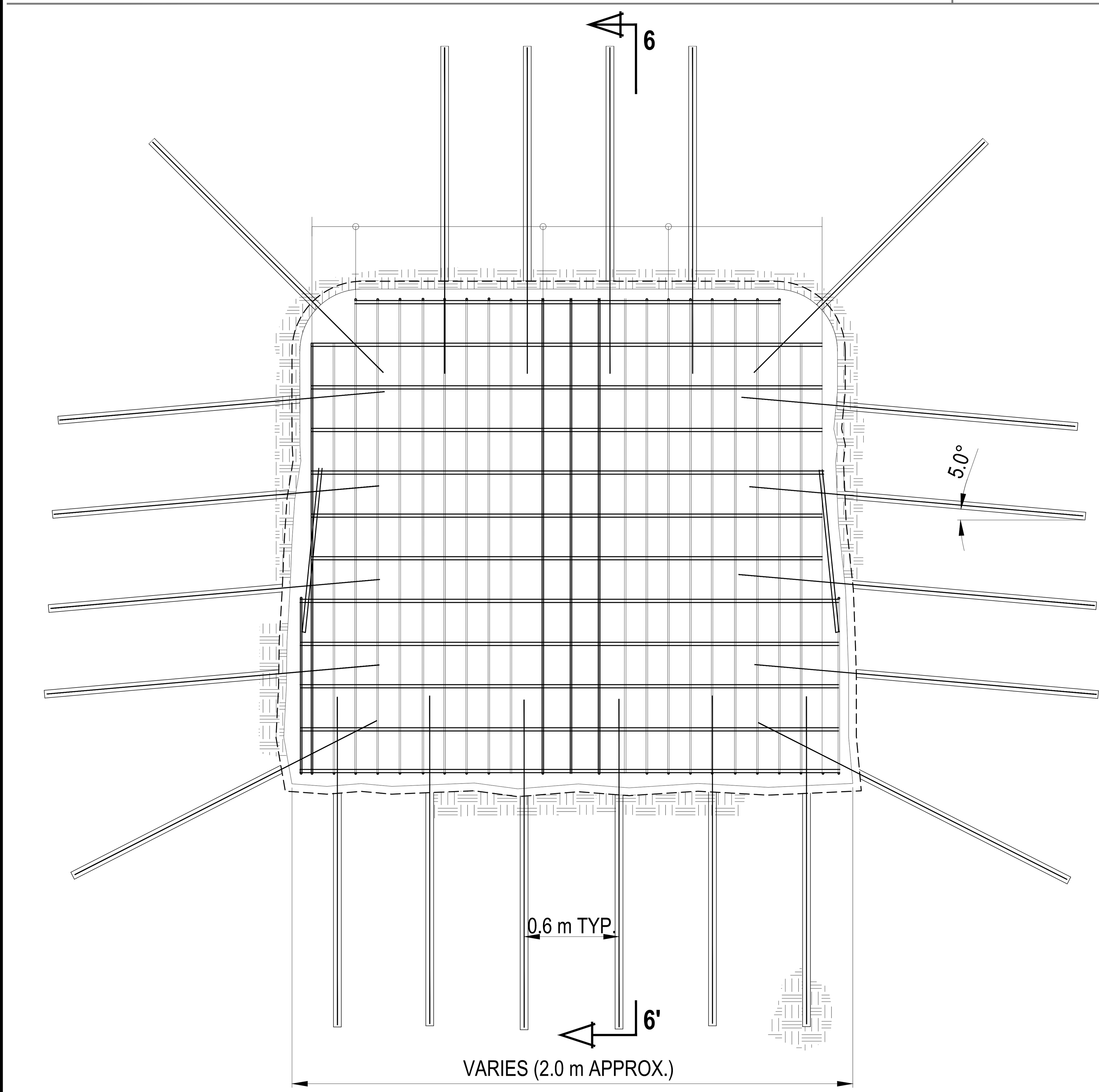
2 - ADIT CROSS SECTION
NOT TO SCALE



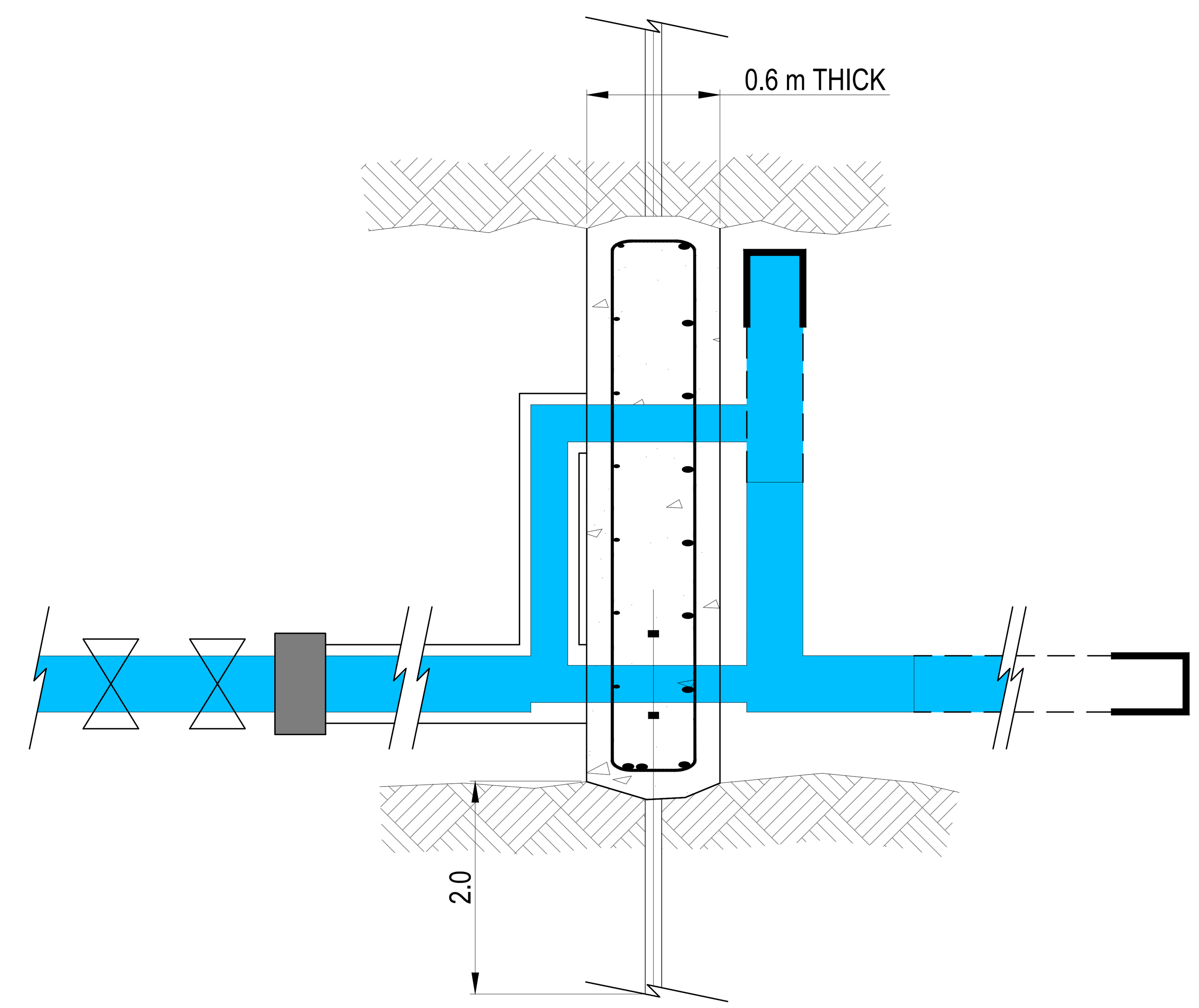
3 - PRESSURE GROUTING
NOT TO SCALE



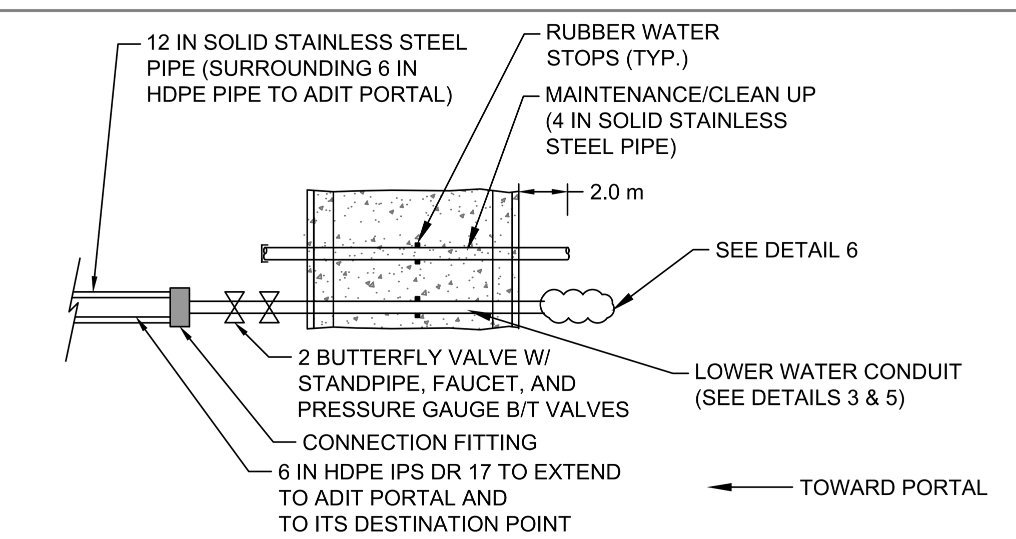
4 - BULKHEAD SITE - TRANSVERSAL SECTION VIEW
NOT TO SCALE



5 - BULKHEAD DOWNSTRAM ELEVATION
NOT TO SCALE



6 - BULKHEAD SITE - LONGITUDINAL SECTION VIEW
NOT TO SCALE



7 - BULKHEAD SITE - PLAN VIEW
NOT TO SCALE

NOTES:

1. Bulkhead designed in accordance with CSA Standard A23.3-04 Design of Concrete Structures.
2. Bulkhead designed to retain 6.0 m of hydrostatic head of fresh water factored by 1.5 for Ultimate Strength Design
3. Consequence of failure is high.
4. Concrete shall have a minimum 40 MPa compressive strength at 28 days.
5. Steel reinforcement shall have a minimum yield strength of 415 MPa (60ksi) and be weldable type.
6. Site preparation shall remove loose rock and weathered rock from the walls, roof and invert of the adit from the footprint of the concrete bulkhead to a depth where the bulkhead will be in contact with and keyed into competent rock. This work shall be performed by hand using suitable scaling bars and may include scaling by compressed air in a controlled manner, or by means of hydraulic splitters. Competency of final rock face shall be reviewed by a professional engineer or geologist. Final rock face shall be fresh, unaltered (not faulty), and with a minimum intact compressive strength of 40 MPa.
7. Rock Anchors shall be hot dip galvanized 32 mm (1 1/4 inch) Ø Williams R-61-6R75 all thread (or equivalent).The boreholes shall be 63 mm Ø to a depth of 2000 mm below the surface on the walls, roof and floor. The wall anchors shall be drilled at 5 degrees from the horizontal, the floor and roof anchors shall be installed vertical.
8. The mine owner/operator shall seal any leaks immediately upon detection with approved quick seal grout on the downstream side or de-water and seal upstream.
9. Grout – Cemented Grout Bolts
   - Cement grout shall be used for all rock anchors installed as part of the water retention bulkhead.
   - Cement grouting for rock anchors shall be a non-shrink, non-sanded grout mixed with the proportion 0.4 water:cement by weight, capable of achieving a minimum compressive strength of 28 MPa at 7 days and 40 MPa at 28 days when tested in accordance with CAN/CSA A23.2-1B.
   - Equipment for mixing and pumping grout shall be capable of satisfactorily mixing and agitating grout and pumping it into the holes at the required water cement ratio.
10. Installation – Cemented Grout Bolts
    - Completely clean holes of all drill cuttings, sludge, debris and water using clean water and air.
    - Grout shall be placed in the hole from the bottom up using a grout tube extending to the lower end of the hole.
    - Rock bolts shall be fully encapsulated in grout to the drill hole collar.
    - If seepage of grout into cracks in the rock prevents the hole from being filled with grout, the hole shall be sealed with an approved grout material, and then redrilled. This sequence shall be repeated until the hole is sealed.
11. Grout and Concrete Testing
    - The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of grout and concrete to establish that minimum grout strength required for anchors and minimum concrete strength for bulkhead has been obtained.
    - The testing agent shall (i) Review and confirm that the grout mix submitted by the Contractor will provide the properties specified herein, (ii) take sample of grout from each continuous mix (Contractor can cast the grout samples under the directions of the testing agency) and (iii) test grout samples to determine compressive strength. The contractor shall provide a minimum of 48 hours notice to the testing agency.

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Keno District Mine Operations
Reclamation and Closure Plan
Drawing No:
AKHM-13-01-S-0302-Bulkhead

Figure 7-31

Portal Closure
Typical Concrete Bulkhead Design

REVISION: A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW

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Bellekeno 625 Existing Water Treatment Facility

The Bellekeno 625 Water Treatment Facility (WTF) (Figure 7-34) includes a lime-addition circuit for metals removal, multi-media filtration system for TSS and an ion exchange system for ammonia removal. The ammonia removal system is only operated when blasting residuals are present in the system, and the filtration system is primarily required only while active rock breaking and/or diamond drilling is occurring underground. In a closure scenario, the Bellekeno 625 WTP is shut down and decommissioned and the lined ponds and tanks are used for the construction of the bioreactor and in situ treatment system.

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.

Figure 7-32 Bellekeno 625 WTP Area Overview

Upon closure, the sludge from the Bellekeno 625 treatment plant will be excavated from the storage cell in the valley tailings and transported either back underground in Bellekeno East decline or placed in the DSTF. Sludge from the Flame and Moth water treatment plant would either be placed in the DSTF or back underground.

The discharge criteria currently authorized in Water Licence QZ09-092 for the Bellekeno 625 water treatment plant is protective of the receiving environment. The discharge criteria for the Bellekeno mine for closure and long-term is the same as the current effluent quality levels during operations and are summarized in Table 7-6.

Bellekeno 625 Bioreactor

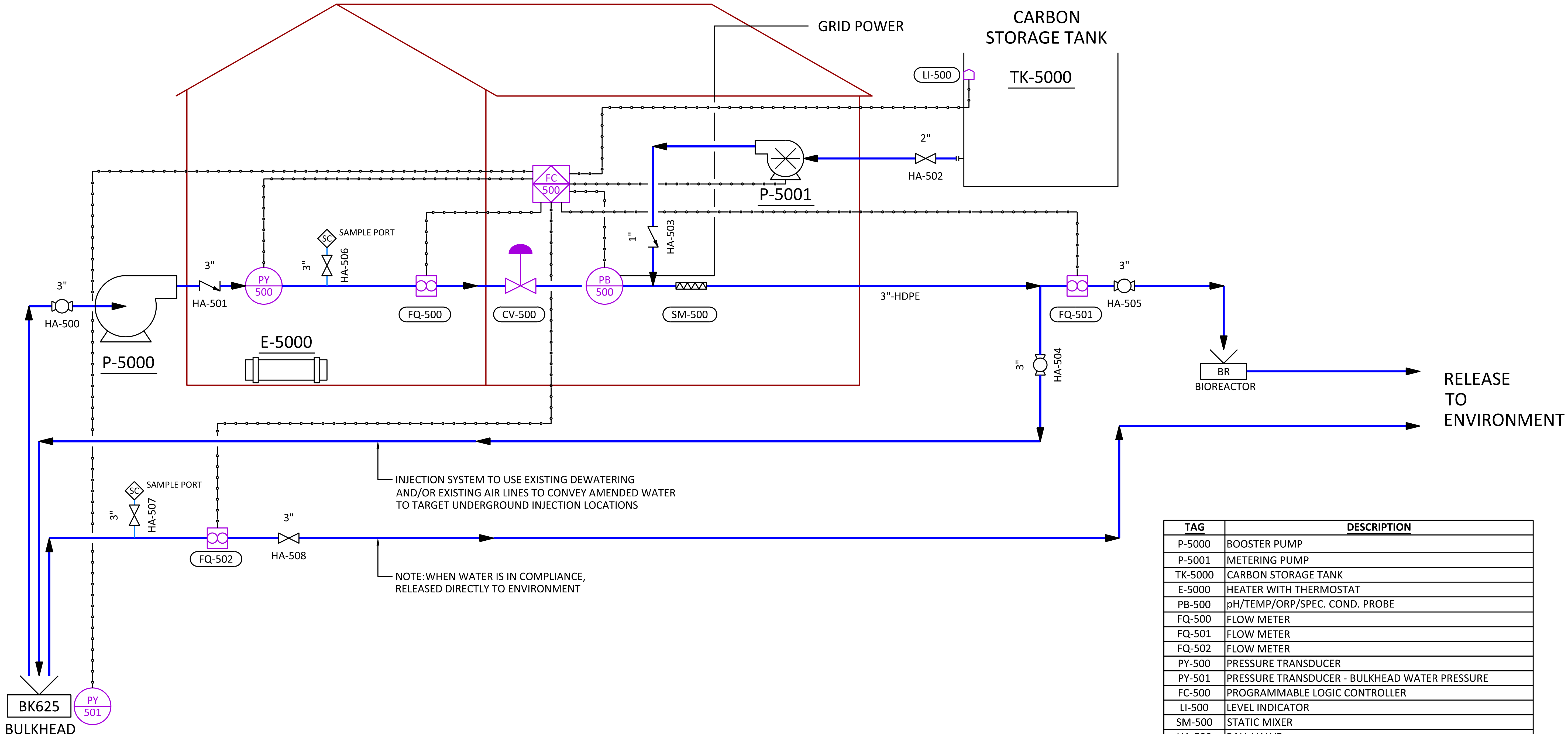
A preliminary design of the bioreactor at 625 is shown in Figures 7-33 and 7-34.

The lined ponds at Bellekeno 625 will be converted into a bioreactor and serve as a contingency treatment system. Although the in situ treatment of Bellekeno is expected to produce direct discharge complaint water, an additional contingency treatment system in the form of a bioreactor adds additional confidence and conservatism in the water management plan for Bellekeno upon closure.

The bioreactor design and construction consists of the following steps:

1. Remove (vacuum truck) remaining sludge in Bellekeno lined ponds.
2. Install piping distribution system in bottom of ponds.
3. Fill ponds with clean gravel sourced from adjacent placer miner.
4. Install geotextile barrier over surface of gravel.
5. Place 2 meter soil cover over top of geotextile.
6. Recirculate mine pool water through bioreactor and commission.

A water treatment and management schedule for Bellekeno 625 is included in Table 7-5. 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 1.3 as support for this approach in closure of the Bellekeno mine.



TAG	DESCRIPTION
P-5000	BOOSTER PUMP
P-5001	METERING PUMP
TK-5000	CARBON STORAGE TANK
E-5000	HEATER WITH THERMOSTAT
PB-500	pH/TEMP/ORP/SPEC. COND. PROBE
FQ-500	FLOW METER
FQ-501	FLOW METER
FQ-502	FLOW METER
PY-500	PRESSURE TRANSDUCER
PY-501	PRESSURE TRANSDUCER - BULKHEAD WATER PRESSURE
FC-500	PROGRAMMABLE LOGIC CONTROLLER
LI-500	LEVEL INDICATOR
SM-500	STATIC MIXER
HA-500	BALL VALVE
HA-501	CHECK VALVE
HA-502	ISOLATION VALVE
HA-503	CHECK VALVE
HA-504	BALL VALVE
HA-505	BALL VALVE
HA-506	GATE VALVE
HA-507	GATE VALVE
HA-508	GATE VALVE
CV-500	THROTTLING VALVE

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	KAB	--

NOTES:

1) Treatment will be performed in treatment campaigns periodically as necessary to maintain low redox potential, and low zinc.
2) A centrifugal booster pump will be installed near the bulkhead, allowing for water to be pumped from the mine, amended with carbon, and injected back underground
3) A throttling valve will control the pump speed.
4) System's flow rate and pressure will be monitored, with carbon injection proportional to flow rate. Monitoring information of all adit discharge will be continuously monitored with datalogging field parameters: specific conductivity, temperature, ORP, pH, and pressure behind the bulkhead.
5) When in compliance, water will be released to the environment.

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Keno District Mine Operations
Reclamation and Closure Plan
Drawing No.: AKHM-13-01-D2601

Bellekeno Closure Treatment System
Piping & Instrumentation Diagram
Figure 7-33

REVISION A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: EJL	REVIEWED BY: JMH

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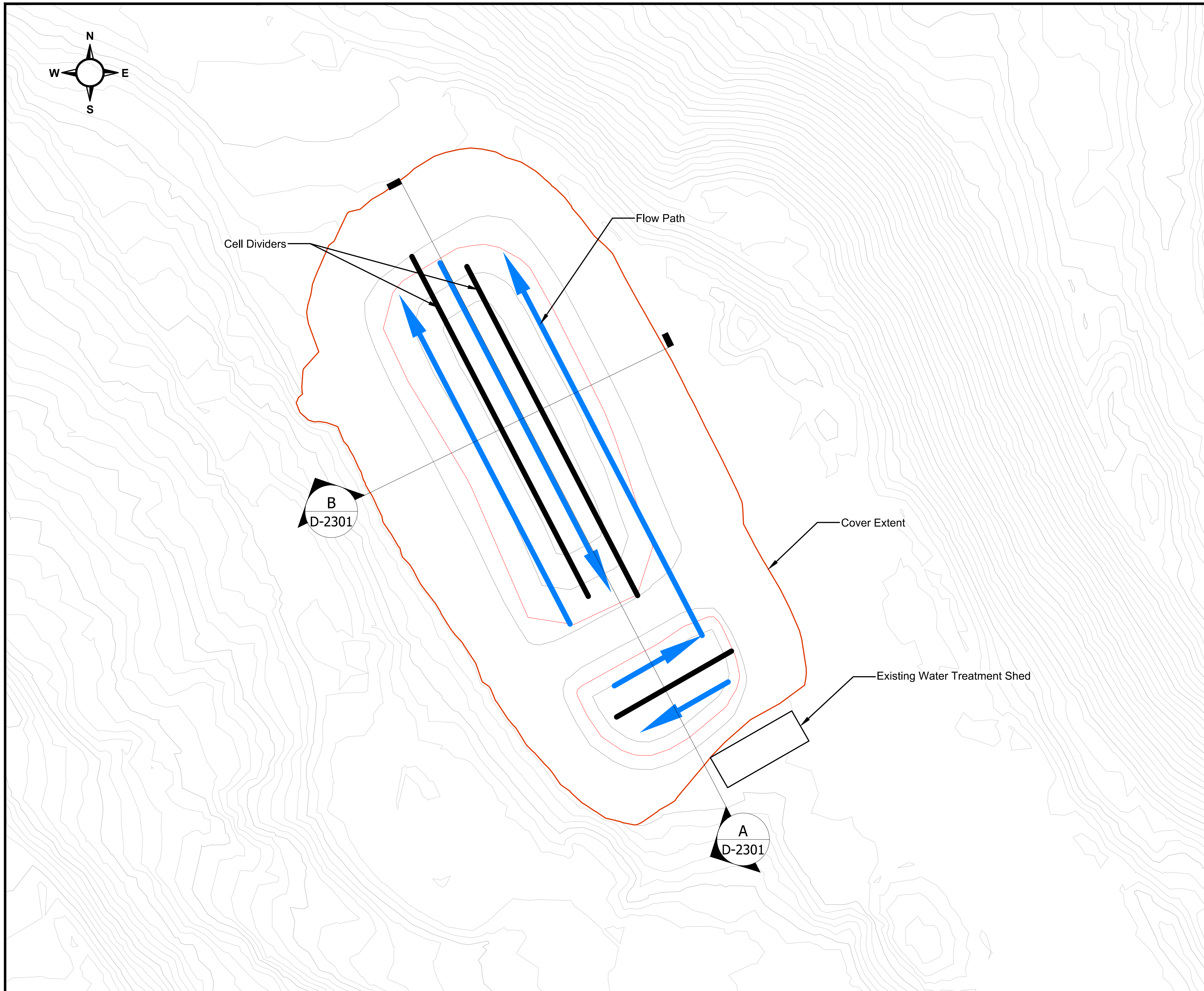

Notes:

Conceptual Design Assumptions:

1. Divide Pond 1 in to two zones with an HDPE liner divider. Two cells of approximately 6 m x 15 m
2. Divide Pond 2 in to three zones with HDPE liner dividers. Three cells of approximately 5.3 m x 42 m
3. Total Volume = 2,800 m^3
4. Porosity = 40%
5. Flowrate = 4 lps
6. Retention Time = (2800 m^3 x 0.40)/4 lps = 3.1 days

Material Quantities:

Placer Gravel Rock Substrate:	2,800 m^3
Geotextile Barrier:	1,410 m^2
Soil Cover:	4,010 m^3

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2018-02-01	Draft for review	A	KAB	--

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Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-D-2102

Figure 7-34

Bellekeno 625
Bioreactor Design

REVISION: A	2018-02-01	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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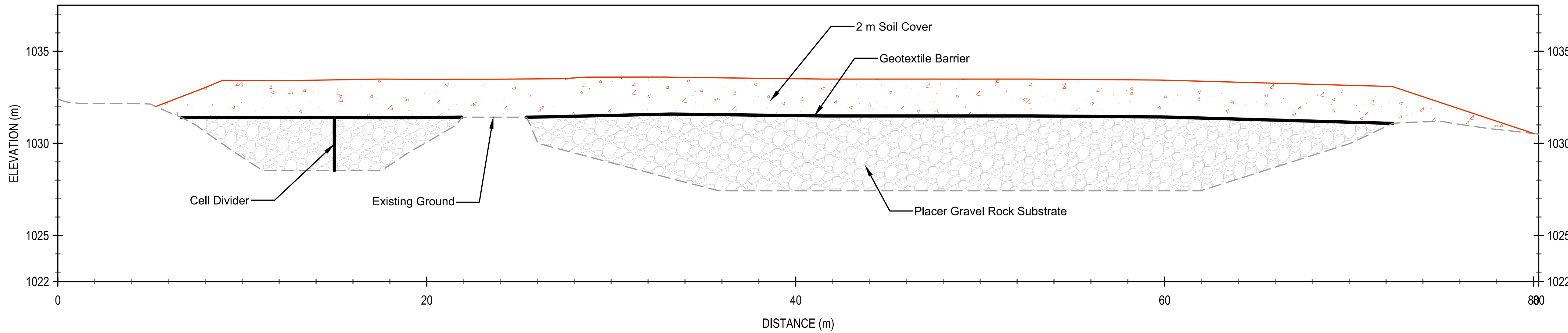
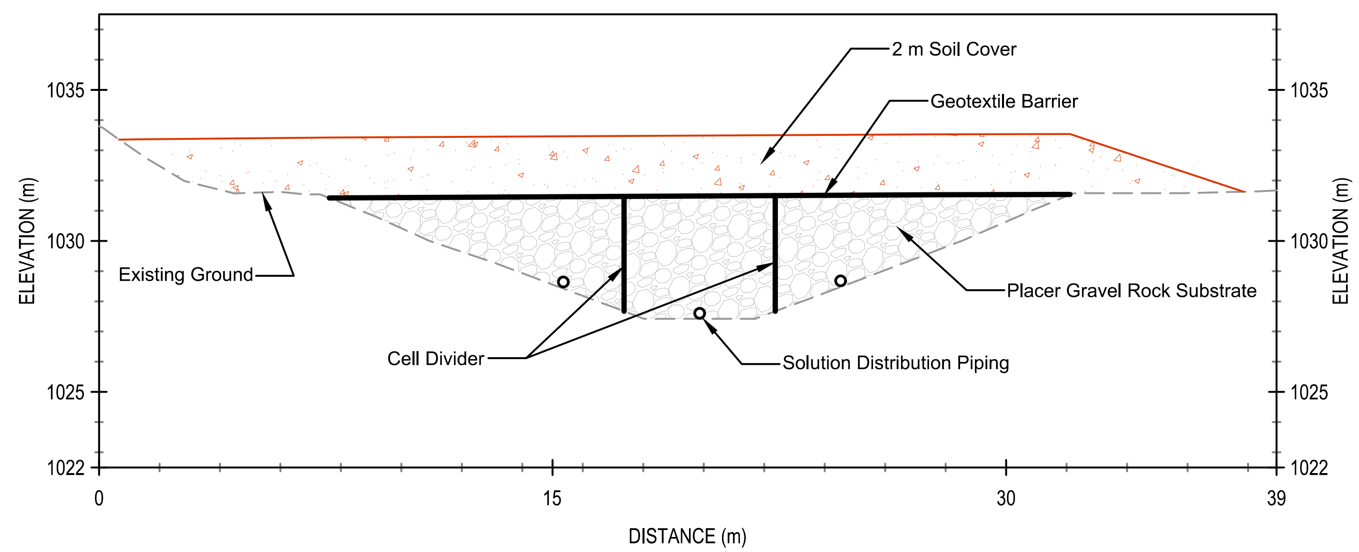


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-01	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-D-2301

Figure 7-35

Bellekeno 625
Bioreactor Design Sections

REVISION: A	2018-02-01	PROJECT No.: AKHM-13-01
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Table 7-5: Underground Mines 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**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Pump shutdown and mine workings flooding																	
In Situ Mine Pool Treatment																	
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**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Construct bioreactor (if required)																	
Commission bioreactor with adit discharge (if required)																	
Passive feed of bioreactor from adit discharge (if required)																	

Months following cessation of mining activities

Flame and Moth Water Management Task	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Pump shutdown and mine workings flooding																	
In Situ Mine Pool Treatment																	

Months following cessation of mining activities

Bermingham Water Management Task	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Pump shutdown and mine workings flooding																	
In Situ Mine Pool Treatment																	

Table 7-6 Bellekeno, Lucky Queen, Bermingham and Flame and Moth Mine Closure Effluent Quality Standards

Parameter	Maximum Concentration in a Grab Sample
pH	6.5 to 9.5 pH Units
Total Suspended Solids	25 mg/L
Ammonia Nitrogen (as N)	5 mg/L
Arsenic (total)	0.1 mg/L
Cadmium (total)	0.01 mg/L
Copper (total)	0.1 mg/L
Lead (total)	0.2 mg/L
Nickel (total)	0.5 mg/L
Radium 226	0.37 BQ/L
Silver (total)	0.01 mg/L
Zinc (total)	0.5 mg/L
Acute Toxicity Testing	
96-hour Rainbow Trout	Non-Toxic, LC_{50} (100%)

7.4.3 Bermingham In Situ Treatment

The mine will flood at closure due to its design of being accessed via a decline and will always remain flooded to the local groundwater table which is located approximately 20 vertical meters down the exploration decline. At closure, discharge from the flooded Bermingham mine (up to 2.5 lps) will infiltrate to ground. The adit discharge chemistry is expected to be similar to that of the nearby historical Bermingham 200 adit, which has an average total zinc concentration of 2.2 mg/L. Given the success of the Silver King in situ treatment pilot test (Appendix 1.2), the relatively low zinc concentration, and the infiltration of discharge to ground, in situ treatment is considered an appropriate closure technology for primary treatment of the Bermingham adit discharge. An active water treatment plant will be constructed during the mine operations phase at Bermingham. This WTP will remain in place and ready for operations as a contingency measure during the closure period at Bermingham. The WTP will not be removed until the in situ treatment system at Bermingham has demonstrated its stability and effectiveness.

An in situ treatment pilot test at Silver King was initiated in September 2014 to evaluate this treatment technology at Keno Hill and is ongoing (Appendix 1.2). Total zinc concentrations in water discharged from the Silver King mine during the in situ pilot are presented in **Error! Reference source not found.**. Zinc is shown since this is the primary metal requiring treatment to meet effluent quality standards (EQS) in the Silver King mine water; however, similar trends are observed for cadmium (Appendix 1.2).

Between September 2014 and December 2016, the mine workings were dewatered approximately 10 to 15 m below the 100 level to help evaluate hydraulic connectivity within the workings and create storage during high recharge periods as the in situ treatment was established. Dissolved organic carbon in the form of molasses and later methanol was injected into the mine working via either an historic borehole or an open pit that drains into the mine workings. Injection of organic carbon stimulates indigenous microbes present in the flooded workings to produce sulphate-reducing conditions, converting the dissolved sulphate to sulphide, which in turn reacts with metals to form insoluble metal sulphide precipitates. These phases are retained in the mine workings as coatings on the walls, floors and broken rock present in the flooded workings. Continuous carbon injection with recirculation pumping occurred over a period of one to two months, with more frequent injections occurring at that start of the pilot in order to develop the sulphate-reducing conditions required for metal (i.e., zinc, cadmium) precipitation within the mine workings. Within weeks of that start of each carbon injection, total zinc concentrations in the water discharged from the Silver King mine declined sharply as zinc precipitated out of solution as a sulphide mineral. Periodic failures in the dewatering pump resulted in reflooding of the mine workings in May/June and October/November 2015 and September 2016. This rapid recharge of more oxidizing waters resulted in a rise in total zinc concentrations likely due to:

- Rinsing of soluble zinc salts that had formed on the previously dewatered mine workings surfaces;
- Oxidative dissolution of a portion of the precipitated zinc sulphides by the more oxidizing recharge waters; and
- Shorter hydraulic residence time (HRT) from rapid recharge resulting in less time for zinc in the recharge water to be treated by the reducing Silver King mine workings water.

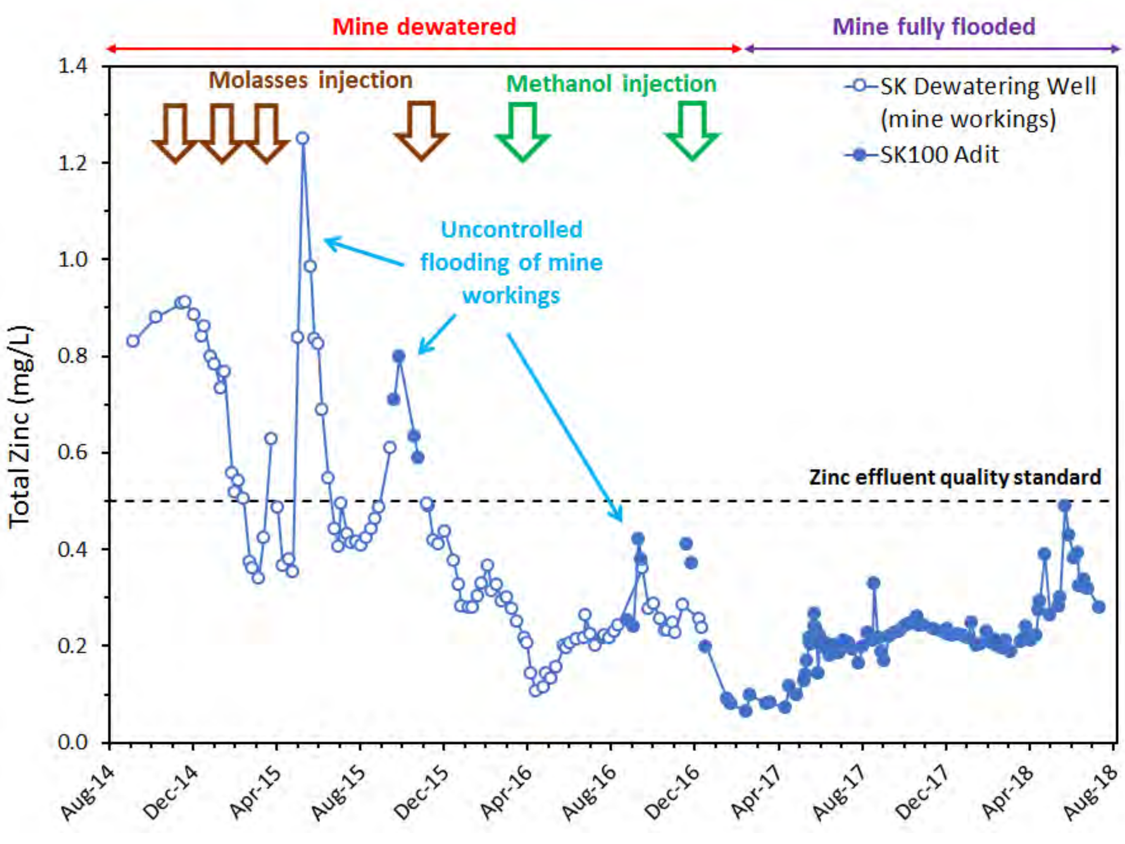


Figure 7-36 Total Zinc Concentration in Water Discharged from Silver King Mine During In Situ Treatment Pilot

Zinc concentrations declined rapidly following the re-establishment of dewatering, often without the coincident injection of organic carbon, indicating the resilience of the system.

Dewatering was terminated in January 2017 allowing the mine water to decant from the Silver King 100 adit again; this configuration more closely resembles the closure plan for both the Silver King and Bermingham mines. The last carbon injection occurred in November/December 2016. Since that time, zinc concentrations have remained low; indeed, total zinc concentrations in water leaving the Silver King mine have met the effluent quality standard (0.5 mg/L) since December 2015.

Following initial treatment by active precipitation, low concentrations are maintained by a "redox buffer" provided by poorly crystalline iron sulphide [FeS(am)] that forms during sulphate reduction. FeS(am) is relatively labile and provides a sacrificial redox buffer towards ingress of more oxidizing waters into the mine workings, prolonging the sequestration of chalcophile metals such as cadmium and zinc. Over time, zinc concentrations will slowly increase as:

- Oxidizing waters cause oxidative dissolution of precipitated metal sulphides; and
- Rapid charge events (e.g., during spring freshet or following prolonged rain events) reduce the HRT within the mine workings, thereby limiting the treatment of dissolved metals brought into the mine workings by recharge waters.

Evidence for the latter process can be found in the total zinc concentration peaks observed in the Silver King adit discharge during spring freshet of 2017 and 2018. During these times, adit discharge flow rates increased resulting in lower HRT within the workings. After both freshet events, total zinc concentrations declined as adit flows lessened and longer HRT were established. That such treatment persisted approximately 5 and 17 months since the last carbon injection points towards the longevity of treatment at Silver King.

A conceptual in situ treatment design similar to that currently in place at Silver King is envisaged for the Bermingham mine. This comprises pumping water from the Bermingham adit discharge as a water source to dilute and deliver soluble organic carbon (e.g., alcohol and/or molasses) back to the flooded workings via an injection well installed in the vent raise or a drill hole. If required, a submersible pump will recirculate water within the flooded mine workings to achieve the optimal conditions for treatment within the workings.

Such injections would occur continuously over a period of a few weeks to ensure adequate carbon is delivered to the workings alongside dispersion throughout the workings. Following discharge from the Bermingham adit, the water may need pH adjustment and/or total suspended solids (TSS) control. This would be achieved via a passive aeration system (e.g., tumbling the discharge over rip rap channel) to promote equilibration with the atmosphere and raise pH via degassing of carbon dioxide. The rip rap channel would then flow into a retention pond to promote settling of TSS and further equilibration with the atmosphere, prior to discharge to the environment.

As part of routine operation, regular (i.e., monthly during first few years of closure transitioning to quarterly) water quality monitoring will be conducted at the Bermingham mine adit discharge and EQS compliance point located immediately downstream of the retention pond. Such monitoring will ensure compliance with the EQS while also providing triggers for addition carbon dosage to the mine workings as needed. Thresholds that would trigger carbon injection include:

- Total metal concentration (i.e., cadmium, zinc, copper, lead) reaches 80% of its EQS;
- Increasing trend in metal concentrations such that EQS may be expected to be exceeded within 3 months

Data from the Silver King mine in situ pilot suggests that these re-injection thresholds would likely be reached on an annual basis or longer as part of routine operation of *in* situ treatment. However, it is important to note that seasonal recharge events (i.e., freshet, heavy summer/fall precipitation) are not anticipated to be as marked for the Bermingham mine as at Silver King. A sizeable fraction of the recharge at Silver King is supplied by Galena Creek, which runs over the mine workings. By contrast, recharge to the Bermingham mine workings is expected to be largely derived from local groundwater, which is not expected to be as oxidizing as recharge to Silver King. Therefore, the passive treatment period between organic carbon injections at Bermingham may be longer than that observed to date at Silver King (i.e., >1 year).

7.5 MINE, MILL AND SURFACE INFRASTRUCTURE

The closure objectives for mine, mill and 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.

7.5.1 Bellekeno Surface Infrastructure

Bellekeno East Surface Facilities

Various surface support buildings and facilities (Figure 7-1) are in place near the entrance to the Bellekeno mine and include:

- Surface maintenance shop;
- Sea container storage units (5 each);
- Skid mounted washroom trailer;
- Skid mounted mine office;
- Skid mounted miners dry/lunchroom;
- Skid mounted explosives magazine; and
- Skid mounted double walled fuel tank.

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.

Figure 7-2 and Figure 7-3 show the current state of the Bellekeno East portal. 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.

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.

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 (will be converted to treat shed for in situ);
- Sea container storage units; and
- Electrical substation (will remain until power not required at Bellekeno in situ).

7.5.2 Onek Surface Infrastructure

Various surface support buildings and facilities (Figure 7-8 and Figure 7-12) are in place near the entrance to the Onek 990 portal and include:

- Sea container storage units;

- Contractor offices; and
- Ventilation fan container.

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.

7.5.3 Lucky Queen Surface Infrastructure

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.

7.5.4 Flame and Moth Surface Infrastructure

The Flame and Moth portal and mine surface facilities sit within the current mill area footprint and disturbance and will utilize as much existing infrastructure as possible. Figure 5-4 and Figure 7-37 shows the location of the Flame and Moth portal in relation to the mill. Surface infrastructure that is new to Flame and Moth and not already included in the mill facilities and infrastructure includes:

- Sea container storage units;
- Maintenance shop; and
- Mine office.

Figure 7-37 Flame and Moth Surface Facilities

An overview of the layout of the Flame and Moth mine surface infrastructure is shown in Figure 5-4. The water treatment plant (WTP) for the Flame and Moth mine will be constructed inside the mill building and closure measures associated with the WTP are included in the mill facilities. The ventilation fan for Flame and Moth will be installed inside the portal to reduce noise emissions.

All of the surface buildings associated with Flame and Moth are portable structures that will be removed and transported offsite for salvage at the end of the mine life.

7.5.5 Bermingham Surface Infrastructure

The Bermingham advanced underground exploration project and associated surface facilities and infrastructure consists of the following:

- Office trailer, miners dry/wash car;
- Generator, MCC, fuel storage tank;
- Sea container storage units;
- Maintenance shop; and
- Compressor, ventilation containers.

A view of the Bermingham surface facilities (current and proposed) and layout is shown in Figures 7-18, 7-19 and 7-20.

7.5.6 Mill Surface Infrastructure

The Keno District Mill is a conventional differential flotation facility producing two separate metal concentrates that are shipped offsite for final processing. A layout of the mill facilities is shown in Figure 5-4 and Figure 7-38.

Reclamation measures for the Mill area are described on Drawing C-6401, and grading details are described on Drawings B-6101 and B-6301, located in Appendix 3.1.

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 (Figure 5-4 and Figure 7-38):

- 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; and
- Lightning Creek bridge.

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; and
- 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.

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 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.

Figure 7-38 Aerial View of Mill Site Infrastructure and Layout

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 x 54 meters in dimension (Figure 7-39).

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.

Figure 7-39 Mill Building

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 (Figure 7-40).

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.

Figure 7-40 Mill Office and Dry

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 (Figure 7-41). 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.

Figure 7-41 Electrical Substation

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 (Figure 7-42). Thickener overflow water from inside the mill building gravity flows via a 6" yellomine pipe into the mill process pond. Process makeup water is pumped from the pond to the process water tank for makeup and recycling in the milling process. The mill process pond is 32 x 79 meters in dimension with a total design capacity of 3,500 m^3.

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.

Figure 7-42 Mill Process Pond

Crushing Plant

Coarse ore from the Bellekeno, Bermingham, Onek, Lucky Queen and Flame & Moth underground mines is transported to a crushing plant (Figure 7-43) 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.

Figure 7-43 Crushing Plant

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 (Figure 7-44). 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.

Figure 7-44 Fine Ore Stockpile

Crusher MCC

A Motor Control Centre (MCC) for the crusher (Figure 7-45) 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.

Figure 7-45 Crusher MCC

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 (Figure 7-46). 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.

Figure 7-46 Assay Lab

Mill Motor Control Centre

A Motor Control Centre (MCC) for the mill building (Figure 7-47) 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.

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 m^3 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.

Figure 7-47 Mill MCC

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 m^3.

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

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.

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.

7.5.7 Flat Creek Camp

Employees and contractors directly related to the Keno Hill Mine Operations are housed in the Flat Creek camp as well as in four staff houses that are located in Elsa (Figure 7-48). Additional personnel and camp accommodation requirements are on-going beyond Bellekeno, Onek, Lucky Queen and Flame & Moth 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, Lucky Queen and Flame & Moth deposits production closure plan and requirement.

Closure measures include dismantling and removal of the excess trailer units to Lot 960 which is a private lot owned by Alexco in Keno City. The expanded septic system, along with the increased freshwater supply will remain in place for continued use by the downsized camp.

Reclamation measures for the Flat Creek Camp area are described on Drawing C-9401, and grading details are described on Drawings B-9101 and B-9301, located in Appendix 3.1.

Figure 7-48 Flat Creek Camp

7.6 HAZARDOUS MATERIALS

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.

7.7 ROADS AND OTHER ACCESS

The closure objectives for linear disturbances, including roads, other access 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.

7.7.1 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 7-49):

- Bellekeno Haul Road (5.7 km L x 9 m W);
- Christal Lake Road (1.3 km L x 6 m W);
- Bermingham Access Road (2.0 km L x 9 m W); and
- Keno City Bypass Road (2.1 km L x 9 m W).

The roads identified for closure range in width from 6-9 meters depending on their primary use. 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 7-50). 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. Figure 7-49 illustrates a typical section of the haul road between the mine and mill and shows the bridge crossing at Lightning Creek.

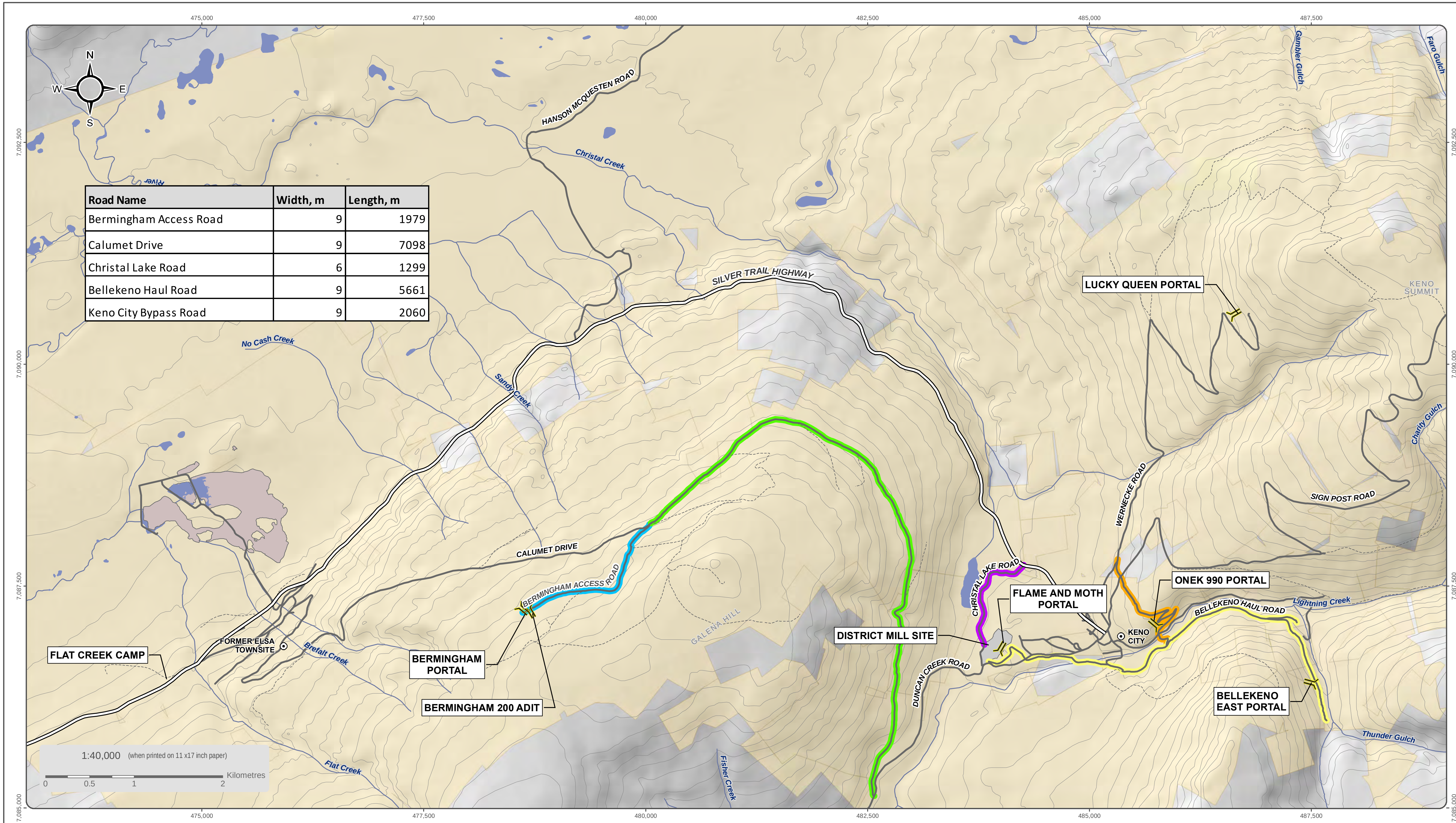
A typical cross-section of road reclamation is described in Drawing B-0301, located in Appendix 3.1.

Alexco will consult EMR Client Services & Inspections and Highways & Public Works, Transportation Branch, to determine appropriate methods for limiting access to the sites. The Wernecke road from Keno City to Lucky Queen is not included in the RCP as this is a designated public road that provides access to private residence and will not be reclaimed or closed.

7.7.2 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.

Figure 7-49 Lightning Creek Bridge and Typical Bellekeno Haul Road Section



Road Name	Width, m	Length, m
Bermingham Access Road	9	1979
Calumet Drive	9	7098
Christal Lake Road	6	1299
Bellekeno Haul Road	9	5661
Keno City Bypass Road	9	2060

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 underlicense from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on January 2018

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

- Chistal Lake Road
- Bellekno Haul Road
- Keno City ByPass
- Calumet Drive
- Bermingham Access Road
- Place of Interest
- Adit
- Valley Tailings
- Alexco/ERDC Quartz Claims
- Silver Trail Highway
- Road
- Limited-Use Road

AKHM

AEG

ALEXCO KENO HILL MINING CORP.
RECLAMATION AND CLOSURE PLAN

FIGURE 7-50

ROADS SUBJECT TO STANDARD DECOMISSIONING AND RECLAMATION

JULY 2018

7.8 BORROW MATERIALS PLANNING

7.8.1 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 7-53) 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 7-53 is approximately 4,225 m^3.

7.9 COVER DESIGN AND REVEGETATION

7.9.1 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 m soil 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.

7.9.2 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 has used the experience and applicable results from the reclamation and closure performance 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. The seed mix used on the progressive reclamation of the DSTF over two periods consists of the following:

40% Violet Wheatgrass

13.5% Glaucous Bluegrass

23.5% Sheep Fescue

23% Rocky Mountain Fescue

The DSTF seed mix is 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. Progressive reclamation has taken place on the DSTF and a summary report on the activities completed in 2012 are included in Appendix 1.1

7.9.3 Cover System Design and Field Trials

The Cover Systems Field Trials is an ongoing research program that began in 2013. The program consists of constructing vegetation plots and seeding/fertilizing followed by monitoring/maintenance of the progress of the vegetation. The results of this program will have closure application in designing suitable covers for any waste rock and tailings facilities in the RCP. The cover field trials consist of 12 cells (5 m x 5m).

With cover plots constructed, a scheduled maintenance program to retain the plots is ongoing including instrumentation and logging, and monitoring activities such as water quality sampling of the infiltration water, seasonal data downloads, and additional reporting.

Typically monitoring tasks include:

- Regularly scheduled data capture;
- Bi-annual water quality sampling of cover trial discharge (where possible);
- Equipment and site inspection;
- Field observations; and
- Vegetation monitoring (percent cover, and biodiversity).

Short growing seasons along with cool temperatures can inhibit successful establishment of agronomic, non-native plant species limiting long term persistence of vegetation and sustainability of vegetation on engineered covers. Collection and monitoring of above-ground biomass will determine if revegetation seed mixture or other agronomic adjustments are required to ensure that prescribed performance objectives are being met. The program includes three years of monitoring cover and vegetation performance. Sampling will take place at the end of the first growing season and repeated in years two and three. This schedule corresponds with the timing of the cover trials operation, so that after the first summer of the cover trials, the first round of biomass sampling can take place. This data will be collected in conjunction with the planned schedule, and the results will be available for inclusion as an appendix in the annual reports.

Maintenance on the plots will be required periodically to ensure that proper data collection and cover plots are not compromised. Typical maintenance activities will include:

- Inspection of the solar panel system;
- Seasonal repair/thawing of the tipping buckets due to ice/freezing damage;
- Replacing worn or damaged parts; and
- Repairing cover damage by animals, water/ice flow, etc.

The data collected throughout the program will be analyzed to determine the effectiveness of the different covers at each location based in the year's data for both the hydrological and vegetation trials. This will include updating the infiltration modelling conducted during the design phase.

Cover Modelling

As part of the development of the ESM Reclamation Plan for the District, preliminary cover performance modelling for WRSA cover options has been completed by O'Kane Consultants Inc. The modelling report is attached as Appendix 1.4. The results of the cover modelling for the District Closure Plan are applicable to the Keno District Mine Operations RCP and presented here for support of the preliminary closure measures proposed. It should be noted, however, that the design basis for control of infiltration on waste rock is different than would be required for a DSTF, where the dry stacked tailings themselves provide the primary control on infiltration and seepage.

The DSTF cover is an additional control on infiltration, as well as providing erosion control and a vegetated surface. The modelling approach shown in Appendix 1.4 will be applied to the DSTF over the next two years as field data are available to quantify boundary conditions for this facility; this is not critical to evaluating closure performance since the primary control on infiltration is the surface configuration and the tailings permeability and unsaturated flow characteristics.

Four reclamation scenarios were evaluated and modeled namely, two cover system types as well as two revegetation options of which one is a 'do-nothing' scenario (i.e. bare waste rock with no revegetation effort). A description of the modelled scenarios is as follows:

Type 1a – Very Low Net Percolation Cover System: 0.3 m of compacted silty-clay material underlying a 1.0 m well-graded local soil layer. Surface re-graded to promote runoff, then revegetated with native plants;

Type 1b – Lower Net Percolation Cover System: 0.3 m well-graded local soil layer as modelled for the waste rock; this cover is comparable to the DSTF cover. The surface re-graded to promote runoff, then revegetated with native plants;

Type 3 – Surface treatment to enhance revegetation: this include a range of surface preparation and limited amendment to promote vegetation on the rock surface, ranging from direct seeding of waste rock to promote revegetation (assumes sufficient fines content to support plant growth). Scarifying and contouring of surface to promote vegetation and enhance physical stability of landform is also included.

Type 4 – Bare Waste Rock Surface: no cover system or site preparation.

Note the terms Type 1a, 1b etc. were used for comparison purposes within the ESM Reclamation Plan for different surface treatments.

Figure 7-51 shows the different soil covers and surface treatment modelled.

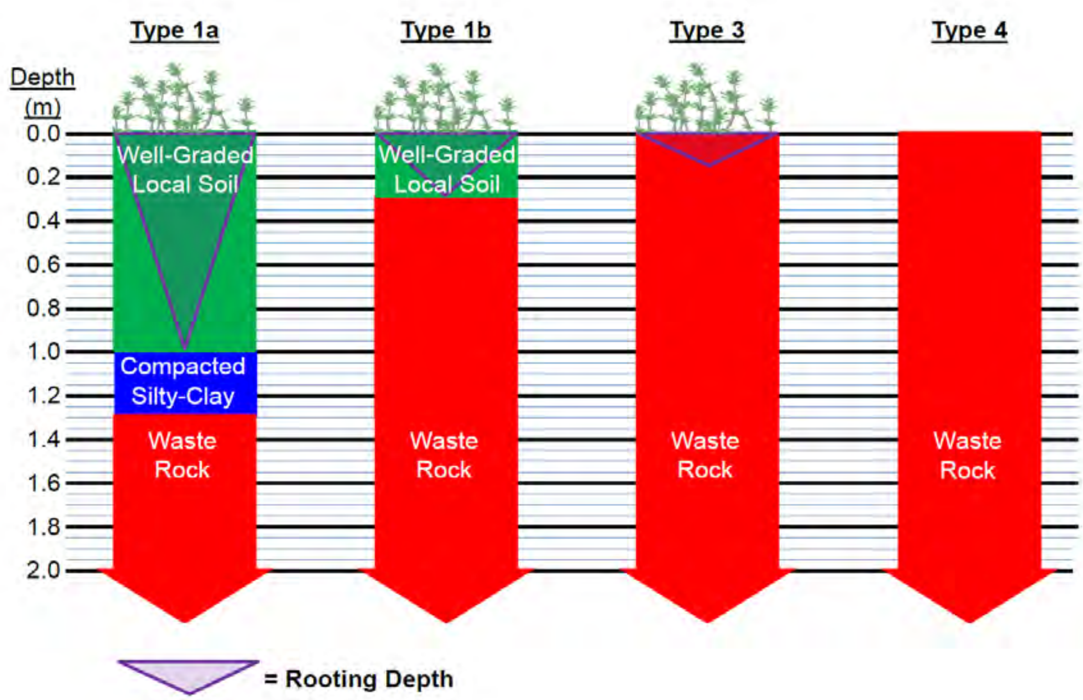


Figure 7-51 Cover Types Modelled

All modelling completed for this project used the computer modelling program VADOSE/W9. The estimated net percolation rates are summarized in Figure 7-52 for the scenarios modelled in the ESM Reclamation Plan. It must be emphasized that the values provided in Figure 7-52 are averages; the components of the water balance will vary greatly from year-to-year, and during any given year. For example, run off (RO) averages 175 mm/yr for the Type 1a cover system at 1,000 masl, but ranges from 40 to 360 mm/yr with most of the RO occurring during spring-melt.

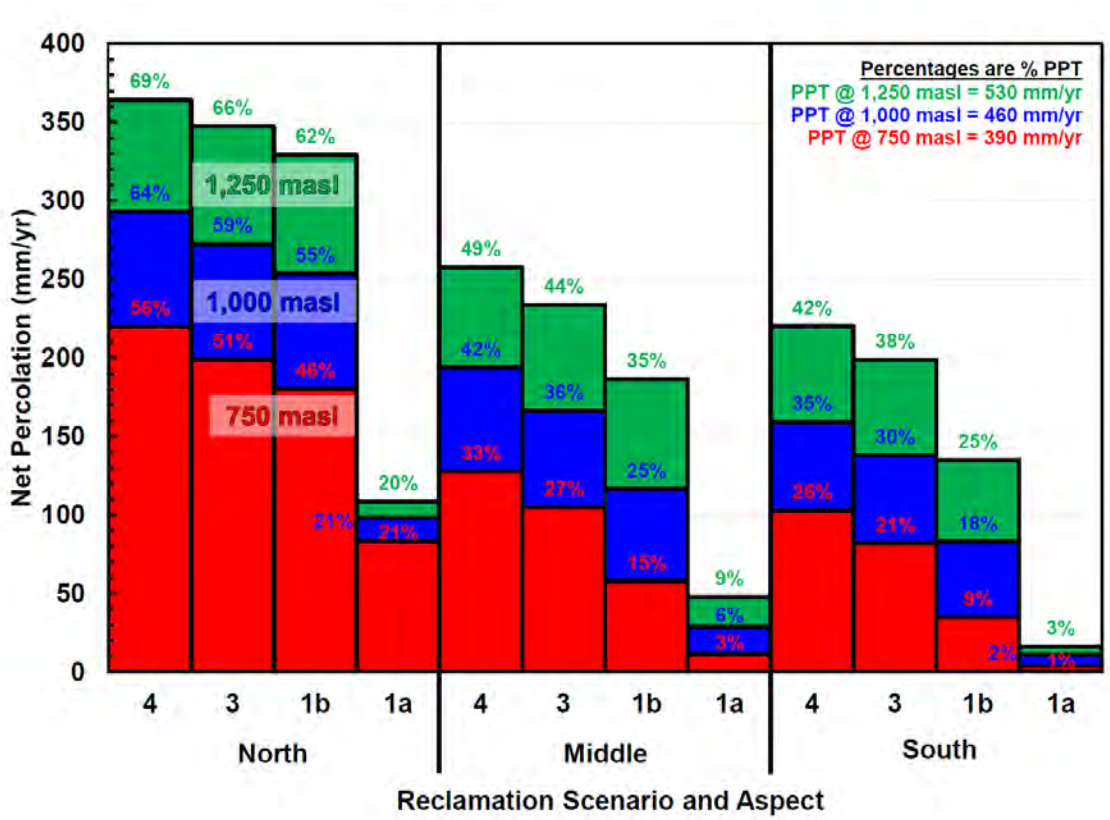


Figure 7-52 Annual Average net percolation rates estimated for range of reclamation scenarios, elevations and slope aspects

7.9.4 Site Revegetation Field Trials

Terrestrial reclamation of mine sites requires an understanding of environmental conditions to develop prescriptions that will have a better chance of success. To date, significant reclamation research has been completed on the ecosystem mapping program at the former UKHM site to understand successional, soil, and nutrient regimes, data collection on soil metals and metals uptake by vegetation, seed collection workshops, biochar amendment trials in the valley tailings and biomass sampling while continuing to develop a clear understanding of successional relationships with disturbed soils and metals uptake.

Additional research in revegetation will include the collection of native plant species seeds and establishing propagules to be used for terrestrial reclamation of sites requiring revegetation. Native plants species are desirable for reclamation efforts because they are adapted to local conditions and suitable candidates for long-term restoration success. Given the complexity and varying degree of degradation of disturbed areas, reclamation designs will be based on site specific needs. Seeds from a total of seventeen different species were collected during the 2013/14 season and germination trials are currently being conducted for thirteen selected grasses and forbs. One hundred seeds per species are being used for the germination trials which will also determine the amount of pure live seed of each species. Depending on the species, seeds collected range from approximately one hundred to several thousand. Ongoing germination trials will give insight as to which species have the highest rates of germination and therefore desirable for future seed collection efforts. Working closely with the FNNND on plant identification and seed collection training ensures there will be sufficient propagules to cultivate in the field for future seed collection.

Growth Media Stockpiles

Mill Pond

Current DSTF

DSTF 322k Tonnes Design

DSTF Future Expansion Phase III

To Be Constructed Features

Adit

Road

Watercourse

AKHM

AEG

KENO DISTRICT MINE OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 7-53
GROWTH MEDIA SITES IN DISTRICT MILL AREA

JULY 2018

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on January 2018

Datum: NAD 83; Projection: UTM Zone 8N

D:\Project\AllProjects\Keno_Area_Mines\ALL-SITES\02-Map\01_Overview\02-District Mill\Growth_Stockpiles_20180129.mxd
(Last edited by: amatlashevska; 30/01/2018/13:53 PM)

7.10 MONITORING AND MAINTENANCE

Prior to commencement of mining operations in the Keno Hill Silver District by Alexco, a number of monitoring programs and a surveillance network were alread 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:

a) Surface water quality monitoring (as per Table 7-7);

b) Hydrological monitoring;

c) Groundwater monitoring;

d) Physical and engineered structures monitoring (geotechnical assessment);

e) Sediment, benthic and aquatic resources monitoring; and

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 Licence.

Table 7-7 Keno Hill Mine Operations Reclamation and Closure Plan Surveillance Network Monitoring Schedule

Surface Water Monitoring Stations

Monitoring Stations QZ09-092	Additional Stations	Stations duplicated in QZ17-084	Proposed closure monitoring station	Easting	Northing	Description	Rationale	Total Metals	Dissolved Metals	Ammonia	Nitrite	Nitrate	Phosphorous	Sulphate	DOC	Hardness	Alkalinity	pH	Conductivity	TSS	Radium	LC50
KV-1		✔		4742790	7092790	South McQuesten River u/s Christal Creek	Not monitored as South McQuesten River will be stable in Closure if Christal Creek is stable and will be monitored	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-2		✔		472076	7090036	South McQuesten River @ Pumphouse		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-6		✔	✔	483909	7088242	Christal Creek at Keno Highway	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-7		✔	✔	478657	7092413	Christal Creek at Hanson Road	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-8		✔		465836	7088410	Christal Creek @ Mouth	Monitoring at KV-6 and KV-7 provides near and far field monitoring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	KV-21	✔	✔	477500	7088750	No Cash Creek at Silver Trail Highway	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-34		✔	✔	486562	7090614	Lucky Queen 500 Level Adit	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	-	-
KV-37		✔		490315	7087776	Lightning Creek u/s Hope Gulch	Monitoring at KV-38 proposed which captures KV-37, which is upstream of Bellekeno	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-38		✔		488193	7087341	Lightning Creek u/s Thunder Gulch	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-39		✔		490252	7087783	Hope Gulch u/s Lightning Creek	Station contributes to KV-38 which will be monitored, and no AKHM mine features in this catchment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-40		✔		488982	7087503	Charity Gulch u/s Lightning Creek	Station contributes to KV-38 which will be monitored, and no mine features in this catchment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-41		✔	✔	485429	7086764	Lightning Creek u/s bridge at Keno City	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	-	-
KV-42			✔	487363	7087062	Bellekeno 625 Adit	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M		
KV-43			✔	487318	7087147	Bellekeno 625 Treatment Pond Decant	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	Q	Q
KV-44			✔	487361	7087195	Bellekeno 625 Seep	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-45		✔		485101	7087288	Onek 400 Adit	No connection between Onek 990 and Onek 400, therefore no monitoring proposed.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-49		✔		483582	7087009	Hinton Creek u/s Christal Creek	Monitoring upper Christal Creek will be at KV-50 and KV-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-50		✔	✔	483575	7086897	Christal Creek u/s Hinton Creek	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-51		✔		483600	7087010	Christal Creek d/s Hinton Creek	Monitoring upper Christal Creek will be at KV-50 and KV-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-52		✔		483756	7087869	Natural Spring to Chrital Lake at Mackeno pump house	Monitoring upper Christal Creek will be at KV-50 and KV-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-65		✔		487464	7086873	Thunder Gulch Upstream of Bellekeno	KV-76 will be monitored on Thunder Gulch upstream of Bellekeno	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-72				482492	7104476	South McQuesten River at McQuesten Lake	Not monitored as South McQuesten River will be stable in Closure if Christal Creek is stable and will be monitored	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-76			✔	487414	7087118	Thunder Gulch d/s of Bellekeno 625 adit	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-77			✔	487742	7086013	Thunder Gulch upstream of Bellekeno East	KV-76 will be monitored on Thunder Gulch upstream of Bellekeno	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-78a				485690	7087474	Onek Waste Rock Storage Facility	P-AML facility will be removed at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-78b				487126	7087052	Bellekeno Temporary Waste Rock Storage Facility	P-AML facility will be removed at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-79				483796	7087919	Christal Creek d/s MacKeno Tailings	Christal Creek to be monitored at KV-6 and KV-50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-80				483790	7087869	Christal Lake u/s Mackeno Tailings	Christal Creek to be monitored at KV-6 and KV-50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-81			✔	483548	7086423	Lightning Creek, South of Mill Site	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-82				483839	7086769	District Mill Pond	Pond will be decommissioned at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-83			✔	483787	7086750	District Mill Pond Discharge	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	Q	Q
KV-96				TBD	TBD	Onek Settling Pond Decant	No discharge from Onek anticipated at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-97				TBD	TBD	Lucky Queen Settling Pond Decant	Montoring will be at KV-34 for Lucky Queen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-98			✔	TBD	TBD	Lucky Queen N-AML WRDA Seep Survey	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-99				TBD	TBD	Lucky Queen P-AML WRSF	P-AML facility will be removed at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-100				TBD	TBD	Onek Settling Pond	No water from Onek adit will be generated at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-101				TBD	TBD	Lucky Queen treatment plant discharge	Treatment plant will be decommissioned at closure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-102			✔	TBD	TBD	Lucky Queen settling pond	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	Q	Q
KV-104				TBD	TBD	Flame and Month Water Treatment Pond Decant	Flame and Moth adit not predicted to produce water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-105			✔	TBD	TBD	Flame and Moth Adit Discharge	Monitoring proposed for the case adit does produce water	M	M	M	M	M	M	M	M	M	M	M	M	M	Q	Q
KV-106				TBD	TBD	Flame and Moth Temporary P-AML Waste Rock Storage Facility	Site is temporary and will be removed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	KV-110		✔	478612	7087231	Bermingham Adit Discharge	Monitoring proposed	M	M	M	M	M	M	M	M	M	M	M	M	M	Q	Q

Groundwater Monitoring Stations

Monitoring Stations QZ09-092	Additional Stations	Stations duplicated in QZ12-084	Proposed closure monitoring station	Easting	Northing	Description	Rationale	Total Metals	Dissolved Metals	Ammonia	Nitrite	Nitrate	Phosphorous	Sulphate	DOC	Hardness	Alkalinity	pH	Conductivity	TSS	Radium	LC50
KV-84Nd			✔	484925	7087117	Keno City Well #1	Monitoring proposed	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-85D			✔	483864	7086952	District Mill Site Groundwater Well #1 PH2	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-85S				483858	7086952	District Mill Site Groundwater Well #2 shallow	KV-85d will be monitored	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-86			✔	483836	7086707	District Mill Site Groundwater Well #3 PH5	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-87			✔	484104	7086854	District Mill Site Groundwater Well #4 PH6	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-88d			✔	483946	7087016	District Mill Site Groundwater Well #4	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-88s				483942	7087016	District Mill Site Groundwater Well #4	KV-88d will be monitored	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-89d			✔	483831	7086864	District Mill Site Groundwater Well #5	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-89s				483825	7086864	District Mill Site Groundwater Well #5	KV-89d will be monitored	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-91				TBD	TBD	Bellekeno Waste Rock Disposal Area Well #1	No intention on constructing BK WRDA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-92				TBD	TBD	Bellekeno Waste Rock Disposal Area Well #2	No intention on constructing BK WRDA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-93				TBD	TBD	Bellekeno Waste Rock Disposal Area Well #3	No intention on constructing BK WRDA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-94				TBD	TBD	Bellekeno Waste Rock Disposal Area Well #4	No intention on constructing BK WRDA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ON-MW-02			✔	485244	7087083	Keno City Well #2	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KC-MW-4			✔	485201	7086919	Keno City Well #3	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
LQ-MW-01			✔	486426	7090576	Lucky Queen Waste Rock Disposal Area Well	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
LQ-MW-02			✔	TBD	TBD	Lucky Queen d/g of P-AML Waste Rock Disposal Area	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-107			✔	TBD	TBD	DSTF Phase 2 Expansion Area	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
BH-39			✔	486973	7086938	DSTF Phase 1 Area	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
FM-MW-01				483854	7086562	Flame and Moth Well #1 (KAR-01)	Only currently monitored for level	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FM-MW-02				484025	7086770	Flame and Moth Well #2 (KAR-02)	Only currently monitored for level	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FM-MW-03				483910	7086628	Flame and Moth Well #3 (KAR-16)	Only currently monitored for level	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-108			✔	TBD	TBD	Upgradient of DSTF Phase 2 Expansion Area	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-
KV-109			✔	TBD	TBD	Lightning Creek near KV-81	Monitoring proposed	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-

Tables 5-4 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, gullying, 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 five years after closure. The requirement for an annual geotechnical inspection will be reviewed five years after closure.

7.11 PERFORMANCE UNCERTAINTY AND RISK MANAGEMENT

7.11.1 Risk Assessment

Management of risk is fundamental to Alexco's business model, operations approach and philosophy. Alexco's risk assessment system has been tailored from other well proven systems and models. It is the objective of Alexco that any major project, expansion or undertaking should undergo a risk assessment process. The benefits of a risk assessment process include:

- Develops a risk profile for the major risks of a project;
- Provides a recognition and documentation of project uncertainties prior to commencing the project;
- Provides common understanding, objectives and direction for projects;
- Provides the framework for an action plan to manage and reduce project risks;
- Enhances project economics; and
- Enhances employee and environmental safety.

The risk assessment process can be summarized in the following steps outlined in Figure 7-54:

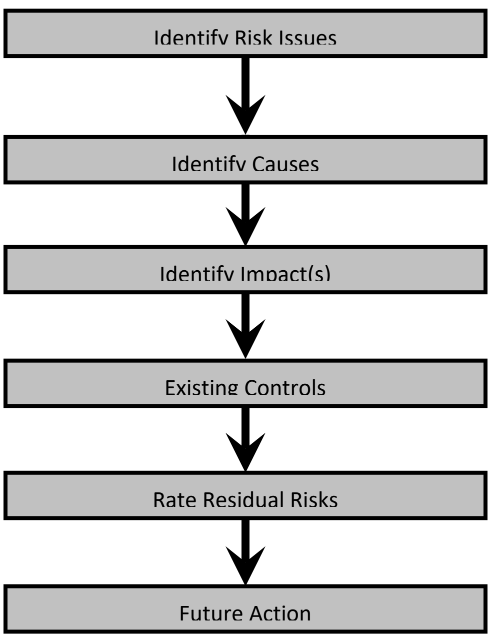


Figure 7-54 Risk Assessment Process Flow Chart

Identify Risk Issue

An area of concern is raised and the questions asked, "what would happen if" or "is it possible that". This identifies a particular risk issue that forms the basis for assessment.

Identify Causes

The potential causes of the risk issue are identified and recorded.

Identify Impacts

The nature and extent of the impact of the risk issue if it were to occur are discussed and agreed to.

Identify Existing Controls

Any existing controls that are currently in place to counter or mitigate the risk issue and impacts are identified.

Rate Residual Risks

The residual risks are rated based on the assumption that the existing controls are in place. The risk rating tools and scoring matrix used for rating the risks are presented in the following tables.

Future Actions

If the current controls are not adequate to reduce the risk, then future actions and controls are identified.

Risk Categories

For the purposes of the risk assessment process, risks are categorized into 5 broad categories. The risk categories used in the risk assessment process include:

- Project NPV Reduction (NPV);
- Health and Safety (HS);
- Natural Environment (NE);
- Reputation/Brand (RB); and
- Legal (L).

Guidelines for Assessing Likelihood

The likelihood of a risk occurring must be estimated in order to determine the potential severity of the risk. Table 7-8 summarizes a guideline for determining the potential likelihood of a risk.

Table 7-8 Risk Likelihood

Likelihood	Site is continuously exposed to the risk, and the outcome …	Outcome is almost certain to happen, but only …
Almost certain	Happens often	All the time
Likely	Could easily happen	Once a month or so
Possible	Could happen and has occurred here or elsewhere	Once or twice a year
Unlikely	Hasn't happened yet but could	Once or twice every 10 years
Very Unlikely	Is conceivable, but only in extreme circumstances	Once or twice every 100 years

Table 7-9 Risk Severity

Severity Level	Reduction Project $ NPV	Health and Safety	Consequence Types Natural Environment	Reputation/Brand	Legal
Extreme	$3M +	Single fatality and/or severe irreversible disability (>30%) to one or more persons	Long-term impairment of ecosystem function	Serious public or media outcry (international coverage)	Major breach of regulation and litigation, prosecution and fines.
High	$1M - $3M	Irreversible disability or impairment (>30%) to one or more persons	Serious medium-term environmental effects	Significant adverse national media/public/NGO attention	Major breach of regulation and litigation
Moderate High	$200K – $1M	Disability or impairment (>30%) to one or more persons	Moderate short-term effects but not affecting ecosystem	Attention from media and/or heightened concern by local community. Criticism by NGO's.	Non-compliance and breaches of regulation
Moderate	$75K – $200K	Injury requiring medical attention and resulting in lost time accident	Minor effects on biological or physical environment	Minor adverse local public or media attention and complaints	Minor legal issue
Low	< $75K	No medical treatment required	Limited damage to minimal area of low significance	Public concern restricted to local complaints	Low-level legal issue

<u>Guidelines for Assessing Severity</u>

Once the likelihood of a risk has been determined, the severity if it were to occur is determined based on a description of the outcome of the risk shown in Table 7-9. The following severity levels were used for the Bellekeno assessment.

RISK SEVERITY AND CONSEQUENCE TYPES

<u>Risk Matrix</u>

The likelihood and severity are combined to determine a risk rating for each of the particular risks. The risk rating matrix is shown in the Figure 7-55.

Likelihood	Consequence Severity				
	Low	***Moderate***	***Moderate High***	***High***	***Extreme***
Almost Certain	High	High	Extreme	Extreme	Extreme
Likely	Moderate	Moderately High	High	Extreme	Extreme
Possible	Low	Moderate	High	High	Extreme
Unlikely	Low	Low	Moderate	Moderately High	High
Very Unlikely	Low	Low	Low	Moderate	High

Figure 7-55 Risk Matrix

7.11.2 DSTF Risk Assessment

With respect to the RCP and risks to reclamation and closure of mine area components, the long-term stability of the DSTF has been expressed by FNNND as one of the areas of consideration and concerns from a risk perspective. In response, Alexco and FNNND and respective technical consultants conducted a risk assessment specific to the DSTF and long-term performance and stability. The results of the DSTF risk assessment are included in Appendix 3.6. These risks and mitigations are incorporated into both the operations and maintenance phase of the facility as well as the final reclamation and closure of the DSTF.

7.11.3 Adaptive Management Plans

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 115 of Water Licence QZ09-092, an Adaptive Management Plan (AMP) is required for the District Mining operations. An updated Adaptive Management Plan that includes the Bellekeno, Bermingham, Onek, Lucky Queen and Flame & Moth Production Unit Areas has been prepared and will be refined as necessary.

8. RECLAMATION AND CLOSURE SCHEDULE AND EXECUTION STRATEGY

The closure phase of the Bellekeno, Onek, Lucky Queen and Flame & Moth 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, Lucky Queen and Flame & Moth 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 be undertaken in the District, a project specific site caretaker or security personnel will not be required.

8.1 RECLAMATION AND CLOSURE 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, Bermingham, Flame and Moth and Lucky Queen is shown in Table 7-5 and 7-8 shows the project decommissioning and reclamation schedule.

8.2 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.*

8.3 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 INAC 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, Bermingham, Onek, Lucky Queen and Flame & Moth 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.

9. RECLAMATION AND CLOSURE LIABILITY

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 Keno Hill Mine Operations. Revision 5 of the RCP includes the Bermingham advanced exploration program and the future Bermingham mine that is not yet permitted. Alexco has completed a cost estimate to implement this RCP for the Keno Hill Mine Operations and the estimated cost to implement the reclamation and closure plan at the End Of Mine Life (EOM) is **$6,566,730** (Table 9-1). Alexco also has estimated the reclamation and closure costs for the current operations at **$5,304,964** and after two years of operations for the current mine plan at **$5,678,488**. The amount of security currently held by YG for reclamation and closure of the Keno Hill Mine Operations is **$6,304,508** and **$194,192** for Bermingham advanced exploration for a total of **$6,498,700.** It is important to note that not all of the liabilities included in the cost estimate have yet been realized or created.

Closure liability cost estimate summary tables are provided below in Table 9-1 to 9-13. 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 AEG's and Alexco's operational and professional experience with other closure program costing estimates prepared for Yukon Government. Equipment unit rates were originally derived from the Third Party Equipment Rental Rates tables produced by Yukon Government (YG, 2014) by averaging the rates for the specified (or equivalent) equipment from multiple contractors, sourced from Mayo, or Whitehorse. These rates have been increased with revisions to this plan, as appropriate based on third party review of this, and similar projects (e.g. Minto). Table 9-1 summarizes closure liability cost estimates for the current conditions (Year 0), after Year 2 of operations and at the end of mine life (EOM). Cost estimates for the separate reclamation components including site management are provided in the remaining tables.

As the mine(s) continue to operate and development of the District advances, this Reclamation and Closure Plan will be reviewed every two years and closure costs updated based on more detailed engineering plans and relevant operating experience. 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.

Table 9-1

Summary Table of Estimated Closure Costs - Keno Hill Mine Operations

Description of Cost	Proposed Cost Current - AKHM 2018	Proposed Cost Year 2 - AKHM 2018	Proposed Cost EOM - AKHM 2018
Closure Implementation			
General & Administration	$673,010	$673,010	$673,010
Waste Rock Dumps/Storage Facilities	$60,563	$73,366	$96,274
Underground Mines	$492,007	$543,927	$650,382
Water and Solutions Management	$436,762	$479,562	$479,562
DSTF	$6,875	$108,252	$337,756
Mill and Infrastructure/Facilities	$526,820	$526,820	$526,820
Haulage and Access Roads	$144,102	$153,254	$153,254
Supporting Studies	$57,000	$67,000	$90,000
Reclamation and Closure Research Program (during operations)	$50,000	$50,000	$150,000
Interim Care and Maintenance	$339,860	$339,860	$339,860
Sub-total	$2,786,999	$3,015,051	$3,496,918
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$418,050	$452,258	$524,538
Cost Inflation [1]	$64,101	$140,079	$507,357
Total Closure Implementation Costs	**$3,269,150**	**$3,607,388**	**$4,528,812**
Post Closure Care, Maintenance, and Monitoring Costs			
Onsite Management	$224,000	$224,000	$224,000
Mobilization and Demobilization	$82,600	$82,600	$82,600
Transport Costs	$50,000	$50,000	$50,000
Water Treatment Costs			
Active Treatment			
Capital Costs	$0	$0	$0
Capital Replacement Costs	$0	$0	$0
Operating Costs	$0	$0	$0
Passive Treatment			
Capital Costs	$65,000	$65,000	$65,000
Operation and Maintenance Costs	$55,000	$55,000	$55,000
Reclamation & Closure Research Plan (Post Closure)	$0	$0	$0
Monitoring & Reporting	$807,240	$807,240	$807,240
Sub-Total	$1,283,840	$1,283,840	$1,283,840
Sub-Total NPV (2.0% DROR)	$1,120,200	$1,102,100	$962,055
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$168,030	$165,315	$144,308
Total (NPV)	$1,288,230	$1,267,415	$1,106,364
Total Financial Security (incl. Indirect Costs)	**$4,557,380**	**$4,874,804**	**$5,635,176**
Contingency Allowance on "Monitoring and Reporting"	10%	10%	10%
Contingency Amount on "Monitoring and Reporting"	$72,559	$71,523	$62,526
Contingency Allowance on All Remaining Items	18.0%	18.0%	18.0%
Contingency Amount	$675,025	$732,161	$869,028
Total Financial Security (Plus Contingency)	**$5,304,964**	**$5,678,488**	**$6,566,730**

[1] Cost inflation is calculated at a rate 2% per year to the midpoint of active closure

Table 9-2

Keno Hill Mine Operations Unit Rates

Equipment Rates		
Equipment	**Unit Rates**	**Per Unit**
D9H Dozer	$350	per hr
D8K Dozer	$325	per hr
A30 Haul Truck	$300	per hr
Tandem Dump Truck	$150	per hr
Cat 235 Excavator	$225	per hr
Cat 235 Excavator w hammer	$275	per hr
Cat 14H grader	$250	per hr
988B Loader	$300	per hr
Tractor Trailer (lowbed)	$195	per hr
Vacuum Truck	$150	per hr
30 ton Crane	$190	per hr
Hiab Flatdeck truck	$180	per hr
3.5 yd LHD	$150	per hr
Cat 950 loader	$180	per hr
Vibratory Roller (84" packer)	$170	per hr
Pickup Truck	$2,500	per mo

Personnel Rates		
Personnel	**Unit Rates**	**Per Unit**
Blaster	$68	per hr
General Labourer	$52	per hr
Trades Labourer	$85	per hr
Site Supervisor	$110	per hr
Design Engineer	$150	per hr
Environmental Scientist	$110	per hr
Project Manager	$10,670	per mo
Camp Labourer	$4,400	per mo
Site Caretaker	$6,710	per mo
Environmental Monitor	$110	per hr
Environmental Monitor	$7,000	per mo

Revegetation Rates		**Per Unit**
Revegetation Seed Mix	$17.50	per kg
Revegetation Seed Mix - 50kg/ha	$875	per ha
Fertilizer	$1.10	per kg
Fertilizer - 250kg/ha	$275	per ha
Tree Seedlings (1,000 seedlings per ha)	$2,000	per ha
Seed/Fertilizer Application	$1,700	per ha
Erosion Barrier	$3	per sq.m
Revegetation cost per ha. Including application cost	**$2,850.00**	**per ha**

Contractor Unit Rates & Camp Costs	**Unit Rates**	**Per Unit**
Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	$4.64	per cu.m
Custom Rate B (Load, haul and dump mineralized rock stockpile in BK East Decline)	$4.77	per cu.m
Compact and Contour Cover	$2.00	per cu.m
Excavation of Soil	$5.00	per cu.m
Supply and place Geotextile	$7.00	per cu.m
Load, haul and place soil cover	$8.00	per cu.m
Haul & Place rock cover	$8.00	per cu.m
Drill, Blast and Screen Rip Rap	$22.00	per cu.m
Load and Haul and Place Rip Rap	$13.00	per cu.m
HDPE Liner Install	$12.00	per sq. m
Erosion barriers	$3.00	per sq. m
Freight run to Whitehorse	$1,000	per load
Camp Cost	$65	per day per person
Power and Heat	$5,500	per month
Employee Transport Costs	$2,250	per month
		per month

Table 9-3

General and Administration Costs

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
3.1	**Onsite Management**							
	Project Management and Engineering - Included in PME Costs in each Closure Component							
	Pre-closure planning and organization	Project Manager	monthly	3	$10,670	$32,010	$32,010	$32,010
	Pickup truck (2 trucks, 7 months per year, 2 years)	Pickup Truck	monthly	28	$2,500	$70,000	$70,000	$70,000
	Seasonal shutdown/startup costs Y1-Y2	Unit Cost Basis	annually	2	$7,500	$15,000	$15,000	$15,000
	Sundry equipment maintenance	Unit Cost Basis	annually	2	$5,000	$10,000	$10,000	$10,000
	Power and heat (7 months per year, 2 years)	Power and Heat	monthly	14	$5,500	$77,000	$77,000	$77,000
	General Administrative expenses (7 months per year, 2 years)	Unit Cost Basis	monthly	14	$2,000	$28,000	$28,000	$28,000
	Geotechnical Inspections (included in T16)		annually	-		$0	$0	$0
	Reclamation Inspections (Active Closure 1 time)		annually	-		$0	$0	$0
	Camp Costs (2 year period)	Camp Cost	man-day	6,300	$65	$409,500	$409,500	$409,500
					Sub-Total	**$641,510**	**$641,510**	**$641,510**
3.2	**Transport Costs**							
	Employee transport costs (7 months per year, 2 years)	Employee Transport Costs	monthly	14	$2,250	$31,500	$31,500	$31,500
					Sub-Total	**$31,500**	**$31,500**	**$31,500**
Total Estimated Cost for General & Administration During Closure						**$673,010**	**$673,010**	**$673,010**

Table 9-4

Waste Rock and Borrow Pits

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
4.1	**Bellekeno East Temporary P-AML WRSF**	**7.3.1.1**	**7-17**	**0.33**							
	Rehandle underground:										
	250 m3 from exploration program @ 24m3/hr cycle time				3.5 yd LHD	hrs.	10	$150	$1,563	$1,563	$1,563
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	2	$300	$600	$600	$600
					Cat 235 Excavator	hrs	4	$225	$900	$900	$900
					General Labourer	hrs	8	$52	$416	$416	$416
	Site Recontouring		C-2401, B-2101		D8K Dozer	hrs	10	$325	$3,267	$3,267	$3,267
			C-2401, B-2101		Cat 235 Excavator	hrs	9	$225	$2,058	$2,058	$2,058
	Revegetation		C-2401		Revegetation cost per ha. Including application cost	ha	0.3	$2,850	$941	$941	$941
	Project Management & Engineering				7% of Total Cost	%		7.00%	$682	$682	$682
								Sub-Total	**$10,426**	**$10,426**	**$10,426**
4.2	**Bellekeno N-AML WRDA**	**7.3.1.2**									
	This has not been constructed and there is no plan or requirement for a Bellekeno WRDA in the LOM Plan										
								Sub-Total	**$0**	**$0**	**$0**
4.3	**Bellekeno Historic WRDAs**	**7.3.1.3**	**7-19**	**3.00**							
	Recontour crests		C-2401, C-2402, B-2101, B-2102		Cat 235 Excavator	hrs	25	$225	$5,662	$5,662	$5,662
	Toe Buttress				D8K Dozer	hrs	6	$325	$1,950	$1,950	$1,950
	Up-slope Diversion Ditch-no lining specified				Cat 235 Excavator	hrs	8	$225	$1,800	$1,800	$1,800
	Downslope Diversion Ditch-armoring Thunder Gulch w riprap (250mx8mx1m)				Cat 235 Excavator	hrs	-	$225	$0	$0	$0
					Drill, Blast and Screen Rip Rap	cu.m.	-	$22	$0	$0	$0
					Load and Haul and Place Rip Rap	cu.m.	-	$13	$0	$0	$0
	Place soil cover (0.5m thickness)				Load, haul and place soil cover	cu.m.	-	$8	$0	$0	$0
	Revegetation (Incl. in Portal reclamation [Table 5])		C-2401, C-2402		Revegetation cost per ha. Including application cost	ha	-	$2,850	$0	$0	$0
	Project Management & Engineering				7% of Total Cost	%		7.00%	$659	$659	$659
								Sub-Total	**$10,071**	**$10,071**	**$10,071**
4.4	**Onek P-AML WRSF**	**7.3.2**	**7-8**	**0.48**							
	Remove impounded water (no water liner not complete)				Vacuum Truck	hrs	2	$150	$0	$0	$300
					General Labourer	hrs	4	$52	$0	$0	$208
	Remove P-AML rock and place underground at Onek				D8K Dozer	hrs	6	$325	$0	$0	$1,950
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	2	$300	$600	$600	$600
					Cat 235 Excavator	hrs	4	$225	$900	$900	$900
					General Labourer	hrs.	8	$52	$416	$416	$416
	Recontour for drainage		C-4401, B-4101		D8K Dozer	hrs	15	$325	$4,858	$4,858	$4,858
	Revegetation		C-4401		Revegetation cost per ha. Including application cost	ha	0.48	$2,850	$1,368	$1,368	$1,368
	Project Management & Engineering				7% of Total Cost	%		7.00%	$570	$570	$742
								Sub-Total	**$8,712**	**$8,712**	**$11,342**
4.5	**Onek N-AML WRDA**	**7.3.2**									
	This has not been constructed and Onek is not in the current LOM plan and therefore no plan to construct an Onek N-AML WRDA					hrs			$0	$0	$0
						hrs			$0	$0	$0
						%			$0	$0	$0
								Sub-Total		**$0**	**$0**
4.6	**Lucky Queen P-AML WRSF**	**7.3.3**		**0.43**							
	Remove impounded water				Vacuum Truck	hrs	2	$150			$300
					General Labourer	hrs	4	$52			$208
	Recontour P-AML rock inside lined WRSF (no rock placed)		C-3401, B-3101		D8K Dozer	hrs	11	$325			$3,639
	Place soil cover				Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	cu.m.	-	$4.64			$0
	Revegetation		C-3401		Revegetation cost per ha. Including application cost	ha	0.43	$2,850			$1,226
	Project Management & Engineering				7% of Total Cost	%		7.00%			$376
								Sub-Total	**$0**	**$0**	**$5,749**
4.7	**Lucky Queen N-AML WRDA**	**7.3.3**		**0.40**							
	Recontour crests		C-3401, B-3101		Cat 235 Excavator	hrs	2	$225			$419
	Scarify surface		C-3401		D8K Dozer	hrs	6	$325			$2,016
	Revegetation		C-3401		Revegetation cost per ha. Including application cost	ha	0.40	$2,850			$1,140
	Project Management & Engineering				7% of Total Cost	%		7.00%			$250
								Sub-Total	**$0**	**$0**	**$3,825**
4.8	**Flame and Moth Temporary P-AML WRSF**	**7.3.4**		**0.23**							
	Rehandle underground										
	1500 m3 @ 24m3/hr cycle time to underground (vol estimate based on Alexco LOM Plan)					hrs.	63	$150		$3,125	$9,375
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	2	$300		$600	$600
					Cat 235 Excavator	hrs	12	$225		$2,700	$2,700
					General Labourer	hrs	8	$52		$416	$416
	Site Recontouring		C-1401, B6101		D8K Dozer	hrs	7	$325		$757	$2,272
	Revegetation		C-1401		Revegetation cost per ha. Including application cost	ha	0.23	$2,850		$219	$656
	Project Management & Engineering				7% of Total Cost	%		7.00%		$547	$1,121
								Sub-Total		**$8,364**	**$17,139**
4.9	**Flame and Moth N-AML WRDA**	**7.3.4**									
	All of the Flame and Moth N-AML waste is scheduled to be used for construction purposes or backfill therefore there is no N-AML WRDA					hrs					
						hrs					
						cu.m.					
						cu.m.					
					7% of Total Cost	%		7.00%	$0	$0	$0
4.10	**Bermingham N-AML WRDA**	**7.3.5**		**0.68**							
	Recontour crests		C-5401, B-5101		Cat 235 Excavator	hrs.	3	$225	$752	$752	$752
	Scarify surface		C-5401		D8K Dozer	hrs.	11	$325	$1,714	$3,428	$3,428
	Revegetation		C-5401		Revegetation cost per ha. Including application cost	ha	1	$2,850.00	$969	$1,938	$1,938
	Project Management & Engineering				7% of Total Cost	%		$0	$240	$428	$428
								Sub-Total		**$6,546**	**$6,546**
4.11	**Bermingham P-AML WRSF**	**7.3.5**		**0.13**							
	Recontour crests		C-5401, B-5101		Cat 235 Excavator	hrs	4	$225	$0	$879	$879
	Place soil cover			0.13	Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	cu.m.	628	$5	$0	$2,912	$2,912
	Revegetation		C-5401		Revegetation cost per ha. Including application cost	ha	0.13	$2,850	$0	$358	$358
	Project Management & Engineering				7% of Total Cost	%		7.00%	$0	$290	$290
								Sub-Total	**$0**	**$4,438**	**$4,438**
4.12	**Borrow Areas (2ha currently, 3ha by EOM)**	**7.8.1**		**2.00**							
	Stabilize slopes				Cat 235 Excavator	hrs	12	$225	$1,782	$1,782	$2,700
					D8K Dozer	hrs	8	$325	$1,716	$1,716	$2,600
	Revegetation				Revegetation cost per ha. Including application cost	ha	2.0	$2,850	$5,700	$5,700	$5,700
	Project Management & Engineering				7% of Total Cost	%		7.00%	$644	$644	$770
								Sub-Total	**$9,842**	**$9,842**	**$11,770**
4.13	**Coarse Ore Pad**	**7.5.6**		**0.30**							
	Concrete Demolition and Burial				Cat 235 Excavator w hammer	hrs	16	$275	$4,400	$4,400	$4,400
					D8K Dozer	hrs	16	$325	$5,200	$5,200	$5,200
	Dismantle Sprung Structure over fine ore stockpile				Misc.	l.s.	1	$6,500	$6,500	$6,500	$6,500
	Haul contaminated soils/materials to DSTF or underground				Cat 235 Excavator	hrs	6	$225	$1,350	$1,350	$1,350
					A30 Haul Truck	hrs	6	$300	$1,800	$1,800	$1,800
	Revegetation				Revegetation cost per ha. Including application cost	ha	0.3	$2,850	$855	$855	$855
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,407	$1,407	$1,407
								Sub-Total	**$21,512**	**$21,512**	**$21,512**
Total Estimated Cost in Reclaiming Overburden and Waste Rock Dumps									**$60,563**	**$73,366**	**$96,274**

Note:

Table 9-5

Mine Workings - Underground

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
5.1	**Bellekeno East Portal and Underground**	**7.1.2**	**7-1, 7-2**	**1.71**							
	Remove underground equipment				3.5 yd LHD	hrs	60	$150	$9,000	$9,000	$9,000
					A30 Haul Truck	hrs	60	$300	$18,000	$18,000	$18,000
					Trades Labourer	hrs	120	$85	$10,200	$10,200	$10,200
					General Labourer	hrs	120	$52	$6,240	$6,240	$6,240
	Remove shop and other buildings (trailers, explosives and cap magazine, etc)					lump sum	1	$15,000	$15,000	$15,000	$15,000
	Load/Haul and place rip rap for portal cover					cu.m.	700	$13	$9,100	$9,100	$9,100
	Screen rip rap					cu.m.	700	$5	$3,500	$3,500	$3,500
	Labour for portal barrier				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Characterize settling ponds sediments analytical costs					unit cost	2	$300	$600	$600	$600
	Remove pond water/sediments				Vacuum Truck	hrs	4	$150	$600	$600	$600
					General Labourer	hrs	6	$52	$312	$312	$312
	Remove settling ponds liners to landfill				A30 Haul Truck	hrs	2	$300	$600	$600	$600
					Cat 235 Excavator	hrs	4	$225	$900	$900	$900
					General Labourer	hrs	8	$52	$416	$416	$416
	Clean out fuel tank residue					lump sum	1	$1,000	$1,000	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfil				Cat 235 Excavator	hrs	6	$225	$1,350	$1,350	$1,350
					A30 Haul Truck	hrs	6	$300	$1,800	$1,800	$1,800
					General Labourer	hrs	16	$52	$832	$832	$832
	Area cleanup and haul debris to landfil				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					A30 Haul Truck	hrs	20	$300	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Test area soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing					unit cost	2	$300	$600	$600	$600
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$4,800	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage		C-2401, B-2101	1.71	D8K Dozer	hrs	27	$325	$8,684	$8,684	$8,684
			C-2401, B-2101		Cat 14H grader	hrs	2	$250	$500	$500	$500
	Revegetation		C-2401		Revegetation cost per ha. Including ap	ha	1.71	$2,850	$4,874	$4,874	$4,874
	Install Signage				Misc.	lump sum	1	$500	$500	$500	$500
	Project Management & Engineering				7% of Total Cost	%		7.00%	$8,298	$8,298	$8,298
								Sub-Total	**$126,845**	**$126,845**	**$126,845**
5.2	**Bellekeno 625 Adit Area**	**7.5.1.2**	**7-1**	**1.29**							
	Remove electrical substation				Misc.	lump sum	1	$15,000	$15,000	$15,000	$15,000
	Remove electrical transmission line (Keno City to BK 625)				Misc.	lump sum	1	$25,000	$25,000	$25,000	$25,000
	Remove shop/loadout facility, compressor station				Misc.	lump sum	1	$20,000	$20,000	$20,000	$20,000
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					A30 Haul Truck	hrs	20	$300	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Test area soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing					unit cost	2	$300	$600	$600	$600
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$4,800	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage		C-2402, B-2102	1.29 ha	D8K Dozer	hrs	20	$325	$6,551	$6,551	$6,551
			C-2402, B-2102		Cat 14H grader	hrs	2	$250	$500	$500	$500
	Revegetation		C-2402		Revegetation cost per ha. Including ap	ha	1.29	$2,850	$3,677	$3,677	$3,677
	Install Signage				Misc.	lump sum	1	$500	$500	$500	$500
									$0		
	Project Management & Engineering				7% of Total Cost	%		7.00%	$6,558	$6,558	$6,558
								Sub-Total	**$100,245**	**$100,245**	**$100,245**
5.3	**Bellekeno 200 Level Vent Raise**	**7.1.2**	**S-0303**								
	Engineering for Concrete Cap				Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
	Concrete Batch				Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
					Cat 950 loader	hrs	12	$180	$2,160	$2,160	$2,160
					Tractor Trailer (lowbed)	hrs	48	$195	$9,360	$9,360	$9,360
	Labour for cap				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Project Management & Engineering				7% of Total Cost	%		7.00%	$2,352	$2,352	$2,352
								Sub-Total	**$35,952**	**$35,952**	**$35,952**
5.4	**Onek 990 Portal and Underground**	**7.1.5**	**S-0301**								
	Remove underground equipment (no material underground after suspension)				3.5 yd LHD	hrs	10	$150			
					A30 Haul Truck	hrs	10	$300			
					Trades Labourer	hrs	20	$85			
					General Labourer	hrs	20	$52			
	Project Management & Engineering				7% of Total Cost	%		7.00%	$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**

Table 9-5

Mine Workings - Underground

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
5.5	**Onek 990 Portal Site and Infrastructure**	**7.5.2**	**7-9**	**0.35**							
	Remove shop and other buildings (explosives and cap magazine)				Misc.	l.s.	1		$0	$0	$0
	Supply rockfill for portal barrier				Load and Haul and Place Rip Rap	m3	700	$13	$9,100	$9,100	$9,100
	Labour for portal barrier				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Clean out fuel tank residue (no tank at site)				Misc.	l.s.					
	Haul fuel tank and liner for reuse or landfill (no tank at site)				Cat 235 Excavator	hrs					
					A30 Haul Truck	hrs					
					General Labourer	hrs					
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					A30 Haul Truck	hrs	20	$300	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing				Analytical Costs	Unit Cost	4	$300	$1,200	$1,200	$1,200
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$1,800	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$2,400	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage		C-4401, B-4101	0.35 ha	D8K Dozer	hrs	5	$325	$1,777	$1,777	$1,777
			C-4401, B-4101		Cat 14H grader	hrs	1	$250	$250	$250	$250
	Recontour crests of pad		C-4401, B-4101		Cat 235 Excavator	hrs	1	$225	$251	$251	$251
	Install Signage				Misc.	l.s.	1	$500	$500	$500	$500
	Remove electrical substation (not yet constructed, not part of LOM Plan)				Misc.	l.s.	1				
	Remove electrical transmission line (not yet constructed, not part of LOM Plan)				Misc.	l.s.	1				
	Characterize settling pond sediments/sludge (not yet constructed)				Analytical Costs	Unit Cost					
	Remove sludge from settling pond (not yet constructed)				Vacuum Truck	hrs					
					General Labourer	hrs					
	Remove settling ponds liners to landfill (not yet constructed)				A30 Haul Truck	hrs					
					General Labourer	hrs					
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$225	$1,800	$1,800	$1,800
					A30 Haul Truck	hrs	12	$300	$3,600	$3,600	$3,600
	Revegetation		C-4401		Revegetation cost per ha. Including ap	ha	0.35	$2,850	$998	$998	$998
	Project Management & Engineering				7% of Total Cost	%		7.00%	$2,745	$3,039	$3,039
								Sub-Total	**$41,961**	**$46,455**	**$46,455**
5.6	**Onek 990 Vent Raise**	**7.5.2**	**S-0303**								
					Misc.	l.s.					
	Not constructed and not in the LOM Plan				Misc.	l.s.					
					Cat 950 loader	hrs					
					Tractor Trailer (lowbed)	hrs					
					General Labourer	hrs					
	Project Management & Engineering				7% of Total Cost	%		7.00%			
								Sub-Total	**$0**	**$0**	**$0**
5.7	**Lucky Queen Underground/Laydown Areas**	**7.1.6**	**7-11**	**0.63**							
	Remove shop and other buildings (explosives and cap magazine)				Misc.	hrs	1	$5,000			$5,000
	Supply rockfill for portal barrier				Load and Haul and Place Rip Rap	m3	700	$13	$9,100	$9,100	$9,100
	Labour for portal barrier				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Clean out fuel tank residue				Misc.	l.s.	1	$1,000	$0	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill				Cat 235 Excavator	hrs	6	$225	$0	$1,350	$1,350
					A30 Haul Truck	hrs	6	$300	$0	$1,800	$1,800
					General Labourer	hrs	16	$52	$0	$832	$832
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$225	$2,250	$2,250	$4,500
					A30 Haul Truck	hrs	20	$300	$3,000	$3,000	$6,000
					General Labourer	hrs	40	$52	$1,040	$1,040	$2,080
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing				Analytical Costs	Unit Cost	3	$300	$900	$900	$900
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$1,800	$1,800	$3,600
					A30 Haul Truck	hrs	16	$300	$2,400	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage		C-3401, B-3101	0.63	D8K Dozer	hrs	10	$325	$3,225	$3,225	$3,225
			C-3401, B-3101		Cat 14H grader	hrs	1	$250	$250	$250	$250
	Recontour crests		C-3401, B-3101		Cat 235 Excavator	hrs	4	$225	$971	$971	$971
	Remove electrical substation (not yet upgraded)				Misc.	l.s.	1	$15,000	$0	$0	$15,000
	Remove electrical transmission cable (not yet constructed)				Misc.	l.s.	1	$15,000	$0	$0	$15,000
	Remove loadout facility				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Install Signage				Misc.	l.s.	1	$500	$500	$500	$500
	Characterize settling pond sediments/sludge				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
					Environmental Monitor	hrs	8	$110	$880	$880	$880
	Remove sludge from settling pond				Vacuum Truck	hrs	40	$150	$1,500	$3,000	$6,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Remove settling ponds liners to landfill (not yet constructed)				A30 Haul Truck	hrs	4	$300	$0	$0	$1,200
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$225	$1,800	$1,800	$1,800
					A30 Haul Truck	hrs	12	$300	$3,600	$3,600	$3,600
	Revegetation		C-3401	0.63	Revegetation cost per ha. Including ap	ha	0.63	$2,850	$1,796	$1,796	$1,796
	Install Signage				Misc.	l.s.	1	$500	$500	$500	$500
	Misc. Supplies & Tools				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$3,581	$4,202	$7,513
								Sub-Total	**$54,732**	**$64,236**	**$114,836**

Table 9-5

Mine Workings - Underground

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
5.8	**Lucky Queen Vent Raise**	**7.5.3**	**S-0303**								
	Engineering for Concrete Cap				Misc.	l.s.	1	$10,000			$10,000
	Concrete Batch				Misc.	l.s.	1	$10,000			$10,000
					Cat 950 loader	hrs	12	$180			$2,160
					Tractor Trailer (lowbed)	hrs	48	$195			$9,360
	Labour for cap				General Labourer	hrs	40	$52			$2,080
	Project Management & Engineering				7% of Total Cost	%		7.00%			$2,352
								Sub-Total	**$0**	**$0**	**$35,952**
5.9	**Flame and Moth Underground**	**7.1.8**									
	Remove shop and other buildings (explosives and cap magazine)				Misc.	hrs	1	$5,000	$5,000	$5,000	$5,000
	Supply rockfill for portal barrier				Load and Haul and Place Rip Rap	m3	700	$13	$9,100	$9,100	$9,100
	Labour for portal barrier				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Clean out fuel tank residue				Misc.	l.s.	1	$1,000	$1,000	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill				Cat 235 Excavator	hrs	6	$225	$1,350	$1,350	$1,350
					A30 Haul Truck	hrs	6	$300	$1,800	$1,800	$1,800
					General Labourer	hrs	16	$52	$832	$832	$832
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
					A30 Haul Truck	hrs	10	$300	$3,000	$3,000	$3,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing				Analytical Costs	Unit Cost	4	$300	$1,200	$1,200	$1,200
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$1,800	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$2,400	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage (Incl. with Mill)		C-1401		D8K Dozer	hrs		$325	$0	$0	$0
			C-1401		Cat 14H grader	hrs		$250	$0	$0	$0
	Remove electrical substation (included in mill facilities)				Misc.	l.s.	1				
	Install Signage				Misc.	l.s.	1	$500	$500	$500	$500
	Characterize settling pond sediments/sludge				Analytical Costs	Unit Cost	2	$300		$600	$600
	Remove sludge from settling pond				Vacuum Truck	hrs	30	$150		$4,500	$4,500
					General Labourer	hrs	30	$52		$1,560	$1,560
	Remove settling ponds liners to landfill				A30 Haul Truck	hrs	4	$300		$1,200	$1,200
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$225	$900	$1,800	$1,800
					A30 Haul Truck	hrs	12	$300		$3,600	$3,600
	Misc. Supplies & Tools				Misc.	l.s.	1	$7,500	$3,750	$7,500	$7,500
	Project Management & Engineering				7% of Total Cost	%		7.00%	$2,795	$4,216	$4,216
								Sub-Total	**$42,717**	**$64,448**	**$64,448**
5.10	**Flame and Moth Vent Raise**	**7.5.4**	**S-0303**								
	Engineering for Concrete Cap				Misc.	l.s.	1	$10,000		$10,000	$10,000
	Concrete Batch				Misc.	l.s.	1	$10,000		$10,000	$10,000
					Cat 950 loader	hrs	12	$180		$2,160	$2,160
					Tractor Trailer (lowbed)	hrs	48	$195		$9,360	$9,360
	Labour for cap				General Labourer	hrs	40	$52		$2,080	$2,080
	Project Management & Engineering				7% of Total Cost	%		7%		$2,352	$2,352
5.11	**Bermingham Underground Portal and Surface Site**	**7.1.10 & 7.5.5**	**19-Jul**	**0.92**							
	Remove underground equipment				3.5 yd LHD	hrs	60	$150	$2,250	$4,500	$9,000
					A30 Haul Truck	hrs	60	$300	$4,500	$9,000	$18,000
					Trades Labourer	hrs	120	$85	$2,550	$5,100	$10,200
					General Labourer	hrs	120	$52	$6,240	$6,240	$6,240
	Load/Haul and place rip rap for portal cover				Load and Haul and Place Rip Rap	cu.m.	700	$13	$9,100	$9,100	$9,100
	Screen rip rap					cu.m.	700	$5	$3,500	$3,500	$3,500
	Labour for portal barrier				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Remove shop and other surface facilities				Misc.	ls	1	$5,000	$5,000	$10,000	$10,000
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$225	$1,800	$1,800	$1,800
					A30 Haul Truck	hrs	12	$300	$3,600	$3,600	$3,600
	Clean out fuel tank residue				Misc.	l.s.	1	$1,000	$1,000	$1,000	$1,000
	Haul fuel tank for reuse				988B Loader	hrs	6	$300	$1,800	$1,800	$1,800
					Tractor Trailer (lowbed)	hrs	6	$195	$1,170	$1,170	$1,170
					General Labourer	hrs	16	$52	$832	$1,664	$1,664
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					A30 Haul Truck	Unit Cost	40	$300	$12,000	$12,000	$12,000
					Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
	Test area for soils for contamination				Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory analysis for soils testing					unit cost	2	$300	$600	$600	$600
	Haul contaminated soils to LTF				Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$4,800	$4,800	$4,800
	Recontour and scarify area and slopes to establish drainage		C-5401, B-5101		D8K Dozer	hrs	14	$325	$4,672	$4,672	$4,672
			C-5401, B-5101		Cat 14H grader	hrs	2	$250	$500	$500	$500
	Revegetation		C-5401	0.92	Revegetation cost per ha. Including ap	ha	0.92	$2,850	$2,622	$2,622	$2,622
	Install signage				Misc.	lump sum	1	$500	$500	$500	$500
	Project Management & Engineering				7% of Total Cost	%		7.00%	$5,859	$6,918	$8,220
								Sub-Total	**$89,555**	**$105,746**	**$125,648**
Total Estimated Cost in Reclaiming Underground Mines									**$492,007**	**$543,927**	**$650,382**

Table 9-6

Water and Solutions Management

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
6.1	**Mill Runoff Collection & Process Pond**	**7.5.6**									
	Pump down collected water				General Labourer	hrs	36	$52	$1,872	$1,872	$1,872
					Pump	daily	3	$100	$300	$300	$300
	Misc. Supplies and Tools				Misc.	l.s.	1	$750	$750	$750	$750
	Characterize pond sediments/sludge				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
					General Labourer	hrs	2	$52	$104	$104	$104
	Remove pond sediments/sludge				Vacuum Truck	hrs	16	$150	$2,400	$2,400	$2,400
					General Labourer	hrs	16	$52	$832	$832	$832
	Breach dyke				D8K Dozer	hrs	4	$325	$1,300	$1,300	$1,300
	Remove & bury HDPE liner				General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
					Cat 235 Excavator	hrs	12	$225	$2,700	$2,700	$2,700
					A30 Haul Truck	hrs	4	$300	$1,200	$1,200	$1,200
	Recontour area				D8K Dozer	hrs	30	$325	$9,750	$9,750	$9,750
	Stabilize slopes with erosion barriers				Cat 235 Excavator	hrs	30	$225	$6,750	$6,750	$6,750
	Remove discharge pipeline				General Labourer	hrs	30	$52	$1,560	$1,560	$1,560
	Project Management & Engineering				7% of Total Cost	%		7.00%	$2,254	$2,254	$2,254
								Sub-Total	**$34,452**	**$34,452**	**$34,452**
6.2	**Diversion Ditches**										
	Recontour Diversion Ditch to Mill Pond			525	D8K Dozer	hrs	20	$325	$6,500	$6,500	$6,500
					Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
	Recontour Diversion Ditch above Mill Area			285	D8K Dozer	hrs	10	$325	$3,250	$3,250	$3,250
					Cat 235 Excavator	cu.m.	5	$225	$1,125	$1,125	$1,125
	Enhance Diversion Ditch above DSTF, to closure criteria			300	D8K Dozer	hrs	10	$325	$3,250	$3,250	$3,250
					Cat 235 Excavator	cu.m.	5	$225	$1,125	$1,125	$1,125
	Revegetate			1	Erosion barriers	m	500	$3	$1,500	$1,500	$1,500
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,330	$1,330	$1,330
								Sub-Total	**$20,330**	**$20,330**	**$20,330**
6.3	**Bellekeno 625 WTP - Mine Pool Treatment Transition**	**7.4.2**									
	625 Adit Bulkhead (S.7.1.3)		S-0302								
	Hydrogeologic study & engineering for concrete bulkhead				Misc.	lump sum	1	$35,000	$35,000	$35,000	$35,000
	Underground Rehab for bulkhead				Misc.	lump sum	1	$30,000	$30,000	$30,000	$30,000
	Construct concrete plug				General Labourer	hrs	120	$52	$6,240	$6,240	$6,240
					Trades Labourer	hrs	120	$85	$10,200	$10,200	$10,200
	Concrete Batch				Misc.	cu.m	31	$1,750	$54,880	$54,880	$54,880
					Cat 950 loader	hrs	80	$180	$14,400	$14,400	$14,400
	Misc for concrete plug (anchors, drainage pipe, etc)				Misc.	lump sum	1	$7,500	$7,500	$7,500	$7,500
	Install Instrumentation (e.g pressure gauge)				Misc.	lump sum	1	$10,000	$10,000	$10,000	$10,000
	Remove salvageable equipment				Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
					Trades Labourer	hrs	16	$85	$1,360	$1,360	$1,360
	Load & return extra reagents/chemicals				General Labourer	hrs	8	$52	$416	$416	$416
					Misc.		1	$2,000	$2,000	$2,000	$2,000
			D-2601								
	In mine pool treatment implementation				Misc.	l.s.	1	$40,000	$40,000	$40,000	$40,000
	Characterize settling ponds sediments/sludge				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
	Remove sludge from settling ponds (to DSTF)				Vacuum Truck	hrs	40	$150	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$52	$2,080	$2,080	$2,080
	Remove sludge from Valley Tailings Production Unit Cell to underground				Cat 235 Excavator	hrs	40	$225	$9,000	$9,000	$9,000
					Tandem Dump Truck	hrs	40	$150	$6,000	$6,000	$6,000
	Remove settling ponds liners to landfill (liners remain in place for bioreactor)				Haul Truck D250E	hrs					
					General Labourer	hrs					
	Complete final design of bioreactor		D-2102		Misc.	lump sum	1	$10,000	$10,000	$10,000	$10,000
	Construct Bellekeno 625 bioreactor		D-2301		A30 Haul Truck	hrs	80	$300	$24,000	$24,000	$24,000
					Cat 950 loader	hrs	60	$180	$10,800	$10,800	$10,800
					General Labourer	hrs	60	$52	$3,120	$3,120	$3,120
					Environmental Monitor	hrs	8	$110	$880	$880	$880
	Operate Bellekeno 625 bioreactor (included in Post Closure)				Misc.	years	10				
	Site levelling				D8K Dozer	hrs	25	$325	$8,125	$8,125	$8,125
	Scrap hauled to solid waste facility				A30 Haul Truck	hrs	8	$300	$2,400	$2,400	$2,400
					Cat 235 Excavator	hrs	12	$225	$2,700	$2,700	$2,700
	Haul BK 625 sludge from Valley Tailings to BK East UG or DSTF				Cat 235 Excavator	hrs	30	$225	$6,750	$6,750	$6,750
					A30 Haul Truck	hrs	40	$300	$12,000	$12,000	$12,000

Table 9-6

Water and Solutions Management

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
	Misc. Supplies & Tools				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$22,754	$22,754	$22,754
								Sub-Total	**$347,805**	**$347,805**	**$347,805**
6.4	**Mill Pond - Bioreactor Transition**										
	Discharge mill pond inventory (3,500 m3)				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
					General Labourer	hrs	10	$52	$520	$520	$520
	Construct bioreactor in mill pond if necessary (DSTF runoff + Flame and Moth if necessary). Costs included in post closure care and maintenance (T.11.3.2)										
	Operate mill bioreactor if necessary (10 years) costs included in Care and Maintenance (T.11.3.2)										
	Construct outlet channel				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					D8K Dozer	hrs	20	$325	$6,500	$6,500	$6,500
					Place rip rap	cu.m.	5	$1,250	$6,250	$6,250	$6,250
					General Labourer	hrs	30	$52	$1,560	$1,560	$1,560
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,395	$1,395	$1,395
								Sub-Total	**$21,325**	**$21,325**	**$21,325**
6.4	**Flame and Moth Water Management**										
	In Mine Pool treatment implementation - not considered necessary										
	Project Management & Engineering				7% of Total Cost	%		7.00%	$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**
6.1	**Bermingham Water Storage / Settling Pond**	**7.4.3**									
	Pump down collected water				General Labourer	hrs	10	$52	$520	$520	$520
					Pump	daily	2	$100	$200	$200	$200
	Misc. Supplies and Tools				Misc.	l.s.	1	$750	$750	$750	$750
	Characterize pond sediments/sludge				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
					Environmental Monitor	hrs	8	$110	$880	$880	$880
	Remove pond sediments/sludge				Vacuum Truck	hrs	8	$150	$1,200	$1,200	$1,200
					General Labourer	hrs	12	$52	$624	$624	$624
	Remove & bury HDPE liner				General Labourer	hrs	12	$52	$624	$624	$624
					Cat 235 Excavator	hrs	8	$225	$1,800	$1,800	$1,800
					A30 Haul Truck	hrs	4	$300	$1,200	$1,200	$1,200
	In mine pool treatment implementation				Misc.	l.s.	1	$40,000	$0	$40,000	$40,000
	Recontour area				D8K Dozer	hrs	6	$325	$1,950	$1,950	$1,950
	Stabilize slopes with erosion barriers				Cat 235 Excavator	hrs	6	$225	$1,350	$1,350	$1,350
	Remove discharge pipeline				General Labourer	hrs	6	$52	$312	$312	$312
	Project Management & Engineering				7% of Total Cost	%		7.00%	$841	$3,641	$3,641
								Sub-Total	**$12,851**	**$55,651**	**$55,651**
Total Estimated Cost in Constructing Primary Drainage Ditches									**$436,762**	**$479,562**	**$479,562**

Table 9-7

Dry Stack Tailings Facility

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
7.1	**DSTF - Current**	**7.2**		**0.5**							
	Recontour slopes to final design and compact			Equipment hours and productivities from 2014 progressive reclamation tracking	D8K Dozer	hrs	4	$325	$1,300		
					Vibratory Roller (84" packer)	hrs	2	$170	$340		
	Place soil cover and spread				A30 Haul Truck	hrs	4	$300	$1,200		
					Cat 235 Excavator	hrs	6	$225	$1,350		
					D8K Dozer	hrs	6	$325	$1,950		
	Revegetation				Revegetation Seed Mix - 50kg/ha	ha	0.1	$875	$88		
					Fertilizer - 250kg/ha	ha	0.1	$275	$28		
					Seed/Fertilizer Application	ha	0.1	$1,700	$170		
	Project Management & Engineering				7% of Total Cost	%		7.00%	$450		
								Sub-Total	**$6,875**		
7.2	**DSTF - Year 2**	**7.2**		**2.0**							
	Recontour slopes to final design and compact				D8K Dozer	hrs	40	$325		$13,000	
					Vibratory Roller (84" packer)	hrs	16	$170		$2,720	
	Place soil cover and spread				A30 Haul Truck	hrs	100	$300		$30,000	
					Cat 235 Excavator	hrs	120	$225		$27,000	
					D8K Dozer	hrs	70	$325		$22,750	
	Revegetation				Revegetation Seed Mix - 50kg/ha	ha	2.0	$875		$1,750	
					Fertilizer - 250kg/ha	ha	2.0	$275		$550	
					Seed/Fertilizer Application	ha	2.0	$1,700		$3,400	
						hrs	-				
	Project Management & Engineering				7% of Total Cost	%		7.00%		$7,082	
								Sub-Total		**$108,252**	
7.3	**DSTF - EOM**	**7.2**		**7.3**							
	Recontour slopes to final design and compact		C-7401		D8K Dozer	hrs	115	$325			$37,223
					Vibratory Roller (84" packer)	hrs	59	$170			$9,969
	Place soil cover and spread		C-7401		A30 Haul Truck	hrs	367	$300			$109,950
					Cat 235 Excavator	hrs	440	$225			$98,955
					D8K Dozer	hrs	119	$325			$38,673
	Revegetation		C-7401		Revegetation Seed Mix - 50kg/ha	ha	7.3	$875			$6,414
					Fertilizer - 250kg/ha	ha	7.3	$275			$2,016
					Seed/Fertilizer Application	ha	7.3	$1,700			$12,461
	Project Management & Engineering				7% of Total Cost			7.00%			$22,096
								Sub-Total			**$337,756**
Total Estimated Cost in Reclaiming Tailings Area									**$6,875**	**$108,252**	**$337,756**

Table 9-8

Mill & Ancillary Facilities

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
8.1	**Mill and Ancilliary Facilities**	**7.5.5**	**04-May**								
	Remove equipment (crusher, conveyors, mill equipment, trailer units, other ancillary facilities - fine ore bin)				General Labourer	hrs	600	$52	$31,200	$31,200	$31,200
					Trades Labourer	hrs	400	$85	$34,000	$34,000	$34,000
					Cat 950 loader	hrs	150	$180	$27,000	$27,000	$27,000
					Cat 235 Excavator	hrs	50	$225	$11,250	$11,250	$11,250
					Tractor Trailer (lowbed)	hrs	120	$195	$23,400	$23,400	$23,400
	Load and return extra chemicals/reagents				General Labourer	hrs	75	$52	$3,900	$3,900	$3,900
					Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Dismantle Mill Building				Cat 950 loader	hrs	70	$180	$12,600	$12,600	$12,600
					Tractor Trailer (lowbed)	hrs	70	$195	$13,650	$13,650	$13,650
					Trades Labourer	hrs	300	$85	$25,500	$25,500	$25,500
					General Labourer	hrs	1000	$52	$52,000	$52,000	$52,000
	Concrete Demolition				Cat 235 Excavator w hammer	hrs	40	$275	$11,000	$11,000	$11,000
					D8K Dozer	hrs	40	$325	$13,000	$13,000	$13,000
	Elec. Substation (disconnect, remove from site)				Misc.	Unit Cost	1	$17,500	$17,500	$17,500	$17,500
	Dismantle/remove other area bldgs (dry, lab, MCCs, etc)				Misc.	Unit Cost	5	$5,000	$25,000	$25,000	$25,000
	Disconnect services				Misc.	Misc.	4	$1,000	$4,000	$4,000	$4,000
	Decommission buried infrastructure				Misc.	Misc.	1	$1,500	$1,500	$1,500	$1,500
	Dismantle/remove fresh water tank				Misc.	Misc.	1	$5,000	$5,000	$5,000	$5,000
	Remove diesel & propane Tanks (owned by vendors)										
	Disconnect services				Misc.	Misc.	2	$1,000	$2,000	$2,000	$2,000
	Crane Support				30 ton Crane	hrs	200	$190	$38,000	$38,000	$38,000
	Haul Scrap to Solid Waste Facility				Cat 235 Excavator	hrs	50	$225	$11,250	$11,250	$11,250
					A30 Haul Truck	hrs	100	$300	$30,000	$30,000	$30,000
	Misc. Supplies and Tools				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$28,193	$28,193	$28,193
								Sub-Total	**$430,943**	**$430,943**	**$430,943**
8.2	**Mill Pad**	**7.5.5**		**4.8**							
	Test area soils for contamination				Environmental Monitor	hrs	16	$110	$1,760	$1,760	$1,760
	Laboratory Analysis for soils testing				Analytical Costs	Unit Cost	20	$300	$6,000	$6,000	$6,000
	Haul any contaminated soils to nearest Land Treatment Facility				Cat 235 Excavator	hrs	16	$225	$3,600	$3,600	$3,600
					A30 Haul Truck	hrs	16	$300	$4,800	$4,800	$4,800
	Regrade embankment shoulders		C-6401, B-6101		D8K Dozer	hrs	7	$325	$2,370	$2,370	$2,370
	Haul & place soil cover (1 m aver. thickness) S.7.5.5.1		C-6401, B-6101		Load, haul and place soil cover	cu.m.	1800	$4.50	$8,100	$8,100	$8,100
	Recontour area to bury any footings & provide drainage, in prep for revegetation		C-6401, B-6101		D8K Dozer	hrs	75	$325	$24,324	$24,324	$24,324
	Revegetate		C-6401		Revegetation cost per ha. Including application cost	ha	4.8	$2,850	$13,652	$13,652	$13,652
	Project Management & Engineering				7% of Total Cost	%		7.00%	$4,522	$4,522	$4,522
								Sub-Total	**$69,128**	**$69,128**	**$69,128**
8.3	**Camp Downsize**	**7.5.6**									
	Dismantle 5 trailer units and transport to Lot 960				Misc.	l.s.	1	$25,000	$25,000	$25,000	$25,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,750	$1,750	$1,750
								Sub-Total	**$26,750**	**$26,750**	**$26,750**
Total Estimated Cost in Reclaiming Mill and Ancillary Facilities									**$526,820**	**$526,820**	**$526,820**

Table 9-9

Haulage and Access Roads

Item No.	Work Item Description	RCP Section #	RCP Drawing/Figure #	Area (ha) / Length (km)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
9.1	**Bellekeno East Portal to Upper Laydown**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	4	225	$900	$900	$900
					General Labourer	hrs	4	52	$208	$208	$208
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	16	225	$3,600	$3,600	$3,600
	Scarify road surface			0.5	Cat 14H grader	hrs	16	$250	$4,000	$4,000	$4,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	500	$3	$1,500	$1,500	$1,500
	Project Management & Engineering				7% of Total Cost	%		7.00%	$715	$715	$715
								Sub-Total	**$10,923**	**$10,923**	**$10,923**
9.2	**Bellekeno 625 Access**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (3 ea)				Cat 235 Excavator	hrs	6	$225	$1,350	$1,350	$1,350
					General Labourer	hrs	6	$52	$312	$312	$312
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	12	$225	$2,700	$2,700	$2,700
	Scarify road surface			0.25	Cat 14H grader	hrs	16	$250	$4,000	$4,000	$4,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	250	$3	$750	$750	$750
	Project Management & Engineering				7% of Total Cost	%		7.00%	$638	$638	$638
								Sub-Total	**$9,750**	**$9,750**	**$9,750**
9.3	**Bellekeno Haul Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (15 ea)				Cat 235 Excavator	hrs	30	$225	$6,750	$6,750	$6,750
					General Labourer	hrs	30	$52	$1,560	$1,560	$1,560
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	40	$225	$9,000	$9,000	$9,000
	Scarify road surface			5.7	Cat 14H grader	hrs	30	$250	$7,500	$7,500	$7,500
	Erosion barrier (50% of length)				Erosion Barrier	m2	5,700	$3	$17,100	$17,100	$17,100
	Project Management & Engineering				7% of Total Cost	%		7.00%	$2,934	$2,934	$2,934
								Sub-Total	**$44,844**	**$44,844**	**$44,844**
9.4	**Keno City Bypass Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (5 ea)				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
					General Labourer		10	$52	$520	$520	$520
	Reslope banks/remove safety berms				Cat 235 Excavator		24	$225	$5,400	$5,400	$5,400
	Scarify road surface			2.1	Cat 14H grader	hrs	16	$250	$4,000	$4,000	$4,000
	Erosion barrier (50% of length)				Erosion Barrier	hrs	12	$3	$36	$36	$36
	Remove Lightning Creek Bridge (Bellekeno)				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					Tractor Trailer (lowbed)	hrs	12	$195	$2,340	$2,340	$2,340
	Erosion barrier (50% of length)				Erosion Barrier	m2	2,100	$3	$6,300	$6,300	$6,300
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,774	$1,774	$1,774
								Sub-Total	**$27,120**	**$27,120**	**$27,120**
9.5	**Christal Lake Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (5 ea)				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
					General Labourer	hrs	30	$52	$1,560	$1,560	$1,560
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	12	$225	$2,700	$2,700	$2,700
	Scarify road surface			1.3	Cat 14H grader	hrs	16	$250	$4,000	$4,000	$4,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	1,300	$3	$3,900	$3,900	$3,900
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,009	$1,009	$1,009
								Sub-Total	**$15,419**	**$15,419**	**$15,419**
9.6	**Keno City Bypass Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (5 ea)				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
					General Labourer	hrs	20	$52	$1,040	$1,040	$1,040
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
	Scarify road surface			2.1	Cat 14H grader	hrs	20	$250	$5,000	$5,000	$5,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	2,060	$3	$6,180	$6,180	$6,180
	Remove Lightning Creek Bridge (Onek)				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					Tractor Trailer (lowbed)	hrs	12	$195	$2,340	$2,340	$2,340
	Project Management & Engineering				7% of Total Cost	%		7.00%	$1,649	$1,649	$1,649
								Sub-Total	**$25,209**	**$25,209**	**$25,209**
9.7	**Lucky Queen Haul and Access Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	20	$225	$4,500	$4,500	$4,500
					General Labourer	hrs	16	$52	$832	$832	$832
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	10	$225	$2,250	$2,250	$2,250
	Scarify road surface			1.2	Cat 14H grader	hrs	12	$250	$3,000	$3,000	$3,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	1,200	$3	$3,600	$3,600	$3,600
	Project Management & Engineering				7% of Total Cost	%		7.00%	$993	$993	$993
									$15,175	**$15,175**	**$15,175**
9.9	**Bermingham Haul and Access Road**	**7.7**	**B-0301 & Fig 7-49**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	16	$225	$900	$3,600	$3,600
					General Labourer	hrs	16	$52	$416	$832	$832
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	10	$225	$563	$2,250	$2,250
	Scarify road surface			2.0	Cat 14H grader	hrs	4	$250	$250	$1,000	$1,000
	Erosion barrier (50% of length)				Erosion Barrier	m2	2,000	$3	$3,000	$6,000	$6,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$359	$958	$958
								Sub-Total	**$5,487**	**$14,640**	**$14,640**
9.10	**Other Roads and Trails**	**7.7**	**B-0301 & Fig 7-49**								
	Scarify road surface			3.0	Cat 14H grader	hrs	20	$250	$5,000	$5,000	$5,000
	Project Management & Engineering				7% of Total Cost	%		7.00%	$350	$350	$350
								Sub-Total	**$5,350**	**$5,350**	**$5,350**
Total Estimated Cost for Haulage and Access Road Closure									**$144,102**	**$153,254**	**$153,254**

Table 9-10

Supporting Studies

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
10.1	**Kinetic Tailings and Waste Rock Materials Testing**							
	Field bin ARD/metal leaching studies/tests	Misc.	l.s.	5	$2,500	$12,500	$12,500	$25,000
	Humidity cells	Misc.	l.s.	3	$3,500	$10,500	$10,500	$21,000
					Sub-Total	**$23,000**	**$23,000**	**$46,000**
10.2	**Other Adaptive Management Plans Required**							
	Inclusion of additional triggers and updating of overall plan as per directives (YWB, YESAB)	Misc.	l.s.	1	$0	$10,000	$20,000	$20,000
					Sub-Total	**$10,000**	**$20,000**	**$20,000**
10.3	**Contaminated Site Assessment Plan**							
	Develop Plan	Misc.	l.s.	1	$4,000	$4,000	$4,000	$4,000
	Site Reportng	Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
					Sub-Total	**$9,000**	**$9,000**	**$9,000**
10.4	**Reclamation & Closure Research Plan**							
	Resesarch to finalize closure plan ($25K per year)	Misc.	l.s.	1	$25,000	$50,000	$50,000	$150,000
					Sub-Total	**$50,000**	**$50,000**	**$150,000**
10.5	**Passive Treatment Design**							
	Design for mill pond bioreactors	Misc.	l.s.	1	$15,000	$15,000	$15,000	$15,000
					Sub-Total	**$15,000**	**$15,000**	**$15,000**
Total Estimated Cost for Supporting Studies						**$107,000**	**$117,000**	**$240,000**

Table 9-11

Post Closure Care, Maintenance, and Monitoring

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Annual Cost	Full Cost	NPV Current	NPV Year 2	NPV EOM
11.1	**Onsite Management**									
	Project Management and Engineering - Included in PME Costs in each Closure Component									
	Pickup trucks									
	Post Closure 10 Years (1 truck for Environmental Monitor , 6 mo/yr))			10		$15,000	$150,000			
	Sundry equipment maintenance									
	Post Closure 10 Years			10		$2,500	$25,000			
	Power and heat (na)									
	Post Closure 10 Years			10						
	General Administrative expenses									
	Post Closure 10 Years			10		$2,500	$25,000			
	Camp Costs									
	Post Closure 10 Years	Unit Cost Basis	man-day	600	$40	$2,400	$24,000			
					Subtotal - Post Closure 10 Years	**$22,400**	**$224,000**	**$236,888**	**$232,243**	**$202,181**
11.2	**Transport Costs**									
	Employee transport costs									
	Post Closure 10 Years	Unit Cost Basis	Years	10		$5,000	$50,000			
					Subtotal - Post Closure 10 Years		**$50,000**	**$45,421**	**$44,530**	**$38,766**
11.3	**Water Treatment Costs**									
11.3.1	Active Treatment (no active treatment at BK 625, ponds are bioreactors)	Misc	monthly							
	Capital Costs	Misc.	annually							
	Capital Replacement Costs	Misc.	annually							
	Operating Costs	Misc.	annually	-	$0	$0	$0	$0	$0	$0
11.3.2	Passive Treatment (BK 625 In situ + bioreactor)									
	Capital Costs	Misc.	ls	10			$65,000	$62,476	$61,251	$53,323
	Operation and Maintenance Costs	Misc.	annually	10		$5,500	$55,000	$49,828	$48,851	$42,528
					Subtotal - Post Closure 10 Years		**$120,000**	**$112,304**	**$110,102**	**$95,850**
11.4	**Reclamation & Closure Research Plan**									
	Reclamation & Closure Research Plan	Misc.	annually	-	$0	$0	$0			
					Subtotal - Post Closure 10 Years		**$0**		**$0**	**$0**
11.5	**Monitoring & Reporting (Sec 7.9)**									
11.5.1	Disbursements (non-labour/non-analytical)	Misc.	annually	12		$4,792	$57,500	$51,576	$50,564	$44,019
11.5.2	Water Quality Monitoring									
	Active Closure 2 year + Post Closure Years 1-5	Misc.	each	188		$60,000	$420,000	$388,319	$380,705	$331,427
	Post Closure Years 6-10	Misc.	each	126		$20,000	$100,000	$82,067	$80,458	$70,043
11.5.3	**EEM Monitoring**									
	Biological Monitoring (Sediment, Benthos, Toxicity):									
	Active Closure 2 year + Post Closure Years 1-5	Misc.	annually	7	$4,000	$4,000	$35,000	$32,360	$31,725	$27,619
	Post Closure Years 6-10	Misc.	annually	5	$4,000	$4,000	$10,000	$8,205	$11,909	$10,368
	Radiums- (Quarterly at 4 mines for 2 Years Active Closure)		each	16	$130	$2,080	$6,240	$3,059	$2,999	$5,221
11.5.4	Geotechnical Inspections									
	Active Closure + Post Closure Years 1-10	Misc.	annually	12		$3,750	$45,000	$40,565	$39,770	$34,622
11.5.5	Reclamation Inspections:									
	Active Closure + Post Closure Years 1-10	Misc.	annually	12		$3,750	$45,000	$40,565	$39,770	$34,622
11.5.6	Site Maintenance									
	Active Closure + Post Closure Years 1-10	Misc.	each	12		$3,375	$40,500	$36,570	$35,853	$31,212
11.5.7	Annual Inspection + report - Active and Post Closure yrs 1-10	Misc.	annually	12		$0	$48,000	$42,301	$41,472	$36,104
						Sub-Total	**$807,240**	**$725,588**	**$715,226**	**$625,258**
Total Estimated Cost for Post Closure Site Management							**$1,201,240**	**$1,120,200**	**$1,102,100**	**$962,055**

Note:

B-625 Active Water Treatment	
Manpower: as per Alexco	**2,500**
Vacuum truck:every 3d for 3hrs@ $120/hr	3,600
Camp costs: 1/4 manday/d, 30d/mo @ $65/d	488
Lime: as per Alexco	1,800
Ferric chloride	**1,200**
Power: as per Alexco	2,500
Mntce of facilities: as per Alexco	600
Replacement of equipment & parts @ $4k/yr	333
WQ analyses, internal 2/wk @ $200 each	1,600
Winter road access: grader 3h/wk x 6mo/yr @$270/hr	1,620
Misc Supplies: consumables	**200**
Treatment Operation at BK 625 / month	**$16,441**

Table 9-12

Interim Care and Maintenance

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Annual Cost	Full Cost
12.1	**Personnel**						
	On-site Caretaker						
	Utilize current ERDC operators - cost share 20%	Site caretaker	$/manmonth	6	$1,342	$8,052	$8,052
	Extra Personnel						
	Electrician (3 days every other month)	Trades Labourer	$/hr	90	$91	$8,190	$8,190
	Mechanic (3 days every other month)	Trades Labourer	$/hr	90	$91	$8,190	$8,190
	Supervisor (5 days/month on site)	Unit Cost Basis	$/hr	300	$110	$33,000	$33,000
	Camp Costs						
	for above personnel (365+30+30+60)	Unit Cost Basis	mandays	360	$65	$23,400	$23,400
	Employee Transport Costs						
	Driving in allowance (4 roundtrips per mo)	Unit Cost Basis	monthly	6	$2,500	$15,000	$15,000
						Sub-Total - Personnel	**$95,832**
12.2	**Equipment**						
	Small Excavator (1)	Misc.	monthly	6	$1,000	$6,000	$6,000
	Small Dozer (1)	Misc.	monthly	6	$1,000	$6,000	$6,000
	Small Loader (1)	Misc.	monthly	6	$1,000	$6,000	$6,000
	Pick-Up Truck (1)	Misc.	monthly	6	$2,500	$15,000	$15,000
	Snow Machine & ATV	Misc.	monthly	6	$350	$2,100	$2,100
						Sub-Total - Equipment	**$35,100**
12.3	**Tasks**						
	SNP/AEMP water sampling	Misc.	monthly	6	$7,756	$46,535	$46,535
	Interim water treatment (active BK-625)	Misc.	monthly	6	$16,441	$98,643	$98,643
	Geotechnical Assessments	Misc.	each	1	$15,000	$15,000	$15,000
	Enhanced Groundwater/Foundation monitoring	Misc.	each	1	$15,000	$15,000	$15,000
	Monitoring of piezometers and thermistors	Misc.	each	2	$3,000	$6,000	$6,000
	Communications & reporting	Misc.	monthly	6	$1,000	$6,000	$6,000
						Sub-Total - Tasks	**$187,178**
12.4	**Miscellaneous**						
	Misc Supplies	Misc.	monthly	6	$3,000	$18,000	$18,000
	Monthly Fuel	Misc.	$/litre	3,000	$1.25	$3,750	$3,750
						Sub-Total - Miscellaneous	**$21,750**
						Cost for ICM	**$339,860**

Table 9-13

Mobilization and Demobilization

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Annual Cost	Full Cost
13.1	**Mobilize Equipment & Fuel**						
	Heavy Equipment						
	3.5 yd LHDUnderground scooptram (1)	Equipment	hrs	10	$300	$3,000	$3,000
	Excavators (2)	Equipment	hrs	10	$150	$1,500	$1,500
	Rock Trucks (2)	Equipment	hrs	20	$200	$4,000	$4,000
	Dozer-large (1)	Equipment	hrs	10	$350	$3,500	$3,500
	Dozer-medium (1)	Equipment	hrs	5	$300	$1,500	$1,500
	Grader-large (1)	Equipment	hrs	10	$250	$2,500	$2,500
	Loader-large (1)	Equipment	hrs	10	$300	$3,000	$3,000
	Loader-medium (1)	Equipment	hrs	5	$180	$900	$900
	Compactor (1)	Equipment	hrs	10	$190	$1,900	$1,900
	Crane (1)	Equipment	hrs	10	$190	$1,900	$1,900
	Light-duty Vehicles (2)	Light truck	hrs	10	$100	$1,000	$1,000
	Misc. Equipment						
	Other						
	Fuel						
	Fuel Freight	Unit Cost Basis	l.s.	1	$5,000	$5,000	$5,000
						Sub-Total - Mobilize Equipment & Fuel	**$29,700**
13.2	**Mobilize Workers & Camp**						
	Workers (15men)						
	Travel costs-bus	Unit Cost Basis	ea	15	$200	$3,000	$3,000
	Workers wages during mob (8hr trip)	Unit Cost Basis	hrs	120	$80	$9,600	$9,600
						Sub-Total - Mobilize Workers & Camp	**$12,600**
13.3	**Demobilize Equipment**						
	Heavy Equipment						
	6 yd LHDUnderground scooptram (1)	Equipment	hrs	10	$300	$3,000	$3,000
	Excavators (2)	Equipment	hrs	10	$150	$1,500	$1,500
	Rock Trucks (2)	Equipment	hrs	20	$200	$4,000	$4,000
	Dozer-large (1)	Equipment	hrs	10	$350	$3,500	$3,500
	Dozer-medium (1)	Equipment	hrs	5	$300	$1,500	$1,500
	Grader-large (1)	Equipment	hrs	10	$250	$2,500	$2,500
	Loader-large (1)	Equipment	hrs	10	$300	$3,000	$3,000
	Loader-medium (1)	Equipment	hrs	5	$180	$900	$900
	Compactor (1)	Equipment	hrs	10	$190	$1,900	$1,900
	Crane (1)	Equipment	hrs	10	$190	$1,900	$1,900
	Light-duty Vehicles (2)	Light truck	hrs	10	$100	$1,000	$1,000
	Misc. Equipment						
	Sea Containers (supplies, mobile offices) (6)	Equipment	hrs	60	$50	$3,000	$3,000
	Other						
						Sub-Total-Demobilize Equipment	**$27,700**
13.4	**Demobilize Wokers & Camp**						
	Workers (15men)						
	Travel costs-bus	Unit Cost Basis	ea.	15	$200	$3,000	$3,000
	Workers wages during demob (8hr trip)	Unit Cost Basis	hrs	120	$80	$9,600	$9,600
	Demob camp (N/A-decommissioned as part of site closure)						
						Sub-Total - Demobilize Workers & Camp	**$12,600**
Total Estimated Cost for Mobilization and Demobilization							**$82,600**

10. REFERENCES

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BGC Engineering, 2002(a). Heap Leach Facility Soil Cover Design Report. Viceroy Minerals Corporation, Brewery Creek Mine. July 2002.

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Hatch, 2016(b). Mass Load Model for Lightning Creek: Description and Results. Draft Report prepared for Elsa Reclamation Development Company Ltd., March 2016.

Lortie, G, February 2009. Current State of Wildlife in the Keno Hill Silver District.

Yukon Government and Yukon Water Board, 2013. Reclamation and Closure Planning for Quartz Mining Projects. Plan requirements and closure costing guidance, August 2013.

Yukon Government, 2014. Third Party Equipment Rental Rates, March 2014.

APPENDIX 1

RECLAMATION RESEARCH SUMMARY REPORTS

APPENDIX 1.1

2012 DSTF INTERIM RECLAMATION AND COVER SUMMARY REPORT

3 Calcite Business Centre, 151 Industrial Road
Whitehorse, Yukon Y1A 2V3
Phone (867) 668-6463 Fax (867) 667-6680
www.accessconsulting.ca

Memorandum

To: Alexco Keno Hill Mining Corp.

From: Access Consulting Group

CC:

Date: March 20, 2013

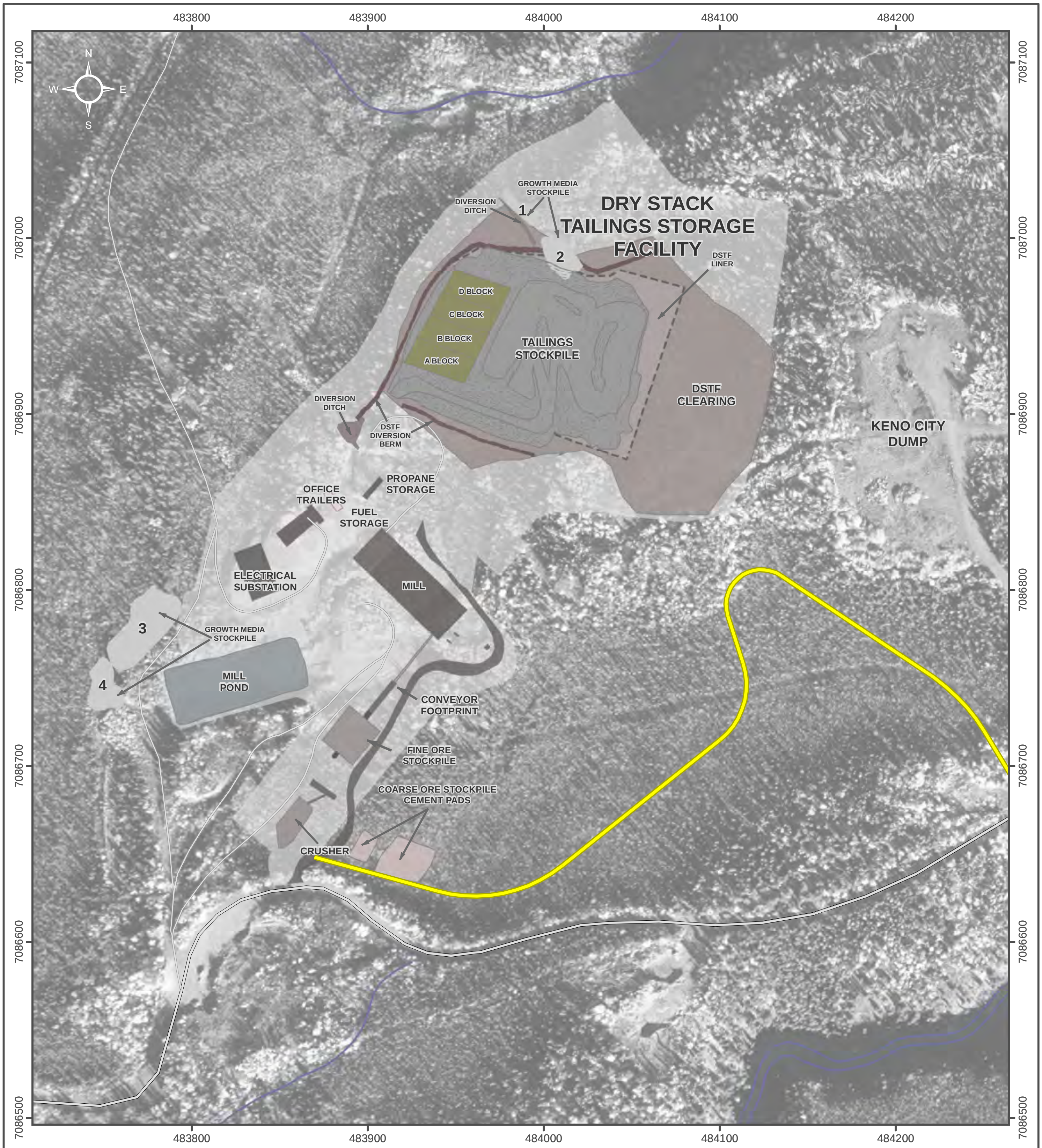
Re: 2012 Dry Stack Tailings Facility Cover Trial

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 Bellekeno Mine is licenced under Quartz Mining License QML-0009 and Water Use Licence QZ09-092.

Progressive reclamation of the Dry Stack Tailings Facility (DSTF), one of several mine components licenced under the authorizations above and shown in Figure 1. The reclamation was initiated during the summer of 2012 as outlined in the Reclamation and Closure Plan (Access, 2012) to prevent infiltration of meteoric water and prevention of dusting and erosion of exposed tailings slopes. The progressive reclamation included four areas (block A, B, C, & D) on the DSTF to be covered with granular material and seeded to test various cover trials.

Progressive reclamation of the DSTF is scheduled to occur after mill generated tailings are deposited, followed by recontouring of the slopes, and placement of a cover consisting of course soil and seeding with suitable vegetation. Reclamation was initiated in 2012 and on schedule with the year 2 start date (EBA 2010b). Ground surface preparation of the tailings prior to soil cover placement was not necessary (EBA 2010a) given that tailings are hauled from the mill at least once daily, and compacted with a drum packer to ensure proper compaction.

Phase I of the progressive reclamation tailings program covered an area of approximately 2,188 m^2 (~0.22 ha) which would correspond to a volume of ~547 m^3 of cover material for a cover thickness of 0.25 m. There was sufficient suitable granular material in the area of the DSTF to allow for construction of the proposed evapotranspiration cover. A conceptual evapotranspiration cover design is shown in Figure 2 and is based on the successful cover design constructed at the Brewery Creek Mine.



1:3,000 *When printed on 8.5 by 11 inch paper*

0 50 100 150 Meters

DSTF Cover Trial
Duncan Creek Road
Mill Access
Haul Road

ALEXCO KENO HILL MINING CORP.

FIGURE 1
DSTF VEGETATION COVER TRIAL 2012

AKHM ACCESS

MARCH 2013

Aerial photography flight date: July 13th 2006. Ortho-rectification produced by Challenger Geomatics Ltd. Site hydrography and contours derived from 2006 aerial imagery. Mill pond survey (Y.E.S. Sept 2010), mill structures, current DSTF footprint and roads survey (ACG, December 2011). Design data obtained from EBA.

Datum: NAD 83; Projection: UTM Zone 8N

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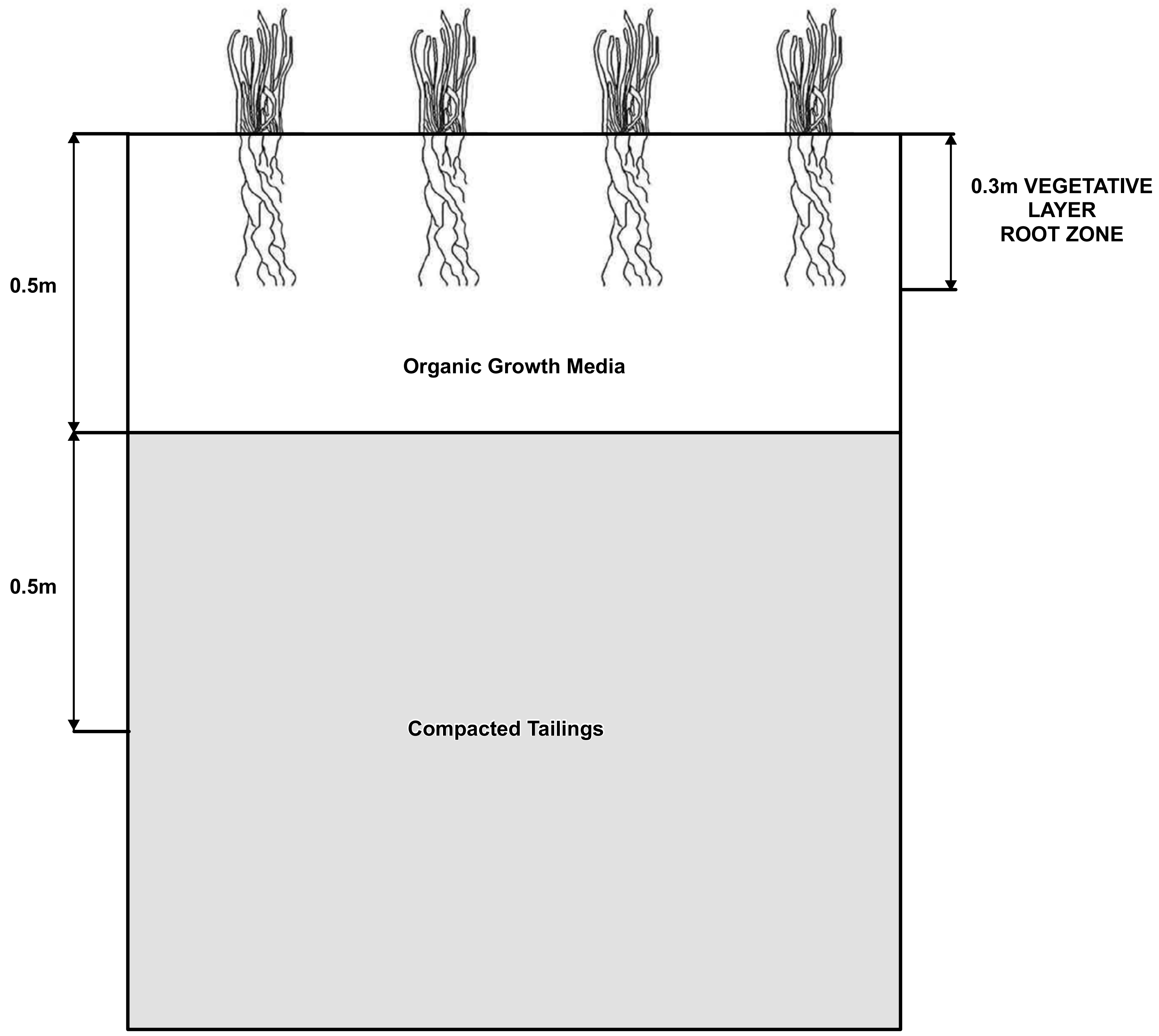
(Last edited by: jpan; 3/20/2013/09:16 AM)

CONCEPTUAL SOIL COVER DESIGN



Conceptual drawing only. Drawing is not to scale.

AKHM
ACCESS

ALEXCO KENO HILL MINING CORP.
RECLAMATION AND CLOSURE PLAN

FIGURE 2

CONCEPTUAL SOIL COVER DESIGN

DRAWN BY JP	NOVEMBER 2011	VERIFIED BY BT

I:\ALEX-05-01\Bellekeno\GIS\mxd\Closure\2011\Submitted_Nov2011\Fig6-11_Soil_Cover_System20111117.mxd
(Last edited by: jpan;11/17/2011/12:25 PM)

In general, there is no dominant type of cover specifically designed for cold climates; rather, the type of cover design is site specific depending on the physical and chemical characteristics of the tailings facility (SRK, 2009). The cover design in this instance is defined as a store-and-release cover, which makes use of a generally thick layer of soil to store water until it can be taken up and evapo-transpired by plants (SRK, 2009).

As stated above and in the Preliminary Engineering Design and Management Plan of the DSTF (EBA, 2010b), progressive reclamation consists of placing an evapo-transpirative cover (a minimum of 0.25 m of loosely placed gravel soil) over the surface of the compacted tailings to temporarily store runoff and allow it to evaporate or be used by plants. Analogous to the successful results realized at the Brewery Creek Mine, the Reclamation Plan includes re-vegetation of the DSTF with plants that promote soil evapo-transpiration such that pore water is released to the atmosphere reducing the net infiltration across the soil system (Tremblay et al., 2001). The performance results of those covers indicate precipitation infiltration rates between 7% – 22% with the variation related to differences in cover thickness and site topography (Access, 2010).

The four stockpiles of growth media that were set aside during development of the mill site and ancillary support buildings (for the future use as DSFT cover material) were surveyed and the volumes calculated (Table 1). To prepare for the upcoming cover program activities over the summer, samples were obtained from each pile and sent to an outside laboratory for analysis of available nutrients, metals and physical properties in late spring, 2012. Nutrient levels ranged from very low to moderate as shown in the Appendix A laboratory analysis while soil pH ranged from neutral to mildly acidic. Physical locations, soil properties, and volumes of the piles are presented below in Table 1.

Table 1 Stockpiled Growth Media for Use as DSTF Cover

Stock Pile Number	Location	Soil Type	Volume (m^3)
1	483987E, 7087017N	Loam	205.5
2	484007E, 7086993N	Loam	301.3
3	483770E, 7086777N	Sandy Loam	3102.9
4	483750E, 7086744N	Sandy Loam	615.0
		Total	4,224.7

The DSTF was constructed to the preliminary engineering design specification and as such has a slope of 3:1. The cover therefore, has a similar slope except in Block D where a small area, by design, has a steeper slope.

As discussed above, the area requiring a cover was estimated to be 2,188 m^2. Block A of the cover trial received a minimum cover thickness of 0.5 m, whereas Blocks B, C and D had a minimum cover thickness of 0.25 m. The actual thickness of the cover on the individual Blocks will vary due to the various types of surface landscaping included in the trial Blocks. The minimum total volume of material used for placement on the DSTF was calculated to be 687 m^3 using the above compacted thicknesses; however, the actual volume of growth media placed is most likely greater due to a compaction factor and the surface landscaping, where the cover was placed thicker than the minimum thickness specification. This cover material was transferred from the stock piles to the DSTF using the Volvo trucks, which have a capacity of 17 m^3 per load. It should be noted that unsuitable material such as boulders and organics were set aside and not used in the construction of the cover. After the material was placed and profiles construction completed, the growth media was compacted by backtracking the hoe parallel to the slope which also created an irregular surface and therefore limiting the susceptibility of soil erosion. Prior to seeding, the dimensions of the individual blocks were measured (Table 2) to determine the appropriate mass of seed required per section. Cross sections of the individual block are presented in Appendix B and a photo log of the cover trial is presented in Appendix C.

Table 2 Area by Section of DSTF Cover

Block	Dimensions (m)	Area (m^2)	Minimum Cover Thickness (m)
A	15.5 m x 36 m	558	0.50
B	16.75 m x 37.5 m	628.13	0.25
C	12 m x 37.5 m	450	0.25
D	16 m x 34.5 m	552	0.25
Total	**60.25 m x ~36 m**	**2,188.13**	**0.25**

The Keno District Dry Land Seed Mix (Table 3) was selected using a blend of suitable species seeded at the Brewery Creek and Minto mine sites, which was custom mixed by Brett-Young Seeds of Alberta and was applied using a seeding rate of 35 kg/ ha. All species used in the seed mix are Yukon natives except for Sheep Fescue which is native to Eurasia; however, it resembles many tufted fine-leaved fescues in North America (Matheus and Omtzigt 2011). This species was chosen because it is closely related to the Yukon native alpine fescue (*Festuca brachyphylla*) which is an ideal native fescue to sow on acidic alpine and subalpine sites; however this seed is not currently available commercially (Matheus and Omtzigt 2011).

Table 3 Seed Mix Used on DSTF (Matheus and Omtzigt 2011)

Common Name	Botanical Name	Origin	Seeds per kg	Percent Mix (%)
Violet Wheatgrass	*Elymus alaskanus*	*native to Yukon*	330,000	40.0
Sheep Fescue	*Festuca ovina*	*not native (Eurasian)*	1,100,000	23.5
Rocky Mountain Fescue	*Festuca saximontana*	*native to Yukon*	1,430,000	23.0
Glaucous Bluegrass	*Poa glauca*	*native to Yukon*	2,907,000	13.5

Fertilizer was applied at a calculated rate of 130 kg/ha (Matheus and Omtzigt 2011). In total, 25 kg of 19-19-19 was used. Individual blocks were seeded and fertilized using a grid and track-back method, using hand held hoppers for dispersal. Seeded areas that had been constructed with a slope greater than 3:1 were raked to ensure good seed-soil contact was made and to reduce the risk of seeds washing downslope in the event of a high intensity rainfall.

A follow up site visit was conducted in August 2012 to assess the progress of the seeding program. Seedlings were present on the cover and areas where seed had been raked into the soil appeared to a higher density of seedlings.

Follow up monitoring later spring 2013 will assess winterkill and survival rates. At this time additional seeding and fertilizing application rates will be calculated. The blocks will also be inspected for signs of rill erosion and will be mitigated should any be present

REFERENCES

Access Consulting Group. 2012. Preliminary Reclamation and Closure Plan, Keno Hill Silver District Mining Operations. Prepared for Alexco Keno Hill Mining Corporation

Access Consulting Group. 2010. Brewery Creek: From Assessment and Permitting Through Production and Closure: A Post Closure Analysis of a Northern Heap Leach Mine. Prepared for Mining, petroleum Environmental Research Group

EBA Engineering Ltd., 2010a. Operation, Maintenance, and Surveillance Manual Dry Stack Tailings Facility, Keno Hill District Mill, YT. Revision 2010-1. Prepared for Alexco Hill Mining Corp. EBA File: W14101178.009

EBA Engineering Ltd., 2010b. Preliminary Engineering Design and Management Plan: Dry-Stacked Tailings Facility, Bellekeno Mine Mill Site, Yukon. Prepared for Alexco Resource Corp. Issued for Use. EBA File: W14101178.003

O'Kane Consultants Inc. (editors) 2004. Design, Construction and Performance Monitoring of Cover Systems for Waste Rock and Tailings. MEND 2.21.4. Volume 4: Field Performance Monitoring and Sustainable Performance of Cover Systems. Prepared for MEND.

SRK Consulting (Canada) Inc. 2009. Mine Waste Covers in Cold Regions. Prepared for Mine Environmental Neutral Drainage Program (MEND).

Tremblay, Gilles and Hogan, Charlene, 2001. "MEND Manual Volume 4 – Prevention and Control". Mine Environment Neutral Drainage (MEND) Program.

APPENDIX A

SOIL ANALYSIS

Maxxam

Your Project #: ALEX-12-BELLE-02
Your C.O.C. #: 08351389

Attention: Scott Davidson
ACCESS CONSULTING GROUP
#3 Calcite
151 Industrial Road
WHITEHORSE, YT
CANADA Y1A 3C8

Report Date: 2012/05/28

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B241340
Received: 2012/05/18, 08:30

Sample Matrix: Soil
Samples Received: 4

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Analytical Method
Cation Exchange Capacity (1)	4	2012/05/25	2012/05/25	AB SOP-00009	SSMA 18.2, EPA 200.7
Conductivity (Soluble)	4	2012/05/24	2012/05/24	BBY6SOP-00029	SM-2510 B
Elements by ICPMS (total)	4	2012/05/24	2012/05/24	BBY7SOP-00001	EPA 6020A
Potassium (Available) (1)	4	2012/05/25	2012/05/25	AB SOP-00042	EPA 200.7
Nitrate-N (Available) (1)	4	2012/05/25	2012/05/25	AB SOP-00023	SM 4110-B
Phosphorus (Available by ICP) (1)	4	2012/05/25	2012/05/25	AB SOP-00042	EPA 200.7
pH (2:1 DI Water Extract)	4	2012/05/24	2012/05/24	BBY6SOP-00028	Carter, SSMA 16.2
Saturated Paste	4	2012/05/24	2012/05/24	BBY6SOP-00030	Carter SSMA 18.2.2
Total Organic Carbon LECO Method (1)	4	2012/05/25	2012/05/25	CAL SOP-00243	LECO# 203-821-170
Texture by Hydrometer (1)	4	N/A	2012/05/25	AB SOP-00030	MMFSPA Ch9
Texture Class (1)	4	N/A	2012/05/25	AB SOP-00030	MMFSPA Ch9
Total Nitrogen in Soil by LECO (1)	4	2012/05/28	2012/05/28	CAL SOP-00243	LECO# 203-821-170

* Results relate only to the items tested.

(1) This test was performed by Maxxam Calgary Environmental

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

LANOY LUANGKHAMDENG, Burnaby Project Manager
Email: LLuangkhamdeng@maxxam.ca
Phone# (604) 638-2636

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Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total cover pages: 1

Maxxam

Maxxam Job #: B241340
Report Date: 2012/05/28

ACCESS CONSULTING GROUP
Client Project #: ALEX-12-BELLE-02

Sampler Initials: LK

NPK (AVAILABLE)

Maxxam ID		DL5561		DL5562		DL5563	DL5564		
Sampling Date		2012/05/14 13:30		2012/05/14 13:30		2012/05/14 13:30	2012/05/14 13:30		
	Units	**WP1 (DSTF)**	**RDL**	**WP2 (DSTP)**	**RDL**	**WP3 (MILL WASTE)**	**WP4 (MILL WASTE)**	**RDL**	**QC Batch**
Nutrients									
Available (NH4F) Nitrogen (N)	mg/kg	<10(1)	10	<2.0	2.0	11(1)	<10(1)	10	5868444
Available (NH4F) Phosphorus (P)	mg/kg	10	5.0	<1.0	1.0	17	77	5.0	5867906
Available (NH4OAc) Potassium (K)	mg/kg	52	10	29	2.0	25	29	10	5867902

RESULTS OF CHEMICAL ANALYSES OF SOIL

Maxxam ID		DL5561	DL5562	DL5563		DL5564		
Sampling Date		2012/05/14 13:30	2012/05/14 13:30	2012/05/14 13:30		2012/05/14 13:30		
	Units	**WP1 (DSTF)**	**WP2 (DSTP)**	**WP3 (MILL WASTE)**	**QC Batch**	**WP4 (MILL WASTE)**	**RDL**	**QC Batch**
Elements								
Cation exchange capacity	cmol+/Kg	24	13	33	5867085	13	10	5867085
Soluble Parameters								
Soluble Conductivity	uS/cm	197	2540	512	5863576	276	1.0	5863576
Saturation %	%	90.5	53.0	88.7	5863551	74.8	1.0	5863551
Physical Properties								
% sand by hydrometer	%	44	53	58	5866937	50	2.0	5866937
% silt by hydrometer	%	44	37	31	5866937	43	2.0	5866937
Clay Content	%	12	11	10	5866937	6.9	2.0	5866937
Texture	N/A	LOAM	LOAM	SANDY LOAM	5860280	SANDY LOAM	N/A	5861607

N/A = Not Applicable
RDL = Reportable Detection Limit
(1) - Detection limits raised due to sample matrix.

Maxxam Job #: B241340
Report Date: 2012/05/28

ACCESS CONSULTING GROUP
Client Project #: ALEX-12-BELLE-02

Sampler Initials: LK

MISCELLANEOUS (SOIL)

Maxxam ID		DL5561		DL5562		DL5563		DL5564		
Sampling Date		2012/05/14 13:30		2012/05/14 13:30		2012/05/14 13:30		2012/05/14 13:30		
	Units	**WP1 (DSTF)**	**RDL**	**WP2 (DSTP)**	**RDL**	**WP3 (MILL WASTE)**	**RDL**	**WP4 (MILL WASTE)**	**RDL**	**QC Batch**
Misc. Inorganics										
Total Nitrogen	%	0.28	0.20	<0.20	0.20	0.25	0.20	0.23	0.20	5871016
Total Organic Carbon (C)	%	7.4 (1)	0.040	2.4	0.020	5.8 (1)	0.20	4.0	0.020	5867097

RDL = Reportable Detection Limit
(1) - Detection limits raised due to dilution to bring analyte within the calibrated range.

Maxxam Job #: B241340
Report Date: 2012/05/28

ACCESS CONSULTING GROUP
Client Project #: ALEX-12-BELLE-02

Sampler Initials: LK

CSR/CCME METALS IN SOIL (SOIL)

Maxxam ID		DL5561	DL5562	DL5563	DL5564		
Sampling Date		2012/05/14 13:30	2012/05/14 13:30	2012/05/14 13:30	2012/05/14 13:30		
	Units	**WP1 (DSTF)**	**WP2 (DSTP)**	**WP3 (MILL WASTE)**	**WP4 (MILL WASTE)**	**RDL**	**QC Batch**
Physical Properties							
Soluble (2:1) pH	pH Units	5.67	6.33	7.25	5.53	0.010	5863833
Total Metals by ICPMS							
Total Aluminum (Al)	mg/kg	12100	9370	9130	11500	100	5863755
Total Antimony (Sb)	mg/kg	1.10	39.5	2.01	2.32	0.10	5863755
Total Arsenic (As)	mg/kg	29.2	712	65.1	58.2	0.50	5863755
Total Barium (Ba)	mg/kg	217	182	188	289	0.10	5863755
Total Beryllium (Be)	mg/kg	<0.40	<0.40	<0.40	<0.40	0.40	5863755
Total Bismuth (Bi)	mg/kg	0.19	1.03	0.44	0.21	0.10	5863755
Total Cadmium (Cd)	mg/kg	1.17	148	2.13	2.66	0.050	5863755
Total Calcium (Ca)	mg/kg	4750	5760	10400	4050	100	5863755
Total Chromium (Cr)	mg/kg	19.0	15.9	17.2	20.5	1.0	5863755
Total Cobalt (Co)	mg/kg	7.39	11.6	9.73	9.90	0.30	5863755
Total Copper (Cu)	mg/kg	19.0	87.0	35.4	28.0	0.50	5863755
Total Iron (Fe)	mg/kg	23200	47000	23300	27600	100	5863755
Total Lead (Pb)	mg/kg	38.9	3730	50.2	134	0.10	5863755
Total Lithium (Li)	mg/kg	11.7	10.1	11.2	11.9	5.0	5863755
Total Magnesium (Mg)	mg/kg	3400	4050	4960	3790	100	5863755
Total Manganese (Mn)	mg/kg	597	7790	610	674	0.20	5863755
Total Mercury (Hg)	mg/kg	0.057	0.223	<0.050	0.062	0.050	5863755
Total Molybdenum (Mo)	mg/kg	1.20	1.66	1.63	1.50	0.10	5863755
Total Nickel (Ni)	mg/kg	15.5	20.7	22.1	21.3	0.80	5863755
Total Phosphorus (P)	mg/kg	469	511	685	659	10	5863755
Total Potassium (K)	mg/kg	494	394	402	435	100	5863755
Total Selenium (Se)	mg/kg	0.72	1.19	0.91	0.76	0.50	5863755
Total Silver (Ag)	mg/kg	0.491	29.0	0.921	1.79	0.050	5863755
Total Sodium (Na)	mg/kg	<100	<100	<100	<100	100	5863755
Total Strontium (Sr)	mg/kg	18.7	15.4	29.0	18.5	0.10	5863755
Total Thallium (Tl)	mg/kg	0.116	0.131	0.101	0.127	0.050	5863755
Total Tin (Sn)	mg/kg	0.42	11.0	0.93	0.44	0.10	5863755
Total Titanium (Ti)	mg/kg	226	197	197	238	1.0	5863755
Total Uranium (U)	mg/kg	0.609	0.643	0.835	0.706	0.050	5863755
Total Vanadium (V)	mg/kg	39.5	28.1	29.0	34.3	2.0	5863755
Total Zinc (Zn)	mg/kg	123	11800	219	251	1.0	5863755
Total Zirconium (Zr)	mg/kg	0.55	<0.50	1.32	<0.50	0.50	5863755

RDL = Reportable Detection Limit

Package 1	1.7°C

Each temperature is the average of up to three cooler temperatures taken at receipt

General Comments

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NPK (AVAILABLE) Comments

Sample DL5561-01 Phosphorus (Available by ICP): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Sample DL5563-01 Phosphorus (Available by ICP): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Sample DL5564-01 Phosphorus (Available by ICP): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Sample DL5561-01 Potassium (Available): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Sample DL5563-01 Potassium (Available): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Sample DL5564-01 Potassium (Available): Due to the sample matrix, sample required dilution. Detection limit was adjusted accordingly

Maxxam Job #: B241340
Report Date: 2012/05/28

ACCESS CONSULTING GROUP
Client Project #: ALEX-12-BELLE-02

Sampler Initials: LK

QUALITY ASSURANCE REPORT

			Matrix Spike		Spiked Blank		Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
5863551	Saturation %	2012/05/24			99	80 - 120	<1.0	%	0.4	30		
5863576	Soluble Conductivity	2012/05/24			111	70 - 130	<1.0	uS/cm	2.5	35		
5863755	Total Antimony (Sb)	2012/05/24	NC	75 - 125	93	75 - 125	<0.10	mg/kg			39	N/A
5863755	Total Arsenic (As)	2012/05/28	NC	75 - 125	102	75 - 125	<0.50	mg/kg	0.5	30	192	N/A
5863755	Total Barium (Ba)	2012/05/24	NC	75 - 125	97	75 - 125	<0.10	mg/kg			470	N/A
5863755	Total Beryllium (Be)	2012/05/24	104	75 - 125	106	75 - 125	<0.40	mg/kg			1.8	N/A
5863755	Total Cadmium (Cd)	2012/05/24	98	75 - 125	105	75 - 125	<0.050	mg/kg			5.0	N/A
5863755	Total Chromium (Cr)	2012/05/24	100	75 - 125	97	75 - 125	<1.0	mg/kg			72	N/A
5863755	Total Cobalt (Co)	2012/05/24	96	75 - 125	98	75 - 125	<0.30	mg/kg			25	N/A
5863755	Total Copper (Cu)	2012/05/24	NC	75 - 125	99	75 - 125	<0.50	mg/kg			367	N/A
5863755	Total Lead (Pb)	2012/05/24	NC	75 - 125	97	75 - 125	<0.10	mg/kg			274	N/A
5863755	Total Lithium (Li)	2012/05/24	95	75 - 125	96	75 - 125	<5.0	mg/kg			31	N/A
5863755	Total Manganese (Mn)	2012/05/24	NC	75 - 125	98	75 - 125	<0.20	mg/kg			1060	N/A
5863755	Total Mercury (Hg)	2012/05/24	111	75 - 125	109	75 - 125	<0.050	mg/kg			44	N/A
5863755	Total Molybdenum (Mo)	2012/05/24	98	75 - 125	88	75 - 125	<0.10	mg/kg			29	N/A
5863755	Total Nickel (Ni)	2012/05/24	88	75 - 125	95	75 - 125	<0.80	mg/kg			104	N/A
5863755	Total Selenium (Se)	2012/05/24	117	75 - 125	118	75 - 125	<0.50	mg/kg			1.3	N/A
5863755	Total Silver (Ag)	2012/05/24	83	75 - 125	89	75 - 125	<0.050	mg/kg			20	N/A
5863755	Total Strontium (Sr)	2012/05/24	NC	75 - 125	91	75 - 125	<0.10	mg/kg			417	N/A
5863755	Total Thallium (Tl)	2012/05/24	94	75 - 125	88	75 - 125	<0.050	mg/kg			43	N/A
5863755	Total Tin (Sn)	2012/05/24	NC	75 - 125	85	75 - 125	<0.10	mg/kg			33	N/A
5863755	Total Titanium (Ti)	2012/05/24	NC	75 - 125	94	75 - 125	<1.0	mg/kg			2070	N/A
5863755	Total Uranium (U)	2012/05/24	99	75 - 125	94	75 - 125	<0.050	mg/kg			2.7	N/A
5863755	Total Vanadium (V)	2012/05/24	NC	75 - 125	97	75 - 125	<2.0	mg/kg			82	N/A
5863755	Total Zinc (Zn)	2012/05/24	NC	75 - 125	115	75 - 125	<1.0	mg/kg			981	N/A
5863755	Total Aluminum (Al)	2012/05/24					<100	mg/kg				
5863755	Total Bismuth (Bi)	2012/05/24					<0.10	mg/kg				
5863755	Total Calcium (Ca)	2012/05/24					<100	mg/kg				
5863755	Total Iron (Fe)	2012/05/24					<100	mg/kg				
5863755	Total Magnesium (Mg)	2012/05/24					<100	mg/kg				
5863755	Total Phosphorus (P)	2012/05/24					<10	mg/kg				
5863755	Total Potassium (K)	2012/05/24					<100	mg/kg				
5863755	Total Sodium (Na)	2012/05/24					<100	mg/kg				
5863755	Total Zirconium (Zr)	2012/05/24					<0.50	mg/kg				
5863833	Soluble (2:1) pH	2012/05/24			101	96 - 104			0.2	20		
5866937	% sand by hydrometer	2012/05/25							17.9	35	99	75 - 125
5866937	% silt by hydrometer	2012/05/25							11.1	35	108	75 - 125
5866937	Clay Content	2012/05/25							3.3	35	85	75 - 125
5867085	Cation exchange capacity	2012/05/25							NC	35		
5867097	Total Organic Carbon (C)	2012/05/25			100	75 - 125	<0.020	%	7.7	50	108	75 - 125

Maxxam Job #: B241340
Report Date: 2012/05/28

ACCESS CONSULTING GROUP
Client Project #: ALEX-12-BELLE-02

Sampler Initials: LK

QUALITY ASSURANCE REPORT

			Matrix Spike		Spiked Blank		Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
5867902	Available (NH4OAc) Potassium (K)	2012/05/25			105	80 - 120	<2.0	mg/kg	3.4	35		
5867906	Available (NH4F) Phosphorus (P)	2012/05/25			102	80 - 120	<1.0	mg/kg	12.6	35		
5868444	Available (NH4F) Nitrogen (N)	2012/05/25	NC	80 - 120	100	90 - 110	<2.0	mg/kg	NC	35		
5871016	Total Nitrogen	2012/05/28			100	75 - 125	<0.20	%	NC	35	101	75 - 125

N/A = Not Applicable
RPD = Relative Percent Difference
Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.
Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Spiked Blank: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (Matrix Spike): The recovery in the matrix spike was not calculated. The relative difference between the concentration in the parent sample and the spiked amount was not sufficiently significant to permit a reliable recovery calculation.
NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Maxxam Analytics Inc

8577 Commerce Court
Burnaby, BC V5A 4N5
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Phone: (604) 444-4808
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08351389

CHAIN-OF CUSTODY RECORD AND ANALYSIS REQUEST

PAGE 1 OF 1

LAB USE ONLY MAXXAM JOB #: B241340

ANALYSIS REQUEST

LAB USE ONLY COC #:

COMPANY NAME: Access Consulting Group

CLIENT PROJECT NO.: ALEX-12-BELLE-02

COMPANY ADDRESS: #3 Calcite Business Center, 151 Industrial Rd., Whitehorse, YT, Y1A 2V3

TEL.: 867-668-6463

E-MAIL:

FAX: 867-667-6680

SAMPLER NAME (PRINT): Lisa Knight

PROJECT MANAGER: Scott Davidson

LABORATORY CONTACT: Lanoy Luangkhamdeng

	FIELD SAMPLE ID	MAXXAM LAB # (LAB USE ONLY)	GROUNDWATER	SURFACE WATER	DRINKING WATER	SOIL	OTHER	DATE DD/MM/YY	TIME	# CONTAINERS	ICP Metals	pH/EC	Texture	TOC	C:N Ration	CEC	Total N	Nutrients	Phosphorus
1	WP1 (DSTF)	DL5561				X		14/05/12	13:30	1	X	X	X	X	X	X	X	X	X
2	WP2 (DSTP)	562				X		↓	↓	1	X	X	X	X	X	X	X	X	X
3	WP3 (Mill Waste)	563				X		↓	↓	1	X	X	X	X	X	X	X	X	X
4	WP4 (Mill Waste)	564				X		↓	↓	1	X	X	X	X	X	X	X	X	X
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			

B241340

TAT (Turnaround Time)

LESS THAN 5 DAY TAT MUST HAVE PRIOR APPROVAL

* Some exceptions apply - please contact laboratory

STANDARD	5 BUSINESS DAYS	
RUSH	3 BUSINESS DAYS	
RUSH	2 BUSINESS DAYS	
URGENT	1 BUSINESS DAY	

OTHER BUSINESS DAYS ____

PO NUMBER OR QUOTE NUMBER:

SPECIAL DETECTION LIMITS / CONTAMINANT TYPE:

CCME / CSR / AB TIER 1 / OTHER

LAB USE ONLY: ARRIVAL TEMPERATURE °C: 1,2,2 | DUE DATE: | LOG IN CHECK:

ACCOUNTING CONTACT:

SPECIAL REPORTING OR BILLING INSTRUCTIONS:

JARS USED:

RELINQUISHED BY	DATE DD/MM/YY	TIME	RECEIVED BY
RELINQUISHED BY SAMPLER:			RECEIVED BY:
RELINQUISHED BY:	18/05/12	08:30	RECEIVED BY: Nicole Lockyer
RELINQUISHED BY: Lisa Knight			RECEIVED BY LABORATORY:

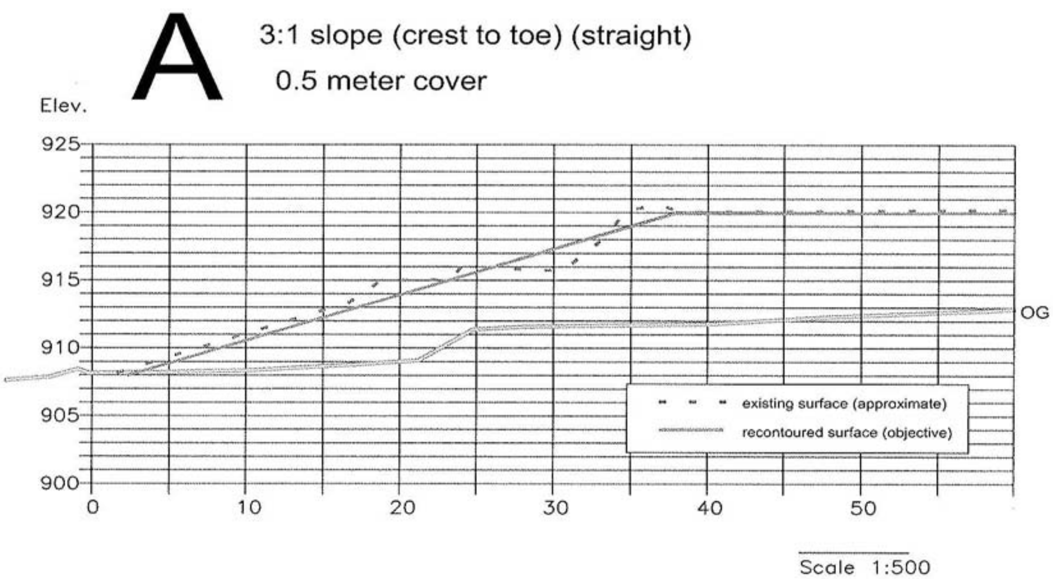
CUSTODY RECORD

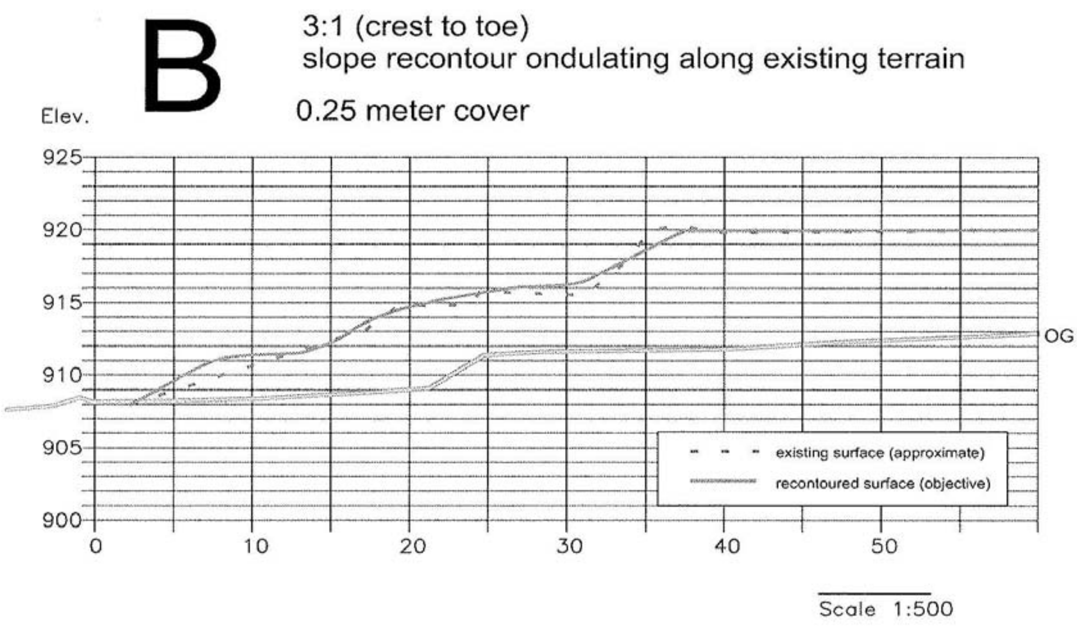
COCFORM - BC - 20070822

APPENDIX B

BLOCK PROFILES

DSTF Phase I Reclamation - Slope Profiles





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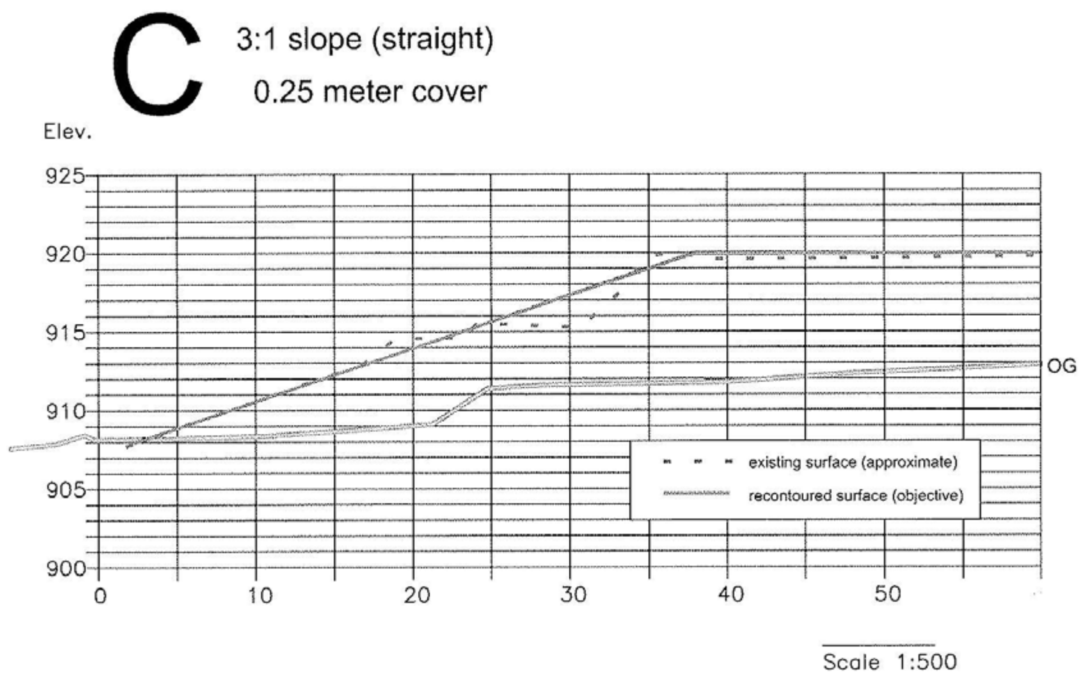
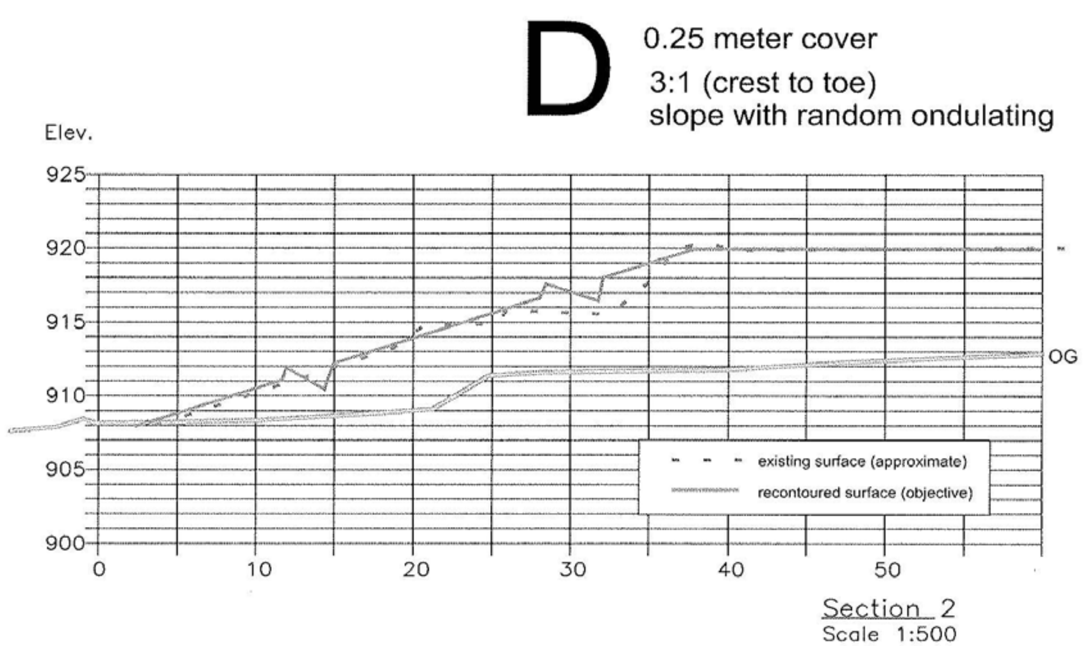

C
3:1 slope (straight)
0.25 meter cover
Elev.
925
920
915
910
905
900
0
10
20
30
40
50
OG
existing surface (approximate)
recontoured surface (objective)
Scale 1:500


D
0.25 meter cover
3:1 (crest to toe)
slope with random ondulating
Elev.
925
920
915
910
905
900
0
10
20
30
40
50
OG
existing surface (approximate)
recontoured surface (objective)
Section 2
Scale 1:500

APPENDIX C

PHOTO LOG


Photo 1: Growth Media Pile 1


Photo 2: Growth Media Pile 2


Photo 3: Growth Media Pile 2


Photo 4: Growth Media Pile 3


Photo 5: Growth Media Pile 4


Photo 6: Growth Media Pile 4

Photo 7: Covered DSTF toe looking north

Photo 8: Covered DSTF mid-slope looking south

Photo 9: Covered DSTF crest looking north

Photo 10: Covered DSTF crest looking south

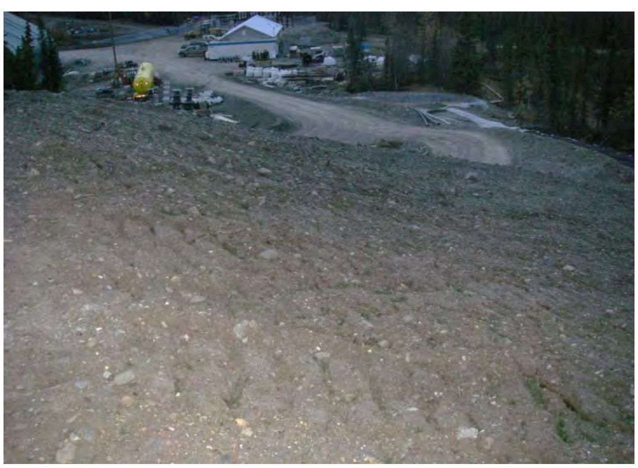


Photo 11: Grass sprouts DSTF looking south from crest

Photo 12: Grass sprouts DSTF looking west from crest

APPENDIX 1.2

SILVER KING IN SITU DEMONSTRATION TEST INTERIM REPORT

Suite 1225, Two Bentall Centre
555 Burrard Street, Box 216
Vancouver, BC V7X 1M9
Phone (604) 633-4888 Fax (604) 633-4887
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Memorandum

To: Elsa Reclamation and Development Company Ltd.

From: Andrew Gault, Cameron Robertson (Alexco Environmental Group)

CC: Linda Broughton, Kai Woloshyn, Jim Harrington (Alexco Environmental Group)

Date: December 18, 2017

Re: Silver King In Situ Treatment Test Update – November 2017, Revision 1

Deliverable 2017-18-033-2_10

1 INTRODUCTION

This memorandum provides an overview of the work performed and results collected for the Silver King (SK) *in situ* treatment test between March 2017 and November 2017. It provides an update to INAC on the latest results from the *in situ* treatment pilot test that was initiated in September 2014 and recommendations on the next steps for the pilot test. Section 2 presents an overview of the data collected to date, placing the data collected since the last reporting event (i.e. April to November 2017) in the context of the work performed since the start of the pilot test in Spetember 2014. Section 3 discusses the implications of the pilot test data to the full scale *in situ* treatment design including a discussion regarding treatment longevity, requirement for an adit plug, post-discharge polishing treatment for selected constituents, and next steps for *in situ* treatment at Silver King. Finally, Section 4 summarizes the key conclusions drawn from the updated *in situ* treatment pilot test dataset.

2 ACTIVITY AND RECENT DATA

2.1 SILVER KING DEWATERING AND GROUNDWATER

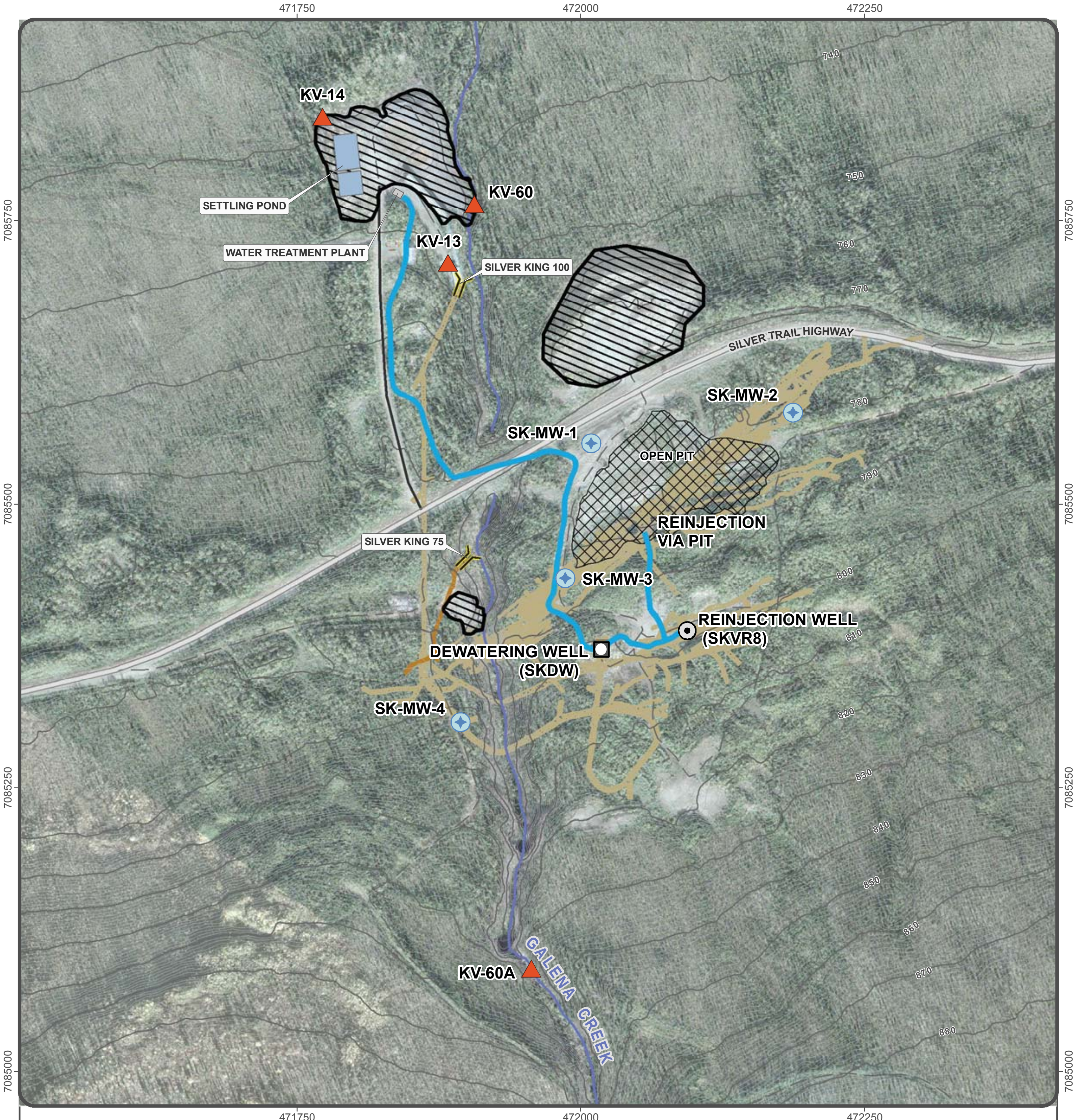
An overview of the Silver King site is displayed in Figure 2-1. The groundwater level within the SK flooded workings is plotted in Figure 2-2. Also shown are the flow rates of the underground (mine pool) water pumped from the dewatering well to the SK water treatment plant (WTP) and water that was reinjected to create a recirculation loop within the flooded mine workings. Since the end of December 2016, dewatering of the mine workings was discontinued, allowing the mine workings to flood and discharge out of the SK100 adit; this discharge was directed to the SK WTP for secondary treatment as necessary. Addition of organic carbon to the flooded mine workings last occurred between 18 November and 22

December 2016 via addition to the SK pit with subsequent infiltration to the Vein 1 workings below; no further carbon amendment has occurred since December 22, 2016.

When the workings were dewatered, significant recharge events such as spring freshet or high precipitation events in the fall resulted in marked increases in the mine workings water elevation (Figure 2-2) within one to two weeks of these high flow events. Since late December 2016, the mine workings have not been actively dewatered by pumping, resulting in minimal variation in the fully flooded workings groundwater elevation, even during freshet (Figure 2-2).

2.2 GEOCHEMISTRY OF SILVER KING FLOODED MINE WORKINGS

The full dataset collected since the start of the SK *in situ* treatment pilot test is displayed for selected constituents of interest in Figure 2-4 and Figure 2-5 in order to place this year's data in context. Additional monitoring wells that intersect the mine workings were installed in October 2016 to augment the SK dewatering well (SKDW) data and improve the understanding of the extent of the treatment (Figure 2-1 and Figure 2-3). Since the suspension of dewatering of the flooded mine workings towards the end of December 2016, the workings have been fully flooded allowing for discharge from the SK 100 adit portal (monitoring site KV-13). Since the SK 100 adit discharge integrates the water flow received from the entire mine workings, monitoring of its discharge chemistry since January 2017 will provide important information regarding the effectiveness of *in situ* treatment to provide adit discharge chemistry that is compliant with the Water Use Licence (QZ12-057) effluent quality standards (EQS). This section therefore discusses well locations within the mine working for insight into treatment conditions *in situ*, but also summarizes the discharge chemistry from the adit (recently) or the SKDW pumping well (2015-2016 discharge source), which is the focus of the WUL, i.e., compliance at discharge to the environment.



Dewatering Well
Reinjection Well
Monitoring Well
Surface Water Station
Existing Pipeline Configuration
Underground Workings (75 level)
Underground Workings (100 level)
Settling Pond
Open Pit
Waste Rock Storage Area
Silver Trail Highway
Local Road
Limited-Use Road

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on February 2017

ERDC

AEG

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

FEBRUARY 2017

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Studies\WaterTreatment\In-SituWaterTreatment\SilverKing_InSitu_Pipeline_Profile\SilverKing_Pipeline_Simple_20170216.mxd
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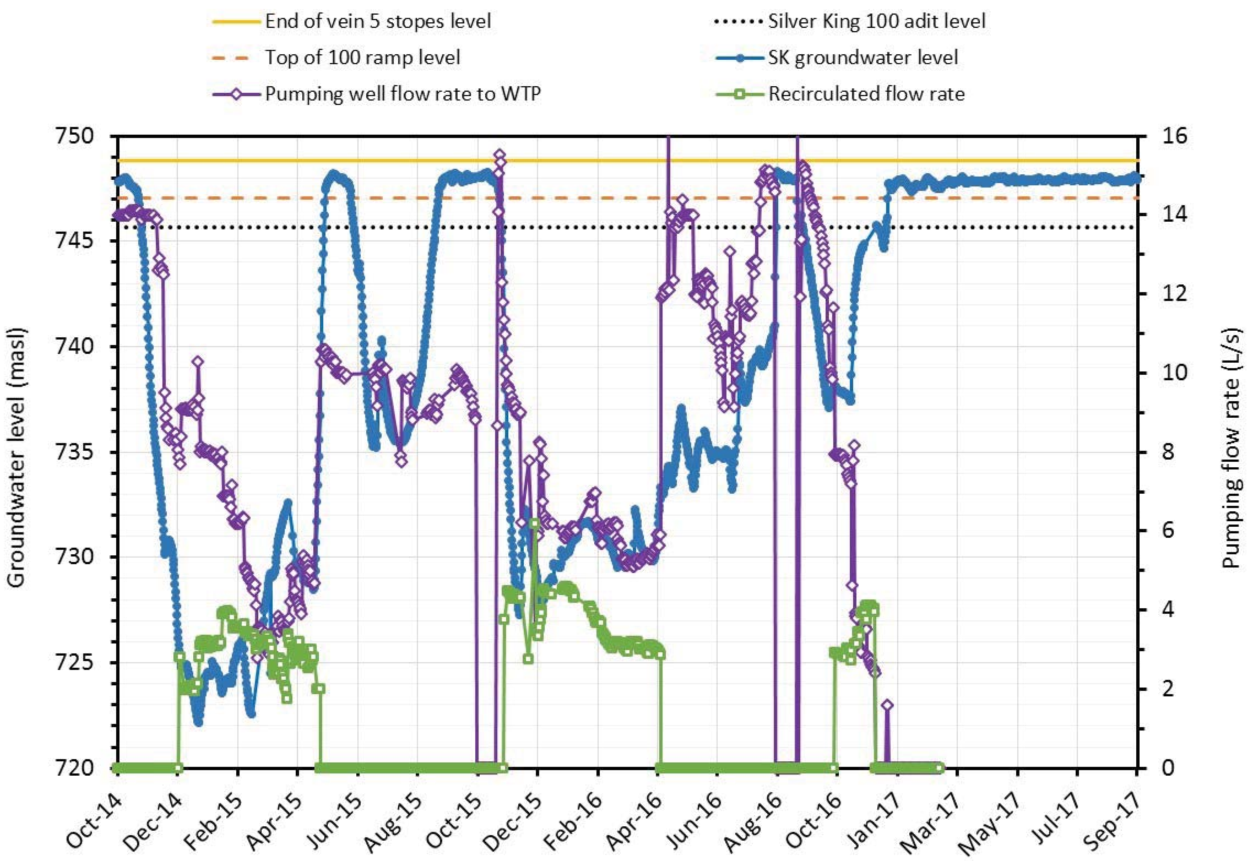

Figure 2-2: Response of Groundwater Level in SK Mine Workings During *In Situ* Treatment Pilot Test. The Level of the End of the Vein 5 Stopes, Top of the 100 Ramp and SK100 Adit are Shown for Reference.

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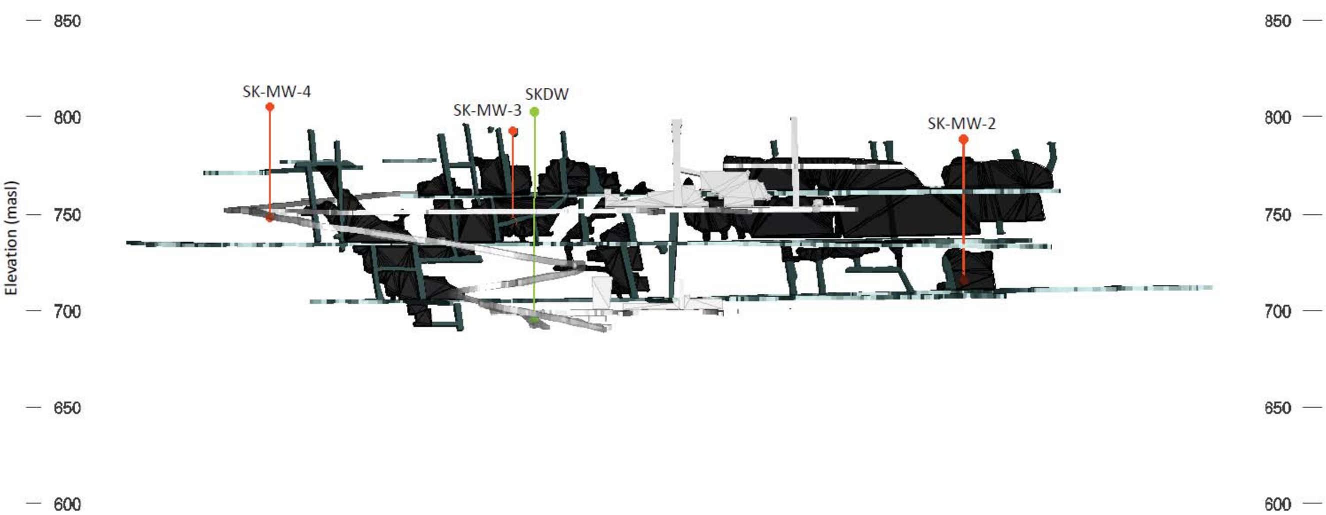


Figure 2-3: Locations of Silver King Monitoring Wells in Longwall Section

2.2.1 Dewatering Well (SKDW)

The dewatering well is located in the Vein 5 workings at the base of the decline (Figure 2-3). Previously this has been used as a pumping well to dewater the Silver King mine workings, however starting in December 2016 the pump was halted allowing for water to overflow from the adit. This well is currently only used as a monitoring well to detect the extent of treatment within the Vein 5 workings.

Sulphate concentrations in samples collected from SKDW increased in spring 2017, from approximately 460 – 490 mg/L observed between January and April to 580 – 650 mg/L observed in May and June (Figure 2-4). Over the same period, sulphide levels declined to below detection (<0.018 mg/L; Figure 2-4), ORP levels rose, and zinc, cadmium, and thallium concentrations increased sharply (Figure 2-4 and Figure 2-5). Taken together, these data suggest that ingress of oxidizing waters following spring freshet likely introduced metal laden waters into the workings sampled by SKDW. Indeed, between May and August 2017, alkalinity levels in SKDW samples decreased markedly (from 220 mg/L to 50 mg/L), coincident with a decline in pH (from 6.9 to 6.2) and an increase in acidity (from 50 mg/L to 120 mg/L; Figure 2-4). These data are suggestive of ingress of oxidized surface waters, which flowed through mineralized and oxidized mine workings, into the base of the SK decline sampled by the dewatering well (SKDW). The zinc concentration peaked at 1 mg/L in July 2017, comparable to pre-*in situ* treated levels; such behaviour was mirrored by other chalcophile metals (e.g., cadmium and thallium). While these concentrations were above the EQS (0.5 mg/L zinc), this location is deep in the workings and is not a point of compliance. The water quality at the point of discharge (as is discussed in section 2.2.5) has remained below EQS despite these zones with high metal contributions that are deep in the workings.

Recent data (September to November 2017) indicate that metal concentrations have abated in this deep area such that dissolved zinc decreased by an order of magnitude (≤0.1 mg/L), with commensurate declines in cadmium and thallium, and increased alkalinity. This coincided with the re-emergence of detectable sulphide concentrations, suggesting that *in situ* treated conditions have been re-established in the Vein 5 workings sampled by the dewatering well.

Interestingly, dissolved organic carbon (DOC) concentrations did not exhibit a peak following injection of organic carbon in this well (Figure 2-5). Instead, DOC concentrations have stabilized since April 2017 at approximately 1.1 mg/L, comparable to the pre-*in situ* treatment levels observed in 2014 prior to the introduction of any organic carbon to the SK mine workings. This suggests that in the absence of continued recycling of water within the flooded SK mine works via dewatering/re-injection, DOC is largely consumed or diluted along the flowpath between the Vein 1 injection location and the base of the Vein 5 decline, but the evidence of sharp decreases in chalcophile metal concentrations in the SKDW samples shortly after the November / December 2016 carbon amendment indicates that the effects of *in situ* treatment clearly reached this location.

Overall, the data indicate that the *in situ* treatment injection in November-December 2016 resulted in treatment of the Vein 5 workings as evidenced by the sharp decline in cadmium and zinc concentrations in January 2017 and maintained low concentrations until June 2017. Oxygenated surface waters likely entered the Vein 5 workings following freshet recharge, which brought in higher dissolved metals to the system, resulting in the spike in metal concentrations observed in SKDW samples between June and September 2017. However, *in situ* treated conditions were soon re-established as cadmium and zinc concentrations declined markedly back to “treated” levels without additional injection, i.e, from the injection in late 2016. Importantly, metal concentrations in the SK adit discharge remained low and in compliance with EQS licence requirements through this time, and appear to be only marginally influenced by this peak. Such behaviour has previously been observed during freshet and other high recharge events and is expected. For example, the mine workings were flooded with oxidizing recharge water during spring freshet in May 2015 and again following heavy rain fall events in September 2015 and September 2016. On all three of these occasions, cadmium and zinc SKDW concentrations initially increased in response to the ingress of surface waters which contained elevated metal concentrations after flowing through mineralized and oxidized mine workings. Very shortly afterwards, metal concentrations declined as *in situ* treated conditions were re-established. This shows that only periodic injection/treatment creates sustainable *in situ* treatment conditions that are capable of maintaining treatment during and after high flow events.

2.2.2 SK-MW-02

Monitoring well SK-MW-02, located at the northeast end of the Vein 1 workings (Figure 2-3), was installed in October 2016 after *in situ* treatment began in late 2014. This makes interpretation of the chemistry in this well, as affected by *in situ* treatment, more difficult because pre-treatment baseline data are not available. The recent chemistry of samples collected in this well between April and November 2017 has not changed significantly. Samples typically show circumneutral (pH 6.5 to 7.2), relatively reducing (ORP -10 to -120 mV) waters with concentrations of dissolved cadmium and zinc that were close to or below detection limits (Figure 2-4 and Figure 2-5). Indeed, this chemistry is relatively similar to that observed prior to the start of the November/December 2016 carbon injection, which may suggest that:

- The base on the Vein 1 workings accessed by SK-MW-02 are relatively hydraulically isolated from the other parts of Vein 1 workings that are treated by the carbon injection to the SK pit; or
- The effects of previous carbon injections to the SK pit in 2015 and early 2016 have resulted in sustained treatment of this portion of the flood workings, resulting in little change in chemistry.

Alternatively, metal leaching in this portion of the Vein 1 workings may be minimal, which coupled with the apparent sulphate-reducing conditions (as indicated by persistent detection of sulphide in these samples at 0.02 to 0.2 mg/L), results in low metal concentrations. In any event, good water quality has been maintained at this location for all monitoring performed to date.

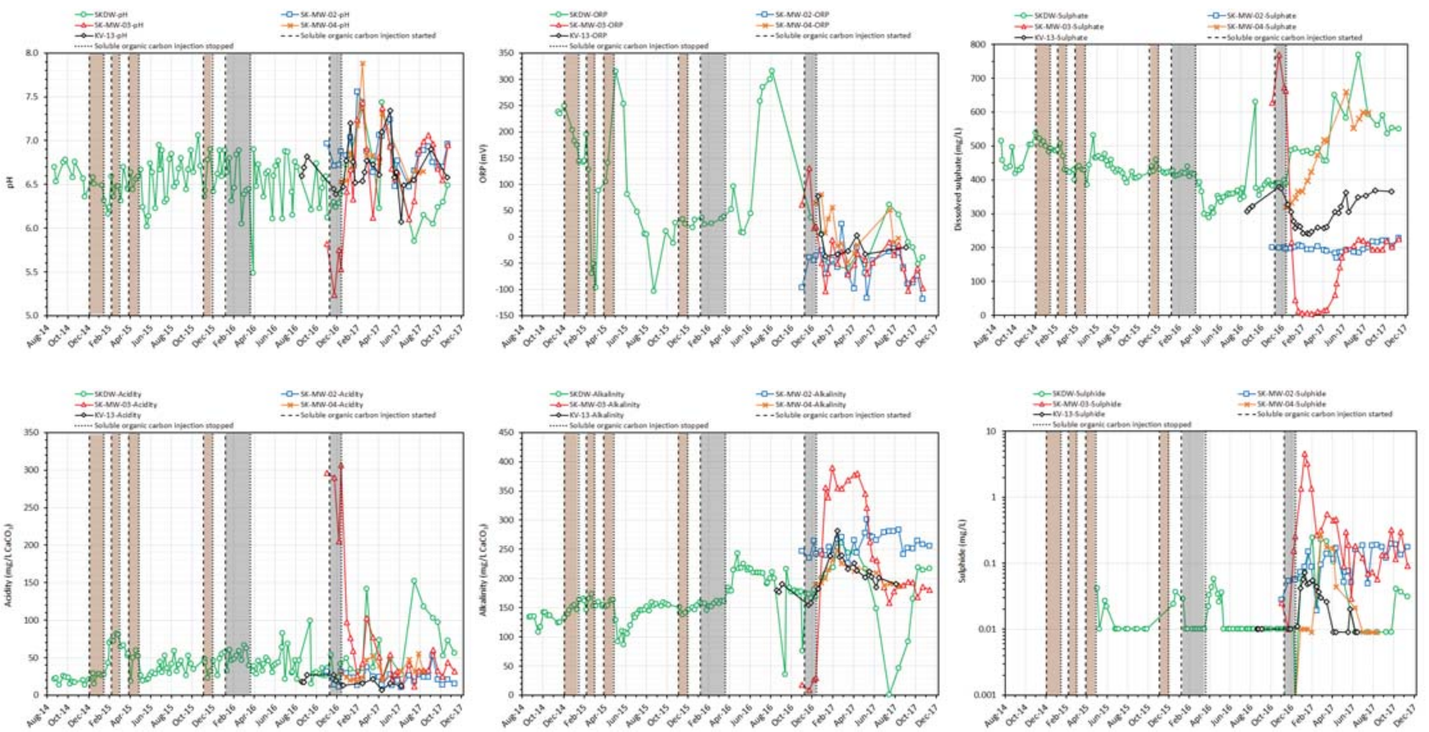


Figure 2-4: Trends in pH, ORP, Alkalinity, Acidity, Sulphate, and Sulphide in Silver King Workings Monitoring Wells and Silver King 100 Adit Discharge

Note: Shaded Areas Indicate when Continuous Injection of Molasses (brown) or Methanol (grey) was Ongoing to the Flooded Workings with Recirculation.

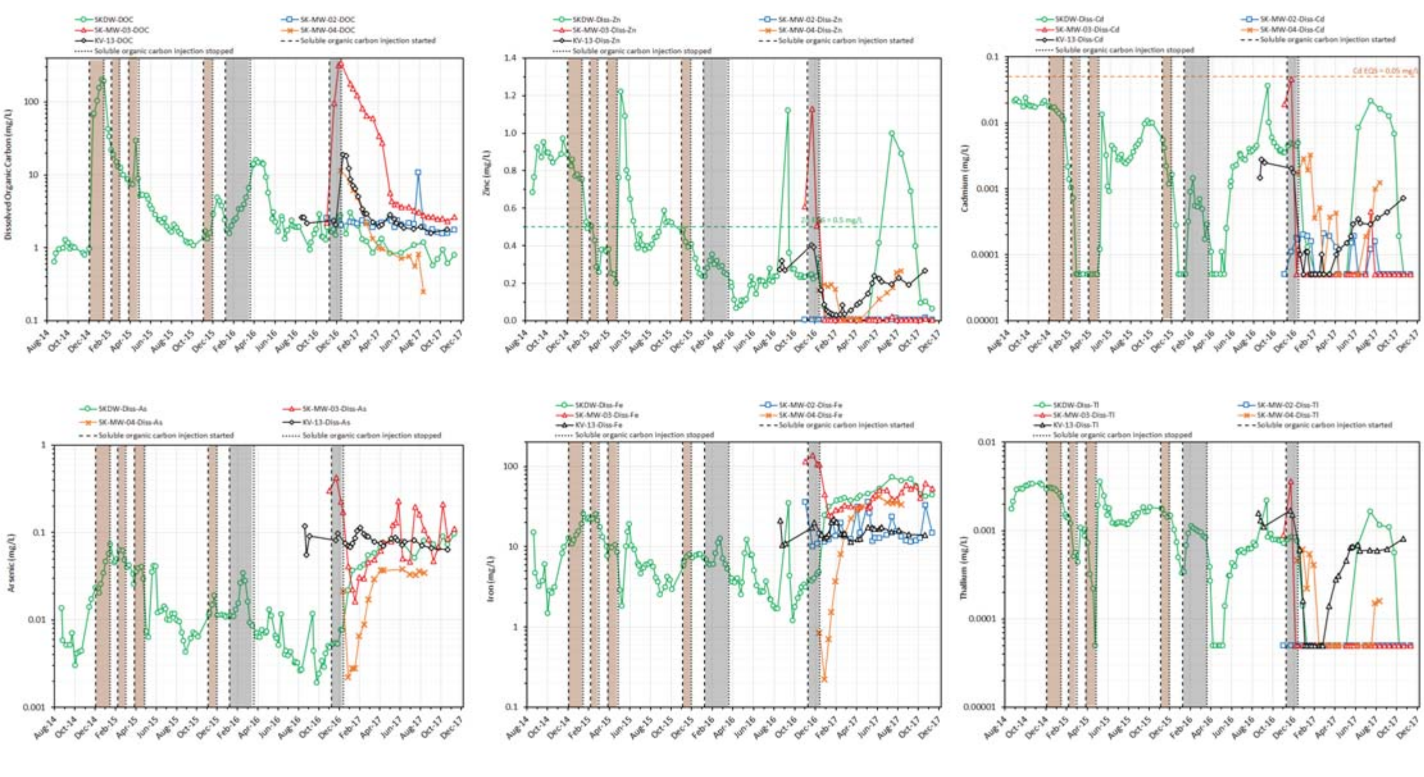


Figure 2-5: Trends in Dissolved Organic Carbon, Zinc, Cadmium, Arsenic, Iron, and Thallium in Silver King Workings Monitoring Wells and Silver King 100 Adit Discharge.

Note: Shaded Areas Indicate when Continuous Injection of Molasses (brown) or Methanol (grey) was Ongoing to the Flooded Workings with Recirculation

2.2.3 SK-MW-03

Monitoring well SK-MW-03 is in the central portion of the Vein 1 workings and is closest to the SK pit organic carbon injection location (Figure 2-3). This well was also installed in October 2016 after *in situ* treatment began in late 2014, which makes interpretation of the chemistry in this well, as affected by *in situ* treatment, more difficult because pre-treatment baseline data are not available. Between April and November 2017, the water sampled from SK-MW-03 has been circumneutral (pH 6.1 to 7.4) and reducing (ORP between -10 and -100 mV; Figure 2-4). The following trends were noted between April and November 2017 (Figure 2-4 and Figure 2-5):

- DOC concentrations declined from 34 mg/L in April 2017 to 2.6 mg/L in November as the carbon was consumed by indigenous microorganisms and/or gradually flushed from the area;
- Sulphide concentrations also decreased over the same period from 0.46 mg/L in April to 0.09 mg/L in November 2017, which was coincident with a rebound in sulphate levels from ~10 to ~200 mg/L over the same period;
- Alkalinity concentrations also declined from 380 mg/L to 190 mg/L, likely reflecting the declining DOC concentrations and associated lower amount of microbial oxidation of DOC (which produces alkalinity) and the recharge and dilution of surface water or shallow infiltration;
- Both arsenic and iron concentrations gradually increased from 0.06 mg/L and 31 mg/L in April to 0.11 mg/L and 53 mg/L in August, respectively. These trends in arsenic and iron are commonly seen around locations where a carbon source was injected, and often remain localized to these injection areas. The rise in iron concentrations may be due to partial oxidative-dissolution of poorly crystalline iron sulphide as more oxidizing waters entered the workings. Arsenic concentrations initially decreased sharply shortly after carbon injection likely due to incorporation within precipitating FeS phases as well as discrete arsenic sulphides. Such arsenic sulphides are more soluble at neutral than acidic pH, therefore, as the pH increased from ~pH 5.5 to pH ~7, arsenic sulphide dissolution, combined with some FeS dissolution, may have resulted in the rise in dissolved arsenic levels; and
- Despite the decline in sulphide levels, concentrations of dissolved cadmium, zinc and thallium have typically remained below detection between April and November 2017, suggesting that these elements have stayed bound in sulphide mineral assemblages.

2.2.4 SK-MW-04

Monitoring well SK-MW-04 is located at the top of the Vein 5 decline, immediately upgradient of the SK100 adit. This well was also installed in October 2016 after *in situ* treatment began in 2015, which makes interpretation of the chemistry in this well, as affected by *in situ* treatment, more difficult because pre-treatment baseline data are not available. The chemistry of this well was largely comparable to that of the dewatering well (SKDW), which is located near the bottom of the Vein 5 decline. Since April 2017, samples from SK-MW-04 have exhibited circumneutral pH (6.5 to 7.3) and mildly reducing ORP (-30 to +50 mV; Figure 2-4). After peaking in December 2016 (12 mg/L), DOC concentrations in samples collected from SK-MW-04 have steadily declined such that they are comparable to the background DOC levels observed at SKDW (~1 mg/L; Figure 2-5). Similar to SKDW, sulphide concentrations declined markedly from 0.17 mg/L in April to below detection (<0.018 mg/L) in August 2017 (Figure 2-4). Over the same period, sulphate concentrations increased from 510 mg/L to 600 mg/L in SK-MW-04, reflecting the increasing sulphate levels at the base of the decline as sampled by SKDW (Figure 2-4).

After increasing markedly between January and April 2017, arsenic and iron concentrations have remained relatively stable since April 2017 at ~0.035 mg/L and ~35 mg/L, respectively (Figure 2-5). Trends in the chalcophile elements cadmium, zinc, and thallium at SK-MW-04 followed those observed at SKDW, but with a lag of approximately one month (Figure 2-5). The dissolved concentrations of cadmium and thallium were below detection between April and June 2017 due to *in situ* treatment, before rebounding. Similarly, dissolved zinc concentrations were below detection in April before steadily increasing to 0.27 mg/L in August (Figure 2-5), following the increasing trend observed at SKDW, albeit at lower concentrations.

SK-MW-04 was installed to address concerns that metals could leach from sludges that coat the adit floor (in some locations, 1-2 meters thick), between SK-MW-04 and the adit portal (KV-13). Although there is some evidence for limited zinc and arsenic leaching (e.g., between January and July 2017, arsenic and zinc concentrations were higher in the adit discharge water than that of both the contributing SK-MW-04 or SK-MW-03 waters), this did not approach an EQS threshold and is not considered to be an impediment to continued successful *in situ* treatment.

While rehabilitation of the adit would be necessary for the construction of a hydraulic plug, it appears that these sludges have at most short term effects on water quality in the adit discharge especially when just flooded. We will continue to observe in the more stable flow regime where the adit is continuously overflowing if this short term condition is no longer significant to long term compliance in the adit discharge.

2.2.5 Silver King 100 Adit Discharge (KV-13)

Between April and August 2017, the pH of the SK adit discharge waters ranged between 6.1 and 7.3 (Figure 2-4). Following the peak in DOC concentrations in January 2017 and subsequent decline over the following two months, DOC levels have remained at pre-carbon injection levels since April 2017 (1.8 to 2.8 mg/L; Figure 2-5) as the carbon was consumed and/or flushed from the workings. Sulphide concentrations followed the same trend and have remained at or below the detection limit (<0.018 mg/L) since April 2017 (Figure 2-4). Conversely, sulphate concentrations have risen gradually from 260 mg/L in April to 350 mg/L in August 2017 (Figure 2-4)., reflecting the contribution of rising sulphate levels observed in both Vein 1 (as measured at SK-MW-03) and Vein 5 (as measured at both SK-MW-04 and SKDW).

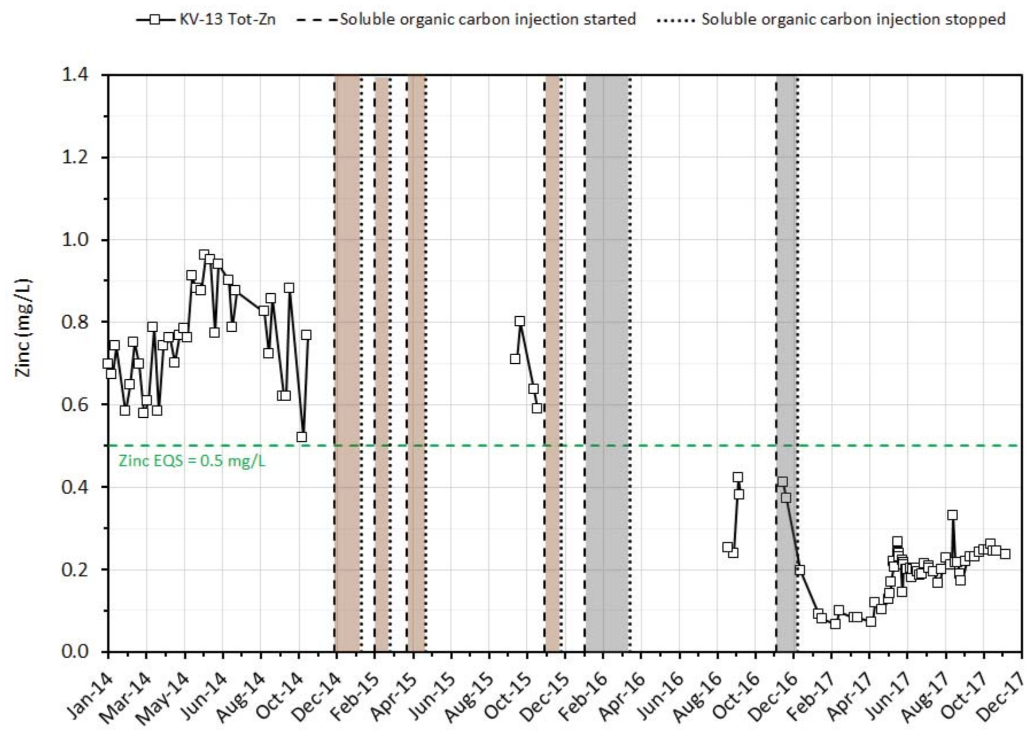
Despite the marked changes in arsenic and iron concentrations observed in the SK-MW-03 and SK-MW-04 wells, which are inferred to represent the respective Vein 1 and Vein 5 chemistries that contribute to the SK adit discharge, the arsenic and iron concentrations in the SK adit discharge have shown more limited variation (Figure 2-5). Ongoing iron oxidation and precipitation of iron oxyhydroxides, with attendant sorption and co-precipitation of arsenic that occurs along the adit passage, as evidenced by the accumulation of orange sludge in the adit, may attenuate the higher arsenic and iron concentrations observed in some “upstream” mine waters.

Dissolved zinc, cadmium, and thallium concentrations all increased steadily between April and May, but remained considerably below the EQS. These metal concentrations have remained stable since the end of May 2017 (Figure 2-5). This short term increase likely reflects the effects of higher recharge during spring freshet bringing oxidizing water into the mine workings and releasing low levels of cadmium, zinc, and thallium. Such recharge may also have brought untreated groundwater into the mine workings, which may have short-circuited the treated zone (for instance, upper levels of Vein 5 discharge are above the treatment zone lower in the workings, but drainage from this untreated area does flow into the adit without first flowing through the mine pool where treatment could occur).

Nevertheless, that concentrations of chalcophile elements have remained stable since freshet points toward the sustained treatment of the workings being the dominant control on water chemistry leaving the mine. Also of note is the lack of response of cadmium or zinc levels in the SK adit discharge water to the marked peak in the concentration of both metals in the SKDW samples collected in July/August 2017. Although the SKDW chemistry has since returned to "treated" levels as of October 2017, this perhaps suggests that the water in Vein 5 that is around the SKDW well is a minor contributor to the adit discharge chemistry relative to Vein 1 or other zones in Vein 5. This is perhaps not unexpected given that the Vein 5 workings volume is much smaller than that of Vein 1. In general, it is expected that local variation will be observed within the mine, with some areas [near injection locations or areas with longer hydraulic residence time (HRT)] showing better treatment and other areas (that are not contacted by injected solutions or with shorter HRT) showing higher concentrations or less treatment. However, the fact that the combined flow from the mine remained within the EQS requirements and showed minimal effects from the localized variability is expected and shows that this treatment process is robust through the range of flow conditions observed at this mine.

Total zinc concentrations in the SK adit discharge are measured on a weekly basis at the Keno site laboratory as part of operation of the care and maintenance WTP at Silver King. These concentrations are regularly verified by accredited laboratory analyses and represent a more detailed dataset of zinc concentrations in the SK adit discharge than that associated with the *in situ* treatment pilot test program. Linear extrapolation of the increase in total zinc concentrations measured between March and August 2017 suggests that the zinc EQS (0.5 mg/L) will not be reached until January 2019 (Figure 2-6). This may be an overestimate since it does not consider the effects of short term high recharge events to the mine workings such as that expected during spring freshet of 2018; however, it does provide a rudimentary indication of the longevity of the "passive" treatment phase that may be expected between carbon injections.

This longevity of *in situ* treatment is an important aspect of the economic benefits of *in situ* treatment, i.e., annual short term campaign treatments can accomplish compliance throughout the variable recharge conditions and through the temperature extremes of this northern environment. Section 3 discusses the implications of this longevity and the use of this treatment approach for Silver King, and for other Keno Hill underground mines.



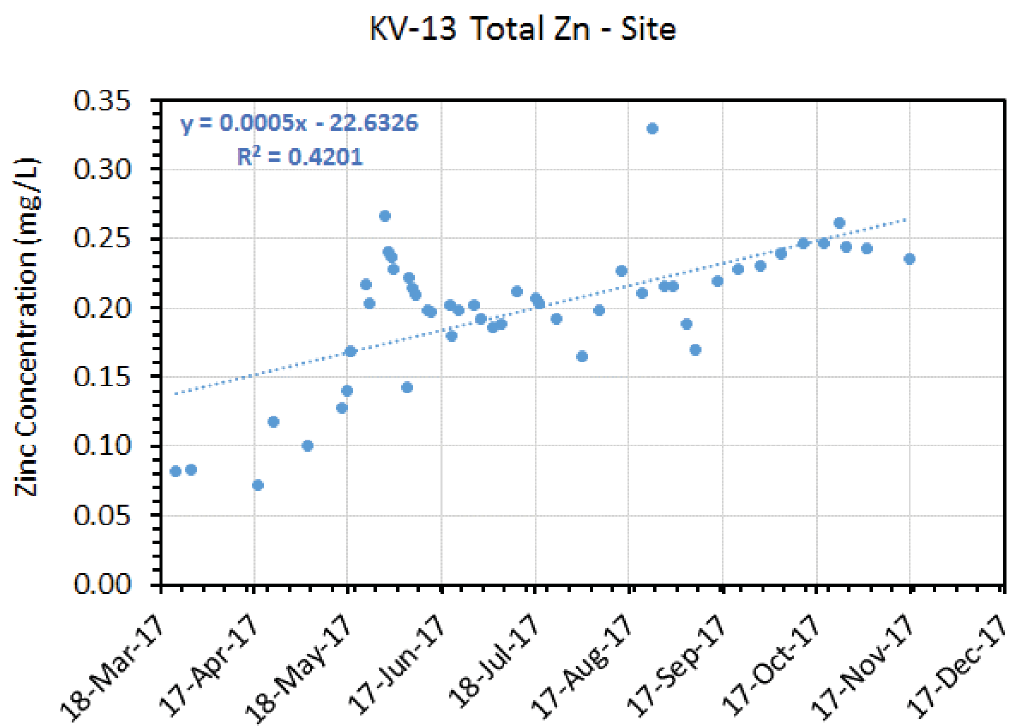


Figure 2-6: Total Zinc Concentrations in SK Adit Discharge (KV-13) Measured at Keno Site Laboratory (top) and Extrapolation of SK Adit Discharge Total Zinc Concentrations Between March and August 2017 (bottom).

2.2.5.1 Other EQS-Regulated Parameters of Interest in KV-13 Ait Discharge

While the *in situ* treatment pilot test has consistently met EQS requirements for most parameters since continuous flow from the SK adit was re-established upon controlled re-flooding of the mine in late December 2016, questions have been raised regarding satisfaction of the EQS for pH (6.5 to 9.5) and total suspended solids (TSS; 25 mg/L). Similarly, although arsenic concentrations have remained below its EQS (0.5 mg/L) for all monitoring locations throughout the pilot test, the mobilization of arsenic under the iron(III)-reducing conditions that occur during the early stages of *in situ* treatment have raised concerns regarding the possibility of transitory exceedances of the arsenic EQS. The final design of the *in situ* treatment infrastructure will include measures to mitigate the concerns associated with these parameters, which are considered in turn below.

2.2.5.1.1 pH

The *in situ* treatment process should help raise the pH of the water via the production of alkalinity from the reductive processes that are stimulated for at least several months after organic carbon addition as organic carbon is converted to inorganic carbon (both bicarbonate alkalinity and dissolved carbon dioxide). This has already been clearly observed following the installation of additional monitoring wells and measurements of the chemistry changes in samples collected from SK-MW-03 following the most recent carbon injection, where *in situ* treatment resulted in the pH increasing from an average of 5.6 prior to *in situ* treatment to 6.7 after treatment (Figure 2-4).

While the SK adit discharge pH has typically been in compliance with the EQS pH range, lime addition at the WTP has been required periodically to bring the pH above 6.5 for discharge to the environment. This is a result of insufficient time for the adit discharge water to equilibrate with the atmosphere, which would allow for degassing of carbon dioxide (CO_2; which is oversaturated in the mine workings water relative to the atmosphere) from the water and result in a rise in pH.

The effects of equilibration of adit discharge water with the atmosphere can be observed by a comparison of the pH measured in the field at the time of sampling and the pH of the same sample measured by the laboratory after several days transit, during which time the sample has partially equilibrated with the atmosphere (Figure 2-7). Between August 2016 and August 2017, three of 22 field pH measurements of SK adit discharge water were below 6.5, whereas none of the laboratory measured pH values was below 6.5. Indeed, comparison of the paired pH data indicates that the laboratory measured pH was on average 0.7 pH units higher than the field pH. This indicates that upon equilibration with the atmosphere, the pH naturally will rise to be within the EQS range. It should be noted that oxidation of dissolved Fe(II) [and to a lesser extent, Mn(II)] followed by precipitation will also occur during this equilibration period. These metal oxidation processes consume alkalinity, which will be buffered by the alkalinity present in SK adit discharge water, while CO_2 degassing will act to raise the pH of settling pond waters prior to discharge.

The final design configuration for *in situ* treatment contemplates both a passive aeration step (i.e., tumbling of the adit discharge waters) followed by a settling pond before the waters are discharged downstream. The aeration step is intended to add oxygen and encourage degassing of CO_2, while the residence time afforded by the settling pond will further allow for CO_2 degassing, resulting in increased pH levels that will be in compliance with the EQS.

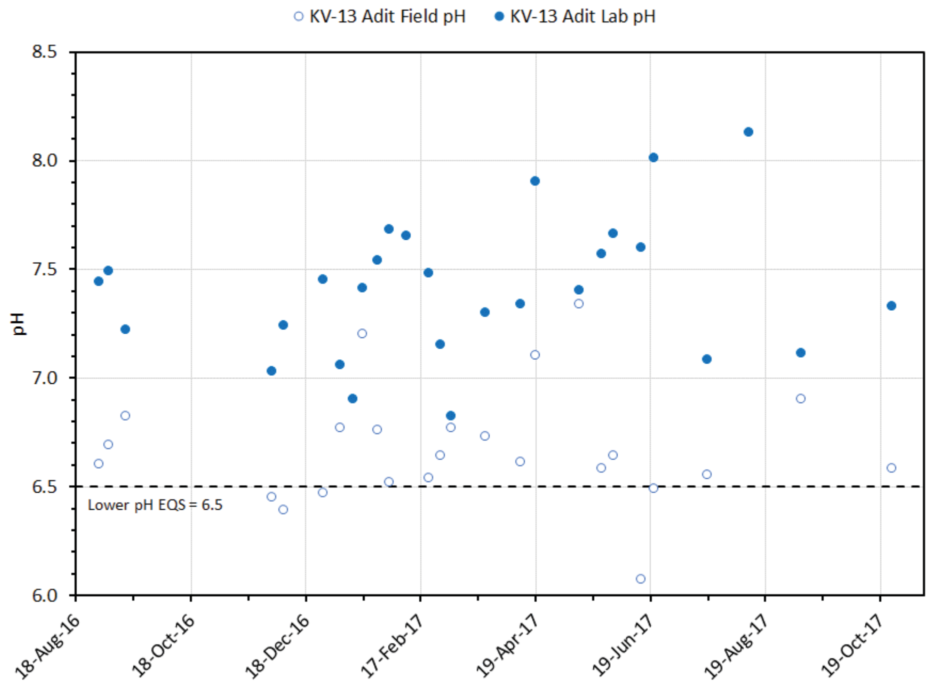


Figure 2-7: Comparison of Adit Discharge (KV-13) pH Measured in the Field and in the Laboratory

2.2.5.1.2 TSS

TSS levels in the SK adit discharge waters have typically exceeded the EQS (maximum concentration in a grab sample of 25 mg/L) by between 1 and 20 mg/L (Figure 2-8). By comparison, the TSS concentration in the decant leaving the WTP settling ponds was generally below the EQS, with the exception of high flow events in September 2016 and May 2017, brought on by heavy rainfall and spring freshet, respectively. TSS levels generally tracked flow, with higher flow, or new flow when the adit started overflowing, corresponding to higher TSS. The lower TSS of the decant waters compared to the adit discharge is in part a function of the settling afforded by the retention ponds. The inclusion of settling ponds to receive the aerated discharge from the SK adit in the final *in situ* treatment design is expected to lower TSS levels such that additional treatment is not required.

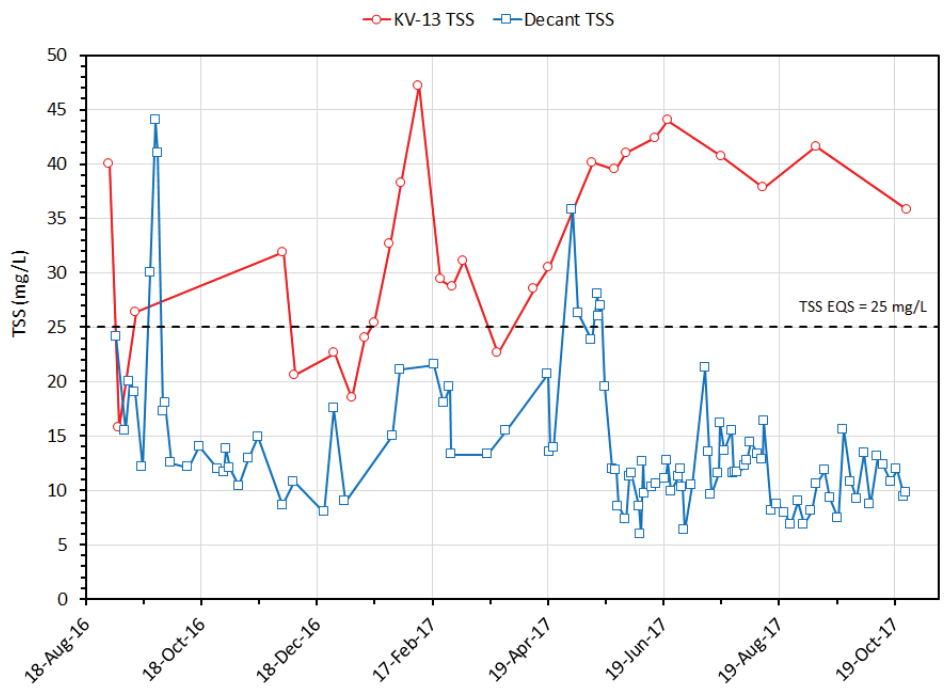


Figure 2-8: Comparison of TSS Levels in Adit Discharge (KV-13) and Downstream Settling Pond Discharge (KV-14)

2.2.5.1.3 Arsenic

Total arsenic concentrations in the SK adit discharge waters have remained well below its EQS (0.5 mg/L) for the duration of the *in situ* treatment pilot program. However, because localized and short term increases in arsenic concentrations can be observed during *in situ* treatment, it is prudent to understand the controls on arsenic chemistry. The same measures that are included in the final *in situ* treatment design to control TSS and pH will also provide further arsenic removal if necessary following discharge from the adit. At the circumneutral pH of the adit discharge, dissolved Fe(II) in the adit discharge water is expected to oxidize within minutes to hours, resulting in precipitation of iron (oxyhydr)oxides. This process will be enhanced by the aeration step planned for the adit discharge in the final *in situ* setup. This iron precipitation is expected to scavenge a significant proportion of arsenic from solution. The downstream settling pond will also allow for further iron precipitation and arsenic sequestration, while also providing time for the arsenic-bearing iron precipitates to settle from the water column.

Preliminary evidence for the efficacy of this process is provided by a comparison of the total arsenic concentrations in the SK adit discharge waters and the decant waters leaving the settling ponds at the Silver King care and maintenance WTP (Figure 2-9). The water treatment process acts by raising the pH of the water to induce the oxidation of dissolved ferrous iron and its precipitation as ferric (oxyhydr)oxide. This process will also be promoted by the aeration of the SK discharge to raise the pH by CO_2 degassing and encourage Fe(II) oxidation, followed by settling of iron precipitates in a retention pond. Date-paired water samples collected since January 2017 (when the SK adit was discharging water) indicate that the total arsenic concentrations in the decant water have been an average of 53% lower than those in the SK adit discharge. In any case, the adit discharge has remained below the arsenic EQS, and is further decreased through the settling pond process.

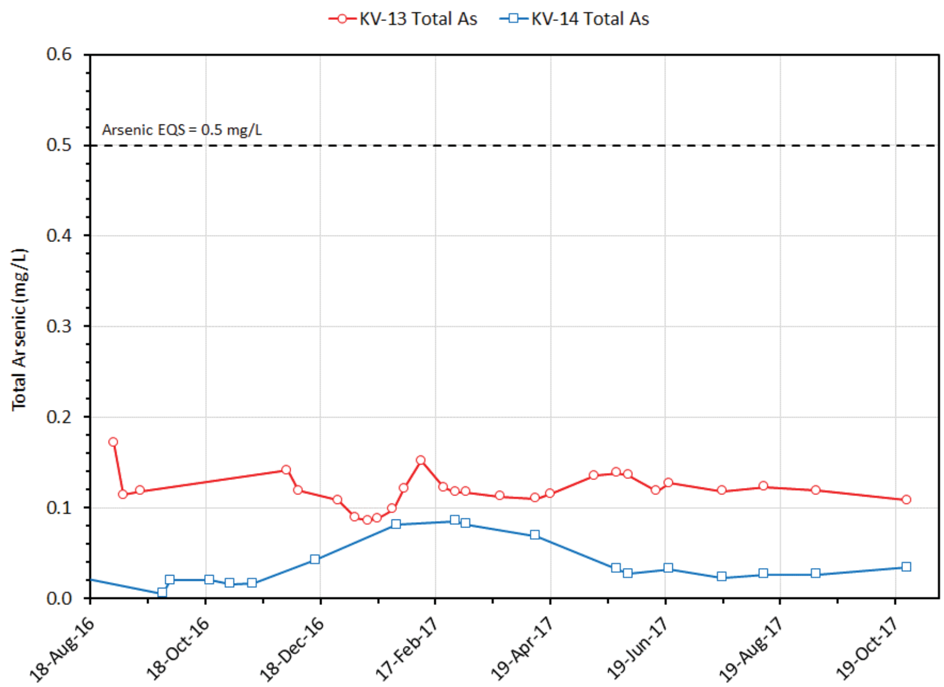


Figure 2-9: Comparison of Total Arsenic Concentrations in Adit Discharge (KV-13) and Downstream Settling Pond Discharge (KV-14)

2.2.6 Comparison of *In Situ* Pilot Test Chemistry with Predictions from Project Plan

In the Silver King Project Plan (deliverable 2016-17-033-2), trends in water chemistry were predicted based on experience from other sites, and an understanding of the biological processes associated with microbial sulphate reduction that produce the expected mineral forms. Figure 2-10 to Figure 2-12 contain the collected data to date and can be compared against the predicted concentration profiles presented in Figure 2-13.

In general, the zinc and DOC concentrations tend to match the expected predicted trends quite accurately. Importantly, the total zinc concentrations discharged from the Silver King mine (either via SKDW during dewatering or via adit discharge when mine was fully flooded) have been below the EQS for the past two years. The arsenic concentration has not exhibited as much volatility in concentration as predicted, but it is worth noting that the concentrations have been lower than expected and well within the arsenic effluent quality standard (0.5 mg/L).

The following passage has been excerpted from the Silver King Project Plan and provides a description of what was expected to occur in each of the stages.

"The test therefore is comprised of three main tasks or stages (indicated in Figure 2-10 to Figure 2-13):

1. Active Recirculation Stage: The purpose of this phase is to establish conditions *in situ* for treatment, specifically create and sustain sulphate reducing conditions such that metals are precipitated (primarily zinc, secondarily cadmium, as well as other metals), and also so that FeS_{am} builds up on the flooded walls of the mine thereby coatings rock surfaces.
    a. Achieve treatment conditions in 5 Vein: Establish sulphate reducing conditions within 5 Vein recirculation loop: from borehole to pumping well. Monitoring which will demonstrate this includes a decrease in oxidation-reduction potential (ORP), removal of metals that precipitate primarily as sulphides in these geochemical conditions, lower concentration of sulphate, and the formation of sulphide, which is precipitated from solution by metals. (This stage was completed December 2014 to February 2015).
    b. Achieve treatment conditions in 1 Vein: Establish sulphate reducing conditions within 1 Vein to 5 Vein recirculation loop: from SK 1 Vein workings below the open pit to pumping well. Note that the connections between 1 Vein and 5 Vein may not be a direct mine openings, and may include fractures or minor veins/faults connecting the workings in each Vein, may include drill holes that were incompletely plugged or plugged holes that subsequently failed. Monitoring conditions that will be used to evaluate progress include drop in ORP, removal of metals that precipitate primarily as sulphides in these geochemical conditions, lower concentration of sulphate, and the formation of sulphide, which is precipitated from solution by metals (completed March to May 2015).
    c. Extend treatment conditions through more SK workings: Sustain sulphate reducing conditions within 1 Vein and 5 Vein workings so that the relevant bulk of the workings are all treated, not just the (potentially short-circuiting) recirculation loop. During the initial installation of the test, there was not an effective way to evaluate the extent of treatment within the SK workings, especially the identification of dead zones that are essentially

non-flowing. With the installation of additional monitoring wells in October 2016 inference can be made about the extent of treatment throughout the mine and this internal monitoring can be used to determine the rate that additional carbon injections will be required.

d. Create FeS_{am} redox buffer: Sustain sulphate reducing conditions within 1 Vein and 5 Vein workings so that the soluble Fe in the workings and solid phase Fe in the rock and sludge in the mine is transformed to FeS_{am}. The carbon source for Stages 1c and 1d will transition from molasses to alcohol (mixed methanol/ethanol with trace other alcohols known as an alcohol "remediation blend") to transition the system from a growth phase of microbes to more of a metabolically active but slower growing phase, i.e., the carbon source becomes primarily an energy source. The monitoring information that will be used to evaluate the formation of FeS_{am} includes the decreased concentration of metals that form sulphides, the decreased concentrations of iron as FeS_{am} forms, and then the rise in aqueous sulphide as available ferrous iron and other metals (which have been titrating sulphide, keeping the concentrations low) is no longer available (this was accomplished in 2016 and is ongoing in 2017 following the carbon injection in Nov/Dec 2016) (Note: the activities in 1b./1c. and 1d. are identical but are described as sequential because the formation of FeS_{am} occurs after other metals have precipitated in the mine.)

2. Passive reactive treatment stage: Operate the mine at steady state pumped flow to maintain a reasonably constant mine water elevation. During this phase, observe continued effective treatment performance over time without active injection/treatment based on reaction of dissolved metals with residual FeS_{am} formed in Stage 1d. Monitoring that will show this will include a rise in ORP, a slow increase of metals that precipitate primarily as sulphides in these geochemical conditions, a slow increase in concentration of sulphate, and a loss of dissolved sulphide that reflects equilibrium with amorphous FeS_{am}. (This stage was observed in the latter half of 2016; the duration of this phase after 1c. and 1d. are complete was extrapolated to be nine months based on the results observed between April 2016 and October 2016, during which time no reagent was added. However, longer periods between treatment injections are expected once the mine is flooded and a greater volume has been treated. This was observed following the last carbon injection in Nov/Dec 2016 and full flooding of the mine, where passive treatment has been extrapolated to persist for at least one year.).
3. Operation Stage of follow up Active/Passive Cycles: Perform further (winter 2017) active treatment followed by passive reactive treatment cycle (i.e., repeat steps 1 and 2). Re-treatment of the mine to restore effective treatment conditions will be performed as the zinc concentrations begin to rise close to the licence EQS. This was extrapolated to be approximately nine months based on the results observed between April and October 2016, although additional treatment since that time and flooding of the workings has prolonged the passive treatment period."

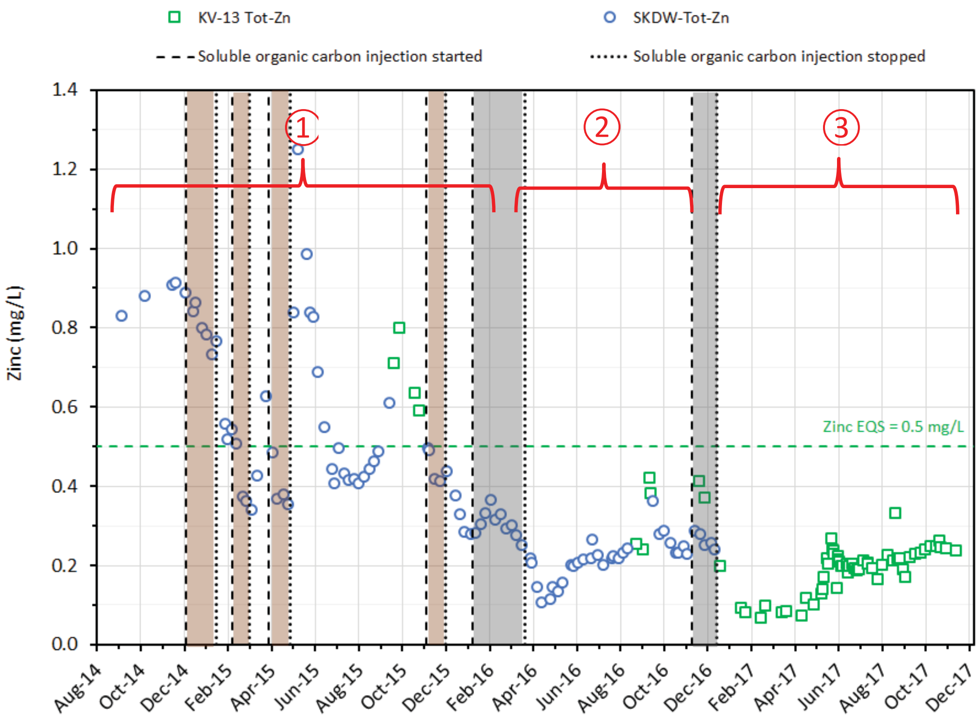


Figure 2-10: Summary of Total Zinc Concentrations in Silver King Mine Discharge (SKDW and Silver King Adit) During *In Situ* Pilot Testing Program

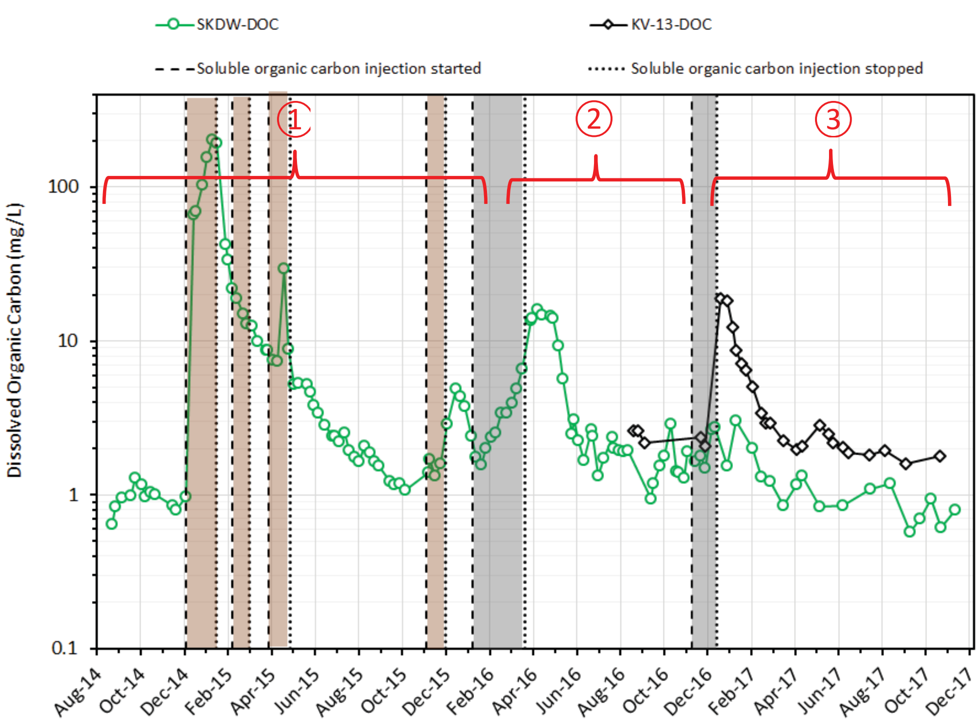


Figure 2-11: Summary of Dissolved Organic Carbon Concentrations in Dewatering Well (SKDW) and Adit Discharge (KV-13) During *In Situ* Pilot Testing Program

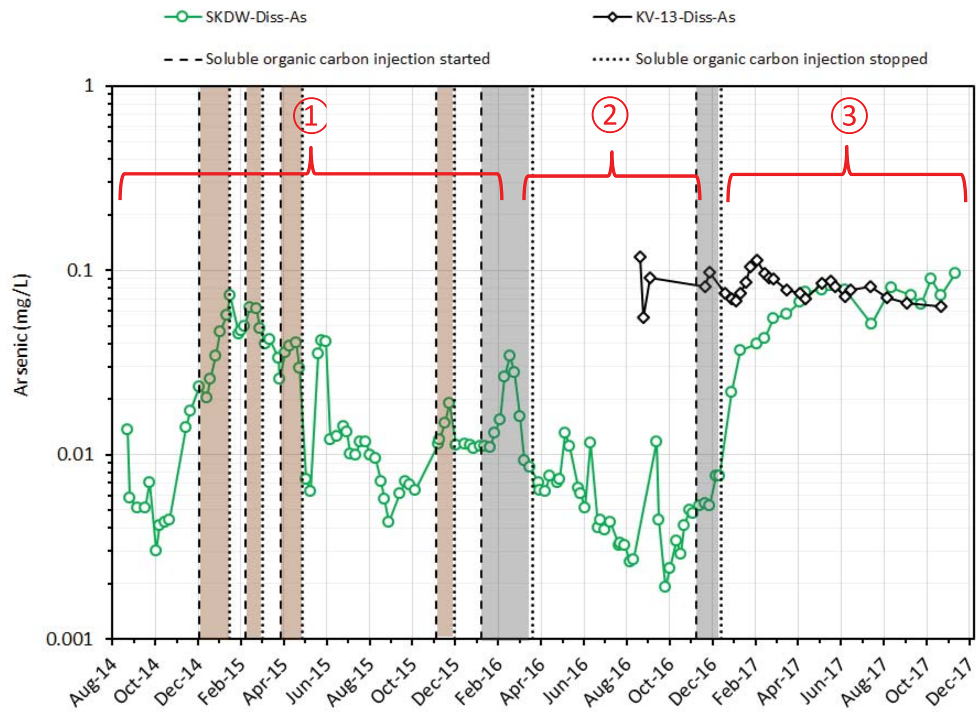


Figure 2-12: Summary of Dissolved Arsenic Concentrations in Dewatering Well (SKDW) and Adit Discharge (KV-13) During *In Situ* Pilot Testing Program

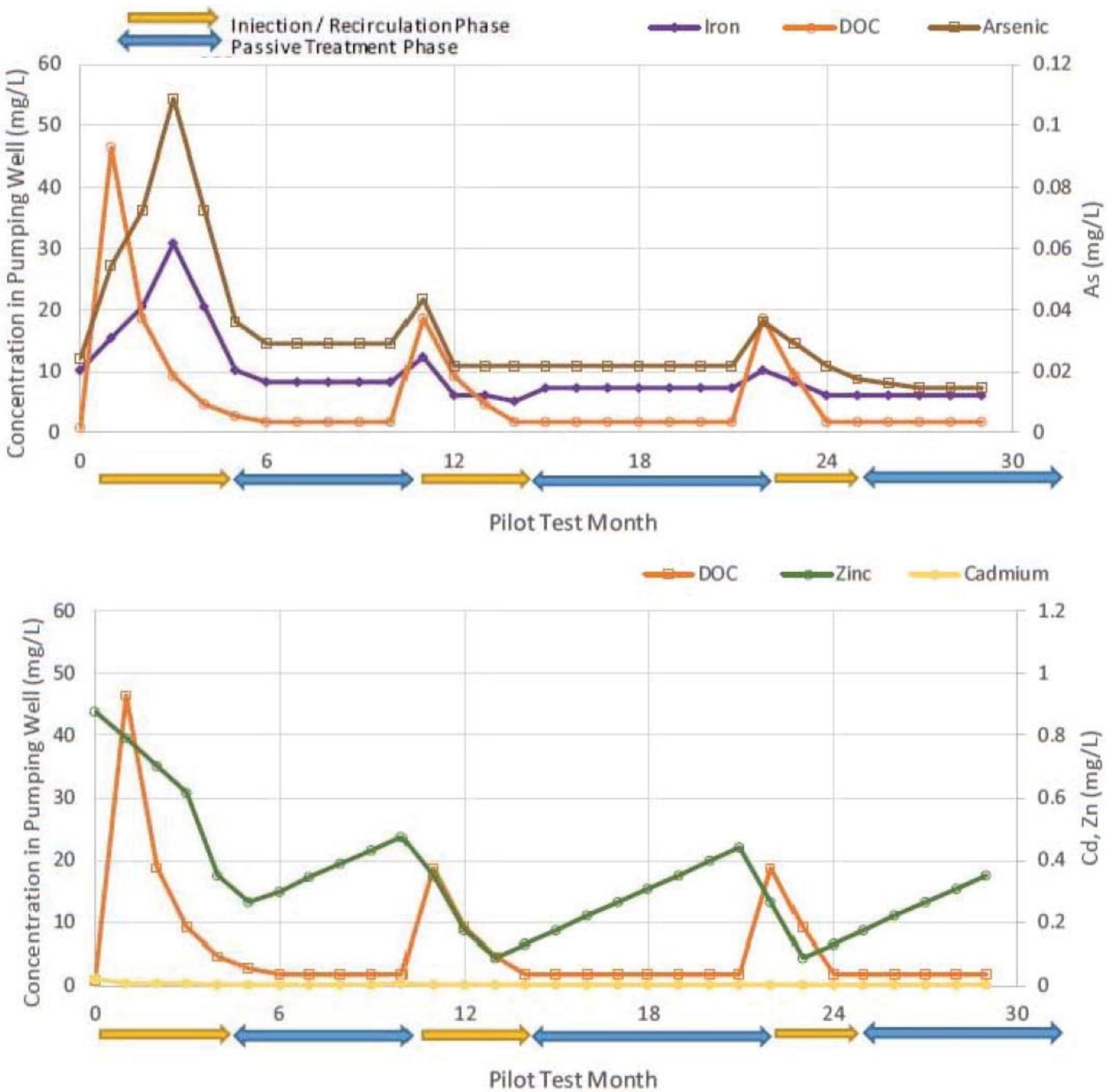


Figure 2-13: Illustration of Water Chemistry Ranges and Evolution Expected During Silver King Treatment Pilot Test

2.3 SILVER KING UNDERGROUND MINE WATER MICROBIOLOGY

Dewatering well samples were collected for microbial community profiling on March 5, 2017 from all four SK mine workings monitoring wells and submitted to Contango Strategies (Saskatoon, SK) for genomic analysis. Further details regarding this analysis are reported in AEG (2016). The objective is to understand the structure of the microbial community that plays an active role in producing the *in situ* treatment conditions and provide further evidence for the biogeochemical processes that result in treatment of dissolved metals in the flooded SK mine workings. This is especially to provide evidence that it is indeed microbial sulphate reduction that is achieving the water quality improvements and sustaining the treatment during the passive phases where injection or recirculation is not occurring.

In brief, DNA was extracted from the water samples and portions of the 16S rRNA gene, which can be used for taxonomic classification, were sequenced and matched against known microorganisms. Similar sequences (97% similarity or higher) were grouped together into operational taxonomic units (OTUs) and compared against a microbial database for classification at the genus level. Following classification, the matched genera were grouped into the following categories according to their ability to mediate redox transformations of sulphur and/or iron:

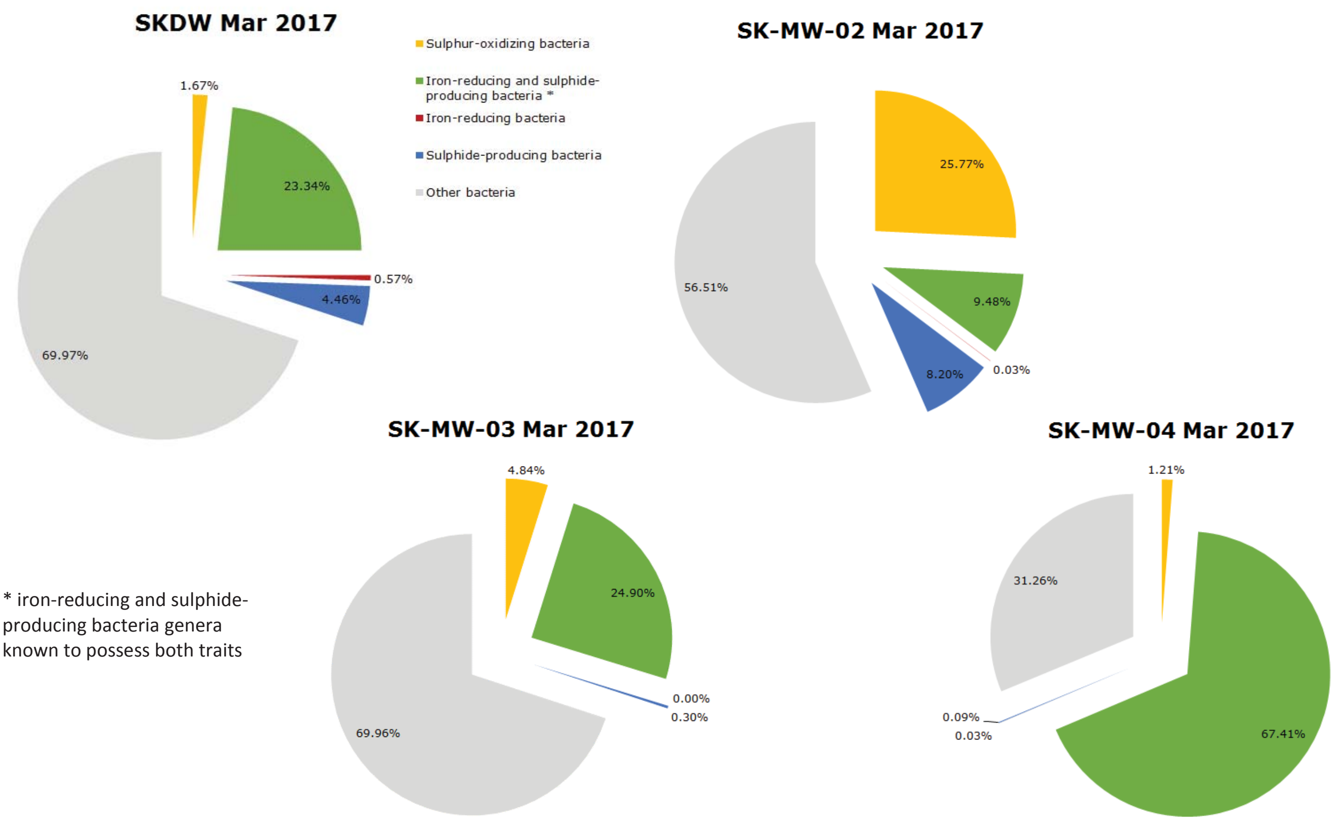
- Iron reducing bacteria (FeRB);
- Sulphur-oxidizing bacteria (SOB); and
- Sulphide-producing bacteria (SPB).

Many microorganisms are capable of both sulphide production and iron reduction; such genera were grouped together. The data were received in late April 2017 for inclusion in this update memorandum and are presented in Figure 2-14, Figure 2-15, and Table 2-1 to Table 2-3.

Microbes capable of sulphide production were present in the March 2017 samples collected from all four mine workings monitoring wells (Figure 2-14). The SK-MW-04 sample had the highest proportion of OTUs that were aligned with microorganisms capable of sulphide production such that they comprised the majority (67%) of microbes sequenced in this sample. The SKDW and SK-MW-03 samples had similar proportions of sulphide-producing bacteria (28% and 25% of the aligned sequences, respectively), whereas approximately 18% of the SK-MW-02 sequences were closely matched with known sulphide producing genera (Figure 2-14). Interestingly, sulphide-oxidizing microorganism made up 26% of the SK-MW-02 sample. Unlike the other monitoring wells, sulphide has always been detected in samples collected from SK-MW-02, likely providing support for a sizeable sulphide-oxidizing microbial community.

Desulfosporosinus typically comprised the bulk of the sequenced sulphide producing genera in all four samples (Figure 2-15 and Table 2-1). *Geobacter* genera and members of the *Desulfobulbaceae* family also featured prominently in the sulphide producers' sequences for the SKDW and SK-MW-02 samples (Figure 2-15 and Table 2-1). Sequences closely aligned to members of the *Gallionella* genera, which are capable of Fe(II) oxidation, also comprised a significant fraction (8% to 19%) of all sequences extracted from the SKDW, SK-MW-02 and SK-MW-04 samples (Figure 2-15), while members of the *Sulfuricurvum* genera comprised the bulk of the sequences matched to known sulphide-oxidizing bacteria (Figure 2-15 and Table 2-3). Given that both *Desulfosporosinus* and *Geobacter* species are also capable of Fe(III)-reduction in addition to sulphide production (Table 2-2), the microbial community in the flooded SK mine workings is suggestive of a closely coupled redox cycling of iron and sulphur species.

These data show that sulphide producing bacteria comprised a sizeable fraction of the microbial community in the flooded SK mine workings. This is consistent with the geochemical data and demonstrates that sulphide producing bacteria have been stimulated by the addition of organic carbon to the subsurface workings, which is a key aspect of *in situ* treatment.



* iron-reducing and sulphide-producing bacteria genera known to possess both traits

Figure 2-14: Percentage of OTUs Assigned as FeRB, SPB and SOB in SK Flooded Mine Workings Samples Collected in March 2017.

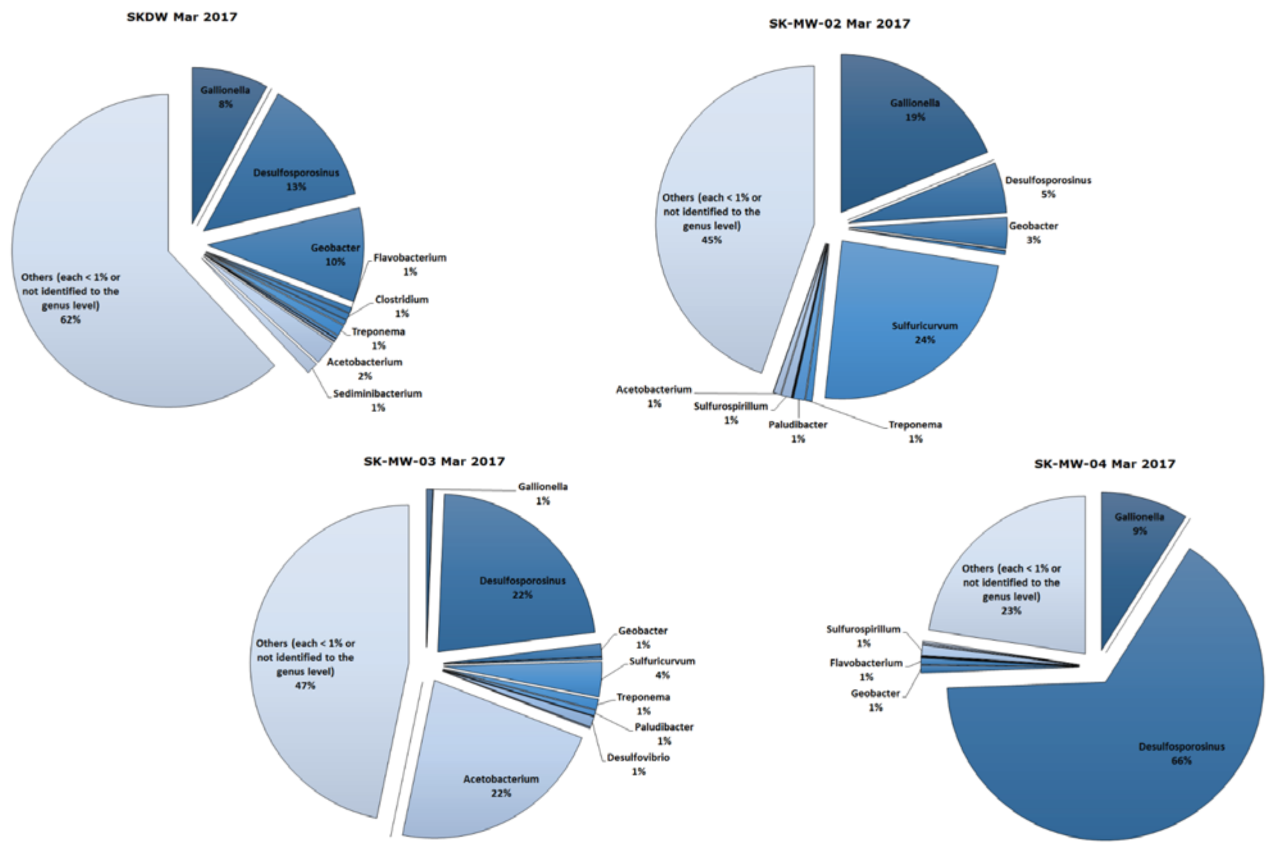


Figure 2-15: Highest Percentage of Organisms Identified to Genus Level in SK Flooded Mine Workings Samples Collected in March 2017

Table 2-1: Identification and Abundance of Known Sulphide-Producing Bacteria in SK Flooded Mine Workings Samples Collected in March 2017

Genus	Can reduce:				Environment			Trait Assignment Category [1]	Percentage of bacterial community			
	Sulphate	Thiosulphate	Sulphite	Sulphur	Aerobe/Anaerobe Characteristics	Temperature	pH		SKDW Mar 2017	SK-MW-02 Mar-17	SK-MW-03 Mar-17	SK-MW-04 Mar-17
Desulfobacca	Yes	Yes	Yes	No	anaerobic	mesophilic	neutrophilic	A	0.16%	0.22%	0.04%	0.02%
Desulfobulbus	Yes	Yes	Yes	No	anaerobic	mesophilic	neutrophilic	A	0.01%	0.06%	<0.01%	<0.01%
Desulfococcus	Yes	Yes	Yes	No	anaerobic	mesophilic	neutrophilic	A	0.03%	0.11%	<0.01%	<0.01%
Desulfotomaculum	Yes	Yes	Yes	Typically no	anaerobic	mesophilic or thermophilic	neutrophilic	A	0.02%	<0.01%	0.06%	0.03%
Sulfurospirillum	No	Yes	Yes	Yes	microaerophilic	mesophilic, some psychrotolerant	neutrophilic	A	0.10%	1.01%	0.12%	1.06%
Desulfosporosinus	Yes	Yes	Yes	Yes	anaerobic	mesophilic, some psychrotolerant	neutrophilic	A	13.24%	5.20%	22.32%	65.52%
Desulfovibrio	Yes	Yes	Yes	Yes	anaerobic	mesophilic	neutrophilic	A	0.24%	0.05%	1.09%	0.03%
Desulfobacteraceae family	Yes	Yes, most	Yes, most	Yes, few	typically anaerobic	mesophilic, some psychrotolerant	typically neutrophilic	A	0.41%	2.99%	0.12%	0.01%
Desulfobulbaceae family	Yes	Yes, some	Yes, some	Yes, some	anaerobic	mesophilic, some psychrotolerant	typically neutrophilic	A	3.85%	4.88%	0.15%	0.06%
Geobacter	No	No	No	Yes	anaerobic	mesophilic	neutrophilic	B	9.72%	3.15%	1.30%	0.77%
Total SPB Percentage									**27.79%**	**17.68%**	**25.19%**	**67.50%**

[1] Trait Assignment Categories:
A = most species in this genus possess these traits or abilities
B = some species in this genus possess these traits or abilities
C = this trait has been noted for this genus in only a few cases or is not well documented. Further investigation may be warranted

Table 2-2: Identification and Abundance of Known Iron-Reducing Bacteria in SK Flooded Mine Workings Samples Collected in March 2017

Genus	Environment			Trait Assignment Category [1]	Percentage of bacterial community			
	Aerobe/Anaerobe Characteristics	Temperature	pH		SKDW Mar 2017	SK-MW-02 Mar-17	SK-MW-03 Mar-17	SK-MW-04 Mar-17
Anaeromyxobacter	facultatively anaerobic	mesophilic	neutrophilic	A	0.07%	<0.01%	<0.01%	0.01%
Geobacter	anaerobic	mesophilic	neutrophilic	A	9.72%	3.15%	1.30%	0.77%
Geothrix	anaerobic	mesophilic	*INA*[2]	A	0.47%	0.03%	<0.01%	0.02%
Desulfobulbus	anaerobic	mesophilic	neutrophilic	B	0.01%	0.06%	<0.01%	<0.01%
Desulfosporosinus	anaerobic	mesophilic, some psychrotolerant	neutrophilic	B	13.24%	5.20%	22.32%	65.52%
Desulfovibrio	anaerobic	mesophilic	neutrophilic	B	0.24%	0.05%	1.09%	0.03%
Rhodoferax	facultatively anaerobic	mesophilic, some psychrotolerant	neutrophilic	B	0.03%	0.01%	<0.01%	<0.01%
Sulfurospirillum	microaerophilic	mesophilic, some psychrotolerant	neutrophilic	B	0.10%	1.01%	0.12%	1.06%
Desulfotomaculum	anaerobic	mesophilic or thermophilic	neutrophilic	C	0.02%	0.00%	0.06%	0.03%
Total FeRB Percentage					**23.91%**	**9.51%**	**24.89%**	**67.44%**

[1] **Trait Assignment Categories:**

A = most species in this genus possess these traits or abilities

B = some species in this genus possess these traits or abilities

C = this trait has been noted for this genus in only a few cases or is not well documented. Further investigation may be warranted

[2] *INA = Information Not Available*

Table 2-3: Identification and Abundance of Known Sulphur-Oxidizing Bacteria in SK Flooded Mine Workings Samples Collected in March 2017

Genus	Can oxidize				Environment			Trait Assignment Category [1]	Percentage of bacterial community			
	Sulphide	Thiosulphate	Sulphur	Tetrathionate	Aerobe/Anaerobe Characteristics	Temperature	pH		SKDW Mar 2017	SK-MW-02 Mar-17	SK-MW-03 Mar-17	SK-MW-04 Mar-17
Acidithiobacillus	Yes	Yes	Yes	*INA*[2]	aerobic	mesophilic or thermophilic	acidophilic	A	0.01%	<0.01%	<0.01%	<0.01%
Sulfuricurvum	Yes	Yes	Yes	*INA*	facultative anaerobe	mesophilic	neutrophilic	A	0.49%	24.18%	3.54%	0.02%
Sulfurimonas	Yes	Yes	Yes	*INA*	facultative anaerobe	mesophilic, some psychrotolerant	neutrophilic	A	0.07%	0.46%	0.07%	<0.01%
Sulfuritalea	*INA*	Yes	Yes	*INA*	facultative anaerobe	mesophilic	neutrophilic	A	0.02%	<0.01%	<0.01%	0.01%
Thiobacillus	Yes	Yes	Yes	Yes	aerobic, some can grow anaerobically	mesophilic	neutrophilic, some acidophilic	A	0.35%	<0.01%	0.01%	<0.01%
Arcobacter	Yes	*INA*	*INA*	*INA*	aerobic, microaerophilic, or anaerobic	mesophilic	variable	B	0.01%	<0.01%	<0.01%	<0.01%
Dechloromonas	Yes	*INA*	*INA*	*INA*	facultatively anaerobic	mesophilic	neutrophilic	B	0.07%	<0.01%	<0.01%	0.01%
Desulfovibrio	Yes	*INA*	*INA*	*INA*	anaerobic	mesophilic	neutrophilic	B	0.24%	0.05%	1.09%	0.03%
Rhodobacter	Yes	Yes	*INA*	*INA*	aerobic or anaerobic, depending on light	mesophilic	neutrophilic	B	0.23%	<0.01%	<0.01%	0.02%
Pseudomonas	Yes	*INA*	*INA*	*INA*	aerobic or facultative anaerobe	mesophilic, some psychrotolerant or thermophilic	neutrophilic	C	0.08%	0.06%	0.01%	0.05%
Sulfurospirillum	Yes	*INA*	*INA*	*INA*	microaerophilic	mesophilic, some psychrotolerant	neutrophilic	C	0.10%	1.01%	0.12%	1.06%
Xanthobacter	*INA*	Yes	*INA*	*INA*	aerobic	mesophilic	variable	C	<0.01%	<0.01%	<0.01%	<0.01%
Total SOB Percentage									**1.67%**	**25.77%**	**4.83%**	**1.21%**

[1] **Trait Assignment Categories:**

A = most species in this genus possess these traits or abilities

B = some species in this genus possess these traits or abilities

C = this trait has been noted for this genus in only a few cases or is not well documented. Further investigation may be warranted

[2] *INA = Information Not Available*

2.4 SCANNING ELECTRON MICROSCOPE ASSESSMENT OF SUSPENDED SOLIDS IN MINE WORKINGS

A two-litre unfiltered water sample was collected from the SK-MW-03 well on August 9, 2017, packed in an anaerobic container and shipped to the University of Ottawa for electron microscopic analysis of suspended particulate material. Upon receipt, the water sample was filtered (0.2 µm pore size filter) under anaerobic conditions and the filter paper was imaged by scanning electron microscopy. The report summarizing the results of the SEM analysis is presented in Appendix A.

The objective of this testing was to identify the presence of metal sulphide minerals that were formed in response to *in situ* treatment. This work was done in response to comments desiring positive identification of mineral phases in the mine workings, as this may provide information about stability of the metal precipitates that are being formed in the mine. The captured suspended particulates largely comprised clay and aluminosilicate material, with occasional TiO_2 rods. Both iron (oxyhydr)oxide and iron sulphides were also identified. Despite the best efforts to maintain anaerobic conditions, it was hypothesized that the iron (oxyhydr)oxides were likely formed following oxidation of dissolved ferrous iron during transit of the sample. Approximately 30% of the iron was estimated to be associated with iron sulphides, which appeared as sub-micron sized irregularly shaped globules (Figure 2-16), reminiscent of biologically produced FeS. No zinc- or cadmium-bearing minerals were detected. The lack of abundant sulphide minerals is likely due to settling of such material from the water column, since the sample was collected in August 2017, approximately eight months after the last carbon injection ended and dewatering/recirculation of mine water ceased, and seven months following the peak sulphide concentrations detected at this location (Figure 2-4).

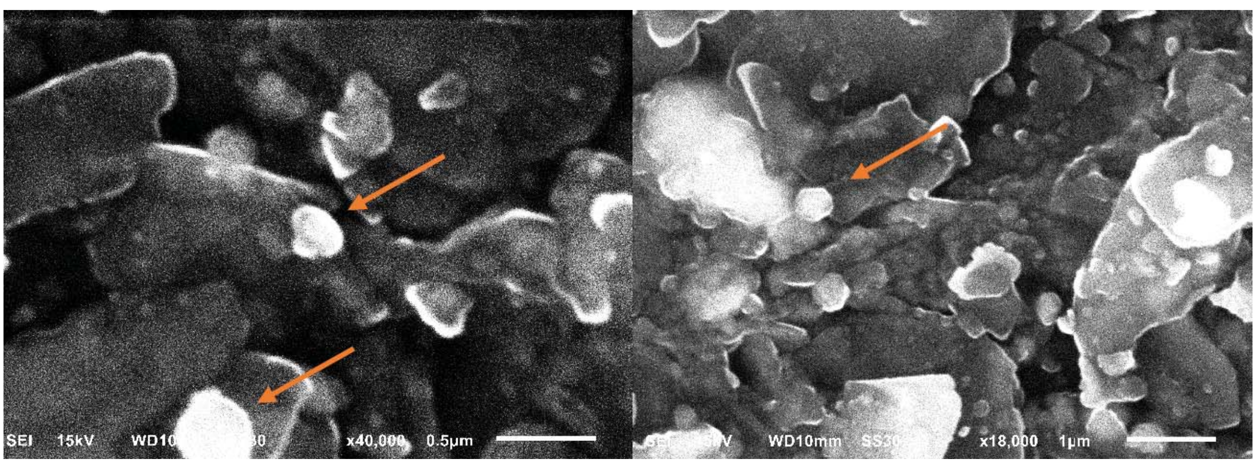


Figure 2-16: SEM Imaging of Suspended Particulates Collected from SK-MW-03 Monitoring Well in August 2017. Orange Arrows Indicate Iron Sulphides.

3 IMPLICATIONS FOR FINAL DESIGN OF *IN SITU* TREATMENT CONFIGURATION

3.1 PASSIVE TREATMENT PERIOD

The most recent organic carbon injection was in November/December 2016, which was followed by cessation of dewatering and subsequent full flooding of the mine workings. Since that time, discharge from the SK adit has been well below the EQS for zinc, which is the only metal that requires treatment in order to meet its EQS for Silver King. Although spring freshet resulted in a temporary and limited increase in zinc concentrations leaving the adit, the concentration rise was well below the EQS and zinc levels have since stabilized with linear extrapolation suggesting that the last carbon injection will result in at least one year of passively treated conditions. Therefore, the passive treatment period between injections for the full-scale configuration may be expected to be at least one year with successful introduction and mixing of organic carbon reagent, notwithstanding strong recharge events such as extended rain storms or a prolonged, high volume freshet.

3.2 REQUIREMENT FOR ADIT REHABILITATION AND HYDRAULIC ADIT PLUG

A hydraulic plug was initially proposed as part of the SK *in situ* treatment design in order to increase the hydraulic residence time of the flooded mine workings such that the volume of treated workings could be as large as possible to provide a buffer to recharge of oxidizing and/or untreated waters (e.g., during freshet). The plug would also allow for settling of precipitate along the adit floor, and transport by pipeline from the adit plug to the discharge, thus providing polishing benefit to TSS levels, and limiting the potential migration or dissolution of the sludge that currently coats the adit floor. These materials would be removed during the installation of the adit plug.

Given the longevity of the current cycle of passive *in situ* treatment, coupled with the lack of clear influence of the adit sludge on EQS-regulated constituent concentrations, the requirement for the hydraulic plug and justification for its associated costs may require review. However, it is important to recognize that other factors such as the ability to better manage the mine outflow and ensure adit integrity via rehabilitation work that would be performed when installing the adit plug (i.e., minimize concerns regarding adit collapse) also inform the requirement for the hydraulic plug.

3.3 TREATMENT OF PH, TSS AND ARSENIC

As outlined in Section 2.2.5.1, the addition of a passive aeration step followed by sediment retention ponds is expected to maintain the discharge pH >6.5 while allowing for mitigation of TSS and polishing of arsenic concentrations. Lab-scale aeration experiments are planned in the coming months that will aid in developing adjustments to the design regarding the benefits of atmospheric equilibration and settling on pH, TSS, arsenic, and other EQS-regulated parameters. Such work will inform subsequent bench and/or field scale aeration and in turn, the final design configuration.

3.4 INJECTION CONFIGURATION

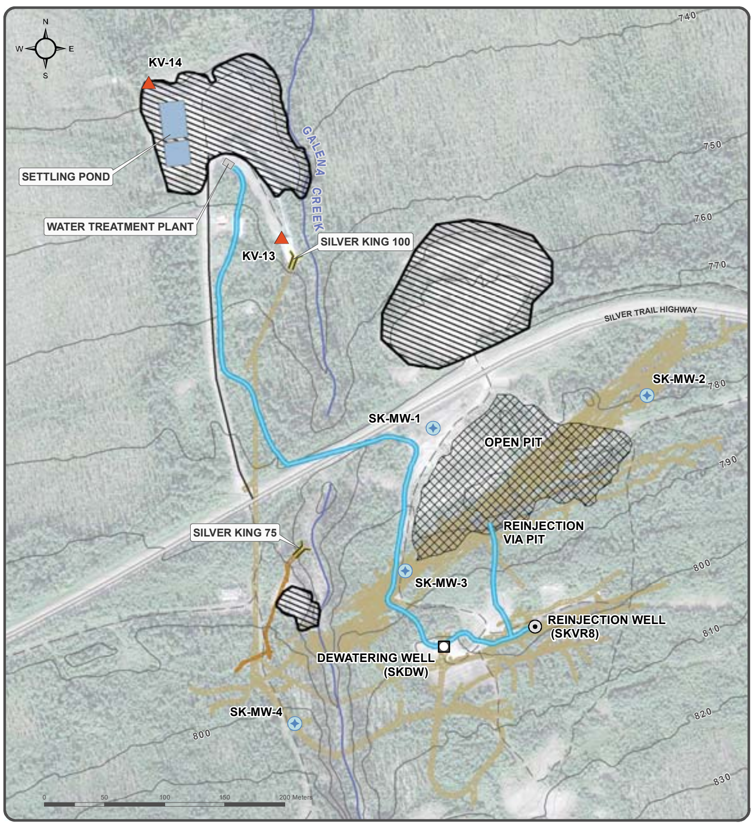
The next phase of the *in situ* treatment pilot will involve a rearrangement of the injection-recirculation configuration such that mine water will be pumped from the far end of Vein 1 via the SK-MW-02 well, amended with organic carbon and re-injected at both the near end of Vein 1 (via well SK-MW-03) and Vein 5 decline (via SKDW and possibly SKVR8; Figure 3-1). This will provide the following anticipated benefits:

- Expand the treatment zone in Vein 1 by pumping from its far end and injecting at the end nearest the adit;
- Expand the treatment zone in Vein 5 by injecting into SKDW and the SKVR8 borehole; and
- Provide larger treatment zones for areas proximate to the adit discharge for both the Vein 1 and Vein 5 systems to limit the effects of ingress of untreated and/or oxidizing waters.

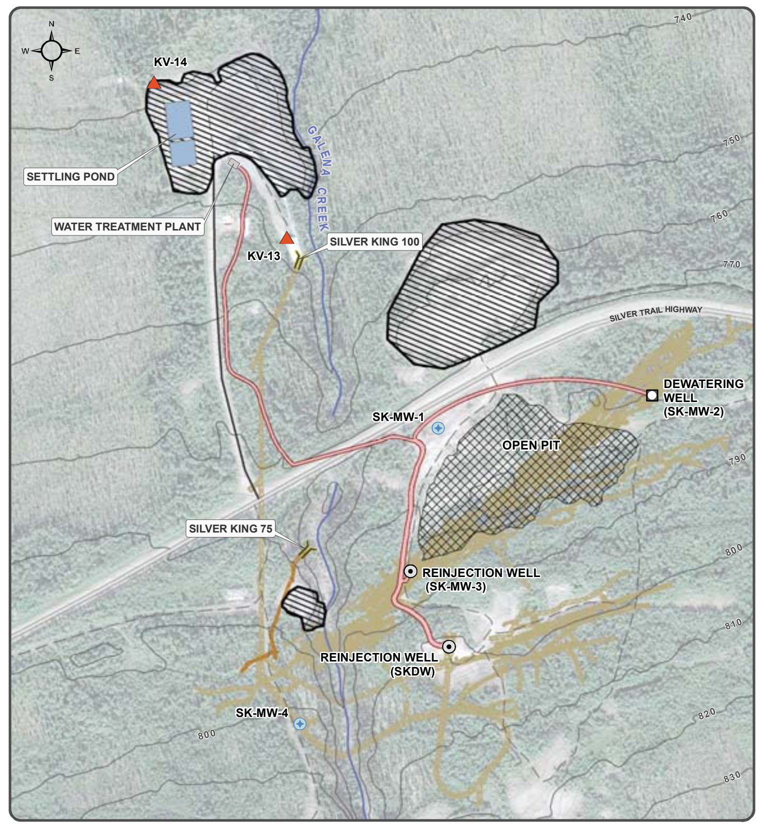
3.5 PATH FORWARD

In FY2018-19 the Silver King *in situ* treatment test is planned to transition into full scale operation (excluding the hydraulic plug), pending the results of the aeration trials and any design adjustments informed by these trials. It is anticipated that only minor changes to the design, to allow for the reaeration of the discharge, will provide adequate adjustments to the drainage chemistry to bypass the active water treatment plant at Silver King and still meet the EQS for all constituents. Although its use is not anticipated, the SK WTP will remain on standby for the first few years to address any unexpected upset events. It is expected that in time the need to maintain this redundant plant will not be required.

EXISTING CONFIGURATION



PROPOSED CONFIGURATION



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

AEG

- Surface Water Station
- Dewatering Well
- Reinjection Well
- Monitoring Well
- Adit
- Shaft
- Existing Pipeline Configuration
- Proposed Pipeline Configuration
- Silver Trail Highway
- Local Road
- Limited-Use Road
- Contours (10 m interval)
- Contours (1 m interval)
- Watercourse
- Underground Workings (75 level)
- Underground Workings (100 level)
- Settling Pond
- Open Pit
- Waste Rock Storage Area

ERDC

AEG

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

FIGURE 1

[illegible]

[illegible]

FEBRUARY 2017

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Studies\WaterTreatment\In-SituWaterTreatment\SilverKing_InSitu_Pipeline_Profile\SilverKing_SiteLayout_Compare_20170210.mxd
(*Last edited by: mducharme;2/10/2017/13:09 PM*)

4 SUMMARY

- The pilot test has demonstrated that the metals that are designed to be treated by the *in situ* treatment are in fact being treated, and continue to be treated, now nearly a full year since the last injection. Total zinc concentrations, which is the only metal that requires treatment at Silver King to meet its EQS in discharge, have been below its EQS for the past two years in SK discharge waters.
- The effects of the last round of organic carbon injection in November/December 2016 were still evident in November 2017 as shown by multiple lines of evidence including the low chalcophile metal concentrations, residual organic carbon, elevated alkalinity, and the continued presence of microbes that are involved in metals removal processes all being present in the Silver King mine waters;
- Although the chemistry of localized areas in the Silver King mine (e.g., SKDW) indicated an increase in zinc and cadmium concentrations in June-September 2017, this appears to likely be due to ingress of surface recharge with associated metal loading from interaction with local mineralization and oxidized mine workings. This increase observed for several summer months was reversed without additional carbon injection, showing that the treatment performed in 2016 was sufficient to support treatment of these areas as recharge has slowed. Recent data indicates that metal concentrations have subsided back to treated levels, and this localized area with elevated metals showed little effect on the SK adit discharge chemistry. Such recharge-related spikes:
    1. have been observed in the past and are expected as high volume pulses of oxidizing waters enter the workings;
    2. have subsided as sulphate-reducing conditions were re-established following the high recharge event; and
    3. have not materially impacted the quality of the adit discharge water – i.e., the zinc concentration in the adit discharge has remained below its EQS at all times
- The effects of *in situ* treatment "wear off" as the metal sulphide pool formed by *in* situ treatment slowly oxidizes in response to the ingress of more oxidizing waters, resulting in a slow increase in dissolved metal concentrations. Extrapolation of total zinc concentrations in the SK adit discharge suggests that the EQS (0.5 mg/L) will not be reached until the winter of 2018/19, however, freshet in the spring of 2018 may shorten this estimate;
- Microbial profiling continued to indicate the presence of bacteria with a close genetic similarity to known sulphate-reducing microorganisms and suggested that their inferred abundance had increased over the course of the *in situ* treatment program;
- Overall, the pilot test has behaved as predicted from both a geochemical and microbiological standpoint and is transitioning to an operational *in situ* treatment system; and

- The incorporation of a passive aeration system and subsequent settling pond will likely address remaining issues associated with pH and TSS, while also providing polishing for arsenic and iron concentrations. The role of aeration and settling in ensuring that pH and TSS comply with their respective EQS thresholds will be examined in laboratory testing planned for this financial year.

5 REFERENCES

Alexco Environmental Group (AEG) (2016) ERDC Task 033-2 Silver King In-Situ Treatment FY2015-16 Summary. Memorandum prepared for Elsa Reclamation and Development Company Ltd., April 1, 2016.

Appendix A

Report on SEM Inspection of Suspended Particulates in SK-MW-03 Water Sample

October 2017

Report to Dr. Andrew Gault

SCANNING ELECTRON IMAGING OF PARTICULATES FROM A WATER SAMPLE

MAEVE MORIARTY, TAREK NAJEM, DR. DANIELLE FORTIN
UNIVERSITY OF OTTAWA

1. Objective

Anaerobic unfiltered water was sent to the University of Ottawa for analysis. The goal was to identify the mineralogy of the solids in the water, to look for evidence of Zn and Cd potentially bound to sulfides and to look for evidence of bacteria.

2. Materials and Methods

2.1. Sample filtration

One 2 L anaerobic unfiltered water sample was received and kept at 4°C until filtration occurred. The water sample was taken into a COY systems anaerobic chamber. The sample was then opened and filtered through a Millipore 0.45 µm mixed cellulose filter using vacuum filtration. A significant amount of precipitate was collected on the filter paper. The paper was anoxically dried in the anaerobic chamber.

A subsample of the filtrate was ultracentrifuged at 13,000 rpm, and dehydrated with ethanol in a sequential manner (50:50 ethanol:water, 75:25 ethanol:water, 90:10 ethanol, 100% ethanol) in air.

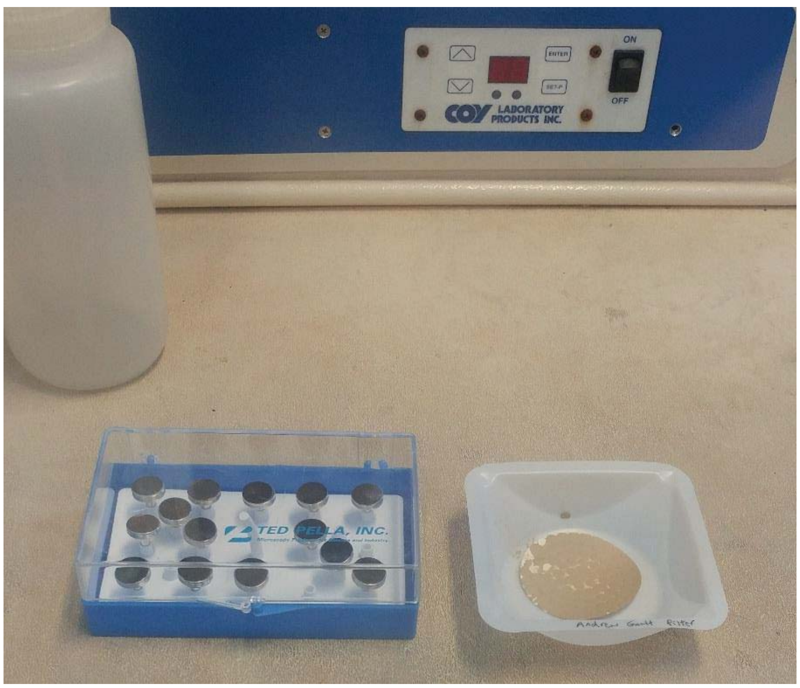


Figure 1. Filter paper and Scanning electron microscopy stubs loaded in an anaerobic chamber

2.2. Scanning electron microscopy (SEM)

The dried filtrate was observed by scanning electron microscopy with a JEOL JSM-6610LV microscope operating at the University of Ottawa (Ontario, Canada). Prior to observation, samples for SEM analysis were prepared by placing a thin layer of dry sample on a carbon tape attached to a sample holder. One of the samples was carbon coated prior to analysis. No gold coating was completed as it was judged to likely add more noise to the pictures. For chemistry, the machine was operated in backscatter mode at 15 kV, while imaging was performed in secondary electron imaging mode at both 5 kV and 15 kV.

3. Results

3.1. Chemistry

The filtrate revealed large amounts of clays, aluminosilcates were present, likely illite. Additionally, both iron oxides and iron sulfides were identified. More oxidized iron may be present in the observed filtrate than in the original water due to oxidation occurring from the time of exposure to air prior to loading samples into the SEM. Approximately 30% of the iron identified was an iron sulfide, and 70% was as an iron oxide. No zinc or cadmium was observed in the solids or in the ultracentrifuged filtrate sample. Small distinct rods were identified as TiO_2.

3.2. Imaging

A number of images were collected. Organics were expected only in low voltage mode. No sulfate reducing bacteria were observed during imaging.

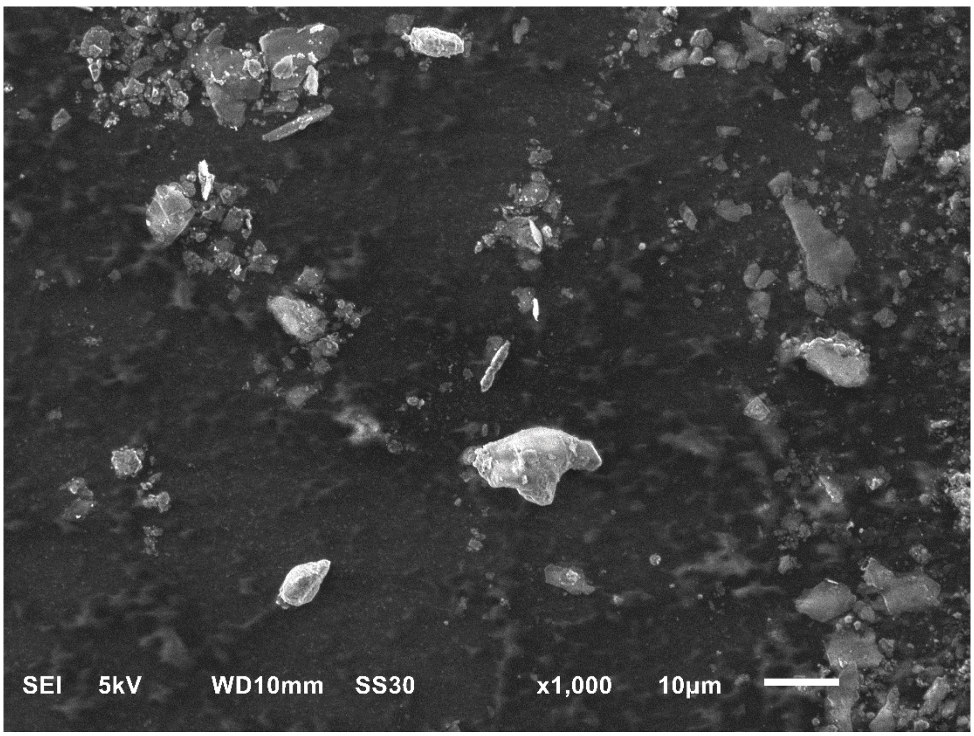


Figure 1. Uncoated solid. Rod shapes identified as containing Ti, likely TiO_2. Large amounts of clays with smaller amounts of iron identified. No bacterial signatures identified.

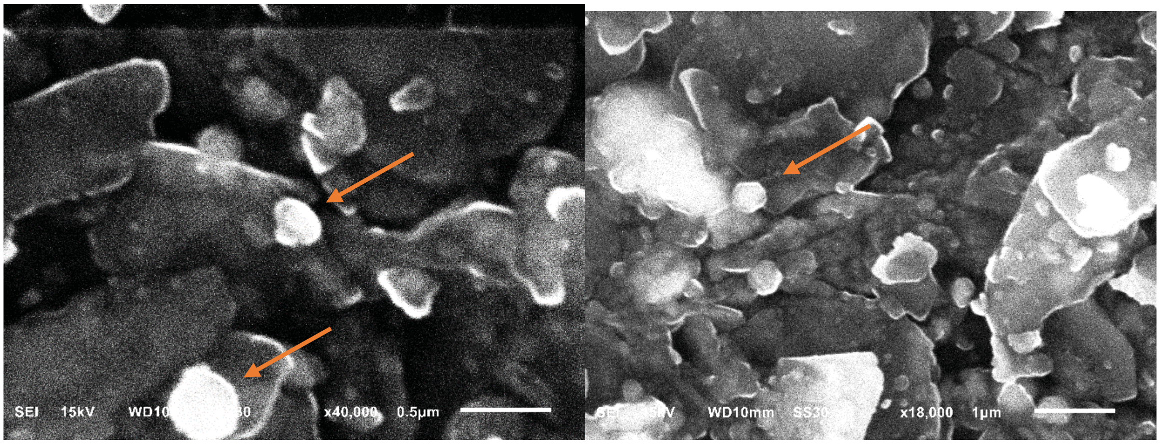


Figure 3. Carbon coated solid. Orange arrows indicate the presence of iron sulfides.

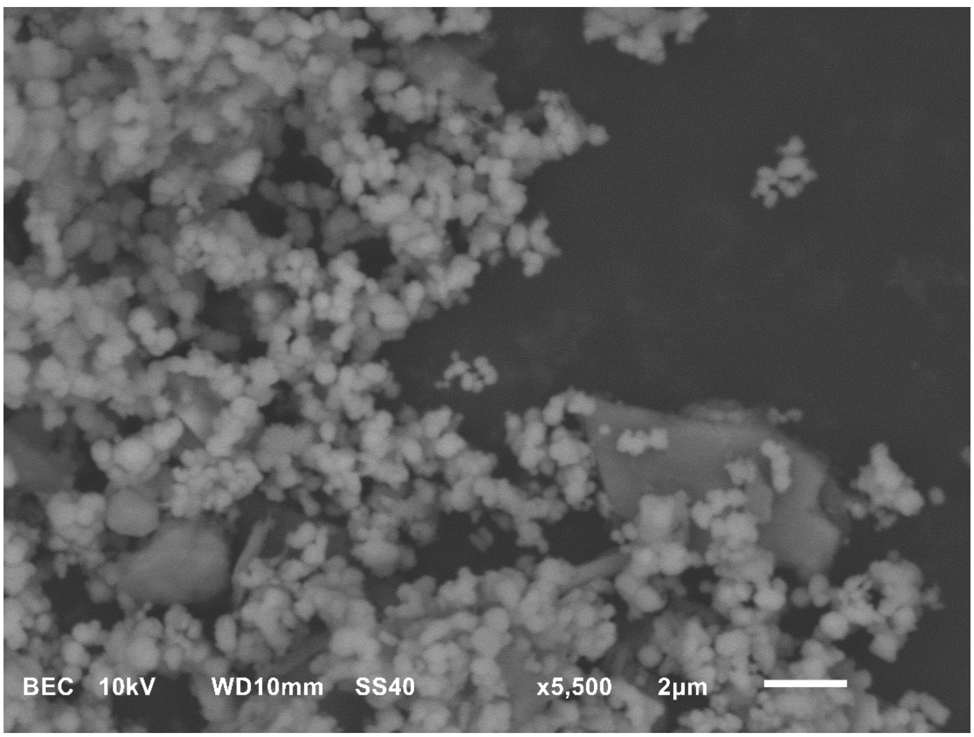


Figure 4. Fine particles from ultracentrifuged filtrate. No evidence of Zn or Cd. In this sample, the small particles contain iron but no sulfur. This is likely due to oxidation and precipitation of dissolved ferrous iron.

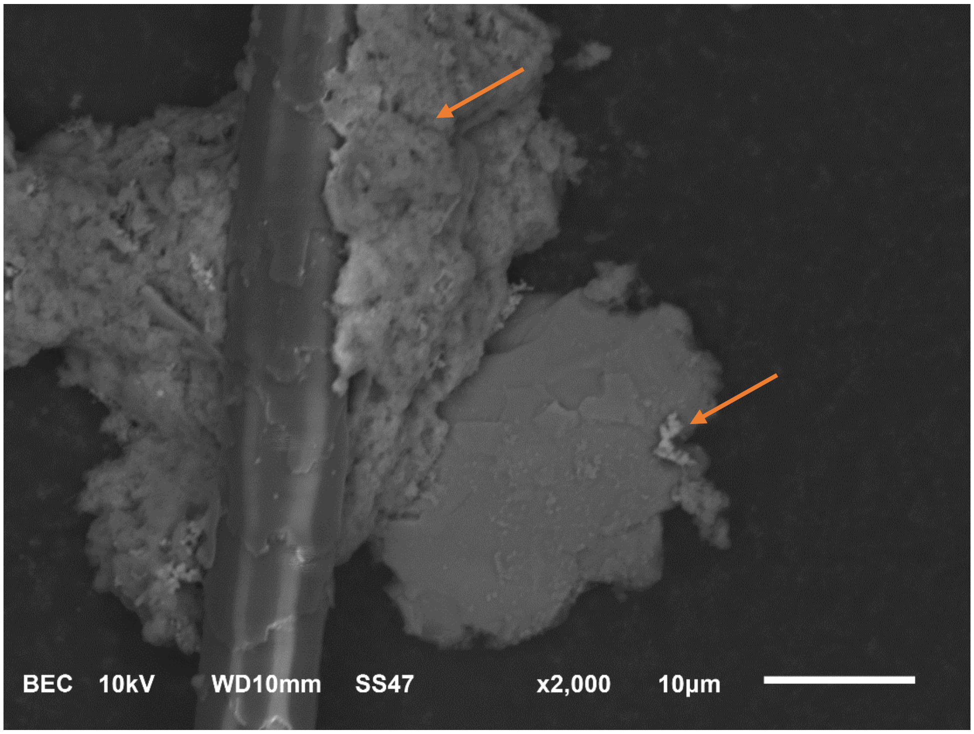


Figure 5. Fine particles from ultracentrifuged filtrate. No evidence of Zn or Cd. In this location, FeS was identified where orange arrows are located.

Appendix

Andrew Gault SEM

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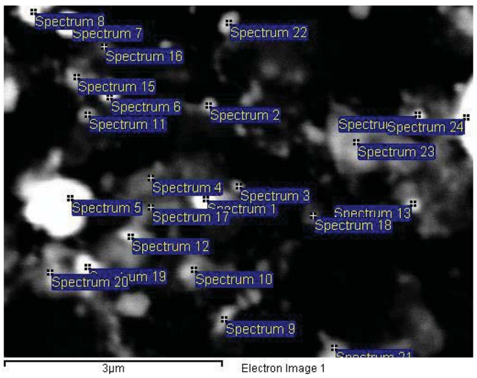

University of Ottawa

Analyzed by: Maeve Moriarty and Tarek Najem

Sample: Solid

Type: Carbon coated

ID: AG1

Processing option : Oxygen by stoichiometry (Normalised)

Spectrum	In stats.	Al	Si	S	K	Ca	Mn	Fe	Zn	O	Total
Spectrum 1	Yes	9.17	12.12		1.58		0.00	42.62		34.50	100.00
Spectrum 2	Yes	4.97	5.84	0.00	1.82		0.00	59.03	0.00	28.35	100.00
Spectrum 3	Yes	5.78	5.56				0.00	59.99		28.67	100.00
Spectrum 4	Yes	10.42	18.34		3.73			28.44		39.07	100.00
Spectrum 5	**Yes**	**4.81**	**4.75**	**5.97**	**4.08**		**0.00**	**47.36**		**33.03**	**100.00**
Spectrum 6	Yes	4.96	7.70		1.70		0.00	56.05		29.59	100.00
Spectrum 7	Yes	4.37	6.61				0.00	60.32		28.70	100.00
Spectrum 8	Yes	4.39	7.00				0.00	59.64		28.97	100.00
Spectrum 9	**Yes**	**5.34**	**5.85**	**6.16**	**4.26**			**44.22**		**34.17**	**100.00**
Spectrum 10	Yes	9.49	15.80					37.52		37.19	100.00
Spectrum 11	Yes	8.86	10.24				0.00	47.70		33.21	100.00
Spectrum 12	Yes	12.15	14.67				0.00	35.49		37.69	100.00
Spectrum 13	Yes	8.72	13.48		4.45			38.34		35.01	100.00
Spectrum 14	**Yes**	**8.65**	**10.11**	**6.72**				**35.16**		**39.35**	**100.00**
Spectrum 15	Yes	12.19	13.90				0.00	36.71		37.20	100.00
Spectrum 16	Yes	12.47	13.45					37.05		37.03	100.00
Spectrum 17	Yes	12.25	17.97		3.85			26.26		39.68	100.00
Spectrum 18	Yes		6.83				0.00	66.37		26.80	100.00
Spectrum 19	Yes	11.35	14.21			1.87		35.38		37.18	100.00
Spectrum 20	Yes	13.39	16.82				0.00	30.08		39.70	100.00
Spectrum 21	Yes	9.44	14.64					39.53		36.40	100.00
Spectrum 22	Yes	7.49	9.88				0.00	50.31		32.33	100.00
Spectrum 23	Yes	9.35	12.15		3.86			40.16		34.46	100.00
Spectrum 24	**Yes**	**3.21**	**2.67**	**9.06**	**6.01**		**0.00**	**45.36**		**33.69**	**100.00**

Spectrum 24 | Yes 3.21 2.67 9.06 6.01 0.00 45.36 33.69 100.00

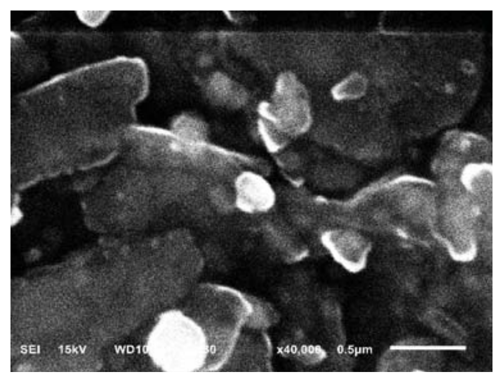

Figure. Zoomed in area around Spectrum 14 (to the left of Spectrum 24)

Andrew Gault SEM

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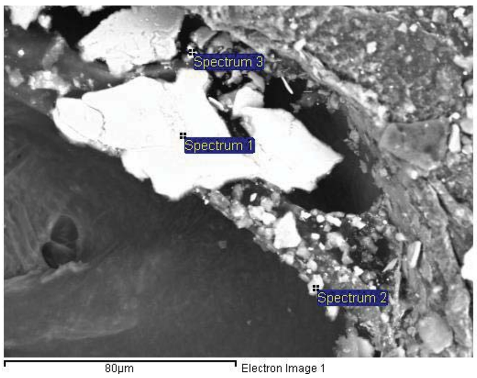

University of Ottawa

Analyzed by: Maeve Moriarty and Tarek Najem

Sample: Solid

Type: Carbon coated

ID: AG4

Processing option : Oxygen by stoichiometry (Normalised)

Spectrum	In stats.	Al	Si	S	K	Fe	O	Total
Spectrum 1	Yes	15.54	25.76		10.59	2.17	45.95	100.00
Spectrum 2	Yes		46.74				53.26	100.00
Spectrum 3	Yes	0.39	0.42	25.89		26.22	47.09	100.00
Max.		15.54	46.74	25.89	10.59	26.22	53.26	
Min.		0.39	0.42	25.89	10.59	2.17	45.95	

All results in weight%

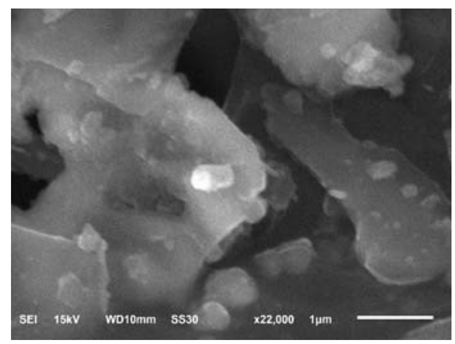

Figure. Zoom in of Spectrum 3.

Andrew Gault SEM

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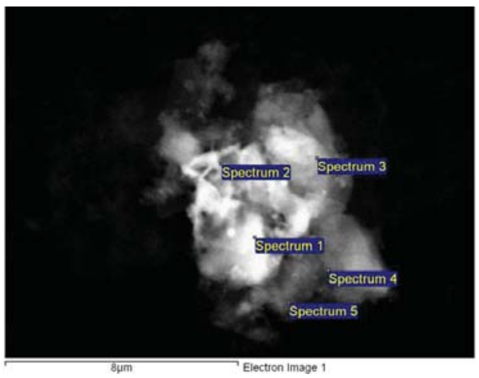


University of Ottawa

Analyzed by: Maeve Moriarty and Tarek Najem

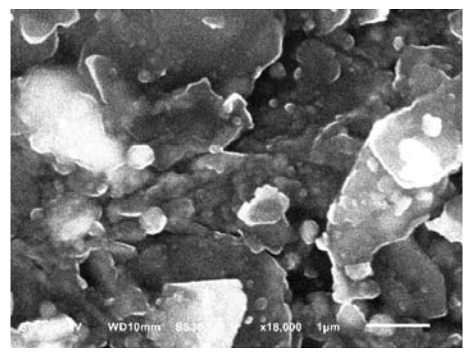
Sample: Ultracentrifuged filtrate

Type: Uncoated

ID: AG5

Processing option : All elements analysed (Normalised)

Spectrum	In stats.	O	Al	Si	K	Ca	Fe	Total
Spectrum 1	Yes	69.60	11.74	12.80	0.71	0.69	4.46	100.00
Spectrum 2	Yes	73.45	5.34	5.59	0.00	1.97	13.65	100.00
Spectrum 3	Yes	70.51	9.13	11.35	3.36	0.00	5.64	100.00
Spectrum 4	Yes	77.11	6.39	6.33	0.00	3.00	7.16	100.00
Spectrum 5	Yes	73.16	8.44	8.90	2.01	0.00	7.49	100.00
Mean		72.77	8.21	8.99	1.22	1.13	7.68	100.00
Std. deviation		2.94	2.50	3.11	1.45	1.32	3.55	
Max.		77.11	11.74	12.80	3.36	3.00	13.65	
Min.		69.60	5.34	5.59	0.00	0.00	4.46	



All results in weight%

APPENDIX 1.3
GALKENO 900 BIOREACTOR PERFORMANCE REPORT

GALKENO 900 SULPHATE-REDUCING BIOREACTOR 2008-2011 OPERATIONS

FINAL REPORT

March 2012

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT CORP.

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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, Bermingham 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.

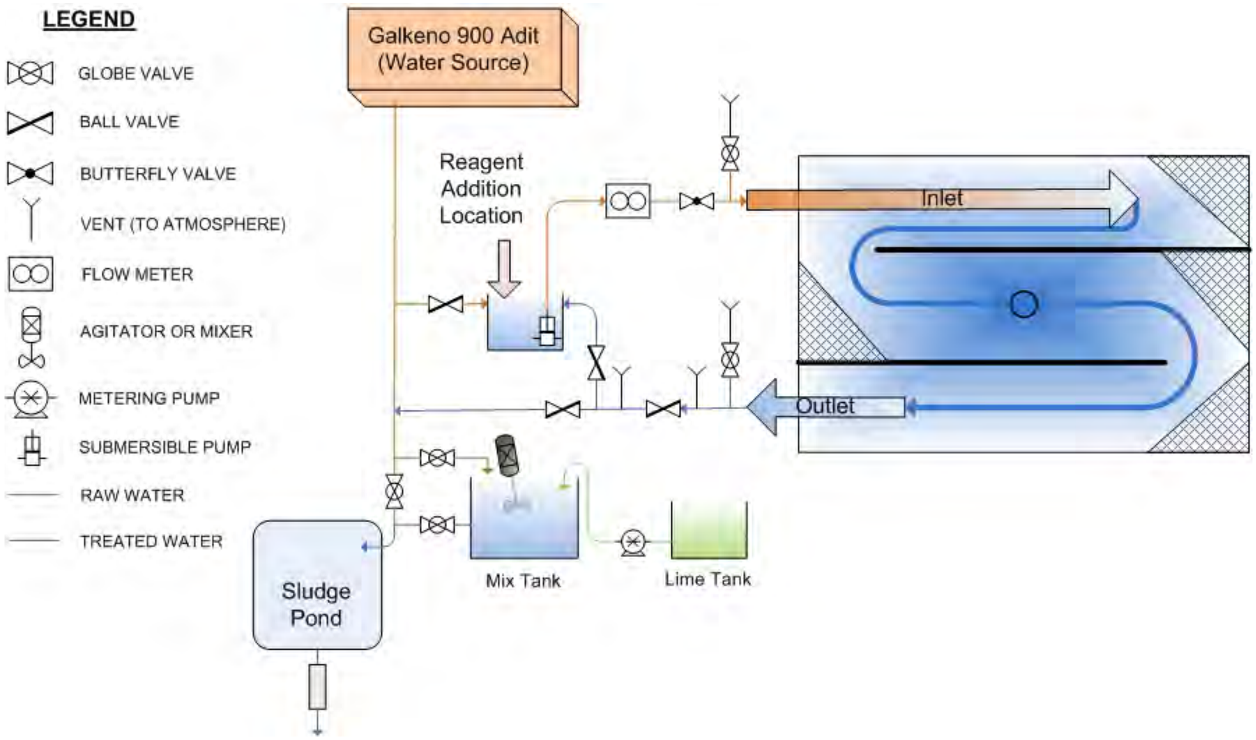

Figure 1 - Galkeno 900 Layout

Water drains from the Galkeno 900 adit at an average annual rate of 4 litres per second (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 where 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.

Figure 2 - Inlet Valve

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 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

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.

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.

Figure 4 - Bioreactor Inlet

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 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 ¾" holes, allowing water to fill the bioreactor and flow back and forth before final release.

Figure 5 - Bioreactor Construction

Figure 6 - Bioreactor Standpipe

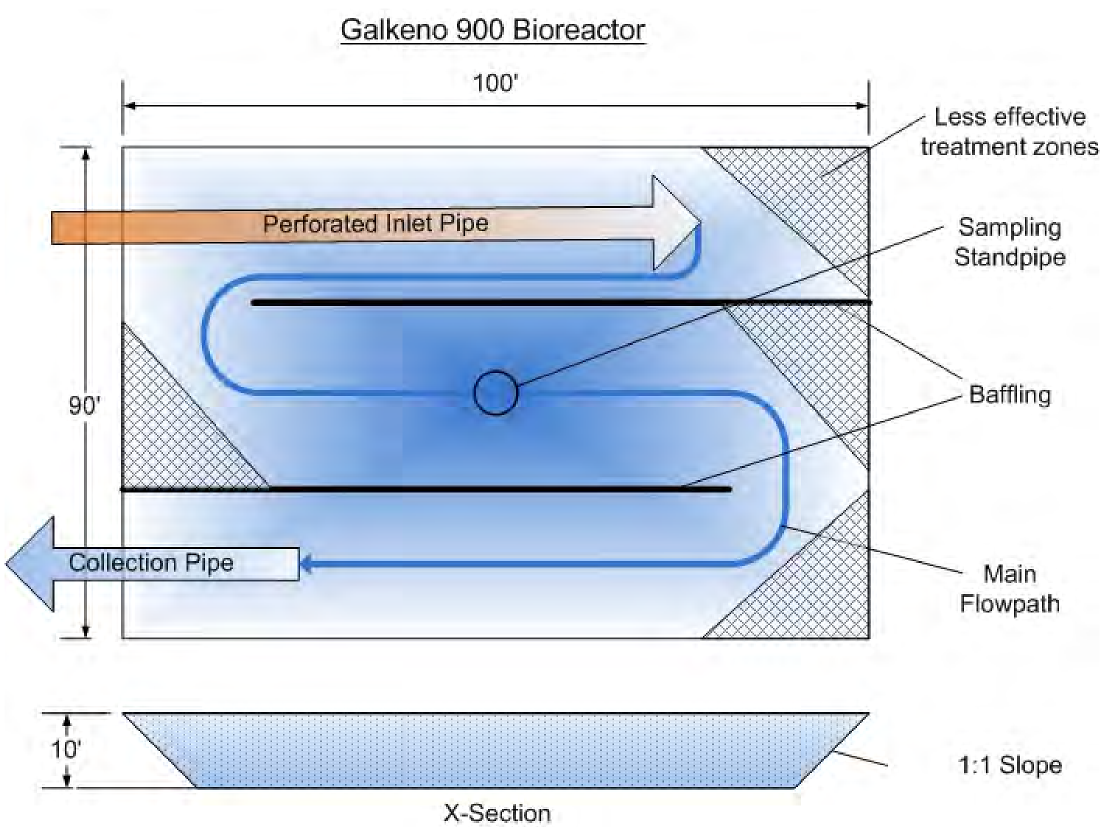

Figure 7 - Bioreactor Layout

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 co-mingled 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 co-mingled 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 litre per second (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 one litre per second (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 → 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^{O}C to 2^{O}C) as it is in natural environments where the long-term temperature is around 20 ^{O}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 μM 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 μM 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 m^3, and a flow rate of 1 lps, the total sulphate removal per day was 115,200 mM, which yields a SRR of 45 mM/m^3/day. For comparison, artic ocean sediments have SRRs in the range of 5-40 mM/m3/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:

Volume of reactor =mass of dye added÷concentration measured

Using this formula, the volume of the bioreactor was calculated to be approximately 909 m^3, 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.

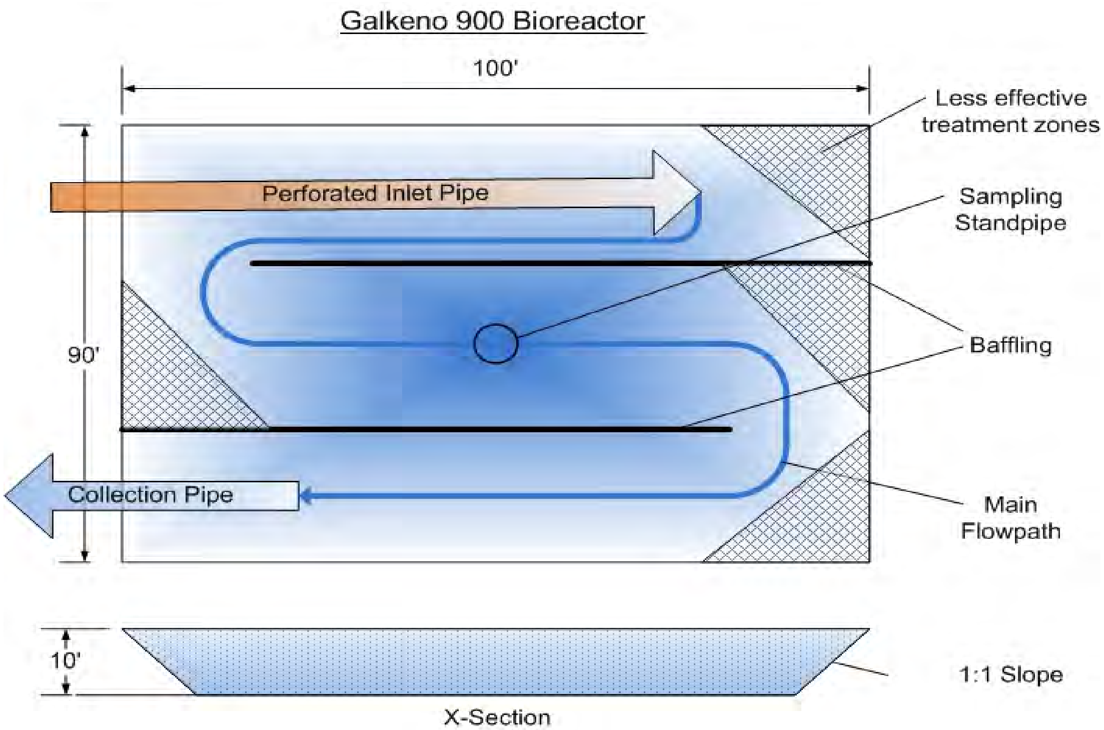

Figure 9 - Conceptualization of Flow Path in the Bioreactor

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.

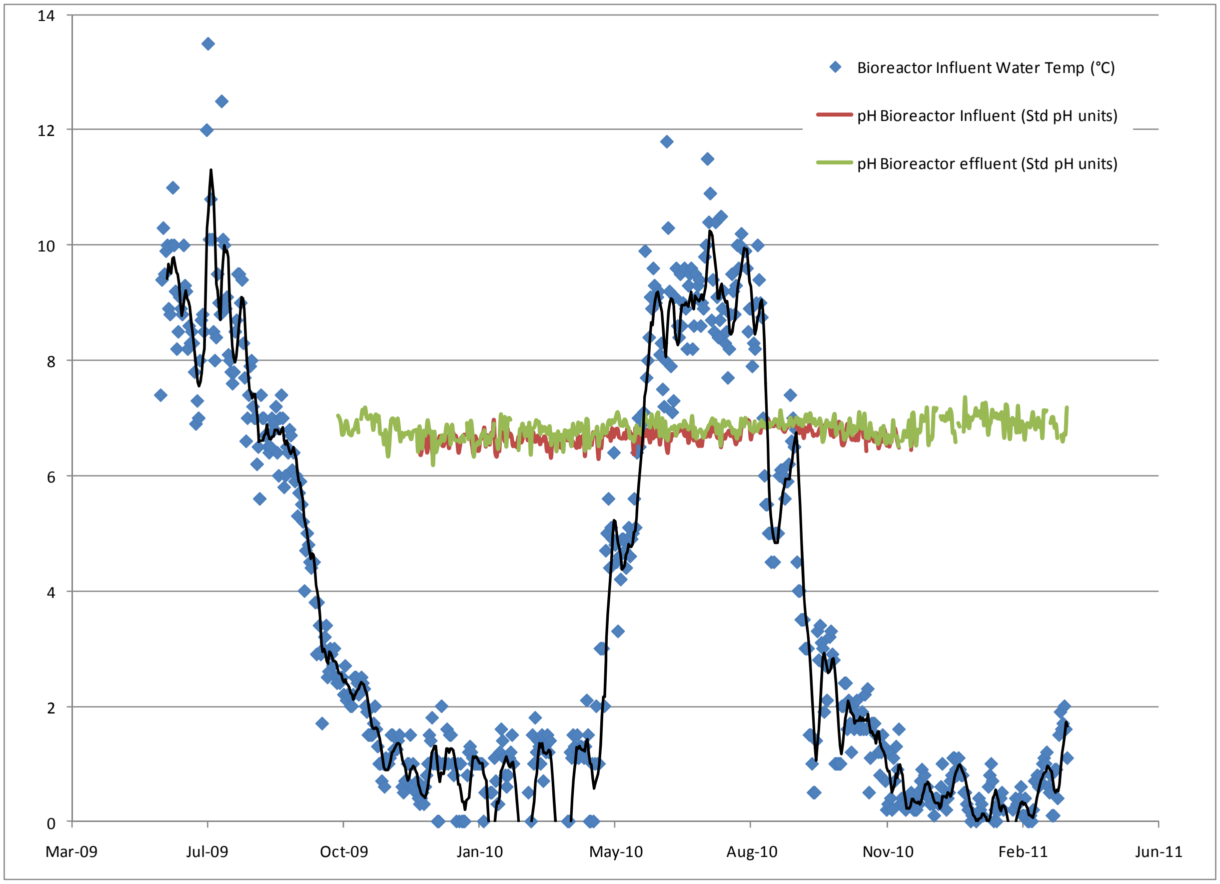

Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp

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%

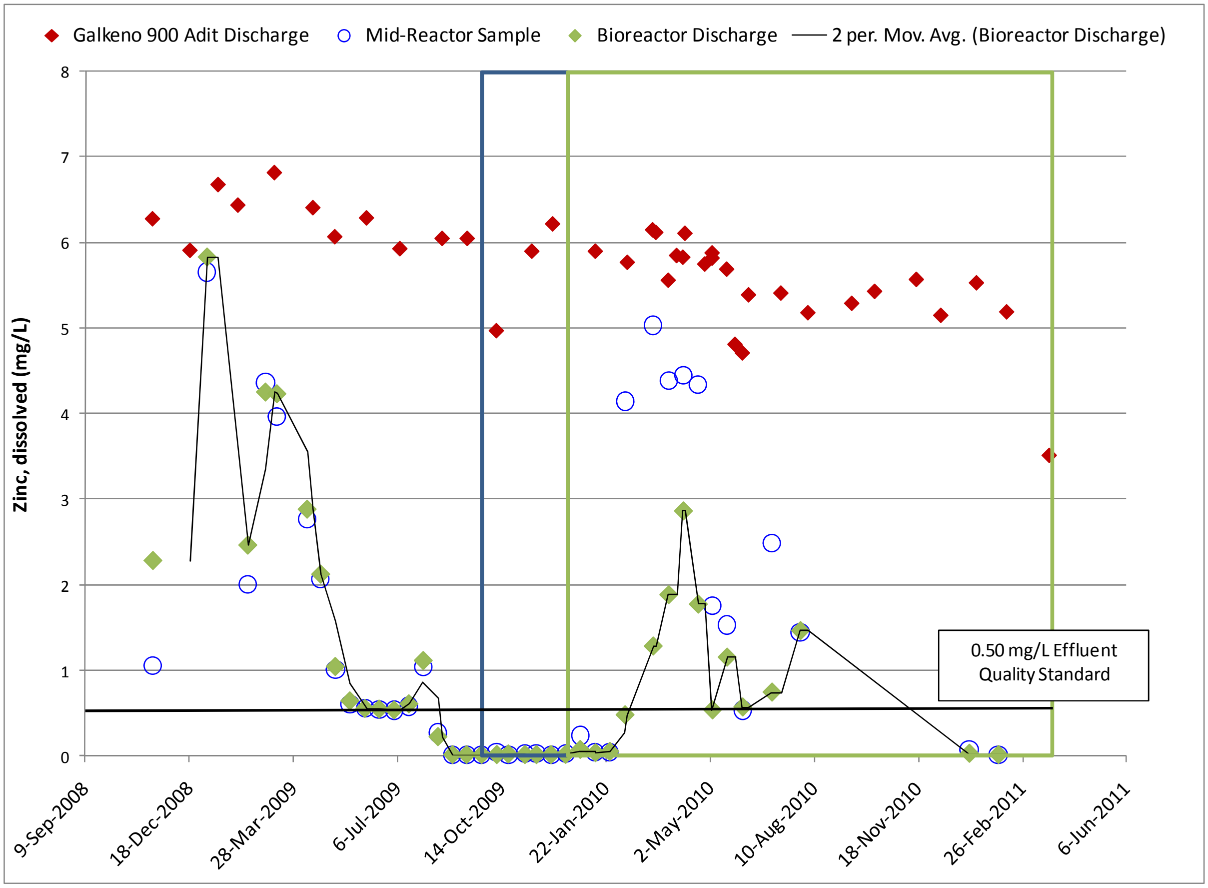

Figure 11 - Zinc removal by the Galkeno 900 Bioreactor

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.

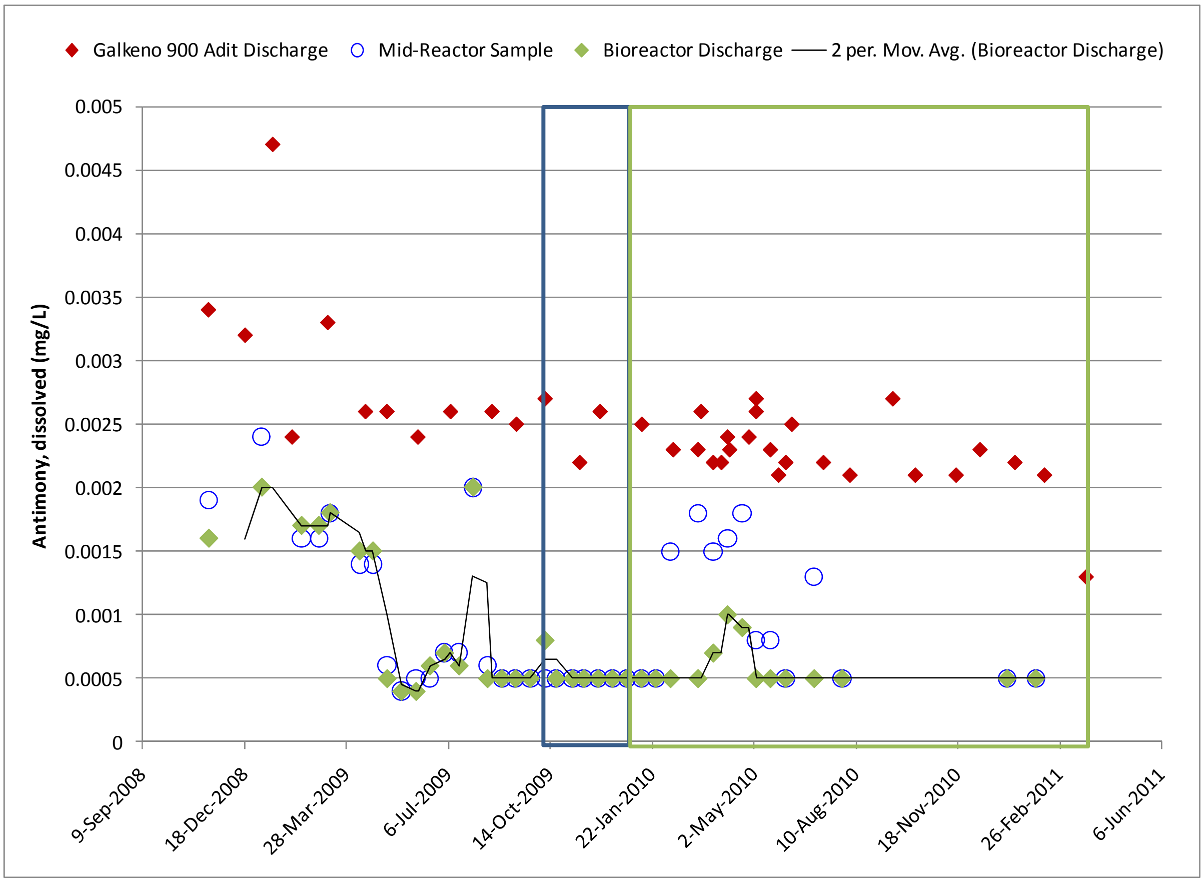

Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor

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.

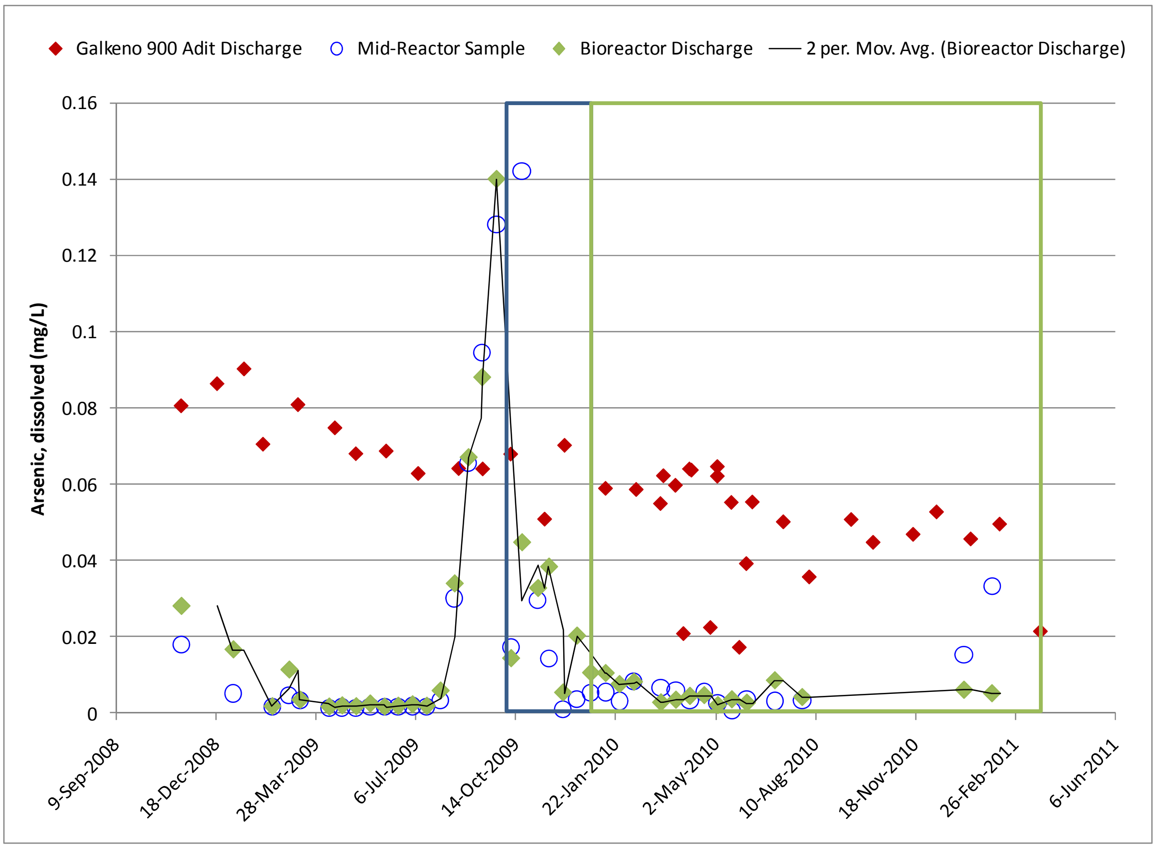

Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor

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.

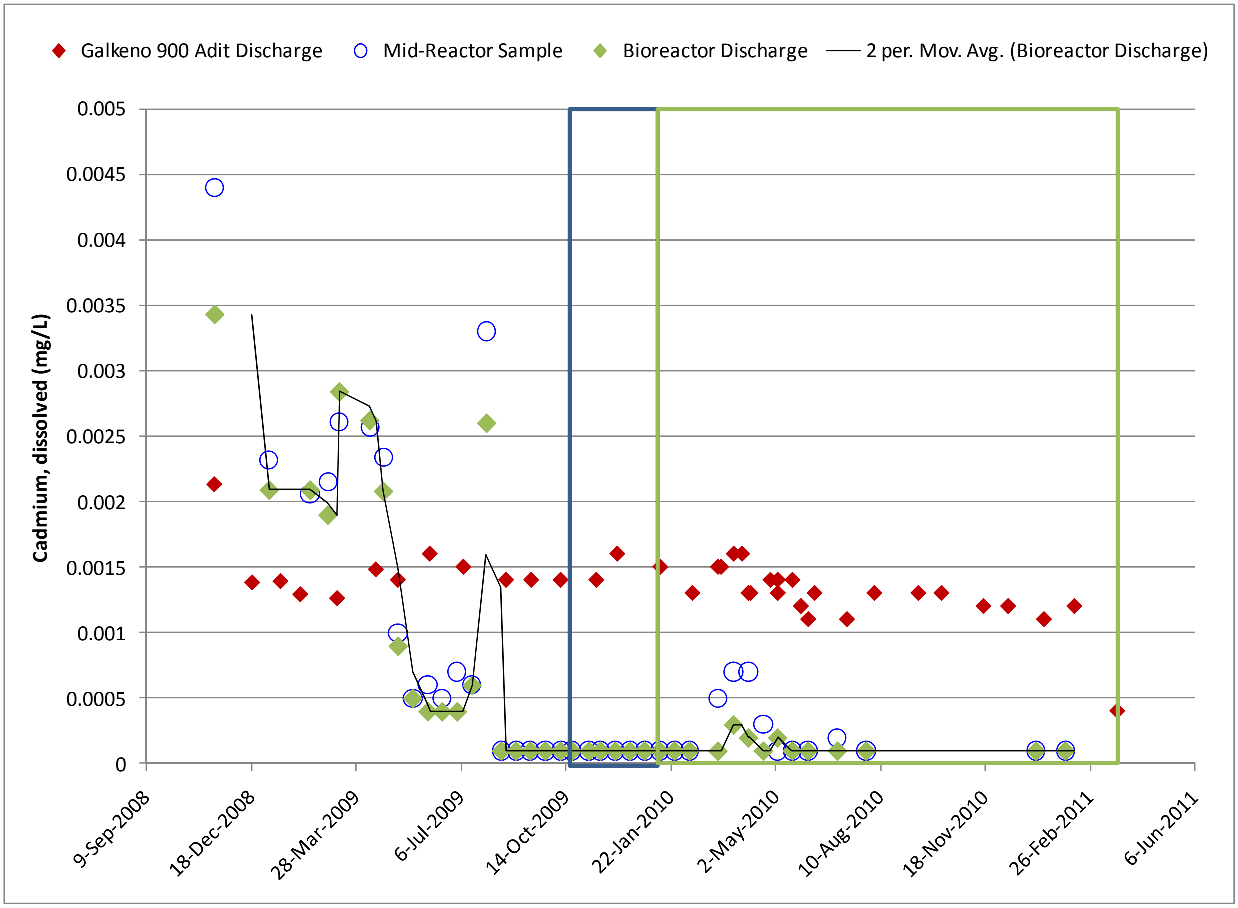

Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor

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.

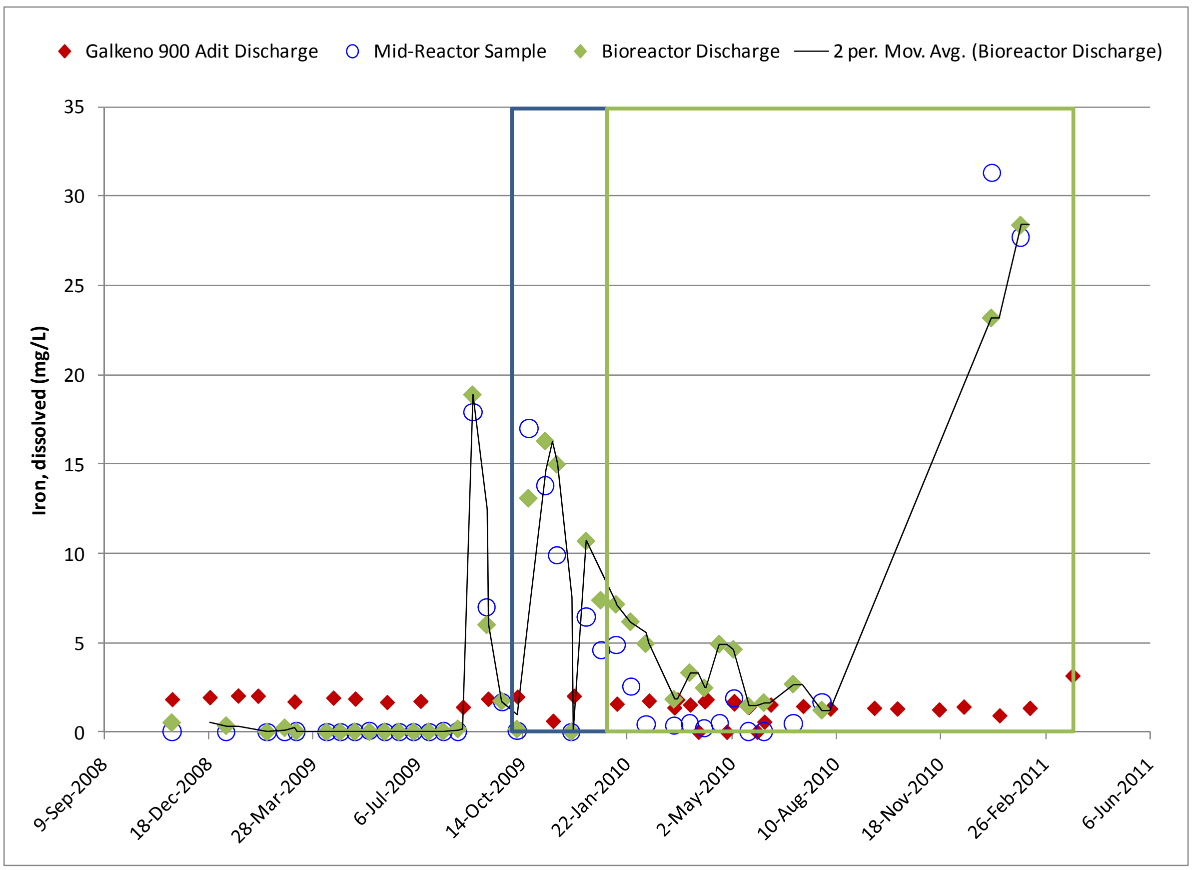

Figure 15 - Iron Removal by the Galkeno 900 Bioreactor

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.

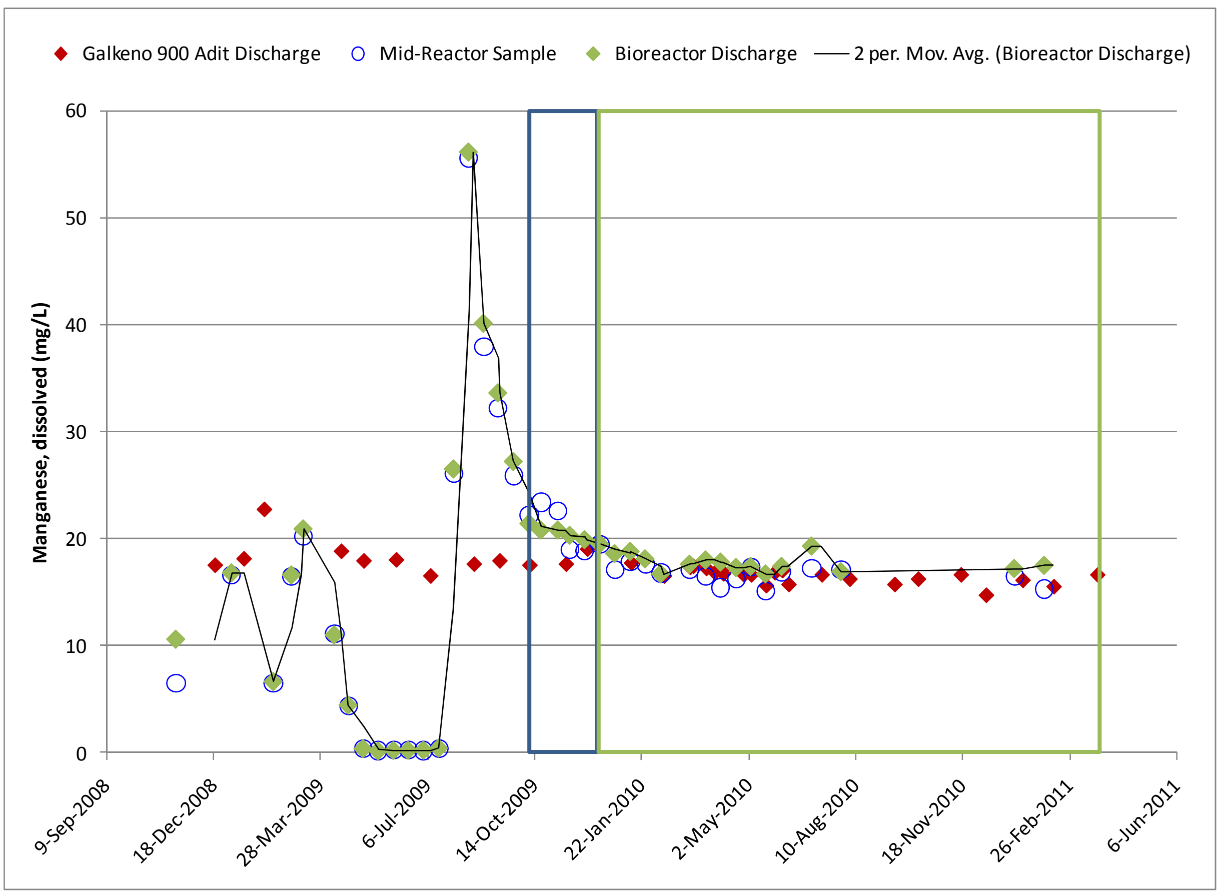

Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor

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.

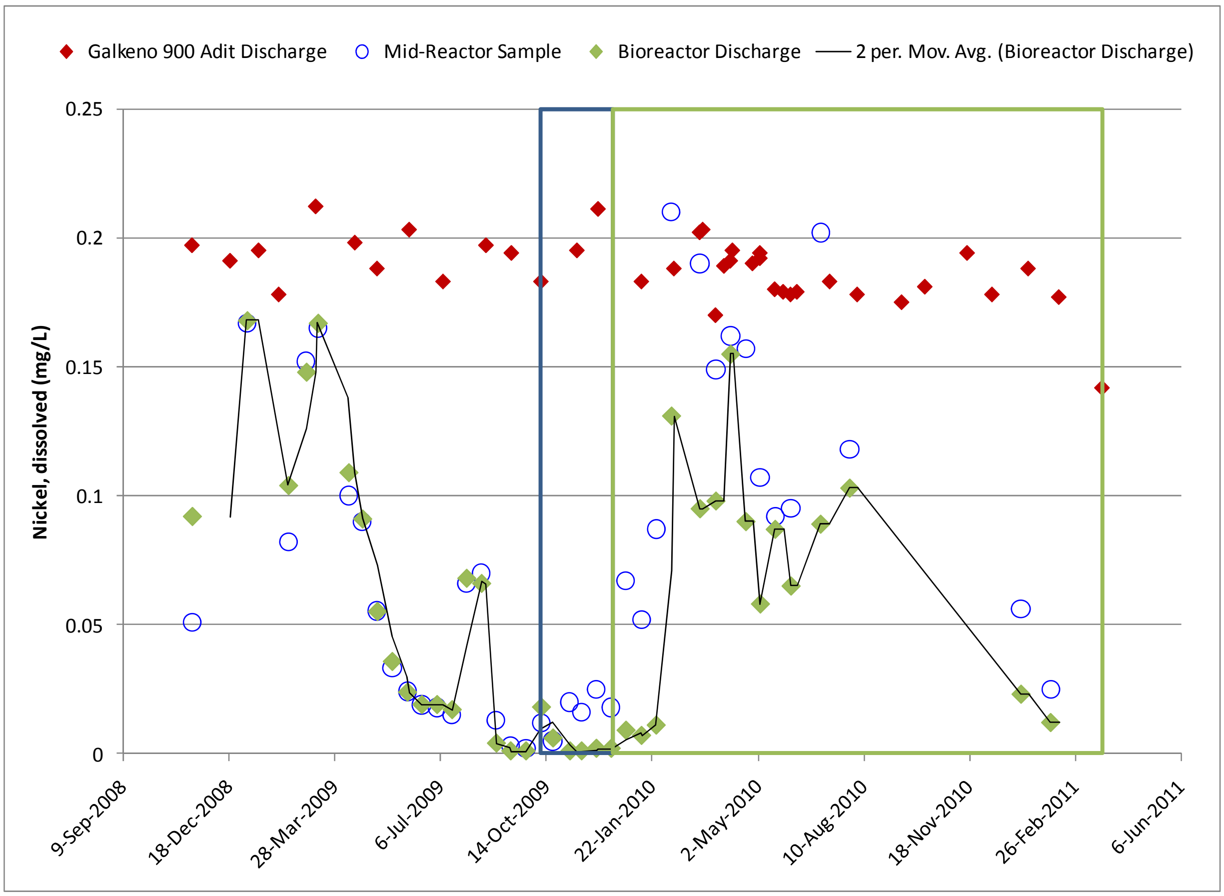

Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor

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 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 course 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 a 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 Leviathin 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 additional 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 licencing ofat 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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Submitted, November 25, 2011

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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 if 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 (~1µm) 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)

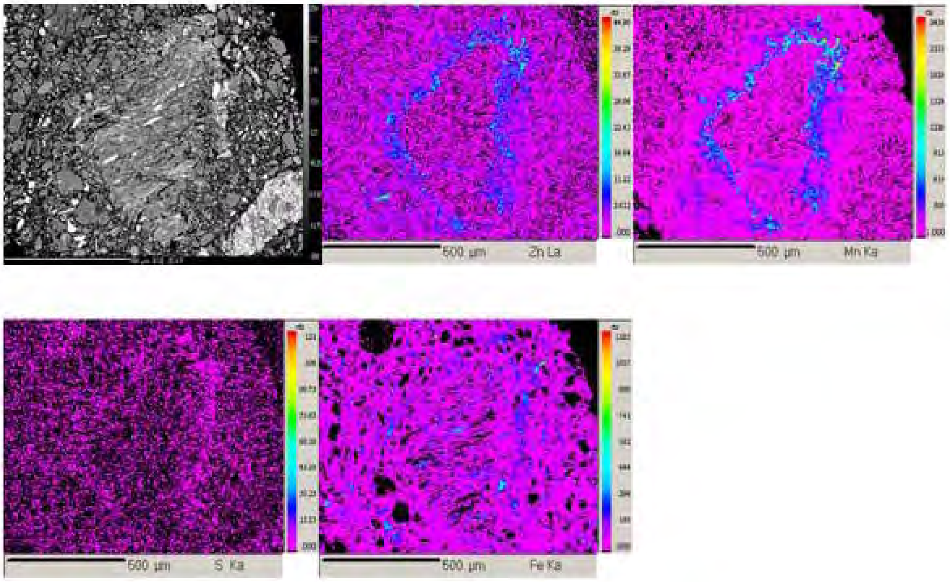

Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain

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 1:1indicating the presence of ZnS (Figure 2).

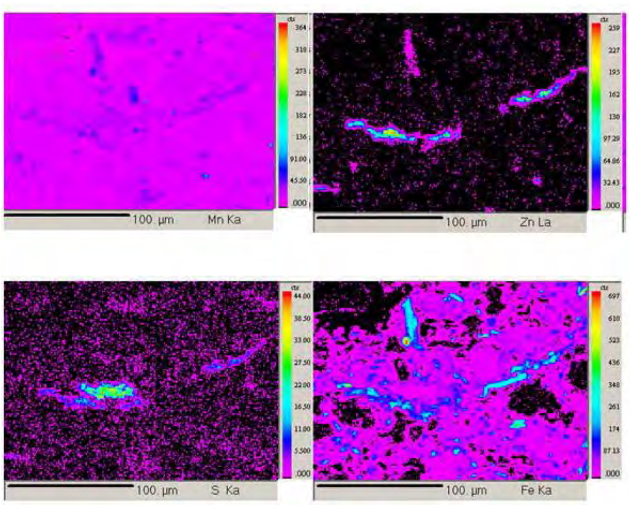

Figure 2: 1B G900 BIO BSE images and element maps

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).

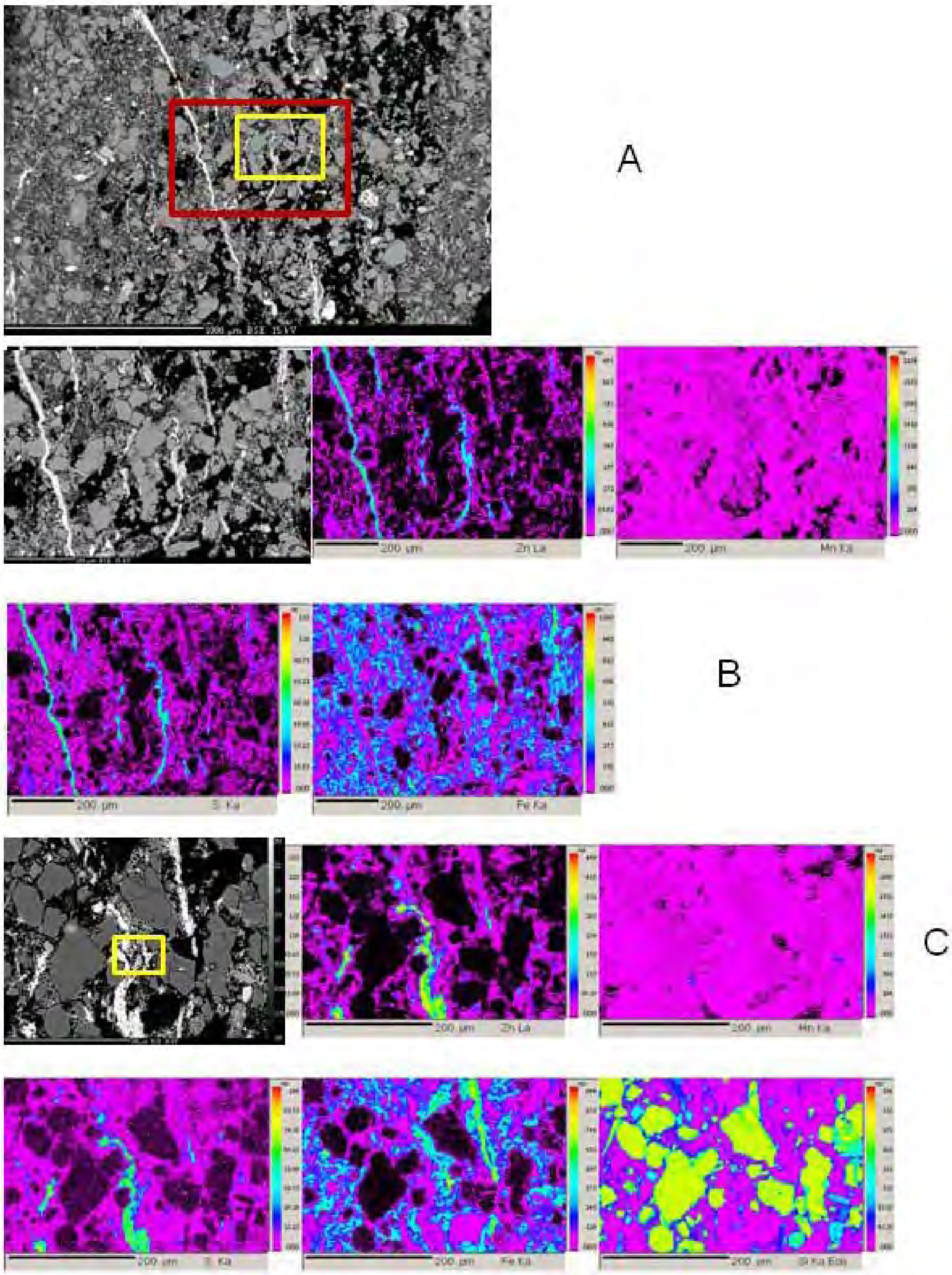

Figure 3 GK900 Bioreactor sample. (A) BSE image showing extensive bright bands of ZnS and Fe(B) BSE image and element scans of area in red box in (A) (C) BSE image and element scans of area yellow box in (A)

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.

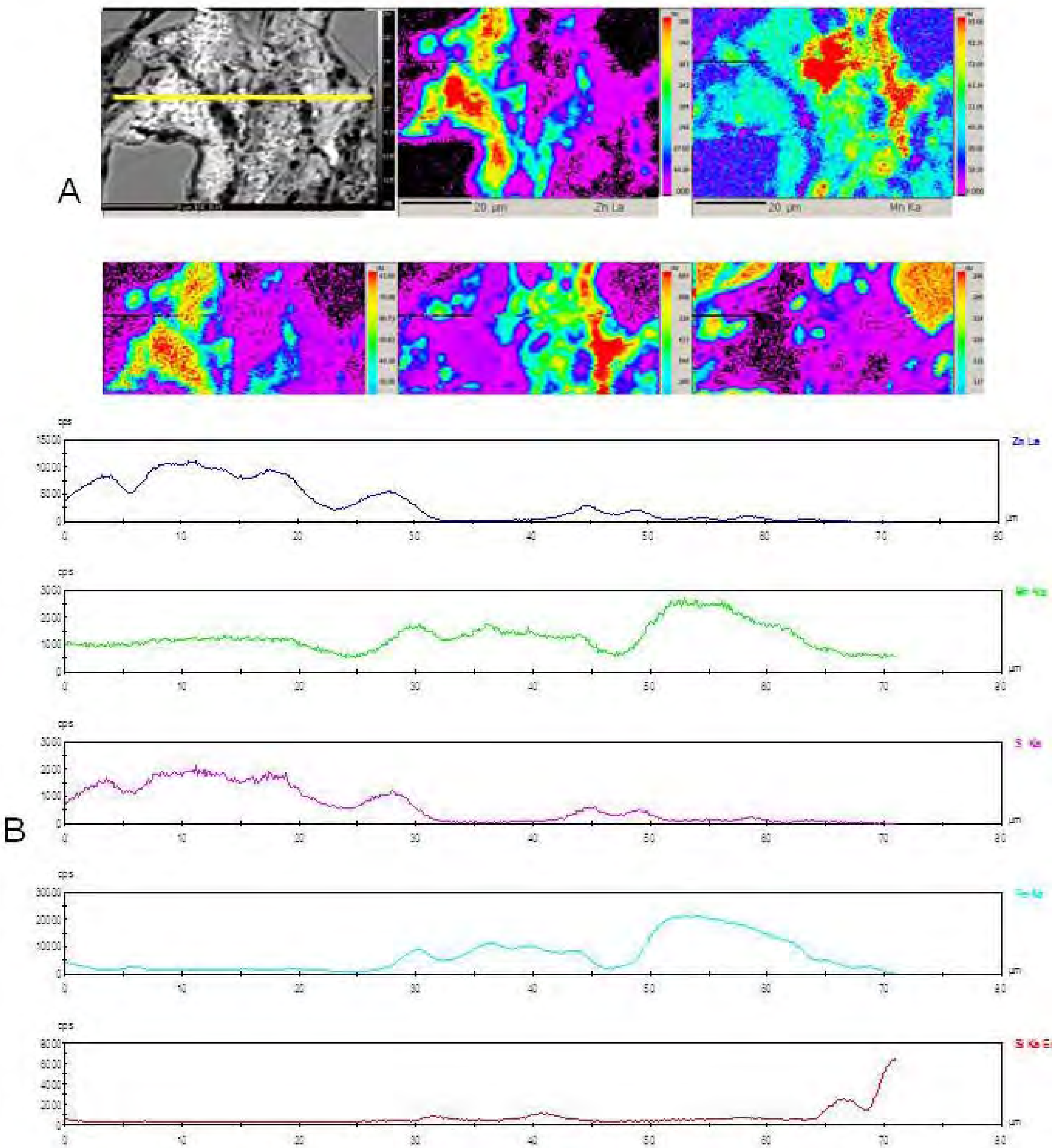

Figure 4: GK900. BSE image and element scans of area in yellow box in Figure 3 Element scans along the yellow line in BSE image (A)

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).

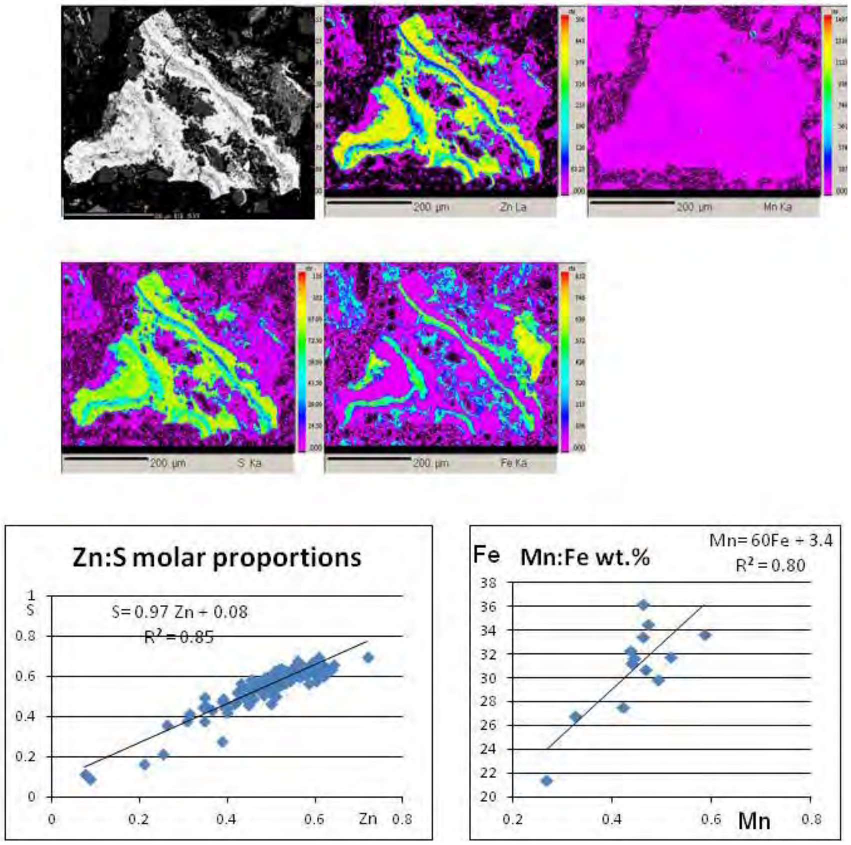

Figure 5: BioR sediment: BSE image and element maps showing the relation ship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.

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

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Sherriff, B.L. (2011b) Interim Report on optical and electron microprobe analysis of Keno Hills samples set 4

APPENDIX 1.4

PRELIMINARY ASSESSMENT OF PERFORMANCE FOR WRSA CLOSURE COVER SYSTEMS

O'Kane
Consultants Inc.

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

March 30, 2015

Leia Fougere
Environmental Engineer (EIT)
Access Consulting, a member of
Alexco Environmental Group
#3 Calcite Business Centre, 151 Industrial Road
Whitehorse, YT Y1A 2V3

Ms. Fougere:

Re: Keno Hill Silver District – Preliminary Assessment of Performance for Closure Cover Systems for Waste Rock Storage Areas

O'Kane Consultants Inc. (OKC) was retained by Alexco Environmental Group (AEG) in February 2015 to provide technical support related to cover system designs for closure of waste rock storage areas (WRSAs) at the Keno Hill Silver District (KHSD) in the Yukon. This report outlines the project context, objectives, and work scope, followed by preliminary estimates of hydrological performance for three different cover system types.

<u>Project Context, Objectives, and Work Scope:</u>

Approximately 60 WRSAs exist within the KHSD, ranging from a few thousand tonnes from exploration trenches to 1.5 M tonnes. They are located in five different drainages; namely, Flat Creek, Christal Creek, No Cash, Sadie Ladue, and Lightning Creek. Based on previous characterization work, about 25 WRSAs have been prioritized for some type of re-contouring / cover / revegetation. Of those, about 10 WRSAs merit consideration of a lower net percolation cover system on some or all of the surfaces. Waste material in the WRSAs is not considered to be net acid-generating; the primary concern is metal leaching with Zn and Cd being of greatest concern. Much of the waste material is unmineralized quartzite or greenstones; the vein structures and schists are the primary sources of metal leaching and acidity. The surrounding peat landscape provides relatively good attenuation within a short migration flowpath.

The KHSD WRSAs are >30 years old and many have vegetation established on some or all of the surfaces. This is considerable time for generation of oxidation products, but on the same hand, the pore spaces have been flushed thoroughly as a result of percolating meteoric waters. Most WRSAs have angle-of-repose slopes on steeper slopes adjacent to adits. Considering the relatively low environmental impact to surface waters or groundwater from most WRSAs, it is difficult to justify the increased footprint, disturbance, and release of stored soluble load that a very low net percolation cover system would incur.

The currently planned end land-use for the reclaimed WRSAs is natural habitat (wilderness). Given this and the geochemical conditions of the waste materials, the primary design objectives of the KHSD WRSA closure cover systems are to:

a) provide an adequate rooting zone for growth of native plants;
b) eliminate dust emissions from the waste deposits;
c) prevent direct contact between waste material and incident meteoric waters; and
d) reduce net percolation rates and thus seepage flows to the greatest extent possible.

The overall objective of OKC's work was to develop conceptual-level or indicative cover system design alternatives for closure cover systems for WRSAs at KHSD. Specifically, AEG requires preliminary estimates of hydrological performance (i.e. long-term net percolation rates) and construction costs for three difference cover system types. This information is required to support an update to the KHSD ESM Reclamation Plan. Preliminary costs for remediation of the WRSAs were submitted to AEG in a separate memorandum.

The following tasks were completed to address the above project objectives:

- Project orientation including review of pertinent background information and participation in a project planning / kickoff meeting in Vancouver on February 19, 2015;
- Development of a conceptual model of hydrological performance of a typical soil cover system for the KHSD site;
- Base case numerical simulations of cover system performance using the soil-plant-atmosphere (SPA) model VADOSE/W[1];
- Provision of technical support on various matters related to cover system design; and
- Development of indicative-level cost estimates (-20% to +30%) for cover system construction.

Conceptual Model of Cover System Performance:

A conceptual model of hydrological performance of cover systems for KHSD was developed prior to the start of SPA numerical modelling. This required consideration of the following water balance fluxes:

- precipitation (Ppt),
- potential evapotranspiration (PET),
- actual evapotranspiration (AET),
- runoff (RO),
- sublimation (Sub), and
- net percolation (NP).

The mean annual precipitation (MAP) for the KHSD and how it is influenced by elevation was previously estimated by Clearwater Consultants in 1996 (Access, 1996)[2]. Clearwater Consultants developed a linear relationship between elevation and MAP:

$$MAP = 0.27 * Elev + 190$$

[1] Geo-Slope International Ltd. 2014. GeoStudio 2012. Version 8.14.1.10087. Online. www.geo-slope.com.

[2] Access Mining Consultants Ltd., 1996a. United Keno Hill Mines Limited, Site Characterization Report, Report No. UKH96/01. Prepared for United Keno Hill Mines Limited.

where:

MAP = mean annual precipitation (mm/yr); and

Elev = elevation above sea level (masl).

OKC performed their own review of the MAP estimate and found it reasonable. Hence, the equation above was used to estimate MAP. Three elevations were simulated for this project: 750 masl, 1,000 masl, and 1,500 masl. Hence, the MAP at each elevation is estimated to be 390 mm/yr, 460 mm/yr, and 530 mm/yr, respectively.

Given the relatively high latitude of KHSD, slope aspect and angle highly influences the amount of solar energy and resultant PET applied to various areas of the site (MEND, 2012)[3]. Hence, for an exposed plateau (i.e. a flat area with no slope influences) or east- or west-facing slope (referred to hereinafter as a middle aspect), average annual PET is estimated to be 370 mm/yr with an annual range from 200 mm/yr to 1,400 mm/yr. However, PET is estimated to be 60% less on north-facing aspects and 50% more on south-facing aspects, resulting in average annual PET rates for these two aspects of 150 mm/yr and 560 mm/yr, respectively.

In general, the ratio of annual AET to precipitation ranges from 40 to 60% for study areas similar to KHSD (Kane and Yang, 2004)[4]. This results in a typical AET:PET ratio of 50 to 70%. However, it must be noted that results for north or south aspects may be outside of the general ranges.

Runoff to precipitation ratios for northern sites typically have an increasing trend with increasing latitude (Kane and Yang, 2004). A runoff rate of 0 to 20% of precipitation is expected for KHSD given the latitude at which the site is located combined with the current knowledge of locally available materials and the range of vegetation conditions.

Sublimation and redistribution of snow constitutes a significant portion of the water balance in several seasonally snow-covered areas of the Canadian North such as KHSD (Pomeroy *et al.*, 1995)[5]. Snow interception and sublimation are important hydrological processes that occur as a result of complex mass and energy exchanges. Comparing KHSD to other northern sites at a similar latitude, a sublimation rate of 25 to 35% of annual snowfall is expected (Kane and Yang, 2004). This corresponds to a sublimation rate of approximately 10 to 15% of total annual precipitation.

NP is a vital component of the water balance for northern climates. Basic water balance accounting of the estimates supplied above leaves between 5 to 50% of precipitation available for NP for a middle aspect. NP is functionally halted during the winter months due to frozen ground conditions. In general, the majority of NP at the KHSD site occurs during spring-melt. Through the summer months, NP rates are lower due to the store and release function of a vegetated soil profile. NP rates generally increase in the fall due to lower PET rates.

[3] MEND (Mine Environment Neutral Drainage). 2012. Cold regions cover system design technical guidance document. Canadian Mine Environment Neutral Drainage Program, Project 1.61.5c, March.

[4] Kane, D. and Yang, D. 2004. Northern Research Basins Water Balance. International Association of Hydrological Sciences. Oxfordshire, United Kingdom.

[5] Pomeroy, J., Hedstrom, N., and Parvianinen., J. 1995. *The Snow Mass Balance of Wolf Creek, Yukon: Effects of Snow Sublimation and Redistribution*. National Hydrology Research Center. Environment Canada: Saskatoon.

Preliminary Estimates of Cover System Performance:

Cover Systems Modelled:

Four reclamation scenarios were evaluated with SPA models (see Figure 1); namely, three cover system types as well as a 'do-nothing' scenario (i.e. bare waste rock with no revegetation effort). A description of the modelled scenarios is as follows:

- *Type 1a – Very Low Net Percolation Cover System:* 0.3 m of compacted silty-clay material underlying a 1.0 m well-graded local soil layer. Surface re-graded to promote runoff, then revegetated with native plants;
- *Type 1b – Lower Net Percolation Cover System:* 0.3 m well-graded local soil layer. Surface re-graded to promote runoff, then revegetated with native plants;
- *Type 3 – Revegetation Cover System:* direct seeding of waste rock to promote revegetation (assumes sufficient fines content to support plant growth). Scarifying and contouring of surface to promote vegetation and enhance physical stability of landform.
- *Type 4 – Bare Waste Rock Surface:* no cover system or site preparation.

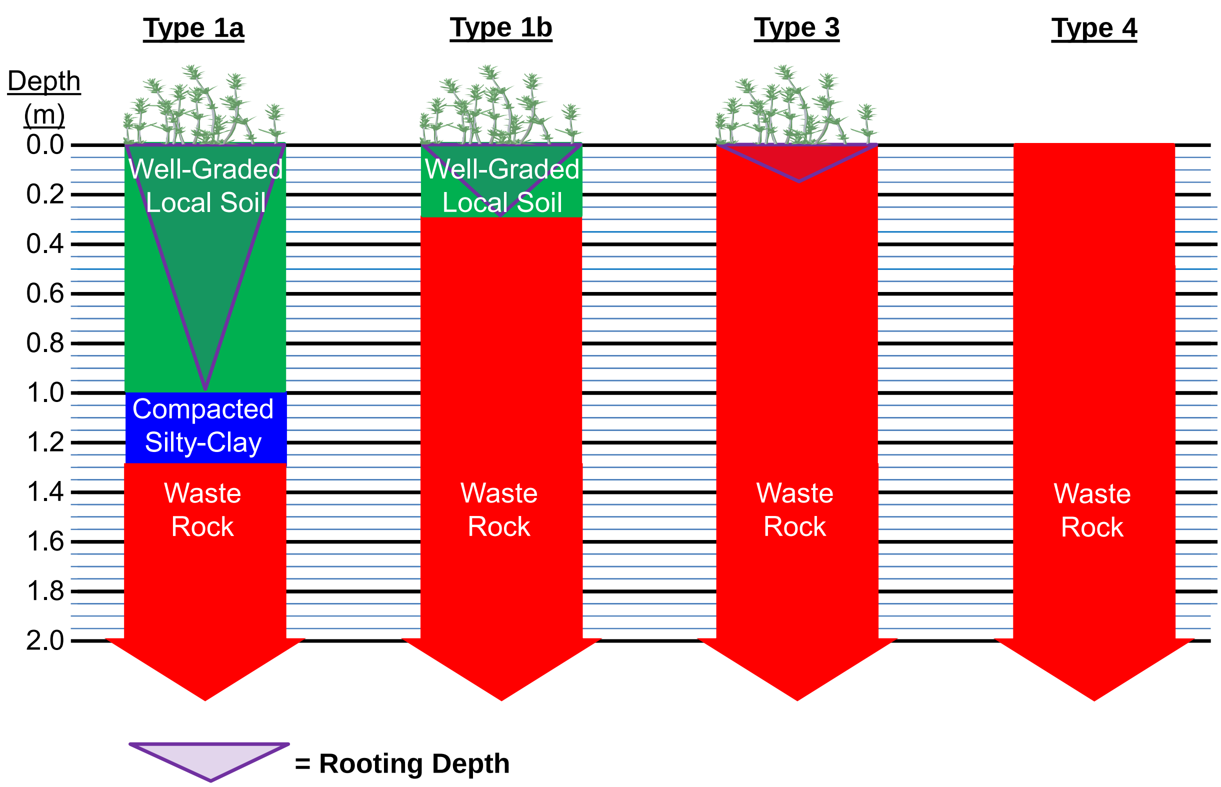

Figure 1 Schematic of four reclamation scenarios modelled for possible closure of WRSAs.

OKC was provided with particle size distribution (PSD) data for various potential borrow materials for cover system construction as well as waste rock materials. For the current SPA modelling program, OKC focused on PSD data for soil samples collected at the Husky site. OKC developed estimates of hydraulic material properties for a growth medium layer based on the following PSD, with the range of percentages for each particle size provide in parentheses:

- Gravel, cobbles, and boulders: 29% (13 to 36%);
- Sand: 32% (26 to 40%);
- Silt: 30% (18 to 40%); and
- Clay: 9% (6 to 14%).

A growth medium layer with the above average PSD is ideal for supporting plant growth as well as storing and releasing meteoric waters back to the atmosphere. However, a growth medium layer with a 39% fines content (i.e. material finer than 0.075 mm) could be susceptible to higher, and potentially unacceptable, rates of erosion and frost action, both of which could result in higher rates of net percolation. Frost action may not be an issue given the drained nature of most WRSAs and thus limited water supply in the subsurface to generate frost action. Nonetheless, some caution is required when evaluating potential borrow sources within or near the KHSD site for WRSA cover system construction; ideally, growth medium layers would consist of well-graded glacial till material with a fines content in the range of 20 to 35%.

Key Inputs and Assumptions:

The inputs into a SPA model can be divided into five categories; namely, geometry, lower and edge boundary conditions, initial conditions, material properties, and upper boundary conditions.

All the models simulated a one-metre-wide column of waste rock overlain with one of the four reclamation scenarios described above. The base of the waste rock was simulated as a unit hydraulic gradient, with the edges of the models simulated as no flow boundaries (i.e. no lateral flows) to simulate a one-dimensional (1D) system. The initial model profiles were started at a constant pressure head of -2 m. Waste rock below a depth of 1.5 m was set at a constant temperature of 2°C so that permafrost would not form in the models. It is presumed that discontinuous permafrost exists at some locations on the KHSD site, particularly at higher elevations and for north-facing slopes; hence, net percolation rates estimated by the SPA models and presented herein are conservative for areas with discontinuous permafrost.

Three materials were defined for SPA modelling; namely, waste rock, well-graded local soil, and compacted silty-clay soil. The required properties or functions for each material are as follows:

- water retention curve (WRC - suction versus volumetric water content);
- hydraulic conductivity function (k-function - suction versus hydraulic conductivity);
- thermal conductivity function (volumetric water content versus thermal conductivity); and
- volumetric specific heat function (volumetric water content versus volumetric specific heat).

Hydraulic properties (i.e. WRCs and k-functions) for each of these materials were estimated by comparing previously measured PSDs and other geotechnical properties to materials in the SoilVision[6] and OKC material databases with similar geotechnical and known hydraulic properties. The hydraulic properties from the databases were compared with those previously measured for each material and found to be similar. Each material was then defined using the van Genuchten[7] or Durner[8] method. A summary of the hydraulic properties estimated for the three materials is provided in Table 1. The thermal properties were estimated using modules included in the VADOSE/W software.

[6] SoilVision Systems Ltd., 2005. Software. SoilVision 4.23. www.soilvision.com
[7] van Genuchten, M. Th., A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Sci. Soc. Am. J., 44, 892-898, 1980.
[8] Durner, W., Hydraulic conductivity estimation for soils with heterogeneous pore structure, Water Resour. Res., 32(9), 211-223, 1994.

Table 1
Summary of key properties for materials included in the SPA modelling program.

Material Type	k_{sat} (cm/s)	Porosity (m^3/m^3)	Residual VWC (m^3/m^3)	Van Genuchten or Durner parameters							
				w1	a1 (cm^{-1})	n1	m1	w2	a2 (cm^{-1})	n2	m2
Waste rock	$1.0X10^{-1}$	0.28	0.0	0.5	1.0	1.35	0.26	0.5	20	4.0	0.75
Well-graded local soil	$5.0X10^{-5}$	0.33	0.0	-	$3X10^{-4}$	1.25	0.20	-	-	-	-
Compacted silty-clay	$1.0X10^{-7}$	0.40	.0.0	-	$1X10^{-4}$	1.15	0.13	-	-	-	-

The upper boundary conditions can be divided into two parts: climate and vegetation. To define the climate for KHSD, a synthetic 80-year climate database was developed by comparing measurements from the Galena Hill weather station (also referred to as the Calumet weather station) to measurements taken at the Environment Canada weather station in Mayo, YT, between 2007 and 2012. Based on this comparison, the Mayo climate data from 1934 to 2012 were adjusted to represent conditions at Galena Hill. Climate data from Galena Hill were also compared to the Valley Tailings and Flame and Moth weather stations to determine additional variations required to account for elevation. These comparisons indicated that only precipitation needed to be varied with elevation using the linear relationship provided in the conceptual model section. Finally, potential evaporation rates were estimated for three slope aspects (i.e. north, south, and middle aspect). Table 2 provides the monthly average climate estimated for the KHSD site.

Table 2
Monthly average values for the 80-year synthetic climate database developed for the KHSD site.

Month	Temperature (°C)		RH (%)	Precipitation (mm) for each Elevation (masl)			Wind Speed (m/s)	Potential Evapotranspiration (mm) for each Aspect		
	High	Low	%	750	1,000	1,250		North	Middle	South
January	-22	-26	80	27	32	37	1.6	0	0	0
February	-16	-21	79	23	27	31	1.8	0	0	0
March	-8	-15	76	21	24	28	2.3	0	0	0
April	2	-3	73	19	23	26	2.3	0	5	10
May	10	4	64	29	34	40	2.2	30	70	100
June	16	9	70	41	49	56	1.8	40	95	140
July	17	10	73	51	60	69	1.8	40	100	150
August	14	7	77	48	56	65	1.8	30	70	105
September	7	2	79	39	46	53	1.6	10	30	50
October	-3	-5	84	34	40	46	1.6	0	0	5
November	-15	-17	85	30	35	41	1.6	0	0	0
December	-21	-24	83	28	34	39	1.0	0	0	0
Annual	*-1*	*-7*	*77*	*390*	*460*	*530*	*1.8*	*150*	*370*	*560*

Vegetation was simulated as grasses and shrubs, with each growing season starting seven days following spring-melt and ending when daily low air temperatures consistently stay below 0°C. The vegetation was simulated as having a rooting depth the thickness of the well-graded local soil layer or 0.15 cm for the bare waste rock scenario. The vegetation was estimated to have a maximum ground cover of 50%. Vegetation was assumed to have its transpiration rate limited when the suction within the growth material increased above 100 kPa. Transpiration was estimated to cease when suction conditions in the growth material increased above 1,500 kPa.

Key Modelling Results:

Tables 3 provides average annual, long-term water balance fluxes for all the model scenarios completed for this project. All modelling completed for this project used the computer modelling program VADOSE/W[9]. The estimated net percolation rates are summarized in Figure 2. It must be emphasized that the values provided in Table 3 and Figure 2 are averages; the components of the water balance will vary greatly from year-to-year, and during any given year. For example, RO averages 175 mm/yr for the Type 1a cover system at 1,000 masl, but ranges from 40 to 360 mm/yr with most of the RO occurring during spring-melt.

Practical Construction Issues for Consideration:

The current stage of this project is to provide conceptual or indicative-level design details for reclamation of the KHSD WRSAs. However, based on OKC's experience with cover system design and performance in cold regions, the following guidelines are provided for consideration as the state of the WRSA closure cover system designs progresses:

- Avoid north-facing slopes to the greatest extent possible due to higher available waters for net percolation.
- Different moisture regimes will exist on south and north slopes; therefore, use natural analogues at site to determine revegetation plans for different slope aspects.
- North slopes should be steeper than south slopes to promote additional runoff and thus reduce net percolation; however, this needs to be balanced against the potential for soil erosion.
- Drainage channels, particularly bench / lateral channels, should be avoided on north slopes to the greatest extent possible due to higher potential for glaciation (this is the formation of ice features in a drainage course as defined in MEND (2012)).
- Plateau catchments should not drain to the north to avoid potential effects of glaciation.
- Coarser-textured materials are preferred on north slopes to reduce potential for solifluction (i.e. silts and clays are more prone to solifluction due to higher water retention).

[9] Geo-Slope International Ltd. 2014. GeoStudio 2012. Version 8.14.1.10087. Online. www.geo-slope.com.

Table 3
Summary of average annual water balance fluxes for 80-year model scenarios.

Aspect	Elevation / PPT (masl / mm/yr)	Reclamation Scenario	Water Balance Flux as Percent of PPT (mm/yr in brackets)			
			Sub	RO	AET	NP
North	750 / 390	1a	5% (60)	30% (117)	33% (130)	21% (83)
		1b	16% (61)	5% (21)	33% (128)	46% (180)
		3	16% (61)	1% (4)	32% (126)	51% (199)
		4	16% (61)	1% (4)	27% (105)	56% (220)
	1,000 / 460	1a	14% (62)	38% (175)	27% (125)	21% (98)
		1b	14% (62)	4% (20)	27% (124)	55% (254)
		3	14% (62)	1% (4)	26% (122)	59% (272)
		4	13% (61)	1% (3)	22% (103)	64% (293)
	1,250 / 530	1a	12% (61)	45% (241)	22% (119)	20% (109)
		1b	12% (62)	4% (20)	22% (118)	62% (329)
		3	12% (62)	1% (4)	22% (116)	66% (347)
		4	12% (62)	1% (4)	19% (100)	69% (364)
Middle	750 / 390	1a	16% (61)	9% (35)	73% (283)	3% (12)
		1b	16% (61)	3% (10)	67% (261)	15% (58)
		3	16% (61)	1% (3)	57% (221)	27% (105)
		4	16% (61)	1% (3)	51% (199)	33% (128)
	1,000 / 460	1a	14% (62)	18% (84)	62% (285)	6% (29)
		1b	14% (62)	3% (13)	58% (269)	25% (117)
		3	14% (62)	1% (3)	50% (228)	36% (167)
		4	14% (62)	1% (3)	44% (204)	41% (191)
	1,250 / 530	1a	12% (63)	27% (141)	53% (278)	9% (48)
		1b	12% (62)	3% (15)	50% (266)	35% (186)
		3	12% (62)	1% (4)	43% (230)	44% (234)
		4	12% (62)	1% (4)	39% (206)	49% (258)
South	750 / 390	1a	16% (61)	5% (19)	78% (306)	1% (4)
		1b	16% (61)	2% (10)	73% (284)	9% (35)
		3	16% (61)	1% (3)	63% (244)	21% (82)
		4	16% (61)	1% (3)	57% (224)	26% (103)
	1,000 / 460	1a	14% (62)	10% (46)	74% (341)	2% (11)
		1b	14% (62)	2% (10)	67% (305)	18% (83)
		3	14% (62)	1% (3)	56% (257)	30% (138)
		4	14% (62)	1% (3)	51% (236)	35% (159)
	1,250 / 530	1a	12% (62)	18% (95)	67% (356)	3% (16)
		1b	12% (62)	2% (10)	61% (322)	25% (135)
		3	12% (62)	1% (4)	50% (265)	38% (199)
		4	12% (62)	1% (3)	46% (244)	42% (220)
Conceptual Model*			10% - 15%	0% - 20%	40% - 60%	5% - 50%

*Conceptual model is based on general water balances for the area; hence, more comparable to middle aspects.

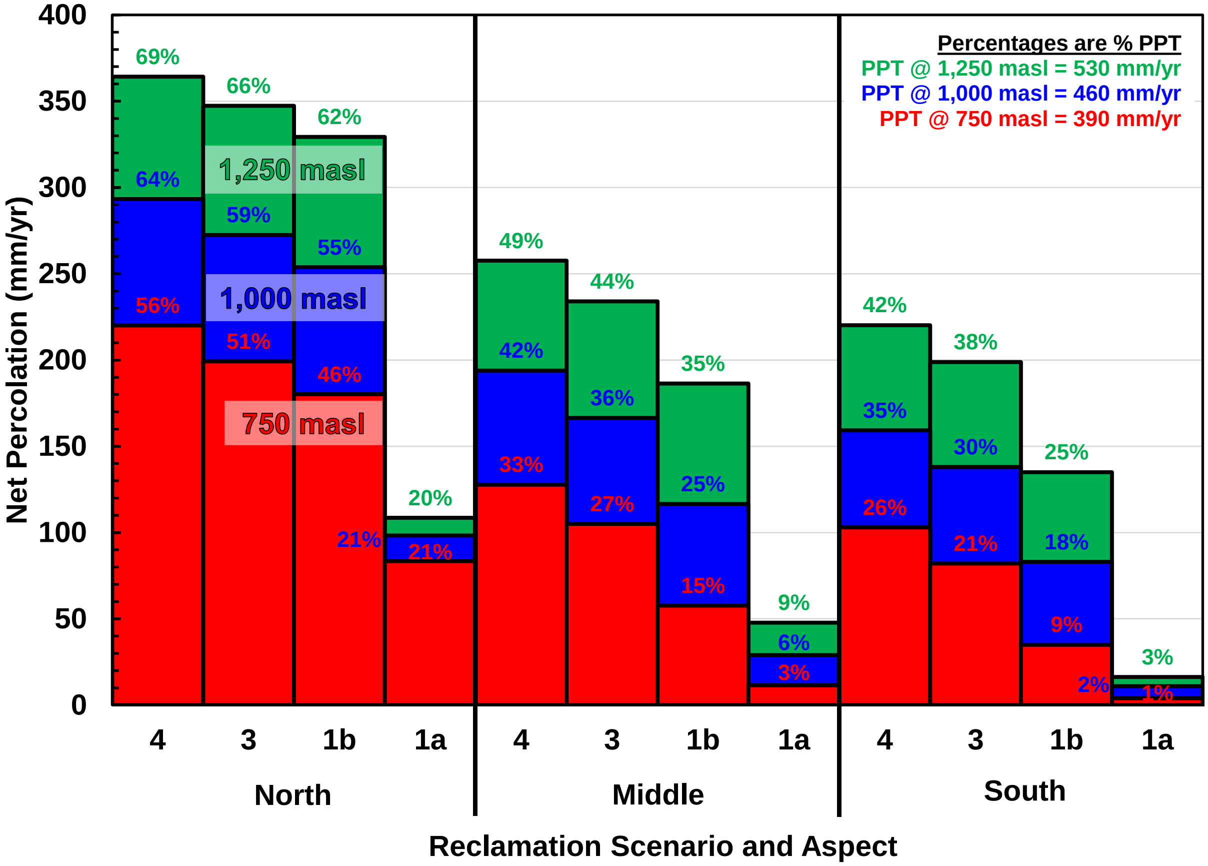

Figure 2 Annual average net percolation rates estimated for range of reclamation scenarios, elevations, and slope aspects.

The following issues should be taken into consideration when developing final landforms for larger WRSAs:

- The maximum slope recommended to support construction and long-term sustainability of a barrier layer such as a compacted silty-clay layer is 3H:1V.
- Slopes to support a simpler cover system can be steeper (e.g. range of 2H:1V to 2.5H:1V), but the potential for soil erosion to occur should be considered, which is generally a function of slope length, vegetation type and time to establishment, rainfall intensities, and texture of surface material.
- Concave slopes are preferred over linear slopes, and most definitely over a benched-landform slope profile.
- Upper slopes can be steeper and coarser-textured, while lower slopes can be flatter and finer-textured, if material availability / balancing requires this flexibility.
- A cover system profile can be thinner in upper slopes, but must be thick enough to support growth of the anticipated climax vegetation species.
- Plateau surface waters must never be allowed to discharge over the crest of a slope without a properly engineered channel.
- A common location for failure of drainage channels is where plateau channels transition to slope channels; an intermediate-slope is recommended at these locations with additional riprap protection.

Closure:

Thank you for the opportunity to assist AEG with closure planning at the KHSD site. Please do not hesitate to contact the undersigned should you have any questions or comments.

Sincerely yours,

Brian Ayres, M.Sc., P.Eng.
Senior Geotechnical Engineer / Chief Operating Officer

cc: Linda Broughton – Alexco Environmental Group
Robert Shurniak and Mike O'Kane – O'Kane Consultants Inc.

APPENDIX 1.5

NATURAL ATTENUATION EVALUATION SUMMARY REPORT

DRAFT REPORT

Natural Attenuation Evaluation Summary Report

United Keno Hill Mines
Elsa, YT

Prepared for:

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Project No: 102003

November 2013

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1 INTRODUCTION

1.1 REPORT OBJECTIVES

The Natural Attenuation Project is a multi-disciplinary, multi-year scientific study that has been developed and implemented to support the Elsa Reclamation and Development Company (ERDC) closure obligations at the Keno Hill Silver District (KHSD) near Elsa, Yukon Territory (YT). This Summary Report was written to provide a concise summary and point of reference for project-related activities conducted since 2009. This report relies on, and condenses, the significant amount of scientific work done by ERDC and Interralogic in collaboration with the Edmonton Waste Management Centre of Excellence, Sherriff Environmental, and Queen's University, as well as previous and parallel work conducted in the area. This report summarizes and brings together the wide variety of data from the diverse disciplines addressed and then focuses conclusions on issues and findings most relevant to closure issues that will be faced during the options evaluation and selection process.

1.2 PROJECT OBJECTIVES

The purpose of the Natural Attenuation Project is to evaluate the technical suitability of a managed natural attenuation approach as a closure option, or as part of a closure option, for the No Cash Creek mines (No Cash 500, Ruby, and Bermingham), Husky SW, Sadie Ladue, and Silver King adit discharges. The option selection process will evaluate the other factors beyond technical feasibility that may affect the use of natural attenuation processes in the closure of mine components in the KHSD. The technical suitability of natural attenuation as a closure option depends on meeting criteria that were developed in consultation with interested parties (team) including:

- ERDC/Alexco Resource Corp.
- AANDC
- Environment Canada
- First Nation of Na-Cho Nyak Dunn (FNNND)
- Yukon Government

Plans for field work were developed and initiated in 2010 and are currently ongoing. The natural attenuation evaluation was conducted through the following iterative/phased approach:

- Evaluation of available historical water quality data for the target sites

- Development and execution of initial phase of field and laboratory activities
- Interpretation of data and presentation of results and conclusions to team members
- Incorporation of team input to develop the next season's field and laboratory activities
- Report development to inform the closure options process.

The technical objectives of natural attenuation relate to the observed decrease in metals (specifically zinc and cadmium) concentrations in adit discharge water, as it flows along the stream course. The observations along No Cash Creek indicated significant attenuation of zinc and cadmium in a relatively short stream reach. The technical goal was to understand the nature of the natural attenuation mechanisms, its seasonality, if there were any environmental constraints or limitations, the sustainability of the processes, and its reliability as part of a potential closure option for the target areas. The technical tasks involved work by field samplers, ecologists, hydrologists, geochemists, mineralogists, microbiologists, water treatment experts, engineers, and others. These technical tasks are described in the specific target area sections below.

1.3 PROJECT OVERVIEW

Reclamation and closure studies of historical United Keno Hill Mines (UKHM) facilities in the KHSD are ongoing. Detailed descriptions of the current environmental issues in the KHSD, as well as climate and general site conditions are provided in ERDC (2006) and Access (2011). The geology is summarized in Cathro (2006) and Interralogic (2012a) which also contains a list of references with more detailed KHSD geology. The KHSD contains over 65 silver ore deposits and prospects that were first mined in 1913. Most mining operations took place on the north-facing slopes of Galena Hill and also in areas to the east on Keno Hill (Figure 1). Both the Galena Hill and Keno Hill mines are within the South McQuesten River watershed. Many of the smaller watercourses, including those draining the northwest side of Galena Hill, terminate in wetlands in the South McQuesten River valley prior to reaching the South McQuesten River (Figure 1). Elevated metal concentrations occur in surface waters and sediments of many of the drainages associated with past mining operations (Kwong et al., 1994; 1997).

There are ten adits/shafts in the KHSD that are known point sources of metal loads to the surface environment. These are listed below with the common name in parentheses:

- Silver King 100 (Silver King Adit)
- Galkeno 300
- Galkeno 900
- No Cash 500 (No Cash Adit)
- Bermingham 200
- Ruby 400
- Onek 400
- Sadie Ladue 600 (Sadie Ladue Adit)
- Keno 700
- Husky SW (Husky SW Shaft[1])

Zinc and cadmium are the metals of concern in the adit discharges of this area, although variable concentrations of manganese and iron are also present in some adit discharges.

The average adit outflows and selected metal concentrations of the 10 known point source adits in the KHSD are summarized in Table 1. Of these metals, only zinc and cadmium have been identified as contaminants of concern in the KHSD (Minnow 2013a). Six of these adits, Silver King 100, No Cash 500, Bermingham 200, Ruby 400, Husky SW Shaft, and Sadie Ladue 600, are located upstream of areas with the potential to attenuate chemical mass in the adit discharge through natural processes.

The mechanisms of natural attenuation have been evaluated and described by Interralogic (2010, 2012a) specifically for the No Cash Adit discharge, which is a significant zinc source in the KHSD (Table 1). For the purpose of this investigation, the Ruby and Bermingham adits are included under the No Cash description because they drain into No Cash Creek (NCC) and become part of its combined flow. The No Cash 500 adit provides the majority of zinc and cadmium to the No Cash bog, although the Bermingham adit is a significant secondary source of cadmium (Table 1). The remaining adits, specifically Galkeno 300, Onek 400, Galkeno 900,

[1] While Husky SW Shaft is technically a shaft, it passively drains like an adit and will be included in the discussion as an adit for the purpose of this report.

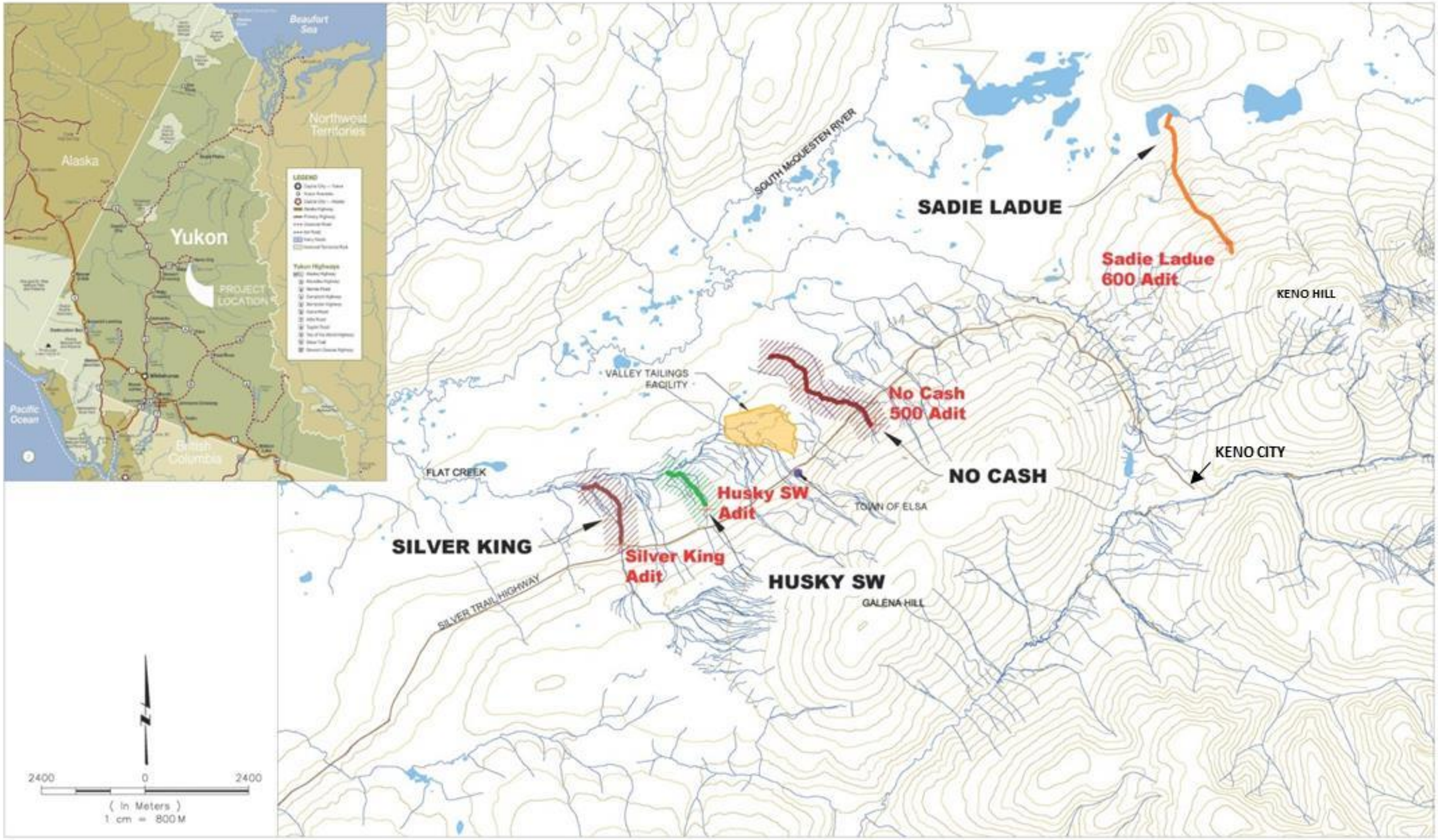
and Keno 700, are not suitable for natural attenuation as a closure option because of overly-elevated zinc/cadmium concentrations, unfavorable hydrologic flow characteristics, and/or the adit discharge does not flow through wetlands where attenuation processes are most effective. The Galkeno 300, Galkeno 900, and Silver King 100 adit discharges are currently collected and actively treated to reduce metal loads. According to the most recent water treatment records, the water treatment systems remove about 80 percent of the total zinc load in the KHSD.

Table 1 - Average adit flows and metals concentrations at the discharging adits[a]

Parameter		Galkeno 300	Onek 400[b]	**No Cash 500[c]**	Galkeno 900	Keno 700	**Silver King 100**	Sadie Ladue 600	**Husky SW**	Bermingham	Ruby
Average Adit Flow (2004 – 2010) (L/s)		9.2	2.3	**5.5**	3.1	3.4	**5.6**	7.6	**0.4**	2.0	1.0
Zn	Concentration (mg/L)	125	85	**13.2**	6	3.5	**1.65**	0.9	**1.3**	3.7	1.5
	Load (kg/yr)	36266	6165	**2260**	587	375	**291**	216	**16**	231	38
	Percent of Total Load	78.1%	13.3%	**4.9%**	1.3%	0.8%	**0.6%**	0.5%	**0.0%**	0.5%	0.1%
Al[d]	Concentration (mg/L)	0.11	0.02	**0.09**	0.02	0.03	**0.19**	0.08	**0.17**	0.09	0.28
	Load (kg/yr)	32	2	**20**	2	3	**34**	19	**2**	7	7
	Percent of Total Load	25.2%	1.3%	**15.5%**	1.6%	2.2%	**26.5%**	15.1%	**1.7%**	5.7%	5.3%
As	Concentration (mg/L)	0.160	0.058	**0.015**	0.087	0.034	**0.079**	0.004	**0.018**	0.043	0.049
	Load (kg/yr)	46.4	4.2	**2.7**	8.5	3.6	**14.0**	0.8	**0.2**	2.2	1.3
	Percent of Total Load	55.2%	5.0%	**3.2%**	10.1%	4.3%	**16.6%**	1.0%	**0.3%**	2.7%	1.5%
Cd	Concentration (mg/L)	0.330	1.671	**0.141**	0.001	0.013	**0.010**	0.004	**0.014**	0.182	0.018
	Load (kg/yr)	96	121	**26**	0.1	1.4	**2**	1.1	**0**	13	0.5
	Percent of Total Load	36.7%	46.4%	**10.1%**	0.1%	0.5%	**0.7%**	0.4%	**0.1%**	4.9%	0.2%
Cr[d]	Concentration (mg/L)	0.0017	0.0008	**0.0007**	0.0014	0.0020	**0.0014**	0.0007	**0.0010**	0.0006	0.0009
	Load (kg/yr)	0.49	0.05	**0.12**	0.14	0.21	**0.25**	0.17	**0.01**	0.04	0.03
	Percent of Total Load	32.5%	3.6%	**8.2%**	9.0%	14.1%	**16.3%**	11.0%	**0.8%**	2.6%	1.7%
Cu[d]	Concentration (mg/L)	0.012	0.018	**0.032**	0.002	0.002	**0.025**	0.004	**0.005**	0.006	0.005
	Load (kg/yr)	3.5	1.3	**5.5**	0.2	0.2	**4.4**	1.0	**0.1**	0.6	0.1
	Percent of Total Load	20.6%	7.8%	**32.5%**	0.9%	1.4%	**26.2%**	5.8%	**0.4%**	3.6%	0.8%
Mn	Concentration (mg/L)	154.00	8.45	**10.57**	17.90	0.17	**2.90**	0.04	**5.20**	1.30	3.00
	Load (kg/yr)	44680	613	**1956**	1750	18	**512**	11	**66**	80	64
	Percent of Total Load	89.8%	1.2%	**3.9%**	3.5%	0.0%	**1.0%**	0.0%	**0.1%**	0.2%	0.1%
Pb	Concentration (mg/L)	0.033	0.008	**0.011**	0.002	0.005	**0.001**	0.008	**0.011**	0.022	0.034
	Load (kg/yr)	9.6	0.6	**1.9**	0.2	0.5	**0.2**	1.8	**0.1**	1.8	0.1
	Percent of Total Load	56.7%	3.5%	**11.4%**	1.3%	2.9%	**1.5%**	10.9%	**0.8%**	10.4%	0.5%

[a] Compiled from flow rates and metals concentrations measured by Alexco personnel on behalf of ERDC. Gray shading indicates adits with water treatment systems; **BOLD** indicates potential natural attenuation site.
[b] Assumes an average flow rate of 2.3 L/s although this value varies significantly seasonally.
[c] "Non-detects" included in calculations at one-half the detection limit.

Figure 1 - Site Map and Attenuation Area Location



1.4 NATURAL ATTENUATION TARGET AREAS

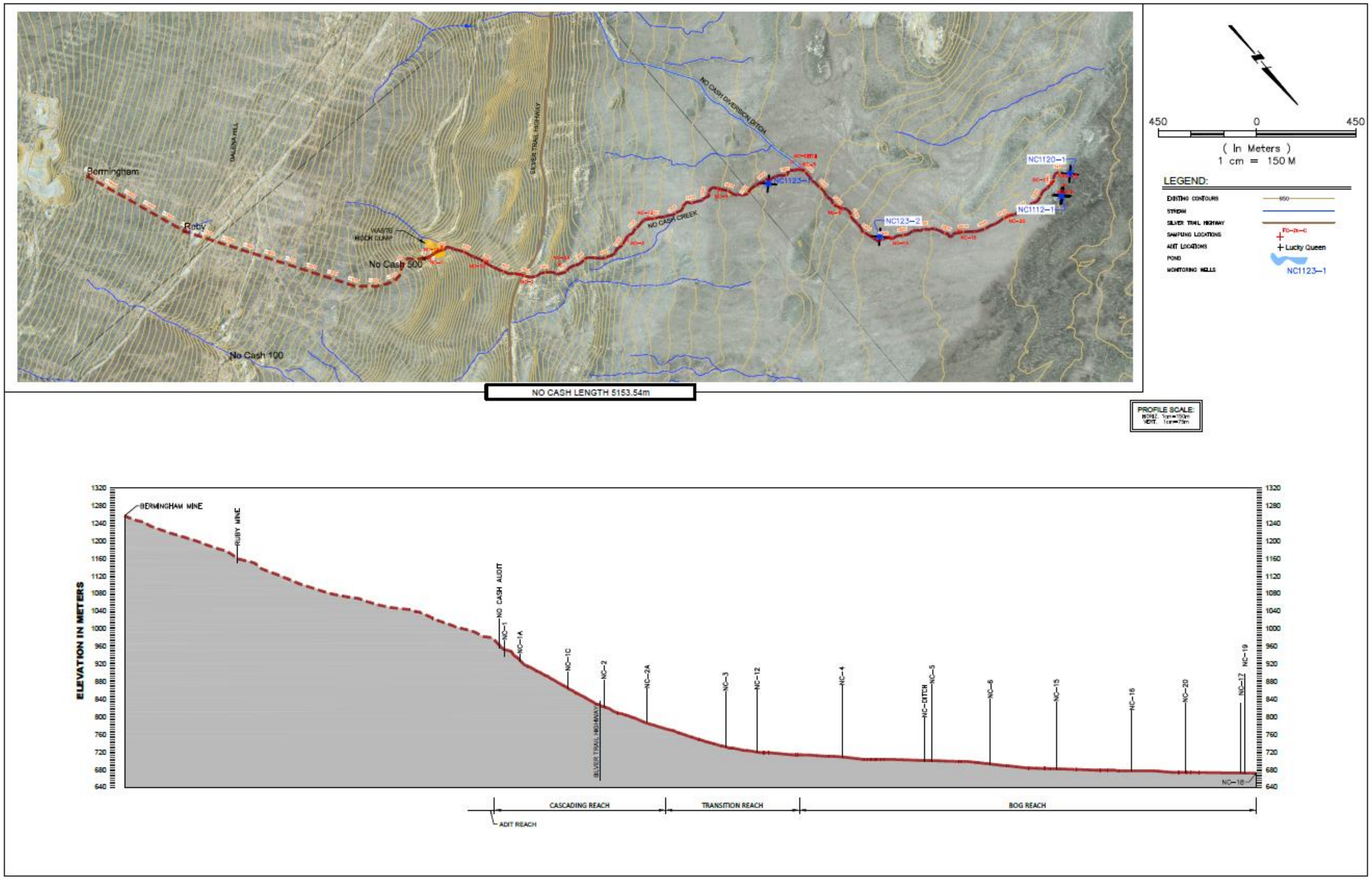
The areas originally targeted for evaluation for natural attenuation were NCC, Husky SW, Silver King, and Sadie Ladue. Each of these had low to moderate zinc mass loading, low to moderate flow, had a hillside (i.e., faster moving) reach where aeration could occur, and also flowed through peaty areas. These criteria indicated the potential for natural attenuation similar to that observed at NCC and were therefore included for evaluation. The Sadie Ladue adit, located on the northwest flank of Keno Hill, was removed for further consideration after initial surveys in 2010 indicated significant quantities of dispersed tailings materials were distributed along much of the length of the stream both within and outside the channel (Interralogic, 2011a). This distributed source of metals and the initial water quality data indicated no significant natural attenuation of metals was occurring in this drainage, or, if natural attenuation was taking place, it was being masked by ongoing mass loading by the dispersed tailings. Sadie Ladue is not discussed further in this report although all data are presented in Interralogic (2012a).

NCC, Husky SW, and Silver King areas all drain historical mine adits located on the northwest flank of Galena Hill near Elsa, and flow down Galena Hill toward the S. McQuesten River Valley (Figure 1). Distances, elevations and water sampling locations are marked on the figures for each watercourse.

1.4.1 NO CASH CREEK AREA

The NCC drainage is located on the northwest side of Galena Hill (Figure 1). Figure 2 shows a plan view and profile section of the drainage from the adit to the terminal pond. NCC is a natural stream that receives water from the historic No Cash, Ruby, and Bermingham mines via the No Cash 500, Ruby 400, and Bermingham 200 level adits, respectively. At each adit, water is discharged directly from the adit and additionally through a culvert from the adit onto the surrounding waste rock (No Cash 500 example shown in Figure 3). The discharge water flows across a waste rock bench and cascades down the side of the waste rock and enters NCC about 0.5 km downstream of the natural headwater source of NCC (Figure 2). Measured flow rates at the surface water monitoring location KV21, where NCC passes the Silver Trail Highway, have ranged from 3 to 15 L/s, based on sampling conducted during July of 2007, 2008, and 2009 (Access 2011).

Figure 2 - No Cash Plan and Profile



Downstream of the confluence of the 500-adit discharge and NCC (which is carrying discharge from the Ruby and Bermingham mines), the channel flows in a northwesterly direction, crossing the Silver Trail Highway in a culvert, and through boreal forest on Galena Hill (Figure 4). It then intersects the No Cash Diversion Ditch and then runs through a poorly drained valley containing extensive areas of heavily-vegetated peat bog/marsh. A series of other seeps and disconnected streams drain Galena Hill parallel to NCC, toward a large peat bog in the South McQuesten River valley (Figure 5).

NCC is not a direct tributary of any other streams but instead terminates in a small pond in a low lying boggy area of the valley approximately 2 km south of the South McQuesten River. Much of the NCC drainage and surrounding wetland area is underlain by thick deposits of peat (up to just over 3 m thickness observed in NCC drill holes), glacial-related sediments and discontinuous permafrost of variable extent and thickness. While there are seeps along the south and east sides of the South McQuesten River that may be down gradient of the terminus of NCC, there is no surface connection between the two areas due to a topographic high north of the terminal pond of NCC. The seep survey of the South McQuesten River did not show any elevated mine-related constituents to be present on the south bank seeps (Interralogic, 2010).

Adit water from the No Cash mine contains elevated levels of metals, namely cadmium, manganese, and zinc, as well as sulphate (Kwong et al. 1994; 1997; MERG 2000; ERDC 2006). The sources of these constituents are oxidative dissolution of metal sulphide minerals and dissolution of metal carbonate and silicate minerals associated with mineralized zones of the No Cash mine. Oxidative dissolution of sulphide minerals has not resulted in acid mine drainage from the No Cash Adit due to high levels of carbonate (mostly calcite) in the major lithologic units that host the mineralization (Kwong et al. 1994; 1997). Major lithologic units in this mine include the Keno Hill Quartzite (Mississippian Era), and Earn Group metavolcanics and metasediments (Devonian-Mississippian Eras). Kwong et al. (1994) reports net neutralization potentials (NNP) ranging from 105 to 934 kg $CaCO_3$/tonne for these rock types. Rock types with NNPs in that range have a very low probability of generating acid rock drainage; except possibly in localized areas of high sulphide mineral content. Water flowing directly from the adit and upper NCC has pH values between 7 and 8.3, and alkalinity measurements of 85 to 286 mg/L $CaCO_3$ equivalent. These high alkalinities are indicative of a strong influence of carbonate mineralogy on water chemistry (Kwong et al.1994; 1997; MERG 2000).

Figure 3 - Sampling at No Cash Adit - October, 2010

Figure 4 - No Cash Creek Cascading Reach

Figure 5 - No Cash Bog

1.4.2 HUSKY SW AREA

The Husky SW site (Figure 6) conditions are similar to those of the No Cash drainage, where natural attenuation processes are effective for improving water quality. The Husky SW mine site comprises a group of historical structures, a waste rock pile, a low-grade stockpile, and fill material. Seepage from the shaft is conveyed beneath the fill material to a dilapidated crib structure (Figure 7) from which water flows into a narrow surface drainage (Figure 8). From this point, the discharge flows northward down Galena Hill toward Flat Creek similar to that of NCC except: 1) the high-energy, cascading reach present at No Cash does not exist downstream of the Husky SW area and, 2) the Husky SW drainage connects with Flat Creek (Figure 9), whereas NCC ends at a terminal pond. However, the extensive forested slope and peat bog area along Husky Creek (Figure 10) are similar to the No Cash bog area.

The water quality of the Husky SW adit seepage is similar to that of the No Cash adit, with elevated zinc, manganese, cadmium, and sulfate. However, zinc and cadmium concentrations are an order of magnitude lower at Husky SW (Table 1). The water is circumneutral with a pH between 7.5 and 8.0 and alkalinity between 250 and 300 mg/L as $CaCO_3$. So while other metals and major ion concentrations are similar to those observed at No Cash, the flow from Husky SW adit is about an order of magnitude lower, resulting in an overall much lower mass loading from Husky SW.

Figure 6 - Husky SW Plan and Profile

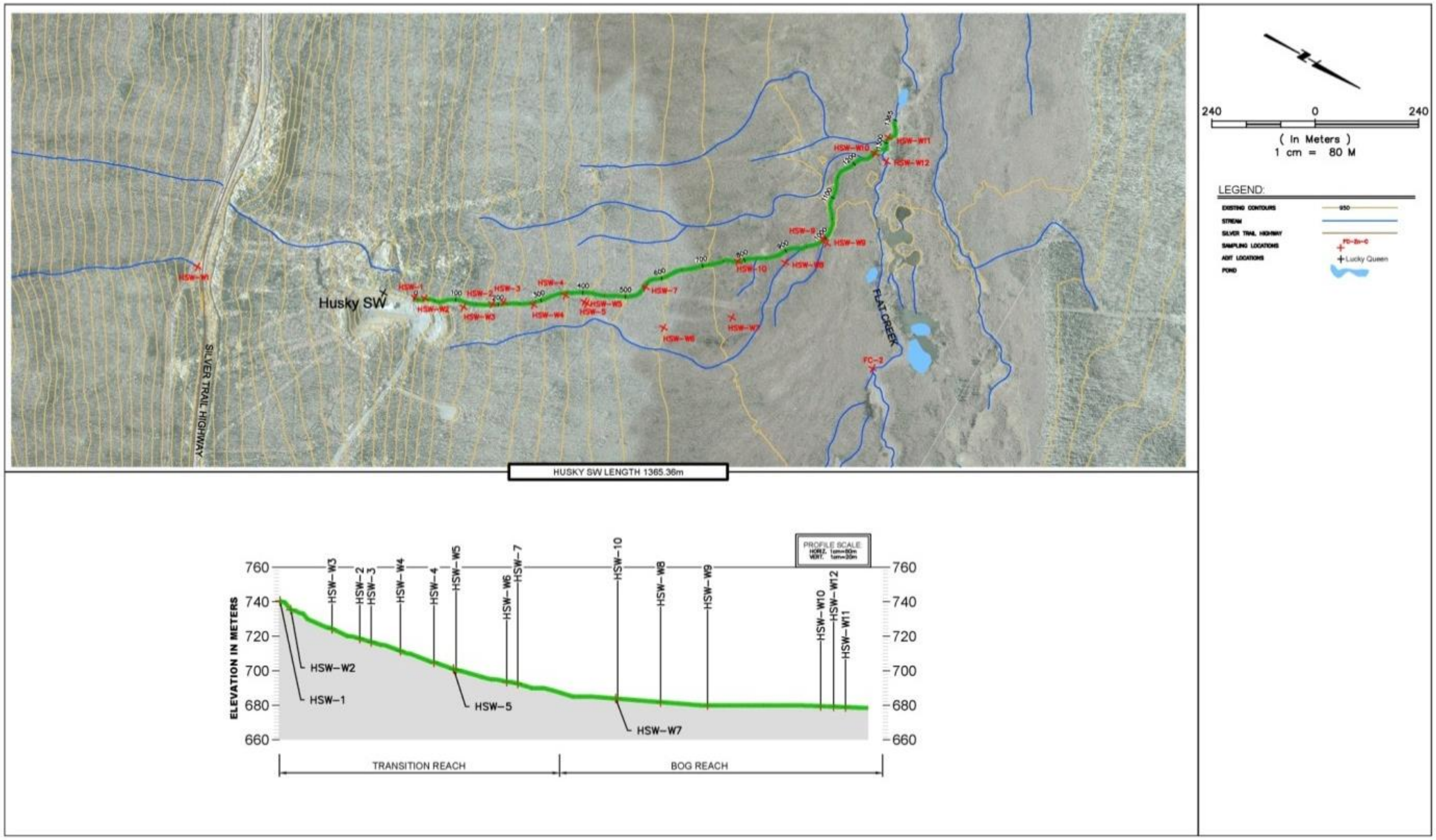


Figure 7 - Husky SW Crib Structure and Flow

Figure 8 - Sampling the Transition Reach of Husky SW

Figure 9 - Intersection of Husky SW and Flat Creek Drainages

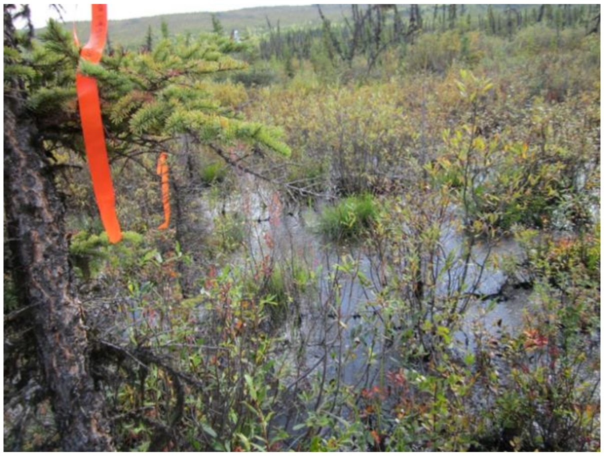


Figure 10 - Husky SW Bog Reach

1.4.3 SILVER KING AREA

The Silver King mine is located west of Elsa about 4 km where the Silver Trail Highway crosses Galena Creek (Figure 11). The mine workings straddle the highway, with the open pit, the 75-level adit, vents and other structures on the south side of the highway; and waste rock (Figure 12), the 100-level adit, various historical structures, lime treatment system/ponds, and the treatment plant outflow on the north side of the highway. The treated water is discharged to ground surface north of the treatment area and west of Galena Creek.

The Silver King 100 adit and drainage has site conditions that are similar to those at the Husky SW drainage where natural attenuation reduces metal concentrations along the stream reach. Similar to Husky SW, the mine is lower on Galena Hill and has no cascading section, but is located in the transition area between the cascading and bog reaches. Flow from the Silver King Mine is treated, and currently discharges at the base of the northernmost waste rock dump into forested and permafrost ground. The treated discharge then flows parallel to Galena Creek in a narrow channel that exhibits thermokarst features, particularly in the autumn when flow is often observed percolating up out of the ground and subsequently disappearing again (Figure 13). The treated discharge stream then intermingles with a complex of braided channels associated with Flat Creek (Figure 14).

Nine samples were collected along the treatment system decant discharge stream downslope of Silver King Adit (Access 2008). Laboratory results from these samples suggested that natural attenuation was occurring along the flow path as shown by further reductions in metals concentration compared to what was achieved by the active lime treatment system, but also indicated areas of complex flow paths and hydrogeochemical processes were occurring near the confluence of Galena Creek and Flat Creek. A more thorough investigation of water quality trends and soils characterization was conducted to develop a baseline dataset. The following sections describe the data collection and results, followed by an assessment of how conditions in the Silver King area compare to the NCC area as a potential natural attenuation area.

The water quality of the Silver King adit seepage is similar to that of No Cash adit, with elevated zinc, manganese, cadmium, and sulfate but with lower zinc, manganese and cadmium concentrations at Silver King. The water is circumneutral with a pH between 7.5 and 8.0 and alkalinity between 250 and 300 mg/L as $CaCO_3$. The flow rate is similar to the No Cash adit at around 5 – 6 L/s.

Galena Creek chemistry is generally good quality above the mine but reflects the presence of the mine workings and waste rock adjacent to the Creek as it passes by. Relatively small increases in metals concentrations such as zinc and cadmium are accompanied by small increases in sulfate in the creek water downstream of the mine. pH is circumneutral and alkalinity present at 50 to 250 mg/L as $CaCO_3$.

Figure 11 - Silver King Plan and Profile

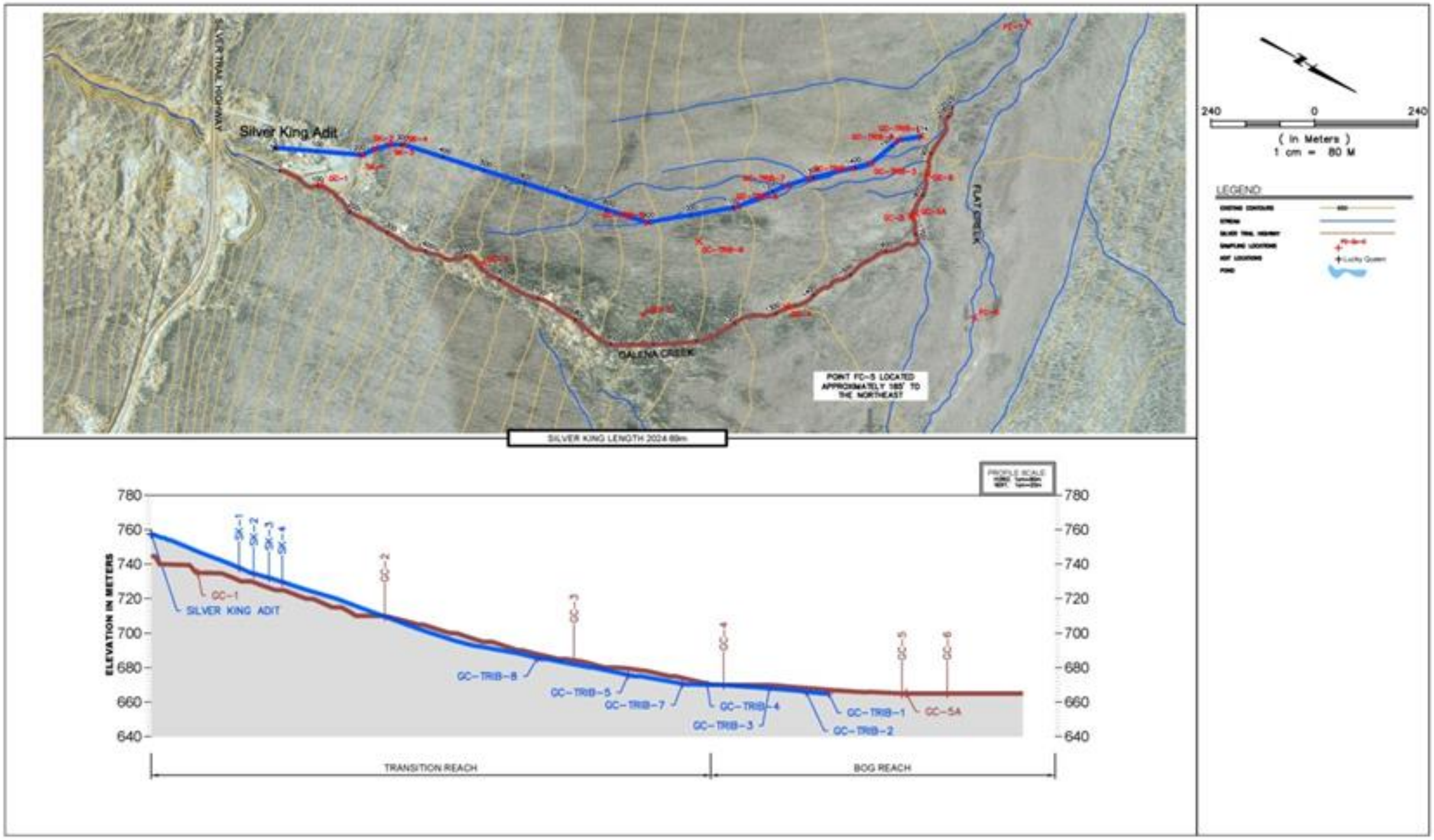


Figure 12 - Wooded Area North of Silver King 100

Figure 13 - Thermokarst Features in Silver King Drainage

Figure 14 - Silver King Bog Reach

2 STUDY METHODS

Project design was conducted in year-to-year phases. The initial work design was based on a review of historical data and publications including, but not limited to, the investigation conducted in 2009 and reported in Interralogic (2010). Peer review comments provided by Dr. Kwong (personal communication 2010), who has conducted geochemical and natural attenuation research in the KHSD, were also used to design the investigations. Results from previous year's work, and feedback from team members, were also used to guide subsequent year's field work and technical analysis. A list of completed (or ongoing monitoring) field studies is presented below.

- Geochemistry of Natural Attenuation
    - Peat sampling and analysis including carbon-14 age dating at NCC
    - Soil sampling and geochemical analysis (NCC, Husky SW, Silver King)
    - Soil water sampling and analysis (NCC, Husky SW, Silver King)
    - Sediment sampling and geochemical analysis (NCC, Husky SW, Silver King)
    - Water sampling and analysis (NCC, Husky SW, Silver King)
    - Seasonal (winter and freshet) water sampling (NCC, Husky SW)
    - Ice sampling (NCC, Husky SW)
    - Microbial evaluation of NCC attenuation and Galkeno 900 bioreactor

  - Detailed mineralogical assessment of attenuation-related mineral phases including optical petrography, scanning electron microscopy, electron microprobe analysis, and high energy synchrotron x-ray elemental and mineralogical analyses (NCC, Husky SW)
  - Metal mineral phase stability testing (NCC)
- NCC Surface Water Pathway Evaluation
  - Summer survey
  - Winter survey
  - Freshet survey
- NCC Groundwater Pathway Evaluation
  - Well Installation
  - Well monitoring (ongoing)
- NCC Surface Peat and Vegetation Sampling
  - Peat thickness/accumulation study including carbon-14 age dating
  - Peat chemistry variations with depth
  - Vegetation sampling (completed as part of KHSD wide study of soil and vegetation metal study (Access, 2012, 2013))
- Closure support
  - Engineering survey of NCC
  - Hydrologic, geochemical, and closure conceptual model development

Table 2 shows the schedule of the field program at each area by year and field element.

Table 2 - Summary of Field Activities at Natural Attenuation Targe Areas

Event	Date	No Cash Creek	Husky Southwest	Silver King	Sadie Ladue
Surface Water Sampling	May-2007			✓	
	June-2007				✓
	July-2009				
	September-2009				
	October-2010	✓	✓	✓	✓
	March-2011	✓	✓		
	May-2011	✓	✓	✓	
	August-2011	✓	✓	✓	
	January-2012	✓			
	July-2012	✓	✓		
	February-2013	✓	✓		
Ice Sampling	March-2011	✓	✓		
	January-2012	✓			
Stream Sediment Sampling (Alluvium & Peat)	October-2010	✓	✓	✓	✓
Soil Sampling	October-2010	✓	✓	✓	
Pore Water Sampling	October-2010	✓	✓	✓	✓
Vegetative Sampling	2012	✓	✓	✓	✓
Monitoring Wells	2010	✓			
Microbial Sampling	2011	✓			
Precipitate Sampling	2012	✓	✓		
Peat (Carbon-14) Sampling	2012	✓			
Engineering Survey	2012	✓			

Surface water samples were collected at sampling locations in the three natural attenuation areas to represent spatial, temporal, and seasonal changes in water chemistry. Industry standard field practices were implemented in collecting grab samples directly from flowing creek water. Samples were filtered in the field and field parameters measured. Total and dissolved metals were analyzed using a certified laboratory. Standard quality assurance methods were implemented including the collection of field and laboratory blanks and duplicates.

Groundwater wells were installed in the NCC area to monitor water levels and to collect groundwater quality samples. Industry standard methods were used in well installation and well purging and sampling.

Channel sediment, alluvium, and peat samples were collected in all areas with as many as possible being collected at the locations where water samples were also collected. Sampling locations are shown in Figure 2, Figure 6, and Figure 11, with stream profiles to indicate sample locations with respect to stream reaches. Alluvium and peat samples were collected from stream banks except for C-14 samples, which were collected from a test pit excavated in the central area of the NCC bog. In some cases peat and alluvium were mixed with vegetation and root mats. Samples of precipitate, where present, were collected from the stream bed sediments.

Analytical results for sediment, soil, and peat samples collected include:

- Multi-element analysis (aqua regia digestion followed by ICP-AES/MS analysis)
- Acid base accounting parameters (sulphur species, carbonate neutralizing potential (NP), paste pH)
- Mineral stability testing
- X-ray diffraction (XRD) analysis
- Optical microscopy
- Scanning electron microscopy, and electron microprobe analysis
- Synchrotron-based X-ray analysis
- C-14 age date analysis

2.1 ANALYSIS OF ZINC AND CADMIUM GEOCHEMISTRY AND MINERALOGY

Polished thin sections were prepared from sediment samples collected along the NCC reach in 2011 and 2012. A smaller suite of thin section samples were prepared from sediments collected along the water course of Husky SW in 2012. These were examined by a range of electron-, laser- and X-ray-based analytical techniques to determine the element associations, the mineralogy and major hosts of zinc within the sediments.

Electron microprobe (EMP) analyses were used to collect major element maps (zinc, manganese, iron, sulphur, silicon) across zinc-bearing grains in the thin sections (typically a few hundred microns in diameter) to show element association, while line scans were run across grains to demonstrate changes in element composition. Spot analyses were obtained to determine major element concentrations and extract element ratios to yield insights into possible mineralogical hosts of zinc. The detection limit of this technique is ≥ 600 mg/kg depending on the element and although it can yield accurate concentration measurements, it is best suited to the analysis of major elements (Sherriff, 2012). This made mapping the cadmium distribution difficult, partly due to the short counting times necessitated by timely map collection, however, spot analyses were able to determine cadmium concentrations in some samples. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) is considerably more sensitive than EMP and was used to obtain major and trace element information in transects run across grains of interest in the thin section samples.

Synchrotron-based X-ray analytical tools were used to probe the zinc and cadmium associations in the No Cash and Husky SW samples. X-ray absorption near edge structure (XANES) spectroscopy was performed to determine the speciation of zinc and cadmium in selected bulk sediment samples from NCC and Husky SW. This technique is element specific (i.e. it only "sees" zinc- or cadmium-bearing phases in the sample) and works by collecting the XANES spectra of a range of zinc- and cadmium-bearing mineral phases and sorption complexes and matching these in various proportions to produce the best fit to the sample XANES spectrum. Micro-focused synchrotron-based X-ray techniques were also applied to the thin sections. Prior to such work, the thin sections were inspected by scanning electron microscopy coupled with energy dispersive X-ray analysis (SEM-EDX) in order to identify zinc-rich grains to investigate further at the synchrotron. At the synchrotron, micro-X-ray fluorescence (μ-XRF) maps were collected to image the distribution of major elements within the sample, primarily concentrating on manganese, iron and zinc, with more recent work including cadmium. Using these maps, areas of variable (high, mid, low) zinc concentrations were targeted for further examination by micro-X-ray diffraction (μ-XRD) alongside zinc and cadmium μ-XANES. Micro-XRD analysis is similar to conventional XRD, except a much smaller X-ray beam spot size is used (*ca.* 5 x 9 μm), allowing minerals present at <5 wt.% in the bulk sample to be detected that would otherwise be missed by bulk XRD. For good diffraction to occur, the crystallites in the sample should be randomly oriented and at least an order of magnitude smaller than the beam diameter. In this sense, the mineral spot under the beam acts like the powdered samples used in conventional XRD analysis. Thus, synchrotron-based μ-XRD is best suited for nanocrystalline materials and will not work well for coarser mineral crystals which are unlikely to diffract under the microfocused monochromatic X-ray beam. Further details regarding synchrotron-based analysis of environmental materials are well described in recent review papers by Lombi and Susini (2009), Lanzirotti et al. (2010), and Jamieson and Gault (2012).

Mineral liberation analysis (MLA) was also used to construct mineralogical maps of portions of the thin section samples. MLA employs SEM imaging, EDX spot analyses and proprietary software to characterize the variety of minerals present in the sample. Thousands of mineral particles are first sorted based on their back-scattered electron intensity then an EDX spectrum is rapidly collected for each different particle. These particle EDX spectra are matched offline against a mineral reference database, building a mineralogical map of the portion of the thin section analyzed. This makes it possible to find zinc hosts that may have been overlooked by other analytical methods, and also has the potential to measure the relative proportions of metal-bearing minerals, assuming that the metal concentration in each library phase is well constrained.

3 RESULTS

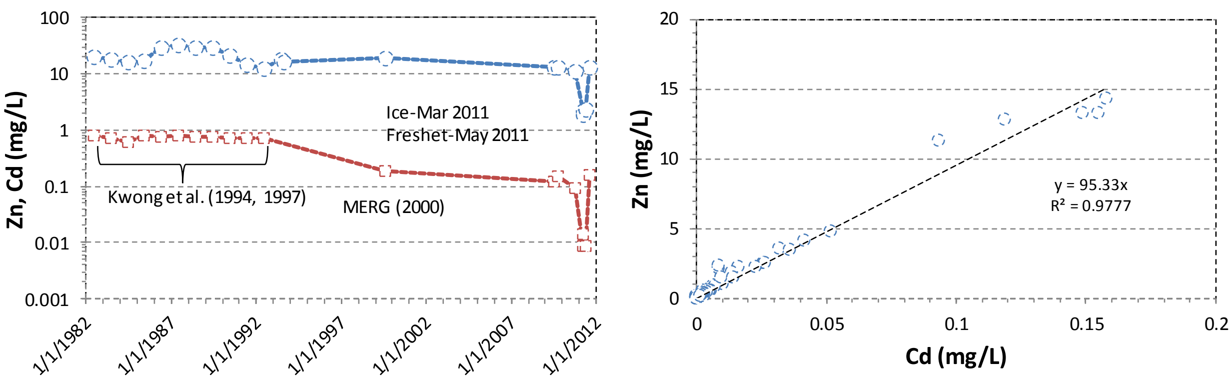
3.1 WATER CHEMISTRY

3.1.1 NO CASH CREEK

No Cash 500 adit discharge water has a Ca-HCO_3-SO_4 composition with pH typically from 7.2 to 8.0. The adit discharge contains elevated concentrations of cadmium, manganese, and zinc. The concentration of zinc has decreased over time from a high of 32 mg/L in 1987 shortly after mining ceased to a typical range of 11 to 13 mg/L in 2009 to 2011 (Figure 15). Cadmium concentrations have decreased from a high of 0.8 mg/L in 1982 to 1987 to 0.1 to 0.2 mg/L in 2009 to 2011. This pattern is not atypical of abandoned mine discharges. Younger (1997) showed that mass loading (as acidity) in abandoned mine drainage starts off relatively high (termed “vestigial”) related to flooding of mine voids and release of readily soluble reaction products. This is typically followed by a "juvenile" phase of relatively lower concentrations related to long-term, slower primary reactions, which are slowed by factors such as loss of source mineral phases, formation of secondary mineral coatings, or burial or saturation of potential source phases.

Data from water samples collected in the adit and also from downstream locations indicate a high degree of correlation between zinc and cadmium (Figure 15), implying that the samples have a similar origin within the mine workings, and similar processes control their environmental fate and transport. Sphalerite is a major ore mineral in the KHSD and is presumed to be the primary source of zinc and cadmium through oxidative dissolution processes in the workings of No Cash Mine and the other mines being evaluated.

Figure 15 - Historical Zinc and Cadmium Concentrations in No Cash Adit Discharge



Trends in metals (zinc, cadmium, manganese, and iron), sulphate, and bicarbonate with distance from the No Cash 500 adit are shown in Figure 16. Total and dissolved concentrations for most metals (except for iron) are very similar, indicating that suspended particulates are not a major component of the water quality analyses. The concentrations of zinc and cadmium (Figure 16) decrease rapidly with distance from the adit particularly within the first kilometer. The zinc concentration shows about a 100-fold decrease and cadmium concentration shows a 100- to 1000-fold decrease along the total flow path, depending on the sample set. Concentrations during winter (March 2011, January 2012 and February 2013 samples) and during freshet (May 2011 samples) are typically about half of the summer/fall concentration at the adit but still show decreases with distance from the adit that are similar to decreases that occur in other times of the year (summer and fall). Overall, there appears to be no distinct seasonality effect to the extent and magnitude of decreases in metal concentrations in our data sets for zinc and cadmium; rather, these metals removal trends occur for all seasons. The median zinc and cadmium concentrations in the terminal pond at the end of the NCC reach are slightly above the CCME guidelines, but are in line with the proposed water quality benchmarks and well below the KHSD water use licence effluent quality standards (Table 3).

Table 3 - Zinc and cadmium concentrations in terminal pond at end of NCC reach

	Zinc (mg/L)	Cadmium (mg/L)
Range	0.047 - 0.067	0.0001 - 0.0005
Average	0.054	0.00028
Median	0.052	0.00026
QZ12-057 EQS[a]	0.5	0.05
Proposed KHSD benchmark[b]	0.075	0.0003
CCME-PAL[c]	0.03	0.000158[d]

[a] Quartz mining water licence – effluent quality standard

[b] Proposed water quality benchmarks for site closure evaluation (Minnow, 2013b)

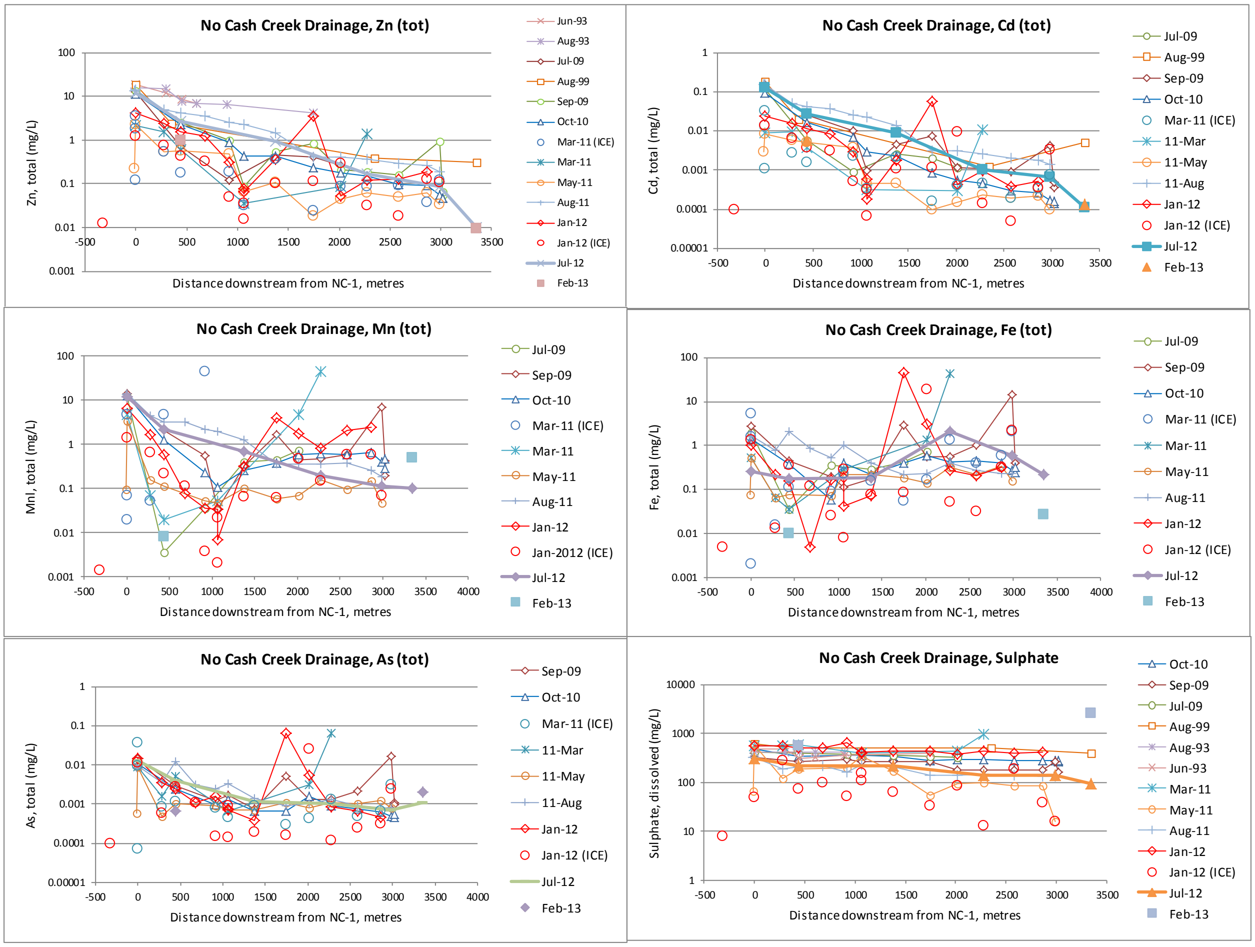
[c] Canadian Council of Ministers of the Environment – Protection of Aquatic Life

[d] Based on draft cadmium October 2012 CCME-PAL guideline at 100 mg/L hardness (NCC waters typically >100 mg/L hardness)

Manganese and iron concentrations also decrease initially within the first kilometer from the adit (Figure 16), then increase slightly or remain approximately constant with further distance, but maintain concentrations that are 1 to 2 orders of magnitude less than in adit discharge. Iron concentrations show more variability than manganese concentrations along the entire length of NCC. The dissolved iron concentrations are high given the neutral pH conditions, implying it may be at least present partially as ferrous iron that persists metastably until oxidized to ferric iron. Slower ferrous iron oxidation is observed in natural environments where organic carbon is present. Dissolved iron concentrations are also generally lower than total iron concentrations, indicating that a significant fraction of the iron is transported as particulates, which might also suggest that a significant fraction of the “dissolved” iron (<0.45 μm filtered) is nanoparticulate. Overall, manganese concentrations show an average of a 20-fold decrease. In contrast to the metals, sulphate concentrations decrease by only about 20 to 80% with distance from the adit (Figure 16), and bicarbonate generally shows little variation (Figure 16).

Sulphate is assumed to be conservatively transported for the most part with the exception of slow flowing areas in the bog where sulphate reduction may be observed; hence, the small decreases in concentration observed with distance for sulphate are expected to be due to dilution from groundwater and side channel inflows. While these dilution effects will also cause small decreases in metal concentrations, the much larger decreases in zinc, cadmium, and manganese concentrations relative to sulphate indicate that geochemical attenuation/precipitation processes are also involved.

Figure 16 - Selected water chemistry trends along the No Cash Creek drainage (note logarithmic scale on y-axis)



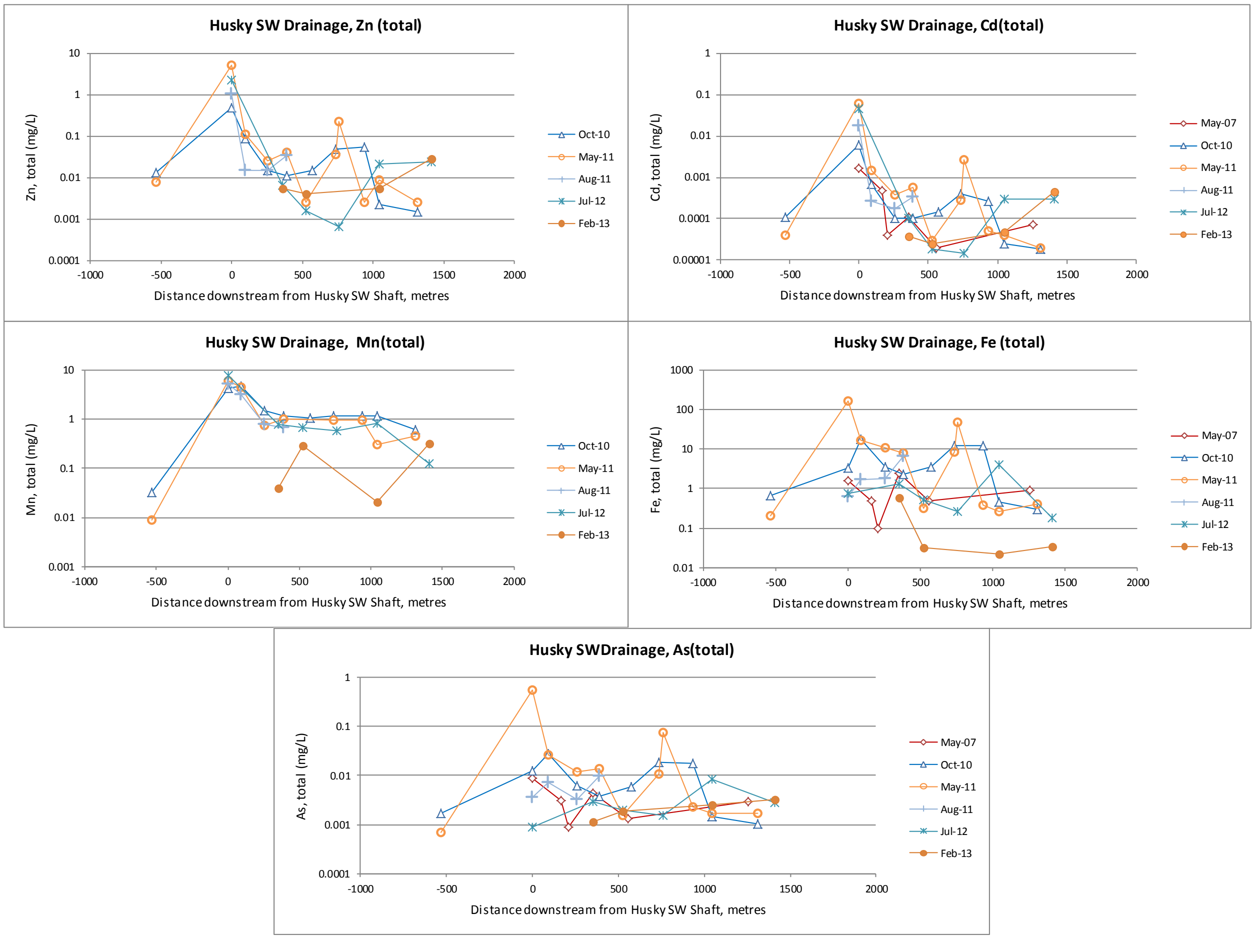
3.1.2 HUSKY SW

Six sampling events were conducted along the Husky SW drainage, from 2007 through 2013. Water samples were collected along Husky SW Creek between the Husky SW crib structure and the confluence with Flat Creek. Field parameters were measured at each location. Figure 17 shows key metals concentrations along the Husky SW drainage.

Husky SW Creek has sections that split and braid. During sampling, the main stream of this creek was not always apparent, and in some cases samples were collected from parallel drainages. The difficulty in tracing the main drainage resulted in sporadic increases and decreases in metal concentrations in lab results. The graphs in Figure 17 suggest a continuous flow path exists between subsequent samples down the flow path due to the line drawn between data points. In the case of Husky SW, however, this may be inaccurate because multiple flow paths exist on the hillside below the mine area.

Samples collected within the first 500m of the adit indicate strong attenuation of metals including zinc, cadmium, and manganese. Zinc and cadmium concentrations decrease over this reach from two to three orders of magnitude and manganese decreases about one order of magnitude. Downstream sampling locations show inconsistent and sometimes higher concentrations of many metals than upstream samples suggesting an unclear or mixed flow path.

Figure 17 – Selected analyte trends along the Husky SW drainage



3.1.3 SILVER KING

Twenty water sampling stations were located along two profiles; the Galena Creek profile which follows Galena Creek on a westerly then easterly arc toward Flat Creek, and the Silver King profile which follows the fall line north directly toward Flat creek. The Silver King profile includes the decant water discharge area and tributaries to Galena Creek. In addition to the 2007 sampling round, five additional rounds of sampling were conducted: October 2010, May 2011, August 2011, July 2012, and a winter event in February 2013. Field parameters were measured at all locations.

Figure 18 shows the metals concentrations along the Galena Creek profile. The Galena Creek profile shows effects of the Silver King operations including waste rock and potential mine (groundwater) seepage. Zinc concentrations along Galena Creek increase between near the mine area but then decrease gradually with distance along the creek.

Figure 19 shows the Silver King treated water profile. The treated water decant discharges immediately north of the site at the base of the waste rock dump into the forested area. Zinc concentrations decline with increasing distance from the discharge pipe by a factor of about 4 within 100 m of the pipe. Tributaries located downstream of the discharge pipe (and mine area in general) showed highly variable chemistry including some areas that were elevated compared to initial concentrations at the pipe discharge. This was also observed at the Husky SW site where multiple flow paths preclude an assumption of a single, continuous flow path.

Figure 18 - Selected water chemistry trends along the Galena Creek drainage

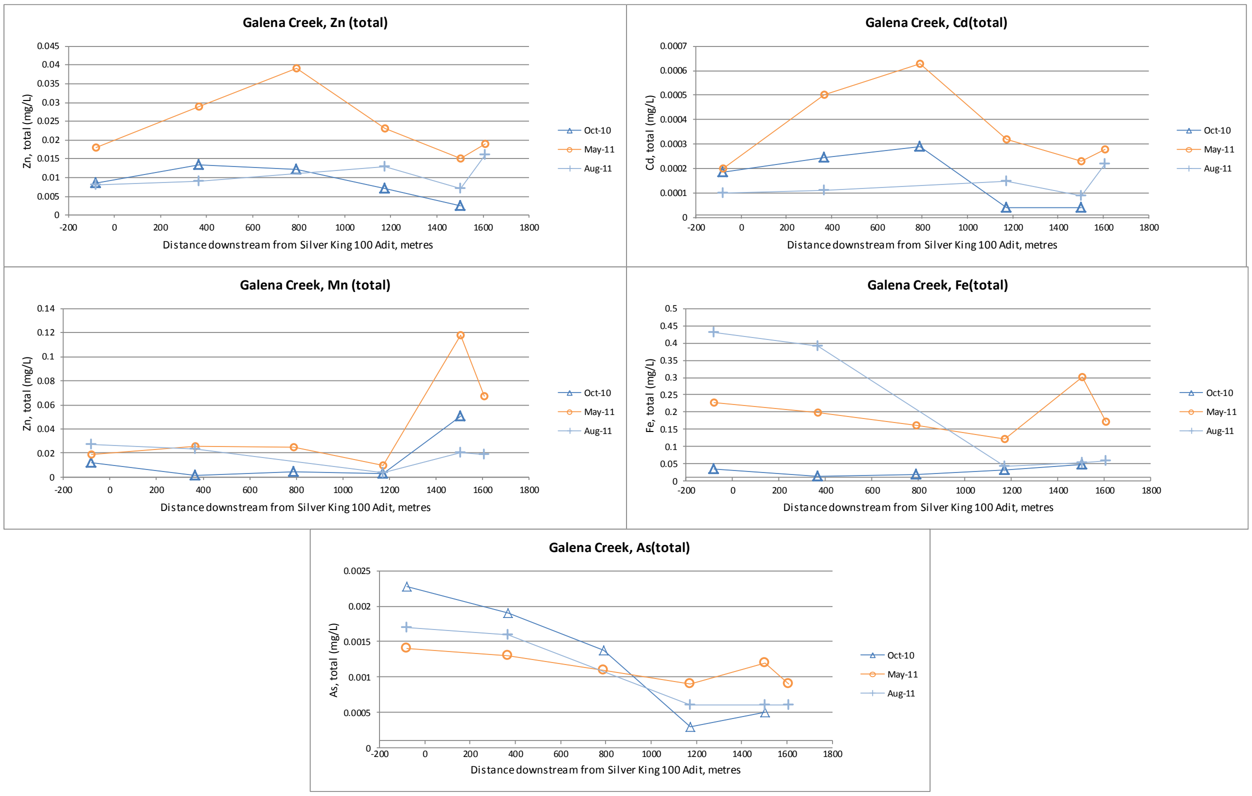
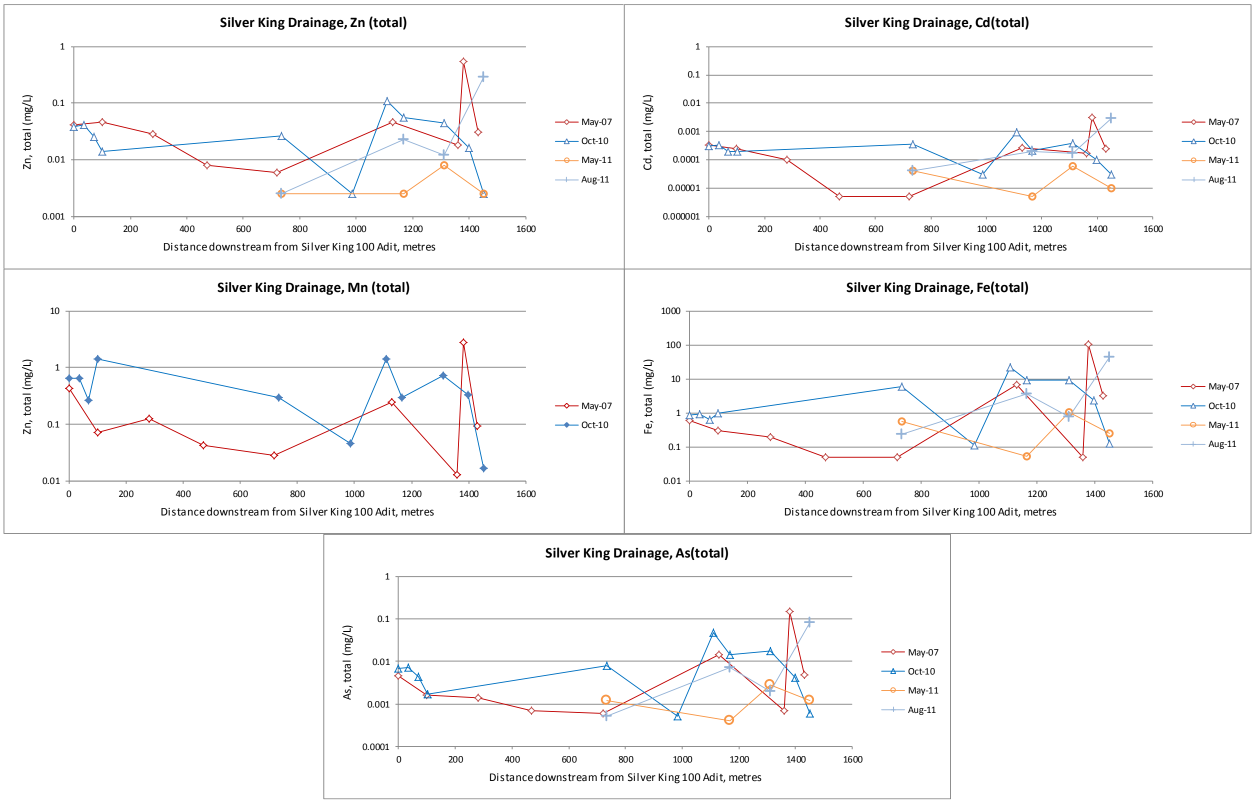


Figure 19 - Selected water chemistry trends along the Silver King decant drainage



3.2 SOLID PHASE GEOCHEMISTRY

3.2.1 NO CASH CREEK

3.2.1.1 GEOCHEMICAL AND MINERALOGICAL CONTROLS ON ZINC AND CADMIUM ATTENUATION

Field data indicate that the zinc and cadmium attenuation is occurring along the entire reach of NCC. Approximately 90% of the zinc and cadmium is sequestered in the initial “cascading” part of the NCC reach. The watercourse then transitions to a low energy, slower flowing stream that passes through an organic-rich wetland. The peaty sediments in this “bog” reach act as a polishing step to the initial attenuation, resulting in an overall removal of >99% of zinc and cadmium from adit discharge water.

3.2.1.2 ZINC AND CADMIUM SEQUESTRATION IN UPPER “CASCADING” REACH

Imaging of 23 thin sections by backscattered electrons using SEM and EMP revealed a preponderance of lithic, and occasionally organic particles that were partially or fully encrusted with banded manganese-zinc-rich coatings (Figure 20; Sherriff 2011a-e, 2012, 2013). These were most noticeable in samples collected close to the adit. The abundance of such colloform coatings declined with distance downstream, and were often found in downstream sediments as detached colloform material rather than grain rims, suggesting that this material has travelled downstream from its precipitation locus near the adit (Sherriff, 2013). EMP and LA-ICP-MS line scans, in addition to synchrotron μ-XRF maps, indicated that manganese, zinc and cadmium concentrations were closely correlated in these coatings (Figure 21), which appeared to be the most visible source of zinc and cadmium in the thin sections. Zinc and cadmium were relatively poorly correlated with iron, although arsenic and iron concentrations appeared to be closely related (Figure 21). Hundreds of spot EMP analyses on the manganese-zinc-rich colloform coatings in samples resulted in a typical manganese/zinc molar ratio of 1.5 – 4, with linear regression lines of such data revealing a manganese/zinc trend of ~3 (Sherriff 2011e, 2013). This is similar to the mean manganese/zinc molar ratio of the bulk sediments (2.9), suggesting that the colloform coatings are the major repository of zinc in the sediments. The relatively low and consistent manganese/zinc ratio suggests that the zinc may be structurally incorporated in a zinc-bearing mineral. By contrast, the manganese/cadmium molar ratios were much higher and more variable, typically ranging between 170 and 600 (Sherriff, 2012, 2013), making a cadmium mineralogical control unlikely.

Synchrotron-based μ-XRD and zinc and cadmium μ-XANES were employed to obtain direct information on the mineralogy and zinc and cadmium speciation within these colloform grain coatings. The only zinc-bearing phases that were consistently identified across numerous colloform coatings were hydrohetaerolite ($Zn_2Mn_4O_8.H_2O$) and hetaerolite ($ZnMn_2O_4$) (Gault et al., 2012, 2013; Figure 22 and Figure 23). Birnessite (nominally $(Na,K,Ca)MnO_2.xH_2O$) was also tentatively identified. Zinc μ-XANES identified hetaerolite and hydrozincite ($Zn_5(CO_3)_2(OH)_6$) as the major mineralogical hosts of zinc, while zinc sorbed and/or co-precipitated with ferrihydrite ($Fe_{10}O_{14}(OH)_2{\cdot}xH_2O$) was also well fitted (Figure 23). No clear trends with sample depth or distance downstream could be discerned from the zinc μ-XANES data. It should be noted that only randomly oriented nanocrystalline phases will diffract under μ-XRD conditions; crystallites similar in size to the μ-X-ray beam (~5 x 9 μm) will not diffract well, if at all, perhaps explaining the lack of hydrozincite and birnessite detected by μ-XRD, while ferrihydrite is poorly crystalline and diffracts only weakly. MLA analysis of complementary thin section samples collected proximal to the adit also identified zinc-manganese-oxides as the primary zinc host by surface area, followed by zinc-bearing birnessite and an unidentified zinc-bearing multi-element aluminosilicate, hypothesized to reflect a mixture of clay minerals (e.g. illite) and iron/manganese (oxyhydr)oxides.

Interpretation of the cadmium μ-XANES data was limited by the spectral similarity of a range of cadmium sorption complexes, however, the XANES patterns for cadmium-bearing minerals such as otavite ($CdCO_3$) and CdS were unique, thus the likely mineralogical hosts of cadmium could be distinguished from cadmium sorbed on mineral substrates. The cadmium μ-XANES collected from cadmium-bearing colloform coatings indicated that cadmium was present as a sorption complex, in line with the EMP data.

Figure 20 - Backscattered (a, b) SEM and (c) EMP images of colloform manganese-zinc-rich coatings on lithic and organic grains observed in No Cash Creek thin sections. Numbers in images (a) and (b) indicate points where energy dispersive X-ray spectra were collected, while the distribution of zinc, manganese, iron, sulphur, and silicon is mapped in (c)

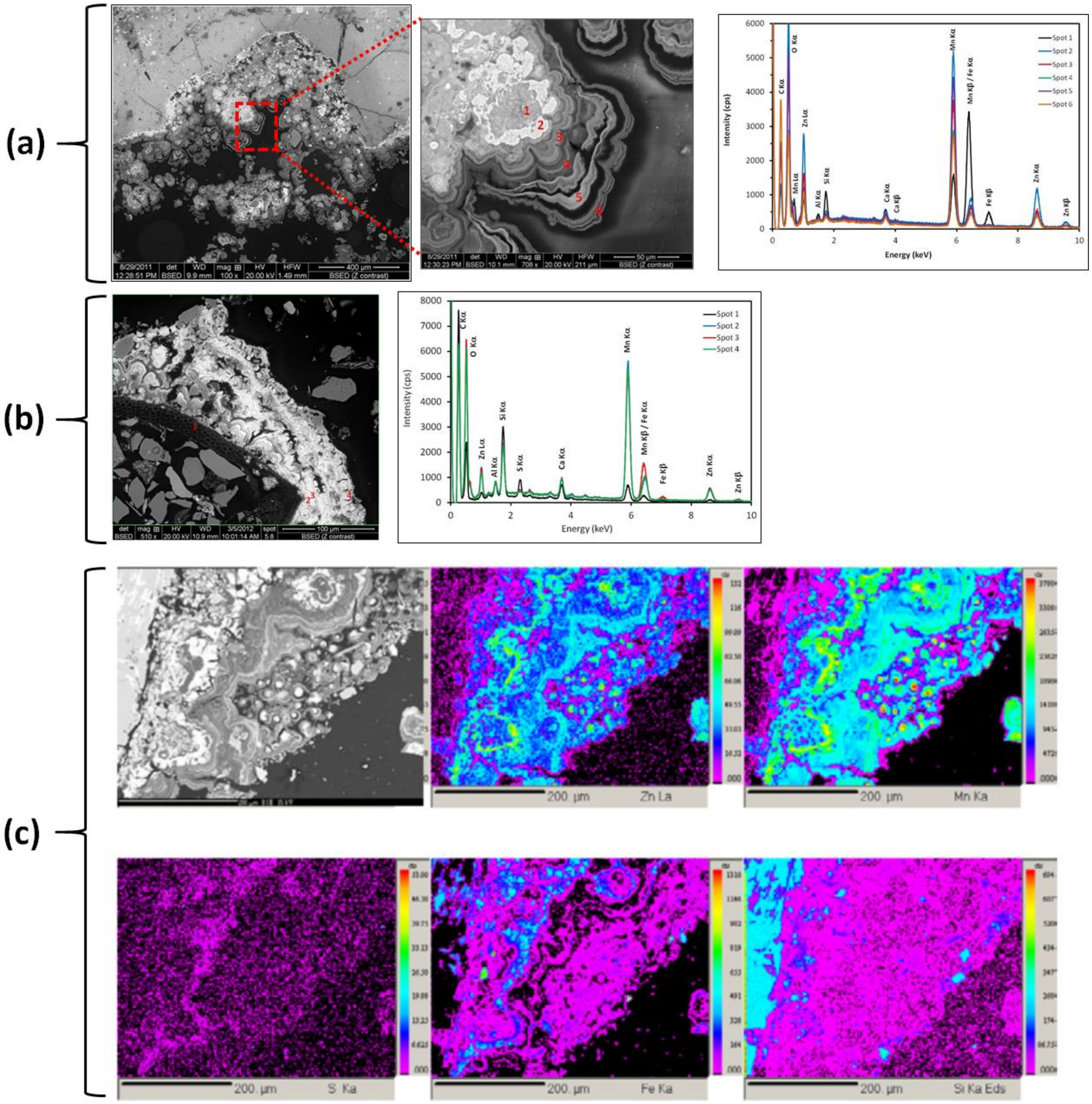


Figure 21 - (a) EMP and (b) LA-ICP-MS line scans across colloform particle coatings observed in No Cash Creek thin sections. Note the close correlation between manganese, zinc and cadmium. Little correspondence was observed between cadmium, zinc and iron, although arsenic concentrations appeared to follow those of iron.

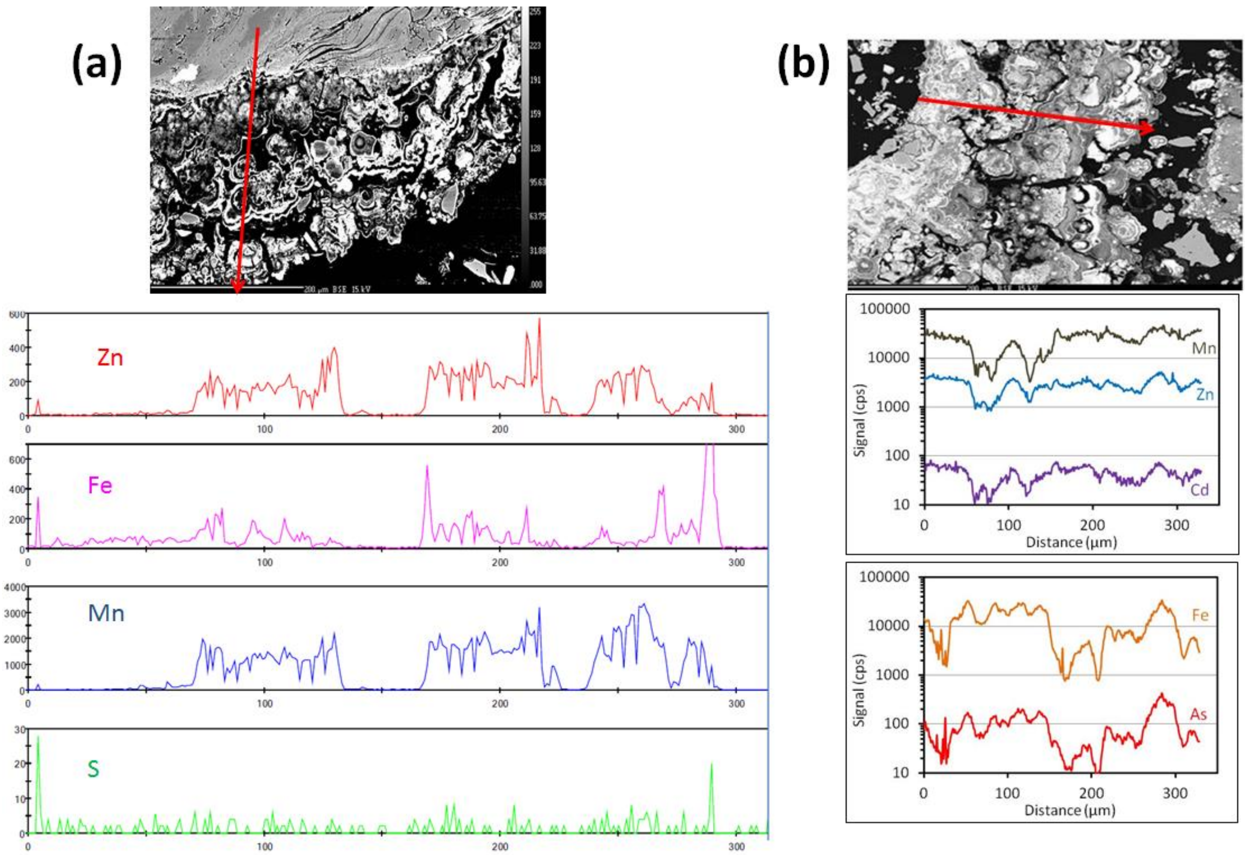


Figure 22 - (a) Backscattered electron and (b) associated synchrotron-based µ-XRF tricolor element map showing the distribution of iron (red), manganese (green) and zinc (blue) in a colloform rim on a lithic particle in a thin section sediment sample collected close to the No Cash Creek adit. Numbers denote points where (c) µ-XRD measurements were collected, which indicated that hydrohetaerolite ($Zn_2Mn_4O_8.H_2O$) was the primary nanocrystalline phase present in the manganese-zinc-rich coating.

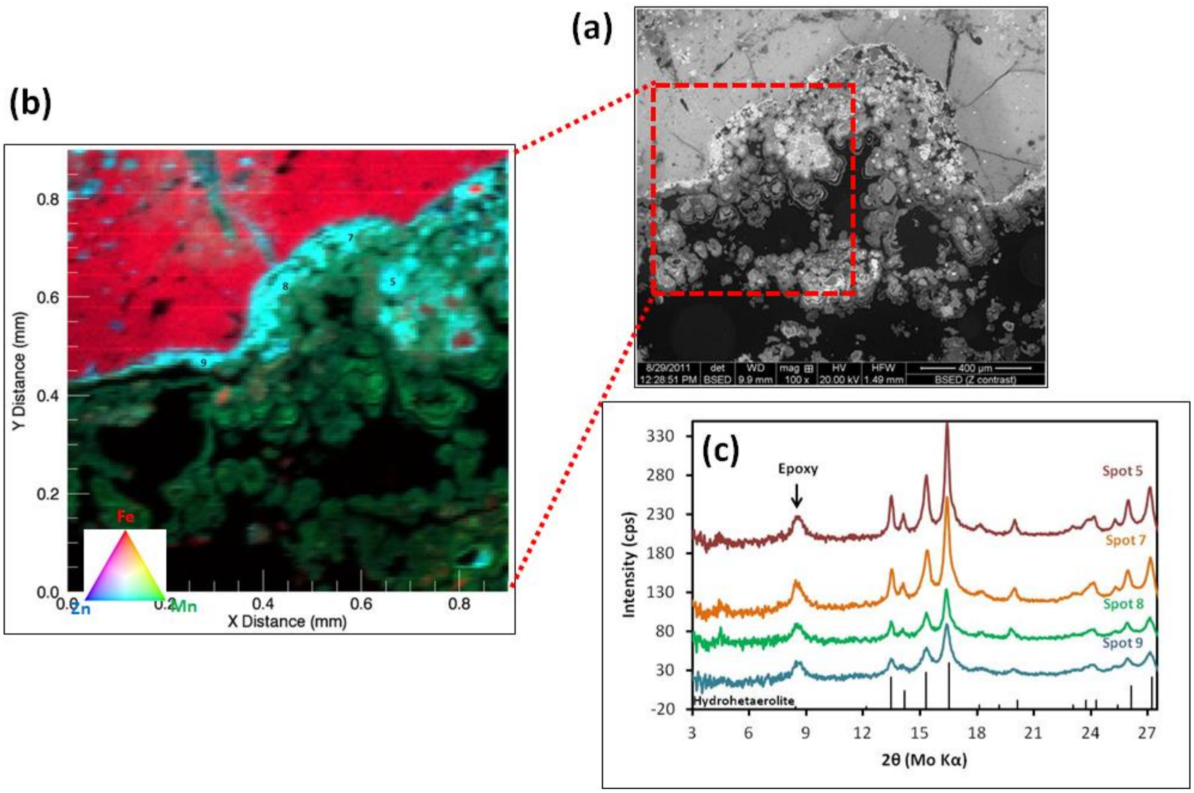
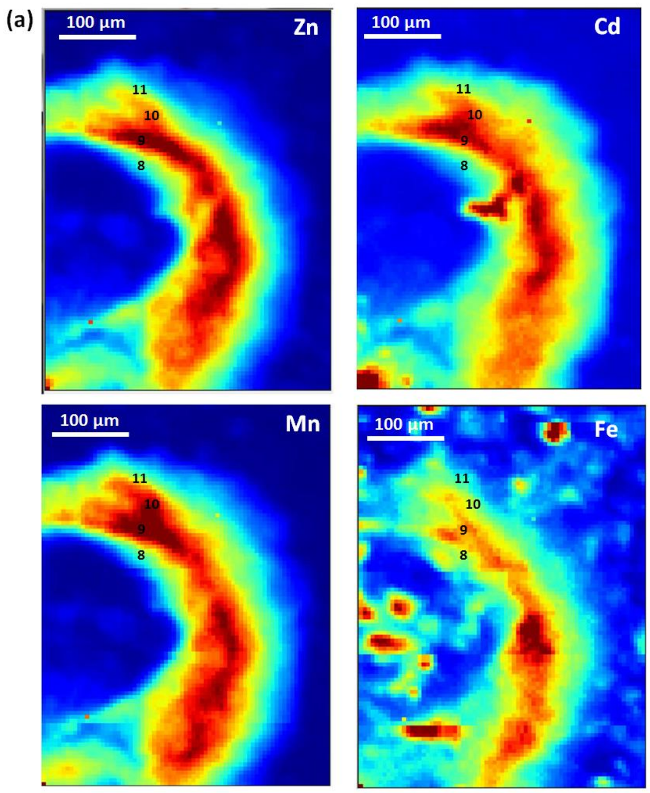
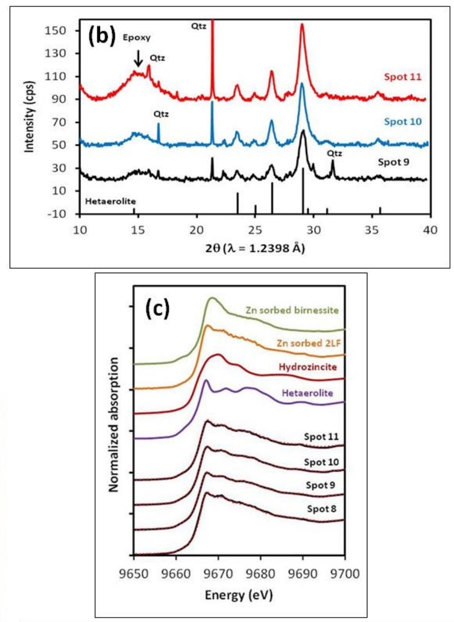


Figure 23 - (a) Synchrotron-based µ-XRF maps of zinc, cadmium, manganese and iron distribution in the colloform rim imaged by backscattered electrons in Figure 20 (b). Numbers denote spots where (b) µ-XRD and (c) zinc µ-XANES measurements were taken. Red dotted lines to sample µ-XANES data represent the best fit listed in (d)





(d)	Hetaerolite	Hydrozincite	Sorbed ferrihydrite	Sorbed birnessite
Spot 8	12%	-	83%	-
Spot 9	44%	32%	24%	-
Spot 10	40%	20%	32%	8%
Spot 11	33%	14%	44%	11%

While zinc and cadmium were predominantly associated with oxidized phases in the colloform coatings, sphalerite ((Zn,Fe)S) grains were also observed occasionally (Figure 24). These appeared to be primarily detrital based on particle morphology and the presence of weathering rims, however, small spheres (1 – 3 μm diameter) of putatively biogenic sphalerite were also observed in one sample collected at 8" depth (Gault et al., 2012, 2013; #38NC12). These were associated with organic structures, perhaps suggesting the presence of micro-niches of microbial sulphate reduction, which may offer added redundancy in zinc (and cadmium) sequestration should reducing conditions develop deeper in the sediment column and further downgradient into the No Cash wetland area.

Zinc and cadmium XANES analyses were also performed on the bulk sediments to evaluate the average speciation in the sediments. Only the adit sediment had a high enough cadmium concentration for cadmium K-edge XANES to be collected, and this was again indicative of a cadmium sorption complex. Zinc bulk XANES were obtained from sediments collected along the watercourse (Figure 25, Table 4). Close to the adit, the data were best fitted with zinc sorbed on ferric oxyhydroxides and birnessite with additional hetaerolite and hydrozincite contributions. Moving downstream zinc was still associated with ferric oxyhydroxides, while zinc-humate complexes became more prominent components as the creek moved into the more organic rich, boggy portion of its reach.

Figure 24 - (a) Backscattered electron image of small (1 – 3 µm diameter) electron dense particles within an apparent organic (cellulose?) matrix found in a No Cash Creek thin section. Red numbers denote spots where (b) energy dispersive spectra were collected, indicating the dominance of zinc and sulphur. (c) Corresponding synchrotron-based µ-XRF maps of zinc, cadmium, manganese and iron distribution and (d) zinc µ-XANES and (e) cadmium µ-XANES point analyses, which suggest the zinc and cadmium is present as sulphide phases.

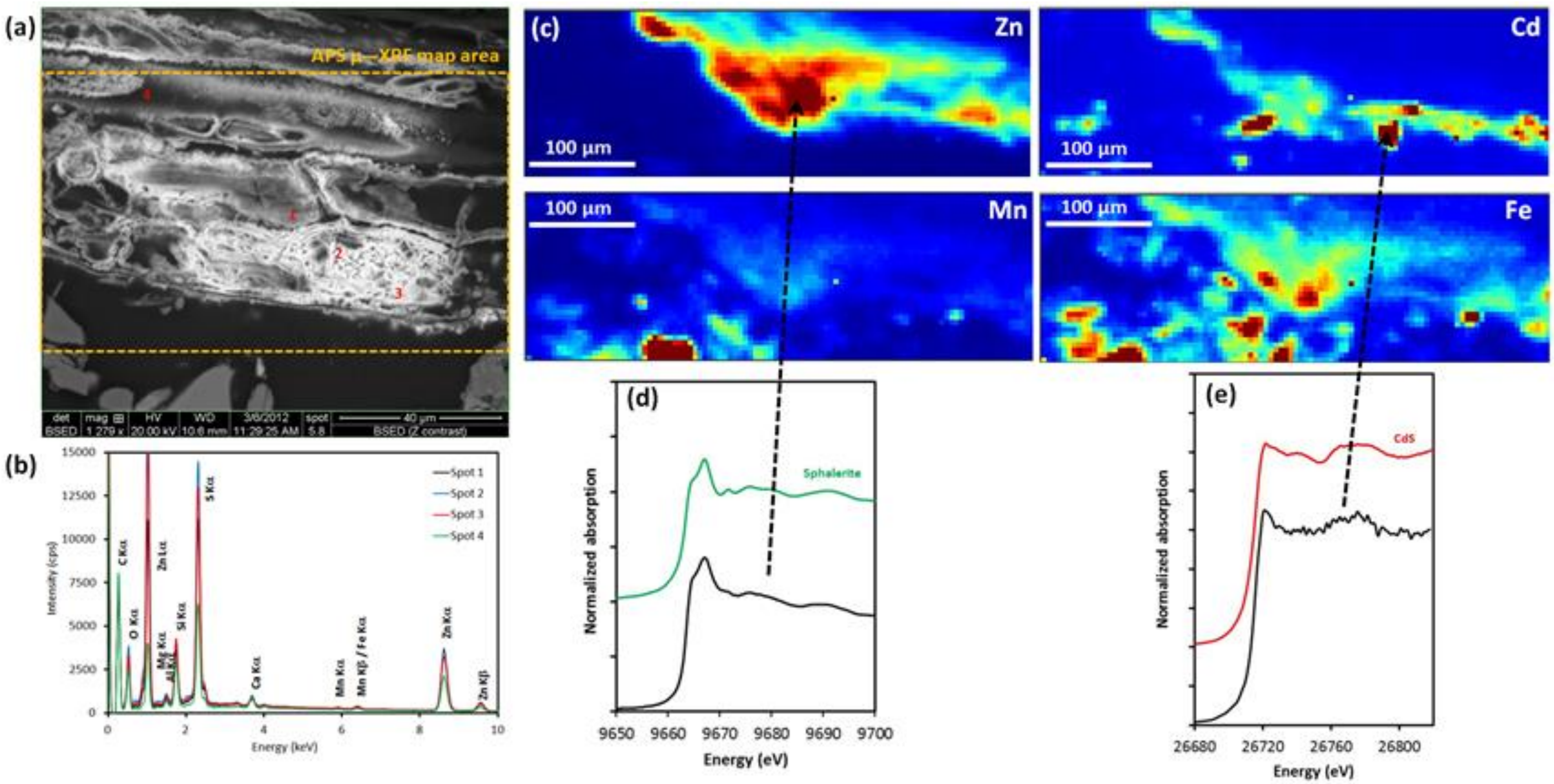


Figure 25 - (a) Zinc K-edge XANES spectra of model zinc-bearing phases used in fitting sample spectra. (b) Zinc K-edge XANES spectra collected for bulk No Cash Creek sediments. Black, solid lines represent sample data and red, dotted lines the best fit listed in Table 4.

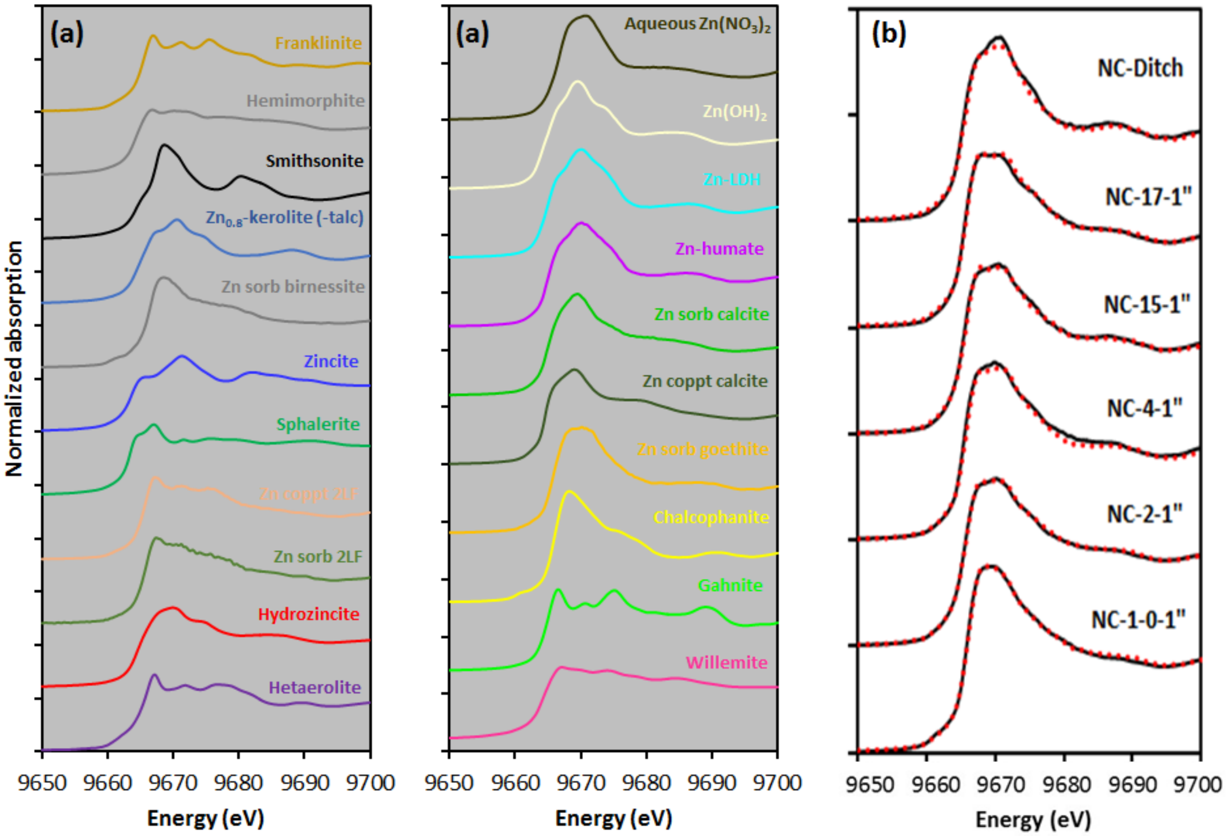


Table 4 - Best fits for bulk zinc K-edge XANES data collected for No Cash Creek bulk surficial sediment samples[a]

	Zn (mg/kg)	Proportion of Zn present as:										
		Coppt 2LF[b]	Sorbed 2LF	Sorbed goethite	Zn-humate	Sorbed birnessite	Hetaerolite	Chalcophanite	Sorbed calcite	Hydrozincite	Sphalerite	$Zn_{0.8}$-kerolite (-talc)
NC-1-0-1"	41,100	-	24	49	-	29	-	-	-	-	-	-
NC-2-1"	3,800	-	17	26	17	-	17	-	-	23	-	-
NC-4-1"	3,540	32	-	28	15	-	-	-	24	-	-	-
NC-15-1"	2,020	-	38	11	42	-	-	-	-	-	7	-
NC-17-1"	1,760	44	-	37	-	-	-	-	20	-	-	-
NC-ditch	186	11	-	-	71	-	-	11	-	-	-	6

[a] The components were not forced to sum to 100% during the fitting process (typically 97 – 103%)
[b] "2LF" denotes 2-line ferrihydrite; "coppt" indicates "co-precipitated with"

3.2.1.3 ZINC AND CADMIUM SEQUESTRATION IN LOWER "BOG" REACH

Approximately 1,000 m downstream of the adit, NCC transitions from its steep "cascading" reach into the much flatter "bog" reach as it travels through a peaty wetland. In the subsequent 2,500 m of the bog reach, aqueous zinc and cadmium concentrations decline further as this portion of the watercourse acts as a polishing step to the rapid zinc and cadmium removal observed upstream. It is hypothesized that the zinc and cadmium are removed via sorption on the peat, although co-precipitation with iron/manganese (oxyhydr)oxides and reductive precipitation as sulphide-bearing phases are also possible. Visual and smell-based observations of black sulphides in quiescent sediments along the saturated bog areas have also been noted throughout the No Cash wetland areas.

Column experiments using peat collected from the NCC wetland have been conducted to assess the role of peat in zinc and cadmium attenuation (Alexco Environmental Group, 2011). Two metre columns were packed with peat from the No Cash area and operated under (i) Column experiments using peat collected from the NCC wetland have been conducted to assess the role of peat in zinc zinc and cadmium attenuation (Alexco Environmental Group, 2011). Two metre columns were packed with peat from the No Cash area and operated under (i) saturated conditions, where water flowed upwards from the bottom, filling the column and was sampled at the top; and (ii) unsaturated conditions, where water was added to the top and allowed to percolate through the column before collection at the base. Water from the Galkeno 900 adit was passed through the columns, which contained initial zinc and cadmium concentrations of 5.76 and 0.0014 mg/L, respectively. Two pore volumes of water were passed through the columns per week and 54 pore volumes were run in total. Zinc and cadmium removal by the peat column was >99% and 94%, respectively, for both saturated and unsaturated experiments for the entirety of the experiment. Significant manganese removal (94%) was also observed for the unsaturated column, with minimal loss of sulphate (<2%), suggesting that aerobic processes such as co-precipitation with manganese (oxyhydr)oxides may have been the primary driver of zinc and cadmium removal, alongside sorption on organic matrices. In the saturated column, manganese removal was much less pronounced (16%), while 22% of the sulphate was removed, indicating that microbial sulphate reduction and the associated precipitation of zinc and cadmium as sulphide phases may be a prominent sequestration process in this column.

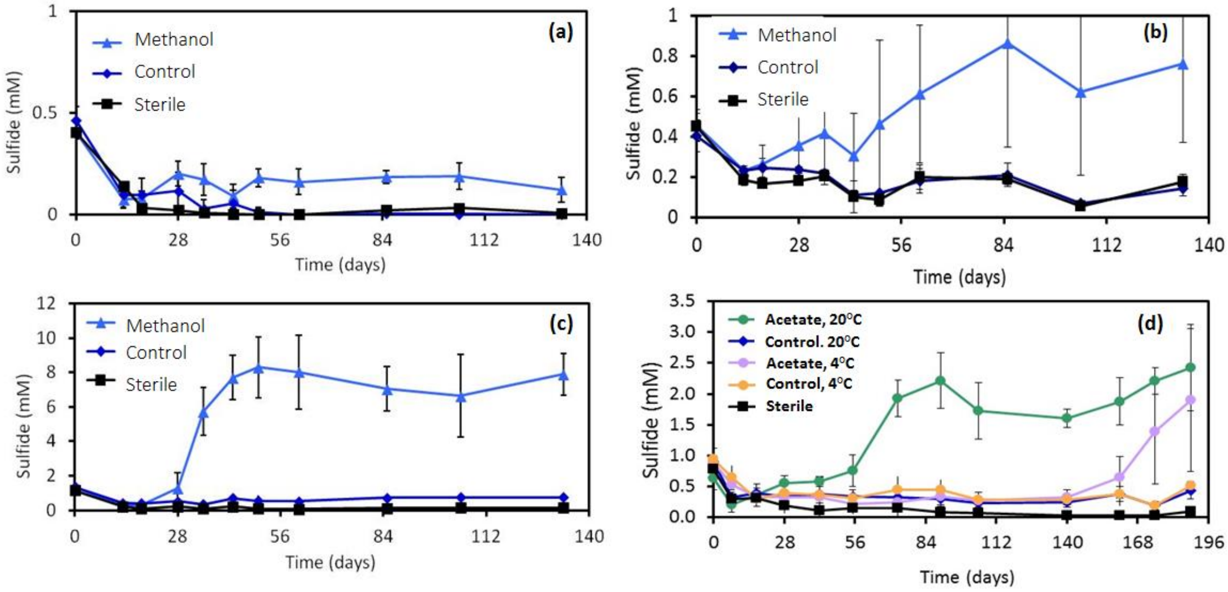
Similar attenuation of cadmium and zinc has been observed in twinned wells in the Valley Tailings Facility screened above and below the peat layer that underlies the tailings. Here, groundwater concentrations of zinc and cadmium are more than three orders of magnitude lower beneath the peat layer than in the tailings porewater (SRK, 2009). This was recorded in an area where tailings have been present for at least 50 years with zinc and cadmium tailings porewater concentration orders of magnitude higher than those in the lower reach of NCC, demonstrating the longevity of the natural metal attenuation offered by this peat layer. The penetration depth of metal contamination into the peat layer is typically <0.5 m (Interralogic, 2012b).

3.2.1.4 MICROBIOLOGY OF NO CASH CREEK SEDIMENTS

Sediments were collected near the No Cash 500 level adit and approximately 250 m downstream for microbiological examination. They were incubated under anoxic conditions in the presence of a variety of organic electron donors in order to assess the importance of such substrates to the onset of microbial sulphate reduction (Londry, 2013). Similar experiments were also conducted at 4 and 20°C to evaluate the role of temperature. Minimal microbial sulphate reduction was observed in both the adit and downstream sediments (Figure 26), ascribed to the high sedimentary metal concentrations which may hinder microbial activity. The addition of an electron donor such as methanol or acetate enhanced the extent of sulphate reduction, while colder temperatures delayed the onset of sulphate reduction by approximately 3 months (Figure 26d), but once established, the rates of sulphate reduction at both 4°C (1.8 mg/L/d) and 20°C (2.2 mg/L/d) were comparable (Londry, 2013). That organic electron donor amendment was required to initiate marked microbial sulphate reduction suggests that the sediments were deficient in the labile organic carbon required to drive this process, however, the work did show that a small community of sulphate-reducing bacteria was present in the NCC sediments. This was reflected in the 16S rRNA profiling work, which indicated that 0.4 – 0.8% of the 16S rRNA gene pyrotags were matched to the Deltaproteobacteria, known to host a wide range of sulphate-reducing bacteria. *Thiobacillus* (9%) species were prominent in the adit surface sediment, suggesting that metal oxidation is likely an important biogeochemical reaction occurring at this site. Psychrophilic *Polaromonas* (9%) species were also prominent in the adit sediment samples, and their presence is consistent with the culturing experiment results that demonstrated sulphate reduction at 4°C.

Given the low abundance of sulphate-reducing bacteria in these sediments, it is unlikely they play a significant role in zinc and cadmium sequestration in the aerobic, upper cascading reach of NCC, but microbial sulphate reduction is likely an active process and an important mechanisms of zinc and cadmium attenuation in the shallower, peaty bog portion of NCC.

Figure 26 - Sulfide production in cultures established from the No Cash Creek (a) adit surface sediment, (b) adit 18" depth sediment, and (c,d) sediment collected 250 m downstream of the adit



3.2.1.5 STABILITY TESTING OF NO CASH CREEK SEDIMENT

Although the streambed precipitates appear durable under the prevailing geochemical conditions (Interralogic, 2012a), future potential changes in temperature, pH or redox conditions along NCC could possibly change their stability. In this work, precipitate collected from close to the No Cash 500 adit was subjected to a variety of environmental stresses, ranging from changes in temperature and pH, to more aggressive (and less likely) tests such as strongly reducing conditions. Such information will help frame the geochemical window of stability for these precipitates, and aid future monitoring and adaptive management programs by identifying geochemical conditions under which metal remobilization might be expected.

Sediment was collected within a few metres of the No Cash 500 adit, mixed with water collected further downstream, and subjected to shake flask style experiments (Gault and Jamieson, 2013). The sediment-water slurry was mixed at 200 rpm on an orbital shaker at 4°C for 48 h, then a sample was taken to establish the baseline analyte conditions. An environmental variable (Table 5) was then changed, the sample shaken for a further 48 h, and a final sample collected to examine the impact of the environmental variable on the mobility of zinc and cadmium.

A temperature rise of 5°C resulted in the mobilization of some zinc and cadmium, whereas a rise of 10°C caused a reduction in soluble zinc concentrations and had negligible impact on cadmium (Figure 27). Such contrasting results are likely due to the competing effects of enhanced mineral dissolution rates and lowered metal carbonate solubility with increasing temperature. Threefold and twofold rises in zinc and cadmium concentrations, respectively, were noted at the end of a rapid freeze thaw experiment. This was attributed to enhanced CO_2 solubility during the cooling step of the experiment, which likely drove the 0.5 pH unit drop observed and promoted partial metal carbonate dissolution and desorption of zinc and cadmium from iron/manganese (oxyhydr)oxide surfaces.

Equilibrium pH increases of 0.5 and 1.2 pH units (from a starting point of pH ~7.2) caused marked drops in dissolved zinc and cadmium due to precipitation as/with metal hydroxide and carbonate phases (Figure 27). Lower pH systems were not examined directly since the NCC watercourse is well buffered and not expected to become acidic. Experiments were conducted that involved some removal of alkalinity (up to 56%), resulting in reductions in aqueous zinc and cadmium levels (Figure 27).

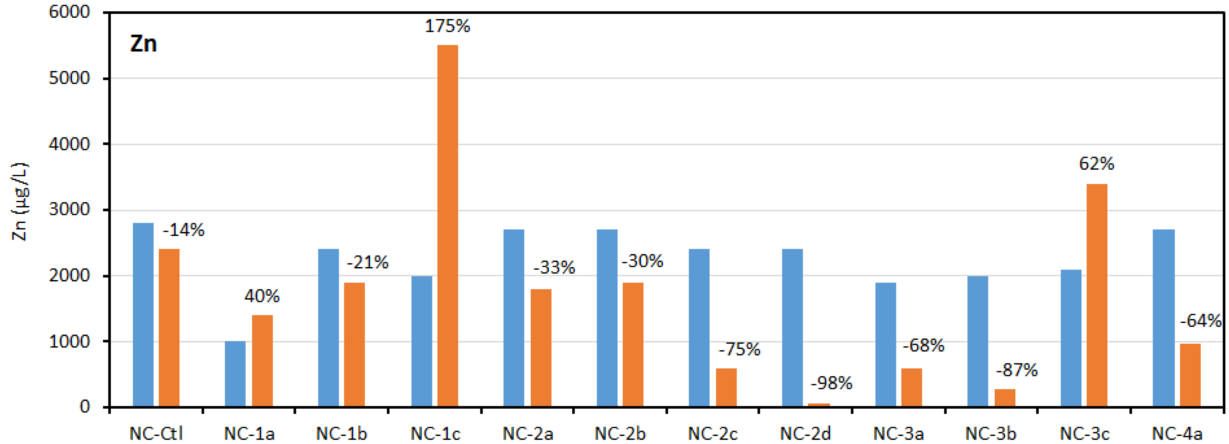
Table 5 - Stability test environmental variables.

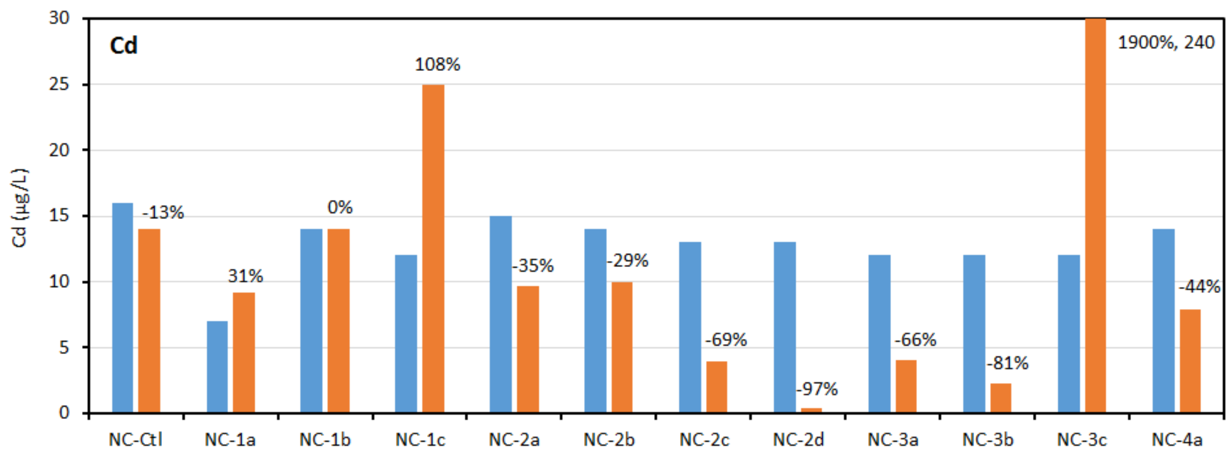
Test ID	Variable	Description
NC-1a	Temperature	Increase temperature by 5° C
NC-1b	Temperature	Increase temperature by 10° C
NC-1c	Temperature	Freeze/thaw
NC-2a	pH/alkalinity	Titrate out 33% of alkalinity
NC-2b	pH/alkalinity	Titrate out 66% of alkalinity
NC-2c	pH/alkalinity	Raise pH by 1 standard unit
NC-2d	pH/alkalinity	Raise pH by 2 standard unit
NC-3a	Redox	Oxidation – bubble with air
NC-3b	Redox	Mild anoxia – lower dissolved O_2 concentration by bubbling with N_2
NC-3c	Redox	Reduction – add sodium dithionite to create reducing conditions
NC-4a	Biological activity	Inhibit biological activity

Bubbling with air or nitrogen, intended to simulate strongly aerobic and mildly anoxic conditions, respectively, caused diminutions in soluble zinc and cadmium concentrations (Figure 27), likely due to the removal of dissolved CO_2 which would have favoured the precipitation of metal carbonate phases. Amendment with 50 mM sodium dithionite, designed to stimulate reducing conditions, resulted in extensive mobilization of manganese (from <0.001 mg/L to 300 mg/L) and cadmium (from 0.012 mg/L to 0.24 mg/L), and more moderate solubilisation of zinc (from 2.1 mg/L to 3.4 mg/L). While the establishment of manganese-reducing conditions was clear from the dissolved manganese concentrations, the lack of soluble iron suggests that iron(III)-reducing conditions were not attained.

The maximum cadmium and zinc concentrations released to solution in these experiments was relatively minor, equivalent to 0.2% and <0.05% of the sedimentary cadmium and zinc content. The freeze-thaw experiment caused the largest release of zinc to solution, alongside a marked rise in cadmium, however, freeze-thawing in the field occurs over longer timescales and may not have been representatively simulated in this experiment. Observations from the field data indicate somewhat lower-than-average metals concentrations in liquid water sampled during winter events. Freshet waters generally have the lowest metals concentration and the late summer water have the highest overall concentrations of metals.

Figure 27 - Changes in selected analyte concentrations for stability experiments NC-Ctl (no environmental changes), NC-1a (+5°C temp rise), NC-1b (+10°C temp rise), NC-1c (freeze-thaw), NC-2a and NC-2b (alkalinity lowered), NC-2c and NC-2d (pH increased), NC-3a (bubbling with air), NC-3b (bubbling with nitrogen), NC-3c (dithionite reduction), and NC-4a (azide microbiocide). Blue and orange bars indicate analyte concentration after 48 h of baseline equilibration and a further 48 h after the environmental variable was changed, respectively. Data label above orange bars indicates percentage change; for NC-3c, additional number indicates analyte concentration, which was off-scale in this expt. Where no data are shown, the analyte was below the limit of detection





Most cadmium mobilization and a sizeable increase in dissolved zinc were observed when manganese-reducing conditions were imposed on the sediment. This is in line with zinc and cadmium XANES data which suggest that a sizeable portion of the solid phase zinc is sorbed on manganese oxyhydroxides, while cadmium is also present as a sorption complex (Gault et al., 2013). The limited zinc remobilization (<0.02% of the sedimentary zinc inventory) likely reflects re-sorption of the zinc onto other mineral phases such as ferric oxyhydroxides that appear not to have been targeted by the dithionite reagent. Thus, although a pulse of elevated zinc and cadmium concentrations might be expected during manganese- (and iron(III)-) reducing conditions, re-adsorption on secondary mineral assemblages, and precipitation as authigenic sulfide minerals under subsequent sulfate-reducing conditions would be expected to limit dissolved zinc and cadmium concentrations. Given the low organic carbon concentrations in the No Cash sediments (<0.5 wt. %; Interralogic, 2011b), it seems unlikely that such reducing conditions would develop, while a pulse of reducing water emanating from the mine is also thought implausible, making such a scenario a very extreme event. Any zinc and cadmium that is released under reducing conditions that diffuses up the sediment column towards the surface would also be expected to be scavenged by the manganese (and iron) oxyhydroxides that would re-precipitate upon meeting the oxidizing surface conditions.

3.2.2 HUSKY SW

3.2.2.1 GEOCHEMICAL AND MINERALOGICAL CONTROLS ON ZINC AND CADMIUM SEQUESTRATION

The majority of zinc-rich areas in the Husky SW thin sections were present as discrete particles or bands within particles (Gault et al., 2012; Sherriff 2012, 2013). Colloform coatings on grains were observed only occasionally, although a few of the discrete manganese-zinc-bearing particles had a colloform appearance, perhaps suggesting they had become detached from the particles around which they formed. Zinc and cadmium concentrations followed those of manganese most closely (Figure 28 - Figure 30), often in particles that appeared to show successive manganese- and iron-rich banding (e.g. Figure 28). Birnessite, goethite (FeO(OH)), and possibly manganite (MnO(OH)) were the most common nanocrystalline phases identified by µ-XRD, while zinc µ-XANES were generally best fitted with a mixture of zinc hosted in hetaerolite and co-precipitated with calcite ($CaCO_3$) and/or ferrihydrite (Figure 31; Gault et al., 2013). SEM-EDX, EMP and LA-ICP-MS spot analyses showed that the manganese/zinc ratios in the zinc-bearing particles were much higher for samples from Husky SW compared with NCC, in line with bulk sediment manganese/zinc ratios (Sherriff, 2012, 2013). The tentative identification of birnessite and other manganese oxide phases in the Husky SW samples is likely responsible for the higher manganese/zinc ratio observed for these samples, and might suggest that zinc sorption complexes are more prevalent for the Husky SW samples. Detrital sphalerite was also observed occasionally, but the small spherules of biogenic sphalerite were absent from the few Husky SW thin sections examined to date. Similar to NCC, multiple cadmium μ-XANES point analyses suggested cadmium was present as a sorption complex, but the similarity of the standard spectra precluded a more detailed examination of cadmium speciation.

Zinc and cadmium XANES spectroscopy were also performed on bulk sediments collected from Husky SW (Gault et al., 2013). The cadmium concentration was only high enough in the Husky SW adit sediment for cadmium XANES analysis, which again indicated that cadmium was likely present as a sorption complex. Relatively poor fits were obtained for the bulk zinc XANES, suggesting a model zinc phase was missing from our standard library, however, zinc sorbed on ferric oxyhydroxides comprised a sizeable fraction of the zinc inventory in most of the sediments analyzed. Chalcophanite ($(Zn,Fe,Mn)Mn_3O_7.3H_2O$) accounted for up to a third of the zinc speciation in the adit sediment, while moving downstream, zinc complexed with humic acid became more prominent, perhaps reflecting more organic-rich conditions.

Figure 28 - (a) EMP images of banded iron- and manganese-rich areas within particles in a Husky SW thin section sample collected close to the adit. The distribution of zinc, manganese, sulphur and iron are also mapped. The red arrow indicates where (b) the EMP linescan was conducted, showing a close correlation between manganese and zinc concentrations.

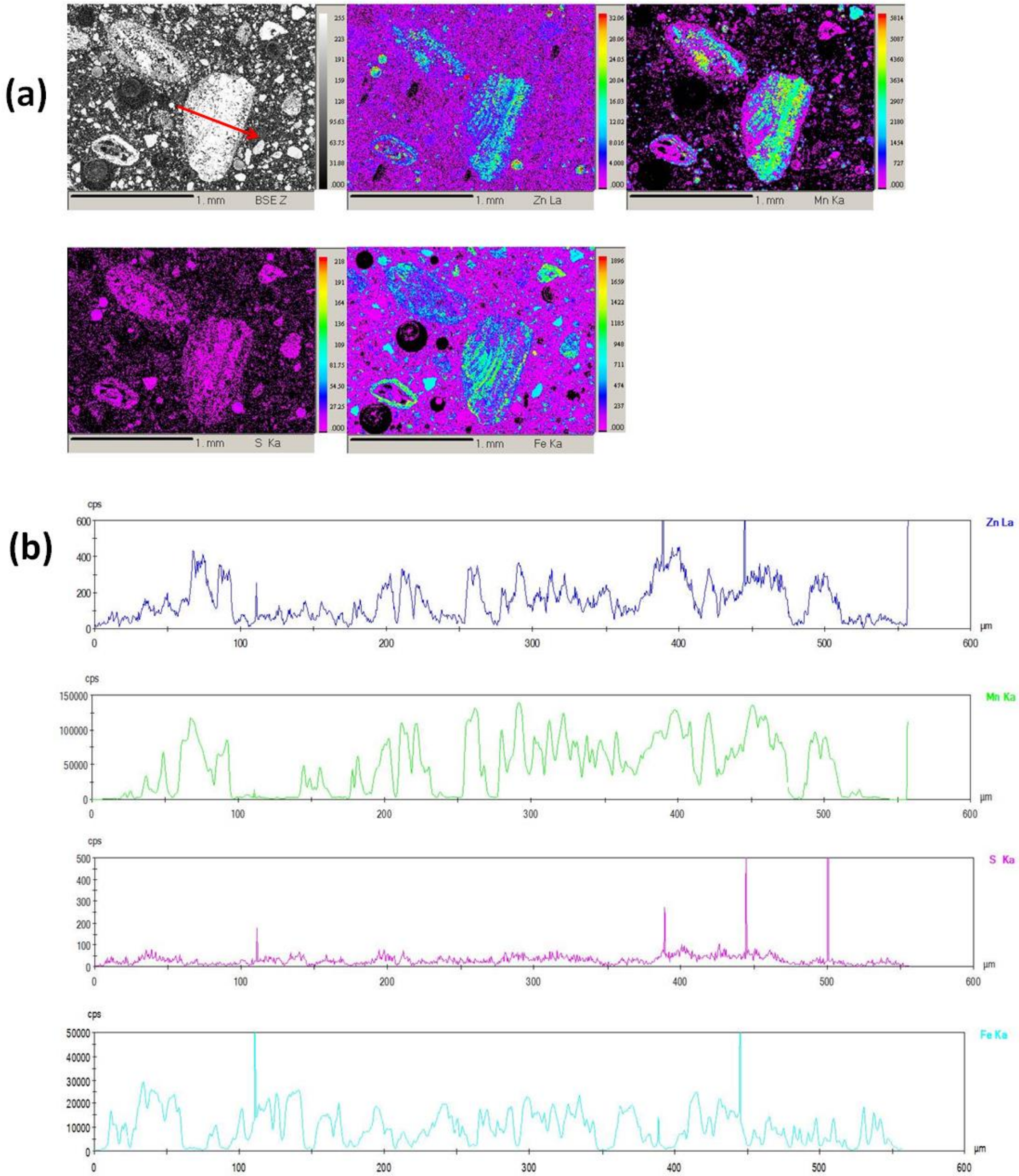


Figure 29 - (a) Backscattered electron image of a zinc-bearing particle in a Husky SW thin section sample collected close to the adit. (b) LA-ICP-MS raster line scan demonstrating the correlation between manganese, zinc and cadmium concentrations. Lead and arsenic concentrations also appear to follow those of iron.

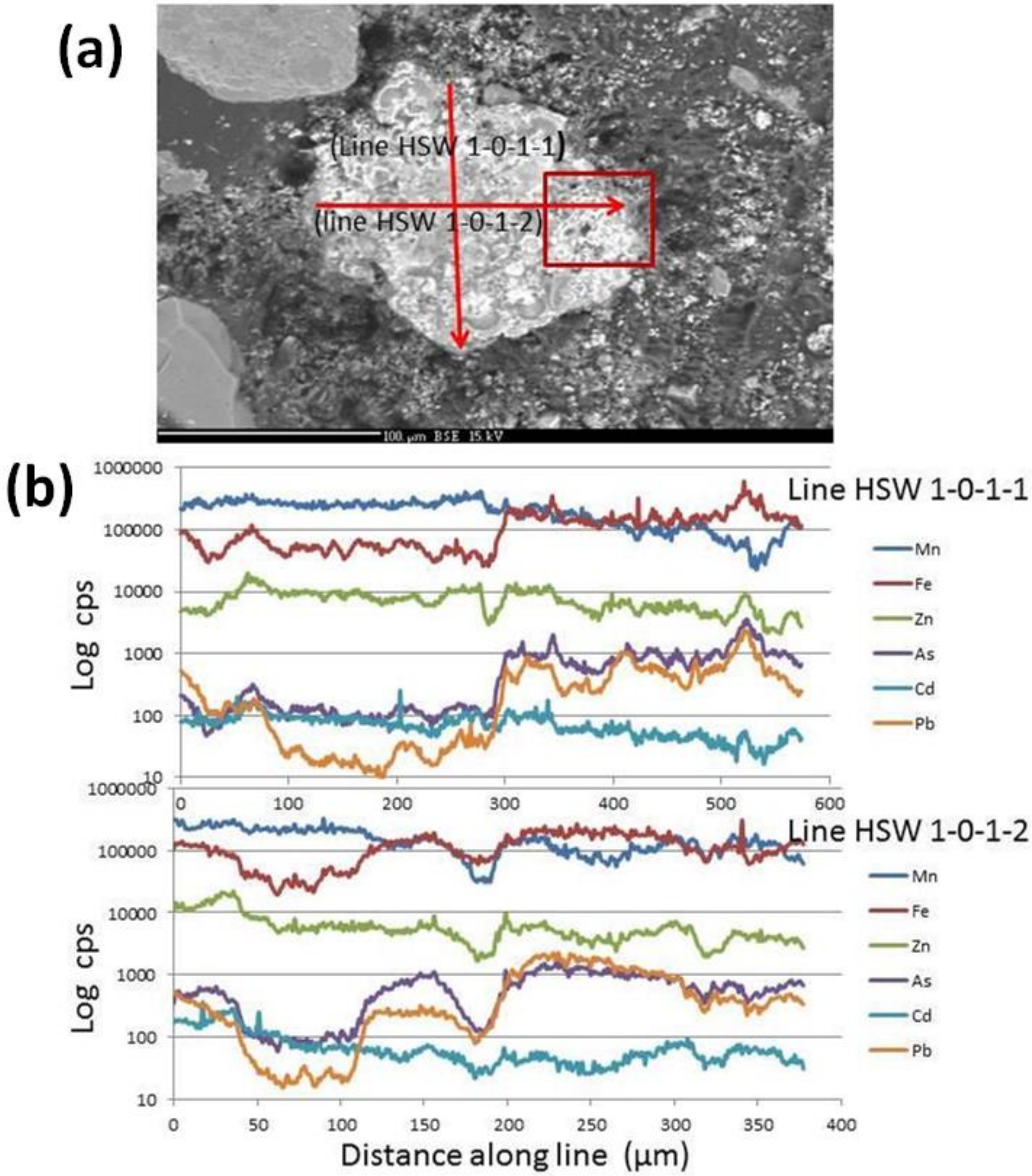


Figure 30 - Synchrotron-based µ-XRF imaging of the distribution of zinc, manganese and iron in a particle in a Husky SW thin section sample collected close to the adit.

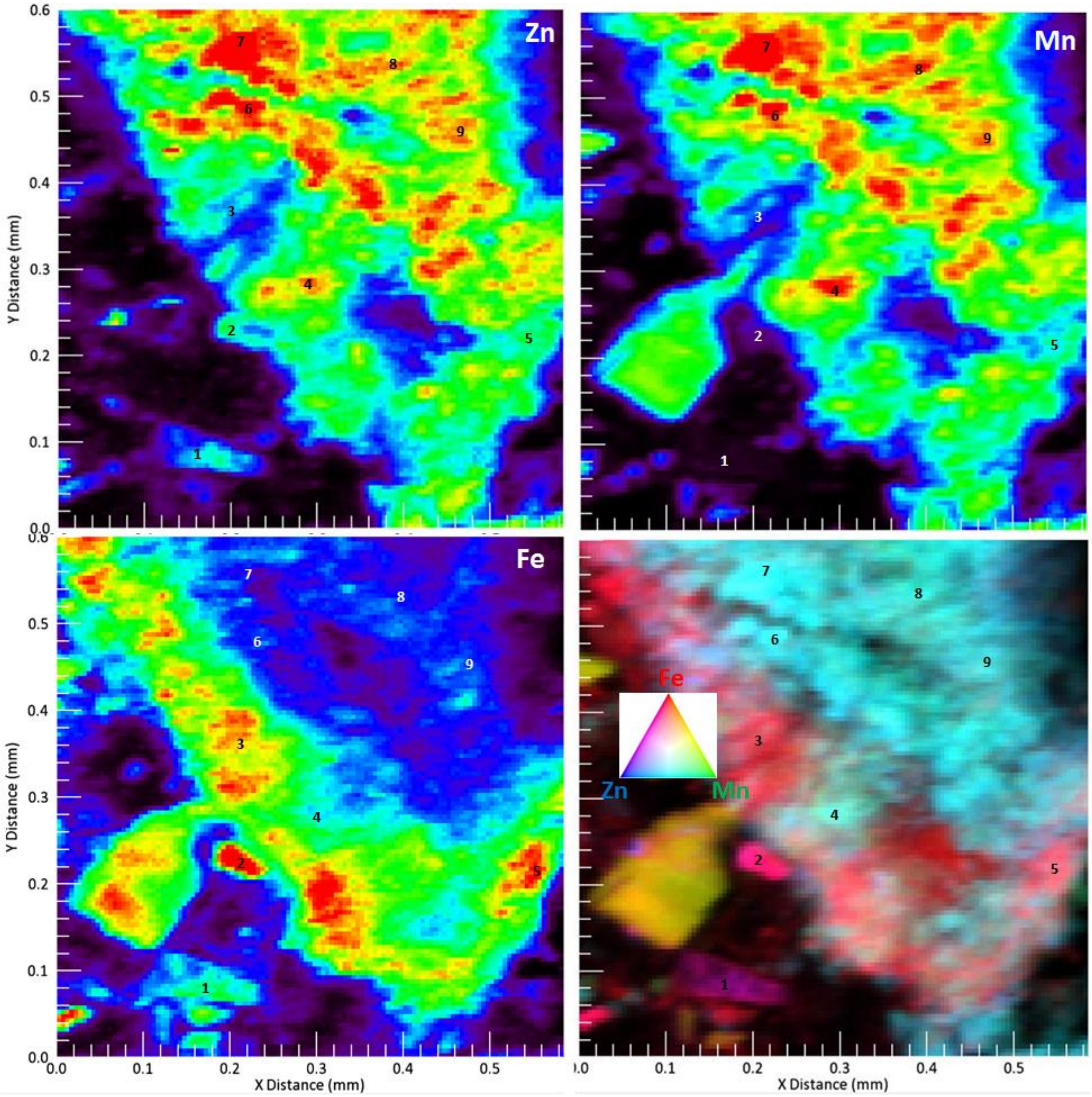
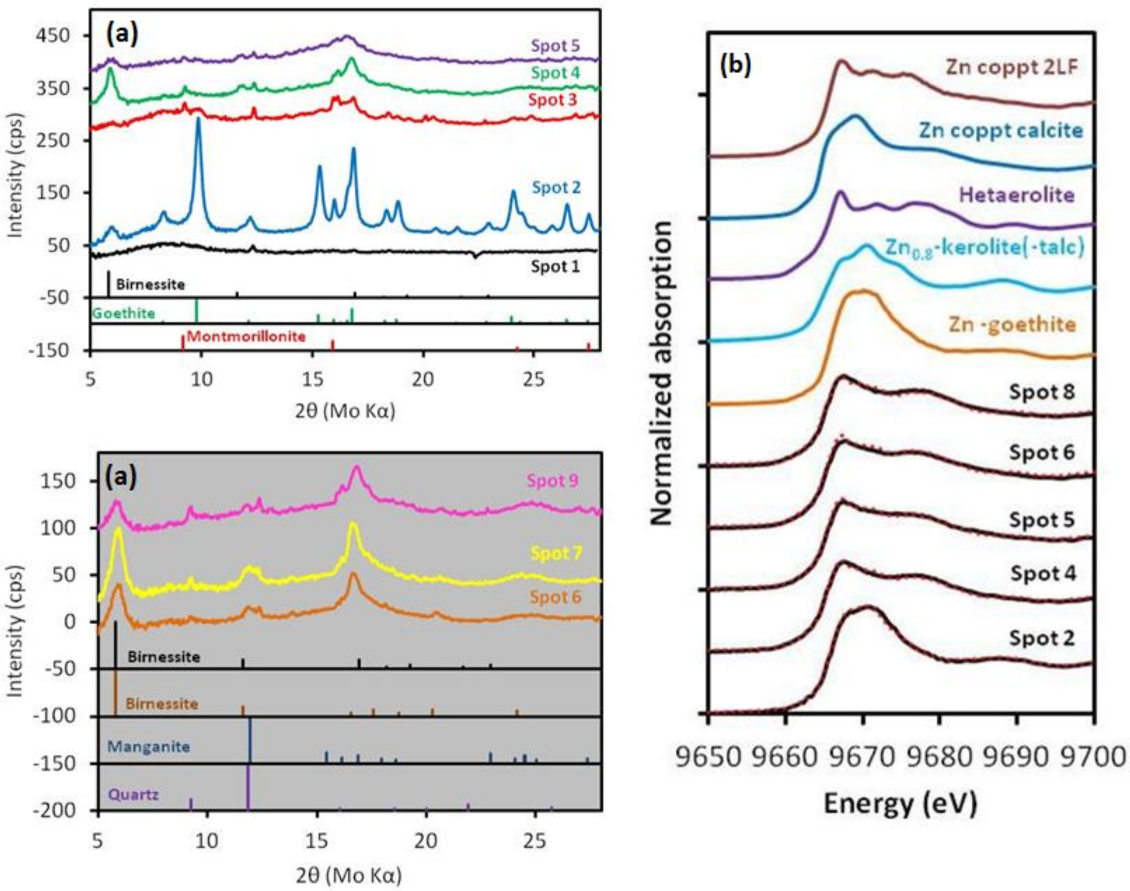


Figure 31 - Synchrotron based (a) μ-XRD and (b) zinc μ-XANES collected for the spots marked in Figure 30 for a Husky SW thin section sample collected close to the adit. The solid, black lines in (b) represent the sample data and dashed, red lines the best fit based on the combination listed in (c).



(c)	Proportion of Zn present as:				
	Hetaerolite	Coppt calcite	Coppt 2LF[b]	Sorbed goethite	$Zn_{0.8}$-kerolite (-talc)
HSW-1-0"					
Spot 2	-	-	-	72	26
Spot 4	49	32	19	-	-
Spot 5	40	25	34	-	-
Spot 6	56	29	16	-	-
Spot 8	62	38	-	-	-

3.3 VEGETATION METAL ACCUMULATION

A baseline study of metal concentrations in soil and vegetation samples collected in the KHSD was initiated in 2011, comprising two sampling seasons during the summers of 2011 and 2012 (Access, 2012, 2013). Alongside soil samples, leaves were collected from willow (*Salix* sp.) and Labrador Tea (*Ledum* sp.). These plant species were selected due to (1) their common occurrence across the KHSD; (2) their consumption by local wildlife that may in turn be consumed by humans (e.g. moose); (3) their use in traditional medicine; and (4) their ability to tolerate elevated metal concentrations in soils allowing them to grow along mine drainage impacted watercourses. Sampling sites included the natural attenuation study areas of No Cash Creek, Silver King and Husky SW, alongside off-claim control areas for use as background comparators. Only one bog blueberry (*Vaccinium uliginosum*) and one scrub birch (*Betula glandulosa*) leaf sample were collected near the NCC, Husky SW and Silver King watercourses, and no samples were collected at control sites, so these sparse data are not discussed further here.

3.3.1 NO CASH CREEK

Zinc concentrations in willow leaves collected along the reach of NCC (62 – 1820 mg/kg) were two to forty-nine fold higher than the average zinc concentration in willow leaves from the control sites (37 mg/kg). Cadmium concentrations in NCC willow leaves ranged from marginally above (1.1 mg/kg) to thirty-four times (34 mg/kg) the control site average concentration (1 mg/kg). Values for arsenic and lead followed similar trends. By contrast, metal concentrations in Labrador Tea leaves collected along NCC showed more limited extremes, ranging between two (17 mg/kg zinc) and eight (0.065 mg/kg cadmium) fold higher than the average metal concentrations of control site Labrador Tea leaves (8.9 mg/kg zinc; 0.008 mg/kg cadmium). This reflects the ability of willow species to hyperaccumulate cadmium and accumulate zinc.

3.3.2 HUSKY SW

Similar trends were observed in samples collected along the Husky SW watercourse. Willow leaf zinc (16 – 540 mg/kg) and cadmium (0.1 – 16 mg/kg) concentrations were up to fifteen and sixteen fold higher than the respective control site willow leaf average levels. However, the zinc and cadmium concentrations in Labrador Tea leaves collected in the Husky watershed were generally comparable to the control site average concentration.

3.3.3 SILVER KING

Zinc concentrations in willow leaves collected near the Silver King adit (59 – 210 mg/kg) exceeded the control site willow leaf average by two to six fold, while only one Silver King willow leaf sample (4.3 mg/kg) exceeded the cadmium control average. The highest willow leaf zinc and cadmium concentrations were found closest to the adit, and exceeded the associated soil metal concentrations, illustrating the (hyper)accumulator characteristics of willow species. The metal concentrations in Labrador Tea leaf samples collected near the Silver King adit were similar to those collected at the control sites. Willow leaves collected further downstream in Galena Creek also showed elevated zinc and cadmium concentrations that were up to five and seven times higher than the control sites, respectively. Willow leaves obtained from the tributary channels to Galene Creek generally contained similar metal concentrations to the control samples. Labrador Tea leaves exhibited background metal concentrations, regardless of their sample location within the Galena Creek watershed.

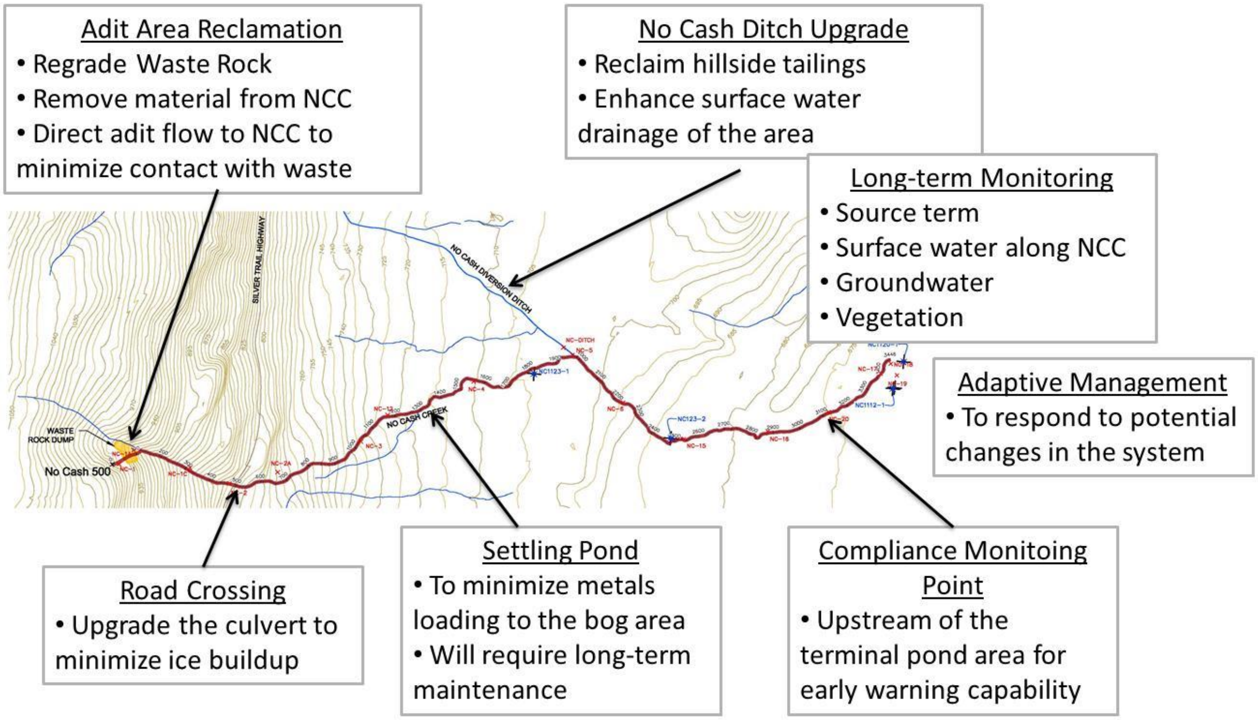
3.4 PRELIMINARY ENGINEERING SURVEY AND CLOSURE CONCEPTUAL MODEL

Figure 32 illustrates the closure conceptual model of the NCC natural attenuation area. This model summarizes the key closure concepts and considerations that could be incorporated into a designed natural attenuation treatment system. Some of the closure concepts are not exclusive to a natural attenuation closure scenario but were included below because they would be part of the natural-attenuation closure plan. The recommended engineering design should include:

1. Adit reclamation activities to effectively minimize mass load and control flow including:
    a. refurbishing the adit portal and discharge area to achieve safety goals. The refurbishment requirements for a natural attenuation scenario would include integration of a suitable flow capture structure (item “c” below).
    b. establish a flat discharge area near the adit to encourage local mineral precipitation reactions and to allow removal of precipitated solids
    c. design of an effective adit-flow capture and conveyance structure

   d. regrading of the waste rock dump and removing waste rock from the NCC channel to eliminate the waste rock as a potential direct source of additional metals mass.
2. Road crossing refurbishment to minimize ice-damming, scour, and road damage. Maintaining a consistent flow through potential bottlenecks will limit surges to the downstream natural attenuation areas.
3. No Cash Ditch refurbishment:
   a. Channel stabilization
   b. Reclamation of the catchment area to minimize metals loading to the ditch (and therefore to NCC)
4. Additional settling pond installation to capture particulate metals mass and minimize metals loading to the lower NCC. This could be a location for long term maintenance/sediment removal if desired or shown to be necessary by monitoring.
5. Long-term monitoring of the system at key locations along the flow path:
   a. Source term flow and chemistry at the adit
   b. Surface water chemistry along NCC at selected locations
   c. Groundwater chemistry in monitoring wells
   d. Vegetation (health and metals uptake)
6. Adaptive management to learn and react to the system as it is implemented and to potential changes in the future. Potential adaptive management activities include:
   a. Additional or reduced monitoring type and frequency
   b. Design adaptations to increase performance of engineered facilities such as settling ponds, conveyance structures, and water spreading areas. These would be considered on a case-by-case basis to considering cost-benefit and potential effects of additional disturbance due to access and construction.
   c. Short- or long-term active treatment with mobile units in response to upsets or long-term changes in the source term
   d. Alternative short or long-term passive treatment system (e.g. bioreactors)

Figure 32 - Natural Attenuation Closure Concepts for No Cash Creek



4 SUMMARY OF FINDINGS

4.1 NATURAL ATTENUATION PROCESSES

The primary hydrologic and (bio)geochemical processes responsible for metals attenuation are summarized in the following two sections. As the most intensively studied system, most attention is focused on NCC, however, the hydrological and (bio)geochemical processes that aid the natural attenuation of zinc and cadmium are similar at NCC and Husky SW. Since the adit water discharging from Silver King is already treated by a conventional lime water treatment plant, the processes responsible further attenuation of zinc and cadmium observed downstream are harder to discern, but are expected to be broadly similar.

4.1.1 HYDROLOGIC

Figure 33 illustrates the hydrologic mechanisms model of the NCC natural attenuation area. This model summarizes the key surface and groundwater processes related to metals attenuation and corresponding closure issues. These issues are described below and correspond to numbered points on the profile in Figure 33.

1. **Adit Reach (surface water)/Upper Hydrologic Area (groundwater) -** Water discharging from the adit spreads out on the waste rock bench and iron and manganese precipitates are formed as mats and sediment. The water cascades down the sides of the waste rock slopes and joins the NCC. Groundwater recharge occurs on Galena Hill, including from NCC where permafrost is not present. Minor increases in flow from the adit occur during freshet resulting in a slightly larger wet area on the waste rock bench. Winter conditions result in no surface flow from the adit portal, however, small flows were observed emanating from the waste rock lower on the slope.
2. **Cascading Reach (surface water)/Upper Hydrologic Area (groundwater) -** Cascading water results in highly aerated water and oxidized conditions, even during the winter months. Freshet flows are significantly higher yet still confined to the well-defined creek channel. Hydrologic conditions are very well suited to precipitation of metal oxyhydroxides. Depth to groundwater is generally shallower in the valley than on hillsides and mine workings.
3. **Transition and Bog Reaches (surface water)/Middle-Lower Hydrologic Area (groundwater) -** Braided and intermittent stream patterns dominate in these reaches Permafrost is ubiquitous in the bog reach. The resulting low-permeability permafrost horizon separates the shallow active zone and surface water flow from the deeper aquifer in the glacial sediments below. Freshet melt conditions result in the bog area becoming completely saturated and with larger areas of standing water in the lowlands. Winter conditions result in ice damming and complete blockage of the NCC channel in some areas, with flow being forced into shallow sediments beneath the ice. Bedrock groundwater discharges into the valley fill glacial sediments and generally flows toward the South McQuesten River.
4. **The surface expression of the Terminal Pond Area -** The NCC ends at the terminal pond, where the NCC water evaporates and infiltrates. Groundwater in this area is assumed to flow in a northerly direction toward the South McQuesten River. Groundwater monitoring wells completed in the terminal pond area show no chemical impacts from NCC infiltration; metals concentrations are low in the NCC terminal pond and groundwater is good quality.
5. **Terminal Pond to South McQuesten River -** Hummocky/thermokarst terrain between the terminal pond and the South McQuesten River has no developed surface drainage

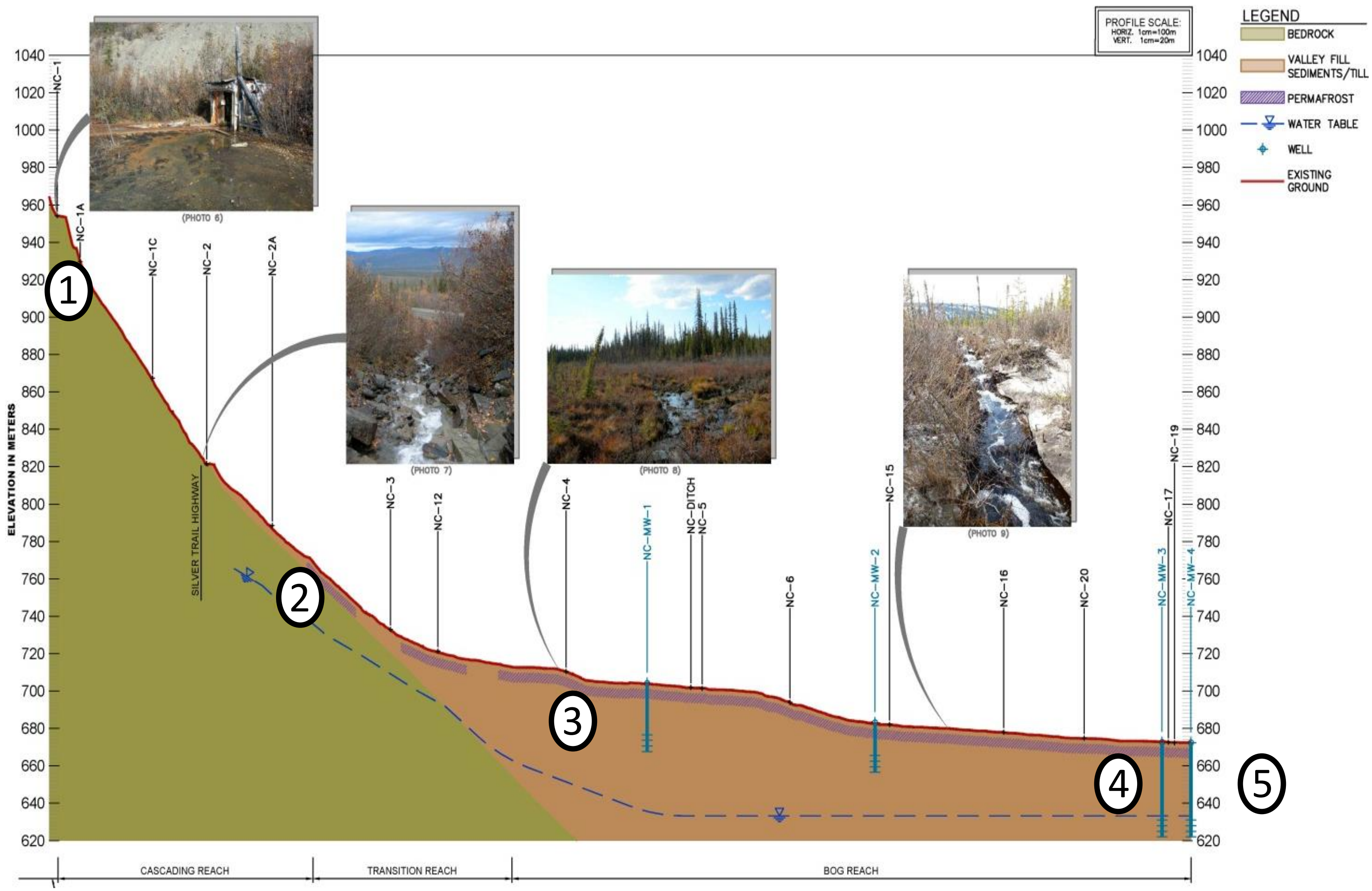
pattern and limited, if any significant runoff. The area is characterized by thick forest and well drained soils where infiltration of snowmelt recharges the glacial sediments below. The South McQuesten River serves as the discharge area for the basin for both groundwater and surface water.

4.1.2 (BIO)GEOCHEMICAL

The key geochemical mechanisms responsible for metals attenuation and relationship to potential closure issues are described below and correspond generally to numbered points on the profile in Figure 33.

1. Iron, manganese and zinc (oxyhydr)oxide minerals, notably ferrihydrite, birnessite and (hydro)hetaerolite, precipitate out of adit discharge water quickly resulting in significant dark orange/black sediment near the adit portal. These mineral reactions occur regardless of hydrologic or seasonal variability. Zinc is present as authigenic zinc-bearing mineral phases ((hydro)hetaerolite, hydrozincite), or co-precipitated/sorbed on iron and manganese oxyhydroxides. Cadmium is almost exclusively present as a sorption complex and although the sorbent could not be directly elucidated, the strong correlation between cadmium and zinc in the sediments suggests they have similar mineralogical hosts (likely iron and manganese oxyhydroxides). Surficial sediments, as well as buried sediments are of similar mineralogy and environmental stress testing of these sediments has indicated that elevated temperatures, pH and lowered alkalinity do not significantly impact the precipitate stability. A switch to reducing conditions in the stability testing did result in marked zinc and cadmium release to solution, however, the low organic carbon content of sediment in the adit reach/upper hydrologic area effectively restricts the development of such conditions within the sediment column. Furthermore, microbiological testing of these sediments indicated they had limited populations of metal- and sulphate-reducing bacteria.
2. Zinc and other metals continue to come out of solution along the cascading reach of the stream as oxyhydroxide phases. Geochemical mechanisms continue during hydrologic or seasonal variability. Suspended metals transport (as sediment and precipitated solids) occurs due to the high energy of NCC in this reach.

Figure 33 - No Cash Creek Hydrologic Profile



3. Similar geochemical reactions occur in the bog reach as in the upper, higher-energy reaches. However, the transition to a higher organic carbon content in stream sediment and surrounding soil horizons results in increased microbial activity and provides additional potential metals attenuation through sulphate reduction and metal-sulphide precipitation (e.g. sphalerite). Small (1 – 3 µm diameter) sphalerite granules have been identified in association with organic material in sediment thin sections and also in the peat itself. The increase in organic material (peat, wood, grasses, etc) also serve as important potential nucleation sites and micro-environments for supporting manganese and iron mineral precipitation reactions. Column experiments indicated that the NCC peat material is a highly effective sorbent, both in saturated and unsaturated conditions. It removed 99% of zinc and 94% of cadmium from 54 pore volumes of water pumped through peat-filled columns. As such, the peat bog may be viewed as a polishing step to the initial massive metals removal further upstream, adding redundancy to the natural attenuation process. Seasonal and hydrologic variability do not adversely affect the metals attenuation in this reach. Carbon accumulation in the bog is robust and consistent with observations from other comparable bogs, with carbon generation being more than sufficient for sustainable attenuation of all zinc generated from the No Cash Adit.
4. The terminal pond area shows very limited accumulation of metal precipitates as sediment. Total soluble zinc concentrations decline to a relatively constant low at about 0.1 mg/L approximately 1 km upstream of the terminal pond.
5. Elevated concentrations of total or dissolved metals are not observed in the monitoring wells adjacent to the terminal pond.

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APPENDIX 2
SUPPORTING ENVIRONMENTAL DATA

KENO HILL SILVER DISTRICT STREAM DISCHARGE MONITORING AND AUTOMATED STREAM DISCHARGE MONITORING 2016 REPORT

Revision 0

Deliverable Number 2016-17-009-7/8_01

31 January 2017

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

ALEXCO ENVIRONMENTAL GROUP SIGNATURES

Report prepared by: ______________________ January 31, 2017

Anthony Bier
Hydrologist

Date

Report reviewed by: ______________________ January 31, 2017

Kai Woloshyn
Environmental Manager

Date

EXECUTIVE SUMMARY

This report meets the requirements for deliverables as specified in the workplans for tasks ERDC 009-7 and ERDC 009-8 through the provision of the hydrometric monitoring results from the 2016 field season. In accordance with the work plans eight hydrometric monitoring stations were maintained through semi-annual visits including winterizing and surveys. Monthly monitoring was carried out by Alexco Environmental Group Inc. (AEG) Whitehorse personnel with assistance from Na-Cho Nyak Dun First Nation.

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1 INTRODUCTION

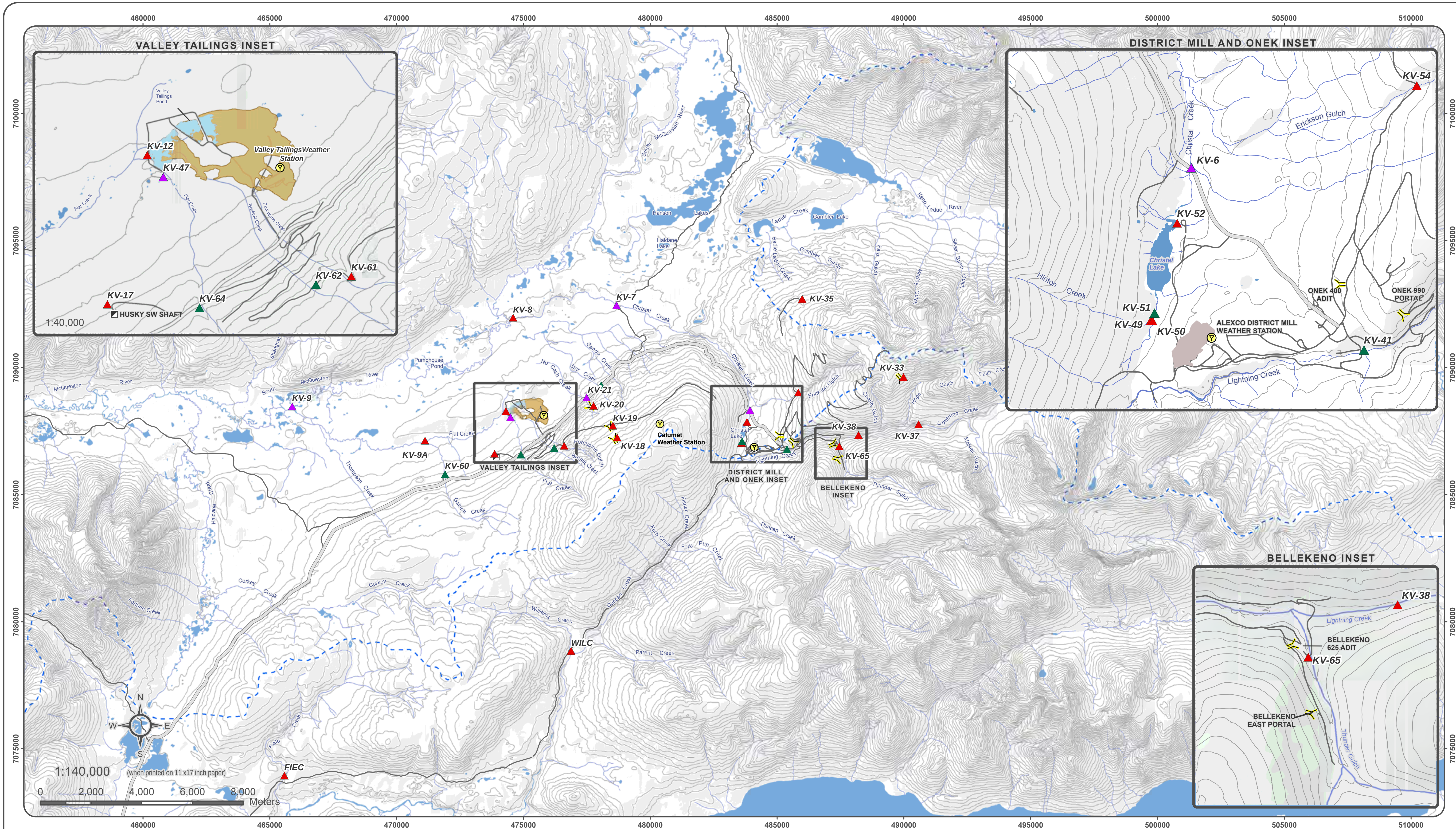
This report presents the surface water discharge data collected in the Keno Hill Silver District (KHSD) during 2016 as part of a site wide hydrometric and water quality program. Table 1 lists the discharge site names and their descriptions as well as the monitoring type and sampling schedule. Most sites require discharge to be measured whenever possible during monthly water quality sampling events, though conditions may occassionally not permit discharge measurements during the ice covered season.

There are eight hydrometric monitoring stations with stilling wells and staff gauges. Formerly there were ten sations, but two stations, KV-62 and KV-47, were not providing reliable data due to unfavourable stream conditions and were decommissioned in 2016. At the eight operational stations, automated water level recorders are deployed in stilling wells to provide a continuous water level record during the ice-free season with interpolated winter data. Alexco Environmental Group Inc. (AEG) personnel from Whitehorse conducted sampling of these sites, with assistance from Nacho Nyak Dun First Nation (NNDFN) environmental monitors. Historic data are included in this report for completeness.

The following is a brief overview of the field program followed by results sections describing the continuously monitored hydrometric stations in more detail. There are four appendices to present that data including: Appendix A, 2016 discrete measurements; Appendix B, Historic discrete measurements; Appendix C, Hydrographs; and Appendix D, Photographs. Figure 1 provides an overview of the hydrometric sampling network.

Table 1 – Surface water sites sampling schedule and type.

Site	Description	Sampling Schedule	Continuous (Y/N)
KV-6	Christal Creek at Silver Trail Highway	monthly	**Y**
KV-7	Christal Creek at Hanson Road	monthly	Y
KV-8	Christal Creek at mouth	monthly	N
KV-9	Flat Creek upstream of South McQuesten River	monthly	Y
KV-9A	Flat Creek between Valley Tailings & KV-9	monthly	N
KV-12	Valley Tailings Pond #3 Decant	monthly	N
KV-17	Husky Southwest Adit	monthly	N
KV-18	Bermingham Adit	monthly	N
KV-19	Ruby Adit	monthly	N
KV-20	No Cash 500 Adit	monthly	N
KV-21	No Cash Creek at Silver Trail Highway	monthly	Y
KV-33	Keno 700 Adit	monthly	N
KV-35	Sadie Ladue Adit	monthly	N
KV-37	Lightning Creek upstream of Hope Gulch	monthly	N
KV-38	Lightning Creek upstream of Thunder Gulch	quarterly	N
KV-41	Lightning Creek upstream of bridge at Keno City	monthly	Y
KV-47	Porcupine Diversion Ditch downstream of Upper Flat Creek	quarterly	N
KV-49	Hinton Creek upstream of Christal Creek	monthly	N
KV-50	Christal Creek upstream of Hinton Creek	monthly	N
KV-51	Christal Creek downstream of Hinton Creek	monthly	Y
KV-52	Natural Spring to Christal Lake at Old Mackeno Pump house	monthly	N
KV-53	UN Adit	quarterly	N
KV-55	Sandy Creek at Silver Trail Highway	quartrly + winter months	N
KV-56	Star Creek at Silver Trail Highway	quarterly + winter months	N
KV-60	Galena Creek upstream of Silver King Adit	monthly	Y
KV-61	Porcupine Gulch at Calumet Road Crossing	monthly	N
KV-62	Brefault Creek upstream of Porcupine diversion ditch	quarterly	N
KV-64	Flat Creek at Silver Trail Highway	monthly	Y
KV-65	Thunder Gulch upstream of Bellekeno 625	monthly	N
KV-66	Klondike Keno Adit	quarterly	N
KV-72	South McQuesten River at McQuesten Lake	monthly	N
WILC	Williams Creek downstream of Duncan Creek Road	monthly	N
FIEC	Field Creek upstream of Duncan Creek Road	monthly	N



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

- Hydrometric Monitoring Station
- Automatic Hydrometric Monitoring Station with Barologger
- Automatic Hydrometric Monitoring Stations
- Weather Station
- Shaft
- Adit
- Watercourse
- Contour (100 feet)
- Watershed Divide
- Keno District Mill Site
- Valley Tailings
- Valley Tailings Ponds

ERDC

KENO HILL MINING DISTRICT

FIGURE 1

KENO HILL SILVER DISTRICT DISCHARGE MONITORING LOCATIONS

DECEMBER 2015

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2 METHODS

2.1 DATA COLLECTION OVERVIEW

Discharge measurements and staff gauge observations, if applicable, are taken during scheduled visits to the stations identified in Table 1. The velocity-area method is used for discharge measurements and taken with an electromagnetic current meter where and when suitable. Salt slug dilution gauging is used where a current meter is not suitable. These data are used to develop rating curves for computation of continuous water level data into derived continuous discharge records for the open water season. Discrete measurements during the winter allow the estimation of continuous winter low flows by drawing a recession curve through the observations. Continuous water levels are recorded at thirty minute or one hour intervals using Solinst Levelogger water level recorders in conjunction with Solinst Barologgers.

A typical hydrometric station installation consists of a cribbing structure (wood or metal) at least one graduated staff gauge, a stilling well (ABS or PVC), a pressure transducer (Solinst Levelogger), and bench marks (large spikes in tree bases or 6+ foot angle iron driven into the ground). Solinst Barologgers are used to compensate the Leveloggers and are shared between multiple stations. An example installation is shown in Figure 2.

Since 2012, all continuous hydrometric data have been processed using Aquatic Informatics' Aquarius time-series software; previous time-series and rating curve development was done in Microsoft Excel and, prior to 2011, by Clearwater Consultants Ltd.

More detailed methodology can be found in the AEG's *Standard Operating Protocol – Surface Water Hydrology – Data Collection and Management.*

Figure 2 – KV-64 hydrometric monitoring station, installed in September 2015, below the Silver Trail Highway

2.2 FIELD ACTIVITIES SUMMARY

AEG and NNDFN monitors conducted monthly site visits in 2016. Data are recorded manually in field books and transcribed into Excel templates for discharge calculation. AEG Whitehorse personnel provide data management and QA/QC for all data collected.

Hydrometric stations were de-winterized in May 2016 and winterized in September 2016. Continuous data are provided to late September 2016 as loggers are not routinely downloaded in winter due to weather conditions and complications with electronic equipment. The hydrometric stations are also surveyed during the two bi-annual maintenance trips. All stations remain in good condition. Data loggers were removed from stations KV-47 and KV-62 and these stations are now monitored quarterly during routine water quality data collection.

There was a greater emphasis in 2016 on gathering discharge from some historic adits which have few measurements and on gathering winter low flow discharge measurements on Sandy and Star creeks to better understand winter baseflow and groundwater. However, it became apparent that these sites lack measurements because they go dry or flows are so low measurement is not possible (i.e. less than 1-2 L/s). Visits to all sites in 2016 are recorded in Appendix A.

3 RESULTS

3.1 DISCRETE MEASUREMENTS

Appendix A lists discrete discharge measurements taken in 2016 for all sites listed in Table 1. Appendix B includes all discrete discharge observations to date at those same sites. Site visits in 2016 where no measurement was taken have also been included in Appendix B when relevant comments on hydrological conditions are included. Climatic conditions in the region present an exceptional challenge to gathering discharge measurements year around which can result in no observations during winter months.

3.2 HYDROMETRIC STATIONS AND CONTINUOUS MONITORING

There were eight hydrometric stations active during the 2016 monitoring season including: KV-6, KV-7, KV-9, KV-21, KV-41, KV-51, KV-60, and KV-64. KV-51 and KV-64 have fewer rating measurements than other longer term sites and therefore there is greater uncertainty in the rating curves and derived discharge records at these sites.

All stations remain stable and did not require maintenance beyond surveys and stilling well de-silting. KV-21 requires removal of built up sediment on a monthly basis to ensure the weir pond does not fill up. KV-60, Galena Creek above Silver King, was relocated in 2014 and though the gradient of the stream lends some uncertainty to the rating curve it continues to provide a continuous derived discharge record. KV-7 and and KV-41 are both older stations with wooden cribbing structures. These stations should be replaced with metal cribbing and new stilling wells and staff gauges in the next 2-3 years to bring them up to the standard of quality of the other stations and ensure continued stability.

All hydrometric stations now yield year round continuous data; although the winter is estimated based on monthly discrete measurements. In 2016 continuous discharge data are available for all eight hydrometric stations.

3.2.1 KV-6 CHRISTAL CREEK ABOVE SILVER TRAIL HIGHWAY

The hydrometric station on Christal Creek at KV-6 is above the Silver Trail highway and several hundred metres downstream of Christal Lake. The catchment area is ~6.1 km^2 with a median elevation of ~1002 metres above sea level (masl). Instantaneous discharge measurements have been collected since June 2008 on a monthly basis where possible.

A Solinst water level recorder was deployed at KV-6 in a stilling well on July 20th 2011 and retrieved on October 23rd 2011. There was one discharge measurement taken during the continuous water level record but no staff gauge was installed.

The 2012 Solinst Levelogger record begins May 1st and extends till mid-October. Ice begins to affect the pressure readings on October 10th making water levels and derived discharge following that unreliable (Figure C1, Appendix C). A staff gauge was installed along with the Levelogger on May 1st with a corresponding BaroLogger (barometric pressure data logger). After mid-July the record becomes unreliable due to a ponding effect (Figure C1, Appendix C).

In 2013, the KV-6 station was moved upstream due to the ponding encountered from the road culvert in 2012, but due to infrequent measurements a continuous record could not be produced. Furthermore, the station was moved again in September 2013 to a more stable reach with a better control section more favourable to measuring flow. The current location remains relatively stable and free of backwater effects.

Reliable stage records began at the new location in late May 2014 (Figure C2, Appendix C) and a derived discharge record has been produced continuously since that time. Winter records are approximated by drawing a line through discrete measurements as appropriate or manipulation of the record relative to the discrete measurements, taking into consideration higer winter measurement uncertainty. The peak annual discharge in 2015 at KV-6 was 0.353 m^3/s on May 11th, 2015 (Figure C3, Appendix C). Figure C4 (Appendix C) shows the 2016 hydrograph including the peak, 0.280 m^3/s, on April 27th, 2016.

Table 2 shows instantaneous discharge measurements taken since 2008 at KV-6, while Table 3 shows all monthly means where continuous data are available. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 2 - Instantaneous discharge measurements at KV-6, Christal Creek below Christal Lake (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2008						0.064	0.130	0.119	0.080	0.161		
2009						0.124	0.101	0.114	0.103	0.033		
2010					0.071		0.094	0.061	0.141	0.094		
2011					0.136	0.080	0.091		0.127	0.088	0.075	0.107
2012		0.077		0.062	0.126	0.089	0.095	0.091	0.089	0.076		
2013						0.123	0.082	0.079	0.091	0.093	0.080	
2014			0.050	0.052	0.143	0.059	0.100	0.063	0.110	0.102	0.080	
2015	0.104		0.07	0.056	0.324	0.106	0.100	0.125	0.137	0.092	0.147	0.142
2016	0.130	0.067	0.086	0.071	0.170	0.104	0.098	0.180	0.122	0.094	0.087	
Mean	0.058	0.077	0.060	0.057	0.160	0.092	0.099	0.093	0.110	0.092	0.096	0.068
95% Confidence limit	0.025	0.010	0.020	0.008	0.069	0.017	0.009	0.027	0.014	0.021	0.026	0.034

Table 3 – Mean Monthly Discharge at KV-6, Christal Creek below Christal Lake, for months where continuous data are available (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2012					0.123	0.089	0.102					
2013												
2014					0.063	0.096	0.073	0.117	0.115	0.107	0.081	0.077
2015	0.092	0.078	0.066	0.084	0.185	0.110	0.119	0.123	0.128	0.116	0.115	0.107
2016	0.101	0.09	0.072	0.115	0.127	0.110	0.136	0.154	0.127			
Mean	0.097	0.084	0.069	0.100	0.125	0.101	0.108	0.131	0.123	0.112	0.098	0.092
95% Confidence limit	0.009	0.012	0.006	0.030	0.049	0.010	0.026	0.022	0.008	0.009	0.033	0.029

3.2.2 KV-7 CHRISTAL CREEK AT HANSON-MCQUESTEN LAKES ROAD BRIDGE

Christal Creek at KV-7 drains an area of ~35.8 km^2 with a median elevation of ~970 masl and includes KV-6, KV-51 and Christal Lake. There are a number of old workings within the watershed including Galkeno 300, Galkeno 900, Brewis Red Lake, Lucky Queen, Klondike Keno and, at least partially, Onek 400. Additionally, the Alexco District Mill, the Silver Trail Highway and parts of Keno City including the Keno City dump are at least partially within the watershed. It includes both a major east facing slope of Galena hill and west facing aspects of Sourdough hill.

Clearwater Consultants Ltd. (CCL) processed and summarized the data for 2004 - 2009 (CCL 2008; 2010). Data for 2010 and 2011 were processed by AEG following the same methodology as CCL. AEG has utilized Aquarius time series software since 2012 to manage the hydrometric data at KV-7. Mean monthly discharge is shown since 2003 at KV-7 in Table 4. Figure C55 to Figure C1011 (Appendix C) show the hydrographs for 2010, 2011, 2012, 2013, 2014, 2015, and 2016, respectively. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

The 2016 hydrograph shows a substantial peak in late April associated with freshet as well as a several peaks throughout the summer and fall associated with storm events. The peak annual discharge was 2.026 m^3/s captured on July 26th, 2016 as a result of summer rain storms (Figure C10, Appendix C). KV-6 did not show the same peak, which is assumed to be as a result of the dampening effect of the lake.

Table 4 – Mean Monthly Discharge at KV-7, Christal Creek at Hanson-McQuesten Road Bridge (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2003								0.42	0.51			
2004			0.15	0.166	1.153	0.314	0.119	0.112	0.163	0.135	0.103	0.101
2005		0.122	0.112	0.391	1.54	0.264	0.294	0.398	0.335	0.259	0.189	0.150
2006	0.166	0.138	0.117	0.124	1.089	0.519	0.397	0.278	0.415	0.368	0.203	0.142
2007	0.151	0.12			0.757	0.327	0.54	0.218	0.335	0.154		
2008								0.43	0.333	0.352		0.134
2009	0.079	0.068	0.048	0.074	1.123	0.338	0.102	0.183	0.368			
2010					0.309	0.24	0.359	0.23	0.232	0.186		
2011					1.26	0.142	0.503	0.419	0.268	0.173	0.126	
2012	0.154	0.078			0.730	0.258	0.400	0.217	0.267	0.200		
2013	0.075	0.066				0.285	0.126	0.08	0.332	0.227	0.140	0.110
2014	0.097	0.103	0.086	0.077	0.740	0.430	0.195	0.573	0.351	0.220	0.176	0.140
2015	0.089	0.072	0.059	0.165	1.091	0.192	0.368	0.517	0.614	0.271	0.165	0.137
2016	0.125	0.125	0.081	0.268	0.580	0.266	0.560	0.692	0.541			
Mean	0.117	0.099	0.093	0.181	0.943	0.298	0.330	0.341	0.362	0.231	0.157	0.131
95% Confidence limit	0.025	0.018	0.026	0.084	0.207	0.057	0.093	0.095	0.065	0.045	0.027	0.013

Note: Grey numbers are discrete discharge measurements (included in means Oct-Apr).

3.2.3 KV-9 FLAT CREEK NEAR THE MOUTH

The Flat Creek headwaters originate on the Northwest face of Galena Hill above the former Elsa town site. Flat Creek at KV-9 also includes Thompson, Galena, Porcupine and Brefault Creeks. Flowing adits and shafts within the Flat creek watershed include, but are not limited to, Silver King and Husky Southwest. The former Elsa town site and the Valley Tailings Facility are also situated within the Flat Creek watershed making it one of the more heavily anthropogenically modified watersheds in the district. The total drainage area of Flat Creek is ~56.5 km^2 with a median elevation of ~830 masl. Station KV-9 is located just above the confluence of Flat Creek with the South McQuesten River approximately 10 km east of Elsa. In recent years, Flat Creek at KV-9 has remained open all winter allowing for accurate low flow measurements with a velocity meter and applicable stage observations. This is an extremely valuable site because of this feature.

Mean monthly discharge values from derived continuous discharge records for KV-9 are presented in Table 5 with some spot flows included as estimates where noted. Figure C122 to Figure C178 (Appendix C) show the discharge time series for 2010, 2011, 2012, 2013, 2014, 2015, and 2016, respectively. The 2016 hydrograph captured the freshet flow with a maximum observed flow of 2.370 m^3/s on May 4th, 2016 (Figure C168, Appendix C). Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 5 – Mean Monthly Discharge at KV-9, Flat Creek near the Mouth (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004								0.116	0.099	0.11	0.046	0.034
2005	0.03	0.028	0.126	0.273	2.077	1.017	0.282	0.34	0.33	0.28		
2008								0.545	0.375	0.448	0.129	0.09
2009	0.053	0.029	0.02	0.01	2.155	0.51	0.088	0.092	0.364			
2010						0.133	0.171	0.086	0.118	0.099		
2011					1.97	0.349	0.927	0.756	0.364	0.299		
2012				0.014	1.574	0.430		0.208	0.361	0.276		
2013					2.825	0.636	0.159	0.084	0.102	0.411	0.081	
2014					1.856	0.520	0.204	0.786	0.535	0.559	0.06	0.015
2015	0.009	0.007	0.01	0.102	1.927	0.178	0.31	0.511	0.873	0.423	0.131	0.057
2016	0.021	0.009	0.001	0.538	1.011	0.202	0.402	0.758				
Mean	0.028	0.018	0.039	0.187	1.924	0.442	0.318	0.389	0.352	0.312	0.092	0.049
95% Confidence limit	0.018	0.012	0.057	0.196	0.356	0.180	0.184	0.172	0.144	0.111	0.044	0.032

Note: Grey numbers are discrete discharge measurements (included in means Oct-Apr).

3.2.4 KV-21 NO CASH CREEK AT THE SILVER TRAIL HIGHWAY

No Cash Creek flows just northeast of Elsa and has a catchment area of ~1.4 km^2 at the Silver Trail Highway (KV-21). The median elevation is ~1212 masl and includes the No Cash 500 adit (KV-20), which is free draining. Calumet Drive (Galkeno 300 Road) bisects the catchment and two culverts convey water at different locations. The physical area of the catchment is a product of the road cut and associated culverts. It is possible that freshet flows may be reduced as a result of water bypassing frozen culverts and being directed into Porcupine Creek.

However, direct observations during this period are absent, but frozen culverts during freshet have been observed at other sites in and around Elsa (e.g. Porcupine diversion along Calumet Drive). Table 6 shows the discrete measurements gathered to date at KV-21.

Previous attempts at continuous gauging at KV-21 have not been successful due to heavy icing and a steep dynamic channel near the Silver Trail Highway. High water velocities, ice and machinery have all contributed to damage to the stilling wells and general channel instability. In September 2013, AEG and AKHM personnel installed a new station approximately 150 m below the Silver Trail Highway where the channel has a lower gradient. An artificial control was installed to create a step pool and provide a convenient place to measure water level. However, flows were so low in 2014 that stage changes were insufficient to establish a reliable rating curve. In June of 2015, AEG Whitehorse personnel installed a V-notch weir to garner reliable continuous data (Figure 3). The weir has provided a high confidence rating curve and continuous discharge has been successfully derived since installation. The highest discharge measured with the logger was 0.081 m^3/s on August 11th as the weir was not installed until after freshet. Figure C19 (Appendix C) shows the 2015 hydrograph but the freshet peak was not captured; however, a discrete measurement of 0.244 m^3/s was measured on May 14th, 2016 during freshet. Freshet was not as large in 2016 but peaked at 0.164 m^3/s on May 2nd, 2016 (Figure C20, Appendix C). Discrete measurements are also included in Appendix A (2016) and Appendix B (all years).

Table 6 – Discrete Discharge measurements at KV-21, No Cash Creek at the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2007							0.015					
2008								0.007				
2009							0.003			0.006		
2010					0.010	0.008	0.007			0.008		
2011					0.020		0.005	0.011				
2012		0.002					0.012					
2013									0.016	0.017	0.004	
2014					0.058	0.005	0.005	0.011	0.026	0.013	0.007	
2015	0.003			0.002	0.244	0.011			0.035	0.017	0.002	0.010
2016	0.005	0.004	0.006	0.003	0.049	0.016	0.022	0.045	0.025	0.010	0.006	0.006
Mean	0.004	0.003	0.006	0.002	0.076	0.010	0.010	0.019	0.026	0.012	0.005	0.008
95% Confidence limit	0.002	0.002	N/A	0.001	0.084	0.005	0.005	0.018	0.008	0.004	0.002	0.004

Figure 3 – Weir at KV-21, June 2015

Table 7 – Mean Monthly Discharge at KV-21, No Cash Creek at the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015						0.010	0.017	0.020	0.027	0.016	0.004	0.008
2016	0.005	0.004	0.005	0.01	0.044	0.017	0.019	0.019	0.019			
Mean	0.005	0.004	0.005	0.010	0.044	0.014	0.018	0.020	0.023	0.016	0.004	0.008

3.2.5 KV-41 LIGHTNING CREEK AT KENO CITY BRIDGE

Lightning Creek at KV-41 has a catchment area of ~59 km^2 and a median catchment elevation of approximately ~1400 masl. Lightning Creek originates east of Keno City and drains the southern aspect of Keno Hill and the northern aspect of Mount Hinton. Lightning Creek flows to the south of Galena Hill into Duncan Creek. Within the Lightening Creek watershed are multiple adits including Keno 200 and 700, multiple old surface workings, Bellekeno workings and active placer mining on Thunder Gulch.

Hydrometric station KV-41 is located above the Keno City Bridge, and downstream of the Bellekeno Mine and local placer mining activity. Figure C2121 through Figure C256 (Appendix C) show the discharge time series for 2010, 2011, 2012, 2014, 2015, and 2016, respectively. Due to a logger failure in 2013 no continuous discharge was available.

Figure C256 (Appendix C) shows the 2016 hydrograph at KV-41 which includes the peak annual discharge 6.334 m^3/s captured June 7th, 2016. As with previous years the peak occurred later on Lightening Creek, presumably due to a lag in snowmelt associated with the higher median elevation of the Lightening Creek Catchment.

Table 8 presents mean monthly data gathered since continuous data collection began and includes discrete discharge measurements in grey in lieu of monthly means where data are unavailable. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 8 – Mean Monthly Discharge at KV-41, Lightening Creek above Keno City Bridge (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004								0.433	0.315	0.24	0.153	0.125
2005	0.098	0.067	0.056	0.13	1.802	1.418	0.989	1.111	0.958	0.637	0.452	0.299
2006	0.219	0.192	0.194	0.272	0.793	1.994	1.326	0.921	1.083	0.889	0.554	0.447
2007					1.231	1.926	1.193					
2008								1.136	0.77	1.03		
2009		0.11	0.128	0.069	1.595	1.628						
2010					1.172	1.383	1.007	0.76	0.57	0.457		
2011						1.206	1.826	1.542	0.926			0.268
2012	0.251	0.159	0.182			2.096	1.404	0.707	0.869	0.566		
2013						1.901	0.71	0.437	0.774	0.766	0.421	0.174
2014	0.149	0.126	0.096		1.25	1.746	0.703	1.264	0.851	0.614	0.336	0.212
2015	0.198	0.198	0.197	0.195	2.487	1.178	1.035	1.377	1.544	0.735	0.388	0.217
2016	0.201	0.211	0.21	0.217	1.27	1.862	0.924	1.246	0.785			
Mean	0.183	0.142	0.142	0.167	1.513	1.619	1.185	1.028	0.876	0.659	0.384	0.249
95% Confidence limit	0.044	0.039	0.044	0.069	0.356	0.192	0.211	0.220	0.181	0.152	0.108	0.077

Note: Grey numbers are discrete discharge measurements (Included in means Oct-Apr).

3.2.6 KV-51 CHRISTAL CREEK DOWNSTREAM OF HINTON CREEK

In 2015, a new hydrometric station was commissioned above Christal Lake to better quantify the water balance of Christal Lake. Provisional data were provided in 2015 and the rating curve was updated for 2016. The 2015 hydrograph begins in early June when the station was established and shows similar event peaks to lower Christal Creek sites, but unfortunately did not capture freshet. However, a discrete measurement of 0.116 m^3/s was taken May 12th during the freshet period (Figure C27, Appendix C). As at KV-7 freshet did not produce the peak annual flow at KV-51; peak discharge occurred on July 25th, 2016 at 0.136 m^3/s (Figure C28, Appendix C). Table 9 summarizes the continuous data collected to date as mean monthly discharge while discrete measurements are included in Appendix A (2016) and B (historic).

Table 9 – Mean Monthly Discharge at KV-51, Christal Creek downstream of Hinton Creek (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015						0.024	0.029	0.034	0.045	0.038	0.035	0.034
2016	0.033	0.031	0.031	0.036	0.053	0.043	0.052	0.067	0.053			
Mean	0.033	0.031	0.031	0.036	0.053	0.034	0.041	0.051	0.049	0.038	0.035	0.034

3.2.7 KV-60 GALENA CREEK ABOVE SILVER KING ADIT

Galena Creek is southwest of Elsa and the upper reaches of the watershed boarder those of Flat Creek with northwest aspect. KV-60 is located below the Silver Trail Highway and adjacent to the Silver King 100 Adit. Treatment water from Silver King does not influence KV-60. The catchment at KV-60 is ~9.4 km^2 with a median elevation of ~997 masl. The channel is deeply incised and flows through a rocky canyon just above the Silver Trail Highway and is characterized by large boulders and step pools, not dissimilar to Flat Creek. The historic Silver King 75 adit is located in the canyon above the highway.

Continuous hydrometric monitoring at KV-60 has been challenging due to the high gradient and flow velocity of the site. Large gravel and cobbles are frequently transported at this. The stream morphology can change each season during freshet compounding data collection challenges. KV-60 was re-established and resurveyed in September 2013 in conjunction with some channel modifications in an attempt to establish a stable control using large rocks in the channel. In September 2014 the channel was modified in an effort to minimize deposition of gravel around the staff gauge, once again altering the stage-discharge relationship. In June 2015 is was found that these efforts had ultimately failed to create favourable conditions for the reach and a decision was made in the field to establish a new staff gauge in the pool just above without any modifications to the natural arrangement of the channel as it was observed that this pool seemed to be stable over the preceding years.

Hydrographs for 2012, 2013, 2014, 2015 and 2016 are included in Appendix C; Figure C29 to Figure C33 respectively. The 2015 hydrograph peaks on May 13th at 4.40 m^3/s which is the highest reliable data point measured to date (Figure C32, Appendix C). Freshet peaked much lower in 2016 at 0.725 m^3/s on April 2nd, 2016 (Figure C33, Appendix C). One discrete measurement in August of 2016 appears to disagree with the derived record, but the measurement showed high uncertainty (45%) so can be disregarded. Table 10 presents the mean monthly discharge since continuous data gathering began in 2012. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 10 - Monthly Discharge at KV-60, Galena Creek above Silver King Adit (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2012	0.007	0.004			0.386	0.039	0.095	0.046	0.065	0.025		
2013				0.994	0.891	0.315	0.018		0.045	0.078		
2014					0.039	0.144	0.017	0.234	0.104	0.112	0.026	0.016
2015	0.010	0.006	0.037	0.149	0.354	0.055	0.143	0.206	0.185	0.084	0.035	0.017

2016	0.013	0.009	0.012	0.117	0.268	0.058	0.094	0.116	0.113			
Mean	0.009	0.005	0.037	0.572	0.388	0.122	0.073	0.151	0.102	0.075	0.031	0.017
95% Confidence limit	0.003	0.003	0.024	0.563	0.274	0.101	0.048	0.084	0.047	0.036	0.009	0.001

Note: Grey numbers are discrete discharge measurements (Included in means Oct-Apr).

3.2.8 KV-64 FLAT CREEK AT SILVER TRAIL HIGHWAY

Flat Creek at the Silver Trail Highway is steep, rocky, and unstable. Water Quality measurements are gathered above the highway, but there is no suitable location for continuous gauging above the highway. Attenuation of peak flows occurs at the highway were significant deposition has covered older culverts and it is clear that water levels rise above the top of the culvert during freshet. Perhaps due to this effect or due to lessened anthropogenic influence the reaches below appear more stable and ultimately a station was established below the highway in September 2015 (Figure 2). The deposition above the highway was excavated and repairs were made to the culverts in 2016 to mitigate ponding above the highway during freshet. Continuous discharge was derived for 2016 and shows a peak on 0.334 m^3/s on May 9th, 2016 (Figure C34, Appendix C). However, due to the lower number of rating measurements there is still greater uncertainty at this site compared to other long term stations in the district. Table 11 presents the mean monthly discharge from the period of the derived discharge record. Discrete measurements are included in Appendix A (2016) and Appendix B (all available)

Table 11 – Mean Monthly Discharge at KV-64, Flat Creek below the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015									0.077	0.037	0.043	0.017
2016	0.007	0.004	0.003	0.029	0.115	0.037	0.047	0.065	0.048			

4 REFERENCES

Clearwater Consultants Ltd. 2008. Memorandum CCL-UKHM-1 United Keno Hill Mines – Hydrological Update and Assessment.

Clearwater Consultants Ltd. 2010. Memorandum CCL-UKHM-3 United Keno Hill Mines – Hydrological Update and Assessment.

APPENDIX A

DISCRETE DISCHARGE MEASUREMENTS 2016

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-6	Christal Creek u/s Silver Trail Highway	06/01/2016	14:45	129.6	0.1	
		02/02/2016	12:40	66.5	38.1	
		05/03/2016	15:13	86.1	2.6	
		06/04/2016	12:22	71.3	0.2	
		03/05/2016	5:18	169.5	4.4	0.265
		15/06/2016	10:37	103.5	7.1	0.215
		14/07/2016	14:20	98.1	4.4	0.226
		07/08/2016	9:21	180.3	1.1	0.294
		23/09/2016	10:00	112	2.6	0.248
		22/10/2016	14:50	93.7	5.1	0.314
		09/11/2016	17:45	86.7	4.1	
		03/12/2016	Entire staff gauge is under ice, overflow backed up from highway, could not find second location with flowing			
KV-7	Christal Creek at Hanson Road	09/01/2016	12:09	163.3	14.5	
		01/02/2016	12:10	144.9	1.6	
		03/03/2016	12:18	110.7	3.1	
		06/04/2016	11:01	100.1	9.6	
		03/05/2016	14:05	1006.1	0.3	0.695
		15/06/2016	9:03	256.5	3.8	0.425
		14/07/2016	12:56	518.7	1.2	0.54
		06/08/2016	16:07	574.8	16.7	0.602
		22/09/2016	12:32	473.4	0.5	0.549
		22/10/2016	13:41	207.2	3.9	
		09/11/2016	13:45	188.7	0.7	
		03/12/2016	10:54	236.5	0.9	
KV-8	Christal Creek at mouth	09/01/2016	10:58			
		01/02/2016	10:48			
		03/03/2016	11:09	166.1		
		06/04/2016	9:59	106.8		
		03/05/2016	12:36	1009.4		
		13/06/2016	15:34	330	10.2	
KV-8	Christal Creek at mouth	14/07/2016	11:39	501.7		
		06/08/2016	13:57	748.6		
		22/09/2016	10:05	465.7		
		22/10/2016	12:09	310.3		
		09/11/2016	11:28	141.6		

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-9	Flat Creek upstream of South McQuesten River	08/01/2016	11:13	47.4	17.7	
		02/02/2016	14:26	19.9	7.5	0.296
		04/03/2016				
		07/04/2016	9:35	20	19.2	0.282
		02/05/2016	13:37	1740.1	3.2	0.85
		13/06/2016	11:50	269.2	2.2	0.459
		13/07/2016	13:45	263	1.6	0.451
		05/08/2016	12:18	543.6	4.6	0.554
		22/09/2016	3:10	551.6	1.6	0.584
		21/10/2016	13:46	93	0.8	0.46
		08/11/2016	13:08	73.5	4.8	
		02/12/2016	9:35	30.7	4.5	0.299
KV-9A	Flat Creek u/s Galena Creek	08/01/2016				
		04/02/2016				
		04/03/2016				
		07/04/2016				
		05/05/2016	10:01	296.8		
		14/06/2016	9:55	148	7.6	
		15/07/2016	9:58	146.2		
		05/08/2016	14:34	204.6		
		24/09/2016	9:21	162.3		
		23/10/2016				
		08/11/2016	15:12	78.3		
		02/12/2016				
KV-12	Valley Tailings Pond #3 Decant	21/06/2016		21.80		
		19/07/2016		16.86		
		16/08/2016		7.87		
		25/09/2016		13.37		
		20/10/2016		12.55		
		31/10/2016		11.92		
KV-17	Husky South West Shaft	05/01/2016				
		03/02/2016		0		
		04/03/2016				
		02/05/2016		0		
		14/07/2016				
		21/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-18	Bermingham 200 Adit	05/01/2016	14:38	2		
		03/02/2016	10:04	2.4		
		05/03/2016	14:01	1.3		
		07/04/2016	15:54	1.1		
		05/05/2016	16:09	1.3		
		15/06/2016	14:10	2.8	6.3	
		14/07/2016	16:18	2.9		
		08/08/2016	13:18	9.9		
		24/09/2016	15:30	3.8		
		20/10/2016	13:12	2.7		
		11/11/2016	9:30	1.8		
		03/12/2016	13:42	6.9		
KV-19	Ruby 400 Adit	05/01/2016	15:26	4		
		03/02/2016	10:53	2.8		
		05/03/2016	13:25	2.7		
		07/04/2016	15:06	2.1		
		04/05/2016				
		05/05/2016	17:19	2.8		
KV-19	Ruby 400 Adit	15/06/2016	13:24	1.3	0.9	
		15/07/2016	9:24	2.3		
		08/08/2016	12:33	2.8		
		24/09/2016	14:12	3.1		
		20/10/2016	12:35	2.9		
		11/11/2016	8:54	2.9		
		01/12/2016	15:02	9.2		
KV-20	No Cash 500 Adit	09/01/2016	15:27	10.3		
		03/02/2016	13:02	4.9		
		05/03/2016	12:44	4.1		
		07/04/2016	14:12	3		
		05/05/2016	14:00	4.4		
		14/06/2016	14:56	10	10.3	
		17/07/2016	9:02	10.7		
		05/08/2016	16:13	13.5		
		23/09/2016	13:35	11.5		
		23/10/2016	14:27	8.8		
		11/11/2016	11:15	5.5		
		03/12/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-21	No Cash Creek u/s Silver Trail Highway	09/01/2016	14:12	5.4	5.1	
		01/02/2016	13:24	3.6	9.2	
		06/03/2016	11:01	5.8		
		05/04/2016	16:26	2.7	6.7	
		04/05/2016	12:50	48.9	10.4	0.546
		16/06/2016	11:30	16.2	1.5	
		15/07/2016	13:55	21.6	2.8	0.458
		06/08/2016	17:18	45.2	9.1	0.503
		23/09/2016	11:59	25.1	13.7	0.45
		23/10/2016	11:30	10.2	3.7	
		10/11/2016	17:40	5.8	0	
		01/12/2016	12:24	6.2	3.5	
KV-33	Keno 700 Adit	07/01/2016	12:30	3.2		
		03/02/2016	15:25	0.42		
		05/03/2016		2.3		
		08/04/2016		2.3		
		19/05/2016	9:30	8.9		
		16/06/2016	10:47	5.8	9.4	0.156
		17/07/2016	11:02	6	5.6	
		08/08/2016	15:11	7.2	15.7	
		21/09/2016	19:49	6.6	3.3	
		20/10/2016	9:27	3.9	17.3	
		11/11/2016	13:22	4.3	4.2	
		04/12/2016	11:17	2.5	25	
KV-35	Sadie Ladue 600 Adit	07/01/2016	14:09	3.3		
		30/01/2016	10:51	3.9	0.5	
		05/03/2016	10:29	2.8		
		08/04/2016	9:54	2.8		
		18/05/2016	17:36	29.2	18.07	
		14/06/2016	17:39	15.8	2.5	
		17/07/2016	15:19	22.7	3.1	
		18/08/2016	16:23	47.3	0.4	
		24/09/2016	15:38	29.7	3	
		19/10/2016	17:36	13.9	3.1	
		09/11/2016	15:56	13	5.2	
		04/12/2016	12:37	11.1	1.6	

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-37	Lightning Creek u/s Hope Gulch	06/01/2016				
		08/02/2016	11:18	112.2	3.5	
		02/03/2016	10:24	102.5		
		08/04/2016	11:46	78		
		01/05/2016	13:20	92.8		
		16/06/2016	12:31	1180.2	0.5	
KV-37	Lightning Creek u/s Hope Gulch	12/07/2016	12:27	440.5		
		07/08/2016	Large beaver dam immediately above site, and small dam below, flooding banks and making poor conditions for measuring discharge, good spot for Q just d/s of sign			
		22/09/2016	14:01	489.6		
		20/10/2016	12:42	211.8		
		11/11/2016	14:31	187.8		
		04/12/2016	15:15	186.6		
KV-38	Lightning Creek u/s Thunder Gulch	08/02/2016	9:28	93.9		
		01/05/2016	11:32	156.4		
		12/07/2016	10:35	688.6		
		22/09/2016	13:09	702.3		
		20/10/2016	10:59	342.3		
KV-41	Lightning Creek u/s Keno City bridge	05/01/2016	12:03	200.3	2.6	
		02/02/2016	11:45	213		
		02/03/2016	9:38	228.8	4	
		06/04/2016	14:46	175.7	1	
		01/05/2016	10:19	236	0.9	0.065
		16/06/2016	9:33	1801.7	1.1	
		12/07/2016	9:45	884.1	5.7	0.144
		07/08/2016	12:58	1365.8	0.8	0.193
		22/09/2016	11:15	1049.5	4.6	0.159
		20/10/2016	10:10	521.5	2.2	
		08/11/2016	18:23	282.2	6.1	
		04/12/2016	14:36	320.7	2.2	
KV-47	Porcupine Diversion Ditch d/s Upper Flat Creek	04/02/2016				
		05/05/2016				0.208
		16/07/2016				0.282
		21/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-49	Hinton Creek upstream Christal Creek	03/02/2016		0		
		04/05/2016				
		15/07/2016				
		23/10/2016				
KV-50	Christal Creek upstream Hinton Creek	03/02/2016	13:48	24.7	1.7	
		04/05/2016	11:30	28.5	4.6	
		15/07/2016	14:38	33.1	20.3	
		23/10/2016	9:47	43.3		
KV-51	Christal Creek d/s Hinton Creek	06/01/2016	15:30	37		
		03/02/2016	13:17	25.3	2.3	
		02/03/2016	16:13	25.8	9.6	
		06/04/2016	16:11	19.2	16.6	
		04/05/2016	10:55	47	6	0.451
		15/06/2016	15:48	46.7	2.5	0.406
		15/07/2016	13:52	41.4	10.9	0.461
		07/08/2016	10:36	78.9	3.2	0.513
		23/09/2016	14:48	53.2	1.7	0.428
		23/10/2016	9:12	41.5	4.7	
		11/11/2016	16:59	29.7		
		05/12/2016	10:01	37.1	1.5	
KV-52	Natural spring to Christal Lake at old pumphouse	07/01/2016	15:09	70.7		
		03/02/2016	11:06	47	0.1	
		05/03/2016	15:53	41.4		
		06/04/2016	13:08	34.5		
		04/05/2016	9:02	29.4		
		15/06/2016	12:40	36.9		
		14/07/2016	15:37	40.4		
		07/08/2016	10:01	33		
		23/09/2016	15:19	41.9		
		22/10/2016	16:04	39.4		
KV-52	Natural spring to Christal Lake	10/11/2016	18:33	41.2		
		03/12/2016	16:33	53.3		
KV-53	UN Adit	05/01/2016				
		05/02/2016				
		02/03/2016				
		01/05/2016		0		
		15/07/2016				
		20/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-55	Sandy Creek at Silver Trail Highway	01/02/2016	Conditions not suitable for salt slug, could only find what appears to be overflow water, large ice jam present at			
		02/03/2016				
		03/05/2016				
		13/07/2016	15:47	5.3		
		23/10/2016				
KV-56	Star Creek at Silver Trail Highway	01/02/2016	Creek appears to be frozen to the ground, moved up from culvert but could find water, only stagnant pools near			
		03/05/2016	16:28	95.3		
		13/07/2016	16:26	20.6		
		23/10/2016				
KV-60	Galena Creek upstream of Silver King 100 adit	08/01/2016	15:19	13.9	2.4	
		04/02/2016	12:06	10.1	2.2	
		04/03/2016	12:44	10.6		
		07/04/2016	12:07	5	1.6	
		05/05/2016	11:13	418.6	11.4	0.359
		14/06/2016	11:58	58.4	2.6	0.253
		15/07/2016	11:10	49.3	0.2	0.248
		06/08/2016	9:15	279.6		0.3065
		24/09/2016	11:06	82.9	0.9	0.26
		23/10/2016	11:56	21.2	0.3	
KV-60	Galena Creek upstream of	10/11/2016	10:10	17.2	1.4	
		02/12/2016	12:31	12.6	7.2	
KV-61	Porcupine Gulch at Calumet Road Crossing	03/02/2016	11:41	5.4		
		04/05/2016	15:41	26.8	8.4	
		15/07/2016	10:11	10.4		
		20/10/2016	11:05	14		
KV-62	Brefalt Creek upstream of Porcupine Diversion	07/02/2016				
		06/05/2016	12:54	65.7	2.7	
		16/06/2016	12:23	1.9		
		15/07/2016	12:51	1.7	3.0	0.259
		20/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-64	Flat Creek at Silver Trail Highway	09/01/2016	16:28	8.8	8.9	
		01/02/2016	10:12	4.2	37.6	
		03/03/2016	15:56	3.4	2.3	
		08/04/2016	11:22	2.7	21.8	
		06/05/2016	10:06	142.9	4.7	0.29
		16/06/2016	15:07	44.5	0.2	0.425
		15/07/2016	11:30	38.6	26.1	0.412
		08/08/2016	10:26	130.8	3.6	0.485
		23/09/2016	13:29	64.3	9.4	0.474
		23/10/2016	14:38	21.9	5.5	
		10/11/2016	16:25	15	0.2	
		02/12/2016	14:57	11.4	1.4	
KV-65	Thunder Gulch upstream of Bellekeno	06/01/2016	13:06	62.5		
		08/02/2016	13:34	47.6	2.9	
		06/03/2016	13:10	45.7		
		07/04/2016	16:30	35.9		
		01/05/2016	14:53	44.8		
		16/06/2016	14:35	223.3	0.2	
KV-65	Thunder Gulch upstream of Bellekeno	12/07/2016	13:48	75.4		
		09/08/2016	8:49	136.6		
		22/09/2016	14:58	97.8		
		20/10/2016	14:01	134		
		24/10/2016				
		11/11/2016	15:17	90.9		
		05/12/2016	8:54	75.6		
KV-66	Klondike Keno Adit	01/02/2016				
		05/05/2016	11:03	2	3.1	
		16/07/2016	16:11	1.2		
		21/10/2016	14:11	1.6		
KV-72	South McQuesten River at McQuesten	07/02/2016				
		03/05/2016	9:51	527.1		
		14/07/2016	9:42	724.4		
		22/10/2016	9:49	357.4		
FIEC	Field Creek upstream of Duncan Creek Road	10/01/2016	10:55	34.3		
		09/02/2016				
		06/03/2016				
		08/04/2016				
		06/05/2016	8:36	931		
		16/06/2016	13:41	126.5		
		16/07/2016	11:46	467.9		
		08/08/2016	8:23	1077.2		
		25/09/2016	14:16	222.2		
		23/10/2016	13:12	84.6		
		12/11/2016	9:13	53		
		04/12/2016	9:29	43.1		

APPENDIX B

DISCRETE DISCHARGE MEASUREMENTS HISTORIC

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
01/01/1994								
27/01/1994						0.1	3	2
01/02/1994								
24/02/1994						0.1	3	2
01/03/1994								
28/03/1994						0.1	3	0.5
23/04/1994						1.5	3	1
10/05/1994							2	
13/05/1994						2		
31/05/1994								12
01/06/1994							2	12
27/06/1994						0.8	2.8	1.5
28/06/1994								
27/07/1994							2	
28/07/1994								
29/07/1994							2	0.4
17/08/1994						0.1	2	0.4
07/09/1994		116						
29/09/1994						0.1	2	0.4
27/10/1994								
31/10/1994						0.1	2	0.5
29/11/1994						0.1	2	0.5
05/01/1995						0.1	2	0.5
06/02/1995							2	0.5
01/03/1995								
29/03/1995							2	0.2
27/04/1995						0.1	1.5	0.5
03/05/1995		298.6					1.3	1.5
06/06/1995								0.7
06/07/1995	18	220				2	2	0.7
11/07/1995								0.5
05/08/1995		236						
11/08/1995						0.1	2.5	2
04/09/1995						0.1	25.3	0.2
05/09/1995								
11/10/1995						0.1	14.5	0.6
05/11/1995						0.7	3	1
12/12/1995						0.1		
01/01/1996						0.1		
09/02/1996						0.1		
05/03/1996						0.1		
07/04/1996						0.1		
28/04/1996								
24/06/1996						9		
18/07/1996						18		

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
02/08/1996						4.9		
16/09/1996						0.1		
03/10/1996						0.1		
30/10/1996						0.1		
30/11/1996						0.1		
28/01/1997						0.1		
26/02/1997						0.1		
27/03/1997								2
12/05/1997						30		
25/06/1997							0.8	6.7
30/06/1997						2.8	1	2.5
31/07/1997						27		
20/08/1997						15		
13/09/1997						10.5		
10/10/1997		92		40		6	3	2.5
21/12/1997						0.33		
15/01/1998				30			1.5	1
13/03/1998				20				1
25/04/1998						0.08		
11/05/1998								
14/05/1998								1
23/05/1998						10.3		
30/05/1998						5.6		
06/06/2000						17		
07/11/2000						5.3		
10/07/2001						32	1.0	7.0
11/07/2001		872						
02/08/2003		165.7		109.2		1.4	0.1	0.5
24/01/2004		127	302	28				
19/02/2004		180						
23/03/2004		150						
24/04/2004		150						
15/06/2004		247	268					
20/07/2004		108						
29/07/2004	85							
30/07/2004		323	347	293				
25/08/2004		121						
21/09/2004		149						
21/10/2004		104						
29/11/2004		102						
17/12/2004		259						
25/01/2005		351.685439	383	24.6				
26/02/2005				28				
27/02/2005		233.065736	302					
22/03/2005		290						

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
21/04/2005		62.099477	357					
22/04/2005	48							
27/05/2005		657.269274						
30/06/2005	73.7	136	268			1.26		
19/07/2005				282				
20/07/2005	93	204						
22/08/2005				245				
23/08/2005		237						
22/09/2005		149						
25/10/2005	73	186	282					
25/01/2006		188	336	117				
22/02/2006		117						
14/03/2006				23				
15/03/2006		159.453969	332					
27/04/2006			313					
28/06/2006	130	858	221			8.4	0.4	
31/08/2006	108.987092	251.196066	263.1					
21/09/2006	112	374						
25/10/2006							0.5	2
15/06/2007						>20		
11/07/2007						>20		3.5
12/07/2007							0.3	
13/07/2007				1092.9				
15/07/2007								
16/07/2007								
17/07/2007								
18/08/2007						7.5		
31/08/2007			159.145					
05/09/2007	60.63	189.2	200.28					
06/09/2007				166.2				
08/09/2007								
10/09/2007							1.6	1.5
11/09/2007						2.6		
13/09/2007								
28/10/2007						3.2		
13/03/2008								2
16/05/2008				1137.0				
18/05/2008 11:45								
03/07/2008		159.4	210	152.2				
05/07/2008								
06/07/2008	129.6							
13/08/2008		437.6	488.35	1020.195				
14/08/2008	119.385					15		
15/09/2008	80.18							
18/09/2008		518.43	412.38	320.64				

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
02/10/2008		419.66						
03/10/2008	160.71		724.44					
04/10/2008				538.36				
05/10/2008						3.15		
26/05/2009 17:15				1940.275			0.16	2
27/05/2009 14:15			1421.154			20		
28/05/2009 12:00								
05/06/2009 17:00	124.365	441.74	356.11	474.39				
06/06/2009						20		
04/07/2009 13:45				173.93			0.25	0.25
05/07/2009 14:35								
06/07/2009 14:10		124.245	94.06					
07/07/2009 09:30	101.233					6.487		
08/09/2009		269.23	220.16	253.095				
09/09/2009	102.54							
11/09/2009						10		
06/10/2009		228.95						
07/10/2009	33.155							1
08/10/2009							0.5	
09/10/2009				201.83				
03/05/2010								
04/05/2010		612.41						
05/05/2010	71.19						0.2	
26/05/2010								5
27/05/2010								
28/05/2010				429.36				
08/06/2010		357.17						
05/07/2010								2
06/07/2010							0.1	
07/07/2010		287.520533	340.0533					
08/07/2010	94.01815							
09/07/2010						12		
04/08/2010	61.129433	231.0865	230.559					
14/09/2010	141.375	186.5	137.65	136.3				
15/09/2010						10		
05/10/2010	94.041	184.638	130.976					1
06/10/2010				109.313			0.2	
07/10/2010								
09/02/2011 12:00								1
12/05/2011 15:30				1179.0934				
13/05/2011 08:50		357.0665						
25/05/2011 15:20	135.975							12
26/05/2011 11:55								
27/05/2011 14:00							0	
21/06/2011 12:00								0.5

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
22/06/2011 15:20	79.95	104.985	106.99					
12/07/2011 13:20							0	2.5
13/07/2011 13:15	90.96							
14/07/2011 15:15				540.63				
19/07/2011 12:20						15		
16/08/2011 14:50								
17/08/2011 10:45	127							9
18/08/2011 16:00		258.7				30		
17/09/2011 08:25								
22/09/2011 15:05								
23/09/2011 09:30		286.48						
24/09/2011 14:40	127.0575		290.185					
25/09/2011 12:55						0		
23/10/2011				155				
24/10/2011		173	188					
25/10/2011								
26/10/2011 16:20								
27/10/2011								
29/10/2011 16:00	88							
30/10/2011 14:30								
31/10/2011 12:30								
20/11/2011 14:25						0		2.6
21/11/2011 11:00	74.8							
22/11/2011 10:00								
24/11/2011 15:00			137.5					
26/11/2011 09:00		125.7						
13/12/2011 14:15						0		
14/12/2011 16:25	107.2							
15/12/2011 12:20			134					
16/12/2011 15:10								
17/12/2011 09:30								2.1
18/12/2011 12:25								
20/12/2011 13:30								
21/12/2011 15:20								
12/01/2012 15:30								1.3
13/01/2012 12:00		153.7	162.2					
14/01/2012 14:40						0		
17/01/2012 13:00								
18/01/2012 09:40								
24/01/2012 15:45								
09/02/2012 15:25								
11/02/2012 15:30						0		
12/02/2012 10:35								
13/02/2012 13:30	77.2							
14/02/2012 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
16/02/2012 13:00					0			
09/03/2012 10:50								
10/03/2012 12:50			90.4					
11/03/2012 10:00	77.3							
12/03/2012 08:45								
14/03/2012 13:30					0			
15/03/2012 12:00						0		
07/04/2012 14:10								
08/04/2012 09:25	61.7			11.7				
09/04/2012 13:50						0		
01/05/2012 11:30	147.0	540.4						
03/05/2012 14:07								
04/05/2012 11:30				1574.2				
05/05/2012 10:17			677.0					
06/05/2012 13:28								
07/05/2012 09:00	104.7	600.0						
08/05/2012 10:35						15.66		
09/05/2012 08:45								
31/05/2012								
01/06/2012		368.9875	388.94					
03/06/2012	88.65							
04/06/2012					221.895			15.636
05/06/2012						12.12		
06/06/2012 14:00								
07/06/2012 09:05				429.68				
01/07/2012 10:00								
02/07/2012 14:47								
03/07/2012 12:05								
04/07/2012 13:40	85.35							
05/07/2012 09:50								
07/07/2012 12:00				243.5	118.2			
08/07/2012 14:55								
09/07/2012 08:50								
10/07/2012 10:30						13.3		
16/07/2012 15:30	104.69	205.67						
01/08/2012 10:25	91							
02/08/2012 12:30		258	192					
03/08/2012 10:00				239	115			
05/08/2012 13:05								3
07/08/2012 08:10						5		
02/09/2012 08:50								1.6
03/09/2012 13:15								
20/09/2012 15:10								
21/09/2012 14:00		270.1	97.1					
22/09/2012 10:33				245.2				

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
23/09/2012 08:15	89.1				109.2			
25/09/2012 09:29						8.7		
10/10/2012 16:40								
11/10/2012 14:00			84.31					
12/10/2012 10:30				136.8563				
14/10/2012 13:30					73.291			
15/10/2012 10:45								
16/10/2012 12:50	76.18							
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30		74.75						
15/01/2013 09:30								
16/01/2013 14:00								1.18
08/02/2013 15:30		65.91						
09/02/2013 10:30								
10/02/2013 12:10								
12/02/2013 11:10								
07/03/2013 15:30								
08/03/2013 14:00		109.69						
12/03/2013 14:00								
14/03/2013 12:00								
04/04/2013 11:45								
06/04/2013 09:15								
09/04/2013 12:40							0	
10/04/2013 11:15								
02/05/2013 15:25								
03/05/2013 09:45								
04/05/2013 09:35								
07/05/2013 11:50								
01/06/2013 12:00								
02/06/2013 16:00								16.2425
03/06/2013 08:45								
04/06/2013 11:50					199.39			
05/06/2013 11:00				765.66				
07/06/2013 14:50		852						
08/06/2013 09:40	122.62							
09/06/2013 08:45								
01/07/2013 13:45				290.41				
02/07/2013 13:50			207.927					
03/07/2013 12:00								
04/07/2013 15:00		223.8						
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45					31.968			

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
12/07/2013 13:45	81.948							
06/08/2013 15:15						12.19		
10/08/2013 16:35			128.34					
11/08/2013 09:30		101.93						
12/08/2013 09:50	107.92							
01/09/2013 14:20								
02/09/2013 12:30		140.115	147.6					
03/09/2013 14:05	87.213							
04/09/2013 13:40				526.40				
05/09/2013 11:00								
07/09/2013 14:30								
08/09/2013 10:14								
09/09/2013 13:00						11.5		
11/09/2013 17:30	91.5							
12/09/2013 13:18		434.72		151.6				
13/09/2013 14:45								
14/09/2013 11:31								
01/10/2013 16:15						9.13		
03/10/2013 15:55								
04/10/2013 10:30				411.02				
05/10/2013 12:25		266.14	284.02					
06/10/2013 15:00								
07/10/2013 10:25								
09/10/2013 14:35								
10/10/2013 08:30	92.7							
04/11/2013 14:30								
06/11/2013 10:05				81.17				
07/11/2013 10:10								
08/11/2013 14:45								
09/11/2013 13:30								
11/11/2013 11:00	80.2							
02/12/2013 13:00								
03/12/2013 08:30								
04/12/2013 14:40								
06/12/2013 13:25		116.82						
02/01/2014 16:05								
03/01/2014 14:05		106.7						
25/01/2014 14:05								
02/02/2014 09:55								
03/02/2014 10:30		85.7						
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50								
12/02/2014 12:20								
18/02/2014 10:00					0			

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
01/03/2014 11:15	49.5							
02/03/2014 13:10								
04/03/2014 14:40					0		0	
04/04/2014 16:00	51.56							
05/04/2014 13:15		97.64						
06/04/2014 12:30							0	
07/04/2014 12:00					0			
03/05/2014 15:35								
04/05/2014 09:35								
05/05/2014 13:00								
06/05/2014 14:50								
07/05/2014 11:50								
08/05/2014 13:15		1760	1490					
10/05/2014 11:25	290							
11/05/2014 11:20							0	
13/05/2014 10:45				1856.458				
14/05/2014 12:00						0		
03/06/2014 15:00							0	
04/06/2014 11:40								
05/06/2014 11:45			120.1					
06/06/2014 10:43					80			
07/06/2014 12:50								
08/06/2014 12:25	58.8	115.6						2.8
09/06/2014 10:45				117.4				
10/06/2014 11:00								
01/07/2014 11:35								
02/07/2014 12:30								
03/07/2014 15:35	99.67	203.09						
04/07/2014 10:15			193.6					2.5
05/07/2014 13:25				253.82				
06/07/2014 09:00					113			
07/07/2014 10:00							0	
01/08/2014 09:50								
02/08/2014 12:00		199.85	201.2					
03/08/2014 09:00	63.01							
04/08/2014 09:30				141.7	110.6			
05/08/2014 16:00								
22/08/2014 15:30							0	
24/08/2014 11:00								5.5
25/08/2014 09:45				913.555				
02/09/2014 14:15								
16/09/2014 13:10						17.22		
18/09/2014 12:20								
19/09/2014 12:00	110.1515	270.11	330					
20/09/2014 10:00								3.163

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
21/09/2014 11:15						11.482		
22/09/2014 12:45					228			
27/09/2014 09:40				493.48				
16/10/2014 10:00								
17/10/2014 11:00								
18/10/2014 14:25			156.1					
19/10/2014 09:00	102.2	282.6						
20/10/2014 13:20				309.6				
21/10/2014 14:30					125.2			
22/10/2014 11:10						0		
23/10/2014 09:40								
24/10/2014 14:55								3
25/10/2014 11:00								
26/10/2014 09:00								
13/11/2014 13:30								
14/11/2014 12:30								
15/11/2014 14:20	80.1	150.2						
16/11/2014 14:45					31.9			
17/11/2014 14:15							0	
18/11/2014 10:00								
19/11/2014 14:05								2.4
20/11/2014 09:59								
21/11/2014 14:00								
22/11/2014 14:31						0		
12/12/2014 13:20								
13/12/2014 13:20								
14/12/2014 11:30								
15/12/2014 13:00		137.1	107.1					
16/12/2014 09:50								
18/12/2014 14:23							0	1.8
19/12/2014 15:40						0		
11/01/2015 13:16								
12/01/2015 11:57								
13/01/2015 13:12		162.7	182.3					
14/01/2015 10:13	104.3							
17/01/2015 13:00								
19/01/2015 15:05							0	
22/01/2015 13:24						0		
28/01/2015 10:00								
05/02/2015 13:07								
06/02/2015 11:50								
07/02/2015 14:00								
12/02/2015 13:07								
14/02/2015 14:47				7.8				
15/02/2015 11:30								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
16/02/2015 15:20						0		
17/02/2015 12:50								0.9
18/02/2015 08:00							0	
06/03/2015 13:30								
07/03/2015 13:00								
09/03/2015 10:30	69.8	87.7						
10/03/2015 12:05						0		0.9
11/03/2015 14:30							0	
13/03/2015 13:00				13				
03/04/2015 11:10								
06/04/2015 09:40								
07/04/2015 13:20		72.5	98.7					
08/04/2015 11:30	55.8							
09/04/2015 13:25						0		0.9
10/04/2015 12:00				16.7				
12/04/2015 10:40								
12/05/2015 10:15	324	2540				0		
13/05/2015 13:01								
14/05/2015 11:30				3682.3				
23/05/2015 14:20			738.9					
24/05/2015 16:14					266.4			
26/05/2015 07:30								
27/05/2015 12:34								
28/05/2015 12:42								
02/06/2015 13:16								
03/06/2015 14:30	105.9	233.6						
04/06/2015 10:30				242.5	122.4			
09/06/2015 13:23								
11/06/2015 10:24								
12/06/2015 11:48								
16/06/2015 08:48								1.7
17/06/2015 08:50			173.9					
18/06/2015 10:41								
19/06/2015 09:30								
23/06/2015 15:05						13.84		
09/07/2015 14:56								
13/07/2015 12:30								
15/07/2015 13:10								
16/07/2015 12:15								
18/07/2015 14:10		1038.5						
19/07/2015 12:20								
26/07/2015 09:22								
28/07/2015 12:00				218.1	120.8			
29/07/2015 10:30	100.0		300.6			19.37		
30/07/2015 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
06/08/2015 11:05		342.1	332.3					
12/08/2015 13:25								2.2
17/08/2015 10:35								
19/08/2015 14:30	125.1							
20/08/2015 14:20								
21/08/2015 11:50				514.8	111.7			
22/08/2015 13:00								
23/08/2015 14:25								
26/08/2015 12:10						11.12		
01/09/2015 11:30	138.2							
03/09/2015 10:56				1049				
04/09/2015 09:15		611.6						
10/09/2015 11:59								
11/09/2015 15:05								5.6
12/09/2015 13:31								
13/09/2015 15:25			640.1		261.2			
15/09/2015 14:46								
16/09/2015				964.3				
17/09/2015 12:07								1.4
18/09/2015	134.5	635.3						
19/09/2015								2.5
10/10/2015 15:07								
11/10/2015 12:07		329.1						
14/10/2015 15:04								
16/10/2015 13:45	91.8							
17/10/2015 15:30								
18/10/2015 10:05			263.9				0	2.8
19/10/2015 12:19				357.1				
20/10/2015 13:16					169.1			
14/11/2015 14:48								
15/11/2015 13:42								
16/11/2015 10:57								
17/11/2015 14:10								1.8
18/11/2015 10:08				77.0				
19/11/2015 10:55	147.3							
20/11/2015 15:38								
22/11/2015 15:30		178.9						
23/11/2015 12:09								
24/11/2015 12:50								
15/12/2015 11:50								
16/12/2015 11:20								
17/12/2015 12:00		179.9						
18/12/2015 12:15	142.2							2.1
19/12/2015 11:44				47				
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
05/01/2016 11:56								2
06/01/2016 13:00	129.6							
07/01/2016 15:00								
08/01/2016 10:41				47.4				
09/01/2016 11:50		163.3						
10/01/2016 10:30								
30/01/2016 10:40								
01/02/2016 11:30		144.9						
02/02/2016 14:00	66.5			19.9				
03/02/2016 11:20							0	2.4
04/02/2016 11:45								
08/02/2016 13:19								
02/03/2016 15:54								
03/03/2016 10:45		110.7	166.1					
04/03/2016 12:15								
05/03/2016 14:55	86.1							1.3
06/03/2016 12:45								
05/04/2016 16:00								
06/04/2016 09:30	71.3	100.1	106.8					
07/04/2016 09:10				20				1.1
08/04/2016 12:50								
01/05/2016 14:35								
02/05/2016 13:00				1740.1			0	
03/05/2016 12:25	169.5	1006.1	1009.4					
04/05/2016 15:28								
05/05/2016 10:20					296.8			1.3
06/05/2016 10:10								
18/05/2016 17:15								
19/05/2016 09:42								
13/06/2016 11:05			330	269.2				
14/06/2016 11:18					148			
15/06/2016 08:37	103.5	256.5						2.8
16/06/2016 14:30								
21/06/2016 14:50						21.80		
12/07/2016 13:30								
13/07/2016 13:20				263				
14/07/2016 11:15	98.1	518.7	501.7					2.9
15/07/2016 10:45					146.2			
16/07/2016 15:51								
17/07/2016 15:00								
19/07/2016 12:15						16.86		
05/08/2016 11:56				543.6	204.6			
06/08/2016 13:43		574.8	748.6					
07/08/2016 08:59	180.3							
08/08/2016 10:02								9.9

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
09/08/2016 08:24								
16/08/2016 13:25						7.87		
18/08/2016 15:54								
21/09/2016 17:45								
22/09/2016 14:18		473.4	465.7	551.6				
23/09/2016 14:20	112							
24/09/2016 10:13					162.3			3.8
25/09/2016 09:35						13.37		
19/10/2016 17:33								
20/10/2016 13:46						12.55		2.7
21/10/2016 13:17				93				
22/10/2016 12:10	93.7	207.2	310.3					
23/10/2016 14:21								
31/10/2016 10:10						11.92		
08/11/2016 12:45				73.5	78.3			
09/11/2016 10:31	86.7	188.7	141.6					
10/11/2016 15:50								
11/11/2016 15:06								1.8
12/11/2016 08:56								
01/12/2016 12:05								
02/12/2016 09:00				30.7				
03/12/2016 10:20		236.5						6.9
04/12/2016 14:15								
05/12/2016 08:40								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
01/01/1994					14			
27/01/1994	1.5	5						
01/02/1994					14			
24/02/1994	1.5	5			14			
01/03/1994					10			
28/03/1994	1.5	5						
23/04/1994	2	5			12			
10/05/1994								
13/05/1994								
31/05/1994	2	6			16			
01/06/1994	2	6			16			
27/06/1994	2	6.5						
28/06/1994					20			
27/07/1994	1	4.2						
28/07/1994					12.9			
29/07/1994	1	4.2						
17/08/1994	1	5			18			
07/09/1994								
29/09/1994	1.3	4			18			
27/10/1994		3.9						
31/10/1994	1.3	4			12			
29/11/1994	1.3	4			12			
05/01/1995	1	3			10			
06/02/1995	1	3			10			
01/03/1995	1.5							
29/03/1995	1	3			10			
27/04/1995	1.5	2.5			3			
03/05/1995	1.5	3			12			
06/06/1995	2							
06/07/1995	2	4						
11/07/1995	2.5	5						
05/08/1995								
11/08/1995	2	5			13			
04/09/1995	1	3.5			13			
05/09/1995		5						
11/10/1995	0.8	3.8			6.5			
05/11/1995	0.5	4			4.7			
12/12/1995								
01/01/1996								
09/02/1996								
05/03/1996								
07/04/1996								
28/04/1996		7.3						
24/06/1996								
18/07/1996								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
02/08/1996								
16/09/1996								
03/10/1996								
30/10/1996	0.1							
30/11/1996	0.1							
28/01/1997								
26/02/1997								
27/03/1997								
12/05/1997								
25/06/1997		5.7		4.0	16.0			
30/06/1997				7	17			
31/07/1997								
20/08/1997								
13/09/1997								
10/10/1997	5			4.5	13			
21/12/1997								
15/01/1998				3	9			
13/03/1998		3			10			
25/04/1998								
11/05/1998		4			11			
14/05/1998								
23/05/1998								
30/05/1998								
06/06/2000								
07/11/2000					9.7			
10/07/2001	2.2	8.5			14.0			
11/07/2001				5.0				
02/08/2003	0.7			1.6		423.7	651.4	641.4
24/01/2004								63
19/02/2004								
23/03/2004								
24/04/2004								
15/06/2004								
20/07/2004								
29/07/2004								961
30/07/2004						589	836	
25/08/2004								
21/09/2004								
21/10/2004								
29/11/2004								
17/12/2004								
25/01/2005								
26/02/2005								
27/02/2005								63
22/03/2005								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
21/04/2005								
22/04/2005								
27/05/2005								
30/06/2005								1526
19/07/2005								1362
20/07/2005								
22/08/2005								963
23/08/2005								
22/09/2005								
25/10/2005								
25/01/2006								192
22/02/2006								
14/03/2006								192
15/03/2006								
27/04/2006								
28/06/2006								
31/08/2006								
21/09/2006								
25/10/2006								
15/06/2007								
11/07/2007	1							
12/07/2007		7.8		5.5				
13/07/2007								
15/07/2007			15					
16/07/2007								
17/07/2007								
18/08/2007								
31/08/2007								
05/09/2007								
06/09/2007								
08/09/2007				1.3				
10/09/2007	1.5	6.7						
11/09/2007								
13/09/2007					6.75			
28/10/2007								
13/03/2008								
16/05/2008								
18/05/2008 11:45						225.3	595.72	
03/07/2008								
05/07/2008						301.1	482.8	664
06/07/2008								
13/08/2008			6.5					
14/08/2008								1492.925
15/09/2008								713.355
18/09/2008								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
02/10/2008					4.5	474.275	842.38	1190.65
03/10/2008								
04/10/2008								
05/10/2008								
26/05/2009 17:15	0.25	2.5						
27/05/2009 14:15								
28/05/2009 12:00				4	7			
05/06/2009 17:00								3589.96
06/06/2009								
04/07/2009 13:45	0.25	3						
05/07/2009 14:35				3	6	421.55	625.68	718.62
06/07/2009 14:10								
07/07/2009 09:30			3					
08/09/2009								1035.19
09/09/2009								
11/09/2009								
06/10/2009			6					645.7
07/10/2009	0.5			3	7	443.8		
08/10/2009		4						
09/10/2009								
03/05/2010								440.68
04/05/2010								
05/05/2010			10					
26/05/2010	0.75	8						
27/05/2010				3	10	900.9395		
28/05/2010								
08/06/2010			8					1675.405
05/07/2010	3							
06/07/2010		4		4				967.45467
07/07/2010								
08/07/2010			7		12	594.67633		
09/07/2010								
04/08/2010								818.157667
14/09/2010								483.2
15/09/2010								
05/10/2010								415.336
06/10/2010	0.5				15	241.745		
07/10/2010		8	8					
09/02/2011 12:00								
12/05/2011 15:30								
13/05/2011 08:50								
25/05/2011 15:20	3							
26/05/2011 11:55				10				
27/05/2011 14:00		15	20					
21/06/2011 12:00	0.2			7				1054.925

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
22/06/2011 15:20		4						
12/07/2011 13:20	0.5	4	5	10				
13/07/2011 13:15					8			1075.31
14/07/2011 15:15						1020.97		
19/07/2011 12:20								
16/08/2011 14:50								
17/08/2011 10:45		1						1713.42
18/08/2011 16:00	2		11					
17/09/2011 08:25						347.615		973.035
22/09/2011 15:05				8				
23/09/2011 09:30								766.75
24/09/2011 14:40								
25/09/2011 12:55								
23/10/2011								
24/10/2011								
25/10/2011								
26/10/2011 16:20								
27/10/2011					1.69			
29/10/2011 16:00			0.181818					
30/10/2011 14:30						206	330.5	404
31/10/2011 12:30								
20/11/2011 14:25								
21/11/2011 11:00								
22/11/2011 10:00						162		
24/11/2011 15:00					10			
26/11/2011 09:00								
13/12/2011 14:15								
14/12/2011 16:25								
15/12/2011 12:20								
16/12/2011 15:10								
17/12/2011 09:30								
18/12/2011 12:25						92.1	205.3	267.6
20/12/2011 13:30								
21/12/2011 15:20								
12/01/2012 15:30								
13/01/2012 12:00								
14/01/2012 14:40								
17/01/2012 13:00								251.2
18/01/2012 09:40						119.7	100.3	
24/01/2012 15:45								
09/02/2012 15:25						135.3	168.7	
11/02/2012 15:30								
12/02/2012 10:35								
13/02/2012 13:30								
14/02/2012 13:40			2.2					

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
16/02/2012 13:00								
09/03/2012 10:50							134.1	182
10/03/2012 12:50								
11/03/2012 10:00								
12/03/2012 08:45								
14/03/2012 13:30								
15/03/2012 12:00								
07/04/2012 14:10						68.74	107.3	
08/04/2012 09:25								
09/04/2012 13:50								
01/05/2012 11:30								202.2
03/05/2012 14:07								
04/05/2012 11:30								
05/05/2012 10:17								
06/05/2012 13:28						62.1	127.8	
07/05/2012 09:00								
08/05/2012 10:35								
09/05/2012 08:45								
31/05/2012								1655.8
01/06/2012						781.25	997.6025	
03/06/2012								
04/06/2012								
05/06/2012								
06/06/2012 14:00								
07/06/2012 09:05								
01/07/2012 10:00						691.05		
02/07/2012 14:47							1544.98	1957.63
03/07/2012 12:05								
04/07/2012 13:40								
05/07/2012 09:50								
07/07/2012 12:00								
08/07/2012 14:55								
09/07/2012 08:50			11.8					
10/07/2012 10:30								
16/07/2012 15:30								
01/08/2012 10:25				7		62	668	884
02/08/2012 12:30								
03/08/2012 10:00								
05/08/2012 13:05								
07/08/2012 08:10								
02/09/2012 08:50								
03/09/2012 13:15								
20/09/2012 15:10						387.1	647	
21/09/2012 14:00								795.1
22/09/2012 10:33								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
23/09/2012 08:15								
25/09/2012 09:29								
10/10/2012 16:40						261.7388		
11/10/2012 14:00								
12/10/2012 10:30								
14/10/2012 13:30								
15/10/2012 10:45								
16/10/2012 12:50							485.33	565.65
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30								
15/01/2013 09:30								
16/01/2013 14:00								
08/02/2013 15:30								
09/02/2013 10:30						94.59	127.78	562.38
10/02/2013 12:10								
12/02/2013 11:10								
07/03/2013 15:30							219.42	
08/03/2013 14:00								
12/03/2013 14:00						134.48		
14/03/2013 12:00								2741.2
04/04/2013 11:45								1018.64
06/04/2013 09:15		0						
09/04/2013 12:40						85.132		
10/04/2013 11:15								
02/05/2013 15:25						70.55	107.05	
03/05/2013 09:45								112.26
04/05/2013 09:35								
07/05/2013 11:50								
01/06/2013 12:00						2210.99		
02/06/2013 16:00								
03/06/2013 08:45								
04/06/2013 11:50								
05/06/2013 11:00								
07/06/2013 14:50								
08/06/2013 09:40								1900.65
09/06/2013 08:45								
01/07/2013 13:45								
02/07/2013 13:50								
03/07/2013 12:00								
04/07/2013 15:00				2.9		495.451	575.523	709.583
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
12/07/2013 13:45								
06/08/2013 15:15								
10/08/2013 16:35								
11/08/2013 09:30						231.37	315.99	437.14
12/08/2013 09:50								
01/09/2013 14:20				4		305.3	427.3	546.22
02/09/2013 12:30								
03/09/2013 14:05								
04/09/2013 13:40								
05/09/2013 11:00								
07/09/2013 14:30								
08/09/2013 10:14			9.7					
09/09/2013 13:00								
11/09/2013 17:30								1002.36
12/09/2013 13:18								
13/09/2013 14:45			22.45					
14/09/2013 11:31								
01/10/2013 16:15								
03/10/2013 15:55								
04/10/2013 10:30								
05/10/2013 12:25								
06/10/2013 15:00						361.17	486.49	765.9
07/10/2013 10:25								
09/10/2013 14:35			17.36					
10/10/2013 08:30								
04/11/2013 14:30								420.7
06/11/2013 10:05								
07/11/2013 10:10								
08/11/2013 14:45						204.3	258	
09/11/2013 13:30			4.2					
11/11/2013 11:00								
02/12/2013 13:00								
03/12/2013 08:30								173.65
04/12/2013 14:40						174.1	271.97	
06/12/2013 13:25								
02/01/2014 16:05								148.8
03/01/2014 14:05								
25/01/2014 14:05						95.6	105.8	
02/02/2014 09:55								
03/02/2014 10:30								125.7
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50								
12/02/2014 12:20						88.15	73.02	
18/02/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
01/03/2014 11:15								95.8
02/03/2014 13:10						56.7	80.8	
04/03/2014 14:40								
04/04/2014 16:00						60.75	77.9	519.4
05/04/2014 13:15								
06/04/2014 12:30								
07/04/2014 12:00								
03/05/2014 15:35								
04/05/2014 09:35								
05/05/2014 13:00								719.5
06/05/2014 14:50						162.9	327.3	
07/05/2014 11:50								
08/05/2014 13:15								
10/05/2014 11:25			57.6					
11/05/2014 11:20								
13/05/2014 10:45								
14/05/2014 12:00								
03/06/2014 15:00								
04/06/2014 11:40						427.5	608	908
05/06/2014 11:45								
06/06/2014 10:43								1471
07/06/2014 12:50								
08/06/2014 12:25			4.5					
09/06/2014 10:45								
10/06/2014 11:00					13.4			
01/07/2014 11:35				4.37		778.34	820	1092.473
02/07/2014 12:30					12.9			
03/07/2014 15:35								
04/07/2014 10:15			4.74					
05/07/2014 13:25								
06/07/2014 09:00								
07/07/2014 10:00								
01/08/2014 09:50				4.695			392.3	429.079
02/08/2014 12:00								
03/08/2014 09:00			10.744					
04/08/2014 09:30								
05/08/2014 16:00								
22/08/2014 15:30								
24/08/2014 11:00								
25/08/2014 09:45						685.51		
02/09/2014 14:15				8.7719		702.21	468.00	705.20
16/09/2014 13:10								
18/09/2014 12:20								
19/09/2014 12:00								
20/09/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
21/09/2014 11:15								
22/09/2014 12:45		11.864	25.646		29.424			
27/09/2014 09:40								
16/10/2014 10:00						348.5	457.2	650.4
17/10/2014 11:00					26.1			
18/10/2014 14:25								
19/10/2014 09:00								
20/10/2014 13:20								
21/10/2014 14:30								
22/10/2014 11:10								
23/10/2014 09:40					16.1			
24/10/2014 14:55								
25/10/2014 11:00		10.5	12.5					
26/10/2014 09:00				3.508				
13/11/2014 13:30							259.2	
14/11/2014 12:30				2.79				
15/11/2014 14:20								
16/11/2014 14:45								
17/11/2014 14:15								
18/11/2014 10:00			6.7					
19/11/2014 14:05								
20/11/2014 09:59		6.4			13.3			
21/11/2014 14:00								
22/11/2014 14:31								
12/12/2014 13:20					10			
13/12/2014 13:20							180.3	186.8
14/12/2014 11:30				2.3		138.2		
15/12/2014 13:00								
16/12/2014 09:50								
18/12/2014 14:23		4.3						
19/12/2014 15:40								
11/01/2015 13:16						104.5	164.4	203.4
12/01/2015 11:57				2.5	6.8			
13/01/2015 13:12								
14/01/2015 10:13		7	3.3					
17/01/2015 13:00								
19/01/2015 15:05								
22/01/2015 13:24								
28/01/2015 10:00					2.7			
05/02/2015 13:07						91.7	112.8	
06/02/2015 11:50								
07/02/2015 14:00					5.6			
12/02/2015 13:07								
14/02/2015 14:47								
15/02/2015 11:30		0.6						

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
16/02/2015 15:20								
17/02/2015 12:50								
18/02/2015 08:00								
06/03/2015 13:30						89.7	122.6	199.6
07/03/2015 13:00					4.2			
09/03/2015 10:30								
10/03/2015 12:05		3.5						
11/03/2015 14:30								
13/03/2015 13:00								
03/04/2015 11:10			2.4					
06/04/2015 09:40					5.3	76	118.7	122.1
07/04/2015 13:20								
08/04/2015 11:30								
09/04/2015 13:25		3.2						
10/04/2015 12:00								
12/04/2015 10:40								
12/05/2015 10:15								
13/05/2015 13:01								1225.3
14/05/2015 11:30			243.5					
23/05/2015 14:20								
24/05/2015 16:14								
26/05/2015 07:30		5.5						
27/05/2015 12:34								
28/05/2015 12:42					44.2			
02/06/2015 13:16								1349.8
03/06/2015 14:30								
04/06/2015 10:30								
09/06/2015 13:23								
11/06/2015 10:24			10.8					
12/06/2015 11:48								
16/06/2015 08:48		5.6						
17/06/2015 08:50				4.3	7.2			
18/06/2015 10:41								
19/06/2015 09:30								
23/06/2015 15:05								
09/07/2015 14:56								
13/07/2015 12:30								
15/07/2015 13:10				6.67				
16/07/2015 12:15							718.4	
18/07/2015 14:10								
19/07/2015 12:20								
26/07/2015 09:22		4.8						
28/07/2015 12:00								
29/07/2015 10:30								
30/07/2015 13:40			0.152		21.8			

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
06/08/2015 11:05								
12/08/2015 13:25								
17/08/2015 10:35								
19/08/2015 14:30								
20/08/2015 14:20					35.6			
21/08/2015 11:50								
22/08/2015 13:00								
23/08/2015 14:25								1319.6
26/08/2015 12:10								
01/09/2015 11:30								2057.8
03/09/2015 10:56								
04/09/2015 09:15								
10/09/2015 11:59								
11/09/2015 15:05								
12/09/2015 13:31								
13/09/2015 15:25		16.3						
15/09/2015 14:46					40.1			
16/09/2015								
17/09/2015 12:07			34.9					
18/09/2015								1790.4
19/09/2015								
10/10/2015 15:07								
11/10/2015 12:07								
14/10/2015 15:04				8				
16/10/2015 13:45							523.6	735.9
17/10/2015 15:30					19.4			
18/10/2015 10:05	1.5	5.8						
19/10/2015 12:19								
20/10/2015 13:16			16.9					
14/11/2015 14:48					9.1			
15/11/2015 13:42								408.7
16/11/2015 10:57				7.8				
17/11/2015 14:10	1.8							
18/11/2015 10:08								
19/11/2015 10:55								
20/11/2015 15:38		4.1	2.3					
22/11/2015 15:30								
23/11/2015 12:09								
24/11/2015 12:50								
15/12/2015 11:50								
16/12/2015 11:20				3.4	6.5			
17/12/2015 12:00								
18/12/2015 12:15		9.5	10.4					162.1
19/12/2015 11:44								
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
05/01/2016 11:56	4							200.3
06/01/2016 13:00								
07/01/2016 15:00				3.2	3.3			
08/01/2016 10:41								
09/01/2016 11:50		10.3	5.4					
10/01/2016 10:30								
30/01/2016 10:40					3.9			
01/02/2016 11:30			3.6					
02/02/2016 14:00								213
03/02/2016 11:20	2.8	4.9		0.42				
04/02/2016 11:45								
08/02/2016 13:19						112.2	93.9	
02/03/2016 15:54						102.5		228.8
03/03/2016 10:45								
04/03/2016 12:15								
05/03/2016 14:55	2.7	4.1		2.3	2.8			
06/03/2016 12:45			5.8					
05/04/2016 16:00			2.7					
06/04/2016 09:30								175.7
07/04/2016 09:10	2.1	3						
08/04/2016 12:50				2.3	2.8	78		
01/05/2016 14:35						92.8	156.4	236
02/05/2016 13:00								
03/05/2016 12:25								
04/05/2016 15:28			48.9					
05/05/2016 10:20	2.8	4.4						
06/05/2016 10:10								
18/05/2016 17:15					29.2			
19/05/2016 09:42				8.9				
13/06/2016 11:05								
14/06/2016 11:18		10			15.8			
15/06/2016 08:37	1.3							
16/06/2016 14:30			16.2	5.8		1180.2		1801.7
21/06/2016 14:50								
12/07/2016 13:30						440.5	688.6	884.1
13/07/2016 13:20								
14/07/2016 11:15								
15/07/2016 10:45	2.3		21.6					
16/07/2016 15:51								
17/07/2016 15:00		10.7		6	22.7			
19/07/2016 12:15								
05/08/2016 11:56		13.5						
06/08/2016 13:43			45.2					
07/08/2016 08:59								1365.8
08/08/2016 10:02	2.8			7.2				

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
09/08/2016 08:24								
16/08/2016 13:25								
18/08/2016 15:54					47.3			
21/09/2016 17:45				6.6				
22/09/2016 14:18						489.6	702.3	1049.5
23/09/2016 14:20		11.5	25.1					
24/09/2016 10:13	3.1				29.7			
25/09/2016 09:35								
19/10/2016 17:33					13.9			
20/10/2016 13:46	2.9			3.9		211.8	342.3	521.5
21/10/2016 13:17								
22/10/2016 12:10								
23/10/2016 14:21		8.8	10.2					
31/10/2016 10:10								
08/11/2016 12:45								282.2
09/11/2016 10:31					13			
10/11/2016 15:50			5.8					
11/11/2016 15:06	2.9	5.5		4.3		187.8		
12/11/2016 08:56								
01/12/2016 12:05	9.2		6.2					
02/12/2016 09:00								
03/12/2016 10:20								
04/12/2016 14:15				2.5	11.1	186.6		320.7
05/12/2016 08:40								

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
01/01/1994									
27/01/1994									
01/02/1994									
24/02/1994									
01/03/1994									
28/03/1994									
23/04/1994									
10/05/1994									
13/05/1994									
31/05/1994									
01/06/1994						0.2			
27/06/1994						0.2			
28/06/1994									
27/07/1994									
28/07/1994									
29/07/1994						0.2			
17/08/1994						0.2			
07/09/1994									
29/09/1994						0.2			
27/10/1994									
31/10/1994									
29/11/1994									
05/01/1995									
06/02/1995									
01/03/1995									
29/03/1995									
27/04/1995									
03/05/1995									
06/06/1995									
06/07/1995						0.1			
11/07/1995									
05/08/1995									
11/08/1995						0.3			
04/09/1995						0.8			
05/09/1995									
11/10/1995						0.4			
05/11/1995									
12/12/1995									
01/01/1996									
09/02/1996									
05/03/1996									
07/04/1996									
28/04/1996									
24/06/1996									
18/07/1996									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
02/08/1996									
16/09/1996									
03/10/1996									
30/10/1996	0.1								
30/11/1996	0.1								
28/01/1997									
26/02/1997									
27/03/1997									
12/05/1997									
25/06/1997									
30/06/1997									
31/07/1997									
20/08/1997									
13/09/1997									
10/10/1997									
21/12/1997									
15/01/1998									
13/03/1998									
25/04/1998									
11/05/1998									
14/05/1998									
23/05/1998									
30/05/1998									
06/06/2000									
07/11/2000									
10/07/2001									
11/07/2001									
02/08/2003	31								0.8
24/01/2004									
19/02/2004									
23/03/2004									
24/04/2004									
15/06/2004									
20/07/2004									
29/07/2004									
30/07/2004									
25/08/2004									
21/09/2004									
21/10/2004									
29/11/2004									
17/12/2004									
25/01/2005									
26/02/2005									
27/02/2005									
22/03/2005									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
21/04/2005									
22/04/2005									
27/05/2005									
30/06/2005									
19/07/2005									
20/07/2005									
22/08/2005									
23/08/2005									
22/09/2005									
25/10/2005									
25/01/2006									
22/02/2006									
14/03/2006									
15/03/2006									
27/04/2006									
28/06/2006									
31/08/2006									
21/09/2006									
25/10/2006									
15/06/2007									
11/07/2007						0.75			
12/07/2007									
13/07/2007									
15/07/2007								5	
16/07/2007					42.22				
17/07/2007		3	2.5	5.6					
18/08/2007									
31/08/2007									
05/09/2007									
06/09/2007									
08/09/2007									
10/09/2007									
11/09/2007	113.49								
13/09/2007									
28/10/2007									
13/03/2008									
16/05/2008									181.5
18/05/2008 11:45									
03/07/2008									
05/07/2008									
06/07/2008									188
13/08/2008									
14/08/2008									
15/09/2008									
18/09/2008									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
02/10/2008									
03/10/2008									
04/10/2008									
05/10/2008									
26/05/2009 17:15									
27/05/2009 14:15									
28/05/2009 12:00					3.5				
05/06/2009 17:00									
06/06/2009									
04/07/2009 13:45									
05/07/2009 14:35									
06/07/2009 14:10									
07/07/2009 09:30							2.5	1.5	
08/09/2009									
09/09/2009									
11/09/2009									
06/10/2009							8	5	
07/10/2009									
08/10/2009									
09/10/2009									
03/05/2010									
04/05/2010									
05/05/2010							10	60	
26/05/2010						0.25			
27/05/2010									
28/05/2010									
08/06/2010									
05/07/2010						0.25			
06/07/2010									
07/07/2010									
08/07/2010							13	9	
09/07/2010									
04/08/2010									
14/09/2010					33.6				
15/09/2010									
05/10/2010					55.918				
06/10/2010									
07/10/2010			10	10					
09/02/2011 12:00									
12/05/2011 15:30									
13/05/2011 08:50									
25/05/2011 15:20									
26/05/2011 11:55									
27/05/2011 14:00							30	20	
21/06/2011 12:00									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
22/06/2011 15:20									
12/07/2011 13:20						0.4			
13/07/2011 13:15							9	7	
14/07/2011 15:15									
19/07/2011 12:20									
16/08/2011 14:50		0							
17/08/2011 10:45			2			0.5			
18/08/2011 16:00									
17/09/2011 08:25									
22/09/2011 15:05			31.4265		48.638				
23/09/2011 09:30									
24/09/2011 14:40									
25/09/2011 12:55									
23/10/2011									
24/10/2011									
25/10/2011									
26/10/2011 16:20									
27/10/2011									28
29/10/2011 16:00	0							20	
30/10/2011 14:30									
31/10/2011 12:30		0	34	35.26	41				
20/11/2011 14:25									22.2
21/11/2011 11:00									
22/11/2011 10:00									
24/11/2011 15:00									
26/11/2011 09:00		0	34.6		49.1				
13/12/2011 14:15									
14/12/2011 16:25									
15/12/2011 12:20									
16/12/2011 15:10									15.2
17/12/2011 09:30									
18/12/2011 12:25									
20/12/2011 13:30		0							
21/12/2011 15:20									
12/01/2012 15:30		0	28.3		46.2				
13/01/2012 12:00									
14/01/2012 14:40									
17/01/2012 13:00									
18/01/2012 09:40									
24/01/2012 15:45									7.2
09/02/2012 15:25									
11/02/2012 15:30						0			
12/02/2012 10:35		0		23.1	40.8				
13/02/2012 13:30							0		
14/02/2012 13:40								0	

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
16/02/2012 13:00									
09/03/2012 10:50									
10/03/2012 12:50									
11/03/2012 10:00		0	21.2		35				
12/03/2012 08:45						0			3.6
14/03/2012 13:30									
15/03/2012 12:00									
07/04/2012 14:10						0			
08/04/2012 09:25		0	19.5		30.5				
09/04/2012 13:50									
01/05/2012 11:30									
03/05/2012 14:07			38.9	41.2	40.5				
04/05/2012 11:30						0.0			
05/05/2012 10:17									
06/05/2012 13:28									
07/05/2012 09:00									
08/05/2012 10:35	105.6								
09/05/2012 08:45									387.0
31/05/2012									
01/06/2012									
03/06/2012		6.741	28.525		40.524				
04/06/2012						0.2			
05/06/2012									
06/06/2012 14:00									75.53
07/06/2012 09:05									
01/07/2012 10:00									
02/07/2012 14:47					37.41				
03/07/2012 12:05			32.23	31.60					
04/07/2012 13:40									
05/07/2012 09:50									
07/07/2012 12:00									
08/07/2012 14:55	26.8								
09/07/2012 08:50							13.5		40.9
10/07/2012 10:30									
16/07/2012 15:30									
01/08/2012 10:25			38.24		36				
02/08/2012 12:30									
03/08/2012 10:00									56
05/08/2012 13:05						0.5			
07/08/2012 08:10									
02/09/2012 08:50						0.6			100.9
03/09/2012 13:15			28.8		38.7				
20/09/2012 15:10									
21/09/2012 14:00									
22/09/2012 10:33									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
23/09/2012 08:15									
25/09/2012 09:29									
10/10/2012 16:40									
11/10/2012 14:00									
12/10/2012 10:30									
14/10/2012 13:30			27.8387	35.13	33.48				
15/10/2012 10:45									24.91
16/10/2012 12:50									
17/10/2012 10:34	36.17								
19/11/2012 13:40		0							
10/12/2012 15:10		0							
12/01/2013 13:30									
15/01/2013 09:30					41.11				
16/01/2013 14:00									
08/02/2013 15:30									
09/02/2013 10:30									
10/02/2013 12:10						0	0	0	
12/02/2013 11:10		0	19.82	24.91	37.25				
07/03/2013 15:30					50.98				
08/03/2013 14:00									
12/03/2013 14:00									
14/03/2013 12:00									
04/04/2013 11:45						0			
06/04/2013 09:15									
09/04/2013 12:40					31.58				
10/04/2013 11:15									
02/05/2013 15:25									
03/05/2013 09:45		0			23.57				
04/05/2013 09:35									
07/05/2013 11:50							0	0	
01/06/2013 12:00									
02/06/2013 16:00									
03/06/2013 08:45						0.24			
04/06/2013 11:50					24.64				
05/06/2013 11:00									
07/06/2013 14:50									
08/06/2013 09:40									
09/06/2013 08:45									93.025
01/07/2013 13:45									
02/07/2013 13:50									
03/07/2013 12:00									17.627
04/07/2013 15:00									
05/07/2013 10:40	8.897								
06/07/2013 09:30			28.238	40.7	21.341				
07/07/2013 09:45									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
12/07/2013 13:45									
06/08/2013 15:15									
10/08/2013 16:35									
11/08/2013 09:30									
12/08/2013 09:50									
01/09/2013 14:20									
02/09/2013 12:30									
03/09/2013 14:05					43.68				
04/09/2013 13:40									
05/09/2013 11:00									4.99
07/09/2013 14:30									
08/09/2013 10:14									
09/09/2013 13:00									
11/09/2013 17:30									
12/09/2013 13:18									
13/09/2013 14:45									
14/09/2013 11:31	20.23								84.93
01/10/2013 16:15									
03/10/2013 15:55									
04/10/2013 10:30									
05/10/2013 12:25									
06/10/2013 15:00									
07/10/2013 10:25	24.165								78.37
09/10/2013 14:35							14.48	6.02	
10/10/2013 08:30			30.43	27.36	41.55				
04/11/2013 14:30									
06/11/2013 10:05									
07/11/2013 10:10									
08/11/2013 14:45									
09/11/2013 13:30									
11/11/2013 11:00					53.9				
02/12/2013 13:00									
03/12/2013 08:30									
04/12/2013 14:40					88.69				
06/12/2013 13:25									
02/01/2014 16:05									
03/01/2014 14:05									
25/01/2014 14:05					46.1				
02/02/2014 09:55							0	0	
03/02/2014 10:30									
08/02/2014 12:30	0								
10/02/2014 11:30		0		7.1	29.1				
11/02/2014 12:50									
12/02/2014 12:20									
18/02/2014 10:00									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
01/03/2014 11:15									
02/03/2014 13:10					26.8				
04/03/2014 14:40									
04/04/2014 16:00					30.80				
05/04/2014 13:15									
06/04/2014 12:30									
07/04/2014 12:00									
03/05/2014 15:35									
04/05/2014 09:35									
05/05/2014 13:00									
06/05/2014 14:50			21.9	49.4					
07/05/2014 11:50									
08/05/2014 13:15									
10/05/2014 11:25							44.4	62.8	770
11/05/2014 11:20	367.42				40				
13/05/2014 10:45									
14/05/2014 12:00									
03/06/2014 15:00									
04/06/2014 11:40									
05/06/2014 11:45									
06/06/2014 10:43									
07/06/2014 12:50					27.5				
08/06/2014 12:25									
09/06/2014 10:45	23.3								
10/06/2014 11:00									23
01/07/2014 11:35									
02/07/2014 12:30							7.0		
03/07/2014 15:35			27.6	30.62	34.94				
04/07/2014 10:15									
05/07/2014 13:25									
06/07/2014 09:00									18.0
07/07/2014 10:00	26.81								
01/08/2014 09:50									
02/08/2014 12:00									
03/08/2014 09:00					31.99				
04/08/2014 09:30									19.73
05/08/2014 16:00	19.419								
22/08/2014 15:30									
24/08/2014 11:00									
25/08/2014 09:45									
02/09/2014 14:15									
16/09/2014 13:10									
18/09/2014 12:20									
19/09/2014 12:00					53				
20/09/2014 10:00						0.67114			

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
21/09/2014 11:15									
22/09/2014 12:45									137.74
27/09/2014 09:40									
16/10/2014 10:00									
17/10/2014 11:00									
18/10/2014 14:25									
19/10/2014 09:00		0	35.2	32.9	48.2				
20/10/2014 13:20									
21/10/2014 14:30									57.9
22/10/2014 11:10									
23/10/2014 09:40									
24/10/2014 14:55									
25/10/2014 11:00							8.1		
26/10/2014 09:00									
13/11/2014 13:30									
14/11/2014 12:30									
15/11/2014 14:20									
16/11/2014 14:45									
17/11/2014 14:15									
18/11/2014 10:00					47.7				
19/11/2014 14:05									
20/11/2014 09:59									
21/11/2014 14:00									22
22/11/2014 14:31									
12/12/2014 13:20									
13/12/2014 13:20									
14/12/2014 11:30									
15/12/2014 13:00									
16/12/2014 09:50					56.9				
18/12/2014 14:23									
19/12/2014 15:40									
11/01/2015 13:16									
12/01/2015 11:57									
13/01/2015 13:12									
14/01/2015 10:13					44.8				
17/01/2015 13:00									9.3
19/01/2015 15:05									
22/01/2015 13:24									
28/01/2015 10:00									
05/02/2015 13:07									
06/02/2015 11:50						0		0	
07/02/2015 14:00									
12/02/2015 13:07		0	21	16.4	39.6				
14/02/2015 14:47									
15/02/2015 11:30									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
16/02/2015 15:20									
17/02/2015 12:50									6.3
18/02/2015 08:00									
06/03/2015 13:30									
07/03/2015 13:00									
09/03/2015 10:30					35.1				
10/03/2015 12:05									
11/03/2015 14:30									
13/03/2015 13:00									
03/04/2015 11:10									
06/04/2015 09:40									
07/04/2015 13:20									
08/04/2015 11:30					31.7				
09/04/2015 13:25									
10/04/2015 12:00									
12/04/2015 10:40									
12/05/2015 10:15			37.2	115.5	95.1				
13/05/2015 13:01									1050
14/05/2015 11:30									
23/05/2015 14:20							39.6		
24/05/2015 16:14								28.9	
26/05/2015 07:30									
27/05/2015 12:34									
28/05/2015 12:42									
02/06/2015 13:16				35					
03/06/2015 14:30									
04/06/2015 10:30									
09/06/2015 13:23									71.5
11/06/2015 10:24									
12/06/2015 11:48	62								
16/06/2015 08:48	71.2								17.7
17/06/2015 08:50									
18/06/2015 10:41					34.1				
19/06/2015 09:30									
23/06/2015 15:05									
09/07/2015 14:56									
13/07/2015 12:30									
15/07/2015 13:10									
16/07/2015 12:15									
18/07/2015 14:10									
19/07/2015 12:20					45.7				275.4
26/07/2015 09:22									
28/07/2015 12:00			28.6	26.1					
29/07/2015 10:30									
30/07/2015 13:40								12	

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
06/08/2015 11:05									
12/08/2015 13:25									
17/08/2015 10:35					38.8				
19/08/2015 14:30									
20/08/2015 14:20									
21/08/2015 11:50									
22/08/2015 13:00									93.5
23/08/2015 14:25									
26/08/2015 12:10									
01/09/2015 11:30									
03/09/2015 10:56									
04/09/2015 09:15									
10/09/2015 11:59									
11/09/2015 15:05									
12/09/2015 13:31					42.3				
13/09/2015 15:25									
15/09/2015 14:46									
16/09/2015									172.1
17/09/2015 12:07									
18/09/2015				45.7					
19/09/2015									
10/10/2015 15:07					38.2				
11/10/2015 12:07									
14/10/2015 15:04									
16/10/2015 13:45									
17/10/2015 15:30			36.3	37.5					
18/10/2015 10:05						0			
19/10/2015 12:19									
20/10/2015 13:16							12.1	6.2	75.6
14/11/2015 14:48									
15/11/2015 13:42									
16/11/2015 10:57									
17/11/2015 14:10									
18/11/2015 10:08									
19/11/2015 10:55					70.8				
20/11/2015 15:38									
22/11/2015 15:30									
23/11/2015 12:09									23.3
24/11/2015 12:50									
15/12/2015 11:50									17.4
16/12/2015 11:20									
17/12/2015 12:00									
18/12/2015 12:15					86.7				
19/12/2015 11:44									
20/12/2015 09:37				34.5					

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
05/01/2016 11:56									
06/01/2016 13:00				37					
07/01/2016 15:00					70.7				
08/01/2016 10:41									13.9
09/01/2016 11:50									
10/01/2016 10:30									
30/01/2016 10:40									
01/02/2016 11:30									
02/02/2016 14:00									
03/02/2016 11:20		0	24.7	25.3	47				
04/02/2016 11:45									10.1
08/02/2016 13:19									
02/03/2016 15:54				25.8					
03/03/2016 10:45									
04/03/2016 12:15									10.6
05/03/2016 14:55					41.4				
06/03/2016 12:45									
05/04/2016 16:00									
06/04/2016 09:30				19.2	34.5				
07/04/2016 09:10									5
08/04/2016 12:50									
01/05/2016 14:35						0			
02/05/2016 13:00									
03/05/2016 12:25								95.3	
04/05/2016 15:28			28.5	47	29.4				
05/05/2016 10:20									418.6
06/05/2016 10:10									
18/05/2016 17:15									
19/05/2016 09:42									
13/06/2016 11:05									
14/06/2016 11:18									58.4
15/06/2016 08:37				46.7	36.9				
16/06/2016 14:30									
21/06/2016 14:50									
12/07/2016 13:30									
13/07/2016 13:20							5.3	20.6	
14/07/2016 11:15					40.4				
15/07/2016 10:45			33.1	41.4					49.3
16/07/2016 15:51									
17/07/2016 15:00									
19/07/2016 12:15									
05/08/2016 11:56									
06/08/2016 13:43									279.6
07/08/2016 08:59				78.9	33				
08/08/2016 10:02									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
09/08/2016 08:24									
16/08/2016 13:25									
18/08/2016 15:54									
21/09/2016 17:45									
22/09/2016 14:18									
23/09/2016 14:20				53.2	41.9				
24/09/2016 10:13									82.9
25/09/2016 09:35									
19/10/2016 17:33									
20/10/2016 13:46									
21/10/2016 13:17									
22/10/2016 12:10					39.4				
23/10/2016 14:21			43.3	41.5					21.2
31/10/2016 10:10									
08/11/2016 12:45									
09/11/2016 10:31									
10/11/2016 15:50					41.2				17.2
11/11/2016 15:06				29.7					
12/11/2016 08:56									
01/12/2016 12:05									
02/12/2016 09:00									12.6
03/12/2016 10:20					53.3				
04/12/2016 14:15									
05/12/2016 08:40				37.1					

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
01/01/1994								
27/01/1994								
01/02/1994								
24/02/1994								
01/03/1994								
28/03/1994								
23/04/1994								
10/05/1994								
13/05/1994								
31/05/1994								
01/06/1994								
27/06/1994								
28/06/1994								
27/07/1994								
28/07/1994								
29/07/1994								
17/08/1994								
07/09/1994								
29/09/1994								
27/10/1994								
31/10/1994								
29/11/1994								
05/01/1995								
06/02/1995								
01/03/1995								
29/03/1995								
27/04/1995								
03/05/1995								
06/06/1995								
06/07/1995								
11/07/1995								
05/08/1995								
11/08/1995								
04/09/1995								
05/09/1995								
11/10/1995								
05/11/1995								
12/12/1995								
01/01/1996								
09/02/1996								
05/03/1996								
07/04/1996								
28/04/1996								
24/06/1996								
18/07/1996								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
02/08/1996								
16/09/1996								
03/10/1996								
30/10/1996								
30/11/1996								
28/01/1997								
26/02/1997								
27/03/1997								
12/05/1997								
25/06/1997								
30/06/1997								
31/07/1997								
20/08/1997								
13/09/1997								
10/10/1997								
21/12/1997								
15/01/1998								
13/03/1998								
25/04/1998								
11/05/1998								
14/05/1998								
23/05/1998								
30/05/1998								
06/06/2000								
07/11/2000								
10/07/2001								
11/07/2001								
02/08/2003								
24/01/2004								
19/02/2004								
23/03/2004								
24/04/2004								
15/06/2004								
20/07/2004								
29/07/2004								
30/07/2004								
25/08/2004								
21/09/2004								
21/10/2004								
29/11/2004								
17/12/2004								
25/01/2005								
26/02/2005								
27/02/2005								
22/03/2005								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
21/04/2005								
22/04/2005								
27/05/2005								
30/06/2005								
19/07/2005								
20/07/2005								
22/08/2005								
23/08/2005								
22/09/2005								
25/10/2005								
25/01/2006								
22/02/2006								
14/03/2006								
15/03/2006								
27/04/2006								
28/06/2006								
31/08/2006								
21/09/2006								
25/10/2006								
15/06/2007								
11/07/2007								
12/07/2007								
13/07/2007								
15/07/2007								
16/07/2007		2						
17/07/2007								
18/08/2007								
31/08/2007								
05/09/2007								
06/09/2007								
08/09/2007								
10/09/2007								
11/09/2007								
13/09/2007								
28/10/2007								
13/03/2008								
16/05/2008								
18/05/2008 11:45								
03/07/2008								
05/07/2008								
06/07/2008								
13/08/2008								
14/08/2008								
15/09/2008								
18/09/2008								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
02/10/2008								
03/10/2008								
04/10/2008								
05/10/2008								
26/05/2009 17:15								
27/05/2009 14:15								
28/05/2009 12:00								
05/06/2009 17:00				1300.56				
06/06/2009								
04/07/2009 13:45								
05/07/2009 14:35				177.475				
06/07/2009 14:10								
07/07/2009 09:30			3.5					
08/09/2009				266.785				
09/09/2009								
11/09/2009								
06/10/2009				188.85				
07/10/2009								
08/10/2009								
09/10/2009								
03/05/2010								
04/05/2010								
05/05/2010	25		142.48					
26/05/2010				527.0095				
27/05/2010								
28/05/2010								
08/06/2010								
05/07/2010	12		150					
06/07/2010				221.428067				
07/07/2010								
08/07/2010								
09/07/2010								
04/08/2010								
14/09/2010								
15/09/2010								
05/10/2010				597.44				
06/10/2010								
07/10/2010								
09/02/2011 12:00								
12/05/2011 15:30								
13/05/2011 08:50								
25/05/2011 15:20								
26/05/2011 11:55					0			
27/05/2011 14:00								
21/06/2011 12:00				246.37				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
22/06/2011 15:20								
12/07/2011 13:20	20							
13/07/2011 13:15					0			
14/07/2011 15:15								
19/07/2011 12:20								
16/08/2011 14:50								
17/08/2011 10:45								
18/08/2011 16:00				271.9				
17/09/2011 08:25								
22/09/2011 15:05								
23/09/2011 09:30								
24/09/2011 14:40								
25/09/2011 12:55				227.9375				
23/10/2011								
24/10/2011						2455		
25/10/2011				115				
26/10/2011 16:20					0			
27/10/2011								
29/10/2011 16:00								
30/10/2011 14:30								
31/10/2011 12:30								
20/11/2011 14:25								
21/11/2011 11:00			8.3					
22/11/2011 10:00							21.3	34
24/11/2011 15:00								
26/11/2011 09:00								
13/12/2011 14:15								
14/12/2011 16:25								
15/12/2011 12:20								
16/12/2011 15:10								
17/12/2011 09:30								
18/12/2011 12:25				52.6				
20/12/2011 13:30								
21/12/2011 15:20							20.2	25.9
12/01/2012 15:30								
13/01/2012 12:00								
14/01/2012 14:40								
17/01/2012 13:00				45.7				
18/01/2012 09:40								
24/01/2012 15:45								
09/02/2012 15:25					0			
11/02/2012 15:30								
12/02/2012 10:35								
13/02/2012 13:30				26.5				
14/02/2012 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
16/02/2012 13:00			4.8					
09/03/2012 10:50								
10/03/2012 12:50								
11/03/2012 10:00								
12/03/2012 08:45				33.7				
14/03/2012 13:30								12.2
15/03/2012 12:00								
07/04/2012 14:10								
08/04/2012 09:25								
09/04/2012 13:50								
01/05/2012 11:30								
03/05/2012 14:07			6.7					
04/05/2012 11:30								
05/05/2012 10:17								
06/05/2012 13:28						3489.7		
07/05/2012 09:00								
08/05/2012 10:35				83.3				
09/05/2012 08:45								
31/05/2012								
01/06/2012						6461		
03/06/2012							263.76	346.12
04/06/2012	324.91			735.36				
05/06/2012								
06/06/2012 14:00			147.77					
07/06/2012 09:05								
01/07/2012 10:00					0			
02/07/2012 14:47								
03/07/2012 12:05							220.55	399.04
04/07/2012 13:40				283.14				
05/07/2012 09:50						5334.22		
07/07/2012 12:00								
08/07/2012 14:55								
09/07/2012 08:50								
10/07/2012 10:30								
16/07/2012 15:30								
01/08/2012 10:25				283				
02/08/2012 12:30						4923		
03/08/2012 10:00								
05/08/2012 13:05	10.1		40				98	13.8
07/08/2012 08:10								
02/09/2012 08:50	8.2		29.6	224.3				
03/09/2012 13:15							117.1	169.8
20/09/2012 15:10								
21/09/2012 14:00						2199.4		
22/09/2012 10:33								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
23/09/2012 08:15								
25/09/2012 09:29								
10/10/2012 16:40								
11/10/2012 14:00						1991.792		
12/10/2012 10:30								
14/10/2012 13:30								
15/10/2012 10:45			22.823					
16/10/2012 12:50				163.7675				
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30								
15/01/2013 09:30				44.94				
16/01/2013 14:00								
08/02/2013 15:30								
09/02/2013 10:30				39.1				
10/02/2013 12:10								
12/02/2013 11:10					0			
07/03/2013 15:30								
08/03/2013 14:00								
12/03/2013 14:00								
14/03/2013 12:00				71.54				
04/04/2013 11:45				30.3				
06/04/2013 09:15								
09/04/2013 12:40								
10/04/2013 11:15				41.23				
02/05/2013 15:25				26.38				
03/05/2013 09:45								
04/05/2013 09:35					0			
07/05/2013 11:50								
01/06/2013 12:00								
02/06/2013 16:00								
03/06/2013 08:45								
04/06/2013 11:50							313.61	329.448
05/06/2013 11:00								
07/06/2013 14:50								
08/06/2013 09:40			67.45	575.46				
09/06/2013 08:45								
01/07/2013 13:45								
02/07/2013 13:50						5511.28		
03/07/2013 12:00					0			
04/07/2013 15:00								
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45							44.77	58.916

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
12/07/2013 13:45								
06/08/2013 15:15								
10/08/2013 16:35								
11/08/2013 09:30						2305.59		
12/08/2013 09:50								
01/09/2013 14:20								
02/09/2013 12:30						1936.8		
03/09/2013 14:05								
04/09/2013 13:40								
05/09/2013 11:00								
07/09/2013 14:30							20.74	32.49
08/09/2013 10:14		3.1						
09/09/2013 13:00								
11/09/2013 17:30								
12/09/2013 13:18								
13/09/2013 14:45		2.09						
14/09/2013 11:31								
01/10/2013 16:15								
03/10/2013 15:55		1.83	30.05					
04/10/2013 10:30								
05/10/2013 12:25						4417.87		
06/10/2013 15:00								
07/10/2013 10:25								
09/10/2013 14:35								
10/10/2013 08:30							139.11	175.14
04/11/2013 14:30								
06/11/2013 10:05								
07/11/2013 10:10						2146		
08/11/2013 14:45								
09/11/2013 13:30								33.2
11/11/2013 11:00								
02/12/2013 13:00							0	
03/12/2013 08:30								
04/12/2013 14:40								
06/12/2013 13:25								
02/01/2014 16:05								
03/01/2014 14:05								
25/01/2014 14:05								
02/02/2014 09:55								
03/02/2014 10:30								
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50					0			
12/02/2014 12:20								
18/02/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
01/03/2014 11:15								
02/03/2014 13:10								
04/03/2014 14:40								
04/04/2014 16:00								
05/04/2014 13:15								
06/04/2014 12:30								
07/04/2014 12:00								
03/05/2014 15:35					0			
04/05/2014 09:35							209.2	492
05/05/2014 13:00								
06/05/2014 14:50								
07/05/2014 11:50				800.13				
08/05/2014 13:15								
10/05/2014 11:25	150		540					
11/05/2014 11:20								
13/05/2014 10:45								
14/05/2014 12:00								
03/06/2014 15:00			336.5					
04/06/2014 11:40								
05/06/2014 11:45								
06/06/2014 10:43							44.9	64.2
07/06/2014 12:50				356.1				
08/06/2014 12:25		2.4						
09/06/2014 10:45								
10/06/2014 11:00								
01/07/2014 11:35								
02/07/2014 12:30				239.4	0			
03/07/2014 15:35								
04/07/2014 10:15	14.3							
05/07/2014 13:25								
06/07/2014 09:00		1.64					73.4	137
07/07/2014 10:00			33.0					
01/08/2014 09:50								
02/08/2014 12:00								
03/08/2014 09:00							51.51	48
04/08/2014 09:30								
05/08/2014 16:00								
22/08/2014 15:30								
24/08/2014 11:00		5.465	102.8					
25/08/2014 09:45				662.4				
02/09/2014 14:15								
16/09/2014 13:10								
18/09/2014 12:20							142.7	115
19/09/2014 12:00						3999		
20/09/2014 10:00	17.7	0.9935		119.9				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
21/09/2014 11:15			42.7					
22/09/2014 12:45								
27/09/2014 09:40								
16/10/2014 10:00								
17/10/2014 11:00					0			
18/10/2014 14:25						3812.2		
19/10/2014 09:00								
20/10/2014 13:20								
21/10/2014 14:30			51.4					
22/10/2014 11:10								
23/10/2014 09:40								
24/10/2014 14:55							129.9	124.7
25/10/2014 11:00	18	3						
26/10/2014 09:00				197.3				
13/11/2014 13:30								
14/11/2014 12:30								
15/11/2014 14:20								
16/11/2014 14:45								
17/11/2014 14:15								
18/11/2014 10:00	10.2		16.1	107.9				
19/11/2014 14:05								
20/11/2014 09:59								
21/11/2014 14:00							48	42.8
22/11/2014 14:31								
12/12/2014 13:20								
13/12/2014 13:20								
14/12/2014 11:30				30.7				
15/12/2014 13:00								
16/12/2014 09:50								
18/12/2014 14:23								
19/12/2014 15:40								35.9
11/01/2015 13:16				50.3				
12/01/2015 11:57								
13/01/2015 13:12								
14/01/2015 10:13								
17/01/2015 13:00								
19/01/2015 15:05								
22/01/2015 13:24		2.7						
28/01/2015 10:00								
05/02/2015 13:07								
06/02/2015 11:50								
07/02/2015 14:00					0			
12/02/2015 13:07								
14/02/2015 14:47								
15/02/2015 11:30				46.1				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
16/02/2015 15:20								
17/02/2015 12:50								
18/02/2015 08:00								
06/03/2015 13:30				47				
07/03/2015 13:00								
09/03/2015 10:30								
10/03/2015 12:05								
11/03/2015 14:30								
13/03/2015 13:00								
03/04/2015 11:10			4.2					
06/04/2015 09:40								
07/04/2015 13:20								
08/04/2015 11:30								
09/04/2015 13:25								
10/04/2015 12:00								
12/04/2015 10:40				29.4				
12/05/2015 10:15								
13/05/2015 13:01		16.4						
14/05/2015 11:30								
23/05/2015 14:20								
24/05/2015 16:14								
26/05/2015 07:30			79.7					
27/05/2015 12:34				846.3				
28/05/2015 12:42							154.3	177.8
02/06/2015 13:16								
03/06/2015 14:30								
04/06/2015 10:30			31.8					
09/06/2015 13:23								
11/06/2015 10:24		3.6						
12/06/2015 11:48								
16/06/2015 08:48								
17/06/2015 08:50				145.7				
18/06/2015 10:41								
19/06/2015 09:30							46.3	73.7
23/06/2015 15:05								
09/07/2015 14:56			18.9					
13/07/2015 12:30	22.5							218
15/07/2015 13:10								
16/07/2015 12:15								
18/07/2015 14:10								
19/07/2015 12:20								
26/07/2015 09:22								
28/07/2015 12:00								
29/07/2015 10:30								
30/07/2015 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
06/08/2015 11:05								
12/08/2015 13:25								
17/08/2015 10:35								
19/08/2015 14:30								
20/08/2015 14:20								270.7
21/08/2015 11:50								
22/08/2015 13:00								
23/08/2015 14:25			59.4	176.9				
26/08/2015 12:10								
01/09/2015 11:30								
03/09/2015 10:56								
04/09/2015 09:15								
10/09/2015 11:59								817.2
11/09/2015 15:05								
12/09/2015 13:31				324.3				
13/09/2015 15:25								
15/09/2015 14:46								
16/09/2015								
17/09/2015 12:07		4.3	119.6					
18/09/2015								
19/09/2015								
10/10/2015 15:07								
11/10/2015 12:07								
14/10/2015 15:04								
16/10/2015 13:45				193.7				
17/10/2015 15:30								
18/10/2015 10:05	15.4				3.1			
19/10/2015 12:19		2.2	34.9					
20/10/2015 13:16							157.3	204.9
14/11/2015 14:48								
15/11/2015 13:42								
16/11/2015 10:57								
17/11/2015 14:10								
18/11/2015 10:08		1.9	102.7					
19/11/2015 10:55				12.6				
20/11/2015 15:38								
22/11/2015 15:30								
23/11/2015 12:09								
24/11/2015 12:50								72.4
15/12/2015 11:50								
16/12/2015 11:20								
17/12/2015 12:00				73.9				
18/12/2015 12:15			8					
19/12/2015 11:44								50.5
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
05/01/2016 11:56								
06/01/2016 13:00				62.5				
07/01/2016 15:00								
08/01/2016 10:41								
09/01/2016 11:50			8.8					
10/01/2016 10:30								34.3
30/01/2016 10:40								
01/02/2016 11:30			4.2					
02/02/2016 14:00								
03/02/2016 11:20	5.4							
04/02/2016 11:45								
08/02/2016 13:19				47.6				
02/03/2016 15:54								
03/03/2016 10:45			3.4					
04/03/2016 12:15								
05/03/2016 14:55								
06/03/2016 12:45				45.7				
05/04/2016 16:00								
06/04/2016 09:30								
07/04/2016 09:10				35.9				
08/04/2016 12:50			2.7					
01/05/2016 14:35				44.8				
02/05/2016 13:00								
03/05/2016 12:25						527.1		
04/05/2016 15:28	26.8							
05/05/2016 10:20					2			
06/05/2016 10:10		65.7	142.9					931
18/05/2016 17:15								
19/05/2016 09:42								
13/06/2016 11:05								
14/06/2016 11:18								
15/06/2016 08:37								
16/06/2016 14:30		1.9	44.5	223.3				126.5
21/06/2016 14:50								
12/07/2016 13:30				75.4				
13/07/2016 13:20								
14/07/2016 11:15						724.4		
15/07/2016 10:45	10.4	1.7	38.6					
16/07/2016 15:51					1.2			467.9
17/07/2016 15:00								
19/07/2016 12:15								
05/08/2016 11:56								
06/08/2016 13:43								
07/08/2016 08:59								
08/08/2016 10:02			130.8					1077.2

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
09/08/2016 08:24				136.6				
16/08/2016 13:25								
18/08/2016 15:54								
21/09/2016 17:45								
22/09/2016 14:18				97.8				
23/09/2016 14:20			64.3					
24/09/2016 10:13								
25/09/2016 09:35								222.2
19/10/2016 17:33								
20/10/2016 13:46	14			134				
21/10/2016 13:17					1.6			
22/10/2016 12:10						357.4		
23/10/2016 14:21			21.9					84.6
31/10/2016 10:10								
08/11/2016 12:45								
09/11/2016 10:31								
10/11/2016 15:50			15					
11/11/2016 15:06				90.9				
12/11/2016 08:56								53
01/12/2016 12:05								
02/12/2016 09:00			11.4					
03/12/2016 10:20								
04/12/2016 14:15								43.1
05/12/2016 08:40				75.6				

APPENDIX C

HYDROGRAPHS

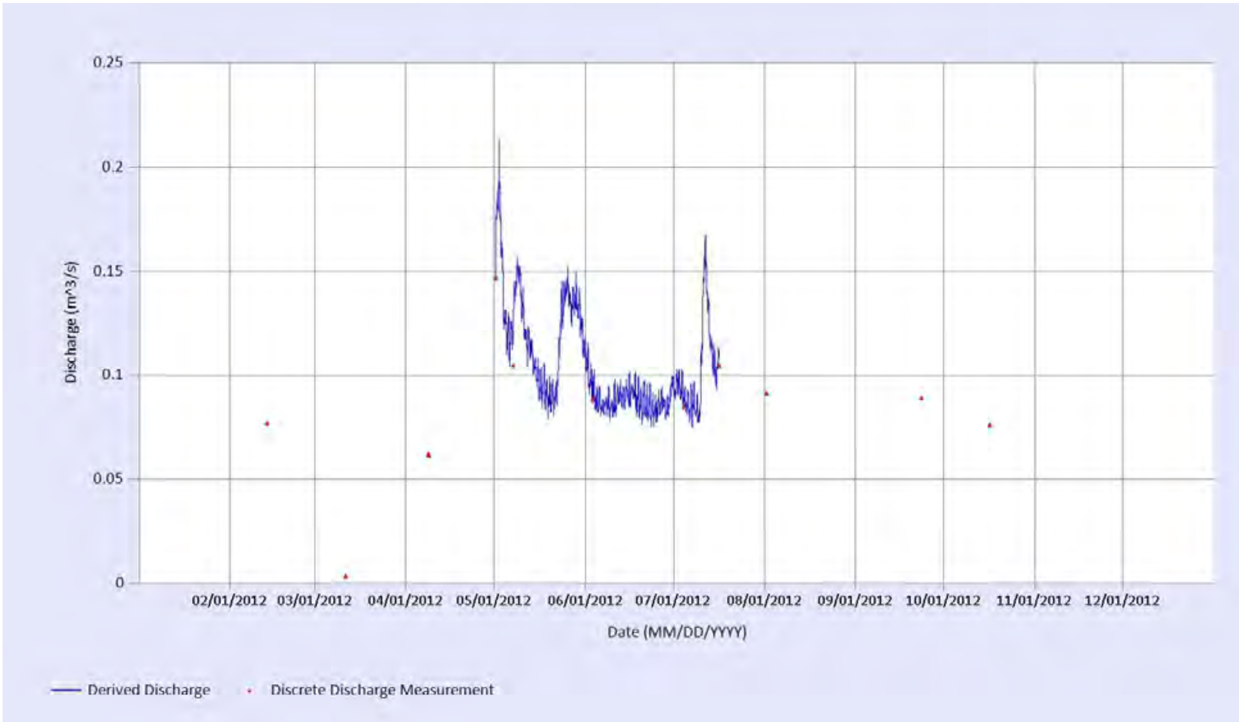


Figure C1 – Discharge at KV-6, Christal Creek below Christal Lake, 2012 open water season

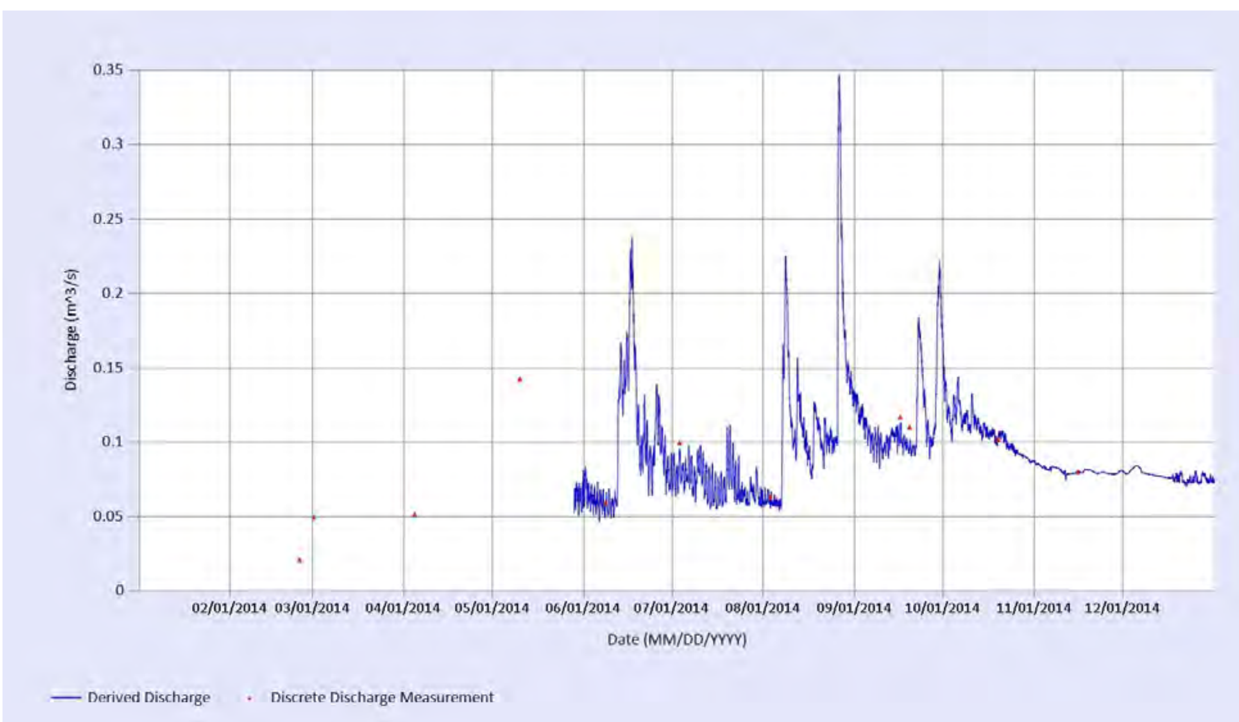


Figure C2 – Discharge at KV-6, Christal Creek below Christal Lake, 2014

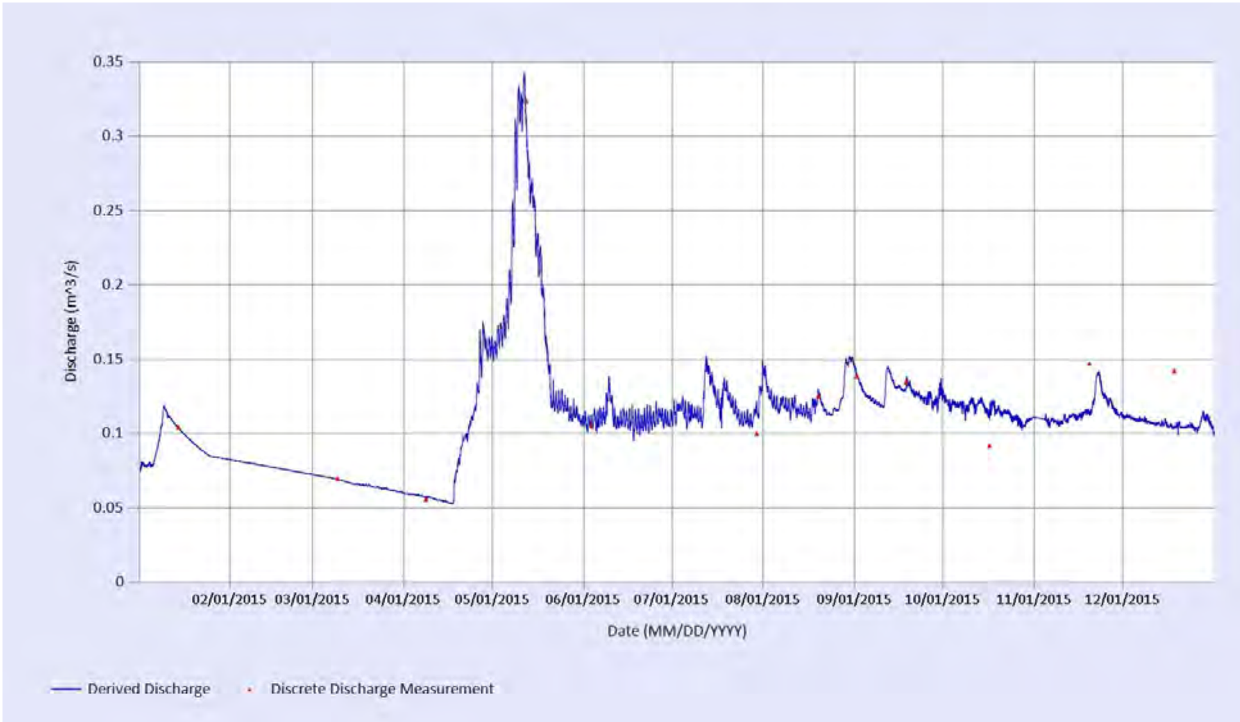


Figure C3 – Discharge at KV-6, Christal Creek below Christal Lake, 2015

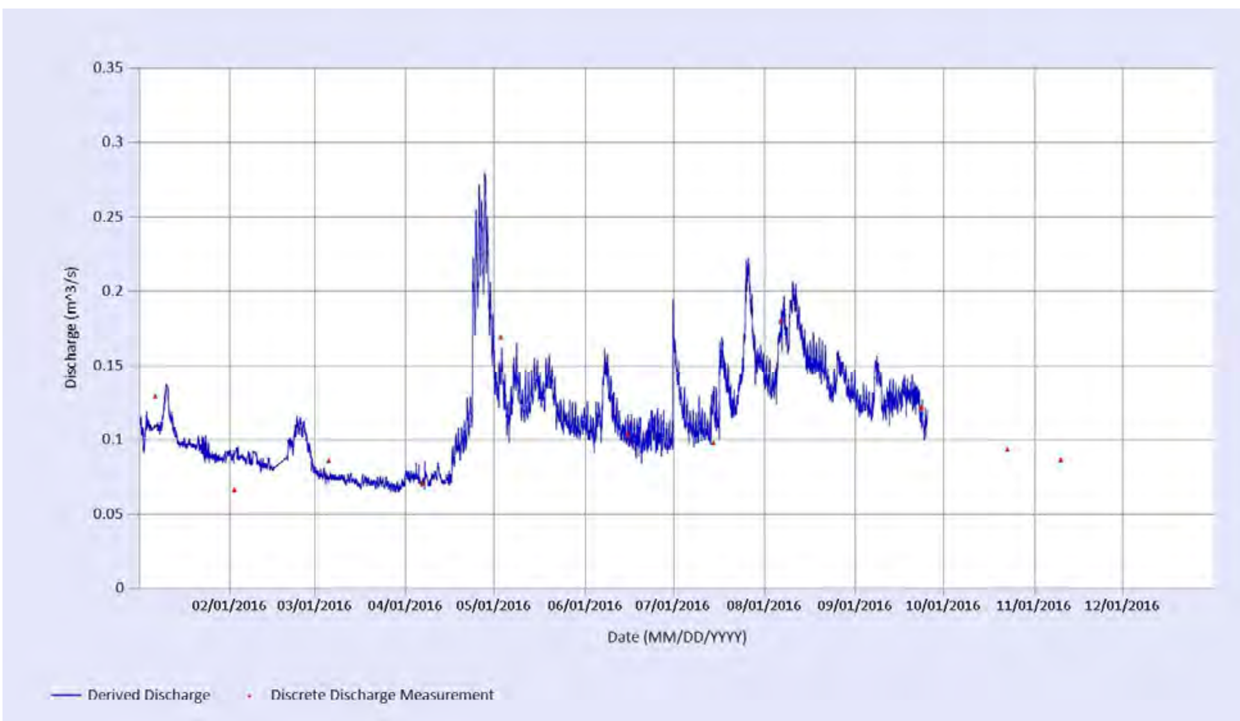


Figure C4 – Discharge at KV-6, Christal Creek below Christal Lake, 2016

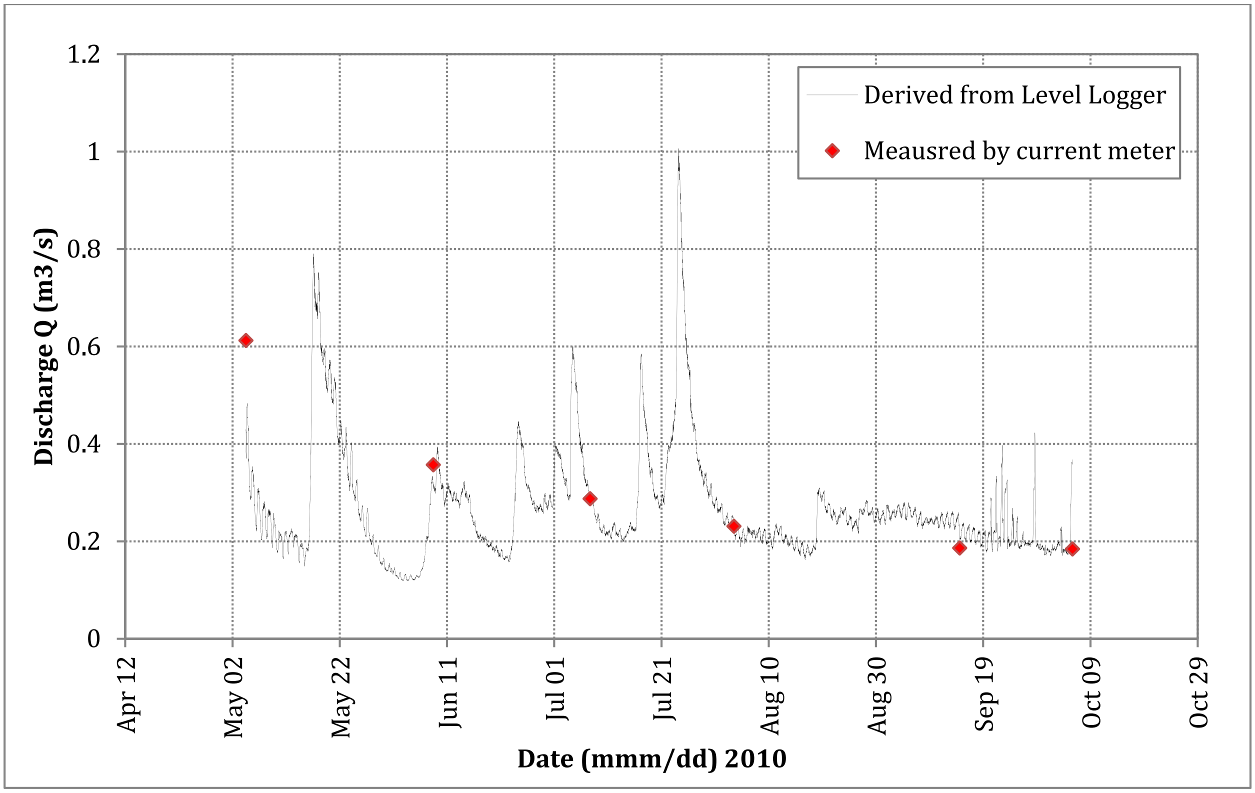


Figure C5 - Discharge at KV-7, Christal Creek at Hansen Road 2010

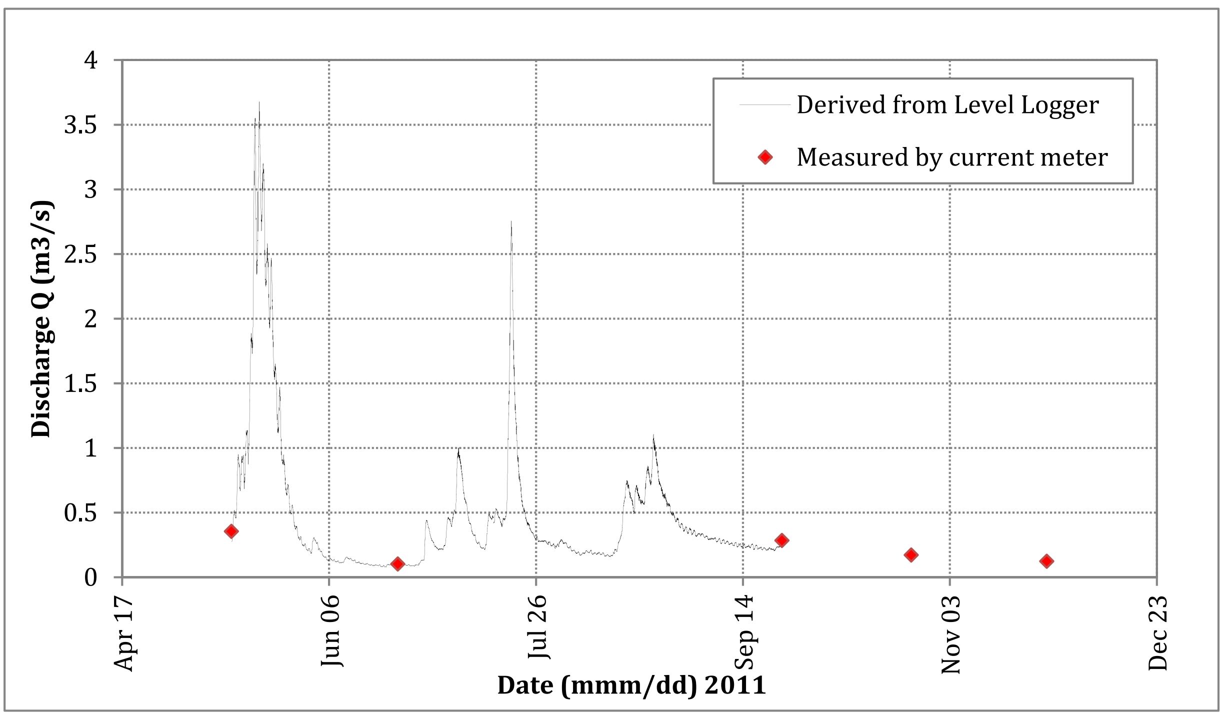


Figure C6 - Discharge at KV-7, Christal Creek at Hansen Road 2011

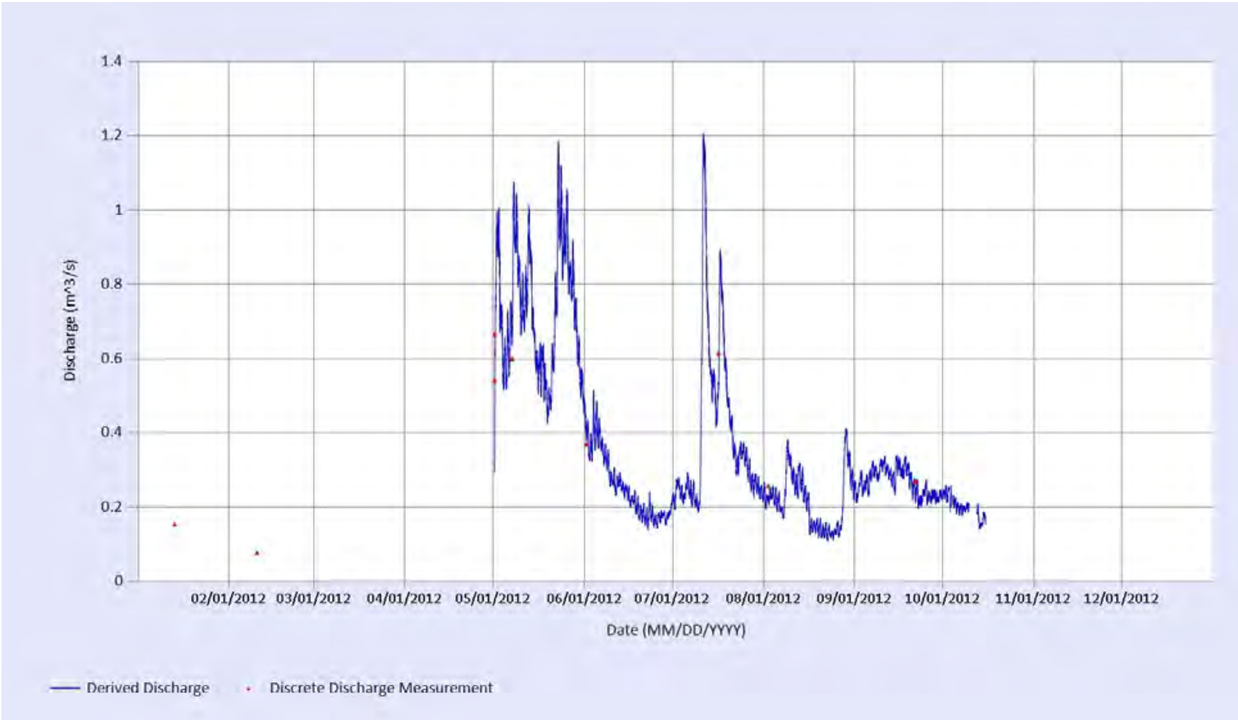


Figure C7 – Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2012

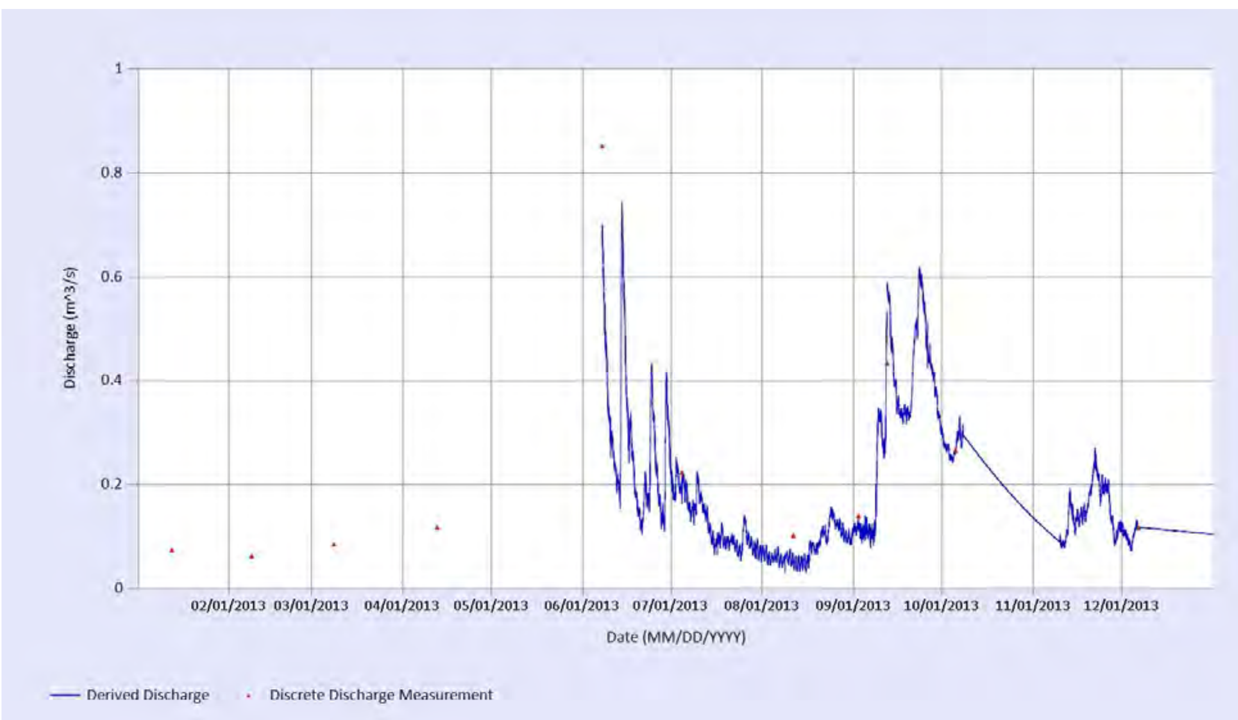


Figure C8 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2013

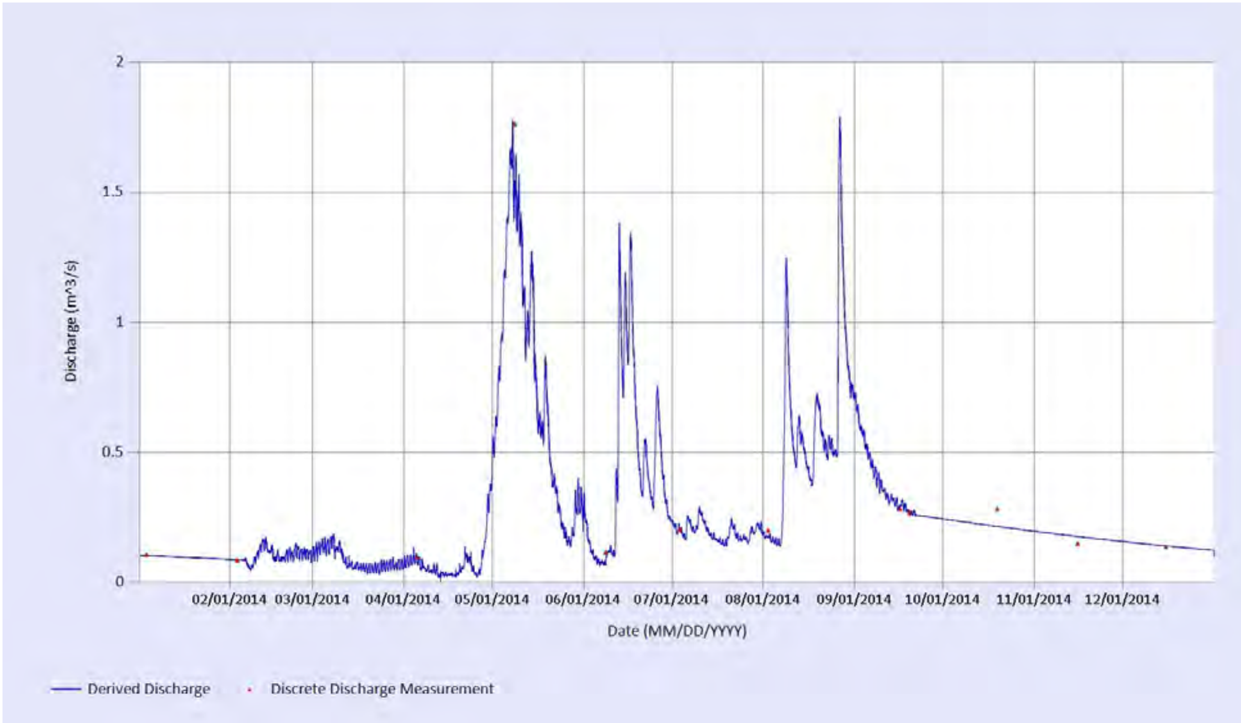


Figure C9 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2014

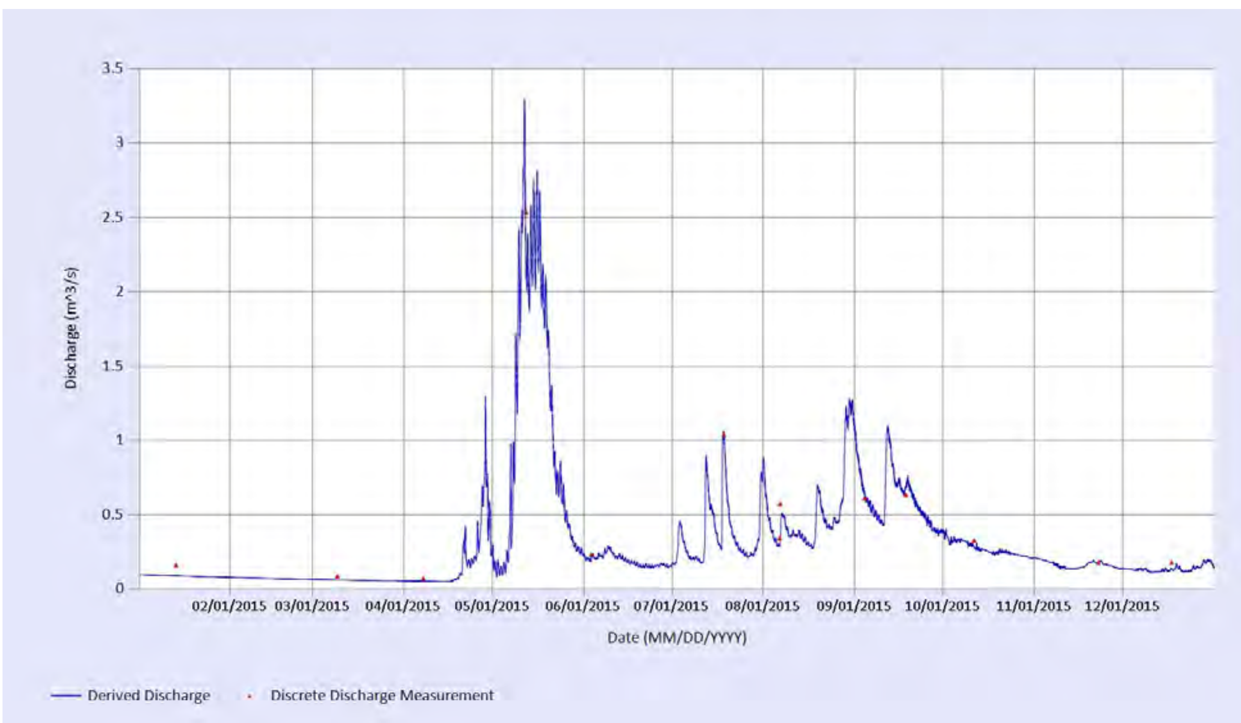


Figure C10 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2015

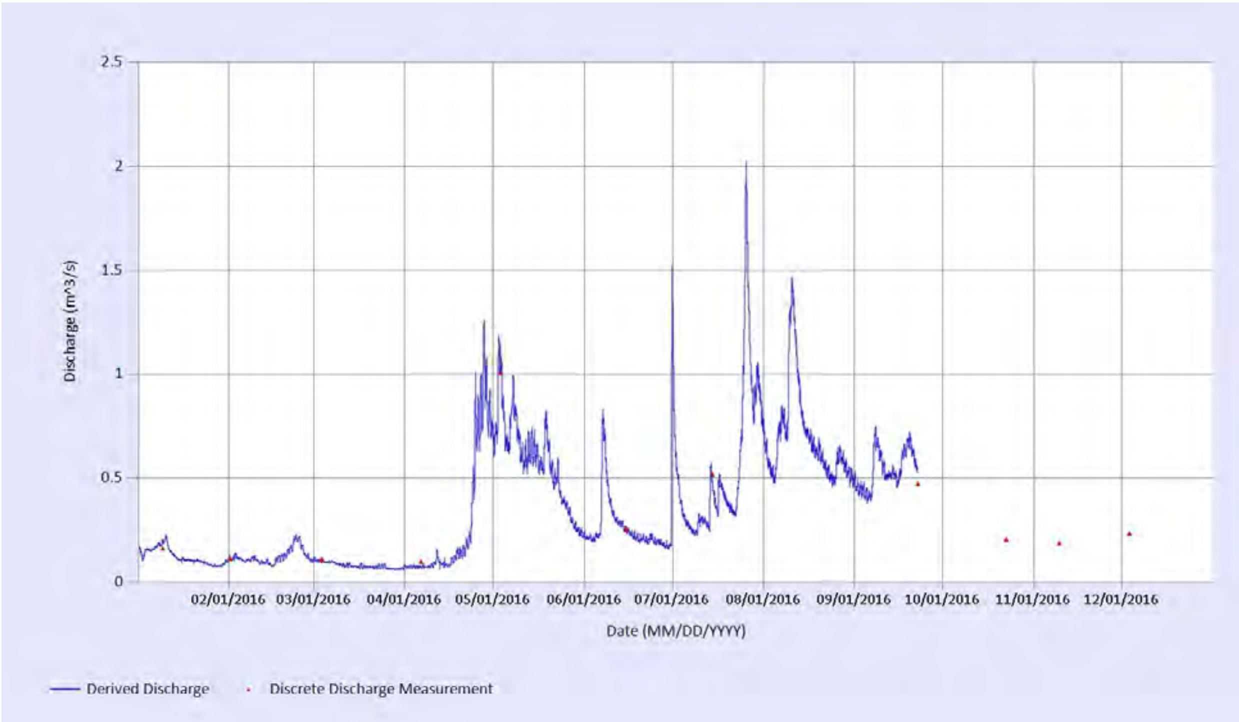


Figure C11 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2016

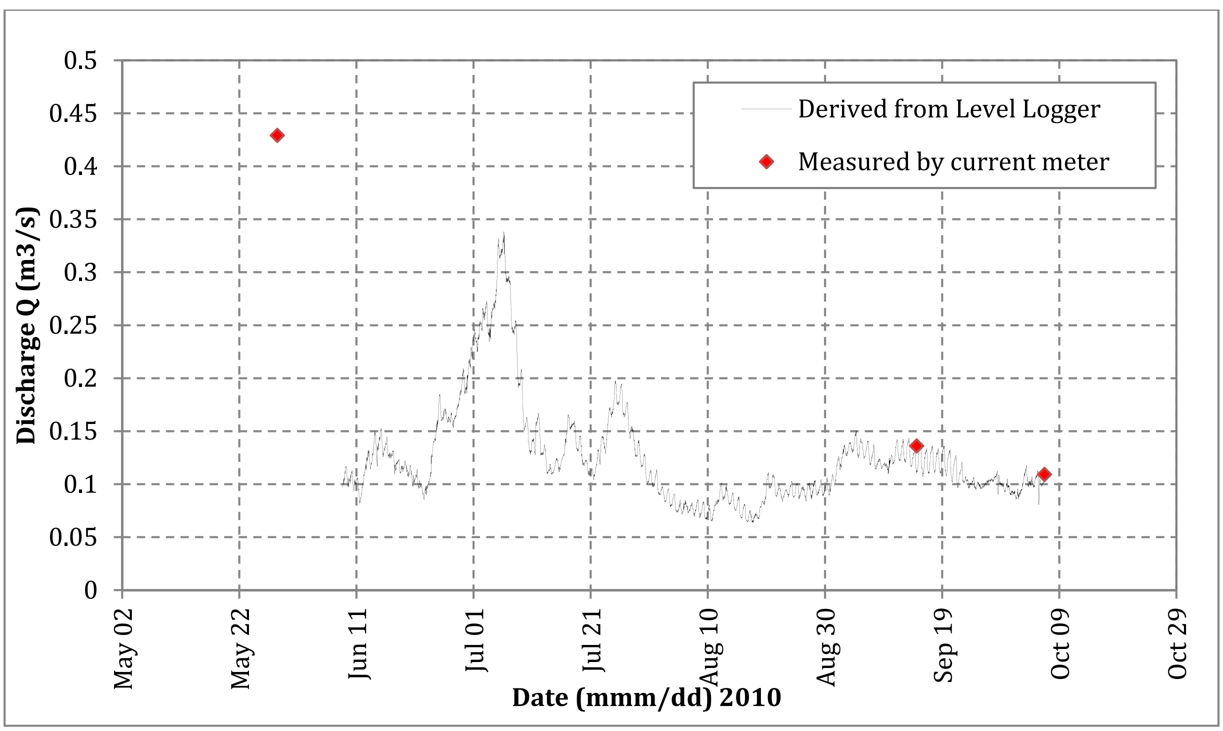


Figure C12 - Discharge at KV-9, Flat Creek 2010

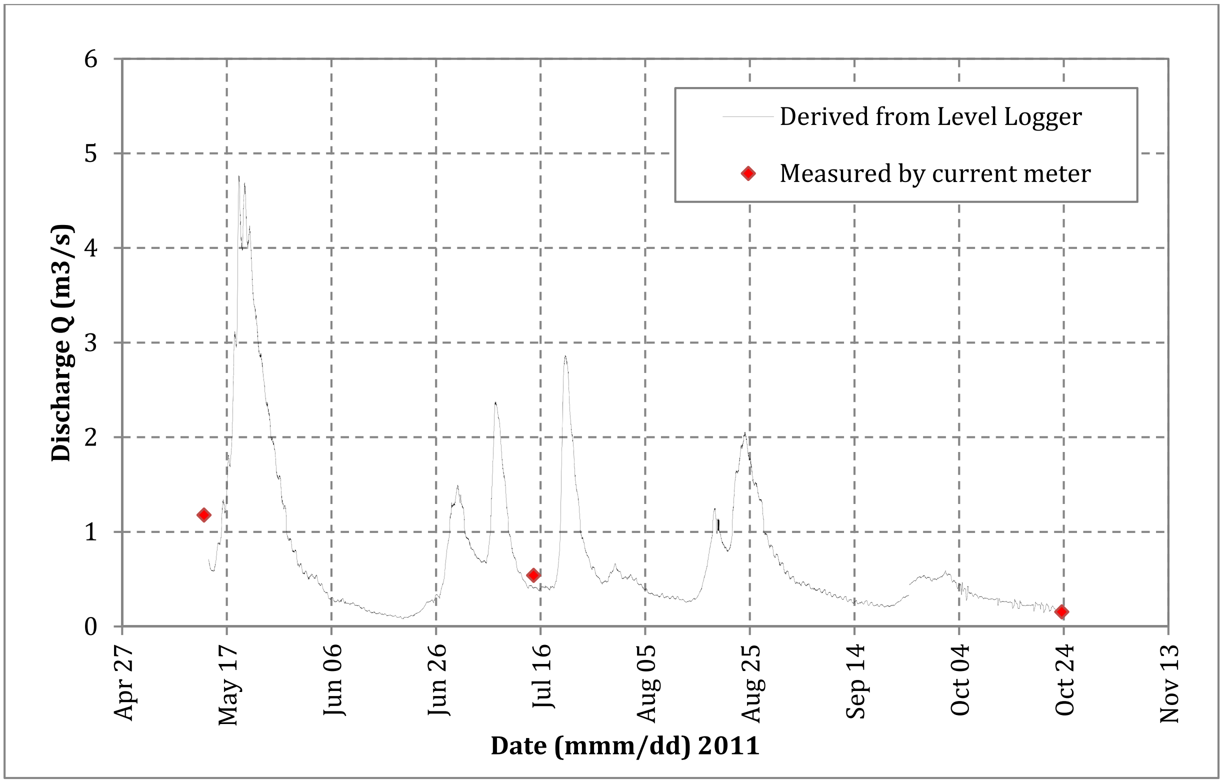


Figure C13 - Discharge at KV-9, Flat Creek 2011

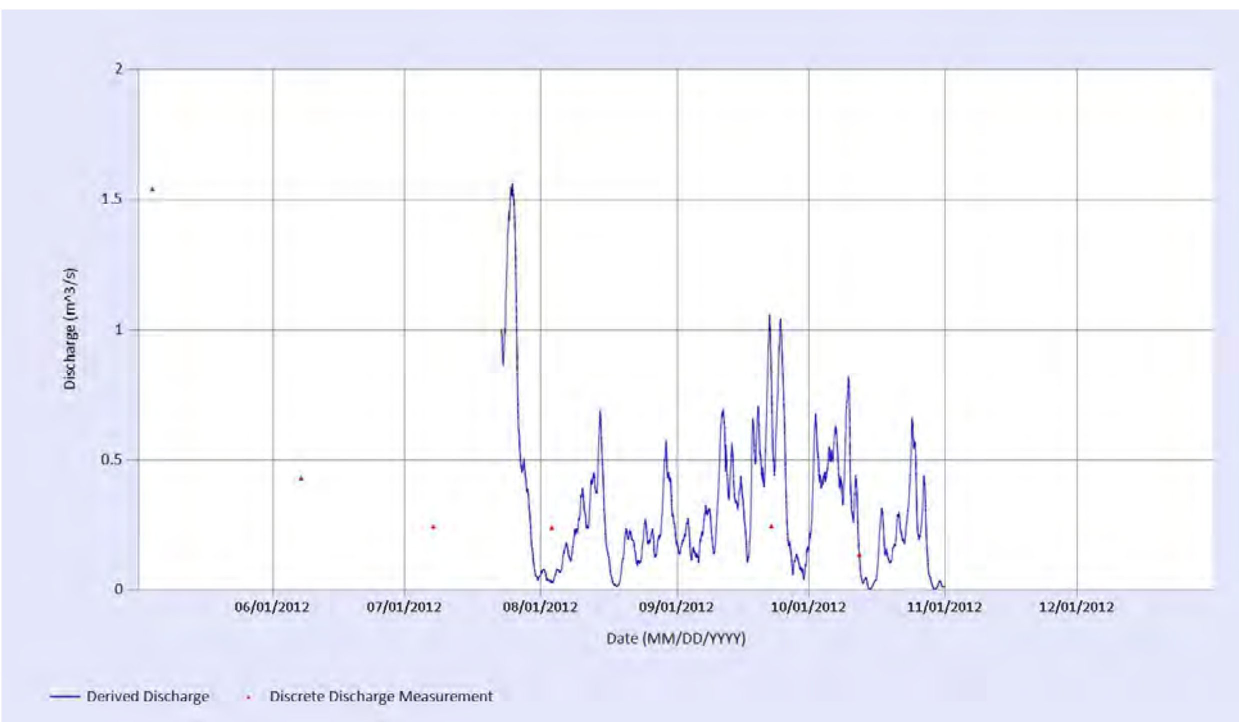


Figure C14 - Discharge at KV-9, Flat creek near the mouth, 2012

Figure C15 - Discharge at KV-9, Flat creek near the mouth, 2013

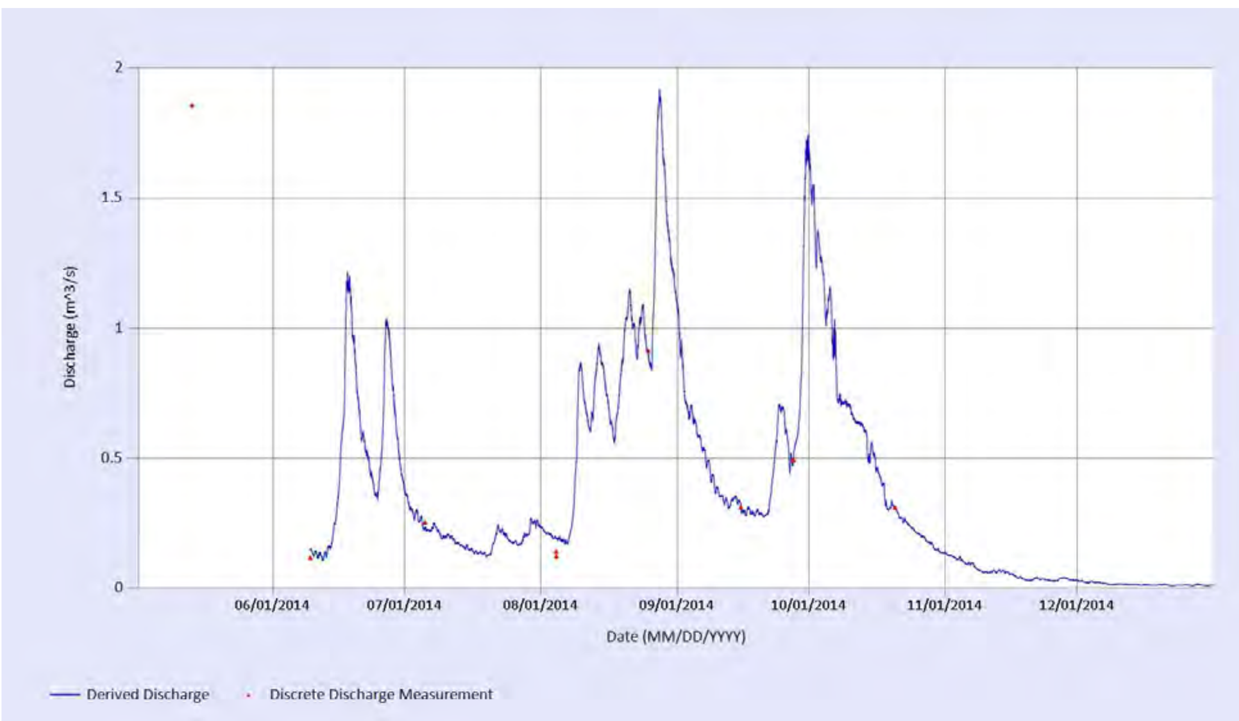


Figure C16 - Discharge at KV-9, Flat creek near the mouth, 2014

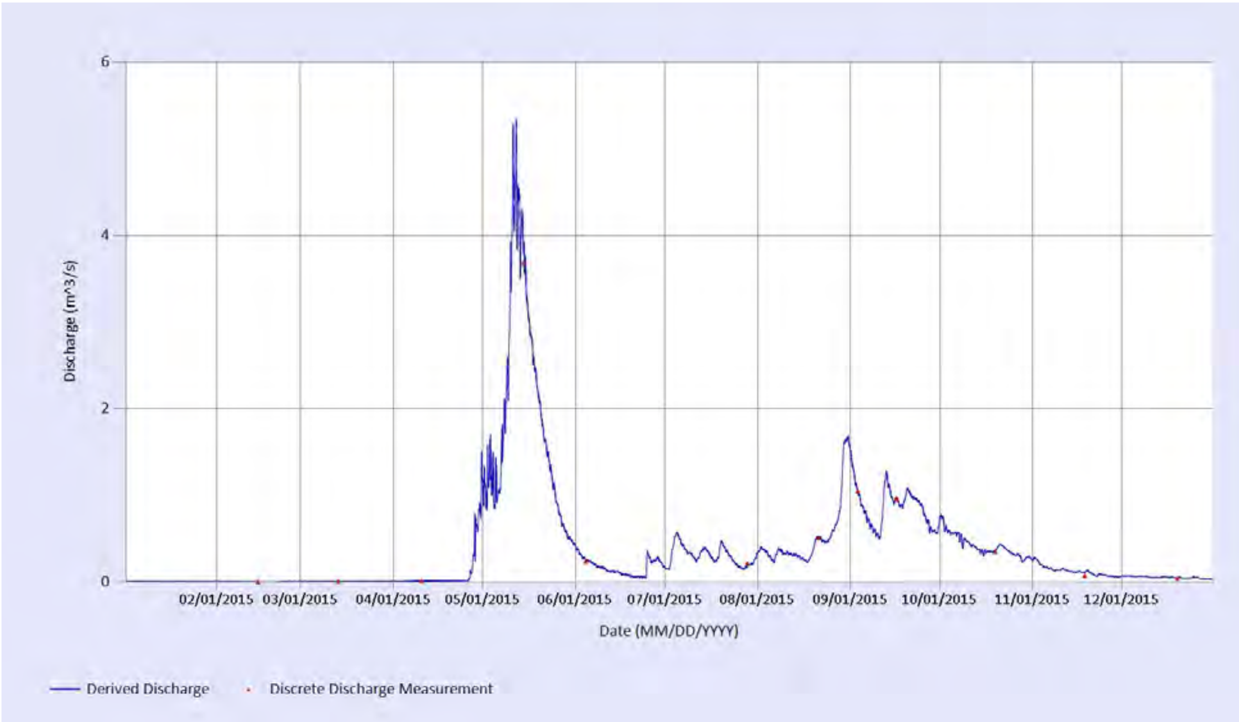


Figure C17 - Discharge at KV-9, Flat creek near the mouth, 2015

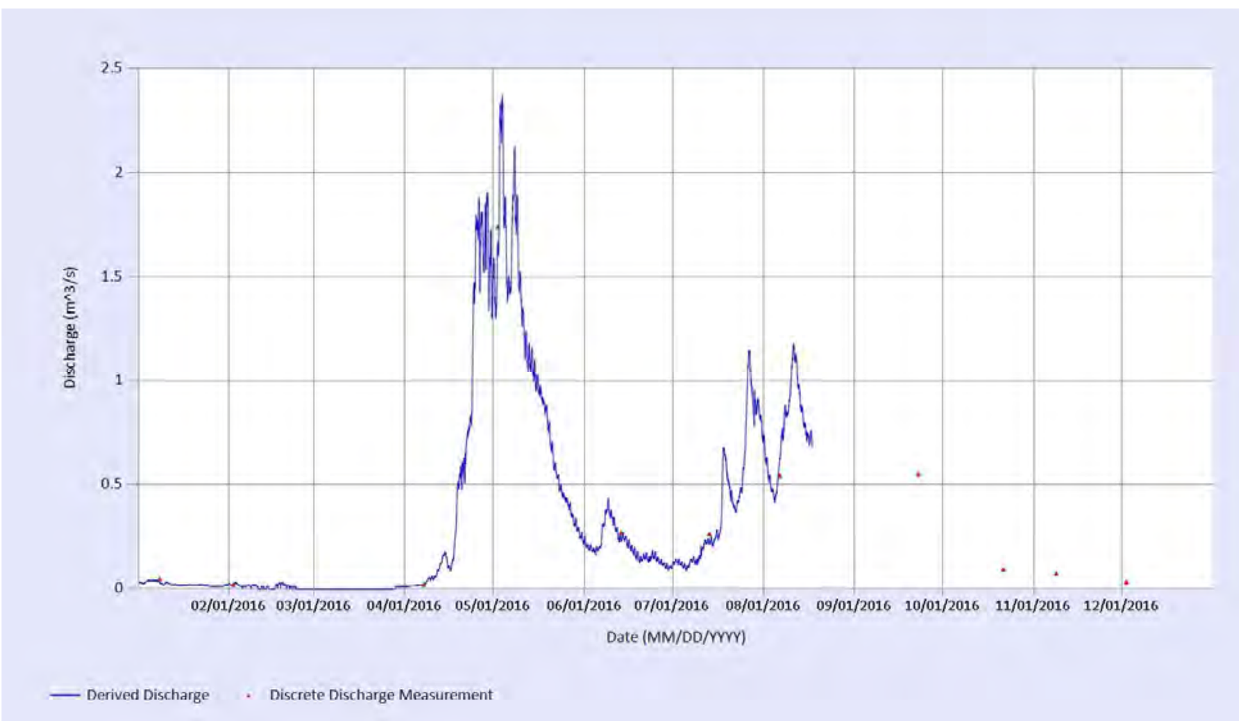


Figure C18 - Discharge at KV-9, Flat creek near the mouth, 2016

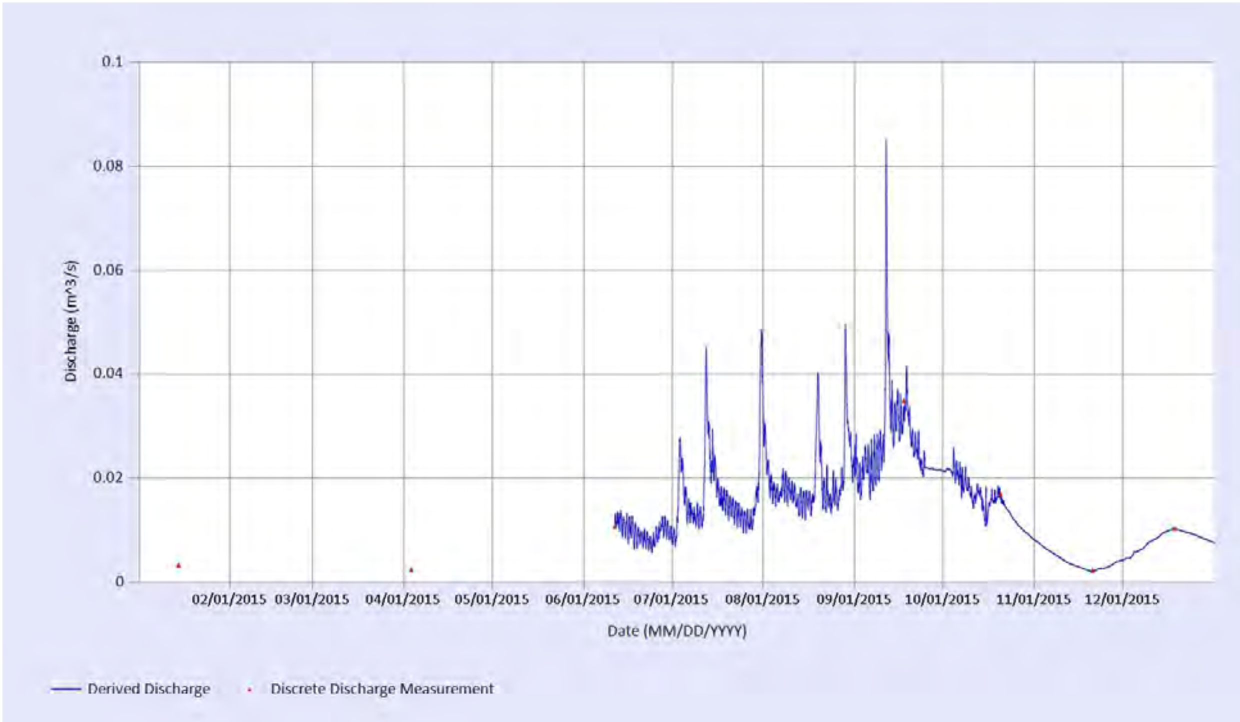


Figure C19 – Discharge at KV-21, No Cash Creek below Silver Trail Highway, 2015

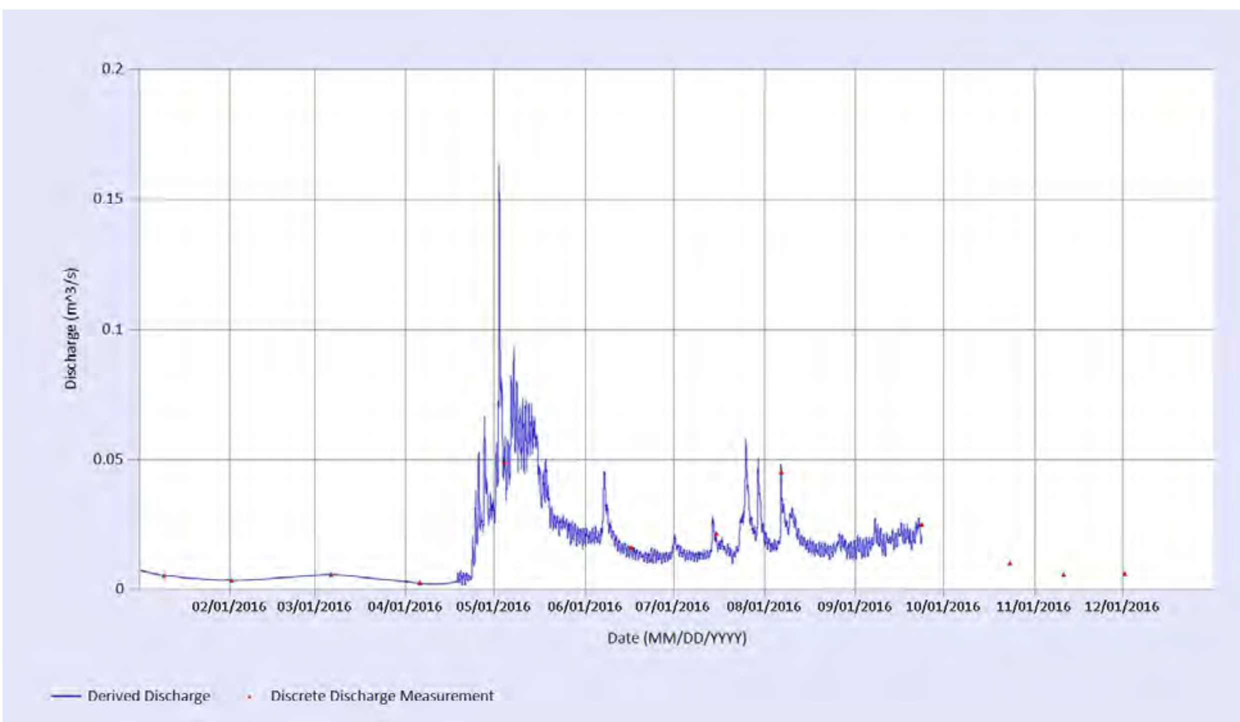


Figure C20 – Discharge at KV-21, No Cash Creek below Silver Trail Highway, 2016

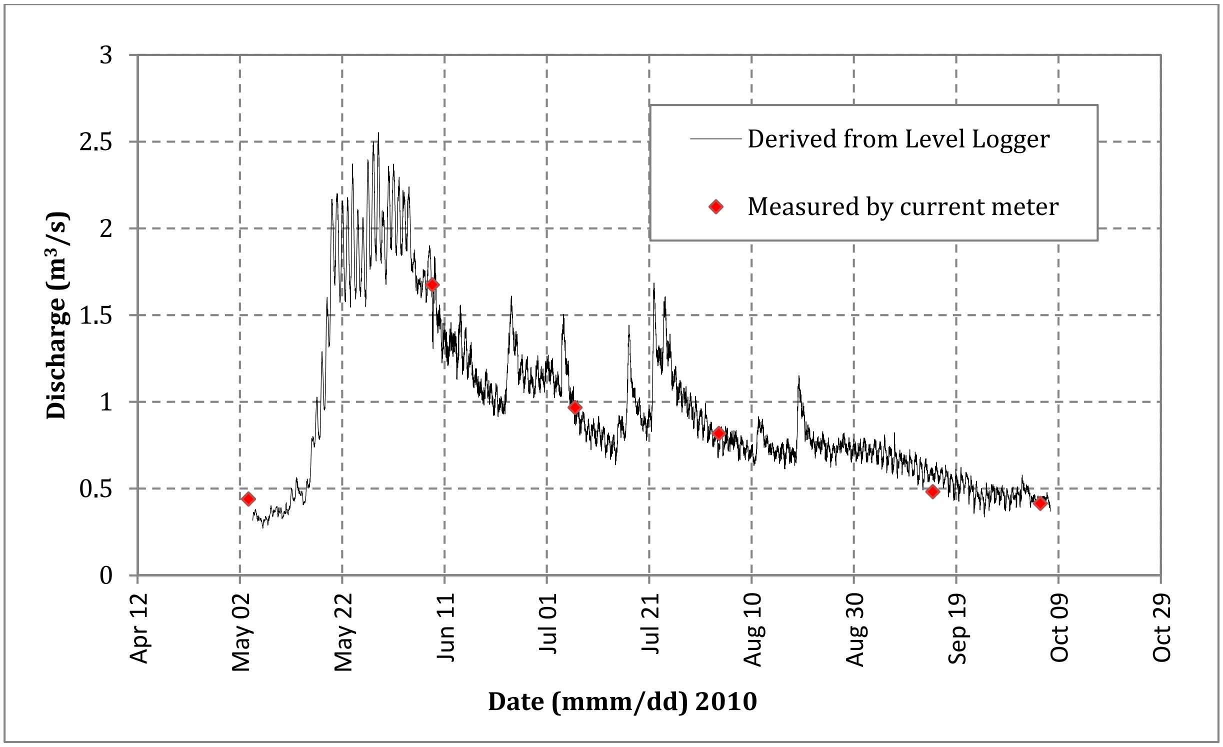


Figure C21 - Discharge at KV-41, Lightening Creek 2010

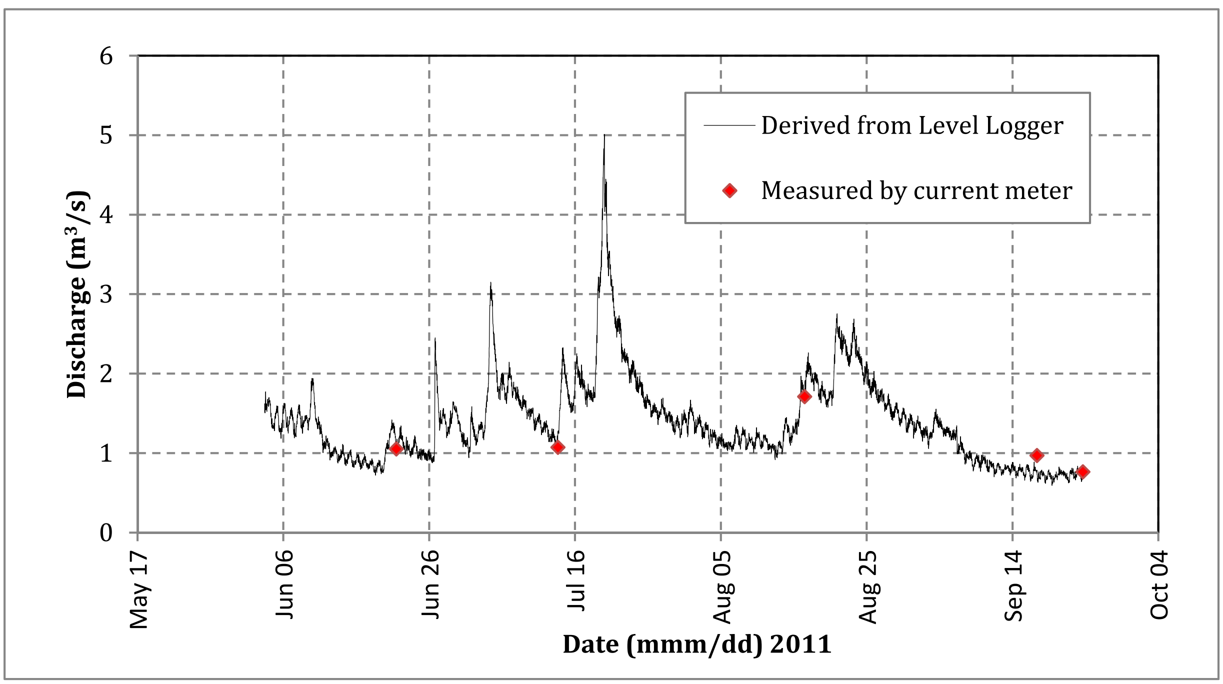


Figure C22 - Discharge at KV-41, Lightening Creek 2011

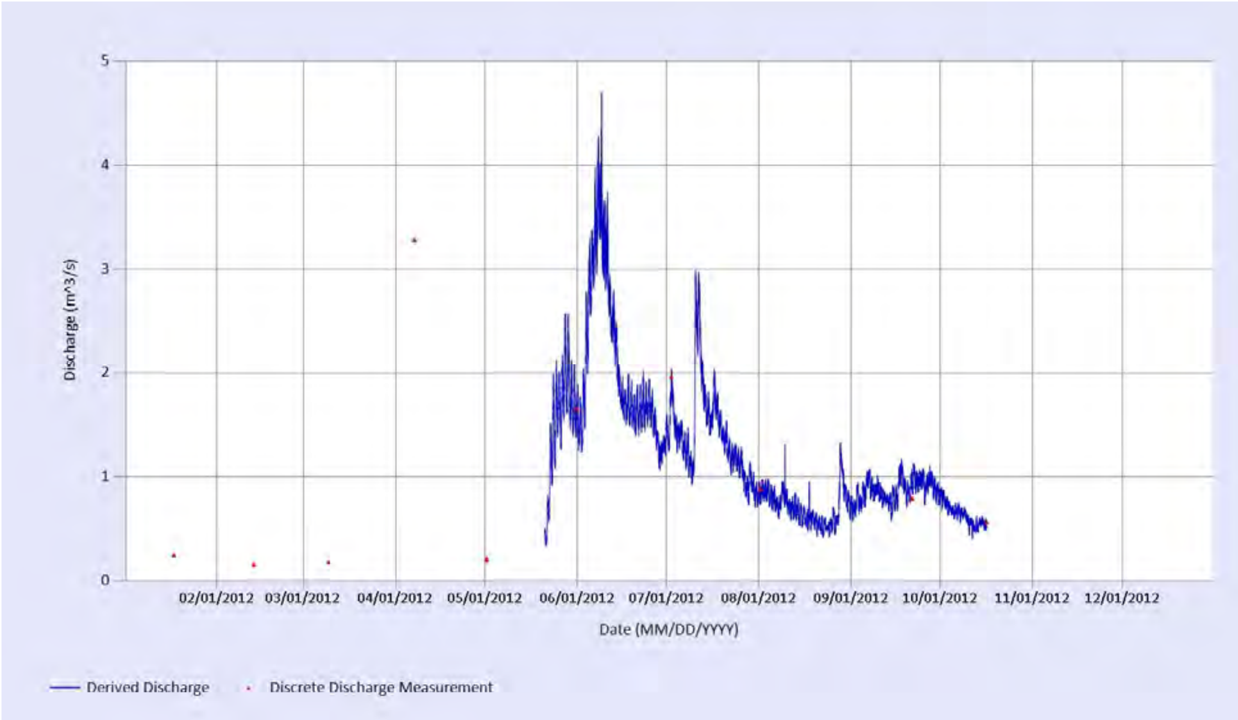


Figure C23 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2012

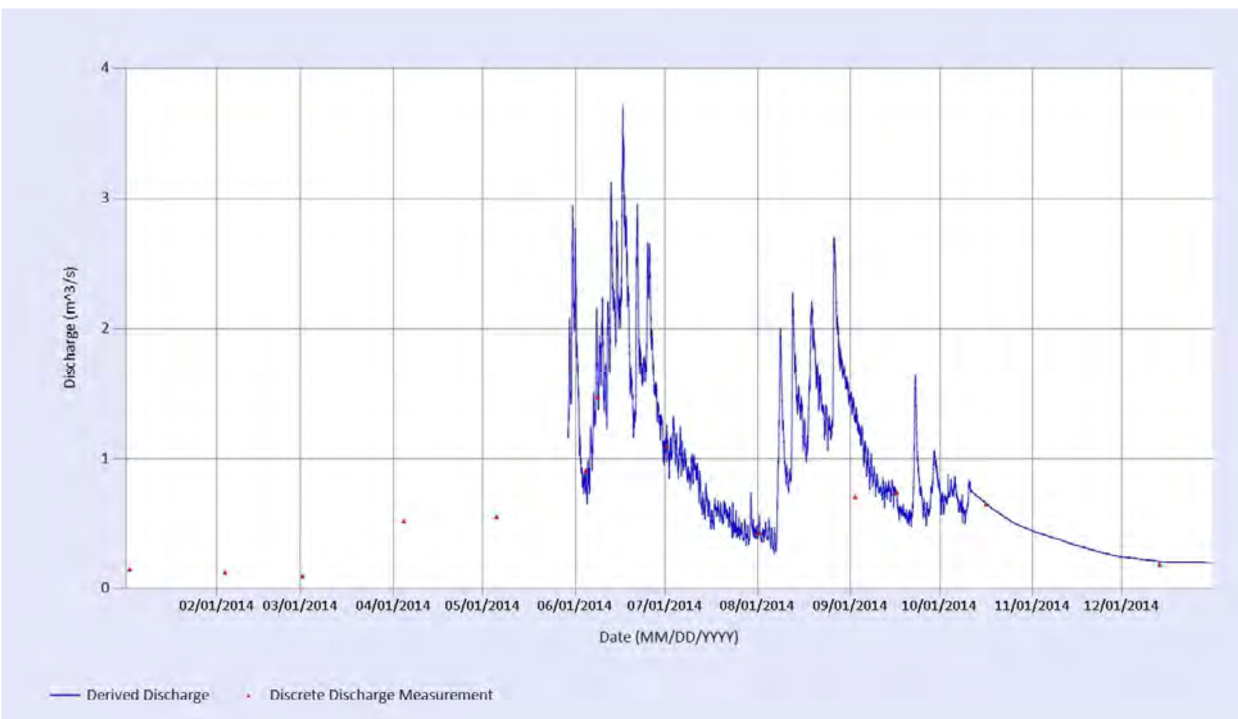


Figure C24 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2014 open water season

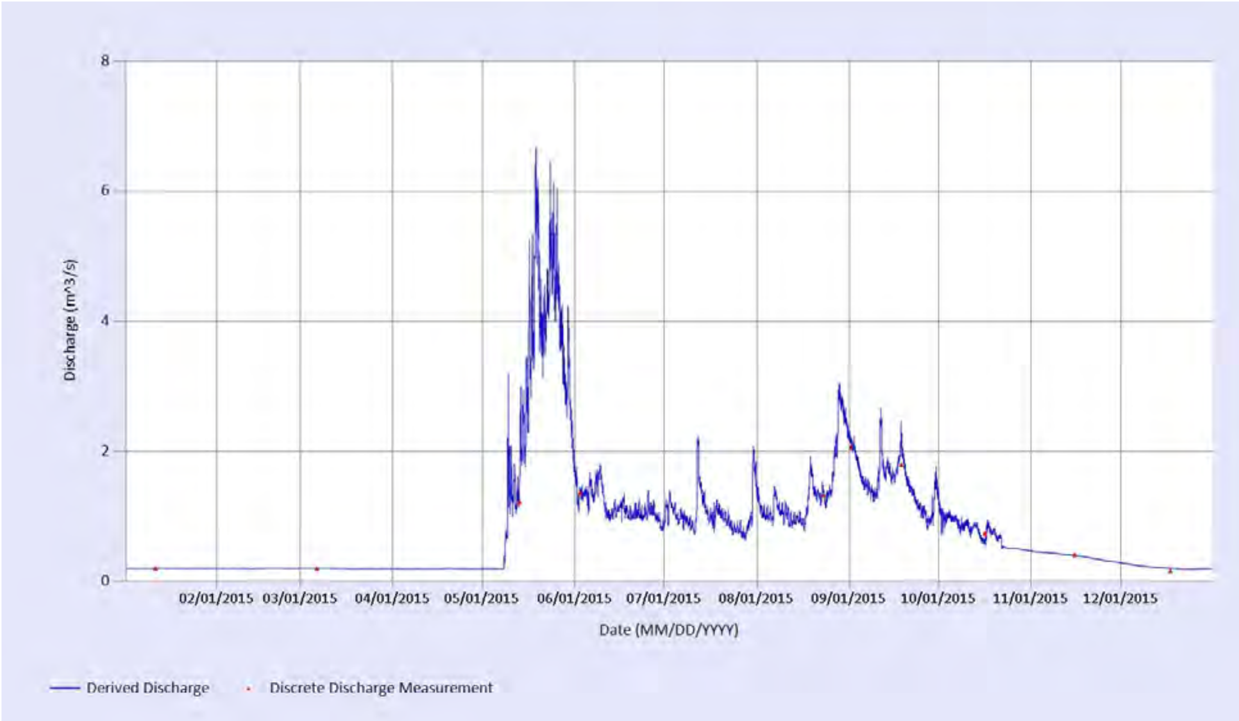


Figure C25 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2015

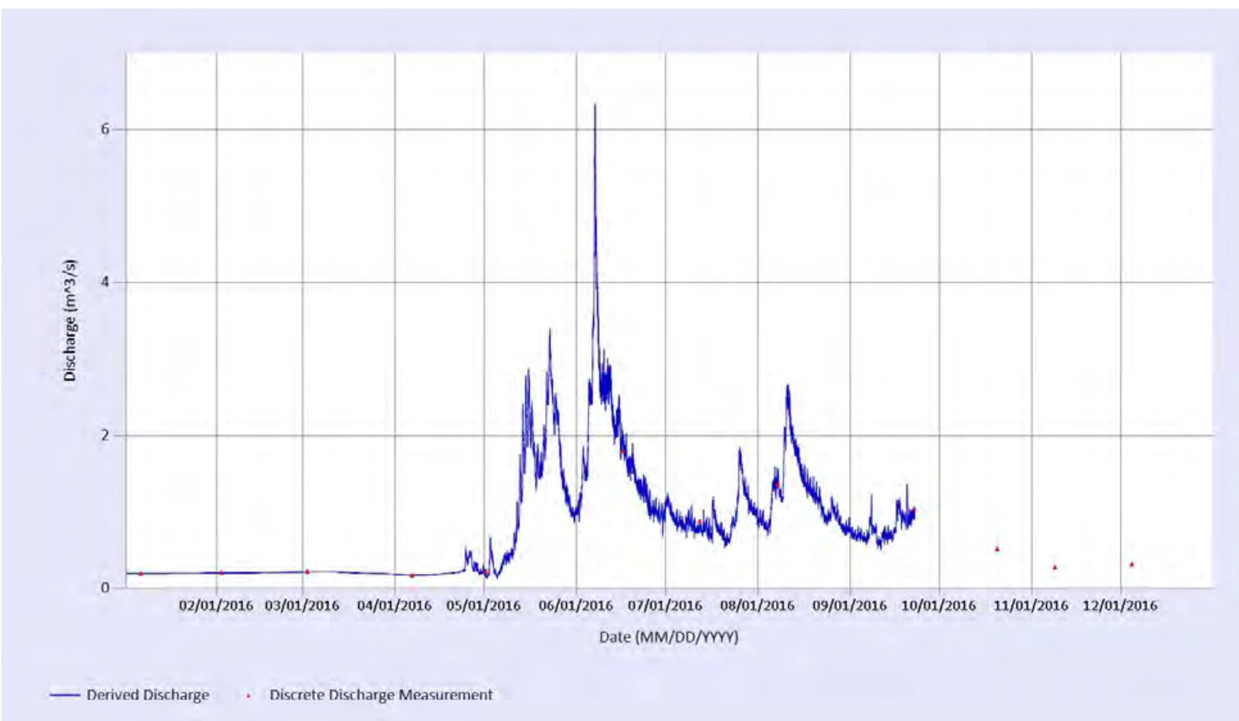


Figure C26 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2016

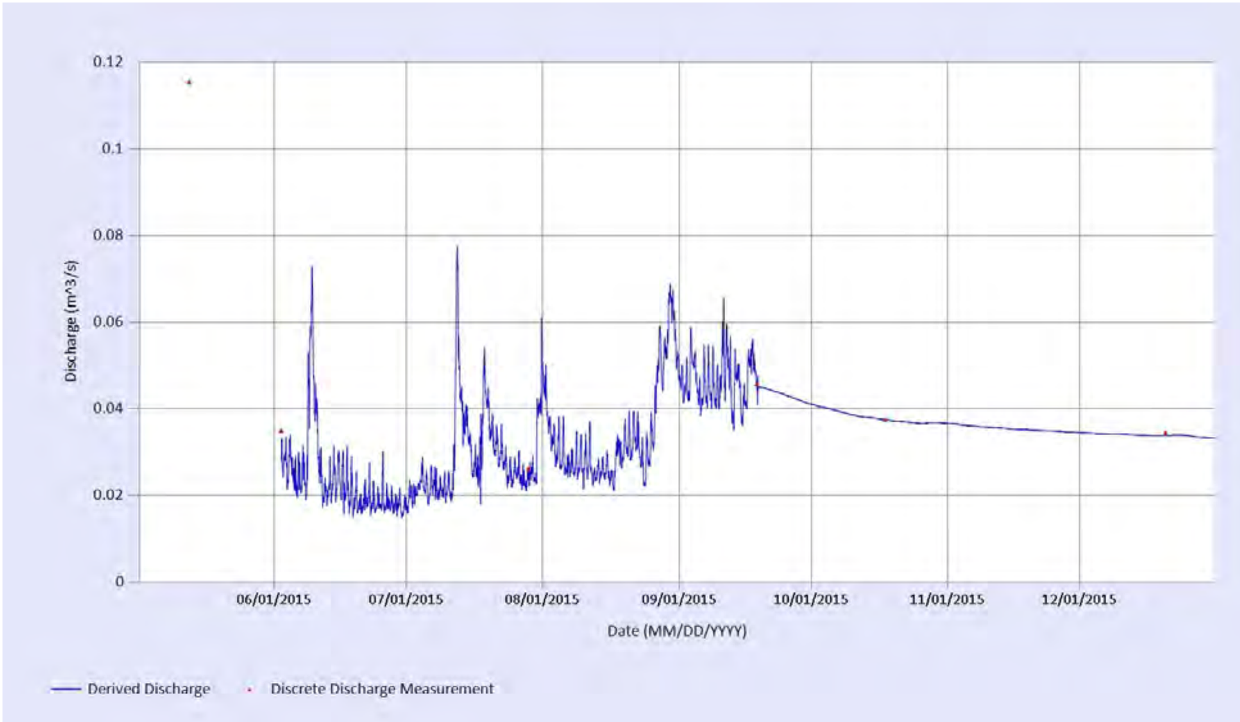


Figure C27 – Discharge at KV-51, Christal Creek downstream of Hinton Creek, 2015

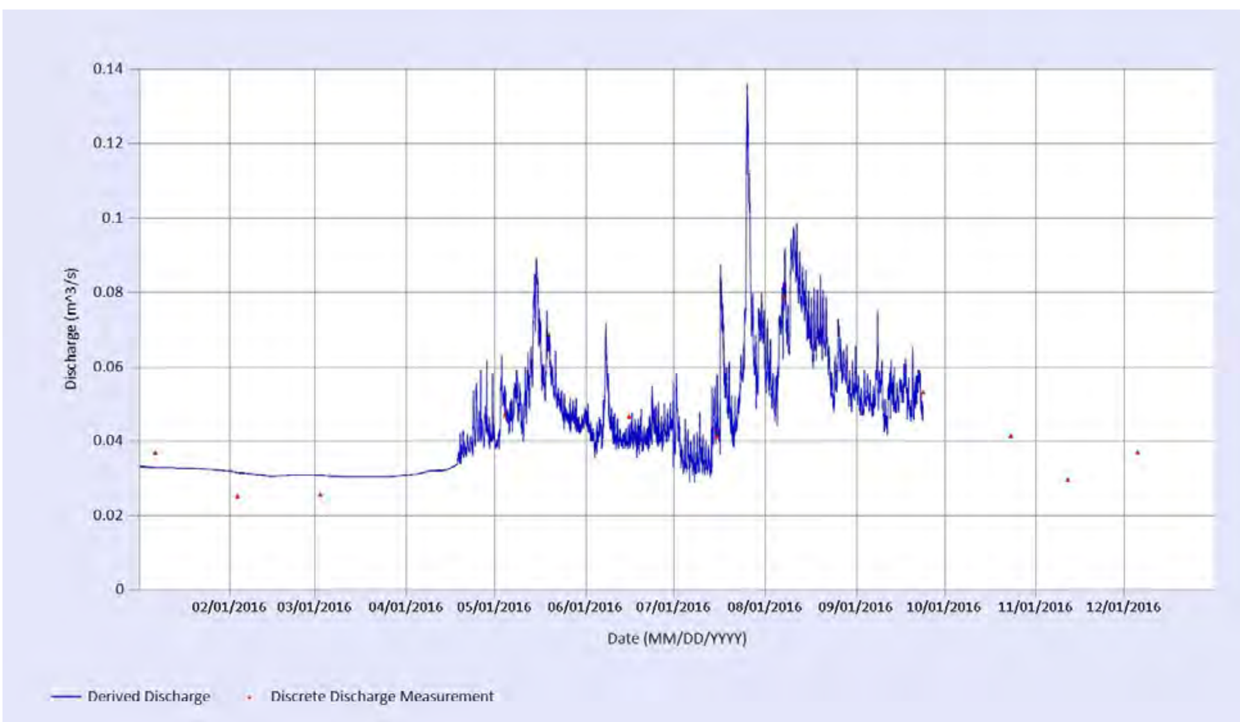


Figure C28 – Discharge at KV-51, Christal Creek downstream of Hinton Creek, 2016

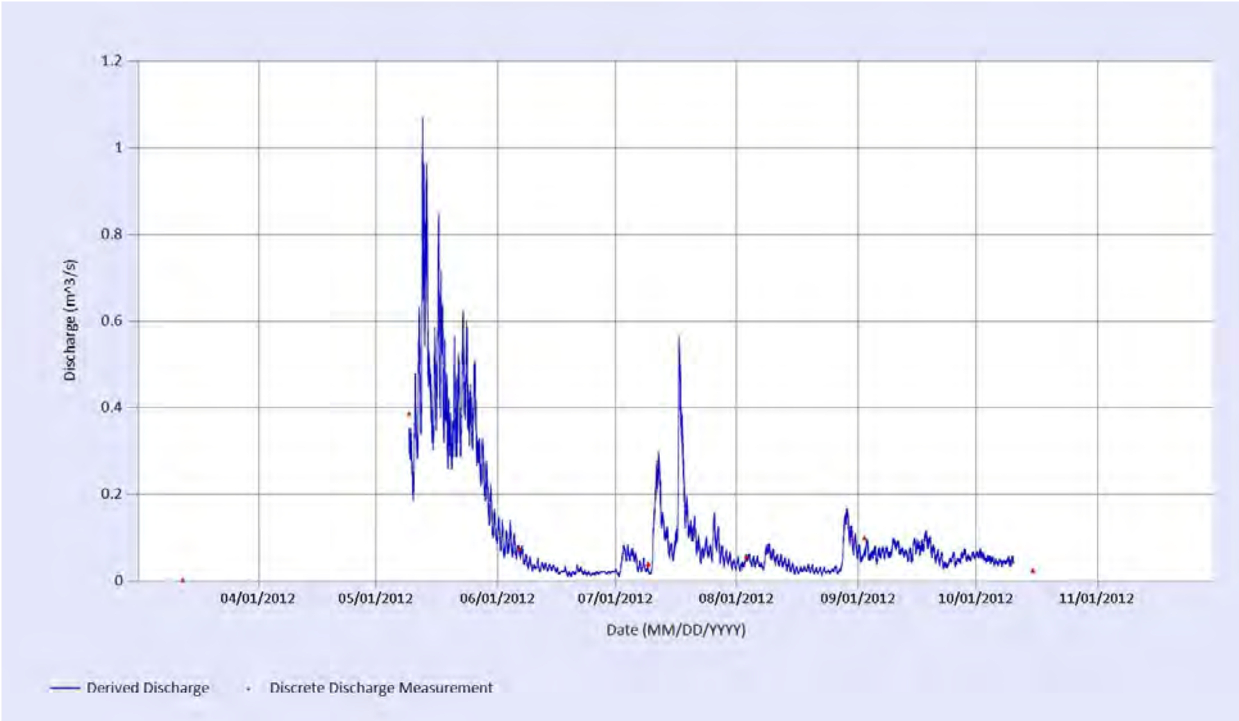


Figure C29 – Discharge at KV-60, Galena Creek above Silver King Adit, 2012 open water season

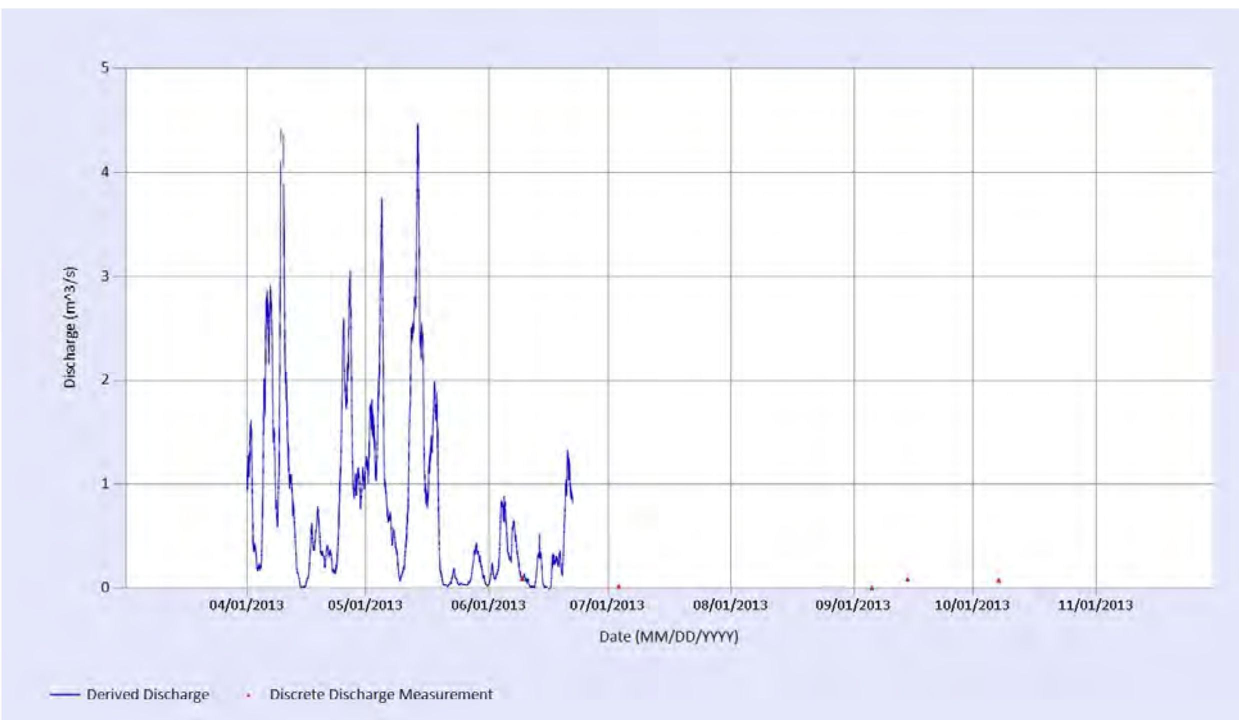


Figure C30 – Discharge at KV-60, Galena Creek above Silver King Adit, 2013 open water season

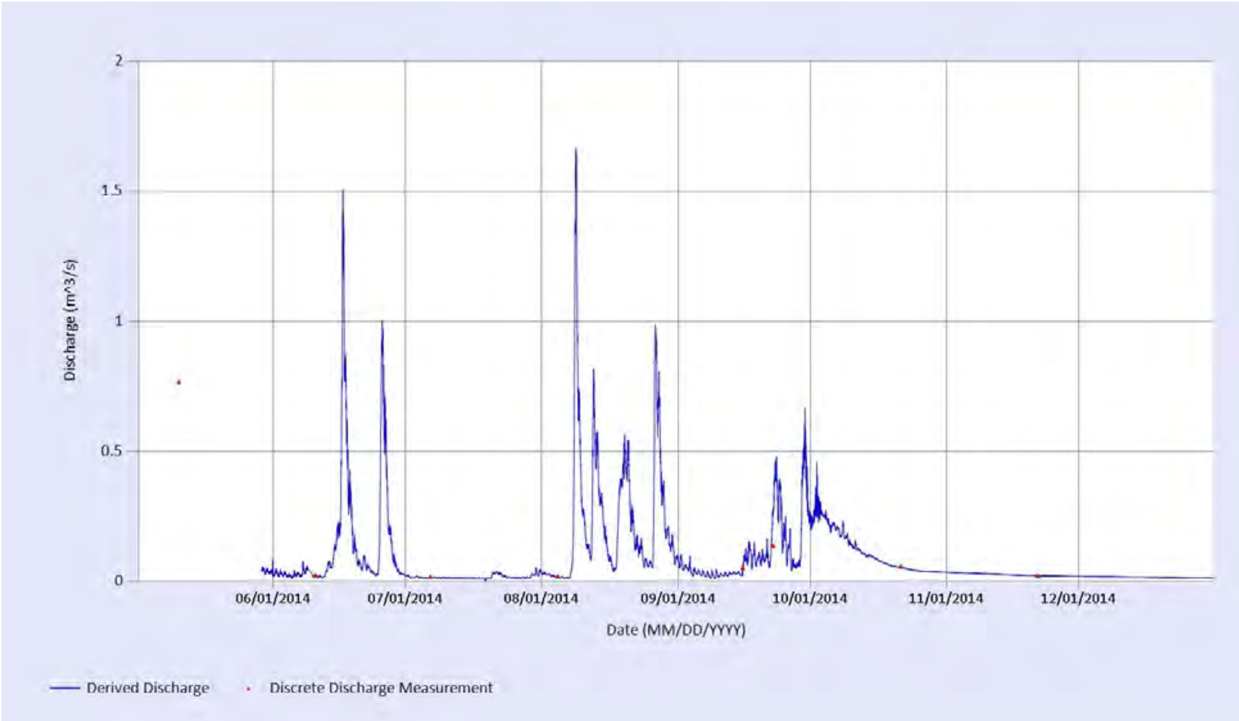


Figure C31 – Discharge at KV-60, Galena Creek above Silver King Adit, 2014 open water season

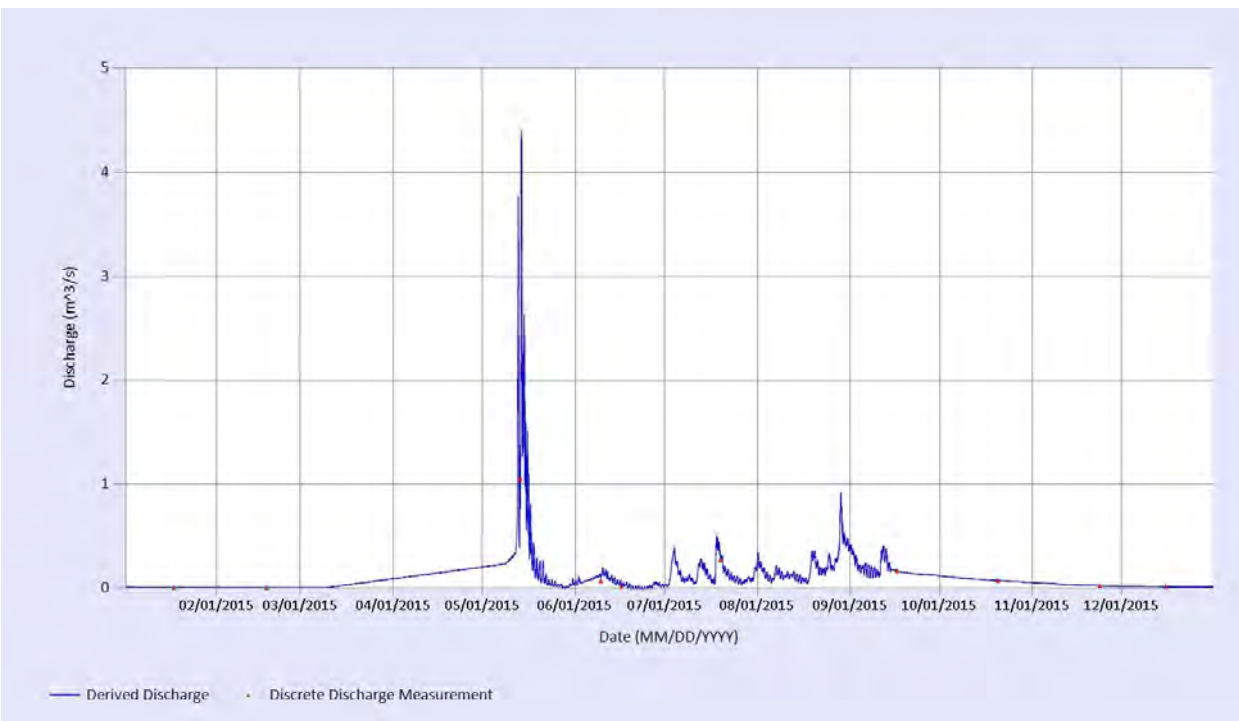


Figure C32 – Discharge at KV-60, Galena Creek above Silver King Adit, 2015

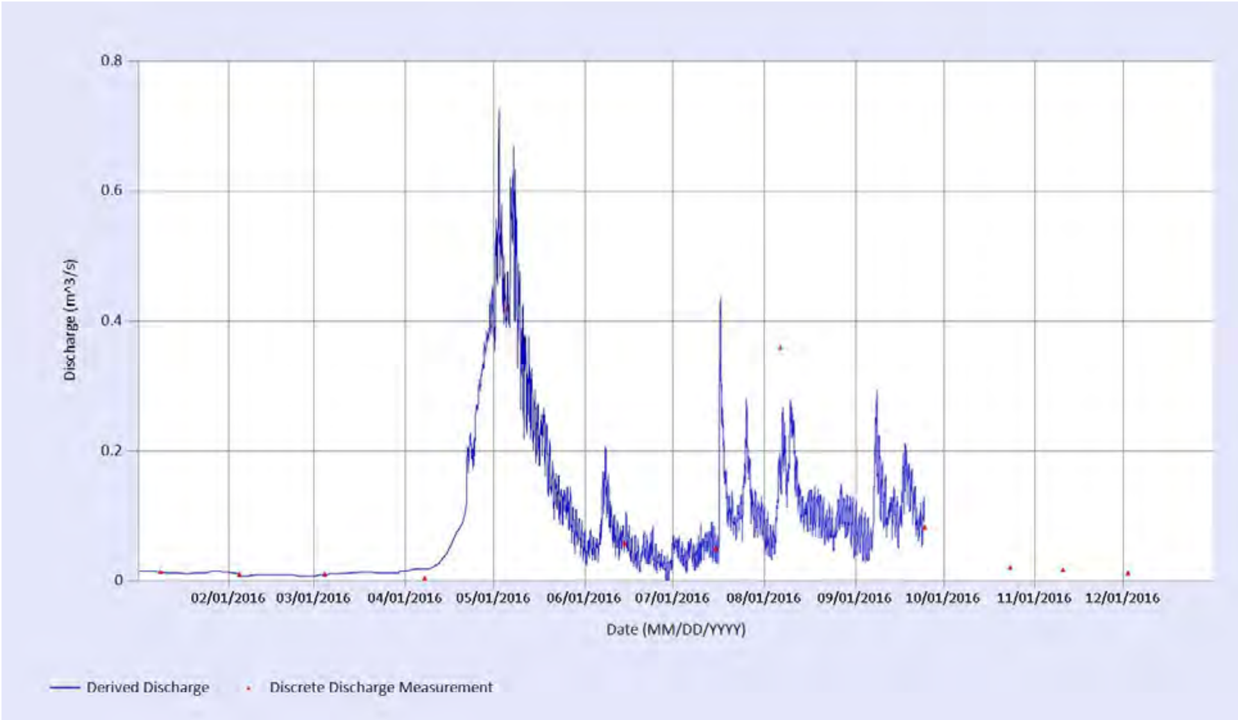


Figure C33 – Discharge at KV-60, Galena Creek above Silver King Adit, 2016

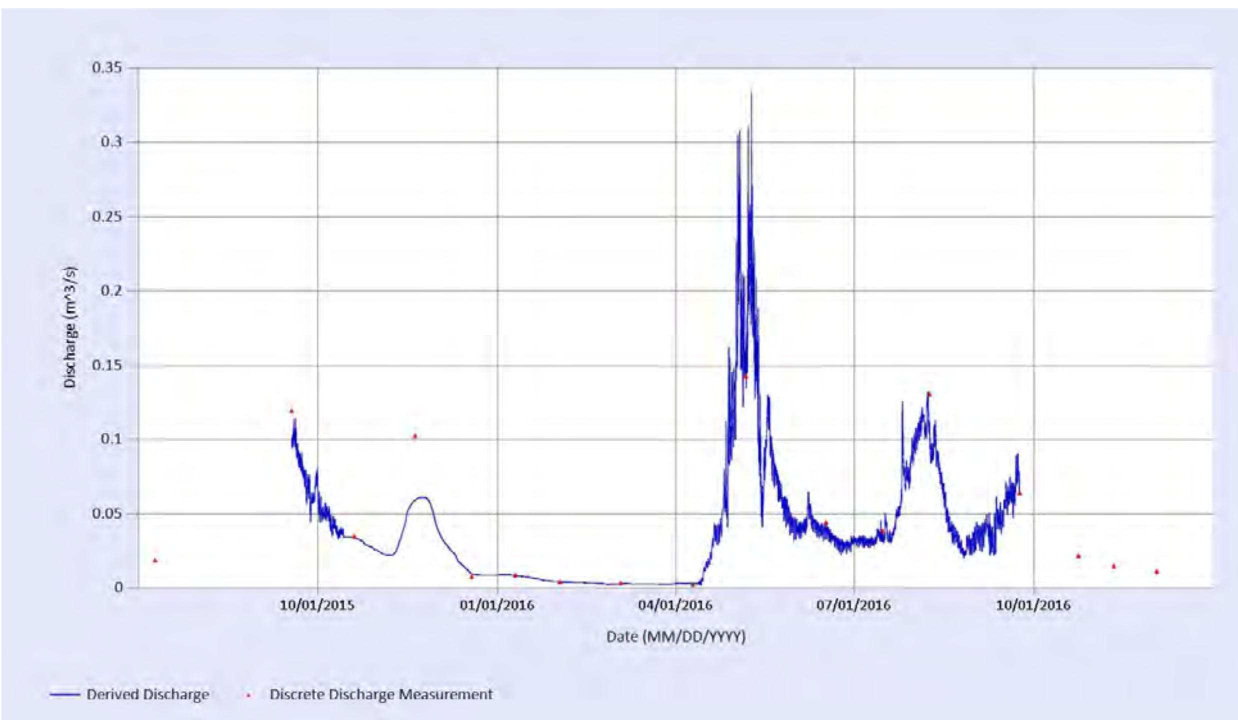


Figure C34 – Discharge at KV-64, Flat Creek below Silver Trail Highway, 2015-2016

APPENDIX D

PHOTOGRAPHS

Photo 1: KV-6, required periodic vegetation control, June 15th, 2016.

Photo 2: KV-7, old wooden cribbing, June 15th, 2016.

Photo 3: KV-9, looking downsteam, moderate-high stage, May 2nd, 2016.

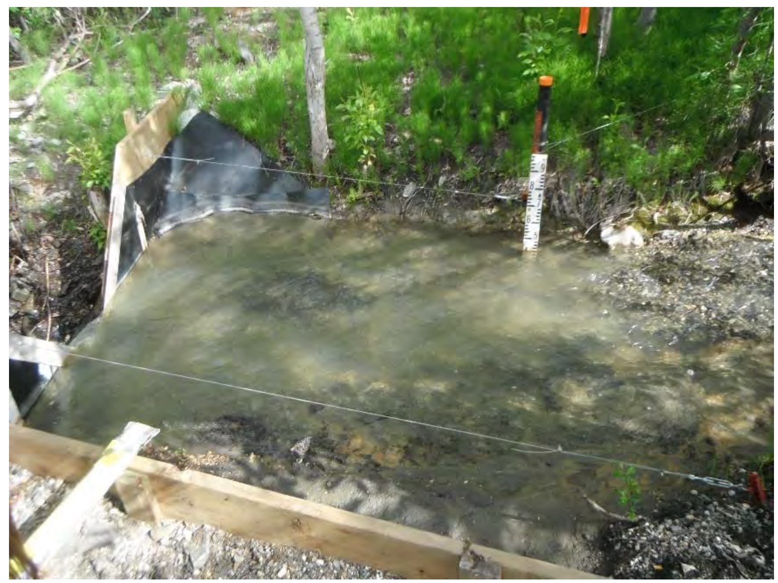


Photo 4: KV-21, weir pond showing significant sediment accumulation, June 16th, 2016.

Photo 5: KV-41, staff gauge and aging wooden cribbing structure, June 16th, 2016.

Photo 6: KV-51, looking upsteam, May 4th, 2016.

Photo 7: KV-60, looking upstream, July 15th, 2016.

Photo 8: KV-64, looking downstream May 5th, 2016.

3 Calcite Business Centre, 151 Industrial Road
Whitehorse, Yukon Y1A 2V3
Phone (867) 668-6463 Fax (867) 667-6680

Memorandum

To: Elsa Reclamation and Development Company Ltd.

From: Catherine Henry

CC: Kai Woloshyn

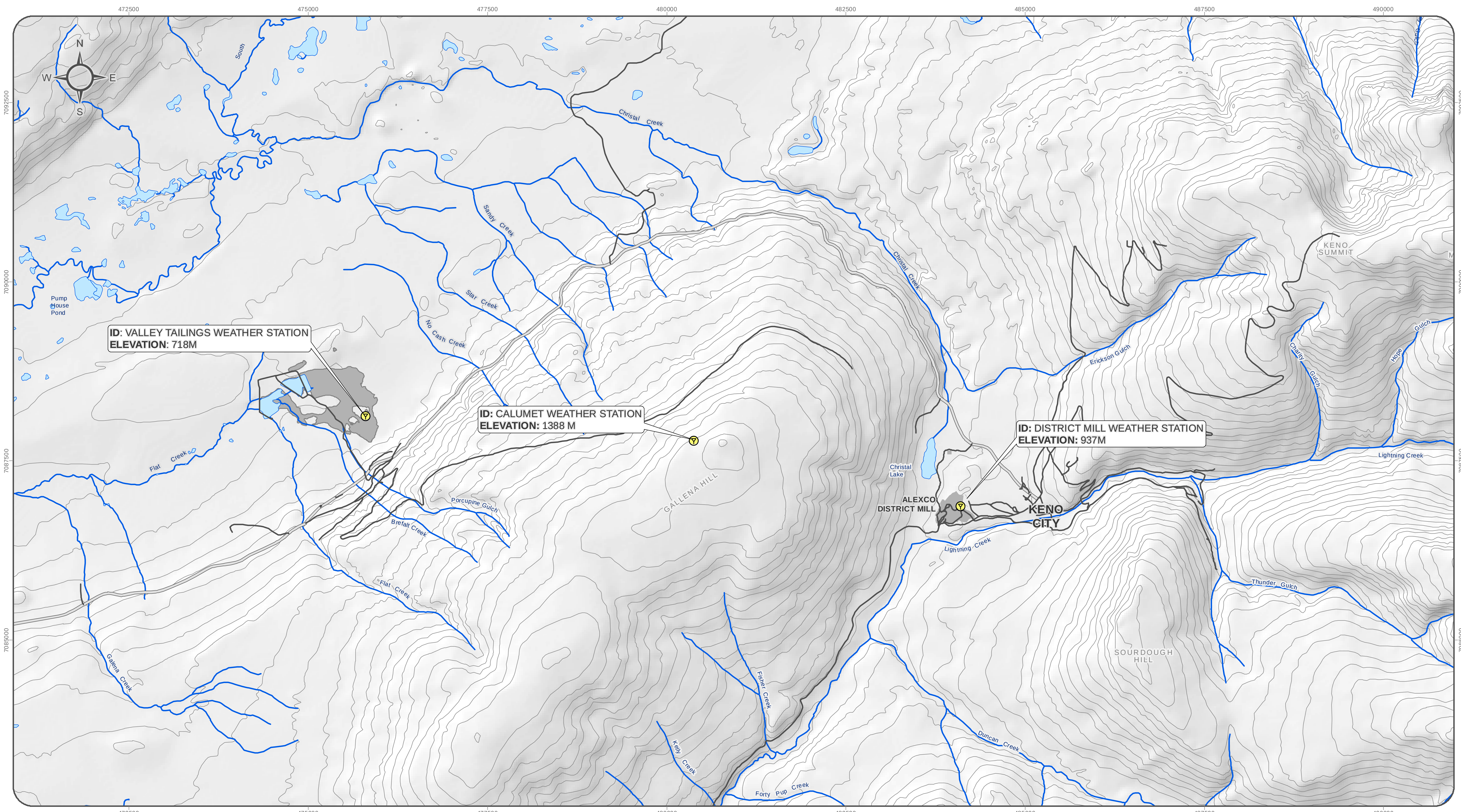
Date: February 11, 2017

Deliverable # 2016-009-9_14

Re: 2016 Meteorological Data Summary, Keno, YT

1. Introduction

This memo describes the meteorological data collected up to 2016 within the Keno Hill Silver Mining District at the Calumet weather station since 2007, at the District Mill meteorological station since 2011 (installed as part of Alexco's Bellekeno mining operations) and at the Valley Tailings meteorological station since 2012. The locations of the three weather stations are shown on Figure 1.



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 underlicense from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

Quartz claim boundaries current as of February 24th, 2011. Ownership data current as of December 20th, 2010. Data source: http://geomaticsyukon.ca.

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

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

0 1 2 3 Kilometers

Weather Station
Highway
Road
Contours (100 ft)
Watercourse
Waterbody

ERDC

KENO HILL MINING DISTRICT

FIGURE 1

KENO METEOROLOGICAL STATIONS

JANUARY 2016

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\SpecifcTopics\Monitoring\Weather Stations\WeatherStations_20160106.mxd
(*Last edited by: mducharme; 1/6/2016/15:53 PM*)

2. CALUMET WEATHER STATION

An automated Onset HOBO meteorological station (Calumet Weather Station) was installed on Galena Hill above the Hector adit at 1,380 masl in June 2007 (UTM coordinates: 08 V 480377 7087790). See Attachment A for the list of components and a photo.

2.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The station was commissioned on June 15, 2007, and logs air temperature, relative humidity, barometric pressure, rainfall, wind speed and direction at a height of 3 meters, solar radiation, and soil temperature all at a 15-minute interval.

- The wind sensor experiences occasional icing during the winter months; as such, extended periods of zero wind speed were invalidated. Also note that winter wind speeds may occasionally be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- No total precipitation gauge or snowfall conversion adaptor is installed at this time, therefore only rainfall is measured. Note that instances of rainfall recorded at temperatures below zero are likely due to snowmelt.

- Datalogger connections for the soil temperature, rainfall and pressure sensors malfunctioned between June 23, 2016 and October 23, 2016, and these data are therefore missing for that period.

2.2. METHODS AND RESULTS

Monthly averages were calculated from 15-minute values recorded by the datalogger (averaged values from a 1 minute sampling interval). Average temperature and total rainfall are presented in Table 1 below.

Table 1 Monthly statistics for average temperature and total rainfall collected at Calumet Station

	Average Temperature (°C)										Total Rainfall (mm)									
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
January	-	-17.18	-18.84	-14.08	-16.78[3]	-18.71[4]	-16.90	[6]	-13.22	*-8.34*[12]	-	-	-	-	-	-	-	[6]	0.0	*0.0*[12]
February	-	-16.99	-16.95	-9.09	-15.88[3]	-9.94[4]	-10.81	-15.69	-13.42	-9.32	-	-	-	-	1.8[3]	[9]	-	-	0.2	0.3
March	-	-11.04	-16.39	-9.21	-12.92[3]	-12.92[4]	-14.45	-11.95	-10.69	-5.84	-	-	-	-	0.5[3]	[9]	0.6	-	2.8	2.8
April	-	-4.93	-4.75	-2.01	-3.77[3]	-1.88[4]	-12.32	-4.39	-3.33	-0.43	-	1	-	1.3[3]	2.8[3]	[9]	0.2	6.2	8.6	7.8
May	-	3.31	3.66	5.35	4.41[3]	1.61[4]	n/a	4.17	7.85	5.55	-	25.4	21.8	32.3[3]	15.5[3]	[9]	n/a	17.2	4.0	23.0
June	*11.25*[1]	8.70	9.58	8.68	8.82[3]	7.76[4]	11.59	*7.31*[11]	8.42	10.07	*55.2*[1]	44.6	*11.8*[7]	56.7[3]	121.8[3]	[9]	45.2	*69.8*[11]	45.2	43.0
July	11.80	8.17	12.45	10.50	3.80[3]	7.84[4]	11.11	[11]	9.67	10.60	108.8	108.4	*22.8*[8]	137.7[3]	135.9[3]	*27.8*[10]	39.2	[11]	135.5	[13]
August	9.63	5.54	7.47	9.61	[2]	8.33[5]	10.58	7.95	6.71	9.25	54.8	110.2	89.4	140.0[3]	[9]	45.0	35.6	112.0	97.0	[13]
September	1.12	2.27	3.58	2.40	[2]	3.39	3.33	1.86	*2.17*[12]	2.95	57.6	61.4	50.4	78.0[3]	[9]	17.4	64.6	43.8	*46.4*[12]	[13]
October	-6.53	-7.20	-4.73	-4.86	[2]	-8.16	-2.52	-5.02	[12]	-6.23	-	12.6	-	16.0[3]	[9]	1.6	14.6	15.2	[12]	*0.0*[13]
November	-9.41	-10.17	-11.94	-11.19	-17.39[4]	-18.44	-15.50	-9.87	[12]	-8.87	-	-	-	-	-	0.2	0.0	0.2	[12]	0.0
December	-16.19	-18.34	-11.16	-17.72	-11.78[4]	-18.83	*-14.55*[6]	-10.43	[12]	-15.27	-	-	-	-	-	0.0	*0.0*[6]	0.0	[12]	0.0

Notes:

Values in *grey italics* indicate a partial month

[1] *Station commissioned June 15, 2007*

[2] *Temperature probe malfunction – no proxy data available*

[3] *Calculated from MAYO A data*

[4] *Sensor occasionally offline but most data complete*

[5] *Sensor replaced August 7*

[6] *The station was down from December 12, 2013 to January 31, 2014.*

[7] *Rainfall gauge malfunction on June 11; total rainfall provided for June 1-11.*

[8] *Rainfall gauge back online; total rainfall provided for July 7-31.*

[9] *Tipping bucket malfunction – no proxy data available.*

[10] *Tipping bucket repaired July 4th; total rainfall provided for July 4-31.*

[11] *Station was down between June 26 and July 31, 2014.*

[12] *Data missing from September 17, 2015 to January 5, 2016.*

[13] *Rainfall data missing from June 23, 2016 to October 23, 2016.*

3. DISTRICT MILL WEATHER STATION

The District Mill Campbell Scientific automated meteorological station is located above the dry stack tailings facility and below the old Keno City dump near Keno, YT (UTM coordinates: 08 V 0484009 7086872, elevation: 936 masl). See Attachment A for the list of components and a photo.

3.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The Campbell Scientific Meteorological Station was commissioned on June 2, 2011 and includes sensors for the measurement of temperature, relative humidity, rainfall or total precipitation, wind speed and direction at a height of 10 meters, and solar radiation, all at a 1-hour interval.

- Relative humidity readings were invalidated from time of commissioning until May 7, 2012, at which time the problem was corrected by sending a revised program to the datalogger.

- A pyranometer (model SP Lite2) was installed on December 13, 2012, and the datalogger program was revised to incorporate hourly solar radiation readings and an evapotranspiration (ET) instruction. The ET instruction uses temperature, relative humidity, wind speed, solar radiation, latitude, longitude and altitude to calculate an evaporation rate for a short grass crop. This provides an approximation of actual evaporation, which varies locally depending on surface type and micro topography. Note that if one of the parameters listed above is invalid, the ET calculation is also invalidated.

- The wind sensor experiences occasional icing during the winter months and extended periods of zero wind speed were invalidated. Also note that winter wind speeds may occasionally be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- The total precipitation gauge or snowfall conversion adaptor was not installed in 2011 or 2012, therefore only rainfall was measured. Note that instances of rainfall recorded at temperatures below zero are likely due to snowmelt. A snowfall converter was installed on October 15, 2013 and now records total precipitation going forward. In 2016, the snowfall conversion adaptor was removed on May 19 and reinstalled on October 22.

- An alter screen was installed around the precipitation gauge on June 3, 2015, to reduce wind induced error in total precipitation measurement.

3.2. METHODS AND RESULTS

Monthly averages were calculated from hourly values recorded by the datalogger (averaged values from a 10 seconds sampling interval) for the following parameters: temperature, daily maximum temperature, daily minimum temperature, relative humidity, wind speed, maximum wind speed and solar radiation. Monthly extreme maximum temperature, extreme minimum temperature, maximum wind speed, total rainfall and total evapotranspiration are also shown in Table 2 below.

Wind data from time of commissioning to December 31, 2016 are also depicted in the wind rose presented in Figure 2, which was produced using WRPLOT View software. This period has a 92.1% data availability.

Table 2 Monthly statistics for meteorological parameters collected at District Mill Station

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
Jun -11[2]	24.72	18.59	11.96	6.30	-2.56	n/a	n/a	1.35	9.14	n/a	n/a
Jul-11	25.67	18.50	12.91	8.00	5.09	n/a	n/a	1.15	8.02	n/a	n/a
Aug-11	22.32	15.58	9.78	5.37	1.93	n/a	n/a	1.18	9.15	n/a	n/a
Sep-11	17.97	11.29	6.07	1.85	-2.47	n/a	n/a	1.43	11.36	n/a	n/a
Oct-11	7.20	0.20	-2.74	-5.41	-9.84	n/a	*2.60*[3]	0.94	13.12	n/a	n/a
Nov-11	-4.23	-16.79	-19.54	-22.47	-34.99	n/a	0.00	0.58	12.05	n/a	n/a
Jan-12	-0.96	-19.10	-23.13	-26.79	-37.32	n/a	0.00	*0.59*	*9.51*	n/a	n/a
Feb-12	2.77	-6.77	-10.00	-13.07	-26.78	n/a	0.10 [4]	*1.38*	*15.62*	n/a	n/a
Mar-12	5.33	-7.69	-13.37	-18.00	-27.80	n/a	0.00	*0.97*	*9.24*	n/a	n/a
Apr-12	9.69	6.13	0.96	-3.87	-15.92	n/a	0.60 [4]	1.37	10.27	n/a	n/a
May-12	17.78	10.73	6.31	1.91	-3.47	*51.81* [5]	18.30	1.78	10.60	n/a	n/a
Jun-12	27.62	18.41	13.46	8.29	4.42	56.35	21.70	1.44	10.26	n/a	n/a
Jul-12	25.14	18.07	12.75	7.73	1.64	69.26	85.80	1.36	12.99	n/a	n/a
Aug-12	21.72	16.31	11.25	6.56	-0.89	67.79	47.00	1.62	9.41	n/a	n/a
Sep-12	20.24	10.33	5.90	2.08	-5.22	69.51	36.40	1.84	14.27	n/a	n/a
Oct-12	7.60	-3.95	-7.35	-10.32	-20.62	79.54	7.60	1.13	10.37	n/a	n/a
Nov-12	-8.98	-19.55	-21.90	-24.32	-33.36	81.43	0.00	0.94	9.36	n/a	n/a
Dec-12	-3.36	-21.30	-23.44	-25.58	-36.32	81.34	0.00	*0.26*	*5.93*	*1.01* [6]	*0.05* [7]
Jan-13	-1.59	-17.06	-20.01	-23.08	-41.48	82.92	0.00	*0.76*	*14.48*	1.06	0.81
Feb-13	1.54	-9.10	-12.52	-15.46	-23.74	88.36	0.30 [4]	*0.85*	*12.25*	10.26	1.27
Mar-13	3.26	-7.52	-13.16	-17.99	-29.96	64.08	3.90	1.59	12.47	95.82	6.33
Apr-13	6.07	-2.76	-7.94	-13.69	-25.07	54.50	8.20	2.44	12.93	190.02	14.48

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
May-13	23.31	10.20	5.27	0.23	-9.46	61.83	39.60	1.77	11.76	215.44	21.70
Jun-13	30.51	19.97	14.27	8.30	1.84	58.72	57.30	1.82	12.87	234.69	29.79
Jul-13	24.93	19.40	14.01	8.60	2.25	62.67	46.90	1.75	16.14	211.00	27.10
Aug-13	27.34	18.54	12.98	8.01	-0.38	66.30	51.90	1.49	11.05	156.25	21.38
Sep-13	16.11	9.69	5.81	2.26	-3.74	77.52	59.70	1.54	10.99	79.69	10.88
Oct-13	8.25	1.61	-1.32	-4.21	-10.10	86.75	44.60	1.11	11.62	35.75	4.26
Nov-13	0.18	-13.41	-16.68	-20.08	-37.96	84.26	10.60	*1.02*	*10.96*	4.93	*1.08*
Dec-13	-1.73	-21.23	-23.91	-26.70	-35.29	78.77	4.90	*0.75*	*9.47*	0.57	*0.62*
Jan-14	3.74	-9.33	-12.16	-15.10	-32.22	89.44	24.9	*0.72*	*10.03*	2.42	*0.641*
Feb-14	-1.93	-15.25	-19.40	-23.02	-33.55	75.20	2.9	0.87	10.85	31.34	1.988
Mar-14	4.57	-5.31	-11.29	-16.16	-26.79	54.77	0.7	1.57	11.98	115.54	9.174
Apr-14	10.93	4.09	-0.96	-5.78	-17.33	57.54	5.1	1.64	12.05	171.28	15.77
May-14	21.30	12.70	7.64	2.03	-3.03	52.18	12.8	2.09	19.21	217.91	29.81
Jun-14	24.93	16.21	11.39	5.95	-0.13	56.14	40.4	1.78	10.43	217.90	28.58
Jul-14	23.44	18.49	13.68	8.73	-0.04	65.01	31.0	1.63	13.38	187.31	23.84
Aug-14	22.09	15.57	10.87	6.93	0.06	74.59	67.7	1.44	11.85	139.84	15.72
Sep-14	17.70	8.76	4.28	0.49	-6.74	70.54	36.4	1.37	11.32	93.38	11.56
Oct-14	7.47	-0.91	-3.79	-6.33	-15.42	88.21	15.7	1.24	12.80	24.83	3.39
Nov-14	-2.21	-12.15	-14.34	-16.59	-30.16	88.64	1.40	*0.59*	*6.27*	3.12	*0.60*
Dec-14	-0.09	-11.05	-13.67	-16.31	-26.66	89.06	1.40 [9]	*0.51*	*8.87*	0.33	*0.40*
Jan-15	-0.34	-13.74	-16.50	-19.13	-34.86	85.85	1.9	*0.49*	*5.488*	1.30	*0.431*
Feb-15	2.87	-12.95	-15.93	-18.78	-39.39	84.95	12.7	0.75	10.36	9.06	0.859
Mar-15	5.54	-4.76	-9.83	-14.37	-28.70	70.52	4.1	1.45	12.6	86.48	6.292

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
Apr-15	10.90	5.36	0.56	-3.89	-10.48	61.71	4.2	1.75	12.37	163.45	16.03
May-15	26.51	16.95	10.96	4.60	-7.00	45.35	1.4	1.89	10.64	246.80	34.67
Jun-15	23.18	16.65	11.37	5.81	0.52	61.05	26.3	1.85	12.62	219.18	26.46
Jul-15	25.43	17.54	12.54	7.72	4.73	68.63	72.4	1.48	12.62	190.74	19.98
Aug-15	24.63	14.03	9.35	5.08	-3.09	75.14	54.9	*1.47*	*9.86*	146.76	*13.87*
Sep-15	13.57	7.07	2.77	-0.72	-7.72	79.33	32.6	1.71	15.64	83.01	10.12
Oct-15	7.32	0.88	-1.78	-4.16	-13.22	89.14	19.4	*1.08*	*10.07*	32.52	*2.92*
Nov-15	0.83	-11.17	-13.75	-17.16	-31.38	89.09	22.8	*0.71*	*12.15*	4.03	*0.60*
Dec-15	0.18	-12.38	-14.60	-16.93	-31.06	89.01	4.0	*4.59*	*14.24*	0.63	*0.13*
Jan-16	1.17	-8.96	-11.14	-13.58	-21.91	88.06	24.9	*0.83*	*15.35*	1.67	*1.45*
Feb-16	2.04	-7.63	-10.94	-14.27	-26.68	82.96	2.3	0.86	9.55	22.80	2.32
Mar-16	12.35	-0.55	-4.96	-8.72	-16.96	73.13	7.1	1.26	8.11	82.81	7.12
Apr-16	13.50	7.12	2.28	-2.23	-12.45	63.20	3.8	1.64	10.66	159.95	15.86
May-16	22.80	13.61	8.44	3.04	-1.59	54.73	14.7	1.89	11.89	210.96	25.97
Jun-16	25.98	18.36	12.88	7.17	2.27	56.52	40.0	1.76	13.37	234.99	29.78
Jul-16	23.73	17.71	13.37	9.07	1.71	73.05	63.4	1.46	12.54	173.59	17.36
Aug-16	24.42	16.67	11.92	7.82	1.22	70.86	42.2	1.50	10.69	152.32	17.72
Sep-16	17.42	10.00	5.01	0.90	-6.18	71.05	28.9	1.50	10.81	100.94	14.02
Oct-16	2.43	-3.20	-7.07	-9.99	-17.15	79.60	11.4	1.12	8.29	50.66	4.15
Nov-16	4.05	-8.20	-10.89	-13.45	-25.46	86.45	7.6	*0.80*	*9.57*	5.70	*1.99*
Dec-16	-4.20	-17.39	-19.62	-21.89	-32.16	83.76	1.3	*0.62*	*8.45*	0.56	*0.51*

Notes: *Values in grey italics indicate a partial month*

[1]January 2012 has 25 days of complete wind data
February 2012 has 28 days of complete wind data
March 2012 has 30 days of complete wind data
December 2012 has 15 days of complete wind data
January 2013 has 21 days of complete wind data
February 2013 has 26 days of complete wind data
November 2013 has 24 days of complete wind data
December 2013 has 20 days of complete wind data
January 2014 has 9 days of complete wind data
November 2014 has 23 days of complete wind data
December 2014 has 6 days of complete wind data
January 2015 has 24 days of complete wind data
August 2015 has 28 days of complete wind data
October 2015 has 29 days of complete wind data
November 2015 has 9 days of complete wind data
December 2015 has 0 days of complete wind data
January 2016 has 16 days of complete wind data
November 2016 has 23 days of complete wind data
December 2016 has 22 days of complete wind data

[2] June 2011 has 29 days of complete data (station commissioned on June 2)
[3] 16 days of complete rain data
[4] Rainfall recorded at temperatures below zero may be due to snowmelt
[5] 25 days of complete RH data
[6] 18 days of complete solar radiation data
[7] 7 days of complete evapotranspiration data
[8] Evapotranspiration is invalid where wind is invalid
[9]Total precipitation likely underestimated due to partial freezing in snowfall conversion adaptor

WIND ROSE PLOT:

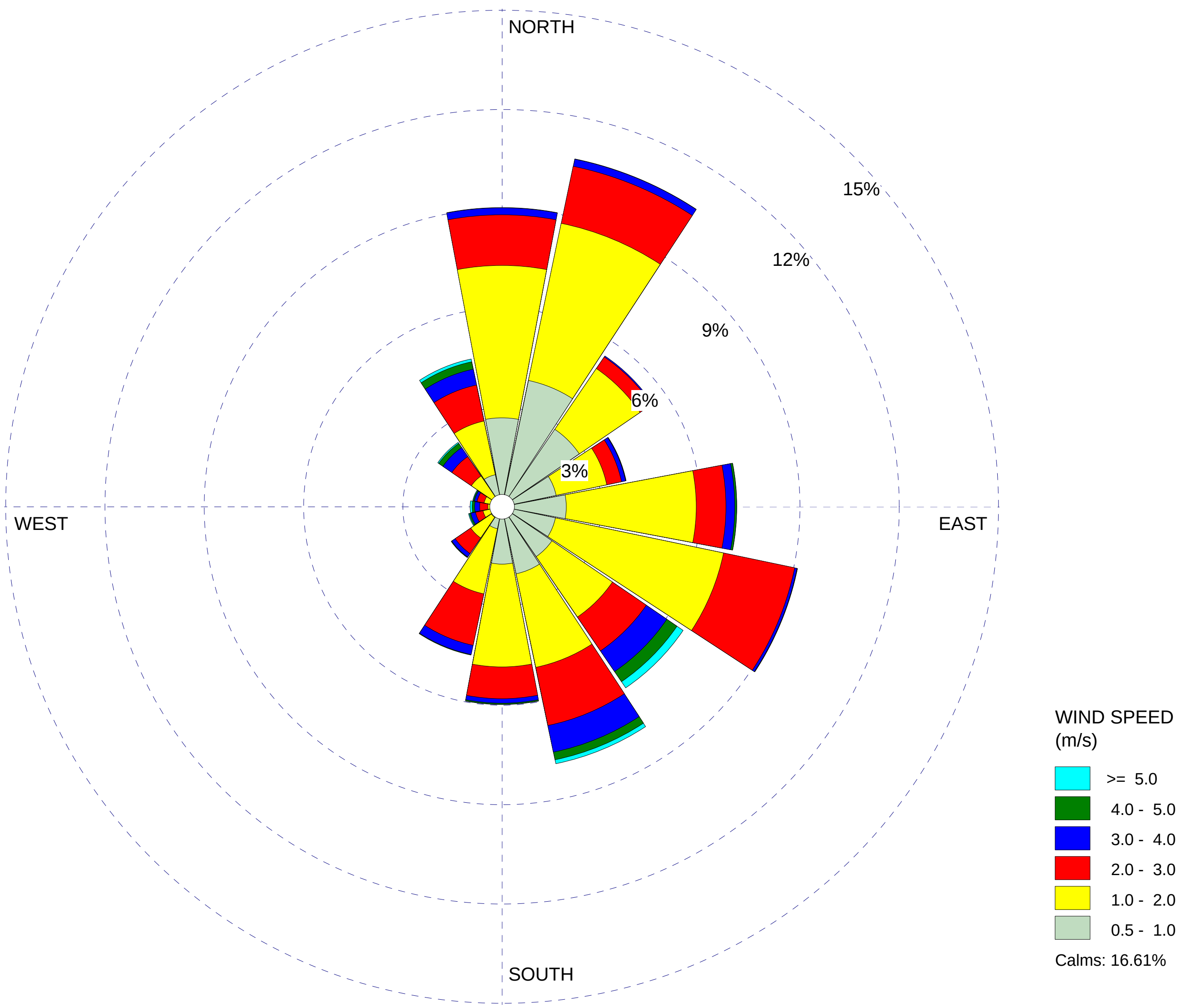
[illegible]

DISPLAY:

[illegible]

COMMENTS:

Excludes periods of ice affected or missing data.
Anemometer height: 10m



DATA PERIOD:

[illegible]

TOTAL COUNT:

[illegible]

CALM WINDS:

[illegible]

AVG. WIND SPEED:

[illegible]

COMPANY NAME:

MODELER:

DATE:

[illegible]

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Since the pyranometer was only installed in December 2012, no evapotranspiration data were calculated for 2011 or 2012. Estimates for evapotranspiration were developed previously from the 1996 data set using the computer program WREVAP developed by Environment Canada's National Hydrology Research Institute (Access, 1996). Since 2013, evapotranspiration is calculated in the datalogger program from local meteorological parameters, using the American Society of Civil Engineers (ASCE) standardized reference evapotranspiration equation (Penman-Monteith). Table 3 presents the comparison between the 2013, 2014, 2015, 2016 and the 1996 evapotranspiration data sets. It shows that the 1996 WREVAP evapotranspiration values may overestimate the local evapotranspiration, although more years of local evapotranspiration data will allow a more reliable comparison. It is interesting to note that results for 2013, 2014, 2015 and 2016 are very similar.

Table 3 Evapotranspiration Data Sets Comparison

Month	2013	2014	2015	2016	1996 WREVAP
January	*0.81*	*0.64*	*0.43*	*1.45*	0
February	*1.27*	1.99	0.86	2.32	0
March	6.33	9.17	6.29	7.12	0
April	14.48	15.77	16.03	15.86	10
May	21.70	29.81	34.67	25.97	42
June	29.79	28.58	26.46	29.78	43
July	27.10	23.84	19.98	17.36	44
August	21.38	15.72	13.87	17.72	20
September	10.88	11.56	10.12	14.02	20
October	4.26	3.39	*2.92*	4.15	0
November	*1.08*	*0.60*	*0.60*	*1.99*	0
December	*0.62*	*0.40*	*0.13*	*0.51*	0
Annual Total	**139.70**	**141.47**	**132.35**	**138.24**	**179**

** Values in grey italics indicate a partial month*

4. VALLEY TAILINGS WEATHER STATION

The Valley Tailings Onset HOBO automated meteorological station is located near the Valley Tailings at UTM coordinates: 08 V 0475799 7088130 and at an elevation of 718 masl. See Attachment A for the list of components and a photo.

4.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The HOBO meteorological station was commissioned on October 19, 2012 and includes sensors for the measurement of temperature, relative humidity, rainfall, barometric pressure, soil water content, wind speed and direction at a height of 3 meters.

- The tipping bucket only records rainfall (not total precipitation). As the air temperature started to rise above 0°C in May 2013, it was noted that still no rain was being recorded. This observation triggered an inspection of the tipping bucket and the tipping mechanism was found to be obstructed. The obstruction was removed on May 16, 2013, and the tipping bucket is now functioning properly.

- The wind sensor experiences frequent icing during the winter months and extended periods of zero wind speed in combination with wind gusts of less than 1 m/s were invalidated. Similarly, extended periods with identical wind directions were also invalidated. Also, note that winter wind speeds may be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- Starting on July 29, 2016, the wind direction data showed very little variability and it is suspected that results are invalid, due to a sensor or connection malfunction. The issue is currently being investigated.

- The logging interval was changed from 10 to 15 minutes on May 16, 2013, as this interval is sufficient for the purposes of this meteorological station and requires less datalogger memory.

4.2. METHODS AND RESULTS

Monthly averages from installation to December 2016 inclusively were calculated from instantaneous 10-minute or 15-minute values recorded by the datalogger for the following parameters: temperature, daily maximum temperature, daily minimum temperature, relative humidity, wind speed, gust speed, barometric pressure and solar radiation. Monthly extreme maximum temperature, extreme minimum temperature, maximum and minimum relative humidity, maximum gust speed and total rainfall are also shown in Table 4 below. Note that the barometric pressure has not been corrected for elevation and therefore represents the absolute pressure.

Table 4 Monthly Statistics for Meteorological Parameters Collected at the Valley Tailings Meteorological Station

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m²)	Soil Average Water Content (%)[4]
Oct-2012[1]	*-23.84*	*-20.12*	*-15.71*	*-9.71*	*-4.05*	*81.92*	*89.16*	*70.76*	n/a	*0.51*	*1.39*	*7.81*	*939.06*	*34.14*	n/a
Nov-2012	-40.71	-27.24	-23.77	-20.42	-8.07	82.04	90.97	69.24	n/a	*0.59*	*1.66*	*7.81*	932.15	7.72	n/a
Dec-2012	-44.20	-29.97	-26.29	-22.98	-3.99	82.75	97.20	71.67	n/a	*0.52*	*1.75*	*6.04*	926.06	1.48	n/a
Jan-2013	-45.56	-25.98	-21.58	-17.72	0.74	84.73	94.43	72.60	n/a	*0.94*	*2.10*	*14.61*	929.62	4.78	n/a
Feb-2013	-24.88	-16.72	-12.96	-8.80	2.40	90.08	96.67	81.42	n/a	*0.90*	*2.09*	*10.83*	919.93	23.70	n/a
Mar-2013	-33.45	-21.40	-13.93	-5.74	5.57	68.05	92.35	53.08	n/a	*0.84*	*2.00*	*13.85*	931.80	93.31	n/a
Apr-2013	-25.05	-14.66	-7.17	-0.87	8.37	53.23	81.57	39.58	n/a	*2.01*	*4.10*	*16.62*	930.07	171.18	n/a
May-2013	-8.36	0.10	6.08	11.66	23.35	62.90	95.00	40.13	*4.80*	*1.42*	*3.26*	*11.84*	928.76	186.87	12.3
Jun-2013	1.64	8.20	15.63	22.00	32.82	58.66	84.24	42.04	46.20	1.50	3.45	22.66	930.76	215.51	8.0
Jul-2013	1.59	8.95	15.68	21.90	29.32	60.65	87.50	38.38	25.40	1.39	3.22	16.12	931.69	194.18	6.9
Aug-2013	-1.90	6.94	13.85	20.49	29.49	68.65	95.18	44.98	43.00	*0.93*	*2.45*	*13.60*	926.92	144.34	9.6
Sep-2013	-2.45	2.00	6.39	10.85	18.06	80.70	98.19	60.89	64.80	*1.19*	*2.83*	*17.38*	921.41	71.21	14.4
Oct-2013	-11.22	-5.32	-1.54	2.56	9.11	91.89	99.04	68.02	49.40	*0.61*	*1.86*	*11.58*	927.19	32.16	12.2
Nov-2013	-42.69	-22.40	-18.25	-14.23	-0.59	88.31	99.71	75.50	0.00	*0.55*	*1.71*	*11.58*	931.23	8.07	n/a
Dec-2013	-40.38	-30.71	-27.25	-23.50	-2.48	83.73	95.83	72.42	0.00	*0.49*	*1.72*	*9.07*	936.80	1.69	n/a
Jan-2014	-37.92	-18.28	-14.50	-10.52	1.67	93.54	99.99	81.10	0.00	*0.17*	*1.96*	*6.30*	926.22	2.73	n/a
Feb-2014	-39.42	-27.88	-22.85	-14.48	-3.33	84.27	91.09	77.57	0.00	*0.34*	*1.43*	*8.31*	933.74	27.52	n/a
Mar-2014	-30.55	-20.48	-12.32	-3.50	5.85	63.32	80.35	46.47	7.00	*0.75*	*2.17*	*9.57*	928.51	103.16	n/a
Apr-2014	-20.69	-6.99	-0.45	6.19	11.52	59.76	87.11	43.10	5.00	*1.34*	*3.20*	*13.09*	923.72	152.86	n/a
May-2014	-3.24	1.34	8.66	14.54	21.94	53.49	74.94	35.74	11.40	*1.39*	*3.41*	*13.35*	931.01	201.57	17.3
Jun-2014	-0.85	6.35	12.79	18.09	28.17	56.74	87.94	38.68	56.80	1.39	3.45	15.61	926.57	206.09	14.0
Jul-2014[5]	*6.86*	*9.96*	*16.01*	*21.50*	*24.85*	*64.71*	*82.34*	*48.07*	*32.20*	*1.30*	*3.24*	*13.35*	*930.01*	*193.02*	*14.0*

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m^2)	Soil Average Water Content (%)[4]
Aug-2014 [5]	Station Down – No data														
Sep-2014 [5]															
Oct-2014 [5]	*-17.47*	*-12.34*	*-7.87*	*-4.47*	*-1.47*	*93.68*	*95.52*	*90.51*	*0.00*	*0.69*	*1.93*	*7.05*	*923.44*	*16.88*	n/a
Nov-2014	-35.71	-18.96	-15.69	-12.75	-2.25	89.63	99.47	80.36	0.00	*0.75*	*2.09*	*8.06*	932.50	8.54	n/a
Dec-2014	-29.59	-18.70	-15.22	-12.12	-1.73	92.55	98.58	85.41	0.00	*0.59*	*1.93*	*10.32*	924.68	1.53	n/a
Jan-2015	-41.27	-22.34	-19.15	-15.78	-0.14	90.13	99.54	78.03	0.00	*0.32*	*1.68*	*9.07*	932.43	2.93	n/a
Feb-2015	-41.50	-21.41	-17.51	-12.68	3.85	89.56	99.96	78.51	13.60	*0.46*	*1.80*	*12.34*	935.86	22.75	n/a
Mar-2015	-31.12	-16.89	-10.20	-3.39	6.84	75.01	91.08	58.48	3.20	*1.00*	*2.33*	*13.35*	927.14	84.81	n/a
Apr-2015	-11.15	-4.79	1.23	7.51	12.53	64.06	88.56	50.40	13.80	*1.45*	*3.36*	*12.84*	921.78	153.92	n/a
May-2015	-6.99	3.25	11.76	18.45	27.55	48.65	67.29	33.82	6.00	*1.43*	*3.41*	*17.12*	932.37	235.70	21.4
Jun-2015	1.24	5.77	12.99	19.00	25.82	59.92	81.85	34.81	27.20	1.48	3.49	16.62	929.55	213.66	13.1
Jul-2015	4.14	7.64	13.90	19.65	27.16	69.15	93.72	43.99	82.60	1.05	2.63	10.83	927.71	180.54	17.2
Aug-2015	-2.57	4.53	10.52	15.76	25.84	76.20	95.53	54.67	69.20	*1.01*	*2.48*	*10.83*	927.00	138.77	20.2
Sep-2015	-8.10	-0.86	3.67	8.66	16.03	81.30	93.24	61.31	42.60	*1.29*	*2.97*	*21.40*	923.36	80.01	20.7
Oct-2015	-12.79	-4.25	-1.37	1.63	7.70	91.95	99.99	65.89	14.00	*0.75*	*2.01*	*8.56*	924.77	33.28	8.6
Nov-2015	-36.15	-18.71	-14.44	-10.89	2.64	92.87	99.34	82.48	0.00	*0.40*	*1.71*	*7.05*	921.85	6.59	n/a
Dec-2015	-33.38	-18.58	-15.58	-12.85	3.01	92.73	97.50	83.71	0.00	*0.46*	*2.12*	*11.84*	919.23	1.26	n/a
Jan-2016	-26.91	-16.61	-13.08	-10.02	4.17	91.42	98.22	78.66	0.00	*0.69*	*2.08*	*17.38*	922.28	4.92	n/a
Feb-2016	-34.26	-17.54	-12.62	-7.02	2.96	89.23	97.60	79.77	2.00	*0.49*	*1.71*	*9.82*	924.51	26.62	n/a
Mar-2016	-15.91	-9.95	-4.83	0.67	13.83	76.08	94.59	62.59	4.80	*1.34*	*2.86*	*9.82*	922.88	80.42	n/a
Apr-2016	-10.97	-2.76	2.77	8.43	15.25	65.43	92.00	46.16	3.20	*1.53*	*3.40*	*14.10*	925.77	151.79	6.8
May-2016	-2.10	2.56	9.64	15.44	23.88	56.10	83.81	36.95	16.40	*1.66*	*3.66*	*15.11*	931.02	205.21	25.5
Jun-2016	3.01	7.16	14.43	20.48	27.53	55.89	88.06	36.60	40.40	1.63	3.64	15.11	927.96	233.69	21.6

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m²)	Soil Average Water Content (%)[4]
Jul-2016	0.63	9.33	14.84	20.11	26.92	73.54	93.34	54.86	67.20	1.08	2.67	11.84	929.36	173.57	23.9
Aug-2016	-1.47	7.05	12.77	18.13	24.80	73.62	94.25	58.18	45.80	1.15	2.75	15.11	932.57	146.43	23.6
Sep-2016	-6.14	0.03	5.67	11.48	18.11	73.70	94.96	34.79	39.40	*0.96*	*2.56*	*14.86*	927.36	98.46	23.4
Oct-2016	-22.37	-11.82	-7.27	-1.85	5.00	84.13	97.87	63.33	0.60	*0.57*	*1.77*	*9.32*	929.65	47.00	5.2
Nov-2016	-32.83	-17.19	-13.41	-9.77	5.62	90.97	99.91	74.28	6.80	*0.49*	*1.84*	*10.83*	919.86	6.43	1.0
Dec-2016	-39.74	-25.23	-21.84	-18.83	-3.42	87.07	96.70	76.06	0.00	*0.43*	*1.68*	*6.55*	931.27	1.78	0.2

Notes: *Values in grey italics indicate a partial month*

[1] Station was commissioned on October 19 so October 2012 has 12 days of complete data

[2] May2013 has 14 days of compete rain data

[3] October 2012 has 2 days of complete and 11 days of partial wind data
November 2012 has 5 days of complete and 24 days of partial wind data
December 2012 has 2 days of complete and 16 days of partial wind data and
January 2013 has 5 days of complete and 16 days of partial wind data
February 2013 has 2 days of complete and 26 days of partial wind data
March 2013 has 4 days of complete and 27 days of partial wind data
April 2013 has 14 days of complete and 16 days of partial wind data
May 2013 has 15 days of complete and 16 days of partial wind data
June 2013 has 29 days of complete and 1 day of partial wind data
August 2013 has 29 days of complete and 2 days of partial wind data
September 2013 has 15 days of complete and 15 days of partial wind data
October 2013 has 6 days of complete and 25 days of partial wind data
November 2013 has 1 day of complete and 28 days of partial wind data
December 2013 has 2 days of complete and 23 days of partial wind data
January 2014 has 0 days of complete and 12 days of partial wind data
February 2014 has 0 days of complete and 13 days of partial wind data
March 2014 has 1 days of complete and 30 days of partial wind data
April 2014 has 10 days of complete and 20 days of partial wind data
May 2014 has 21 days of complete and 10 days of partial wind data
December 2014 has 3 days of complete and 12 days of partial wind data
January 2015 has 0 days of complete and 14 days of partial wind data

February 2015 has 1 day of complete and 17 days of partial wind data
March 2015 has 5 days of complete and 26 days of partial wind data
April 2015 has 12 days of complete and 18 days of partial wind data
May 2015 has 27 days of complete and 4 days of partial wind data
August 2015 has 29 days of complete and 2 days of partial wind data
September 2015 has 14 days of complete and 16 days of partial wind data
October 2015 has 12 days of complete and 19 days of partial wind data
November 2015 has 1 day of complete and 23 days of partial wind data
December 2015 has 0 day of complete and 9 days of partial wind data
January 2016 has 4 days of complete and 19 days of partial wind data
February 2016 has 2 days of complete and 17 days of partial wind data
March 2016 has 8 days of complete and 23 days of partial wind data
April 2016 has 22 days of complete and 4 days of partial wind data
May 2016 has 30 days of complete and 1 day of partial wind data
September 2016 has 22 days of complete and 8 days of partial wind data
October 2016 has 4 days of complete and 27 days of partial wind data
November 2016 has 3 days of complete and 11 days of partial wind data
December 2016 has 0 day of complete and 18 days of partial wind data
[4] Negative values reported from Oct 2012 to April 2013, from Nov 2013 to Apr 2014, from Oct 2014 to Apr 2015 and from Nov 2015 to March 2016 were invalidated – soil assumed to be frozen
[5] Station was down between July 16 and October 26, 2014

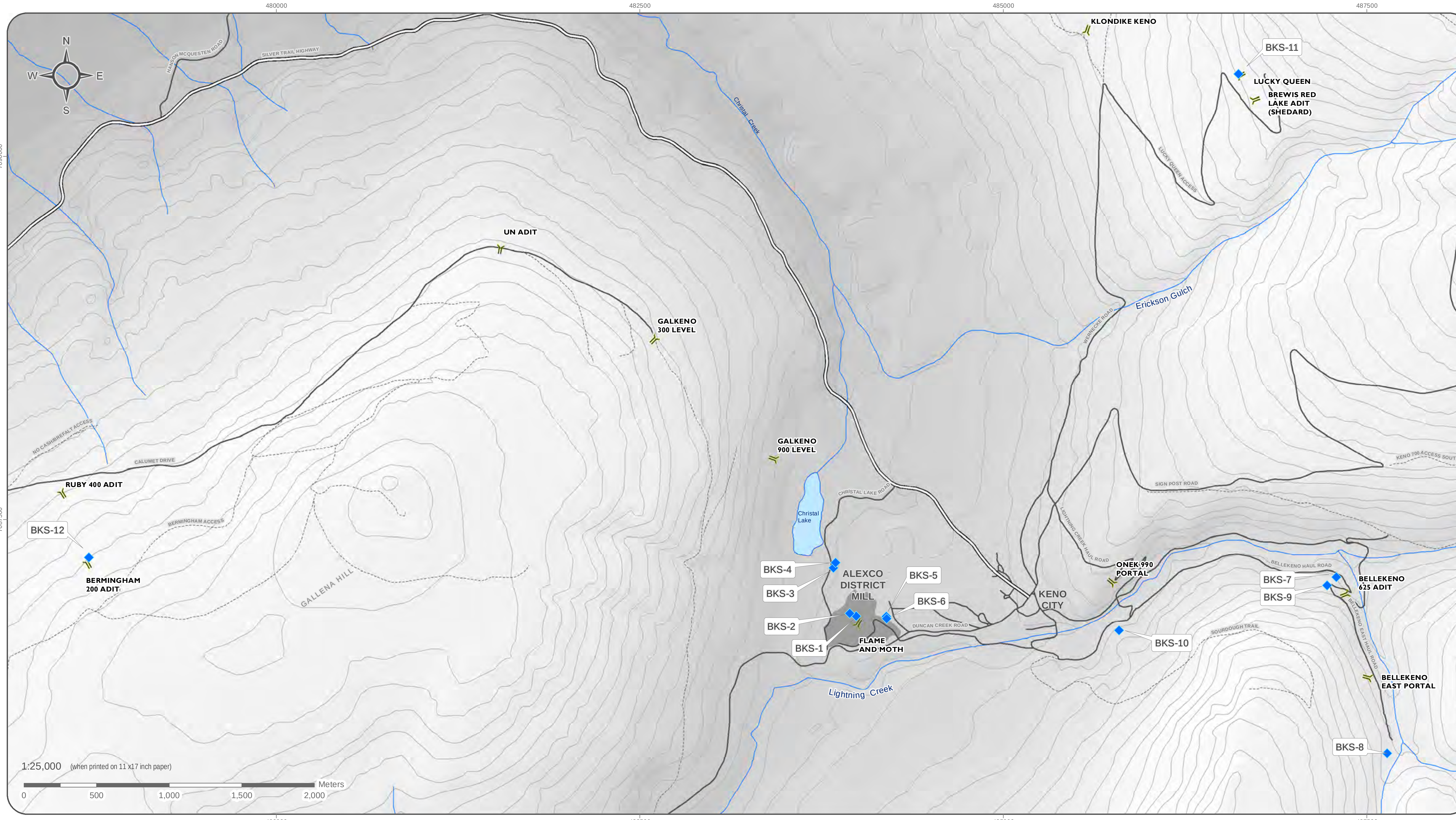
5. SNOW SURVEYS

Alexco has been conducting manual snow surveys since 2011 at ten monitoring stations in order to adequately represent the varying snow conditions as a function of aspect, elevation, etc. In 2016, surveys were conducted on January 30, March 2 and April 5. Snow water equivalent (SWE) results are presented in Table 5 below and the station locations are shown of Figure 3. Figure 4 presents the average snow water equivalent (SWE) across all stations.

Table 5 Snow Survey SWE Results (cm)

Station	Description	Jan 2011	Feb 2011	Mar 2011	Jan 2012	Feb 2012	Mar 2012	Apr 2012	Jan 2013	Feb 2013	Mar 2013	Apr 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	Feb 2015	Mar 2015	Apr 2015	Feb 2016	Mar 2016	April 2016
BKS-1	tall spruce up hill near dry stack	7.6	7.6	5.1	6.0	16.1	18.7	8.7	7.3	11.3	13.0	15.0	12.3	14.0	12.3	9.7	8.0	9.3	8.7	4.0	8.7	7.7
BKS-2	log pile near dry stack	7.6	7.6	7.6	12.2	13.6	9.3	20.8	9.3	10.7	11.7	13.8	10.3	10.7	10.0	7.7	9.0	10.3	9.0	8.0	11.0	10.3
BKS-3	Between 1 and 2 marker on CLR road	7.6	10.2	7.6	9.6	12.5	4.4	7.7	7.3	10.0	14.3	14.7	13.0	12.3	11.0	9.7	9.3	7.0	10.7	8.0	9.3	10.7
BKS-4	down road from BKS 3, closer to #2 CLR marker	7.6	7.6	7.6	8.5	17.6	12.3	8.8	9.3	11.7	18.3	14.3	12.7	12.0	11.7	7.3	3.7	8.7	7.3	10.0	8.7	12.3
BKS-5.0	Keno dump area. Near scrub trees	5.1	7.6	5.1	13.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BKS-5.1	Keno dump area. Near scrub trees	-	-	-	-	11.3	12.2	9.6	6.7	9.7	13.3	13.0	11.0	12.0	10.7	8.7	8.3	10.7	12.0	10.0	8.7	10.7
BKS-6	Keno dump area. On sloping hillside	2.5	2.5	0	11.2	12.6	14.8	19.8	6.7	9.2	12.0	11.3	10.7	10.3	8.7	8.3	7.3	8.7	9.0	8.0	8.0	8.3
BKS-7	Uphill from Bellekeno treatment pond	7.6	10.2	7.6	12.5	13.6	4.8	8.5	6.7	11.0	10.3	13.7	13.3	13.0	13.0	10.0	9.0	12.7	14.0	7.3	7.0	11.3
BKS-8	Far end of Bellekeno East. Nr explosive storage shed	7.6	7.6	5.1	9.9	13.8	17.6	19.5	8.0	10.0	18.5	19.7	9.3	12.7	12.7	10.7	6.7	17.0	12.3	7.3	9.3	-
BKS-9	At BKR 16 marker. Slightly up on hillside	7.6	10.2	10.2	12.4	13.3	17.1	0.00	7.3	10.0	15.0	14.0	12.3	11.7	11.3	9.0	7.7	10.7	8.3	7.3	7.0	0.0

Station	Description	Jan 2011	Feb 2011	Mar 2011	Jan 2012	Feb 2012	Mar 2012	Apr 2012	Jan 2013	Feb 2013	Mar 2013	Apr 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	Feb 2015	Mar 2015	Apr 2015	Feb 2016	Mar 2016	April 2016
BKS-10	Near BKR 8 pull out. Up on hillside	10.1	7.6	5.1	13.3	16.5	27.7	10.7	9.3	10.0	12.3	14.3	14.0	15.7	14.3	7.0	10.0	10.0	12.0	10.7	6.0	11.7
BKS-11	Lucky Queen, upslope of the pond	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.3	20.7	15.0
BKS-12	East of Bermingham 200 adit, Upslope of road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.3
Mean	-	7.1	7.9	6.1	10.9	14.1	13.9	11.4	7.8	10.4	13.9	14.4	11.9	12.4	11.6	8.8	7.9	10.5	10.3	8.1	8.4	9.8



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 underlicense from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.
Quartz claim boundaries current as of February 24th, 2011. Ownership data current as of December 20th, 2010. Data source: http://geomaticsyukon.ca.

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

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Legend			
Snow Monitoring Station	Silver Trail Highway	Contours (100 ft)	
Adit	Other Road	Watercourse	
	Limited-Use Road	Waterbody	

ERDC
AEG

ENVIRONMENTAL CONDITION REPORT

FIGURE 3

SNOW SURVEY STATIONS LOCATION

JANUARY 2017

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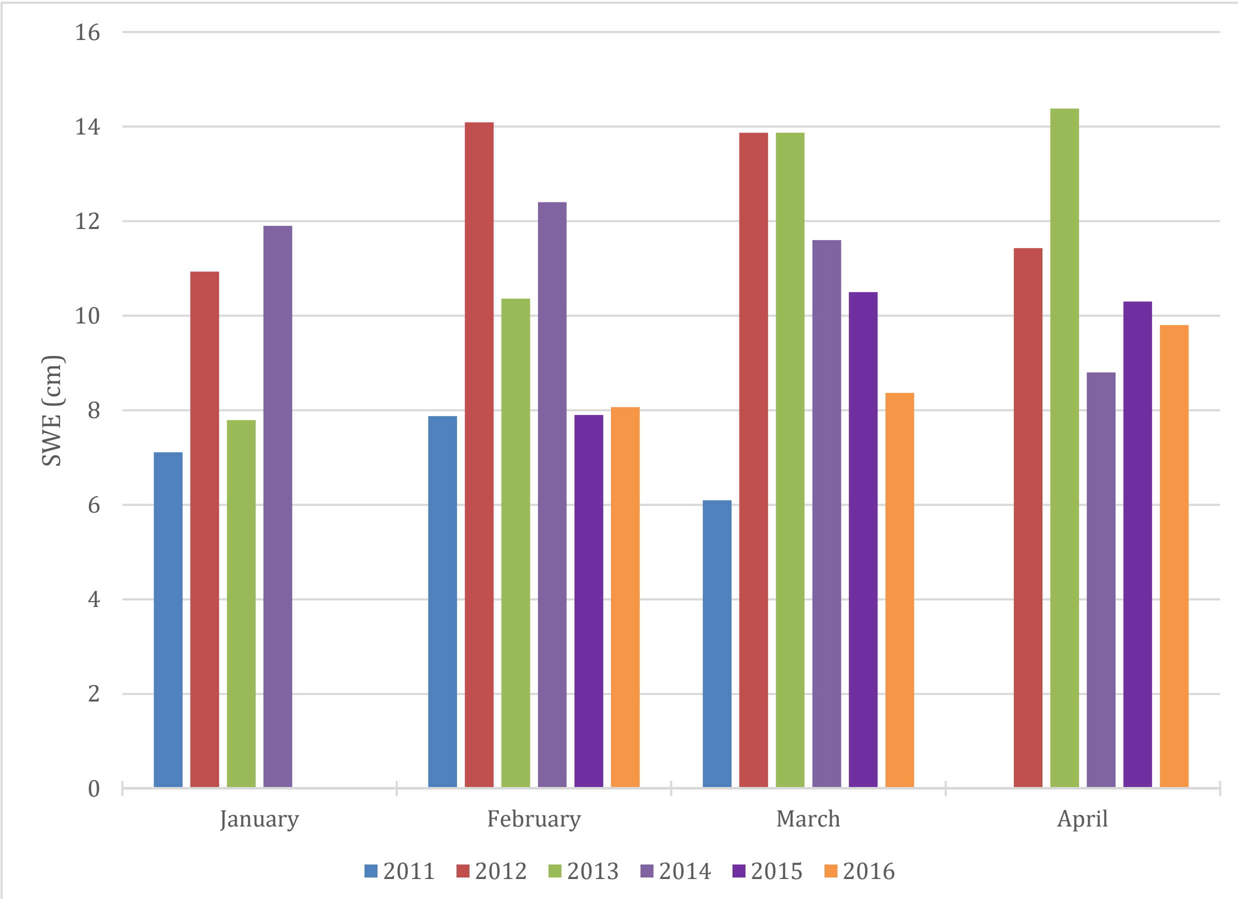


Figure 4 Average Snow Water Equivalent across all Snow Survey Stations

6. MEAN ANNUAL PRECIPITATION (MAP)

Mean annual precipitation (MAP) within a mountainous region typically increases with increasing elevation. The significant relief over which the Keno Hill area spans is well represented by two historical weather stations with Elsa at 814 masl and the Keno Hill weather station at 1472 masl. In 1996, Clearwater Consultants Ltd. used data from these two stations as well as from Environment Canada's station located at Mayo airport (504 masl.) to derive a relationship between MAP and elevation. Assuming a linear relationship, a line was fitted to the data of these stations (see Figure 5) (Access, 1996). The slope of this line indicates that MAP increases by an average of 27 mm for every 100 m of ascent, a value not too dissimilar from that observed in other regions of the Yukon interior.

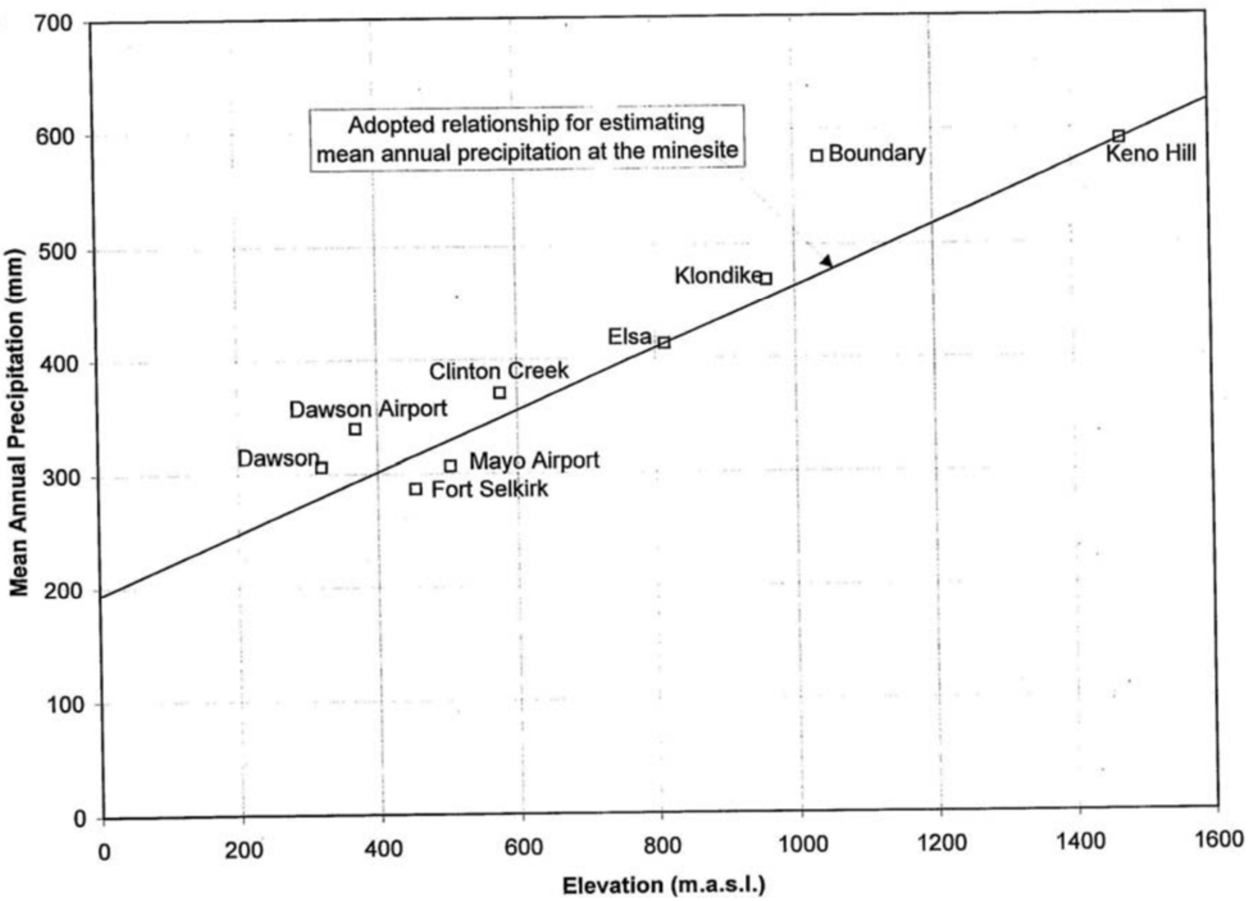


Figure 5 Mean Annual Precipitation as a Function of Elevation

As with MAP, the seasonal distribution is influenced by elevation. To demonstrate this influence, the seasonal distributions for Mayo Airport, Elsa, and Keno Hill have been plotted on Figure 6, as part of the same assessment conducted by Clearwater Consultants in 1996. The proportion of total precipitation which falls as rain decreases as elevation increases (60% of total precipitation at Mayo Airport, 53% at Elsa, and 41% at Keno Hill). Again, a simple linear relationship can be derived and the slope indicates that the proportion of total precipitation that falls as rain decreases by about 2% for every 100 m ascent.

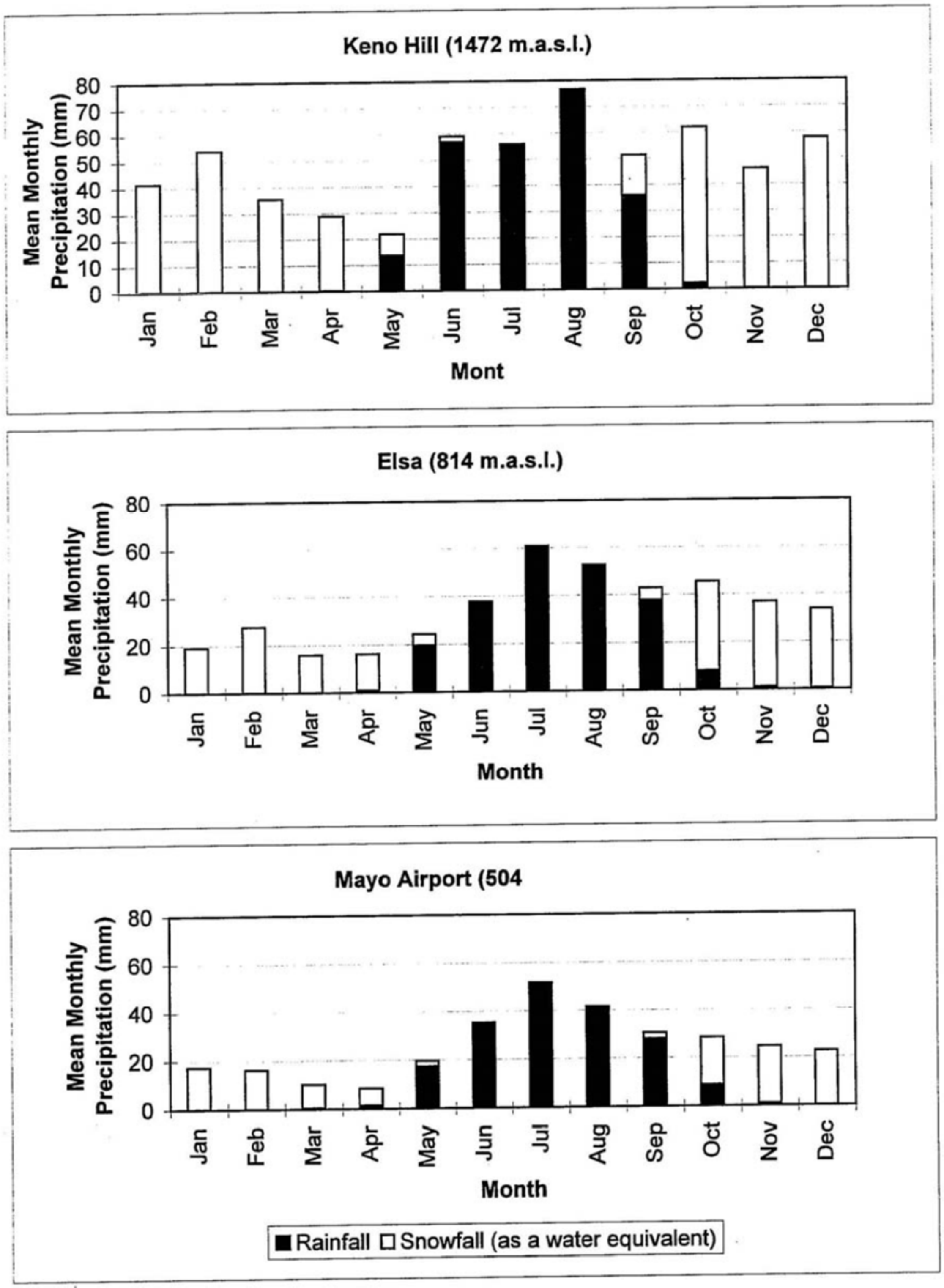


Figure 6 Mean Monthly Precipitation

Recent precipitation data from Mayo A, Calumet, District Mill and the Valley Tailings weather stations were used to verify the empirical relationships presented above. Validated precipitation data at Mayo A are available until the end of 2016, with the exception of the year 2013, which is missing, therefore, the common periods with Calumet station (2007-2016), with the District Mill station (2012-2016) and the valley Tailings (2014-2016) were used for this comparison. Mayo A reports both rain and total precipitation, while Galena Hill and the Valley Tailings weather stations record rainfall only. The District Mill weather station recorded rainfall only in 2012 and 2013 and total precipitation in 2014 and 2015. Table 6 presents the proportion of total precipitation that fell as rain for the 2007-2016 period at Mayo A.

Table 6 Annual Precipitation at Mayo A, 2007-2015

	Total Rain (mm)	Total Snow (cm)	Total Precipitation (mm)	% rain
2007	217.2	188.4	345.8	62.8
2008	309.3	157.8	429.3	72.0
2009	186.9	181.6	304.3	61.4
2010	198.1	129.8	293.7	67.4
2011	329.5	164.9	452.9	72.8
2012	171.7	158.4	276.1	62.2
2013	n/a			
2014	259.4	69.4	376.3	68.9
2015	133.9	123.5	393.4	34.0
2016	245.5	124.2	316	77.7
AVG	**227.9**	**144.2**	**354.2**	**64.4**

For this 9-year period, the average proportion of total precipitation that fell as rain was 64.4%, which is slightly higher than the original estimate of 60%. Since the value of 60% was estimated using data collected between 1974 and 1982, it is possible that the proportion of total precipitation falling as rain has increased with the warming temperature trend. Figure 7 shows the temperature trend at Mayo A since 1925; maximum, minimum and mean temperatures recorded over the 1925 to 2010 time period all show an increasing trend.

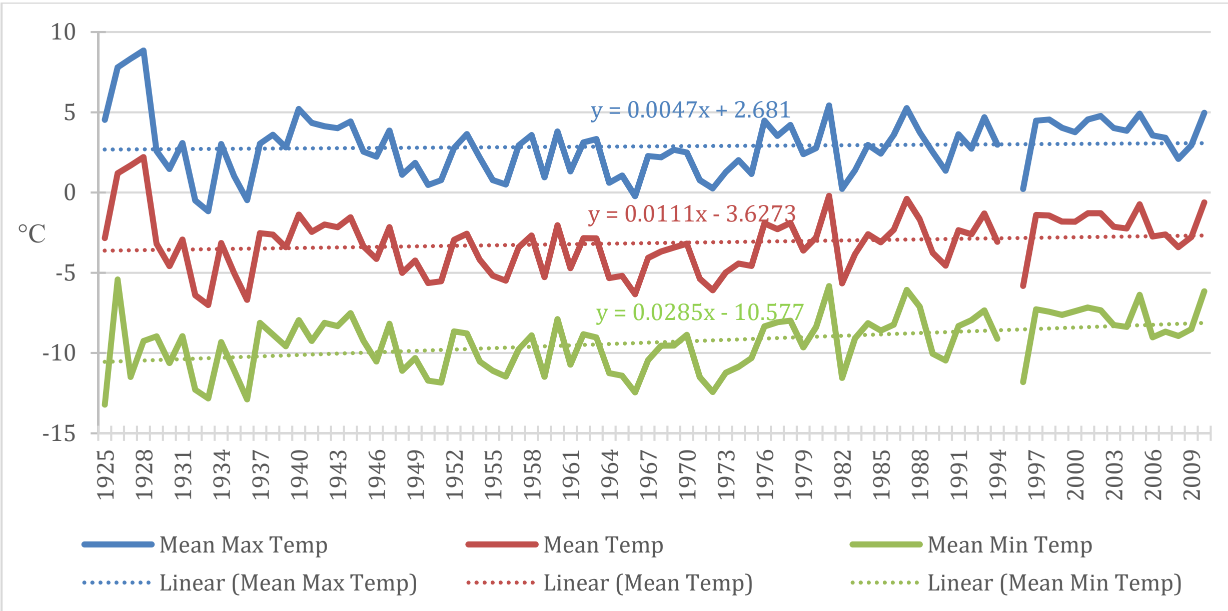


Figure 7 Mayo A Annual Temperatures, 1925-2010

Assuming the empirical linear relationship where the proportion of total precipitation that falls as rain decreases by about 2% for every 100 m ascent, it is expected that 45.2% of total precipitation falls as rain at Calumet, 54.1% at the District Mill and 58.4% at the Valley Tailings station. Since total precipitation was not measured at Galena Hill, Valley Tailings nor at the District Mill in 2012, this assumption was used to verify the linear relationship between MAP and elevation developed by Clearwater. Based on Mayo A annual total precipitation from 2007 to 2016 (Table 6), predicted total rainfall is compared to total rainfall measured at Galena Hill and the District Mill (Table 7). Note that Galena Hill observed rainfall data for 2016 are largely incomplete (see Table 1 for details) and that year was therefore not included in the comparison below.

Table 7 Predicted Versus Measured Total Rain (mm)

Year	Predicted Annual Total Precipitation (mm)	Predicted Total Rain (mm)	Measured Total Rain (mm)	Actual – Predicted (mm)	Difference (%)
Calumet (1380 masl)					
2007	582.3	263.1	*276.4*	13.3	4.8
2008	665.8	300.8	363.6	62.8	17.3
2009	540.8	244.3	*196.4*	-48.0	-24.4
2010	530.2	239.6	462.2	222.7	48.2
2011	689.4	311.5	*305.5*	-6.0	-2.0
2012	512.6	231.6	*137.0*	-94.6	-69.0
2013	n/a				
2014	612.8	276.9	264.4	-12.5	-4.7
2015	629.9	284.6	*339.7*	55.1	16.2
AVG	**595.5**	**269.0**	**293.1**	**24.1**	**-1.7**

Year	Predicted Annual Total Precipitation (mm)	Predicted Total Rain (mm)	Measured Total Rain (mm)	Actual – Predicted (mm)	Difference (%)
District Mill (936 masl)					
2012	419.5	226.8	217.5	-9.3	-4.3
2013	n/a				
2014	519.7	n/a	292.6**	-227.1	-77.6
2015	536.8	n/a	296.9**	-239.9	-80.8
2016	459.4	n/a	277.7**	-181.7	-65.4
AVG	**483.8**	**226.8**	**271.2**	**-164.5**	**-57.0**
Valley Tailings (718 masl)					
2014	460.8	269.2	*112.4*	-156.8	-139.5
2015	477.9	279.2	272.2	-7.0	-2.6
2016	400.5	234.0	226.6	-7.4	-3.3
AVG	**446.4**	**260.8**	**203.7**	**-57.1**	**-48.4**

**Values in grey italics indicate a partial total*
*** Measured total precipitation, corrected for winter undercatch and wind defelction*

Note that some years have incomplete rain data at Calumet (refer to Table 1 for specific details) and Valley Tailings, and this could explain the negative difference between actual and predicted rainfall in 2009 and 2012 at Calumet and 2014 at the Valley Tailings. In other cases however, the difference is positive even though the Calumet data set in incomplete (e.g. 2015). For the three years where the Calumet dataset is complete, the difference between actual and predicted total rainfall is positive for 2008 and 2010, and negative for 2014. The average difference between actual and predicted for those three years is positive (20.2%), implying that the linear relationship between MAP and elevation developed by Clearwater might underestimate total precipitation increase with elevation. A confounding factor is the assumed relationship between the proportion of total precipitation that falls as rain and elevation, which may also need to be refined. At the Valley Tailings station, the 2015 and 2016 dataset are complete and actual versus predicted rainfall are relatively similar (-2.6% and -3.3% difference respectively).

In the case of the District Mill, there is good agreement between predicted and measured total rain for the year 2012. In 2014, 2015 and 2016 however, comparison is made for total precipitation since a snowfall conversion adaptor was installed in 2013. In that case, the measured amount is considerably less than the predicted amount, indicating probable under catch of the snowfall conversion adaptor. Literature reports a cumulative winter catch efficiency of 0.66 for a Campbell Scientific TE525 tipping bucket gauge with a CS705 snow fall adaptor and alter screen (MacDonald and Pomeroy, 2007). Total precipitation data (2014-2016) from October through April were therefore corrected using this factor. Also, because the use of an alter screen for wind deflection has a documented improvement of 10 to 16% in snow collection efficiency and 6% to 10% for all types of precipitation (Belfort Instrument, 2013), average correction factors of 8% and 13% for summer and winter months respectively were applied to precipitation data collected prior to the installation of the alter screen in June 2015. Corrected total precipitation data are still below the values predicted from the MAP-elevation relationship, suggesting that the snowfall undercatch might be greater at this site than the average value reported in the literature, or that there is uncertainty in the MAP-elevation relationship. Refinement of the MAP-elevation relationship derived by Clearwater will be possible as more years of data become available at Galena Hill and at the District Mill, and as total precipitation data become available at the District Mill weather station.

7. REFERENCES

Access Mining Consultants Ltd., 1996a. United Keno Hill Mines Limited, Site Characterization Report, Report No. UKH96/01. Prepared for United Keno Hill Mines Limited.

Belfort Instrument. 2013. Reducing Precipitation Gauge Inconsistencies Using Modern Wind Deflection Methodologies.

MacDonald, Jimmy P. and John W. Pomeroy. 2007. Gauge Undercatch of Two Snowfall Gauges in a Prairie Environment. 64th Eastern Snow Conference. St. John's, Newfoundland, Canada, 2007.

ATTACHMENT A: METEOROLOGICAL STATIONS COMPONENTS

Galena Hill HOBO Meteorological Station

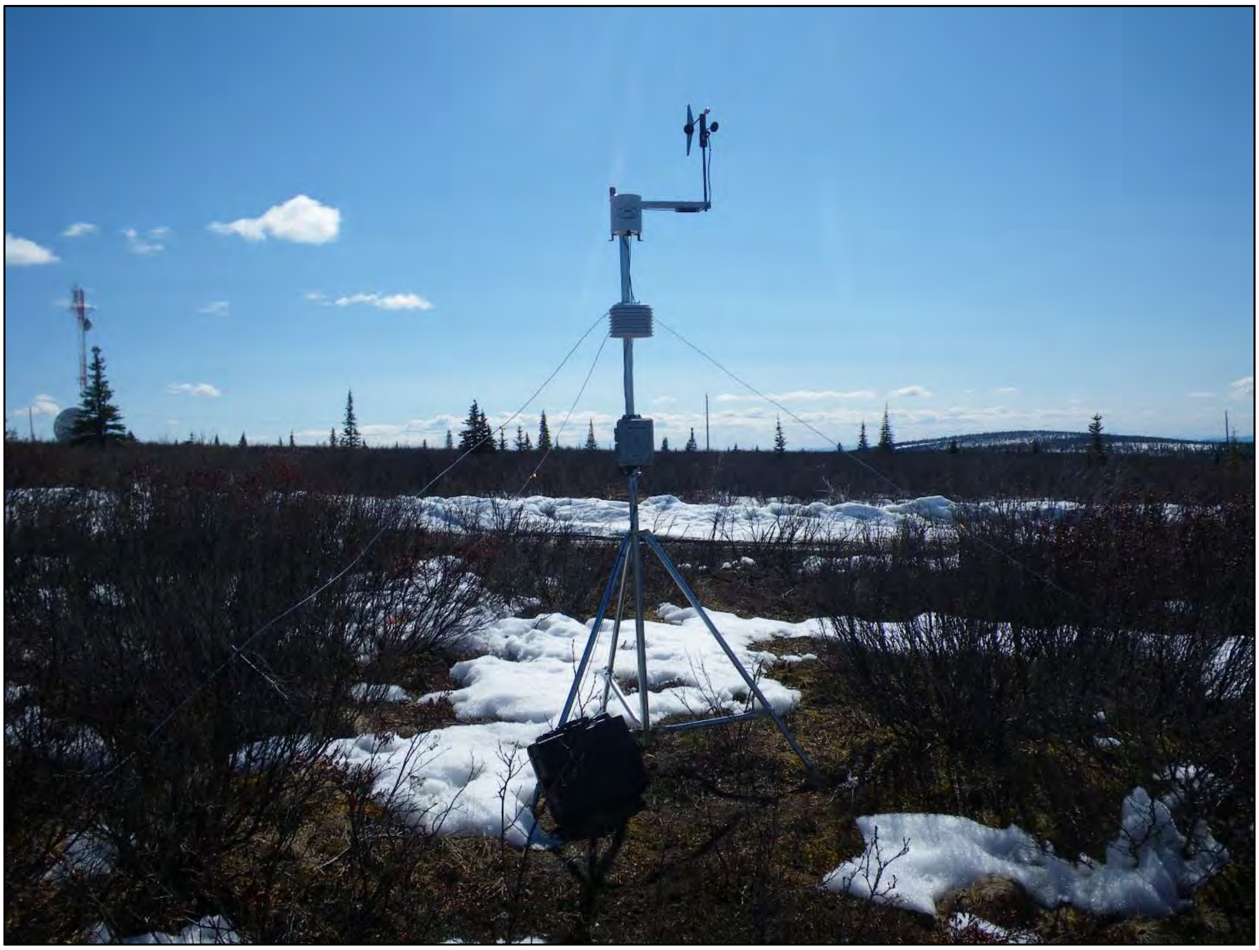
Component	Model	Serial Number
Datalogger	HOBO Weather Logger	1153440
Temp & RH Sensor	S-THB-XXXX	10064003
Soil Temp Sensor	S-TMB-XXXX	985390
Pyranometer	S-LIB-XXXX	1048627
Rain Gauge	S-RGB-M002	1017667
Wind Speed & Direction Sensor	S-WCA-XXXX	1254995
BP Sensor	S-BPA-XXXX	1037089

District Mill Campbell Scientific Meteorological Station

Component	Model	Serial Number
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
Pyranometer	SP Lite2	125766

Valley Tailings HOBO Meteorological Station

Component	Model	Serial Number
Datalogger	U30 NRC	10231016
Input Expander kit		
Solar Panel	6W	
AC Power Adaptor	120V - 60Hz	
HOBOware	Pro	2580 2976 6309 4793
Temp & RH Sensor	THB-M002	10220040
Solar Radiation Shield	RS3	
Pyranometer	LIB-M003	10191222
Rain Gauge	RGB-M002	10222664
Light Sensor Bracket	LBB	
Light Sensor Level	LLA	
Wind Speed & Direction Sensor	WSET-A	10233230
Full Cross Arm	CAA	
BP Sensor	BPB-CM50	10212093
Soil Moisture Sensor	SMC-M005	10225679
Tripod	TPA-KIT 3m	



Galena Hill HOBO Meteorological Station

District Mill Campbell Scientific Meteorological Station

Valley Tailings HOBO Meteorological Station

APPENDIX 3

ENGINEERING SUPPORTING DOCUMENTS

APPENDIX 3.1
ENGINEERING DESIGN PACKAGE

Sheet List	
Sheet Number	Sheet Title
AKHM-13-01-G-0000	Sheet List
AKHM-13-01-S-0301	Rock Pile Portal Closure
AKHM-13-01-S-0302	Bulkhead Closure
AKHM-13-01-S-0303	Shaft Cap
AKHM-13-01-B-0301	Road Reclamation - typ.
AKHM-13-01-D-2102	Bellekeno Bioreactor
AKHM-13-01-D-2301	BioReactor Sections
AKHM-13-01-D-2601	Bellekeno P&ID
Reclamation Measures	
AKHM-13-01-C-1401	Flame & Moth Reclaim Measures
AKHM-13-01-C-2401	Bellekeno East Relcaim Measures
AKHM-13-01-C-2402	Bellekeno 625 Relcaim Measures
AKHM-13-01-C-3401	Lucky Queen Relcaim Measures
AKHM-13-01-C-4401	Onek Relcaim Measures
AKHM-13-01-C-5401	Bermingham Relcaim Measures
AKHM-13-01-C-6401	Mill Site Relcaim Measures
AKHM-13-01-C-7401	DSTF Relcaim Measures
AKHM-13-01-C-8401	Sludge Pond Relcaim Measures
AKHM-13-01-C-9401	Flat Creek Camp Relcaim Measures
Final Grading Details	
AKHM-13-01-B-2101	Bellekeno East Grading Plan
AKHM-13-01-B-2102	Bellekeno 625 Grading Plan
AKHM-13-01-B-3101	Lucky Queen Grading Plan
AKHM-13-01-B-3301	Lucky Queen Grading Sections
AKHM-13-01-B-4101	Onek Grading Plan
AKHM-13-01-B-4301	Onek Grading Sections
AKHM-13-01-B-5101	Bermingham Grading Plan
AKHM-13-01-B-5301	Bermingham Grading Section
AKHM-13-01-B-6101	Mill Site Grading Plan
AKHM-13-01-B-6301	Mill Grading Sections
AKHM-13-01-B-9101	Flat Creek Camp Grading
AKHM-13-01-B-9301	Flat Creek Camp Sections

Sheet Naming Convention

A-1234

- A = Discipline
- 1 = Site
- 2 = Sheet Type
- 3,4 = Sequential Number

Disciplines	Sites	Sheet Types
G = General	0 = General (Not site specific)	1 = Plans (Horizontal Views)
H = Hazardous Materials	1 = Flame & Moth	2 = Elevations (Vertical Views)
V = Survey/Mapping	2 = Bellekeno	3 = Sections (Sectional Views)
B = Geotechnical	3 = Lucky Queen	4 = Large Scale Views (Plans, Sections & Elevations that are not Details)
C = Civil	4 = Onek	5 = Details
L = Landscape	5 = Bermingham	6 = Schedules and Diagrams
S = Structural	6 = Mill Site	7 = User Defined
A = Architectural	7 = DSTF	8 = User Defined
I = Interiors	8 = KHSD Sludge Pond	9 = 3D Representations (Isometrics, Perspectives and Photographs)
Q = Equipment	9 = Flat Creek Camp	
F = Fire Protection		
P = Plumbing		
D = Process		
M = Mechanical		
E = Electrical		
W = Distributed Energy		
T = Telecommunications		
R = Resource		
X = Other Disciplines		
Z = Contractor/Shop Drawings		
O = Operations		

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	KAB	--

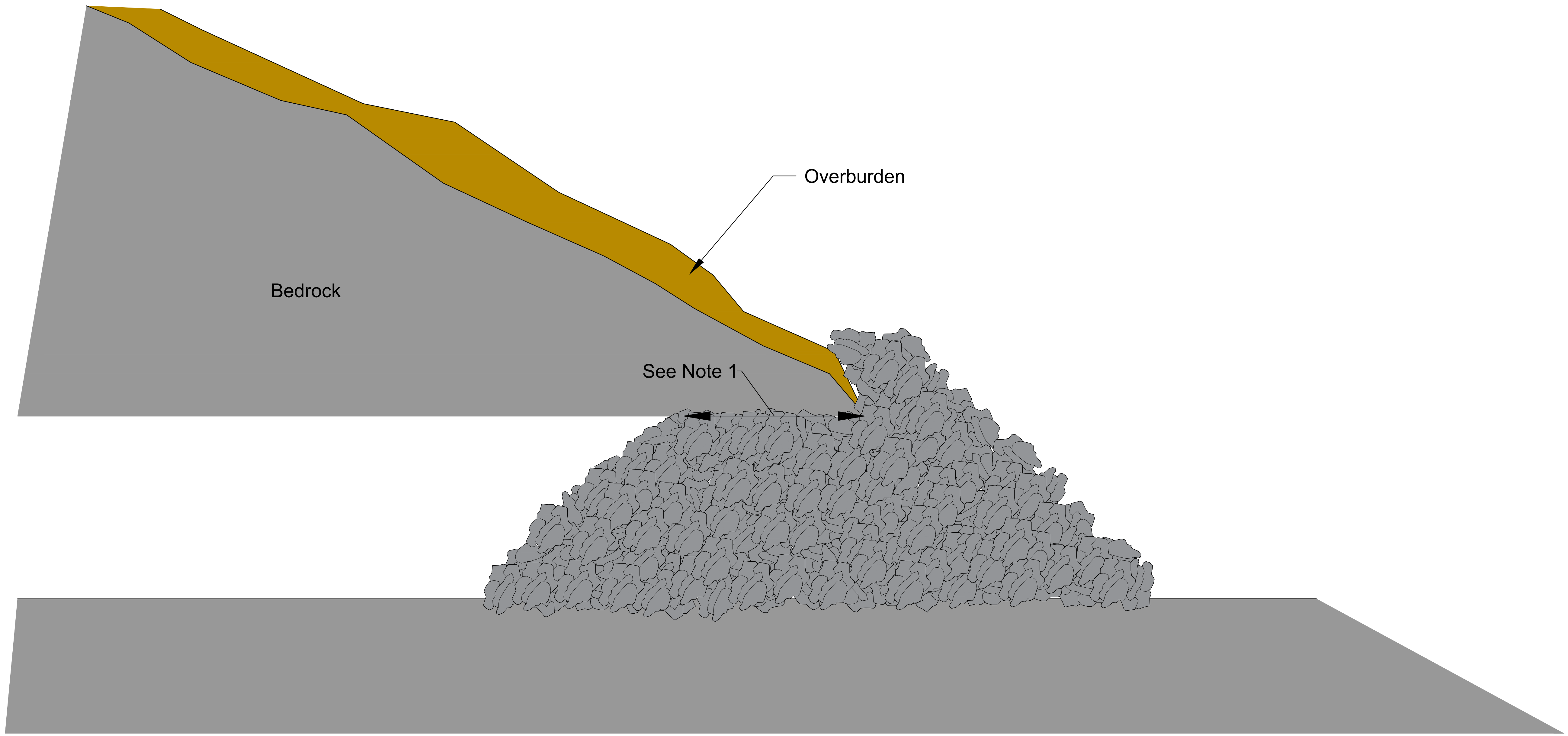
ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-G-0000

Sheet List

REVISION: A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW



Notes:

1. Backfill should extend to a minimum length equal to the largest opening dimension.
2. Backfill material should consist of well graded, durable rock fill and coarse rip-rap.
3. The use of well graded rock intermixed with large boulders will discourage people from digging into the backfill.
4. Backfill should be inert, or material that poses no additional threat to mine water quality.
5. Backfill should extend past the opening and mound over the top of the entrance to completely seal the opening and compensate for settlement.
6. Backfill outside the entrance should be covered with either coarse rip-rap to reduce erosion, or a native till, to permit vegetation.

Not to scale

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-02	Draft for review	A	KAB	--

Alexco Environmental Group

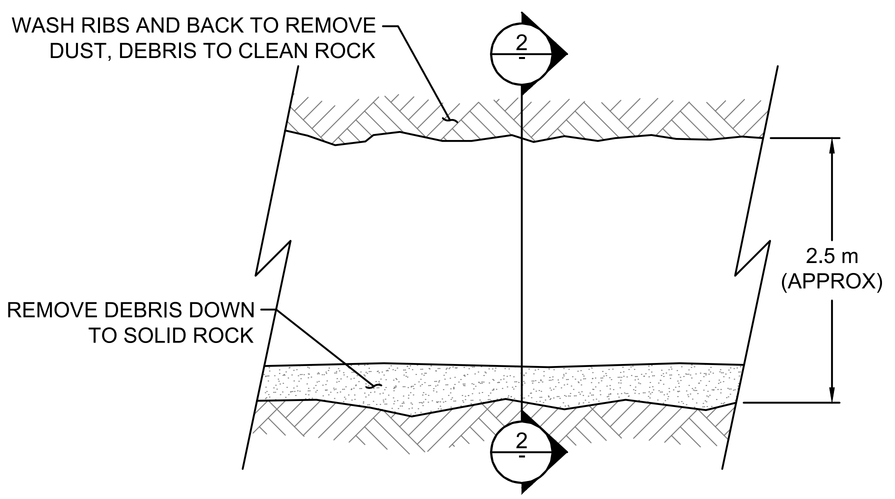
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-S-0301

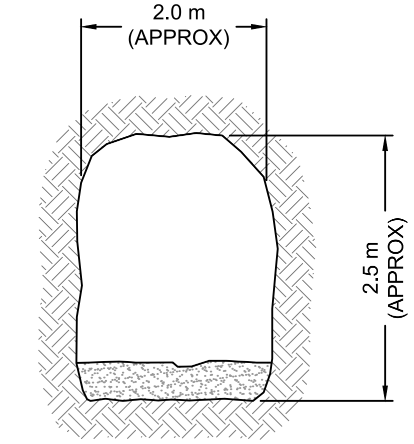
Portal Closure
Typical Rock Pile Closure Design

REVISION: A	2018-01-02	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

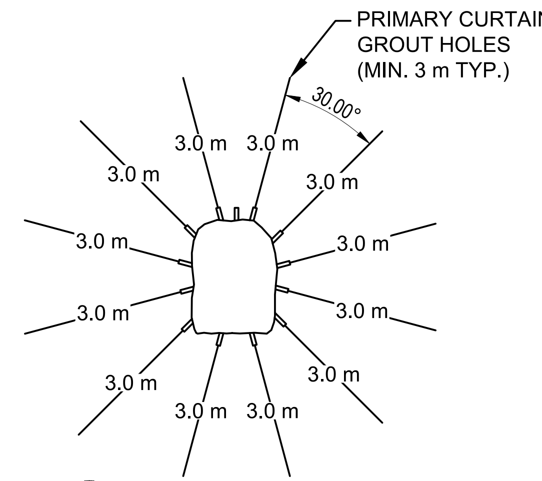
D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\0-General\AKHM-13-01-S-0301-RockPilePortalClosure.dwg (last edited by: KBoldt; 2018/02/15 - 2:15 PM



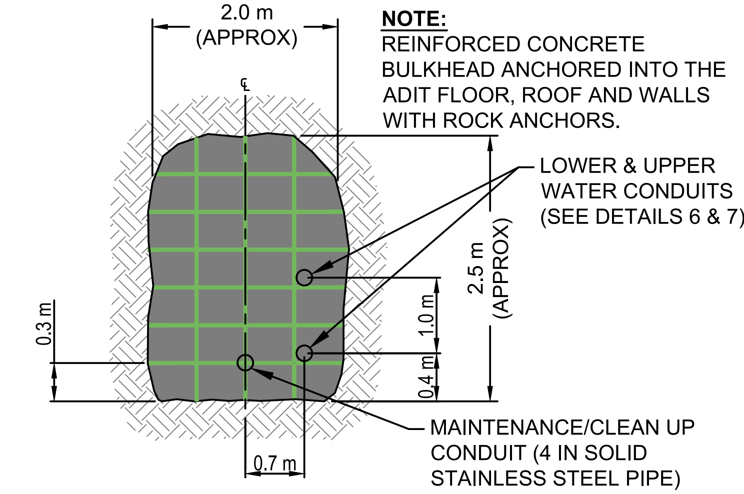
1 - PREPARE PLUG LOCATION - LONGITUDINAL SECTION VIEW
NOT TO SCALE



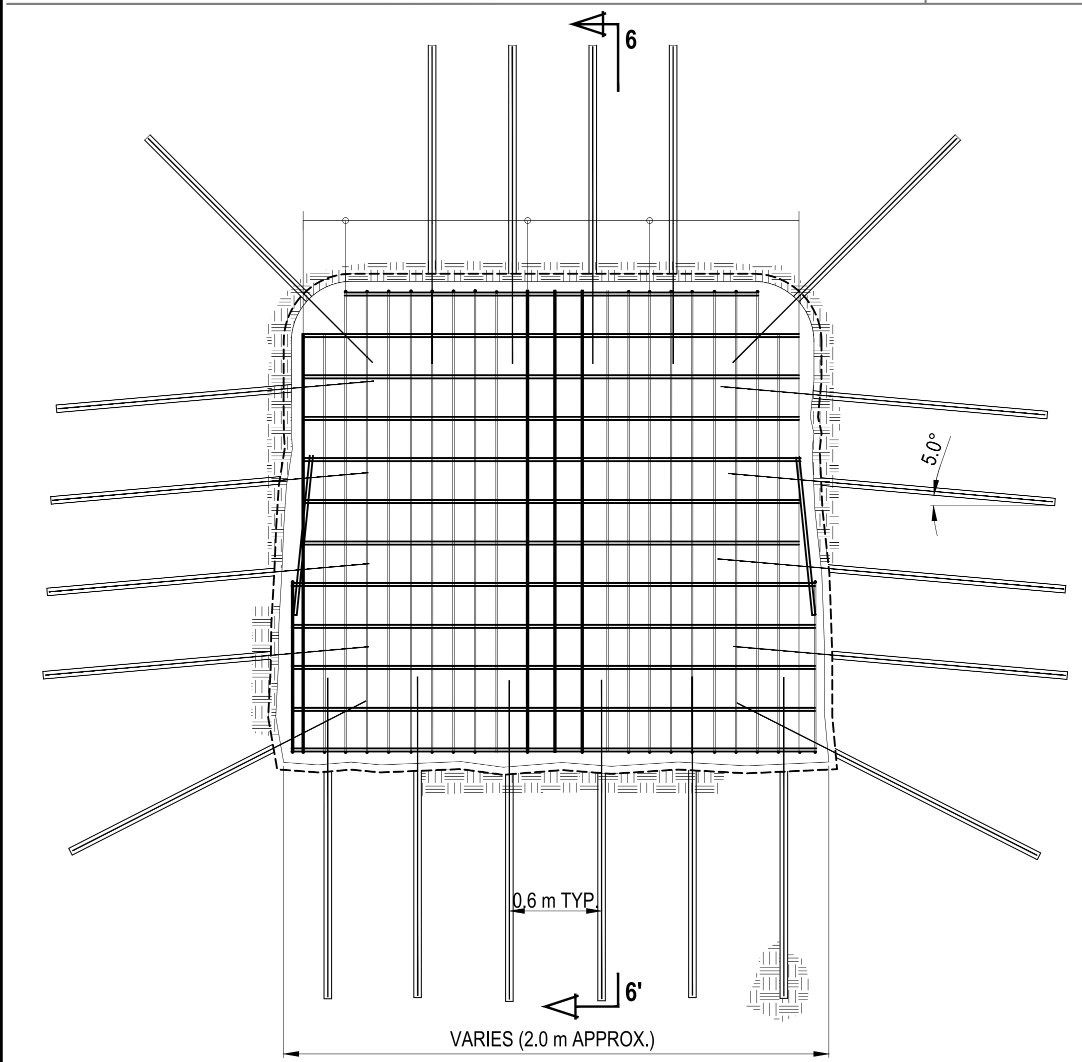
2 - ADIT CROSS SECTION
NOT TO SCALE



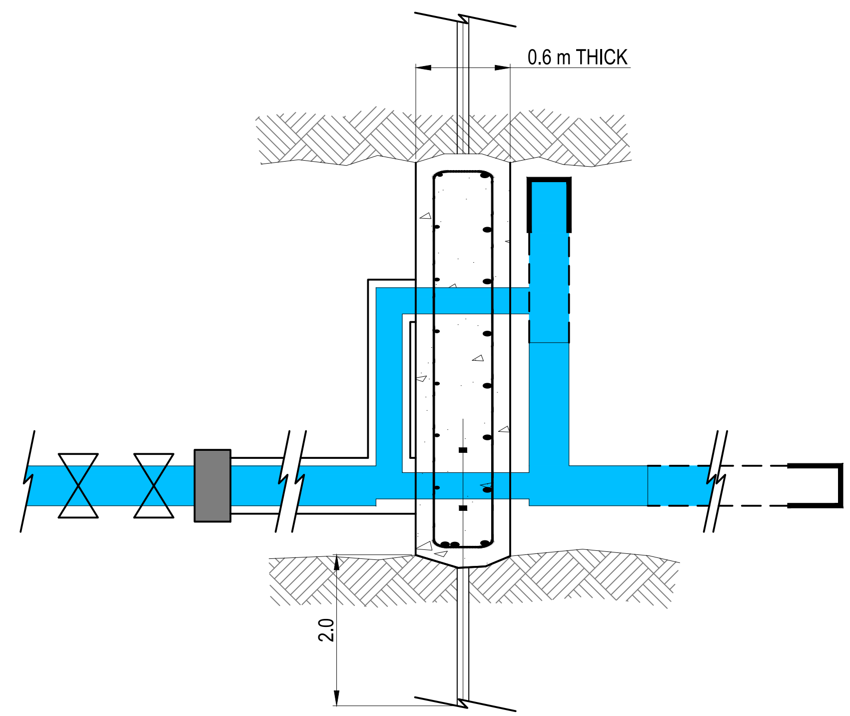
3 - PRESSURE GROUTING
NOT TO SCALE



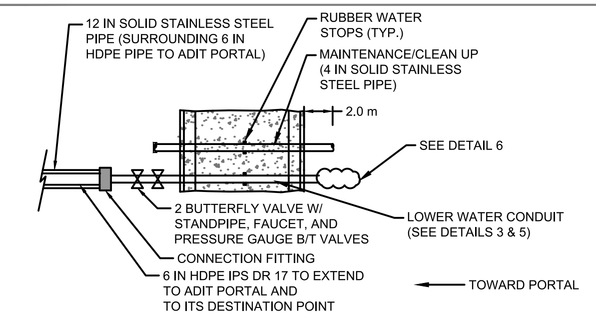
4 - BULKHEAD SITE - TRANSVERSAL SECTION VIEW
NOT TO SCALE



5 - BULKHEAD DOWNSTRAM ELEVATION
NOT TO SCALE



6 - BULKHEAD SITE - LONGITUDINAL SECTION VIEW
NOT TO SCALE



7 - BULKHEAD SITE - PLAN VIEW
NOT TO SCALE

NOTES:

1. Bulkhead designed in accordance with CSA Standard A23.3-04 Design of Concrete Structures.
2. Bulkhead designed to retain 6.0 m of hydrostatic head of fresh water factored by 1.5 for Ultimate Strength Design
3. Consequence of failure is high.
4. Concrete shall have a minimum 40 MPa compressive strength at 28 days.
5. Steel reinforcement shall have a minimum yield strength of 415 MPa (60ksi) and be weldable type.
6. Site preparation shall remove loose rock and weathered rock from the walls, roof and invert of the adit from the footprint of the concrete bulkhead to a depth where the bulkhead will be in contact with and keyed into competent rock. This work shall be performed by hand using suitable scaling bars and may include scaling by compressed air in a controlled manner, or by means of hydraulic splitters. Competency of final rock face shall be reviewed by a professional engineer or geologist. Final rock face shall be fresh, unaltered (not faulty), and with a minimum intact compressive strength of 40 MPa.
7. Rock Anchors shall be hot dip galvanized 32 mm (1 1/4 inch) Ø Williams R-61-6R75 all thread (or equivalent).The boreholes shall be 63 mm Ø to a depth of 2000 mm below the surface on the walls, roof and floor. The wall anchors shall be drilled at 5 degrees from the horizontal, the floor and roof anchors shall be installed vertical.
8. The mine owner/operator shall seal any leaks immediately upon detection with approved quick seal grout on the downstream side or de-water and seal upstream.
9. Grout – Cemented Grout Bolts
   - Cement grout shall be used for all rock anchors installed as part of the water retention bulkhead.
   - Cement grouting for rock anchors shall be a non-shrink, non-sanded grout mixed with the proportion 0.4 water:cement by weight, capable of achieving a minimum compressive strength of 28 MPa at 7 days and 40 MPa at 28 days when tested in accordance with CAN/CSA A23.2-1B.
   - Equipment for mixing and pumping grout shall be capable of satisfactorily mixing and agitating grout and pumping it into the holes at the required water cement ratio.
10. Installation – Cemented Grout Bolts
    - Completely clean holes of all drill cuttings, sludge, debris and water using clean water and air.
    - Grout shall be placed in the hole from the bottom up using a grout tube extending to the lower end of the hole.
    - Rock bolts shall be fully encapsulated in grout to the drill hole collar.
    - If seepage of grout into cracks in the rock prevents the hole from being filled with grout, the hole shall be sealed with an approved grout material, and then redrilled. This sequence shall be repeated until the hole is sealed.
11. Grout and Concrete Testing
    - The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of grout and concrete to establish that minimum grout strength required for anchors and minimum concrete strength for bulkhead has been obtained.
    - The testing agent shall (i) Review and confirm that the grout mix submitted by the Contractor will provide the properties specified herein, (ii) take sample of grout from each continuous mix (Contractor can cast the grout samples under the directions of the testing agency) and (iii) test grout samples to determine compressive strength. The contractor shall provide a minimum of 48 hours notice to the testing agency.

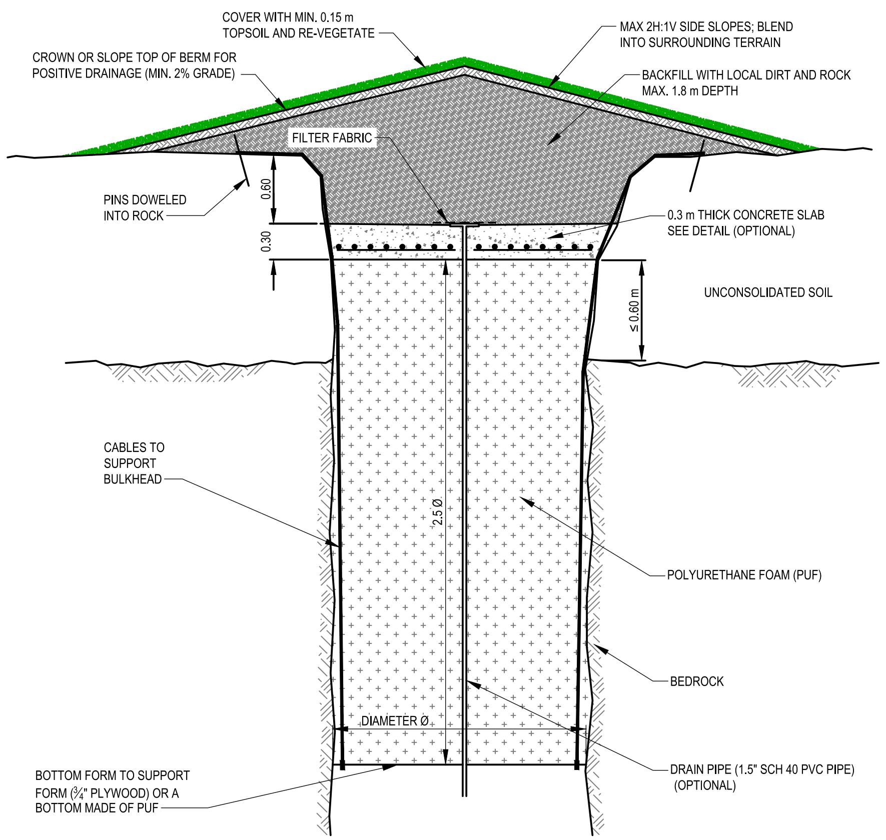
DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	TT	--

ALEXCO ENVIRONMENTAL GROUP
AKHM
TETRA TECH EBA

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No:
AKHM-13-01-S-0302-Bulkhead

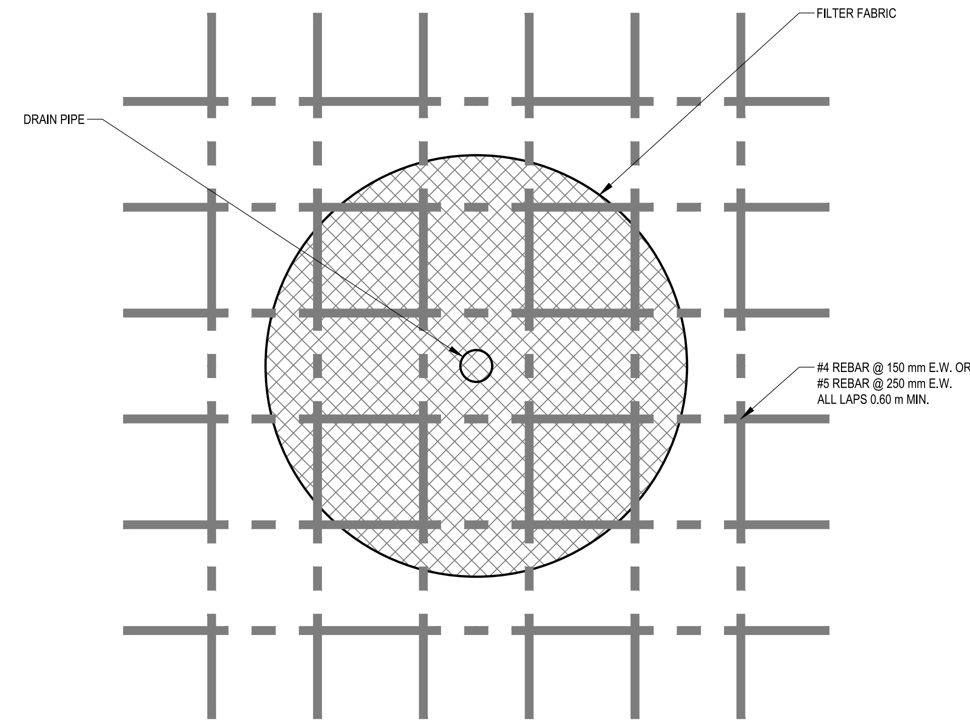
Portal Closure
Typical Concrete Bulkhead Design

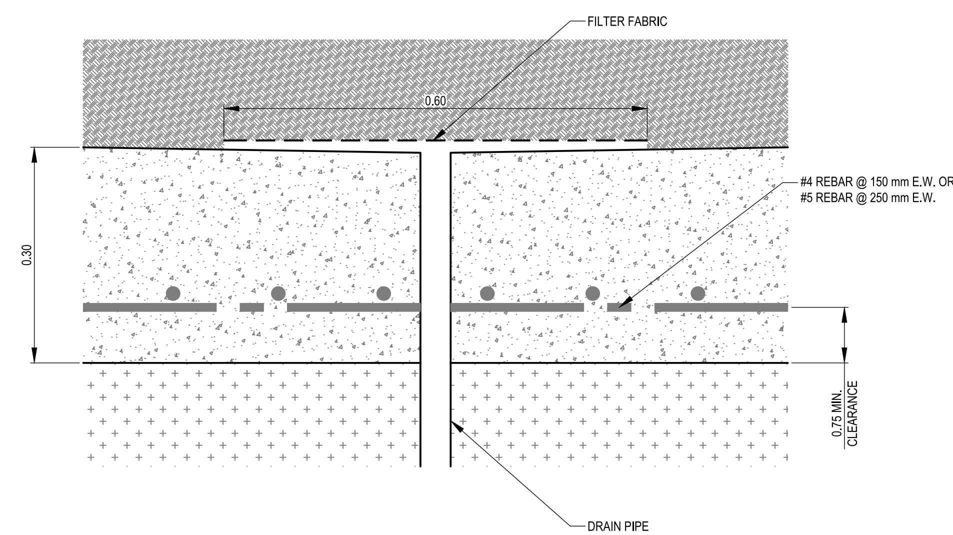
REVISION: A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW



SHAFT PUF WITH CONCRETE SLAB CLOSURE

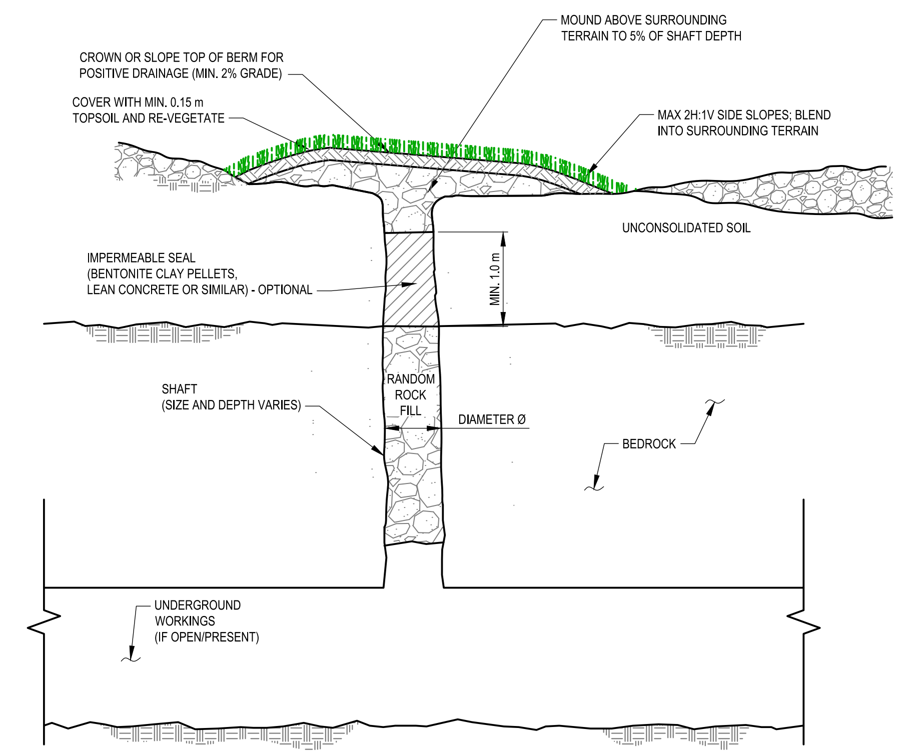
NOT TO SCALE





CONCRETE SLAB DETAILS

NOT TO SCALE



SHAFT BACKFILL (DRY SEAL) CLOSURE

NOT TO SCALE

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Lower the bottom form into the shaft to the final depth of the Polyurethane foam (PUF)
3. Install drain pipe (1.5 " SC 40 PVC) extending from below the bottom form to planned top of concrete cap.
4. Place seals into the cracks between the edges of the bottom form to prevent foam from falling down the shaft.
5. Pour the mixed PUF foam onto the bottom form to form the plug.
6. Construct the 0.3 m concrete slab. Concrete slab sloped outwards to drain (2%)
7. Back fill on top of the concrete slab with local dirt and rock.
8. Concrete shall have a minimum 20 MPa compressive strength at 28 days
9. The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of concrete to establish that minimum strength required for concrete slab has been obtained.

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Quantities will vary with shaft depth, connection to underground workings, and other conditions.
3. Mobile equipment must never operate on ground that shows signs of subsidence without taking adequate precautions.
4. Remove as practical, if present, 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.
5. Existing steel pipe, concrete rubble (if present) should be removed or incorporated into backfill as directed by engineer.
6. Random rock fill must be:
   a. Non-acid generating rock fill
   b. Sized to contain no rocks greater than ¼ the diameter of the shaft.
7. Every effort should be made to keep all debris other than rock fill from going underground.

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2018-02-05	Draft for review	A	TT	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

TETRA TECH EBA

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No:
AKHM-13-01-S-0303-ShaftCap

Shaft/Raise to Surface Typical Concrete Cap Design

REVISION: A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW

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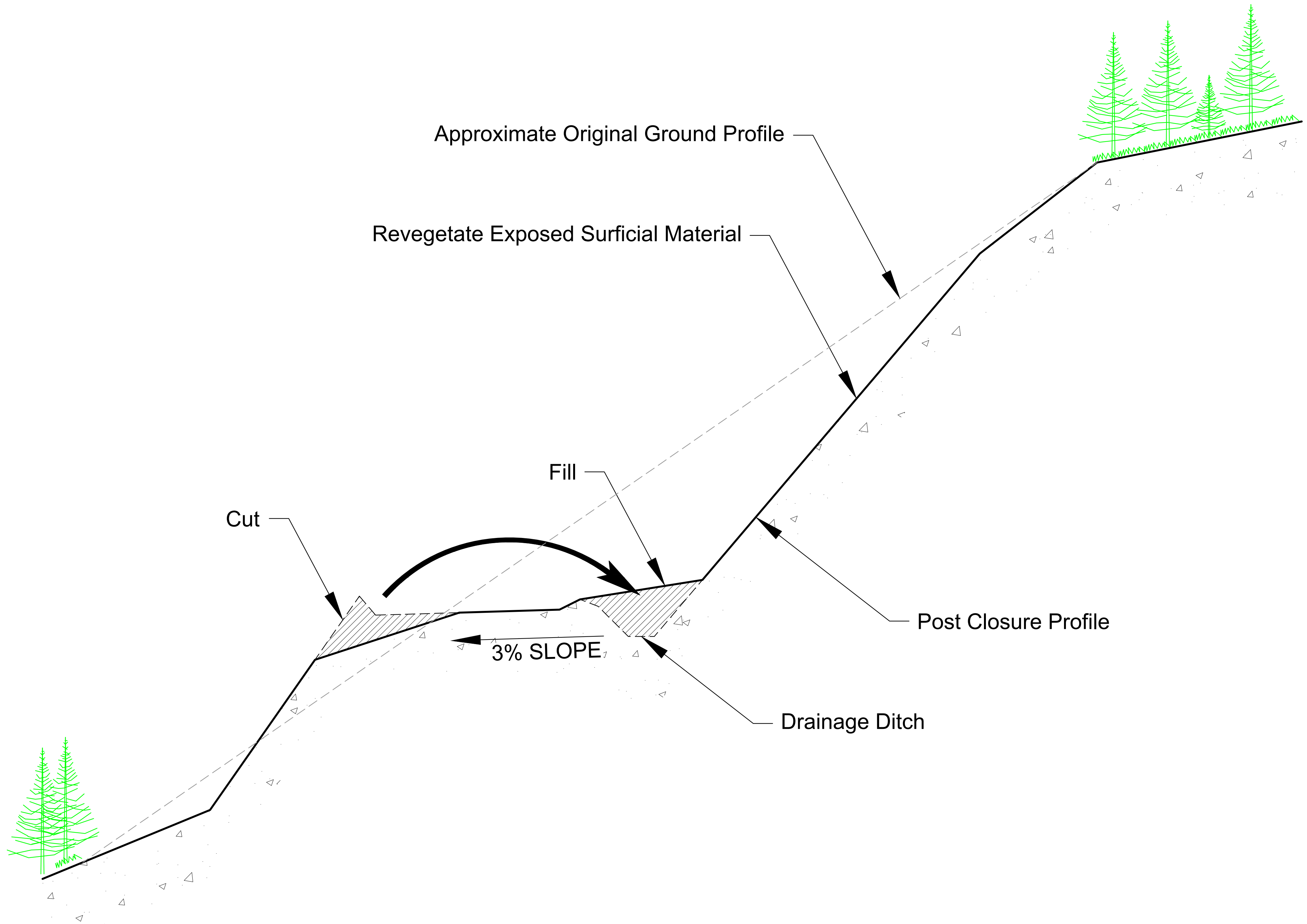
Notes:

1. Pull back slope and fill ditch.
2. Remove culverts.
3. Install erosion breaks on steep slopes as necessary.
4. Scarify road surface and prepare for natural revegetation.



DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-29	Draft for review	A	KAB	--

Sand & Gravel

Existing Vegetation

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-0301

Haul Road and Site Road Reclamation
Typical Section

REVISION: A	2018-01-29	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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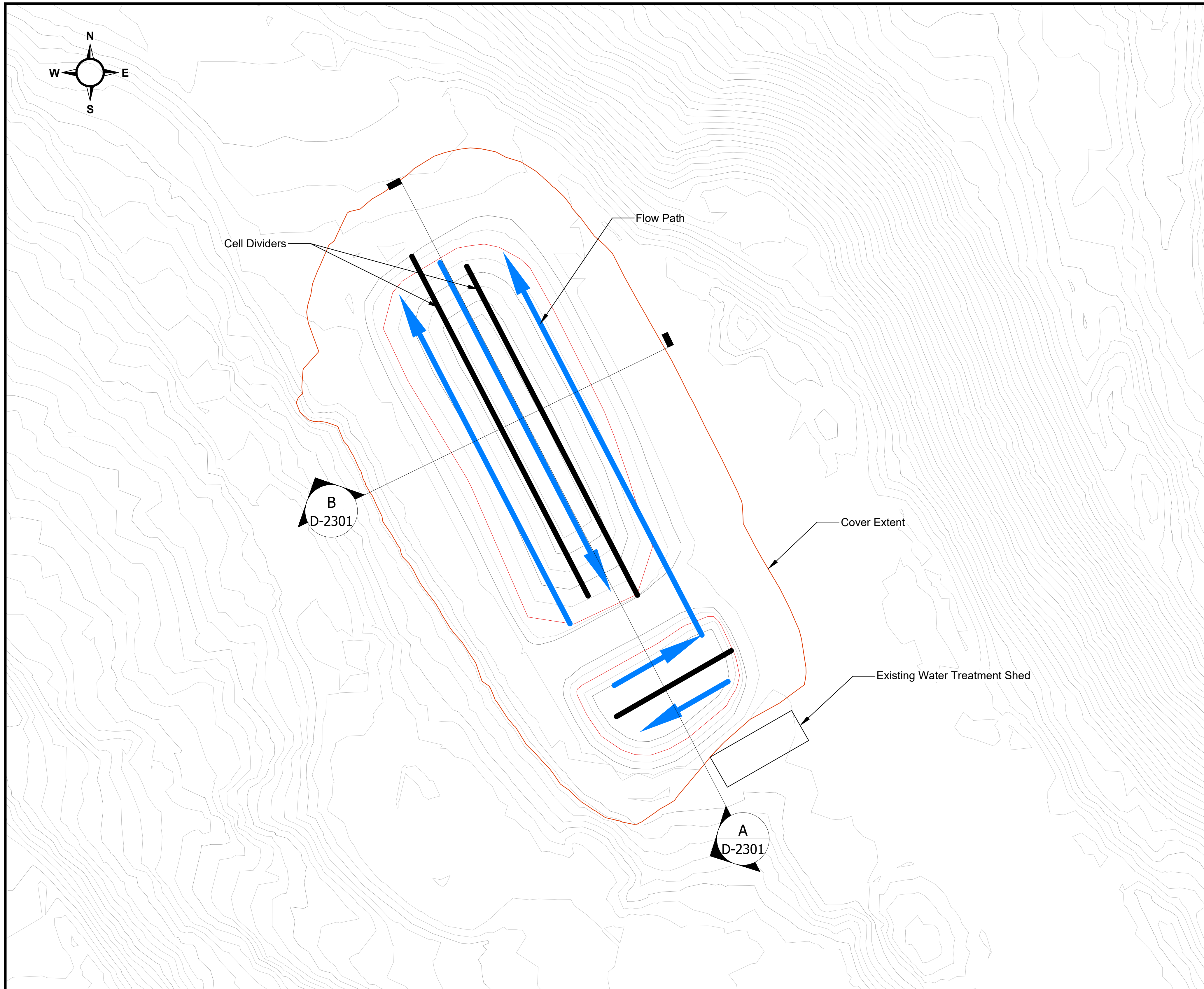

Notes:

Conceptual Design Assumptions:

1. Divide Pond 1 in to two zones with an HDPE liner divider. Two cells of approximately 6 m x 15 m
2. Divide Pond 2 in to three zones with HDPE liner dividers. Three cells of approximately 5.3 m x 42 m
3. Total Volume = 2,800 m^3
4. Porosity = 40%
5. Flowrate = 4 lps
6. Retention Time = (2800 m^3 x 0.40)/4 lps = 3.1 days

Material Quantities:

Placer Gravel Rock Substrate:	2,800 m^3
Geotextile Barrier:	1,410 m^2
Soil Cover:	4,010 m^3

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2018-02-01	Draft for review	A	KAB	--

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-D-2102

Bellekeno 625
Bioreactor Design

REVISION: A	2018-02-01	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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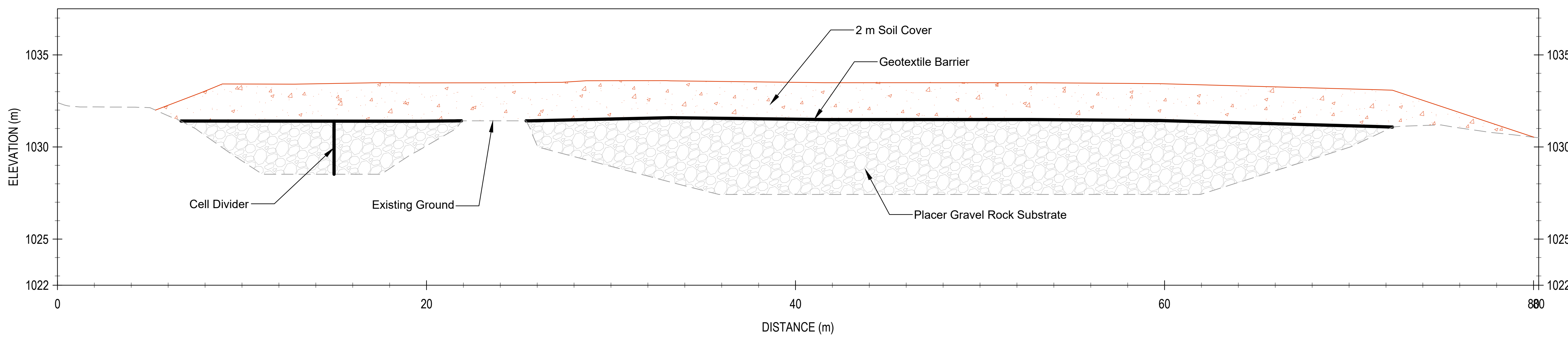
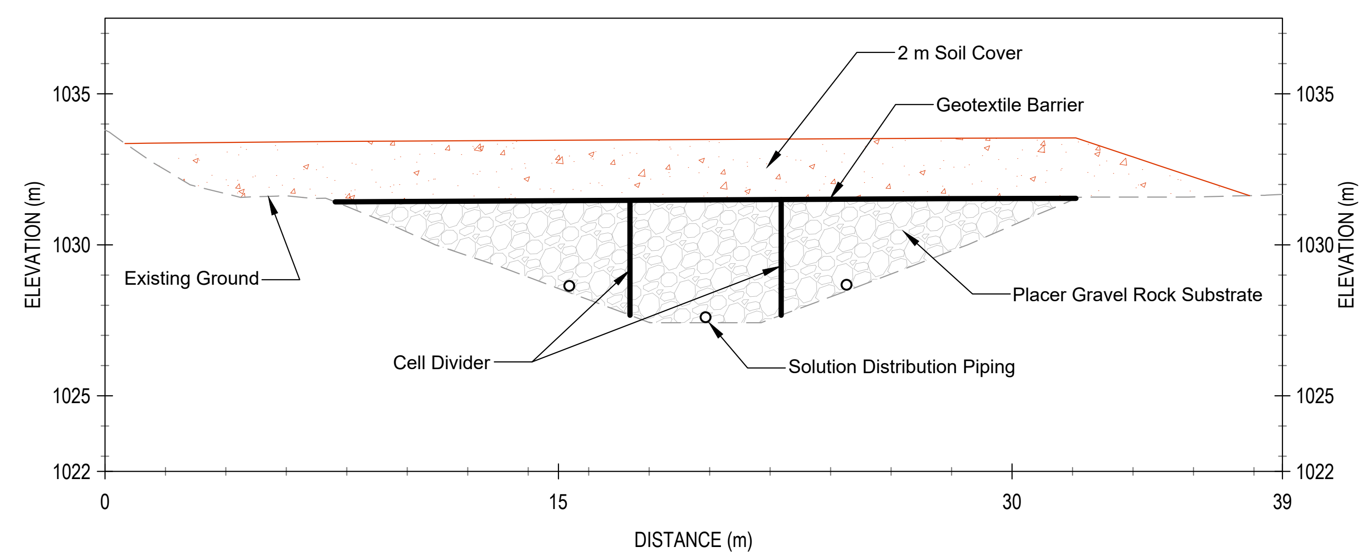


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-01	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

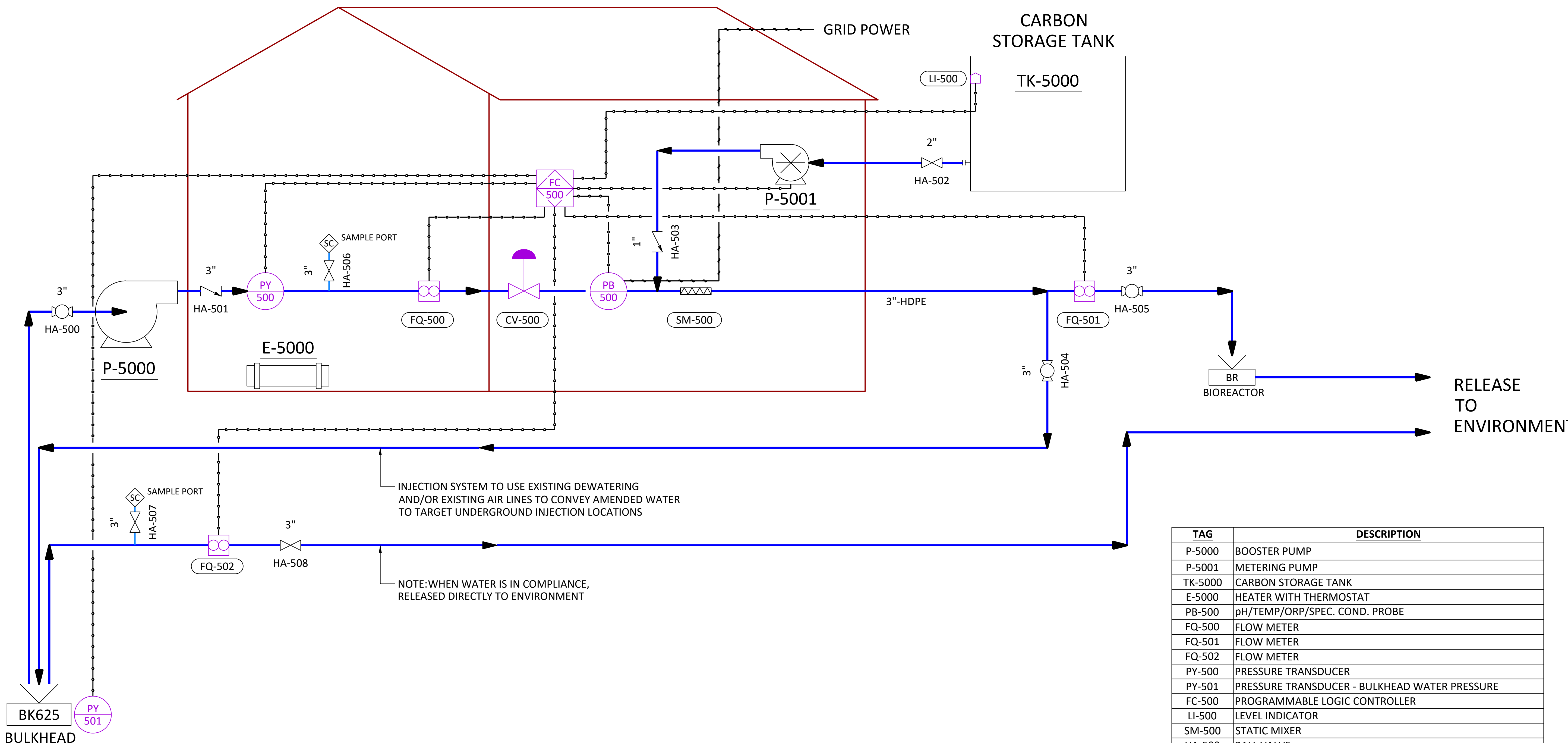
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-D-2301

Bellekeno 625
Bioreactor Design Sections

REVISION: A	2018-02-01	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\2-Bellekeno\D-Process\AKHM-13-01-D-2102-BK625Bioreactor.dwg (last edited by: KBoldt; 2018/07/19 - 12:21 PM



TAG	DESCRIPTION
P-5000	BOOSTER PUMP
P-5001	METERING PUMP
TK-5000	CARBON STORAGE TANK
E-5000	HEATER WITH THERMOSTAT
PB-500	pH/TEMP/ORP/SPEC. COND. PROBE
FQ-500	FLOW METER
FQ-501	FLOW METER
FQ-502	FLOW METER
PY-500	PRESSURE TRANSDUCER
PY-501	PRESSURE TRANSDUCER - BULKHEAD WATER PRESSURE
FC-500	PROGRAMMABLE LOGIC CONTROLLER
LI-500	LEVEL INDICATOR
SM-500	STATIC MIXER
HA-500	BALL VALVE
HA-501	CHECK VALVE
HA-502	ISOLATION VALVE
HA-503	CHECK VALVE
HA-504	BALL VALVE
HA-505	BALL VALVE
HA-506	GATE VALVE
HA-507	GATE VALVE
HA-508	GATE VALVE
CV-500	THROTTLING VALVE

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	KAB	--

NOTES:

1) Treatment will be performed in treatment campaigns periodically as necessary to maintain low redox potential, and low zinc.
2) A centrifugal booster pump will be installed near the bulkhead, allowing for water to be pumped from the mine, amended with carbon, and injected back underground
3) A throttling valve will control the pump speed.
4) System's flow rate and pressure will be monitored, with carbon injection proportional to flow rate. Monitoring information of all adit discharge will be continuously monitored with datalogging field parameters: specific conductivity, temperature, ORP, pH, and pressure behind the bulkhead.
5) When in compliance, water will be released to the environment.

ALEXCO ENVIRONMENTAL GROUP

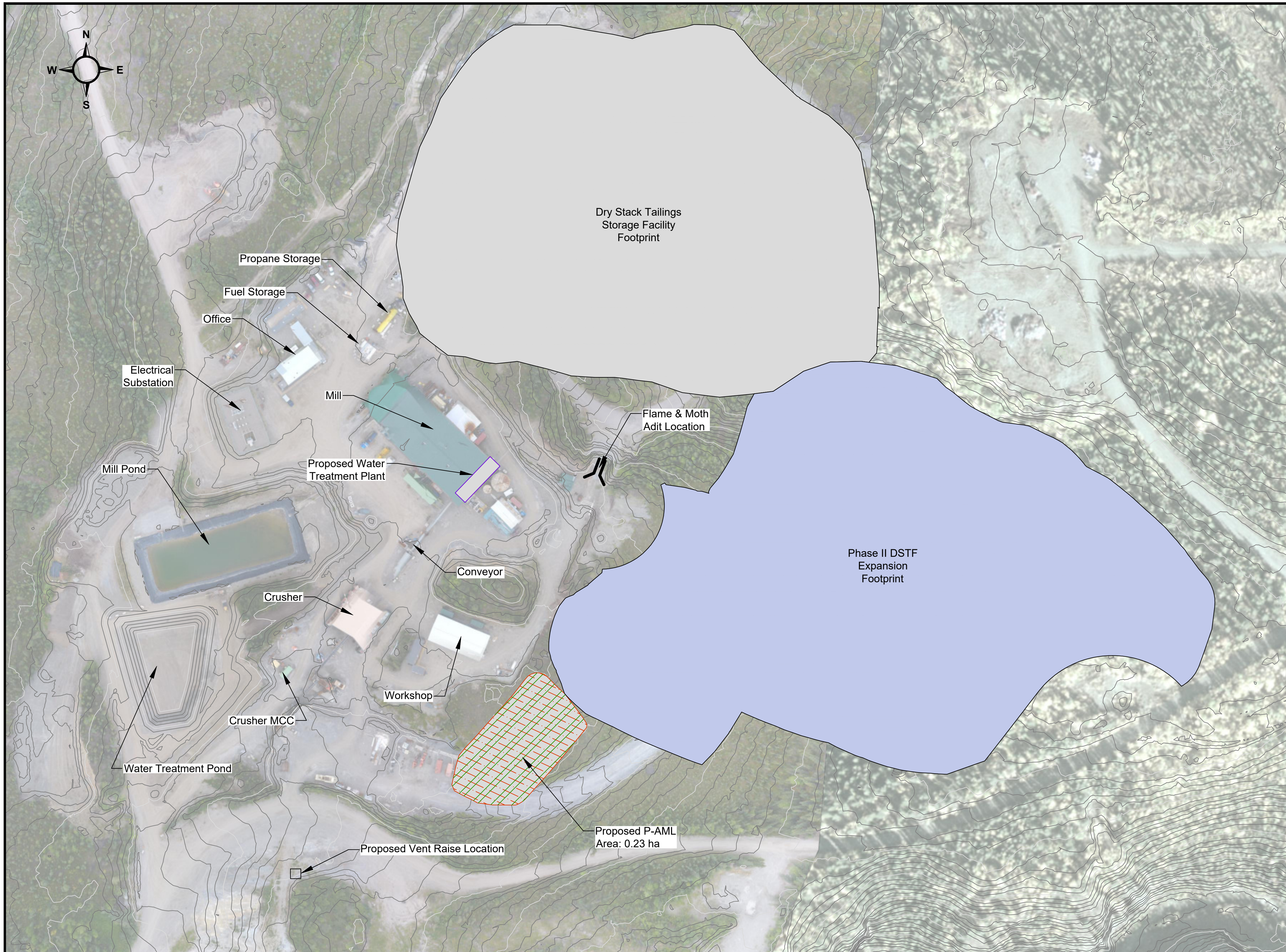
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No.: AKHM-13-01-D2601

Bellekeno Closure Treatment System

Piping & Instrumentation Diagram

REVISION A	2018-02-05	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: EJL	REVIEWED BY: JMH



Notes:

1. Surface buildings associated with Flame and Moth are portable structures that will be removed and transported offsite for salvage.
2. P-AML rock stored within the temporary facility will be moved back underground as backfill.
3. Rock pile portal closure to be installed. See drawing AKHM-13-01-C-S0301.
4. Surface areas to be regraded as required for positive drainage, and scarified to promote revegetation
5. Further surface amendments detailed on drawings AKHM-13-01-C-6401 and AKHM-13-01-B6101.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
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Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-1401

Flame & Moth
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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Notes:

1. Remaining P-AML waste rock on surface, stored in the lined storage facility will be backfilled to underground.
2. The WRSF liner will be removed and disposed of in a waste facility.
3. The WRSF will be regraded to promote positive drainage and the area will be covered and revegetated.
4. The Bellekeno East portal will receive a rock pile closure. See drawing AKHM-13-01-S-0301.
5. The mine will be allowed to flood and will receive *in situ* mine pool treatment. Water will exit via the Bellekeno 625 adit. See drawing AKHM-13-01-C-2402
6. The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.
7. All the surface buildings at Bellekeno East are portable structures will be removed and transported offsite for salvage at closure.
8. Sediment ponds at Bellekeno East for the development of the decline will be progressively reclaimed prior to mine closure.
9. Contaminated soil will be removed and treated in a land treatment facility.
10. The Bellekeno East portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
11. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	7,400 m^2
Area of scarification and revegetation:	20,400 m^2

Scale: 1:3000
0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2401

Bellekeno East
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\2-Bellekeno\C-Civil\AKHM-13-01-C-2401-BKSiteLayout.dwg (last edited by: KBoldt; 2018/08/03 - 10:29 AM

Notes:

1. The Bellekeno 625 adit will be sealed with a hydraulic bulkhead. See drawing AKHM-13-01-S-0302.
2. The mine will be allowed to flood and will receive *in situ* mine pool treatment.
3. Current water treatment ponds at the Bellekeno 625 adit will be converted into a bioreactor passive treatment system to treat mine water exiting the bulkhead. See drawing AKHM-13-01-D-2101.
4. The current water treatment facility will be shut down and decommissioned. The treatment buildings will be conveted into treatment sheds for *in situ* treatment.
5. The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.
6. A WRDA was proposed to be constructed along the northeast flank of Sourdough Hill, but is not currently planned for construction. If constructed, at closure, the slopes will be regraded to 3H:1V. Surfaces will be scarified and revegetated.
7. The existing Bellekeno 625 WRDA will have surface equipment removed, the crests pulled back with an excavator, and flat surfaces will be scarified and revegetated.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	2,300 m^2
Area of scarification and revegetation:	12,900 m^2

Scale: 1:1250

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

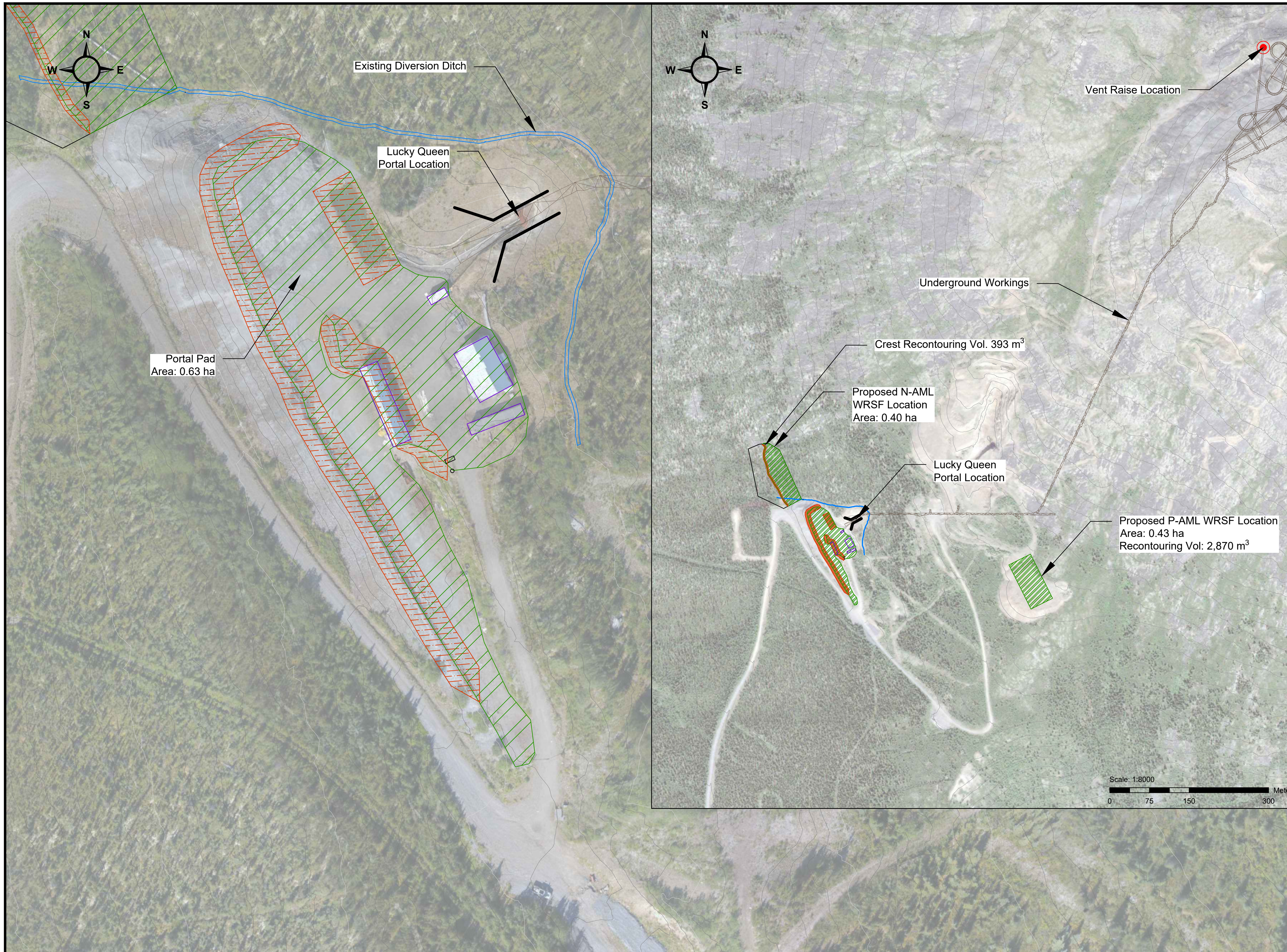
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2402

Bellekeno 625 Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\2-Bellekeno\C-Civil\AKHM-13-01-C-2402-BK625SiteLayout.dwg (last edited by: KBoldt; 2018/02/15 - 4:55 PM



Notes:

1. Any remaining P-AML waste rock on surface will be backfilled to underground.
2. A concrete adit bulkhead will be constructed to close the portal. See drawing AKHM-13-01-S-0302.
3. If the P-AML WRSF is declared as part of the Production Unit Area, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope. The WRSF will receive a 0.5 m depth cover consisting of low permeability borrow material, as well as growth medium in the top portion of the cover which will be seeded for revegetation.
4. If a N-AML WRSF is constructed, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope.
5. Shop and other buildings and infrastructure will be removed for salvage or reuse.
6. Contaminated soil will be removed and treated in a land treatment facility.
7. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
9. The Lucky Queen vent raise will be capped with an engineered concrete cap. See drawing AKHM-13-01-S-0303.

Quatities:

Area of recontouring:	2,910 m^2
Area of scarification and revegetation:	14,600 m^2

Satelite imagery for inset obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-12.

Scale: 1:1250

Meters

0 10 20 40

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-3401

Lucky Queen Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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Notes:

1. A rock pile cover will be constructed to close the portal opening. See Drawing AKHM-13-01-S-0301.
2. The constructed P-AML WRSF contains no P-AML rock. Closure will include the removal of the liner, and recontouring of the containment berms, followed by scarification of the surface, and seeding.
3. If a N-AML WRDA is constructed, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope.
4. Shop and other buildings and infrastructure will be removed for salvage or reuse.
5. Contaminated soil will be removed and treated in a land treatment facility.
6. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
7. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
8. The Onek vent raise will be capped with an engineered concrete cap. See drawing AKHM-13-01-S-0303.

Quantities:

Area of recontouring:	5,600 m^2
Area of scarification and revegetation:	8,300 m^2

Scale: 1:3000

0 25 50 100 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-4401

Onek
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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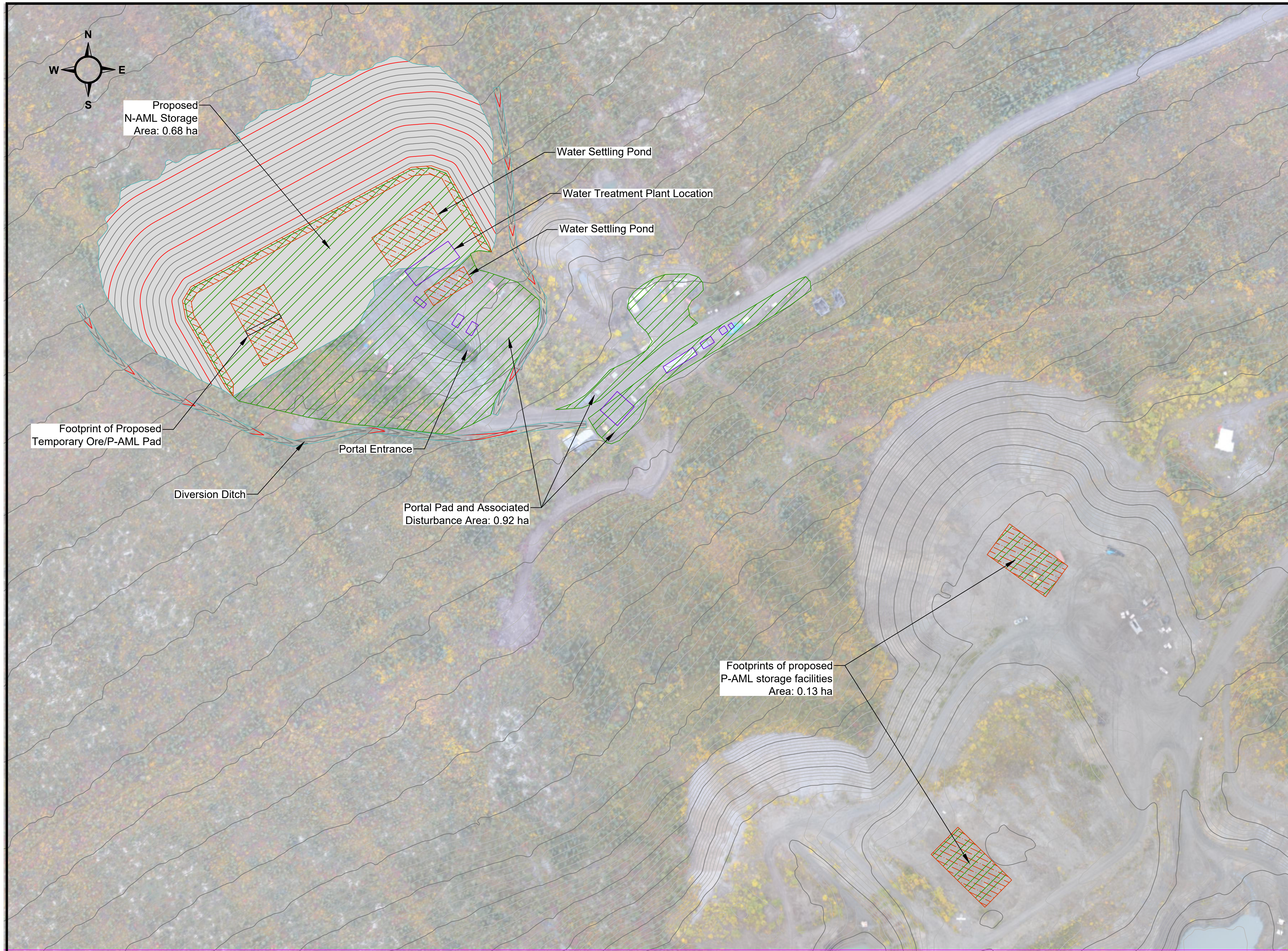

Notes:

1. A rock pile cover will be constructed to close the portal opening. See Drawing AKHM-13-01-S-0301.
2. P-AML waste rock contained in the P-AML WRSF will be relocated to underground.
3. The liner of the P-AML WRSF will be removed, and the containment berms will be recontoured, followed by scarification of the surface, and seeding.
4. The crest of the N-AML WRDA will be pulled back. Flat surfaces will be scarified and revegetated.
5. Shop and other buildings and infrastructure will be removed for salvage or reuse.
6. Contaminated soil will be removed and treated in a land treatment facility.
7. The surrounding portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
6. The vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.

Quantities:

Total area of recontouring:	3,475 m^2
Total area of scarification and revegetation:	17,300 m^2

Scale: 1:2000

0 15 30 60 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2017-12-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-5401

Bermingham Reclamation Measures

REVISION: A	2017-12-18	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: --

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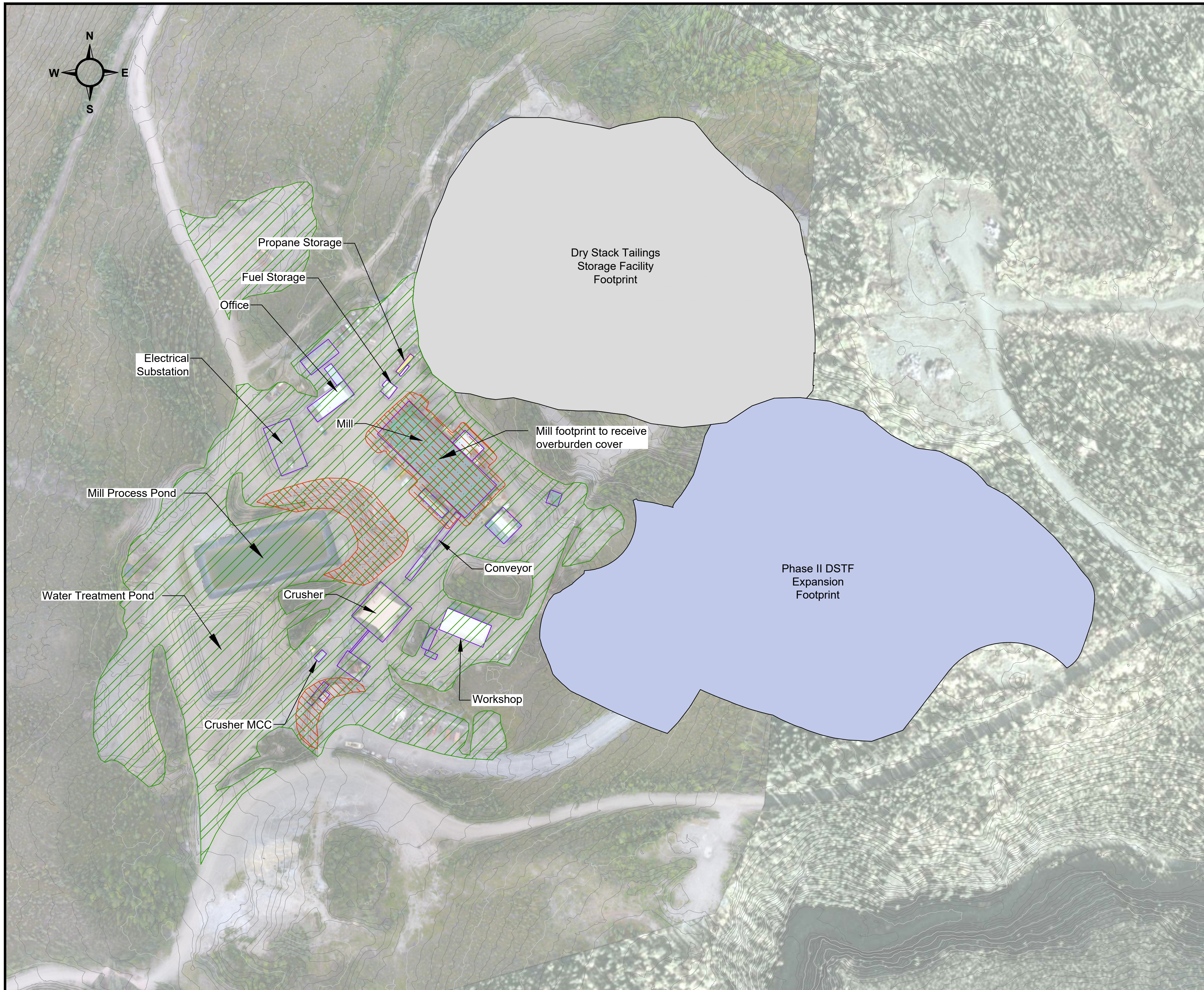

Notes:
1. Modular prefabricated trailer style buildings will be removed from site and salvaged.
2. Rigid steel frame buildings will be dismantled on site. The steel will be sold for salvage.
3. Concrete slabs and above grade footings and foundations will be broken up and covered with 1 m overburden cover, scarified, and revegetated.
4. Both the mill process pond and water treatment pond will have the liners removed. The slopes will be scarified and revegetated. The ponds will serve as a sedimentation ponds during closure until revegetation is stabilized.
5. Crusher equipment will be removed from site for salvage.
6. Sea-containers will be removed from site for salvage.
7. Any remaining fine ore will be excavated from the stockpile and milled.
8. The buried tunnel associated with the crushing plant and ore stockpile will be removed and salvaged.
9. Diesel storage tanks and propane tanks will be removed and returned to their suppliers.
10. Buried infrastructure will be left in ground and marked on a site plan to be submitted to regulatory authorities for future reference.
11. Surface piping will be decontaminated and removed for salvage or disposal.
12. Above ground electric cabling will be de-energized and removed for salvage or disposal.
13. Contaminated soil will be removed and treated in a land treatment facility.
14. The mill site will be recontoured and scarified to establish drainage and facilitate revegetation.
15. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	2,700 m^2
Area of scarification and revegetation:	47,900 m^2
Area to receive overburden cover:	3,150 m^2

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend
- Infrastructure to be removed
- Area to receive overburden cover
- Area to be scarified and revegetated

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-6401

Mill Site Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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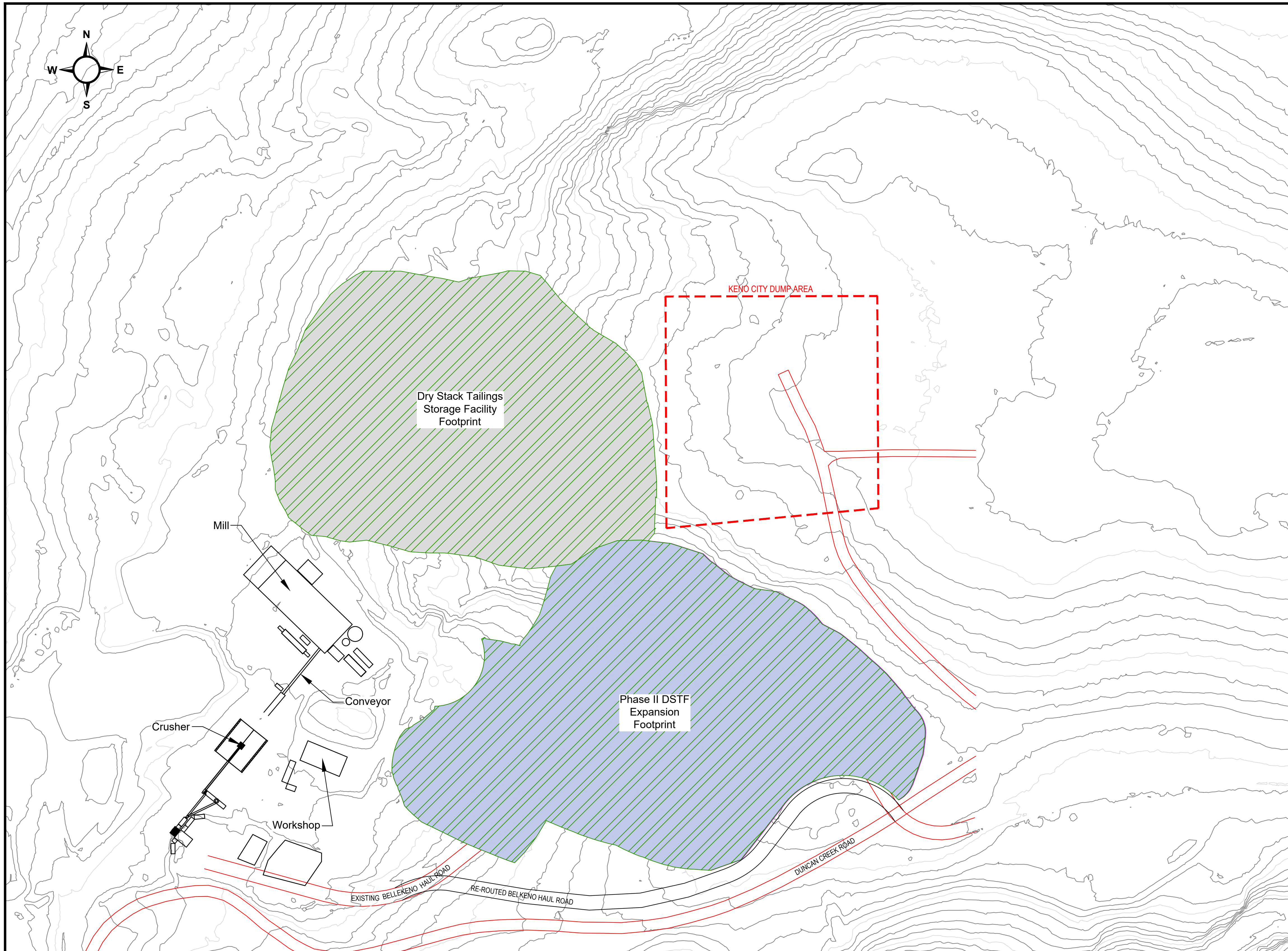
Notes:

1. The DSTF has been progressively reclaimed but recontouring to a 3H:1V slope, with the placement of a 0.25 - 0.5 m cover and seeding.
2. Upon closure, any remaining, unreclaimed areas of the DSTF will be recontoured, covered, and revegetated in the same manner.

Quantities:

Area of scarification and revegetation: 71,500 m^2



Scale: 1:2500

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-7401

Dry Stack Tailings Facility Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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Notes:
1. Sludge contained in the storage cells in the Valley Tailings will be transported either back underground in Bellekeno East decline, or placed in the DSTF.
2. The sludge storage cells are wholly contained within the area of the VTF which is to be excavated and relocated as part of the District Closure Plan. Therefore no other closure activities are planned within the Keno District Mine Operations RCP.

Scale: 1:5000

0 40 80 160 Meters

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2018-01-18	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-8401

KHSD Sludge Ponds
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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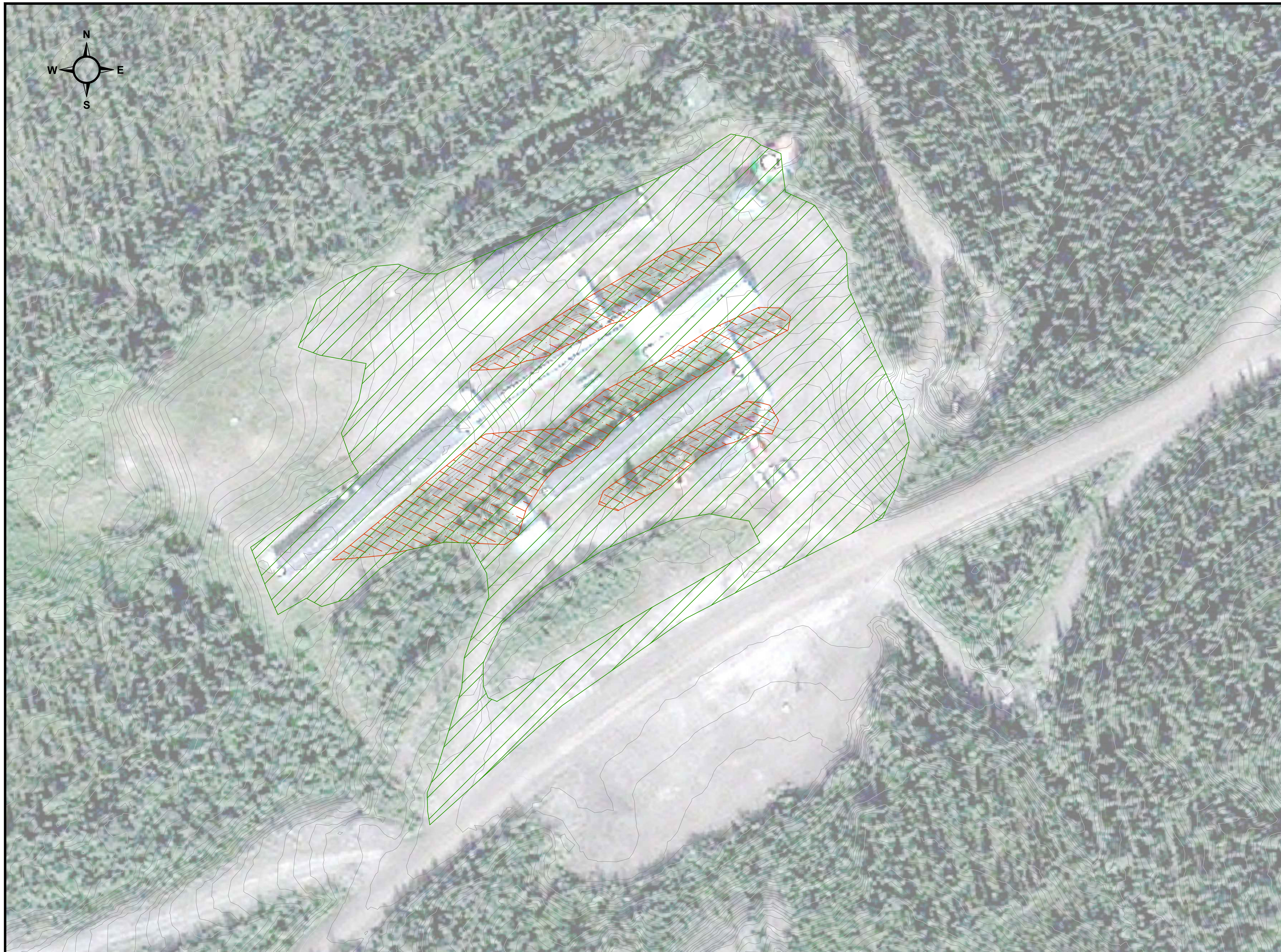

Notes:
1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:

Area of recontouring:	3,200 m^2
Area of scarification and revegetation:	18,000 m^2

Satellite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend
- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-9401

Flat Creek Camp Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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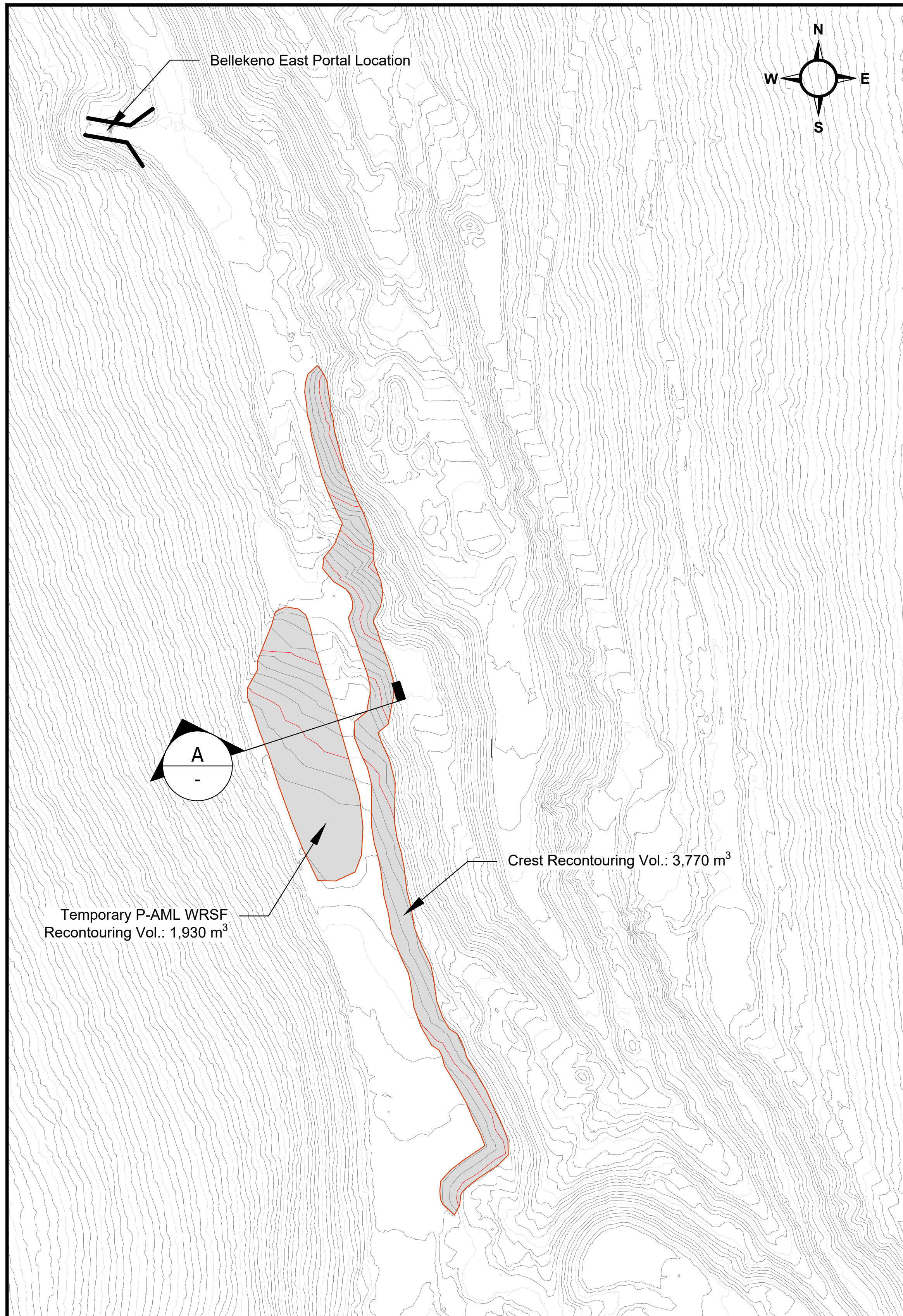
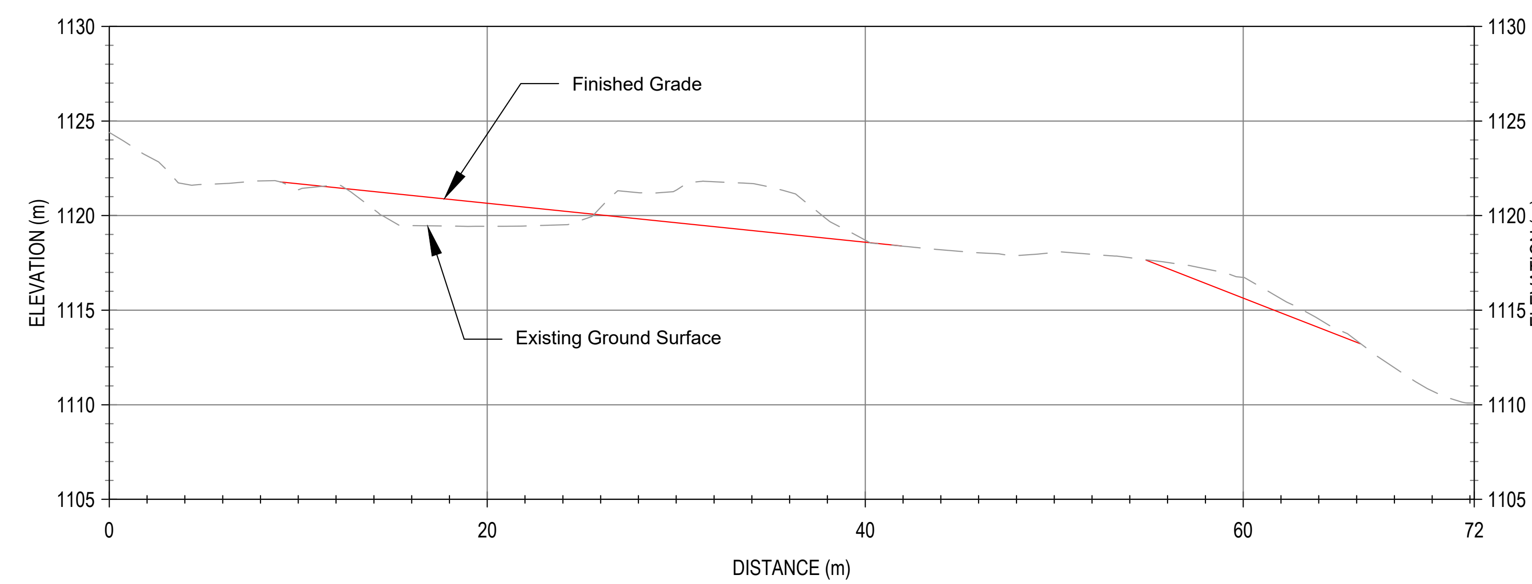


Notes:

1. Remaining P-AML waste rock on surface, stored in the lined storage facility will be backfilled to underground.
2. The WRSF liner will be removed and disposed of in a waste facility.
3. The WRSF will be regraded to promote positive drainage.
4. Portal area crests will be rolled back via excavator.

Quantities:

Volume of material to be recontoured: 5,700 m^3



Section A

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Scale: 1:2500

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-01	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-2101

Bellekeno East Grading
Plan and Cross Section

REVISION: A	2018-02-01	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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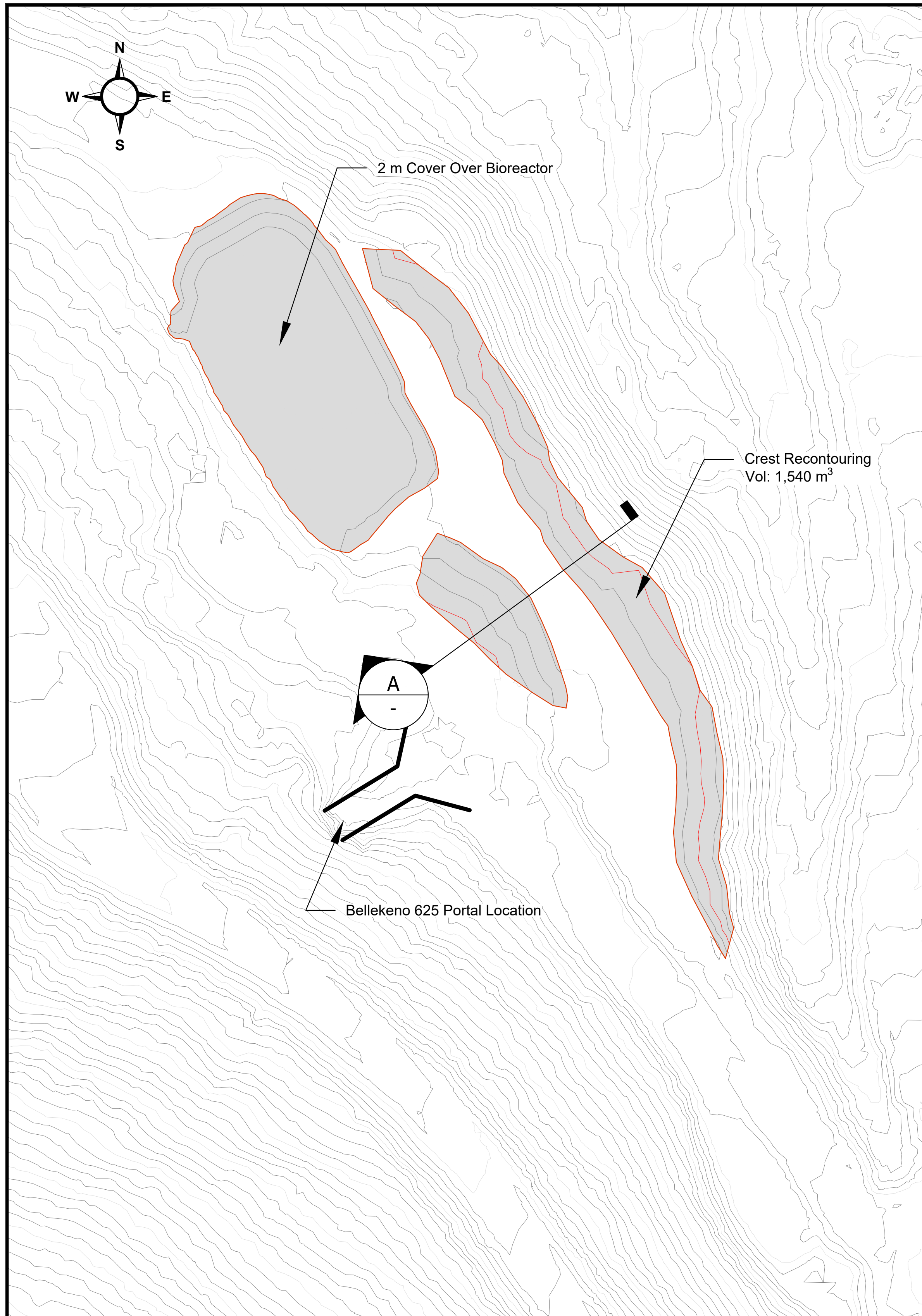
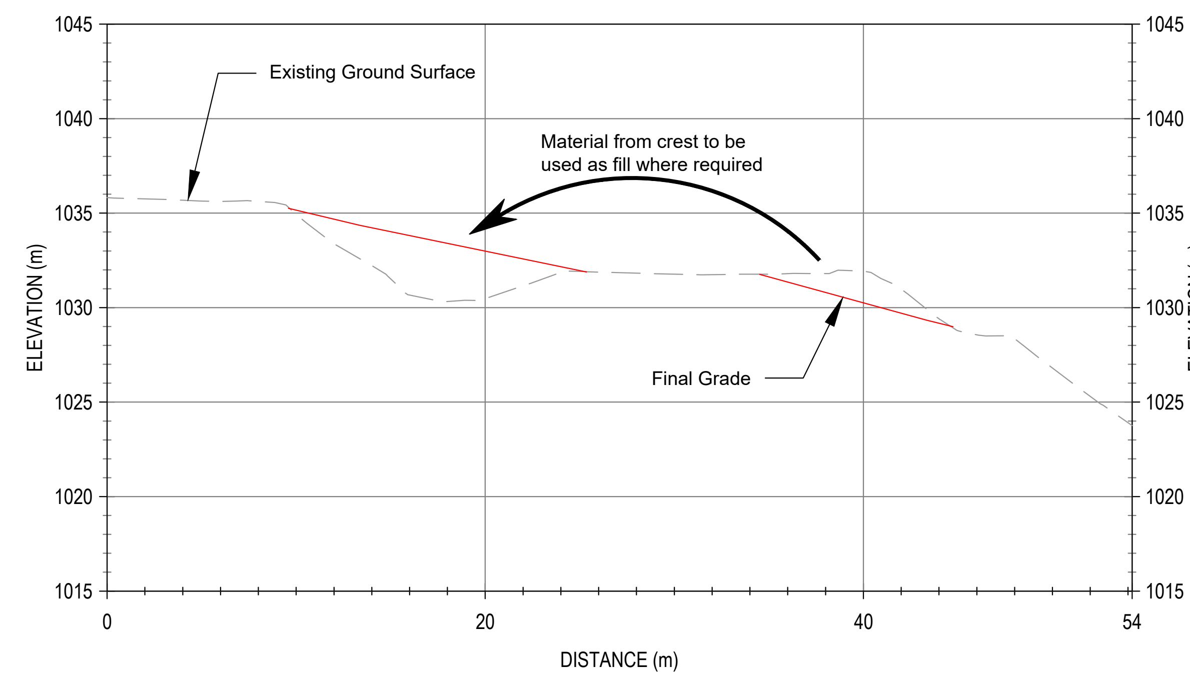


Notes:

1. Current water treatment ponds at the Bellekeno 625 adit will be converted into a bioreactor passive treatment system to treat mine water exiting the bulkhead. See drawing AKHM-13-01-D-2101.
2. A WRDA was proposed to be constructed along the northeast flank of Sourdough Hill, but is not currently planned for construction. If constructed, at closure, the slopes will be regraded to 3H:1V. Surfaces will be scarified and revegetated.
3. The existing Bellekeno 625 WRDA will have surface equipment removed, the crests pulled back with an excavator, and flat surfaces will be scarified and revegetated.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured*: 1,540 m^3
* Does not include cover material over bioreactor



Section A

Scale: 1:1250

0 12.5 25 50 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-02	Draft for review	A	KAB	--

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-2102

Bellekeno 625 Grading
Plan and Cross Section

REVISION: A	2018-02-02	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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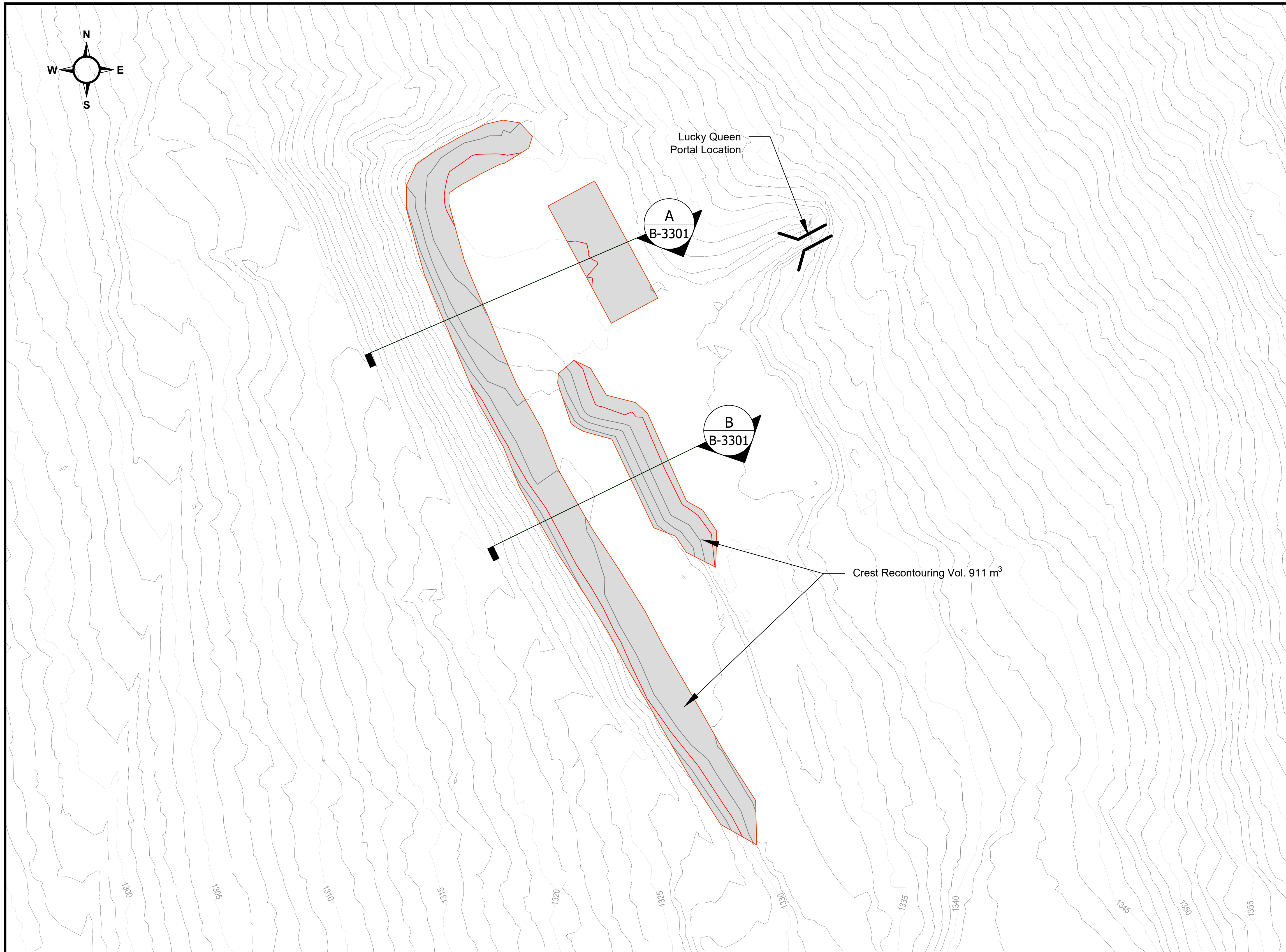

Notes:
1. Crest of the portal pad will be rolled back via excavator.
2. Existing settling pond will be recontoured to match surrounding grade.

Quatities:

Volume of material to be recontoured: 927 m^3

Satelite imagery for inset obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-12.

Scale: 1:1000

0 10 20 40 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-30	Draft for review	A	KAB	--

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3101

Lucky Queen Grading Plan

REVISION: A	2018-01-30	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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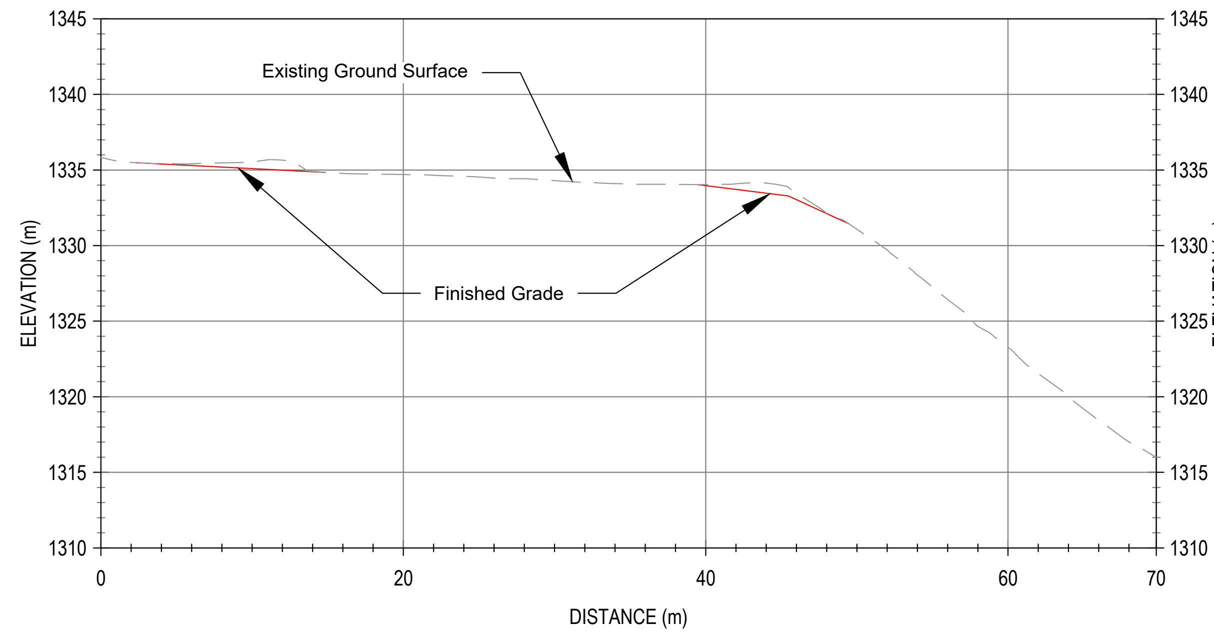
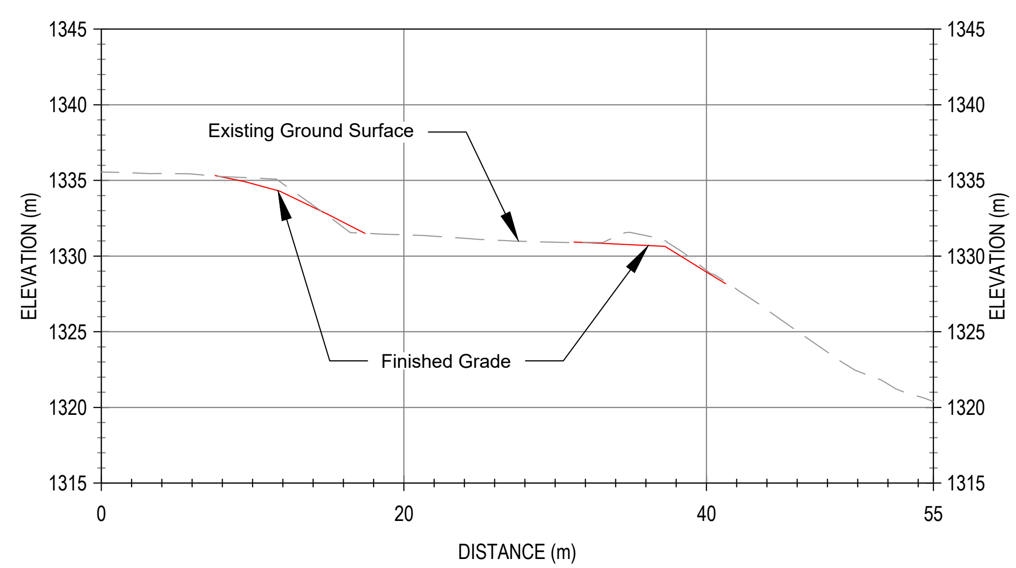


Section A



Section B

Scale: 1:500

0 5 10 20 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-30	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3301

Lucky Queen Grading Cross Sections

REVISION: A	2018-01-30	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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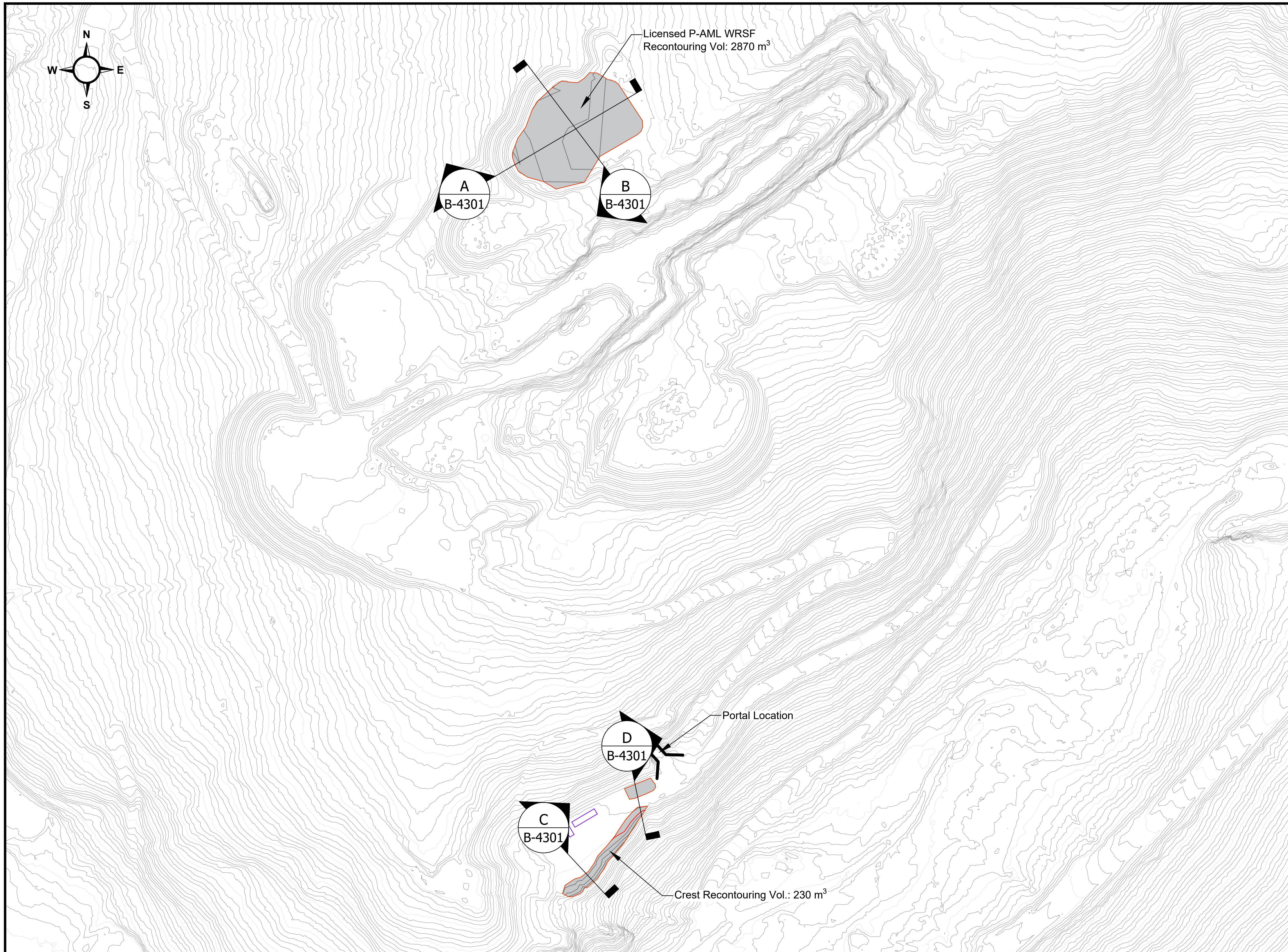

Notes:

1. The constructed P-AML WRSF contains no P-AML rock. Closure will include the removal of the liner, and recontouring of the containment berms, followed by scarification of the surface, and seeding.
2. The constructed settling pond will be recontoured to match surrounding grade.
3. The portal area crest will be rolled back via excavator.

Quantities:

Volume of material to be recontoured: 3,100 m^3

Scale: 1:3000

0 25 50 100 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-31	Draft for review	A	KAB	--

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4101

Onek Grading Plan

REVISION: A	2018-01-31	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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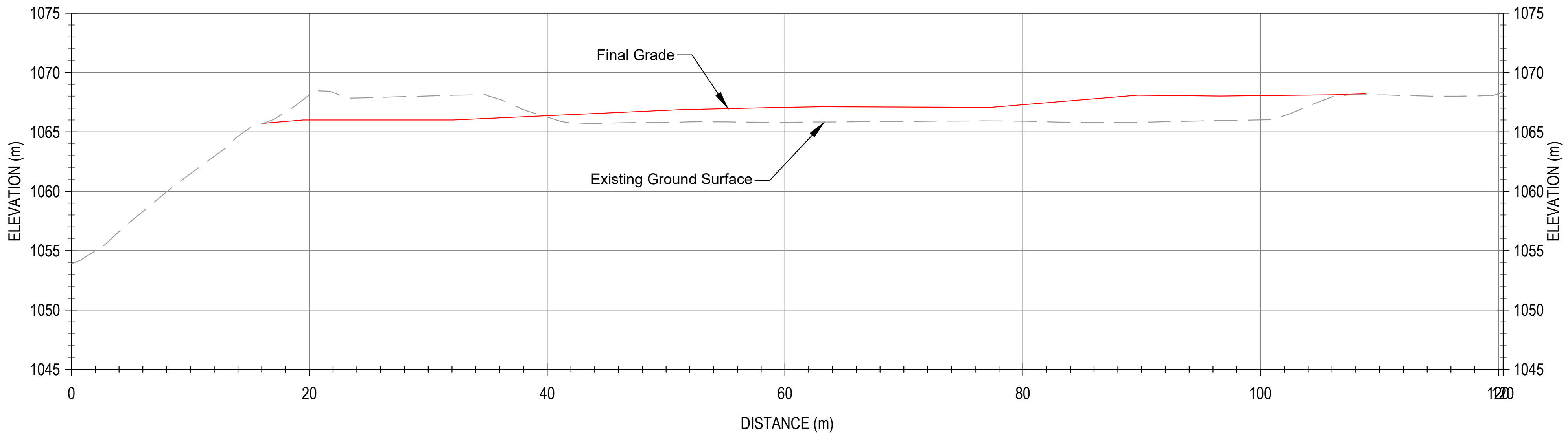

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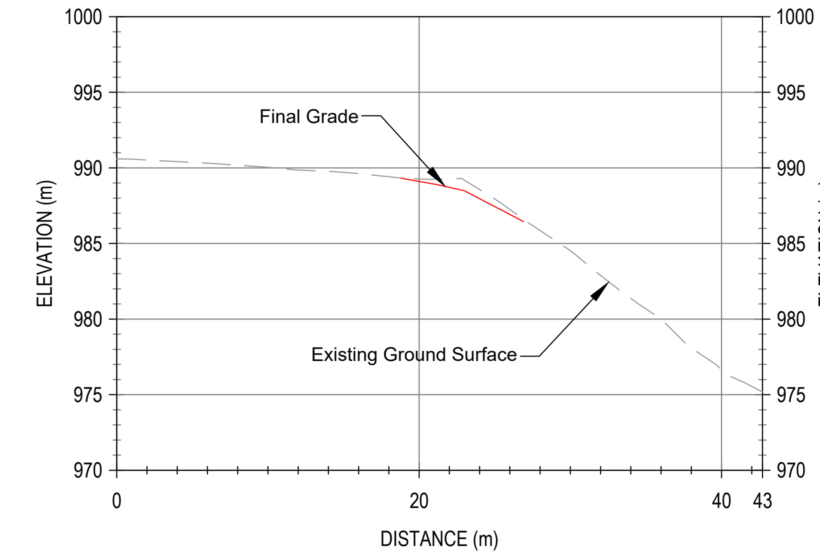

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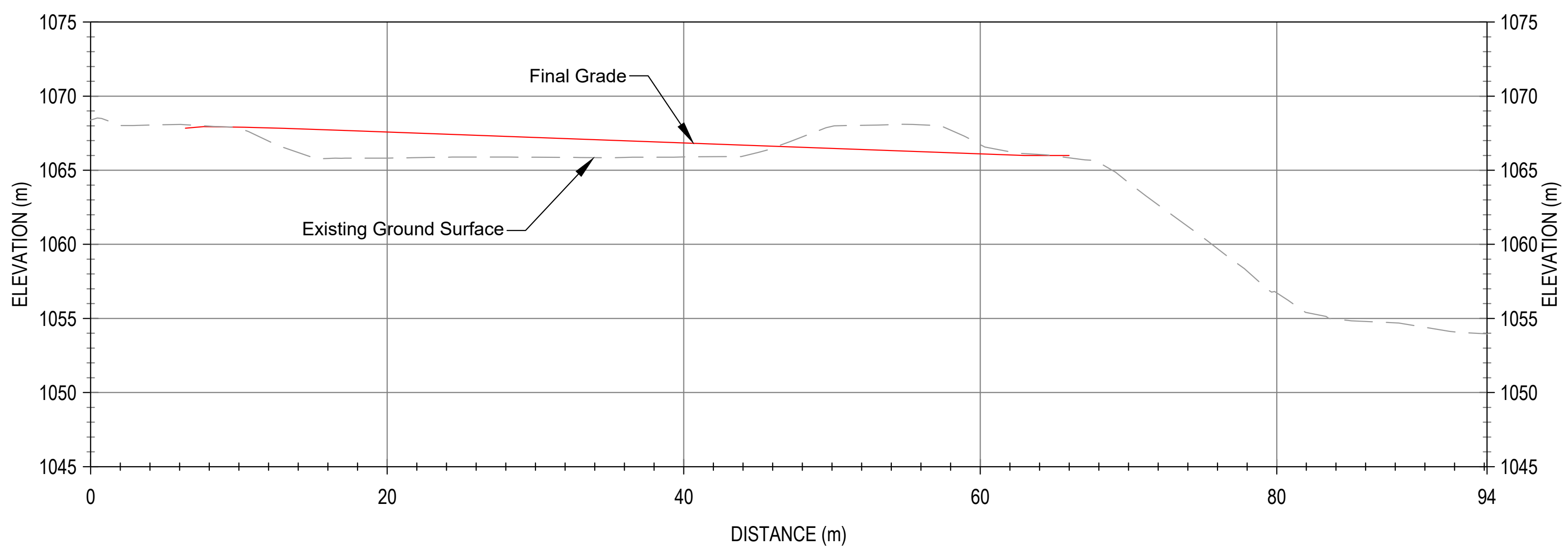
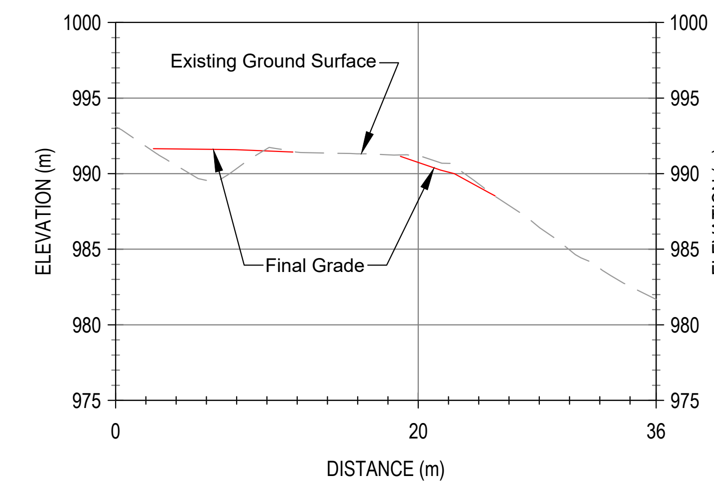


Section B



Section D

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-31	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4301

Onek Grading
Sections

REVISION: A	2018-01-31	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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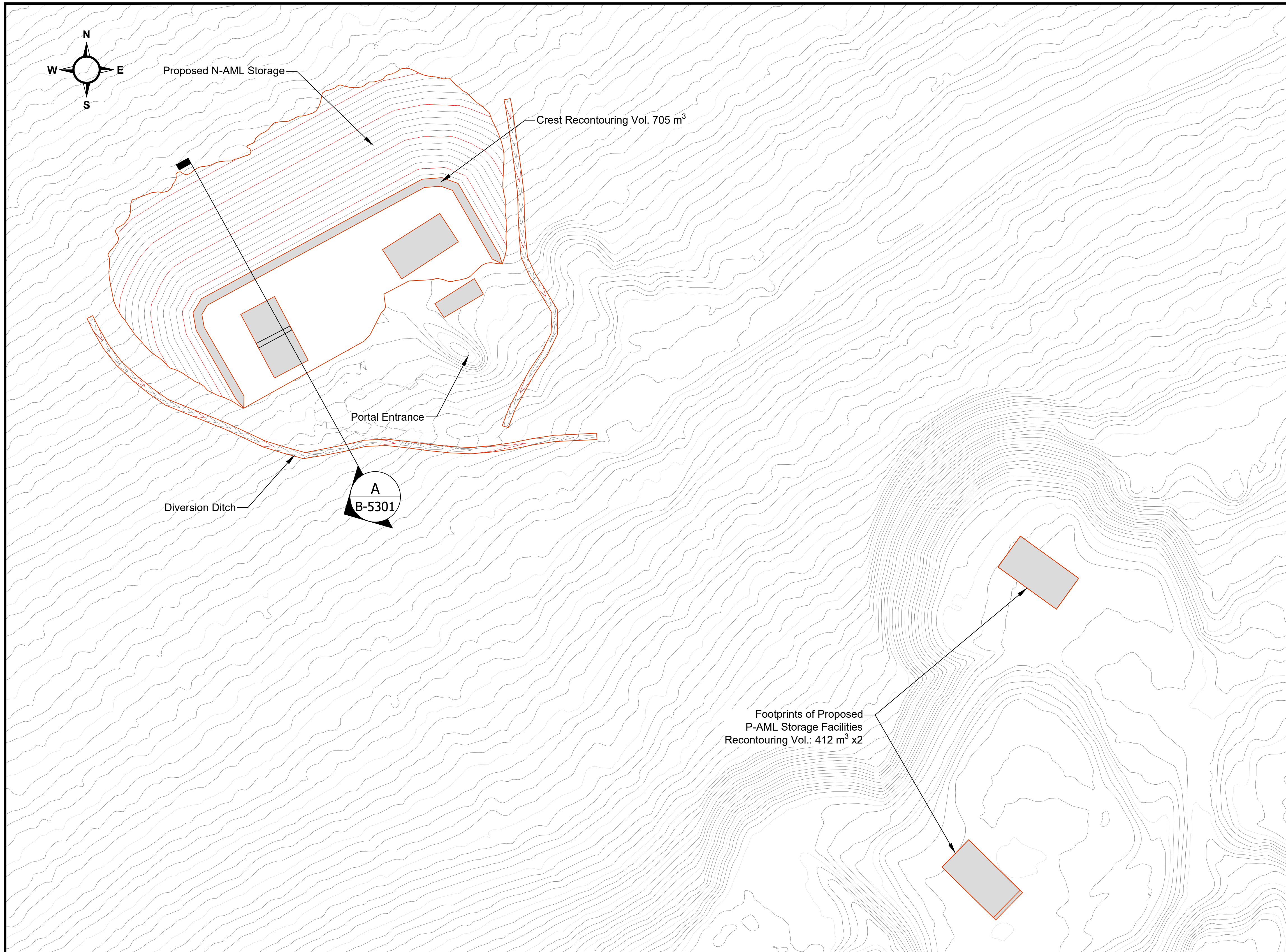

Notes:

1. P-AML waste rock contained in the P-AML WRSF will be relocated to underground.
2. The liner of the P-AML WRSF will be removed, and the containment berms will be recontoured, followed by scarification of the surface, and seeding.
3. The crest of the N-AML WRDA will be pulled back as required. Flat surfaces will be scarified and revegetated.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured: 420 m^3

Scale: 1:2000
0 12.5 25 50 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5101

Bermingham Grading Plan

REVISION: A	2018-02-05	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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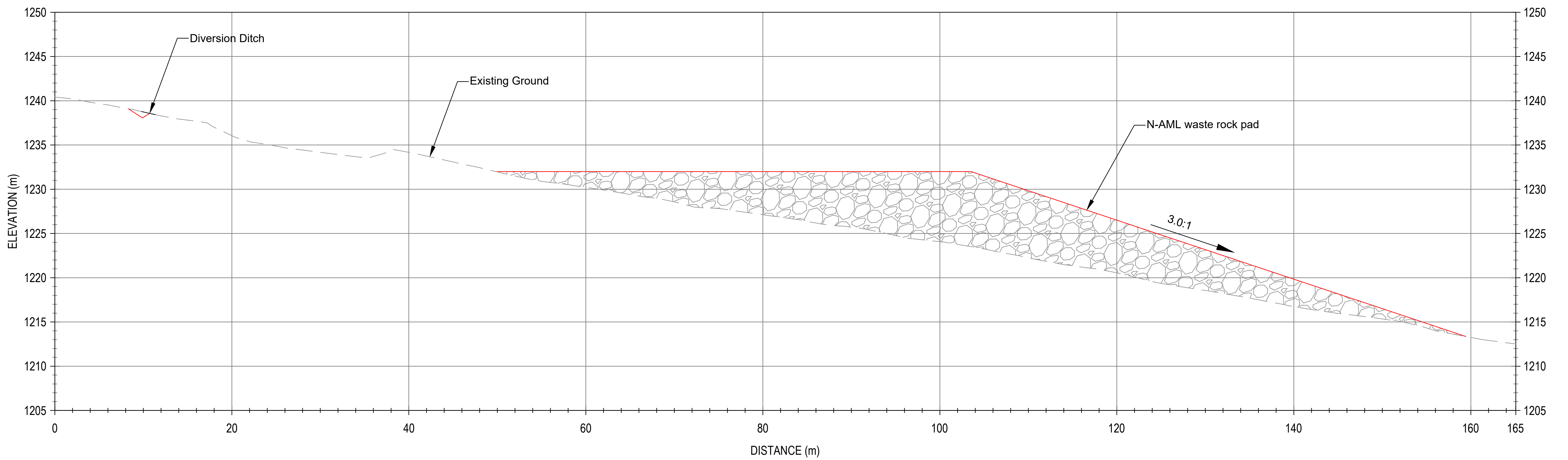

Section A

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-05	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5301

Bermingham Grading
Cross Section

REVISION: A	2018-02-05	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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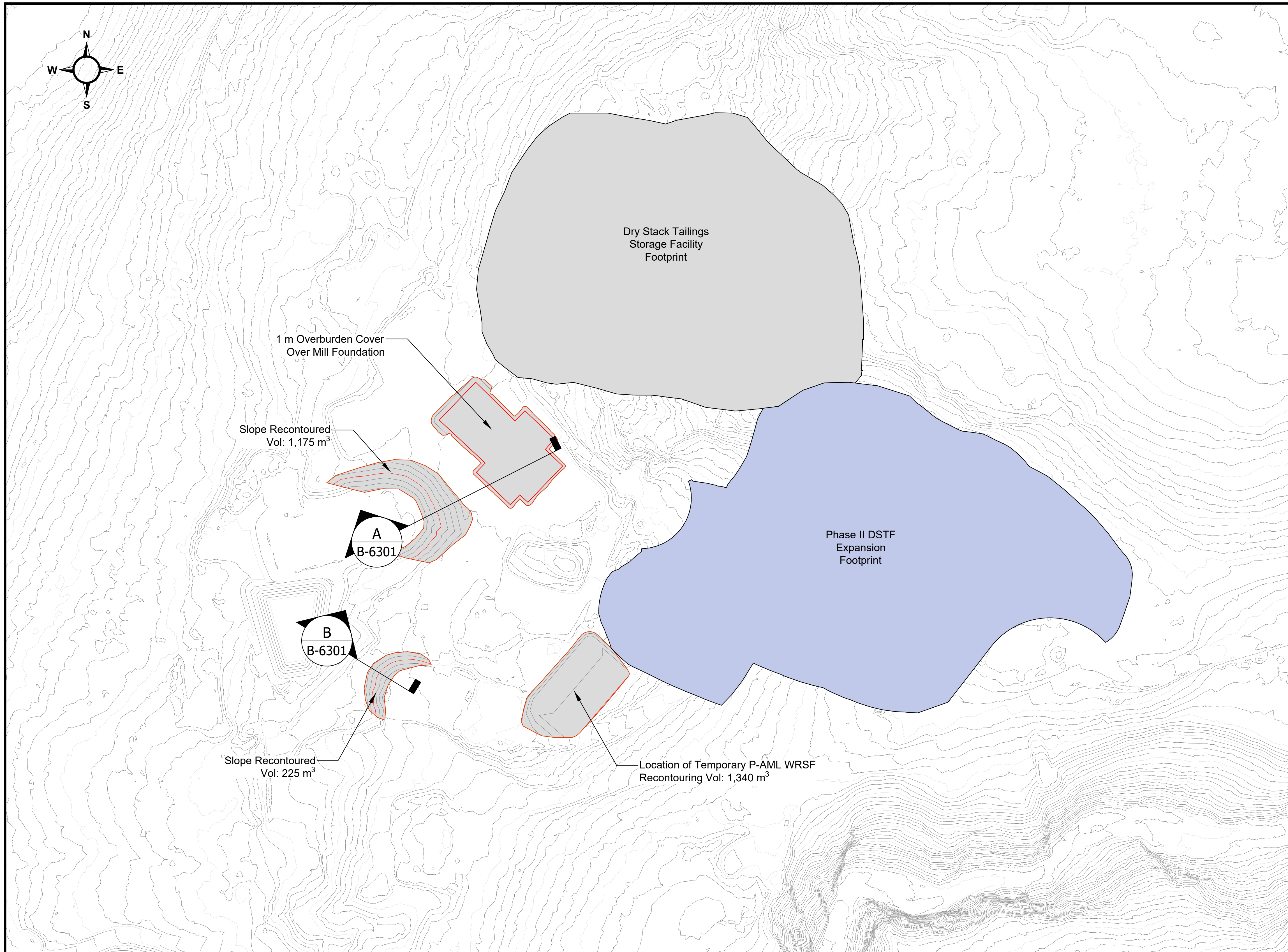

Notes:

1. Concrete slabs and above grade footings and foundations will be broken up and covered with 1 m overburden cover, scarified, and revegetated.
2. The mill process pond will have the liner removed. The slopes will be scarified and revegetated. The pond will serve as a sedimentation pond during closure until revegetation is stabilized.
3. The mill site will be recontoured and scarified to establish drainage and facilitate revegetation.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured:	2,740 m^3
Volume of overburden cover:	1,800 m^3

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ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6101

Mill Site Grading Plan

REVISION: A	2018-02-02	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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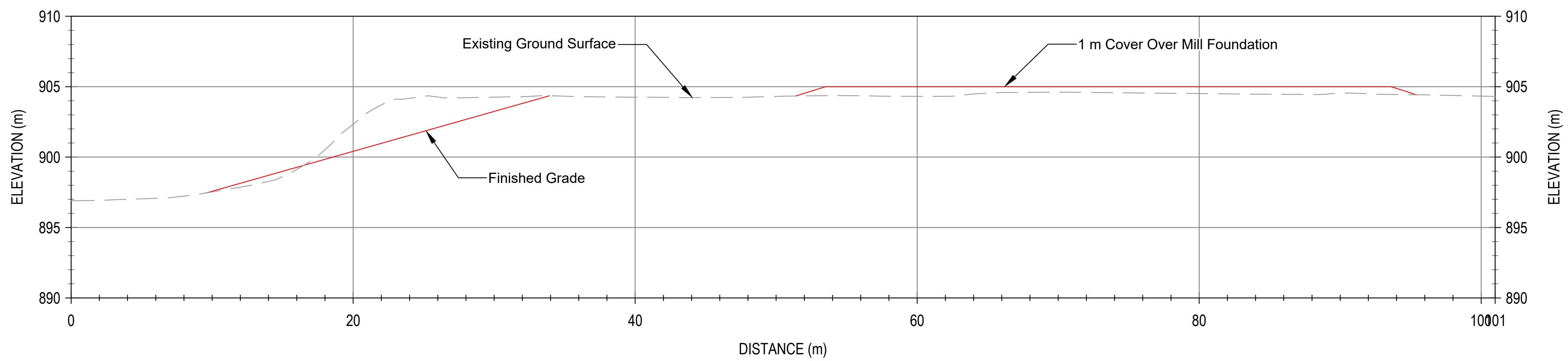
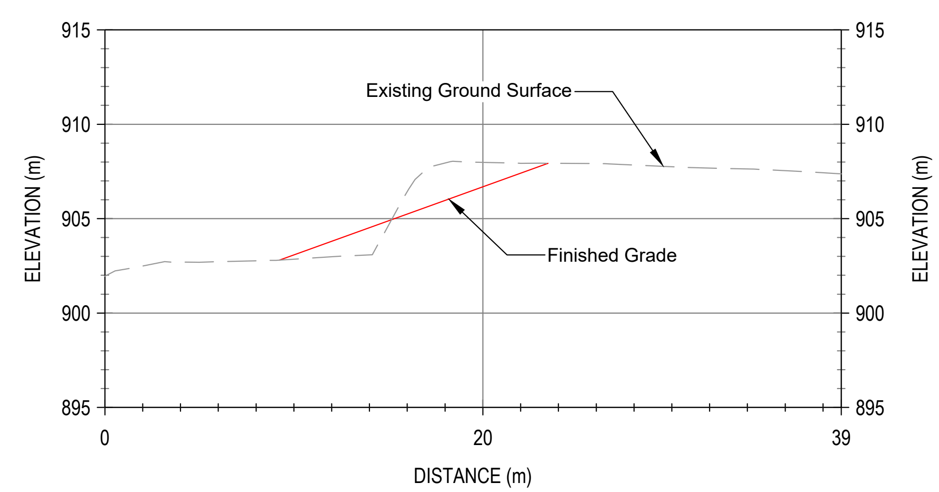


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-02-02	Draft for review	A	KAB	--

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6301

Mill Site Grading Cross Sections

REVISION: A	2018-02-02	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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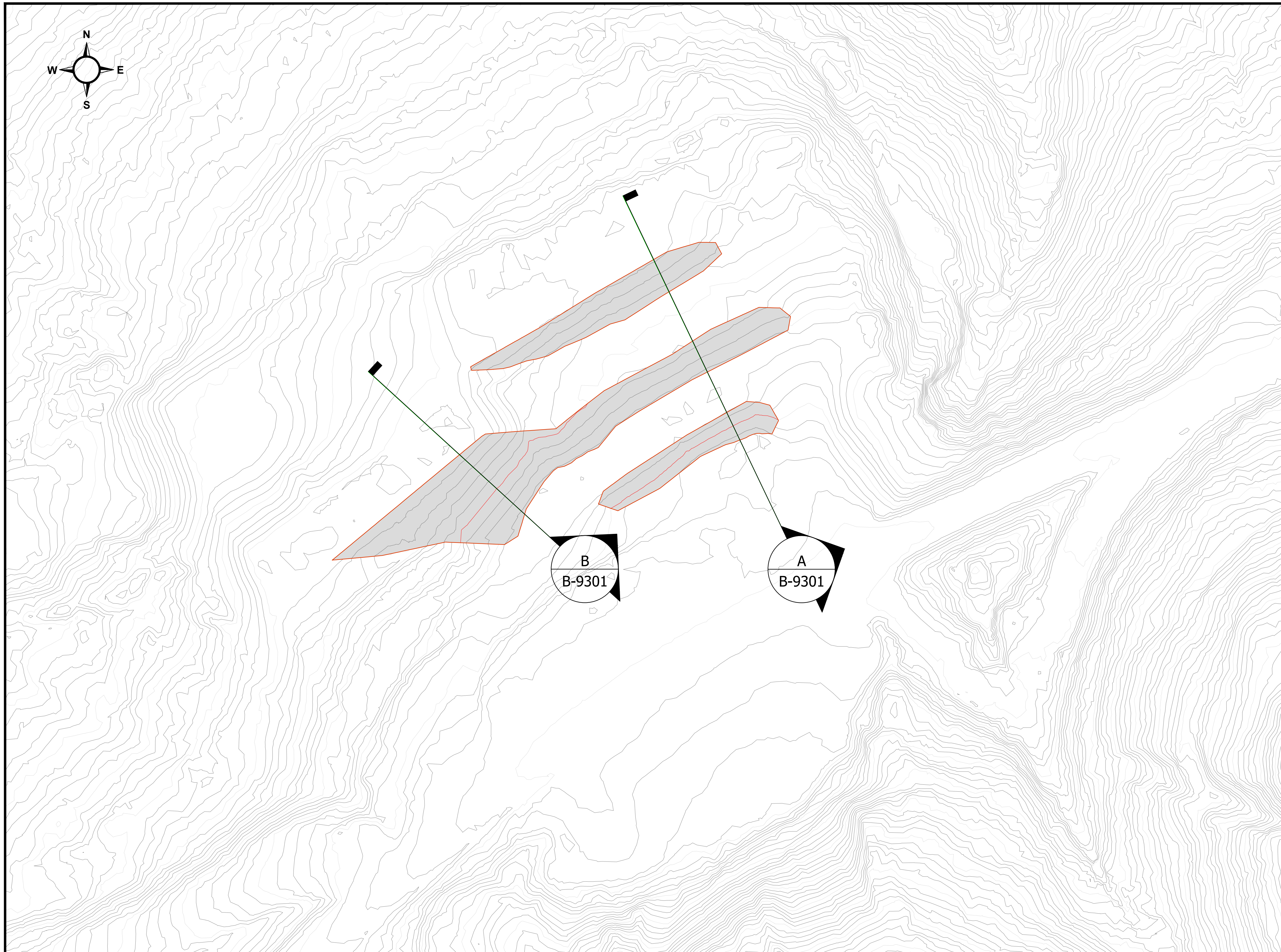

Notes:

1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:

Volume of material to be recontoured: 1,060 m^3

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

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2018-01-18	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9101

Flat Creek Camp Grading Plan

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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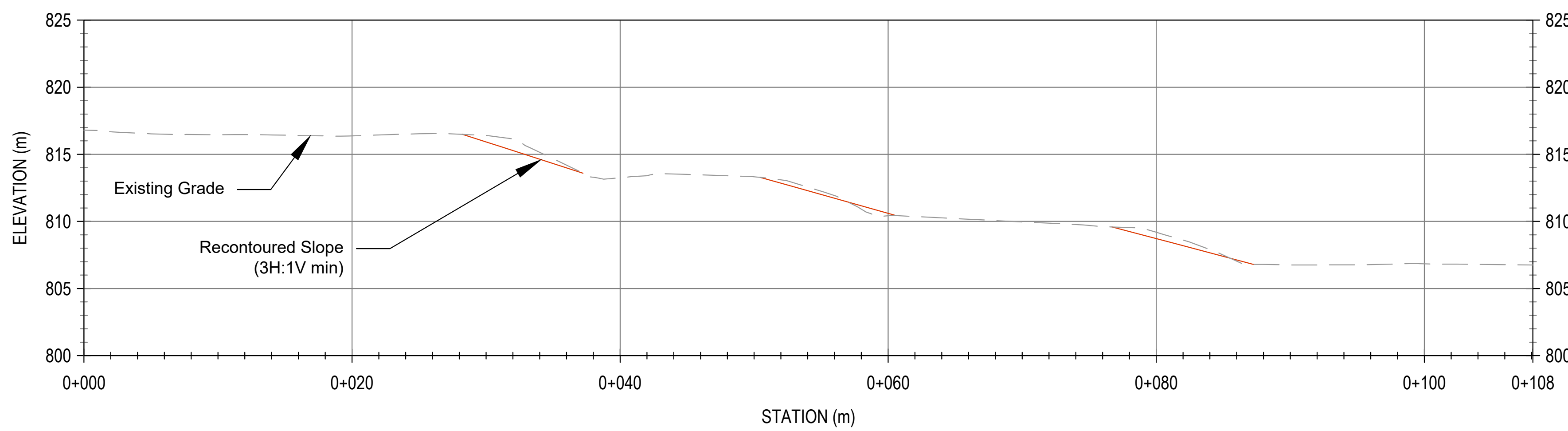
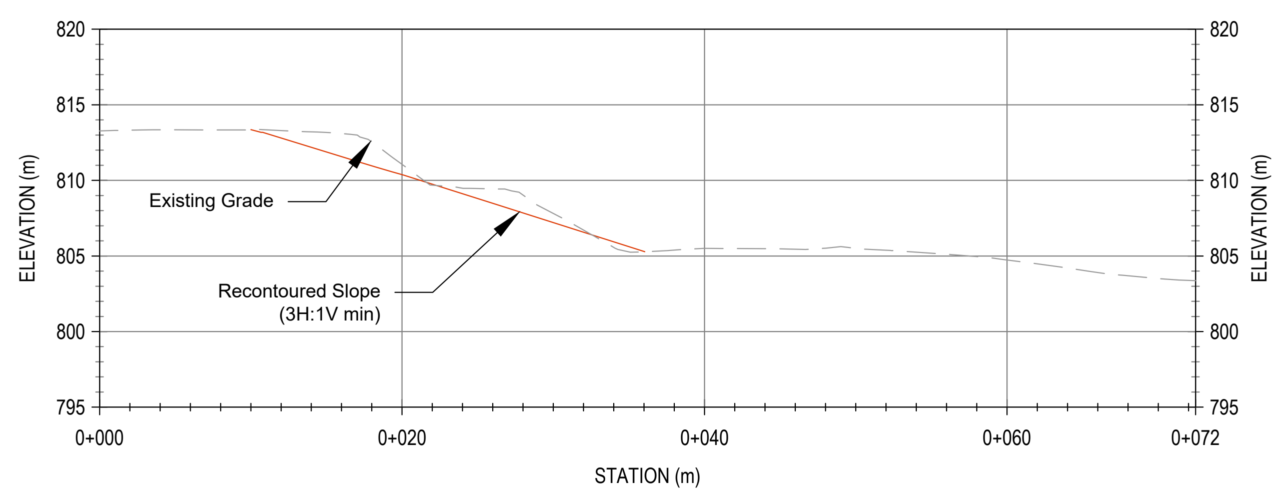
Notes:

1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:



Alignment-A



Alignment-B

Satellite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9301

Flat Creek Camp
Grading Plan - Sections

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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APPENDIX 3.2
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

EBA Engineering Consultants Ltd.
p. 867.668.3068 • f. 867.668.4349
Calcite Business Centre • Unit 6, 151 Industrial Road • Whitehorse, Yukon Y1A 2V3 • CANADA

TABLE OF CONTENTS

APPENDICES

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/m^2. 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 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/ft^3 (600 kN-m/m^3))

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 m^3 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 m^3 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 lever 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.

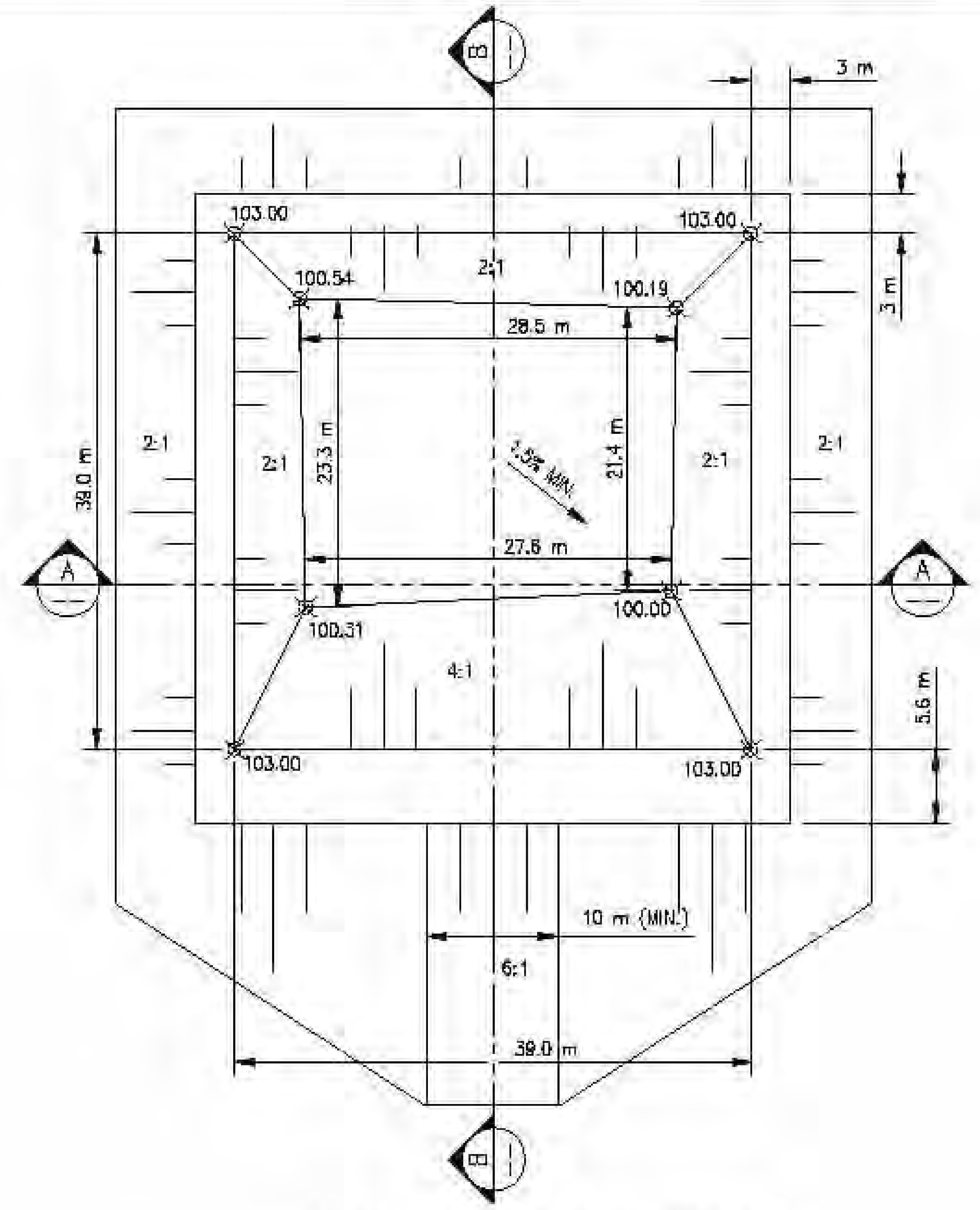
.4 The vegetative cover must have sufficient density and species diversity to stabilize the surface against the effects of long term erosion.

.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

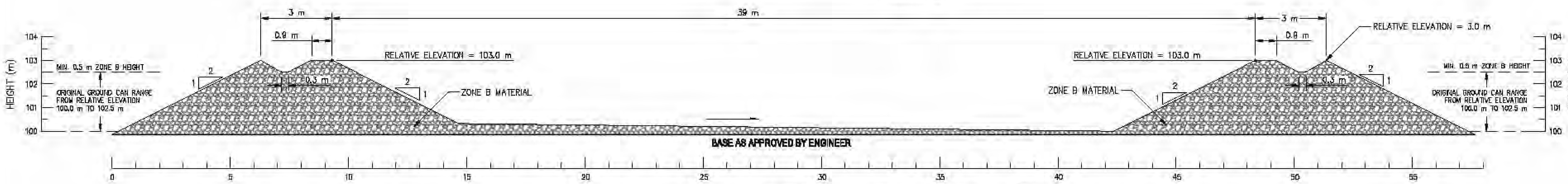
APPENDIX

APPENDIX A CONSTRUCTION DRAWINGS



PLAN – ZONE B MATERIAL

SCALE: 1 : 400



CROSS–SECTION A

SCALE: 1 : 100

CROSS–SECTION B

SCALE: 1 : 100

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1600 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEM AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.
3. ALL ELEVATIONS ON PLAN ARE FOR TOP OF ZONE B MATERIAL.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPS	ISSUED FOR CONSTRUCTION
A	08/06/26	JPS	ISSUED FOR REVIEW

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng. Date: July 8, 2008

Seal: Jason Berkers, P.Eng. Date: July 9, 2008

The signed Professional Seal and Permit to Practice stamps reside on the executed drawing which is held and controlled by EBA Engineering Consultants Ltd.

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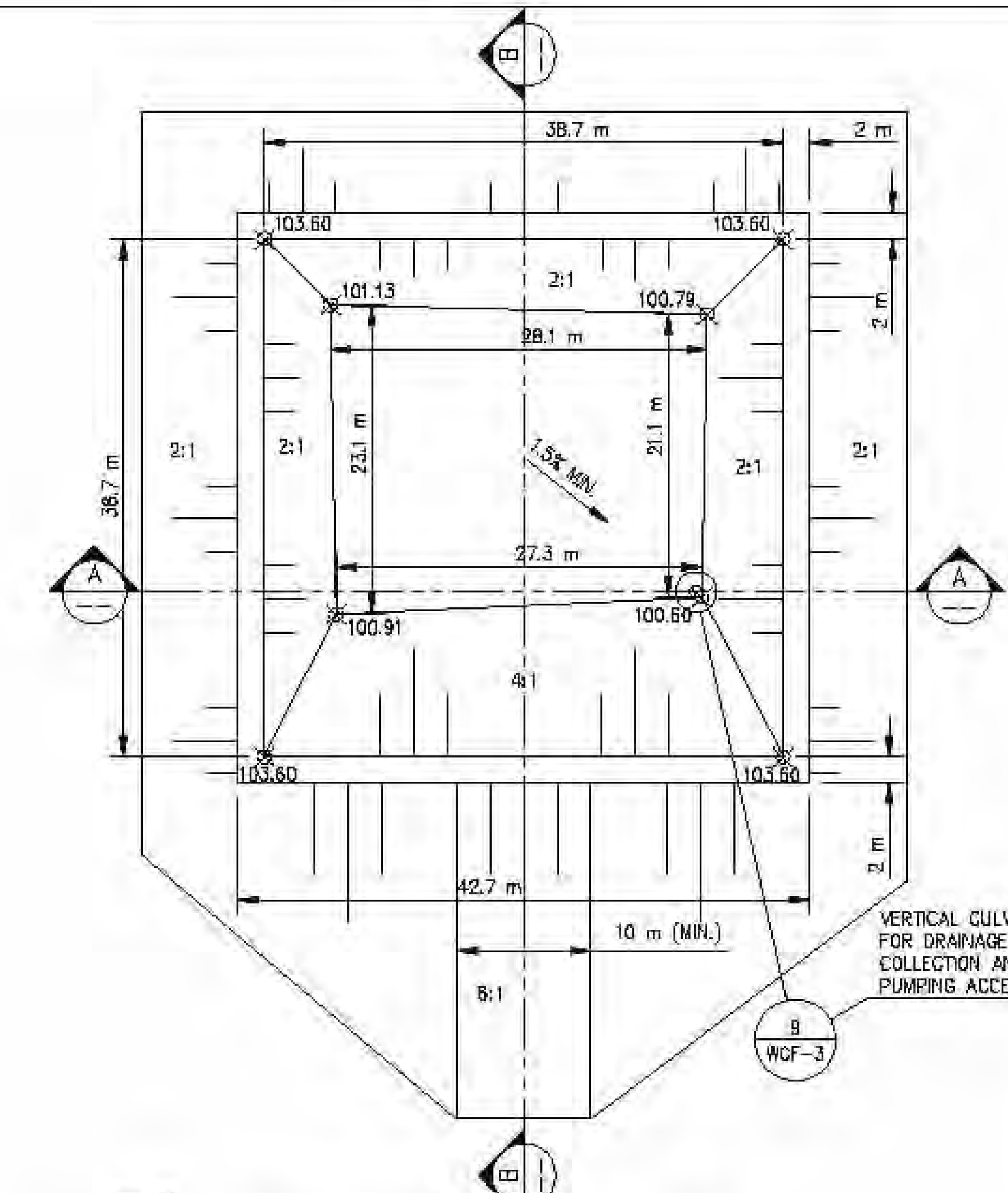
TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE B MATERIAL PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DSR	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPS	0	WCF-1
DATE	SHEET No.	DWN	APP	STATUS	
June 26, 2008	1 of 4	KJT	JRT	B	



PLAN – ZONE A MATERIAL

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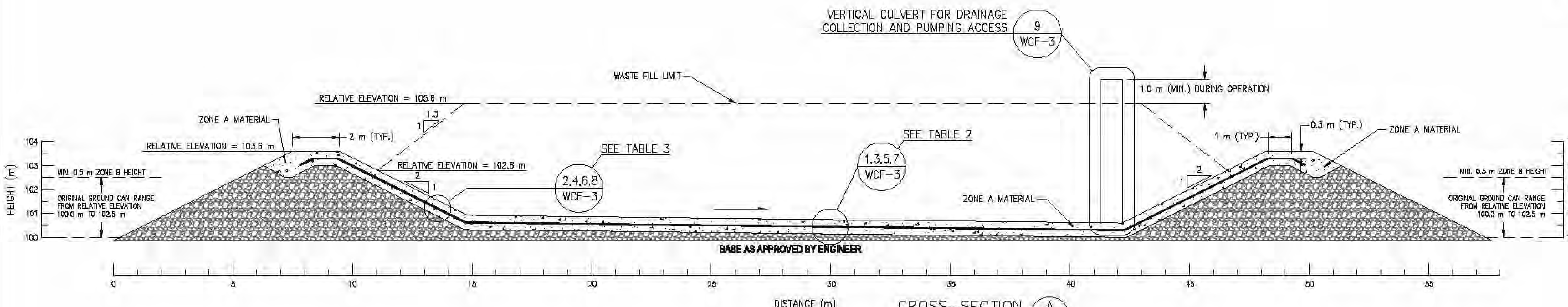

CROSS–SECTION A

SCALE 1 : 100

CROSS–SECTION B

SCALE 1 : 100

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1600 m^2 OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.
3. ALL ELEVATIONS ON PLAN ARE FOR TOP OF ZONE A MATERIAL.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPB	ISSUED FOR CONSTRUCTION
A	08/06/26	JPS	ISSUED FOR REVIEW

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Permit: J. Richard Trimble, P.Eng. Date: July 8, 2008

Seal: Jason Berkers, P.Eng. Date: July 9, 2008

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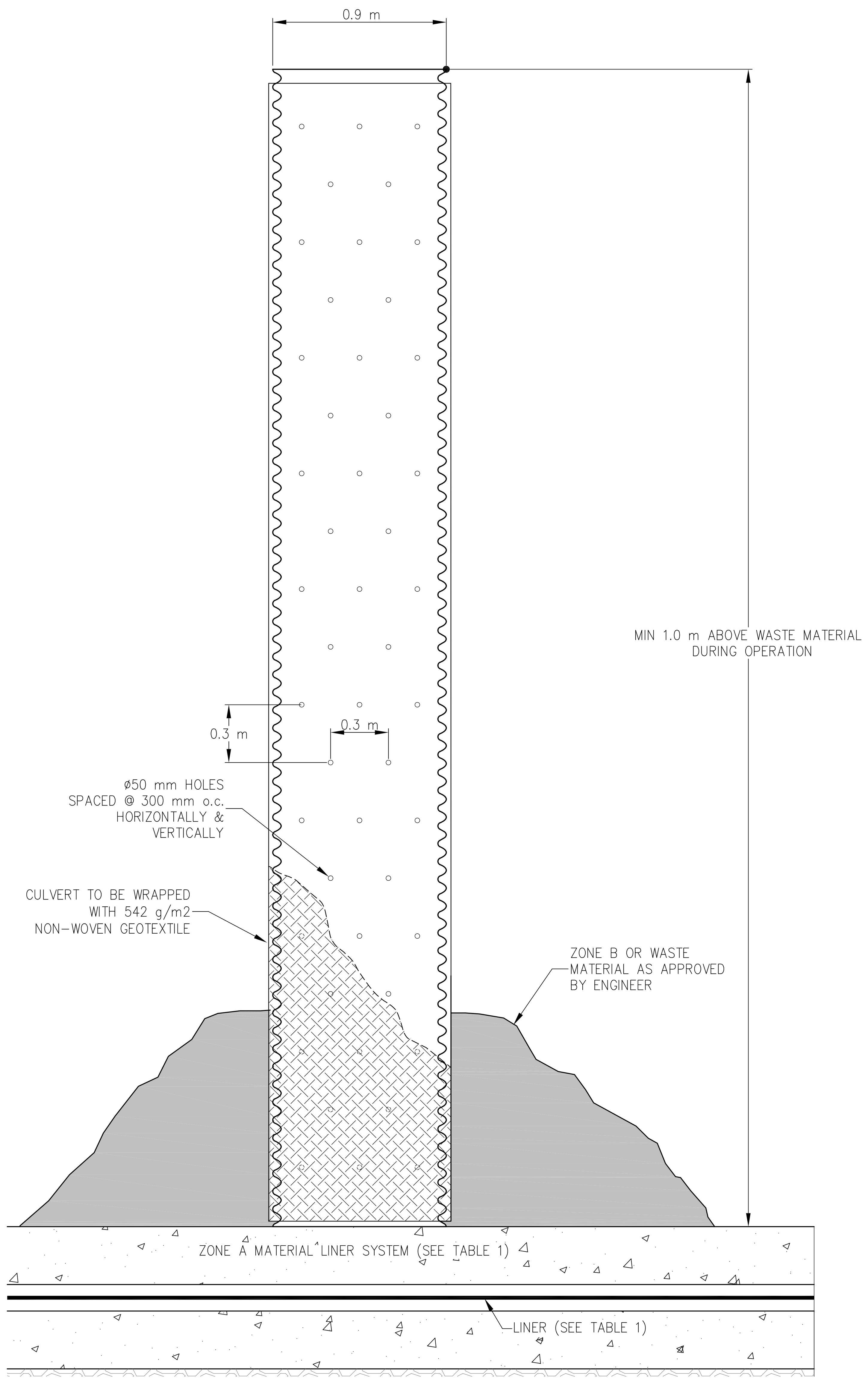
TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE A MATERIAL PLAN & CROSS SECTIONS

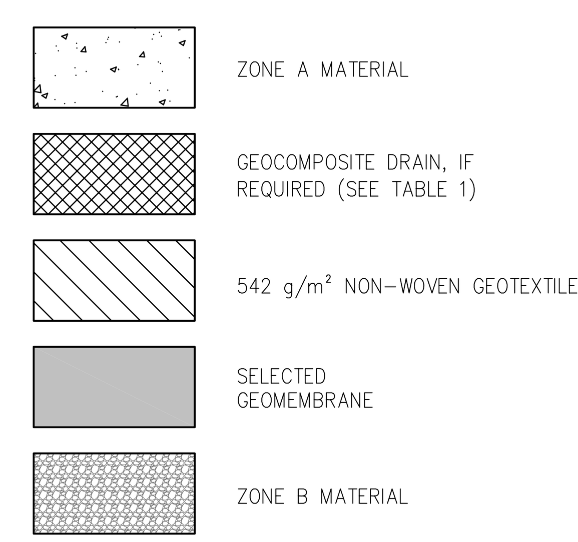
PROJECT No.	OFFICE	DSR	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPB	0	WCF-2
DATE	SHEET No.	DWN	APP	STATUS	
June 26, 2008	2 of 4	KJT	JRT	B	



DETAIL 1 – VERTICAL CULVERT (9 / WCF-1)

SCALE: 1 : 20

LINER SYSTEM DETAIL KEY



LINER SYSTEM FLOOR & APPROACH BERM

LINER SYSTEM BERMS

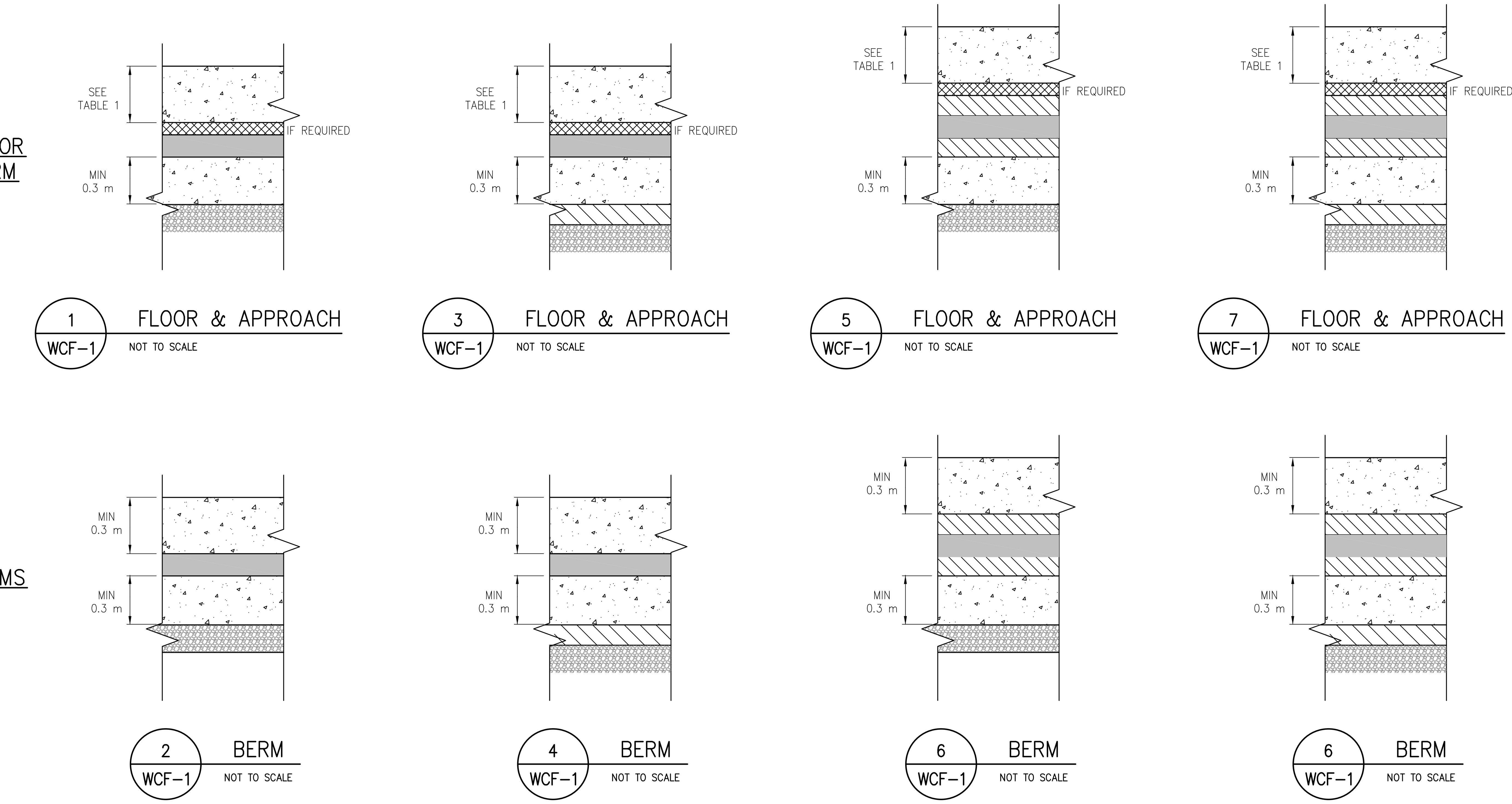


Table 1: Recommended Minimum Cover Thicknesses

Liner Material	Drainage Composite	Minimum Required Thickness
Enviro Liner® 4040 (Without Geocomposite)	Not Required	1.3 m
Enviro Liner® 4040 (With Geocomposite)	Required	0.3 m
HDPE 60	Not Required	0.3 m
PVC 40 (With Geocomposite)	Required	0.3 m

Table 2: Liner System Floor and Approach Berm

		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	Detail 1	Detail 1	Detail 3
	Gradation Below Fine Limit	Detail 3	Detail 3	Detail 3
	Gradation Above Coarse Limit	Detail 5	Detail 5	Detail 7

Table 3: Liner System Berm

		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	Detail 1	Detail 1	Detail 3
	Gradation Below Fine Limit	Detail 3	Detail 3	Detail 3
	Gradation Above Coarse Limit	Detail 5	Detail 5	Detail 7

Table 4: 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

Table 5: 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

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1900 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPB	ISSUED FOR CONSTRUCTION
A	08/06/25	JPB	ISSUED FOR REVIEW

ORIGINAL SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng. Date: July 8, 2008

Seal: Jason Berkers, P.Eng. Date: July 8, 2008

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CLIENT: ALEXCO

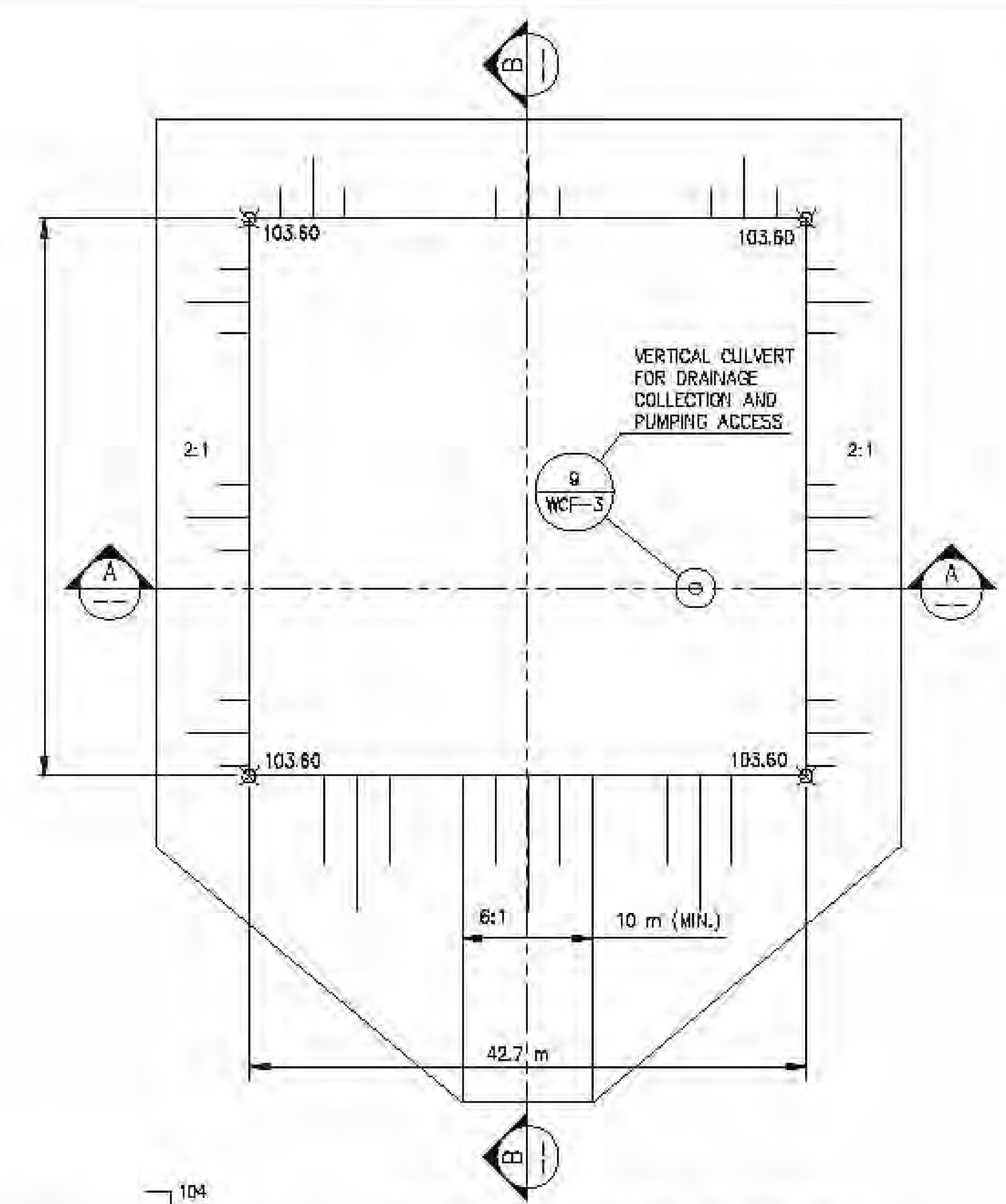
EBA Engineering Consultants Ltd.

ISSUED FOR CONSTRUCTION

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

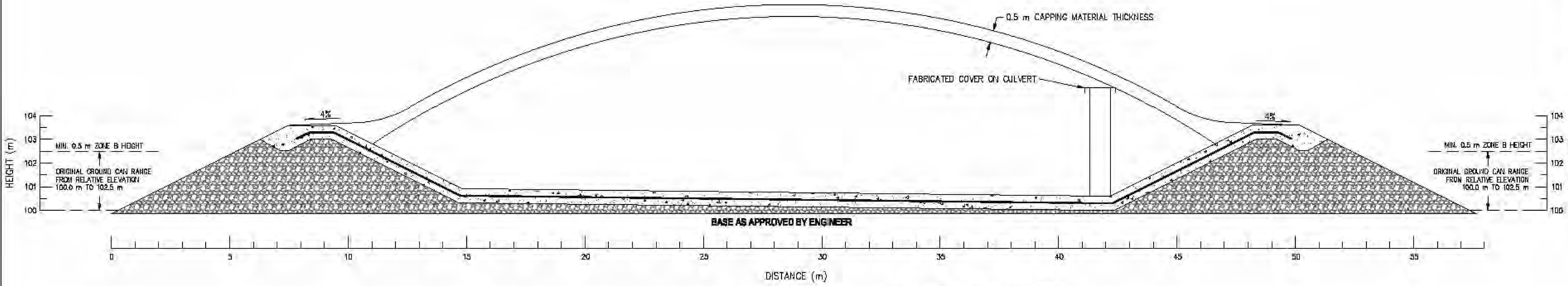
DETAILS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPB	0	WCF-3
DATE: JUNE 25, 2008	SHEET No. 3 of 4	DWN KJT	APP JRT	STATUS B	



PLAN – FACILITY CLOSURE

SCALE: 1 : 400



CROSS–SECTION A

SCALE: 1 : 100

CROSS–SECTION B

SCALE: 1 : 100

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1600 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTUCTION.

NUM	DATE	DWN	CKD	APR	DESCRIPTION

REVISIONS

NUM	DATE	APR	DESCRIPTION
2	08/07/08	JPS	ISSUED FOR CONSTRUCTION
1	08/06/26	JPS	ISSUED FOR REVIEW

DRAWING STATUS

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng.
Date: July 8, 2008

Seal: Jason Berkers, P.Eng.
Date: July 9, 2008

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EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

FACILITY CLOSURE PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DSR	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPS	0	WCF-4
DATE	SHEET No.	DWN	APP	STATUS	
June 26, 2008	4 of 4	KJT	JRT	B	

APPENDIX 3.3

GEOCHEMISTRY SUMMARY FOR WASTE ROCK AND TAILINGS

Memorandum

To: Kai Woloshyn, Alexco Resource Corp.

From: Cheibany Ould Elemine and Andrew Gault, Alexco Environmental Group Inc.

CC: Brad Thrall, Alexco Resource Corp.

Date: December 17, 2018

Re: AKHM Waste Rock ARD/ML Characterization Update – December 2018

1 Introduction

Acid rock drainage and metal leaching (ARD/ML) characterization of waste rock produced from prospective production areas in the Keno Hill District (KHSD) has been ongoing since Alexco Keno Hill Mining Corp. (AKHM) initiated exploration in 2006. This dataset includes static (e.g., acid base accounting, elemental metals, shake flask leach test) and kinetic (e.g., humidity cells and field barrels) of material from the following areas:

- Bellekeno;
- Onek;
- Lucky Queen;
- Flame & Moth;
- Silver King; and
- Bermingham.

This memorandum summarizes the waste rock static and kinetic data collected by AKHM to date. More detailed reporting can be found in the source documentation cited throughout.

2 Regional and District Geology

The KHSD is primarily composed of Yukon Group metasedimentary rocks which are described in the Keno Hill Silver District Environmental Conditions Report (AEG, 2016a) and the NI43-101 technical report for the Bermingham Exploration Project (Roscoe Postle and Associates Inc., 2017). The mineralization of the KHSD is hosted within the Mississippian Keno Hill Quartzite Formation in the Tombstone Thrust Sheet, which conformably overlies the Devonian Earn Group to the north and is structurally overlain by the Upper Proterozoic Hyland Group Yusezyu Formation across the Robert Service Thrust Fault in the south (Roscoe Postle and Associates Inc., 2017).

The stratigraphic units in the district are mainly composed of the Earn Group and the Keno Hill Quartzite. The Earn Group comprises typically phyllitic, grey graphitic metasediments with an upper band of greenish chlorite-sericite meta-felsic volcanics, and minor interbedded quartzite proximal to the conformable transition to the overlying Keno Hill Basal Quartzite Member. The Keno Hill Quartzite is structurally approximately 1,900 m thick and contains the lower massive blocky Basal Quartzite Member (approximate structural thickness of 1,100 m) with thin to thick quartzite and graphitic schist interbeds and the Sourdough Hill Member (~800 m) with basal horizons of sericitic meta-rhyolite and graphitic schist, intermediate units of an Upper Quartzite, quartz eye grits, and chloritic schist that enter an overlying carbonate rich section containing well-defined black limestone beds. Mid-Triassic greenstone lenses up to 100 m thick are also contained within the Keno Hill sequence but only to the top of the Basal Quartzite Member (Roscoe Postle and Associates Inc., 2017).

One to two phases of deformation and chloritic grade regional metamorphism and isoclinic folding produced overturned isoclines in the Keno Hill Quartzite Basal Member overlying the Earn Group. The mineralization was developed in northeast striking, southeasterly dipping normal oblique normal faults with displacement of tens to hundreds of metres formed likely during the early stages of deformation.

The KHSD mineralization is in the form of silver-rich base metal quartz-carbonate veins that are predominantly present in steep southeasterly dipping vein-filled faults with deposits hosted by thick competent Basal Quartzite of the Keno Hill Quartzite or occasionally where greenstone forms part of the Earn Group wall rock (Roscoe Postle and Associates Inc., 2017).

A brief descriptive overview of the major lithology types is summarized below from Boyle (1962), Altura (2008) and (Roscoe Postle and Associates Inc., 2017).

- Quartzite (QTZT): The dominant lithology unit at the Bermingham deposit development rock and occurs both as thickly and thinly bedded sequences with assemblages of graphitic schist. The quartzites are variably silicified with purer quartzites a few metres thick and darker grey, impure quartzites on to four metres thick. Quartzites are comprised primarily of quartz but also contain some mica, carbonate minerals and carbonaceous materials. Accessory minerals include leucoxene, tourmaline, zircon, apatite and pyrite. Calcareous quartzite (CQTZT) contains disseminated primary calcite that fizzes readily when subjected to dilute hydrochloric acid.

- Schist (SCH): The schist within the Bermingham development area are most commonly graphitic schist (GSCH), which are black or dark gray in color due to their significant carbon content, occur in beds from millimetre to many meters in scale, and can be intercalated with quartzites as well as the other lithologies. In addition to graphite; quartz, mica, carbonates, feldspar, chlorite, isotropic colloidal material and pyrite metacrysts have been identified in thin sections within these rocks. Although not anticipated to be present in significant quantities in the Bermingham development (i.e., <5%), other forms of schist are documented elsewhere in the KHSD. These include quartz sericite schist (SSCH) and chlorite schists (CHSCH), which are pale to dark green in colour. Thin sections of sericite schists show primarily quartz and sericite composition, with trace carbonate minerals and leucoxene. Accessory minerals include apatite, zircon, tourmaline and pyrite metacrysts. Calcareous schist (CSCH) contains disseminated primary calcite that fizzes readily when subjected to dilute hydrochloric acid (HCl). Interbedded carbonaceous quartzite and schist (ICQS) and thin bedded quartzite (TQTZT), the latter of which does occur in the Bermingham development area, are also included as their own lithologies, but these units are predominantly composed of schist.

- Greenstone (GNST): Greenstones vary from narrow (0.3 – 2 m wide) to 100 m thick and vary in color from greyish green to dark green. Greenstones occur in conformable elongated lenses and sills as a result of boudinage, particularly within the more ductile schist units. Greenstones units are generally more resistant than the quartzites and schists and appear geomorphologically as the prominent hills in the KHSD. Thin sections show significant variety in mineral composition and texture but generally show a high degree of alteration. The primary mineralogy of the greenstones includes hornblende, actinolite, saussurite (zoisite, epidote, albite, sericite, carbonate), plagioclase (oligoclase to andesine), chlorite, stilpnomelane, biotite, sericite, leucoxene, and carbonate minerals. Quartz, K-feldspar, ilmenite, magnetite, limonite and apatite are minor constituents with some pyrite. Chlorite is also generally present, which is primarily responsible for this rock's color.

3 DATA SOURCES

The data presented in this summary memorandum are primarily sourced from AKHM's growing database of ARD/ML static and kinetic testing of waste rock samples generated from exploration of deposits of interest in the KHSD. These largely comprise waste rock from:

- Bellekeno;
- Lucky Queen;
- Onek;
- Flame & Moth;
- Silver King; and
- Bermingham.

3.1 STATIC TESTING

Static testing of these materials has typically consisted of:

- Acid base accounting (ABA) analyses, including:
  - Paste pH;
  - Siderite-corrected neutralization potential (NP) using the method of Skousen et al. (1997);
  - Total sulphur by Leco;
  - Sulphate sulphur by HCl extraction;
  - Sulphide sulphur by difference, used to calculate acid potential (AP); and
  - Total inorganic carbon (TIC) by HCl leaching.
- Bulk elemental analysis by aqua regia digestion and ICP-MS analysis of digestate; and
- Shake flask extraction (MEND SFE) to determine soluble constituents associated with these materials (Price 2009).

3.2 KINETIC TESTING

Kinetic testing has largely comprised of laboratory-based humidity cells and site-based field leach barrels. Humidity cells tests have all been completed for the following materials:

- Flame & Moth non-acid generating/metal leaching (N-AML) waste rock composite (98 weeks, completed);
- Bermingham N-AML waste rock composite (57 weeks, completed);

Five field barrels have also been in operation at the KHSD site since June 2013 and comprise Flame & Moth waste rock drill core (280 to 340 kg) in barrels that are open to atmospheric weathering conditions. The field leach barrels contain a range of N-AML and potentially acid generating/metal leaching (P-AML) waste rock Precipitation that percolates through the barrels is collected in pails that are sampled on a monthly basis during the ice-free months.

4 STATIC TESTING DATA

ARD/ML data of waste rock samples collected from exploration drill core at prospective production zones shown in Figure 4-1 within the KHSD were compiled. These included the:

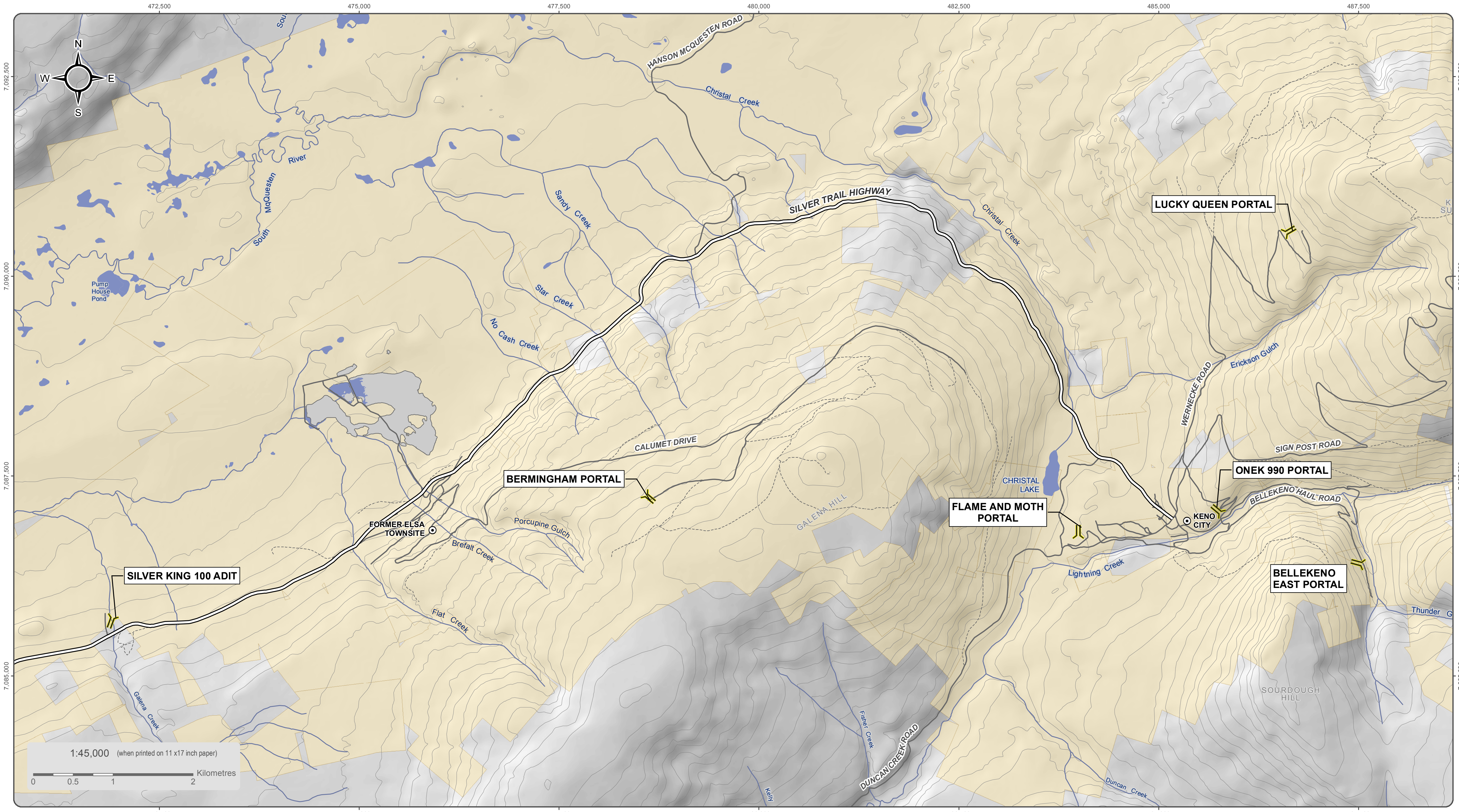
- Bellekeno (Altura, 2008);
- Onek (ACG, 2011a);
- Lucky Queen (ACG, 2011b);
- Silver King (ACG, 2011c);
- Flame & Moth (AEG, 2016b); and
- Bermingham zones (AEG, 2018.

The lithological distribution of samples in each production zone is presented in Table 4-1.

Table 4-1: AKHM Prospective KHSD Production Zones Sample Lithologies Sampled for ARD/ML Characterization

Production Zone	Lithology (Number of Samples)									Total
	GNST	GSCH	QTZT	SSCH	TQTZT	ICQS	CQTZTZ	CHSCH	CSCH	
Bellekeno	12	13	12	11	0	0	12	1	0	61
Onek	4	14	17	8	0	0	0	1	0	44
Lucky Queen	0	2	13	0	9	0	0	0	0	24
Silver King	1	2	7	3	7	4	0	0	0	24
Flame & Moth	1	5	28	6	7	0	2	0	1	50
Bermingham [a]	3	26	97	1	51	0	0	0	0	178
Total	**21**	**62**	**174**	**29**	**74**	**4**	**14**	**2**	**1**	**381**

[a] Three fault samples collected from Bermingham not included



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 underlicense from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on September 2017

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

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⊙ Place of Interest	Valley Tailings	Watercourse
Adit	Alexco/ERDC Quartz Claims	Silver Trail Highway
	Waterbody	Other Road
		Limited-Use Road

AKHM

ALEXCO ENVIRONMENTAL GROUP

ALEXCO KENO HILL MINING CORP.

FIGURE 4-1

LOCATIONS OF WASTE ROCK ARD/ML STUDIES TO SUPPORT ALEXCO KHSD DEVELOPMENT

SEPTEMBER 2017

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\Property_Overviews\Alexco_Proposed_Deposits_Overview_20170914.mxd
(*Last edited by: amatlashevska;15/09/2017/12:55 PM*)

4.1.1 Acid Base Accounting

The purpose of ABA is to quantify the content and ratio of potentially acid producing and potentially acid consuming minerals in each sample. This provides an indication of the acid generation potential of geologic materials.

Plots of NP versus AP, which provide an overview of the potential for net acid generation, are displayed for all the KHSD production units waste rock samples in Figure 4-2, and broken out by lithology in Figure 4-3 to Figure 4-7. In general, three categories of potential acid generation can be defined based on the NP/AP ratio (or neutralization potential ration; NPR) of a sample (Price, 2009):

- NPR<1 samples are classified as potentially acid generating (PAG);
- 1≤NPR≤2 samples are capable of acid generation but with some uncertainty; and,
- NPR>2 samples are considered not potentially acid generating (non-PAG).

In general, the majority of waste rock samples collected from potential production zones across the KHSD are non-PAG (i.e., NPR>2; Figure 4-2). Samples from Silver King had the highest proportion that were PAG (i.e., NPR<1; 68%), largely due to their low NP content (Figure 4-2). Twenty-nine percent (29%) of the samples collected from Bermingham were also PAG and 23% fell in the uncertain category largely due to low NP and AP. Onek also had a handful of samples that were PAG (16%); however, these generally had high AP and NP. The majority of the Lucky Queen, Onek, Flame & Moth, Bermingham, and Bellekeno waste rock samples were non-PAG (58%, 73%, 74%, 48%, and 87% of samples, respectively). Overall, the waste rock from the easternmost deposits (e.g., Bellekeno, Onek, and Flame & Moth) tended to have higher NP than that found in samples from the deposits located in the western portion of the KHSD (i.e., Silver King and Bermingham).

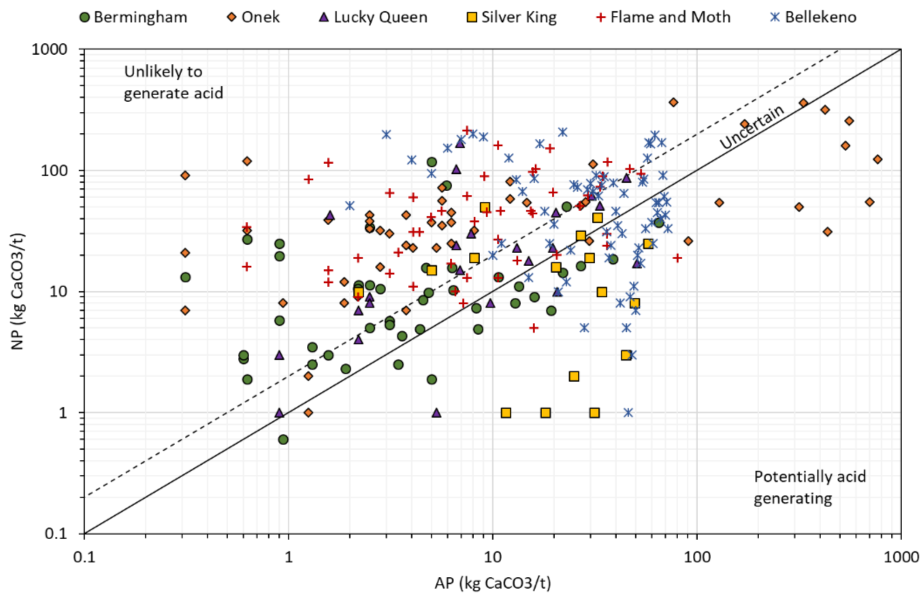
Broken down by major lithology, the QTZT, TQTZT, and GSCH samples broadly reflected the general NPR sample distribution (11% to 31% PAG samples; 44% to 76% non-PAG; Figure 4-3 to Figure 4-5), consistent with the numerical dominance of these lithologies. The GNST and SSCH samples are predominantly non-PAG (Figure 4-6 and Figure 4-7).

4.1.2 Bulk Elemental Chemistry

Bulk concentrations of antimony, arsenic, selenium, silver, cadmium, and zinc often exceed their respective average crustal abundance by an order of magnitude (CRC, 2005) in waste rock from the KHSD. Also, elevated lead concentration is notable in a few rock samples from all deposits except Lucky Queen and Flame & Moth. Although the bulk concentration of an element does not offer a direct measure of how mobile an element may be during weathering, it can provide a preliminary indication of constituents that should be monitored for high solubility in subsequent leach and/or kinetic test. The concentrations of these elements in waste rock (as accessed by aqua regia digestion) from the Bermingham, Bellekeno, Onek, Lucky Queen, Silver King, and Flame & Moth deposit areas are displayed in Figure 4-8.

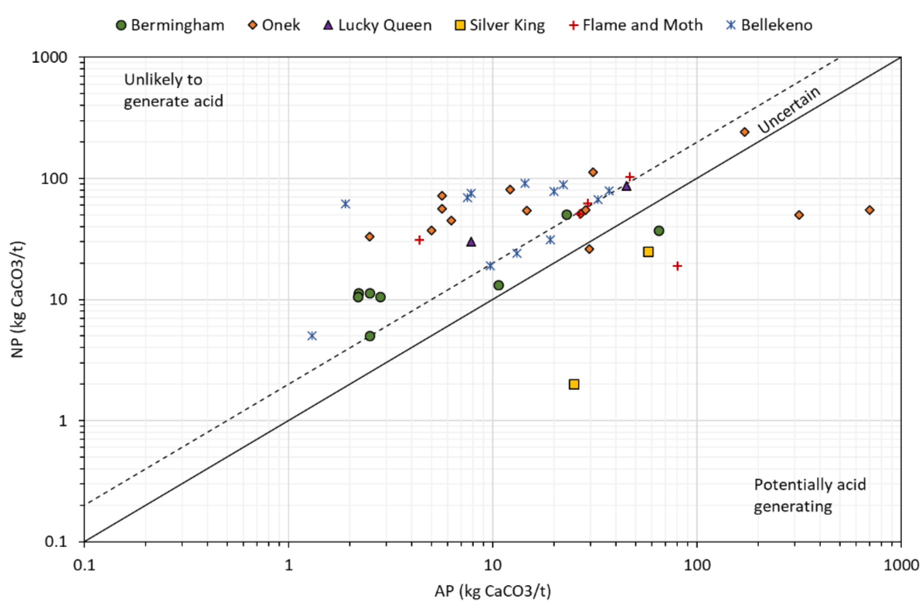
Bulk antimony and silver concentrations were higher than their respective 10x crustal abundance (2 and 0.85 ppm, respectively) for the majority of waste rock samples from Bermingham, Bellekeno, Onek, Lucky Queen, and Silver King. Lower concentrations were observed for Flame & Moth waste rock. Bulk selenium concentrations were elevated (>10x crustal abundance; 0.5 ppm) in the majority of Bermingham and Flame & Moth samples and exhibited similar distributions. Poor detection limits (10 ppm) prevented interpretation of the Lucky Queen and Silver King selenium dataset, while selenium was not analyzed in the aqua regia digests of Bellekeno or Onek waste rock.

The highest arsenic, cadmium, and zinc concentrations were observed in waste rock from Onek, Bermingham and Bellekeno. The lowest concentrations of these metal(loids), in addition to silver and lead, were returned by Flame & Moth waste rock, which were consistently lower than the crustal abundance for all three elements.



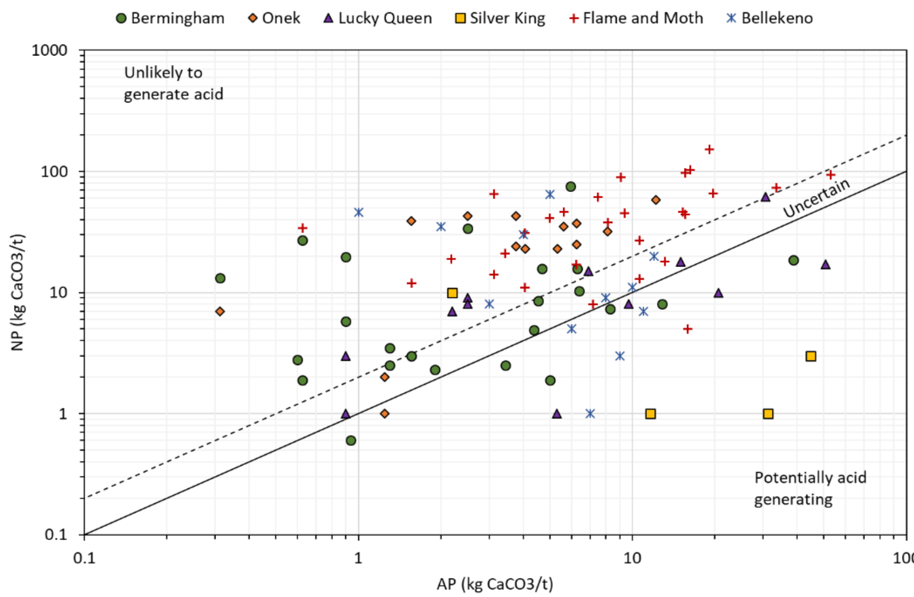
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-2: Variability in NP and AP of Waste Rock Samples from KHSD Deposits



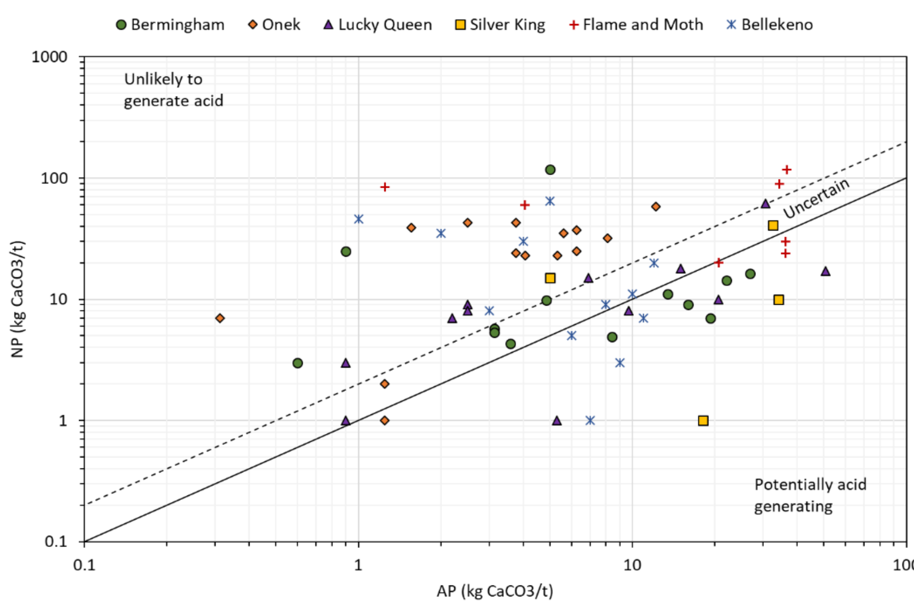
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-3: Variability in NP and AP of GSCH Lithology Waste Rock Samples from KHSD Deposits



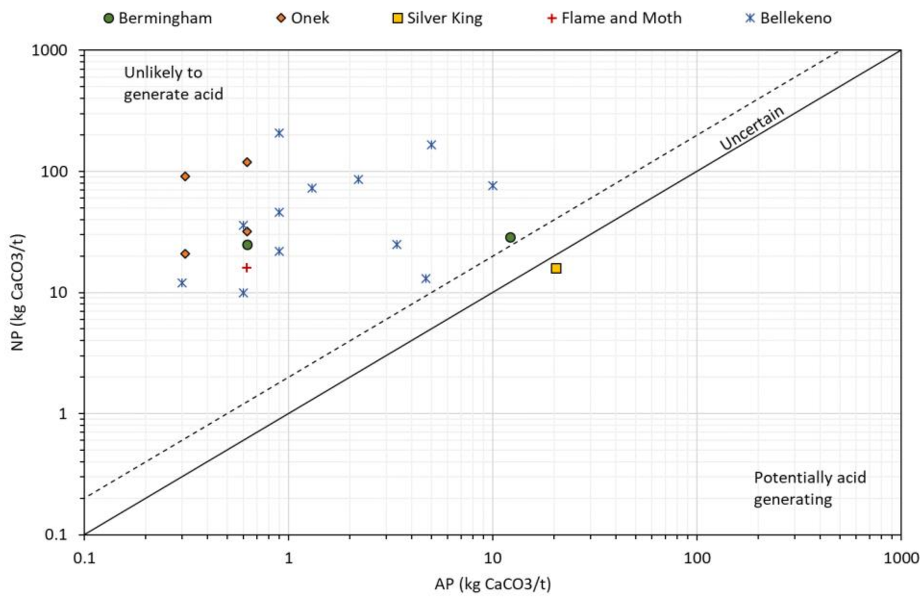
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-4: Variability in NP and AP of QTZT Lithology Waste Rock Samples from KHSD Deposits



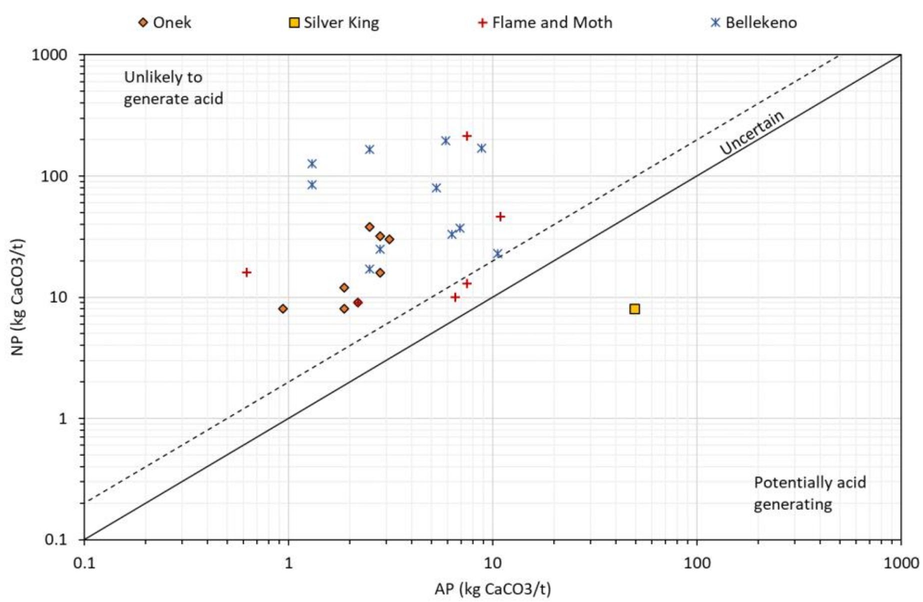
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-5: Variability in NP and AP of TQTZT Lithology Waste Rock Samples from KHSD Deposits



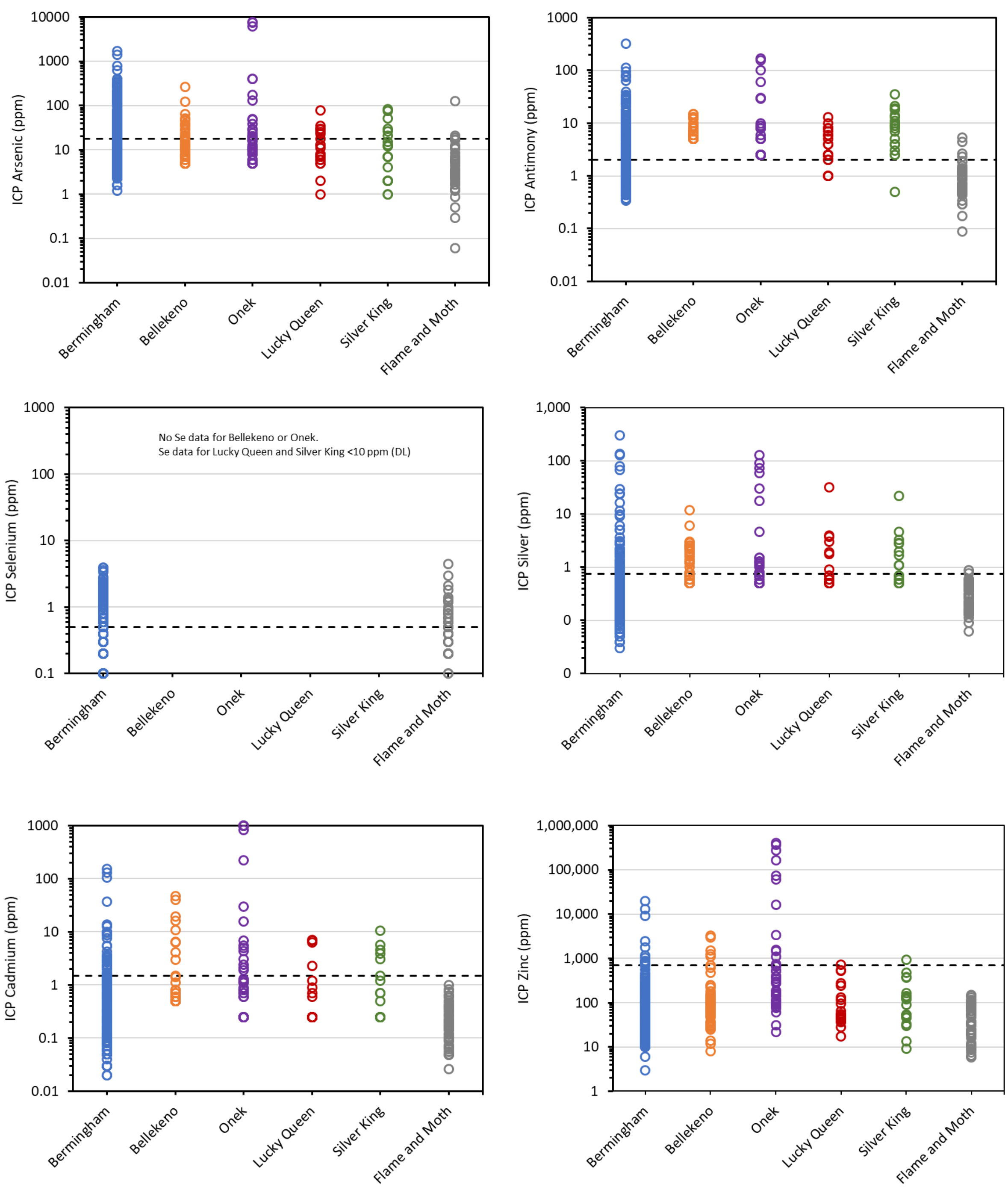
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-6: Variability in NP and AP of GNST Lithology Waste Rock Samples from KHSD Deposits



Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-7: Variability in NP and AP of SSCH Lithology Waste Rock Samples from KHSD Deposits



Dashed line represents 10x crustal abundance

Figure 4-8: Distributions of Bulk Concentrations of Antimony, Arsenic, Selenium. Silver, Cadmium, and Zinc by Deposit

4.1.3 Shake Flask Extraction

SFE provides a measure of the soluble metals in the sample that may be mobilized in the short term upon leaching processes. A summary of SFE leach tests carried out on samples from the main lithologies at Flame & Moth zone samples (n=50) and Bermingham (n = 29) are shown in Table 4-2 and Table 4-3, respectively. No SFE data are available for the other deposit areas that have appropriate trace element detection limits.

The discussion of the results is focussed on constituents that were found to be elevated relative to crustal abundance from bulk elemental analysis and/or had SFE test data that were elevated relative to Canadian Council of Ministers of the Environment (CCME, 2017) or British Columbia Ministry of the Environment (BCMoE, 2016) long-term water quality guidelines for freshwater aquatic life. Where both CCME and BCMoE guidelines were available for a constituent, the most recently updated guideline was used since this captures the most recent scientific publication related to environmental risk. Although such short-term leach extractions are not strictly comparable to water quality guidelines, such comparison aids in the identification of elevated concentrations of potentially soluble constituents and the potential for trace element leaching. This comparison is strictly for reference purposes and does not indicate compliance or otherwise with CCME, BCMoE or other water quality guidelines.

The pH of both sets of SFE sample datasets was circumneutral to alkaline, with a few samples (three Bermingham and two Flame & Moth) in exceedance of the upper CCME pH guideline (pH 9.0). Also, four Bermingham samples had SFE pH lower than the CCME pH lower guideline (pH 6.5). Elevated concentrations of SFE leachable fluoride (92% of samples exceeded 0.12 mg/L CCME guideline) and aluminum (76% of samples exceeded 0.1 mg/L CCME guideline) were observed in the Flame & Moth samples, whereas a lower proportion of exceedances (and lower concentrations) were obtained for the Bermingham samples (45% and 31% of samples exceeded guidelines for fluoride and aluminum, respectively).

A high proportion of SFE leachable antimony concentrations exceeded the BCMoE interim guideline (0.009 mg/L; 78% of samples) in the Flame & Moth dataset, whereas only six (21%) exceedances were observed for the Bermingham samples despite higher bulk antimony concentrations in the Bermingham waste rock samples (Figure 4-8 and Figure 4-9). Conversely, a higher proportion of Bermingham samples had SFE leachable arsenic concentrations that exceeded the CCME water quality guideline (0.005 mg/L; 41% of samples) compared with the Flame & Moth SFE results (6% of samples), consistent with the higher bulk arsenic in Bermingham samples (Figure 4-9). On the other hand, a similar proportion of Flame & Moth SFE leachable selenium concentrations exceeded the BCMoE guideline for selenium (0.002 mg/L; 46% of samples) as with the Bermingham dataset (45% of samples), although both sample datasets spanned a similar concentration range (Figure 4-9).

Broadly positive correlations were observed between SFE leachable and aqua regia bulk concentrations of aluminum and selenium (Figure 4-9), although the selenium correlation appears stronger within each deposit area's lithology rather than for the entire dataset.

Overall, the same constituents (fluoride, and selenium) were observed at elevated levels in the SFE leachate from both the Bermingham and Flame & Moth samples. The only notable differences were the elevated arsenic concentrations observed in 41% of the Bermingham samples, but only 6% of the Flame & Moth samples, and the elevated antimony and aluminum concentrations which were recorded in the majority of Flame & Moth dataset, but which were generally lower than the water quality guidelines in the Bermingham samples.

Table 4-2: Comparison of SFE data from Flame & Moth Zone Samples with Water Quality Guidelines

n = 50	pH	Fluoride	Aluminum	Antimony	Arsenic	Selenium
		mg/L	mg/L	mg/L	mg/L	mg/L
Guideline for Comparison	**CCME**	**CCME**	**CCME**	**BCMoE**	**CCME**	**BCMoE**
Aquatic Life Guideline	**6.5 - 9.0**	**0.12**	**0.1 [a]**	**0.009**	**0.005**	**0.002**
Maximum	9.2	4.49	6.2	0.13	0.012	0.030
3rd Quartile	8.7	0.94	0.63	0.027	0.0018	0.0036
Median	8.6	0.51	0.29	0.013	0.0012	0.0018
1st Quartile	8.4	0.28	0.10	0.0094	<0.0005	0.00085
Minimum	7.9	0.068	0.017	0.00099	<0.0005	0.00025
Samples >CCME/BCMoE	4%	92%	76%	78%	6%	46%
Highlighted Results Exceed CCME/BCMoE						

[a] Guideline based on receiving waters with pH>6.5

Table 4-3: Comparison of SFE data from Bermingham Zone Samples with Water Quality Guidelines

n = 29	pH	Fluoride	Aluminum	Antimony	Arsenic	Cadmium	Selenium
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Guideline for Comparison	CCME	CCME	CCME	BCMoE	CCME	CCME	BCMoE
Guideline Value	6.5 - 9.0	0.12	0.1 [a]	0.009	0.005	0.0002 b	0.002
Method Detection Limit	-	0.01	0.0005	0.00005	0.00002	0.000005	0.00004
Maximum	9.3	0.80	0.58	0.032	0.066	0.0004	0.03
3rd Quartile	8.8	0.26	0.11	0.005	0.011	0.00004	0.004
Median	8.1	0.10	0.04	0.002	0.003	0.00002	0.002
1st Quartile	7.1	0.07	0.02	0.001	0.002	0.00001	0.0004
Minimum	6.2	0.04	0.004	0.0004	0.0006	0.000003	0.00005
Samples >CCME/BCMoE	7	13	9	6	12	1	13
Percent >10x Crustal Abundance	24%	45%	31%	21%	41%	3%	45%
Highlighted Results Exceed Water Quality Guideline							

[a] Guideline based on receiving waters with pH>6.5

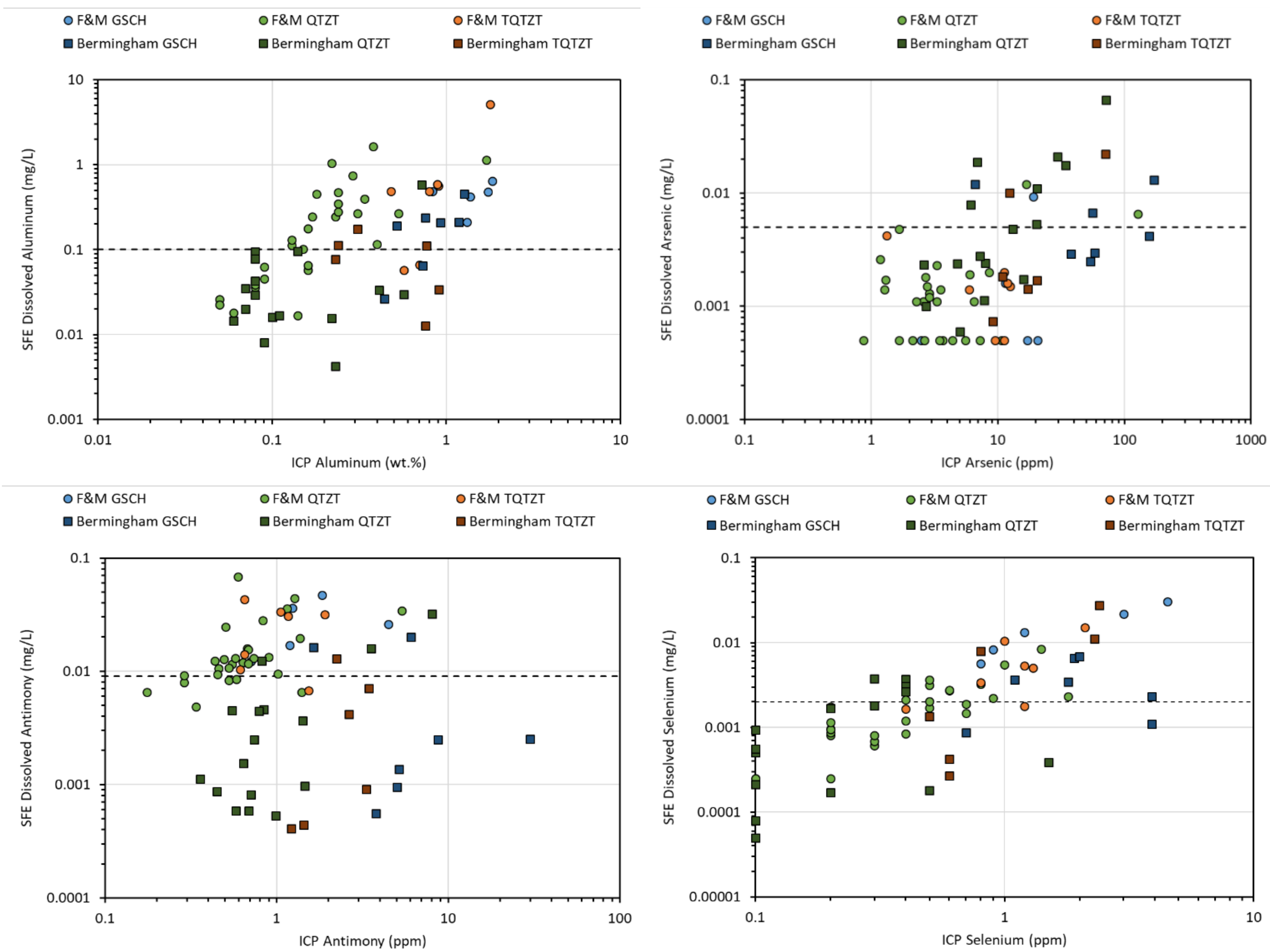


Figure 4-9: Comparison of SFE Leachable and Aqua Regia Bulk Concentrations of Aluminum, Antimony, Arsenic, and Selenium for the main lithologies in Bermingham (squares) and Flame & Moth (circles)

5 Kinetic Testing Data

Concentrations of constituents of interest in the leachate from the kinetic experiments conducted using waste rock are presented and discussed here. The effluent quality standards (EQS) set out in water licence QZ09-092, water quality objectives (WQO) at KV-21 for Bermingham, and Canadian Council of Ministers of the Environment (CCME) or British Columbia Ministry of Environment (BCMOE) (whichever is the most recent) water quality guidelines for the protection of aquatic life are also displayed where applicable for comparative purposes. The lower (i.e., 25th) percentile hardness for the nearest receiving environment was used to calculate hardness-dependent guidelines based on the 2013 to 2017 dataset:

- Station KV-51 in Christal Creek was used for Flame & Moth waste rock (25th percentile hardness 527 mg/L); and
- Station KV-21 in No Cash Creek was used for Bermingham waste rock (25th percentile hardness 316 mg/L).

5.1 Humidity Cells

5.1.1 Flame & Moth

One humidity cell was conducted using a composite of N-AML Flame & Moth waste rock and operated for 98 weeks. Details regarding the composition (ABA, metal content, etc.) of this humidity cell can be found in AEG (2016b).

pH, Acidity, Alkalinity and Sulphate

The Flame & Moth N-AML humidity cell leachate remained slightly alkaline, ranging from pH 7.5 to 8.4 (Figure 5-1)throughout the test period., The alkalinity was higher than the acidity generated during the entire test period. But declined from a peak of 127 mg/L $CaCO_3$ at week 1 to stabilize between 49 and 61 mg/L $CaCO_3$ since week 60 (Figure 5-1). Acidity was not measured during the first 9 weeks of humidity cell operations. At week 10, acidity was 16.9 mg/L $CaCO_3$, but since then remained below 6 mg/L $CaCO_3$, typically ranging between 1 and 2 mg/L $CaCO_3$ (Figure 5-1). Dissolved sulphate concentrations were the highest during the initial rinse cycle (183 mg/L at week 0) as soluble metal sulphate salts, which likely accumulated during sample storage, were washed out of the cell. Sulphate concentrations then declined slightly before reaching a plateau of between 98.9 and 129 mg/L for weeks 2 to 11 (Figure 5-1), which was likely due to a supply of metal sulphides undergoing weathering within the humidity cell. Sulphate levels declined thereafter, stabilizing between 20 and 28 mg/L since week 66 (Figure 5-1). Sulphate concentrations was below the BCMOE guideline (429 mg/L) at all times.

Trace Elements of Interest

Concentrations of cadmium, zinc, silver, lead, nickel, and copper in the Flame & Moth N-AML humidity cell leachate were typically below their respective detection limits for the majority of the 98 week operation, and well below their respective water quality guidelines (Figure 5-1 and Figure 5-2).

Antimony concentrations were highest during the initial rinse (0.011 mg/L), marginally exceeding the BCMOE working water quality guideline (0.009 mg/L), before they gradually declined over time. Antimony concentration stabilized and remained ≤0.001 mg/L since week 41 (Figure 5-3). Arsenic concentrations exhibited a stable concentration between 0.00071 and 0.00091 mg/L between week 0 and week 15 (Figure 5-3). After week 15, arsenic levels began to slowly increase, reaching 0.0024 mg/L by week 54, before declining slightly and stabilizing between 0.0016 and 0.002 mg/L since week 70 (Figure 5-3). Throughout the test period, the humidity cell leachate arsenic concentration was still at least two times lower than the CCME guideline (0.005 mg/L).

Selenium concentrations in the humidity cell leachate showed a different pattern than all other constituents. it initially declined from the initial flush value of 0.0028 mg/L to approximately 0.001 mg/L over the first two weeks before rising sharply to a peak concentration of 0.0031 mg/L at week 8 (Figure 5-3). The selenium peak coincided with the sustained elevated sulphate levels, suggesting that the dissolution of selenium-bearing metal sulphides are the likely source of selenium, and hence result in these higher selenium concentrations. Dissolved selenium concentrations then tailed off sharply as it rose, stabilizing between 0.0003 and 0.0005 mg/L from week 31 onwards (falling below the BCMOE guideline of 0.002 mg/L after week 12).

It is estimated that that the time to sulphides and NP depletion are in order of 16 and 54 years, respectively, indicating that significant portion of NP will remain after the sulphide minerals have been exhausted. The humidity cell was terminated after the concentrations of constituents of interest have stabilized. Preliminary closedown static test results show that the acidity potentially generated from remaining sulphides is less than 0.5 kg CaCO3/t significantly lower than remaining NP (51 kg CaCO3/t).

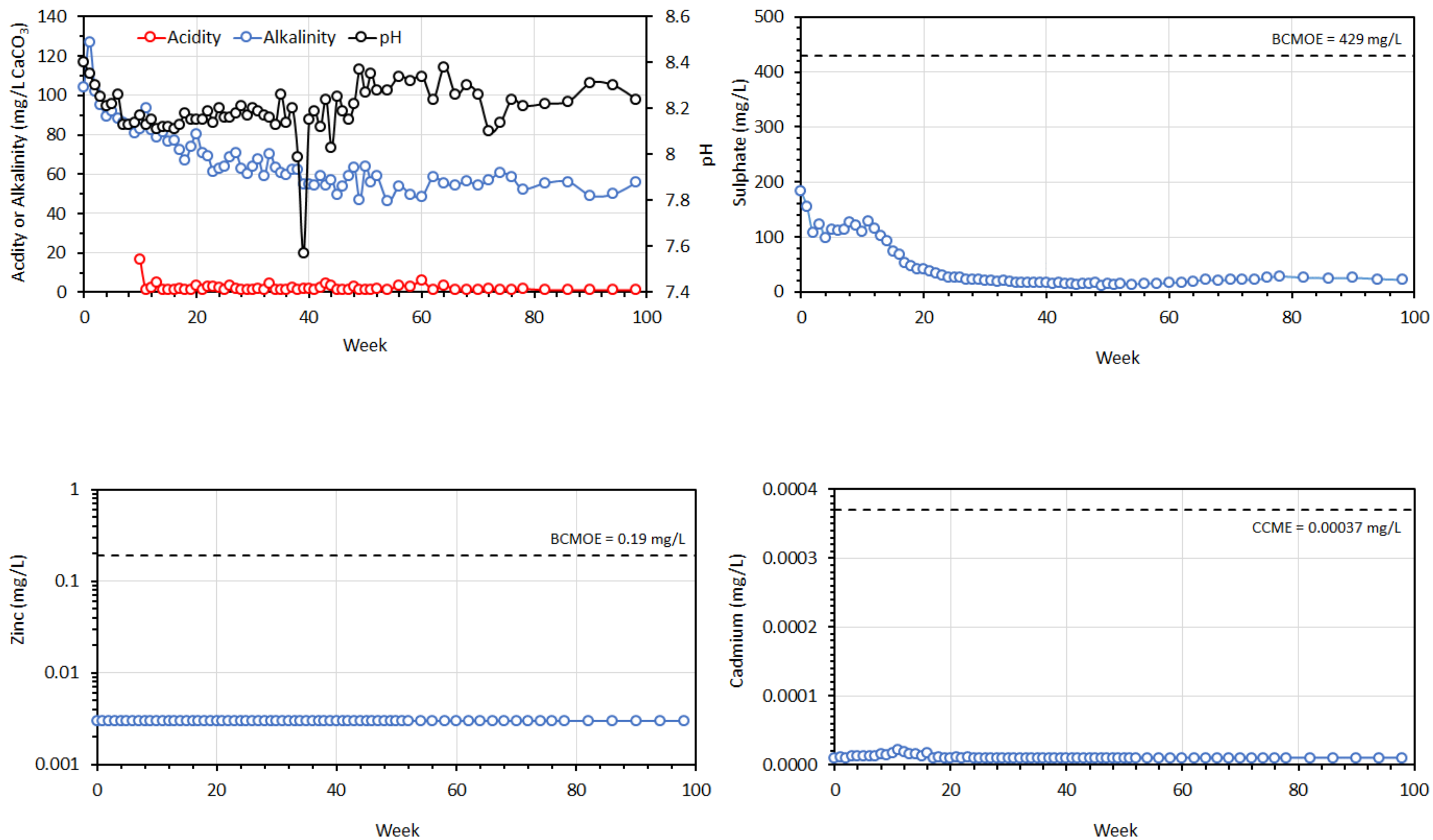


Figure 5-1: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

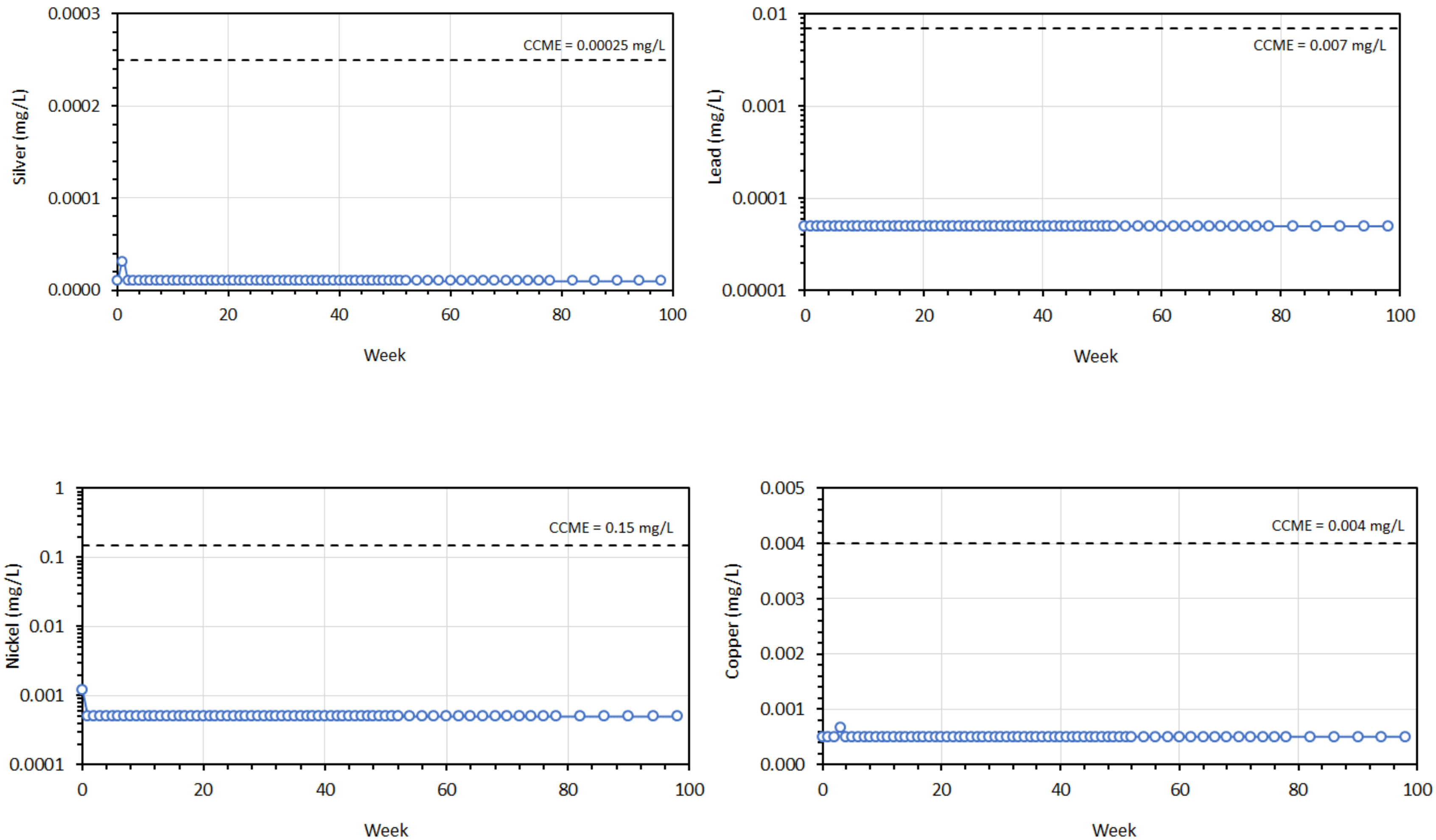


Figure 5-2: Silver, Lead, Nickel, and Copper Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

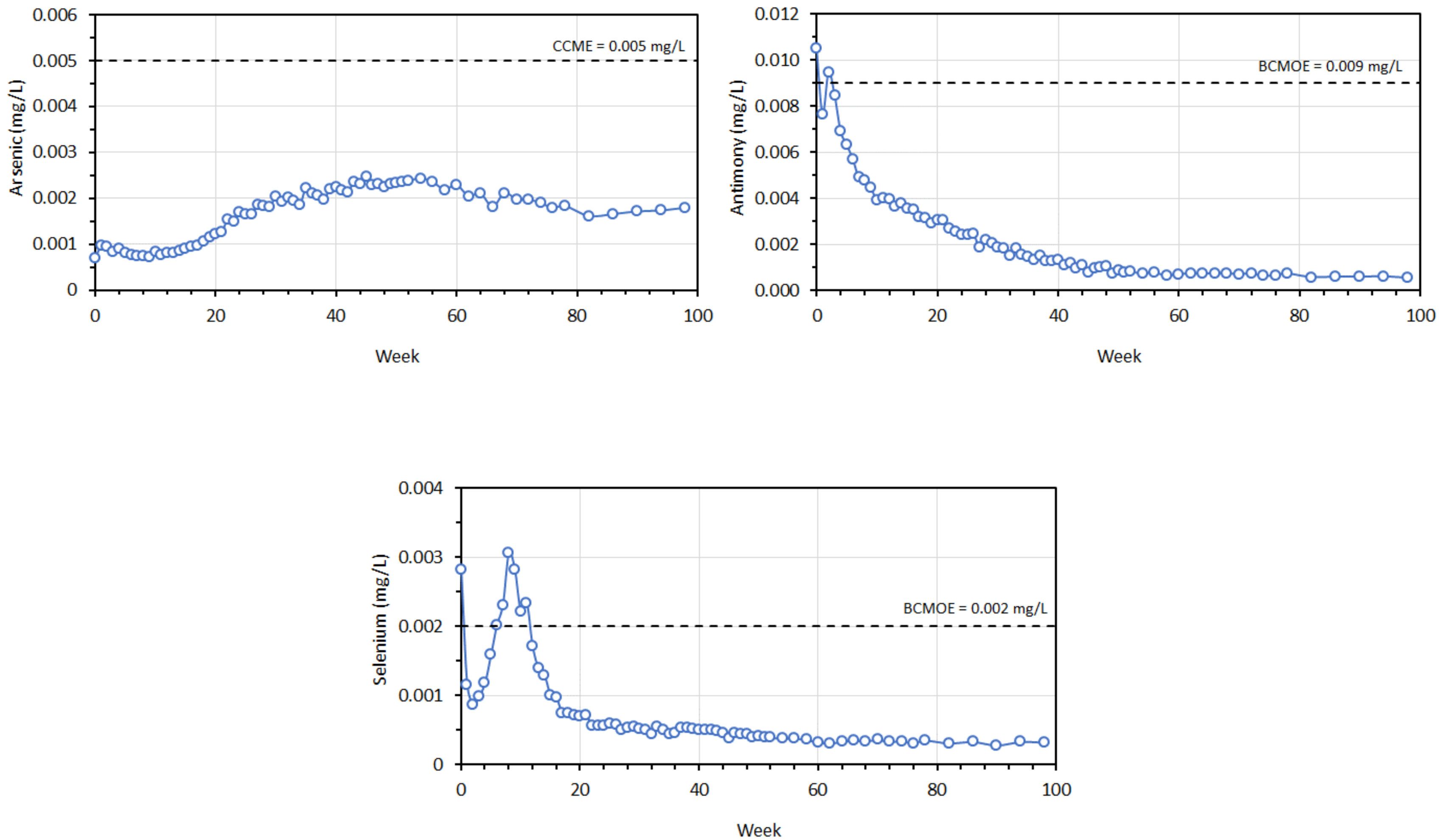


Figure 5-3: Arsenic, Antimony and Selenium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

5.1.2 Bermingham

One humidity cell was constructed using a composite of N-AML Bermingham waste rock and operated for 57 weeks. Figure 5-4 to Figure 5-6 present the humidity cell leachate data collected for constituents of interest.

pH, Acidity, Alkalinity and Sulphate

The Bermingham humidity cell leachate was circumneutral (pH 6.7 to 7.6), one pH unit lower than Flame & Moth waste rock humidity cell leachate, with relatively low levels of alkalinity (4.5 to 16 mg/L as $CaCO_3$) and negligible acidity (below or at the detection limit of 0.5 mg/L as $CaCO_3$; Figure 5-4). Sulphate concentrations were also low, ranging between 2.5 and 15.3 mg/L, over an order of magnitude lower than the WQO (359 mg/L; Figure 5-4). The sulphate release pattern in the Bermingham leachate is comparable to that of Flame & Moth but an order of magnitude lower due to its lower sulphide content compared to the Flame & Moth humidity cell composite sample.

Trace Elements of Interest

Aside from selenium (and cobalt first flush), the concentrations of all constituents of interest in the Bermingham N-AML humidity cell leachate were well below their respective WQO (Figure 5-4 to Figure 5-6). Selenium concentrations peaked at 0.009 mg/L after week one, then continued to decline gradually such that by week 11 (0.0018 mg/L) they were below the WQO (0.002 mg/L). Selenium concentrations stabilized between 0.0008 and 0.0016 mg/L from week 21. It is worth nothing that among all constituents of interested analyzed only selenium concentrations were regularly higher in the Bermingham humidity cell leachate compared to Flame & Moth. Arsenic and cadmium concentrations were also higher in the Bermingham leachate than Flame & Moth during the first ~20 and ~40 weeks, respectively, before declining below (arsenic) or becoming comparable (cadmium) with Flame & Moth concentrations thereafter (Figure 5-4 to Figure 5-6).

The concentrations of cadmium, zinc, silver, lead, nickel, and copper in the Bermingham N-AML humidity cell leachate were relatively low and more than an order of magnitude below their WQO (Figure 5-4 and Figure 5-5). Aside from cadmium, the concentrations of these elements in the Bermingham humidity cell leachate were also lower than those observed in the Flame & Moth humidity cell; however, this is largely due to the lower detection limits available for the Bermingham test work.

The time to sulphide and NP depletion in the Bermingham N-AML waste rock humidity cell was calculated to be 21 and 39 years, respectively, indicating that a significant portion of NP will remain after the sulphide minerals have been depleted. The humidity cell was terminated after the concentrations of constituents of interest had stabilized. Preliminary closedown static test data indicated that the acidity potentially from the remaining sulphides was less than 2 kg CaCO3/t, significantly lower than the remaining NP (7.3 kg CaCO3/t), consistent with the sulphide and NP depletion calculations.

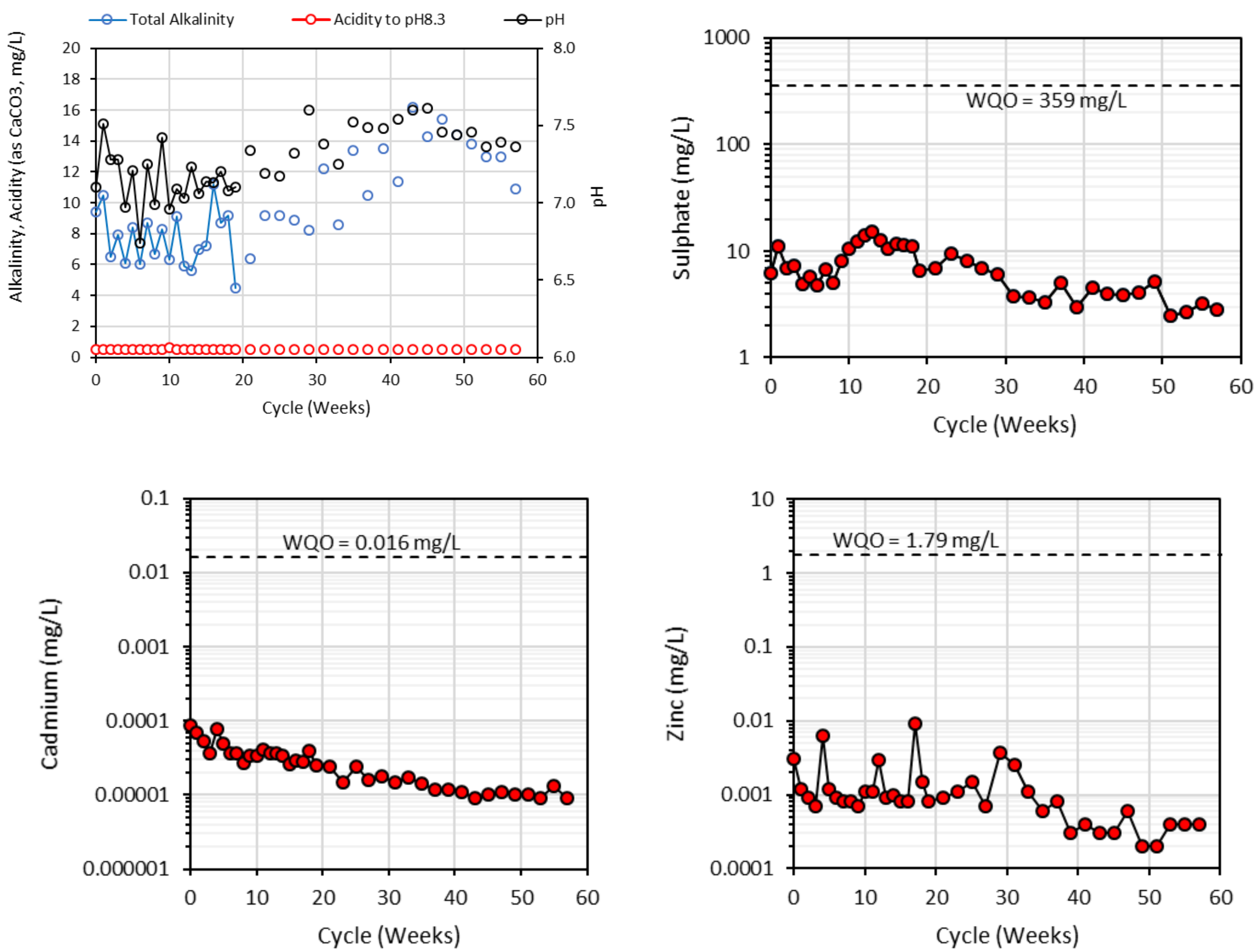


Figure 5-4: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Bermingham N-AML Waste Rock Humidity Cell

ALEXCO ENVIRONMENTAL GROUP

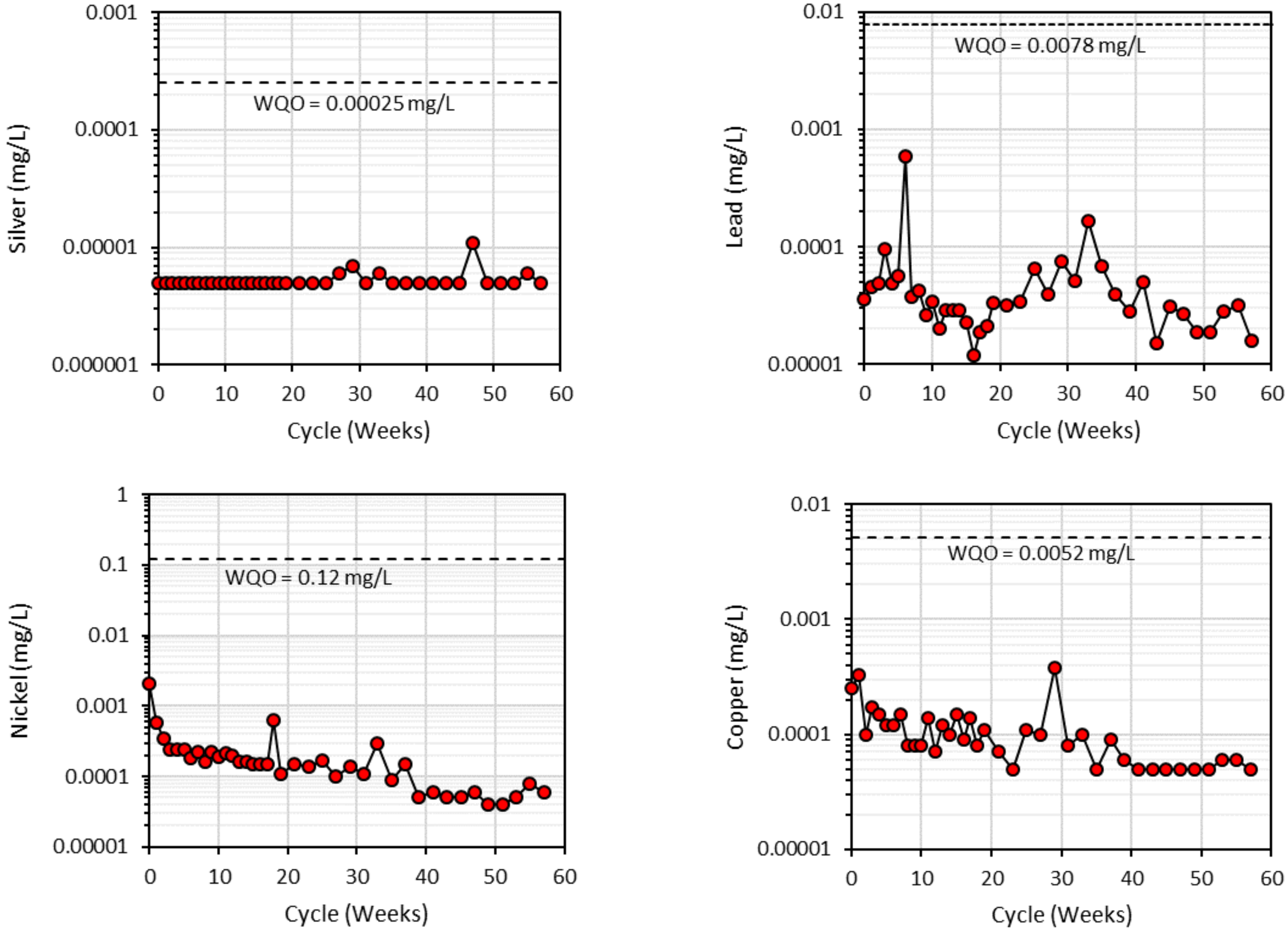


Figure 5-5: Silver, Lead, Nickel, and Copper Trends within the Bermingham N-AML Waste Rock Humidity Cell

ALEXCO ENVIRONMENTAL GROUP

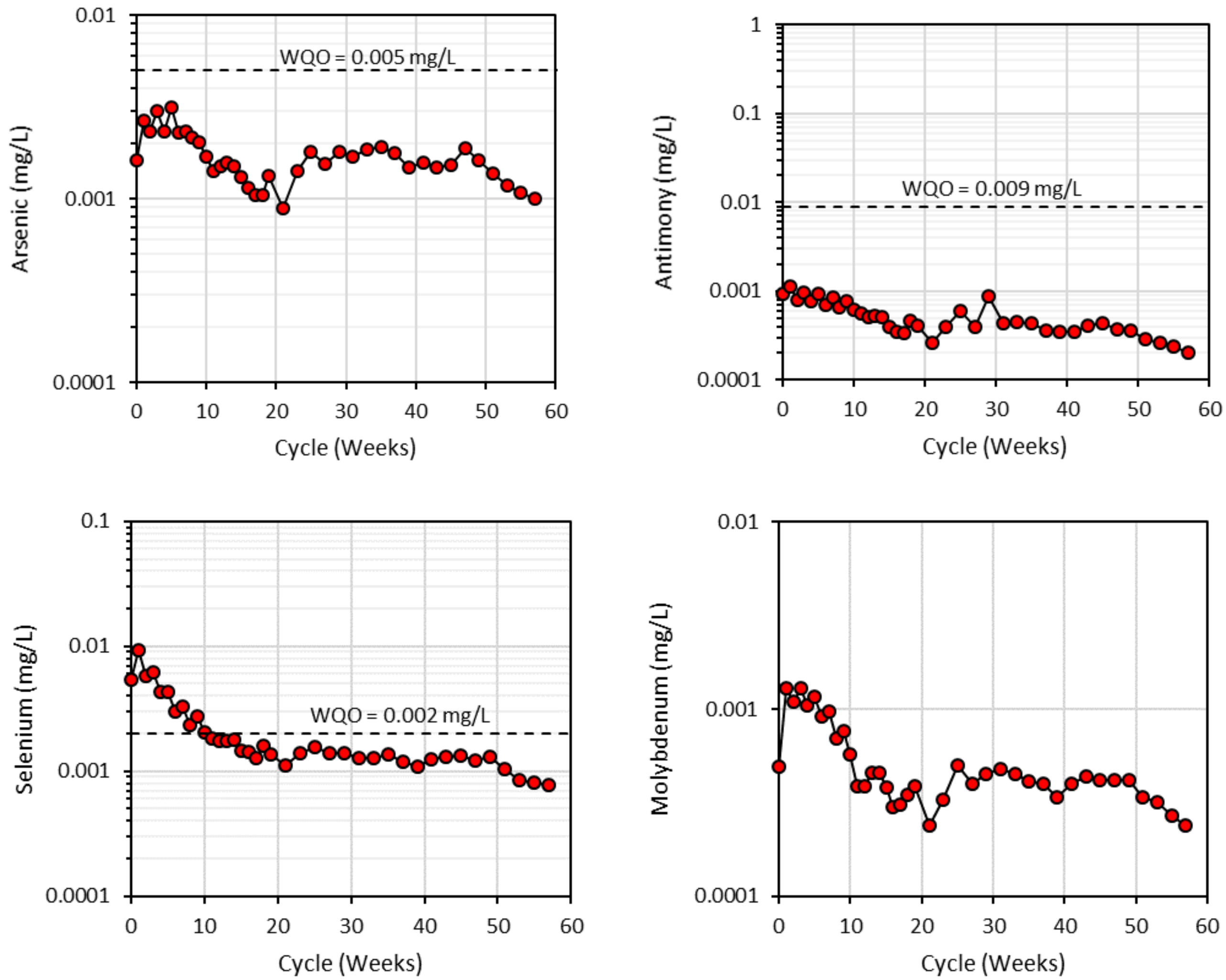


Figure 5-6: Arsenic, Antimony Selenium and Molybdenum Trends within the Bermingham N-AML Waste Rock Humidity Cell

5.2 FIELD BARRELS

Five field barrels containing Flame & Moth waste rock were constructed onsite in the June 2013 and continue to be monitored to-date. Only field leach barrels 1 to 4 are used to evaluate the proposed Flame & Moth geochemical waste rock management screening criteria and their results are discussed and displayed here. The bulk composition of field bin 5 is not representative of the material to be generated by the screening criteria proposed for Flame & Moth, therefore the results are not discussed in this memorandum.

Field barrels 1 through 4 were built to examine P-AML and N-AML from the dominant lithologies to be encountered in the development of the Flame & Moth deposit, specifically in the area of the decline. Field barrel 1 (FMB1) was filled with P-AML rock as indicated by its elevated sulphur content (median 2.79% sulphur), median NPR <1, and high maximum metal concentrations. Field barrel 2 (FMB2) was filled entirely with N-AML rock using the Bellekeno geochemical screening criteria, and has the highest median NP, relatively low sulphur content and lowest median and maximum metal content of all the field bins. Field barrels 3 and 4 (FMB3 and FMB4) were filled with N-AML rock using the proposed Flame & Moth screening criteria, but which according to the Bellekeno screening criteria contained portions of P-AML designated waste rock. This is primarily reflected in the sulphur content (median 0.39% and 0.43% for FMB3 and FMB4, respectively) and NPR (median 1.9 and 3.1 for FMB3 and FMB4, respectively) for these field barrels. These field barrels were constructed to examine the impact of P-AML rock on the overall acid rock drainage/metal leaching (ARD/ML) behaviour from the dominantly N-AML waste rock materials that would be extracted and stored within surface waste rock dumps during the development of the Flame & Moth decline/deposit. Further details regarding the composition of the field barrels can be found in AEG (2016b).

pH, Acidity, Alkalinity and Sulphate

Throughout the monitoring conducted to date, the field barrel leachate pH has remained circumneutral to slightly alkaline, ranging from pH 5.9 to 8.7 (Figure 5-7). FMB1 generally displayed the lowest pH values, whereas the highest pH values were often recorded in the leachate from FMB3. This trend reversed for the acidity levels, where FMB1 consistently exhibited acidity levels (9 – 226 mg/L $CaCO_3$) that were significantly higher than FMB2, FMB3 and FMB4 (1.8 – 3.2 mg/L $CaCO_3$; Figure 5-7). Alkalinity levels showed some limited correlation with pH, as FMB1, which was at the lower end of the leachate pH range also had the lowest alkalinity (<0.5 – 56 mg/L $CaCO_3$). This is consistent with the P-AML bulk rock materials composition that comprised FMB1. In general, alkalinity levels were the highest at the start of the field barrel experiment, declined over the next few months, and then generally stabilized. FMB1 and FMB3 showed the highest and lowest dissolved sulphate concentrations, respectively (Figure 5-7). Dissolved sulphate concentrations were typically highest in the warmer summer months and lowest for the spring and fall sampling events, except for the 2017 dataset, which showed a general increase in sulphate concentrations through the year (Figure 5-7). Indeed, leachate from the P-AML FMB1 recorded its highest sulphate concentrations to date (2,870 mg/L) in the September 2017 sampling event. Only leachate from FMB3 generally had sulphate concentrations below the BCMOE guideline (429 mg/L). Sulphate concentration in FMB2 and FMB4 oscillated about the BCMOE guideline, whereas FMB1 sulphate concentrations always exceeded the guideline.

Trace Elements of Interest

The trace element leaching trends were broadly in line with the P-AML / N-AML classification of the rock that comprised each field barrel. FMB1 was composed of P-AML material and the leachate from this bin regularly contained the highest concentrations of zinc, cadmium, nickel, lead, copper, and silver (Figure 5-8 and Figure 5-9) with cadmium and zinc constantly exceeding the EQS. FMB2, FMB3, and FMB4 were primarily composed of N-AML rock. These field barrels generally exhibited much lower zinc, cadmium, nickel, lead, copper, and silver leachate concentrations, and did not exceed any QZ09-092 EQS (Figure 5-8 and Figure 5-9).

Zinc

Leachate from the N-AML rock-bearing materials found within FMB4 had the lowest zinc concentrations that were consistently below the BCMOE guideline (0.19 mg/L; Figure 5-8). Leachate zinc concentrations from FMB2 were also typically lower than the BCMOE guideline. Leachate zinc concentrations from FMB3 were higher than FMB2 and MFB4 often higher than the BCMOE guideline but constantly lower than the EQS. FMB1 consistently showed the highest zinc concentrations (0.4 – 105 mg/L). Almost all the FMB1 samples exceeded the effluent quality standard (EQS) for zinc (0.5 mg/L), and were an order of magnitude higher than the zinc levels recorded in the other field barrels. Zinc concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. This metal leaching behaviour is in line with the predominantly P-AML rock that comprises FMB1. The zinc concentration in leachate collected from the N-AML field barrels FMB1, FMB2, and FMB3 has not exceeded the EQS to date.

Cadmium

Cadmium concentrations followed a similar trend to those of zinc (Figure 5-8). The cadmium concentration in the leachate for all the field barrels exceeded the CCME guideline (0.00037 mg/L) for all FMB1 and FMB3 samples collected to date. FMB2 leachate cadmium concentrations occasionally dipped below the CCME guideline, whereas FMB4 cadmium concentrations were regularly lower than CCME (Figure 5-8). FMB1 displayed the highest leachate cadmium levels (0.01 – 1.5 mg/L), all of which exceeded the EQS (0.1 mg/L), further confirming the P-AML nature of the rock used for this field barrel. Cadmium concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. Leachate from the other three N-AML rock filled field barrels contained cadmium levels that were below the EQS, although a rise in cadmium concentration over the summer of 2014 was noted for FMB2 and FMB3. Contrasting behaviour was noted in 2015, when the cadmium concentration in the FMB2 and FMB3 leachates peaked in July, then declined throughout the subsequent summer and fall sampling events.

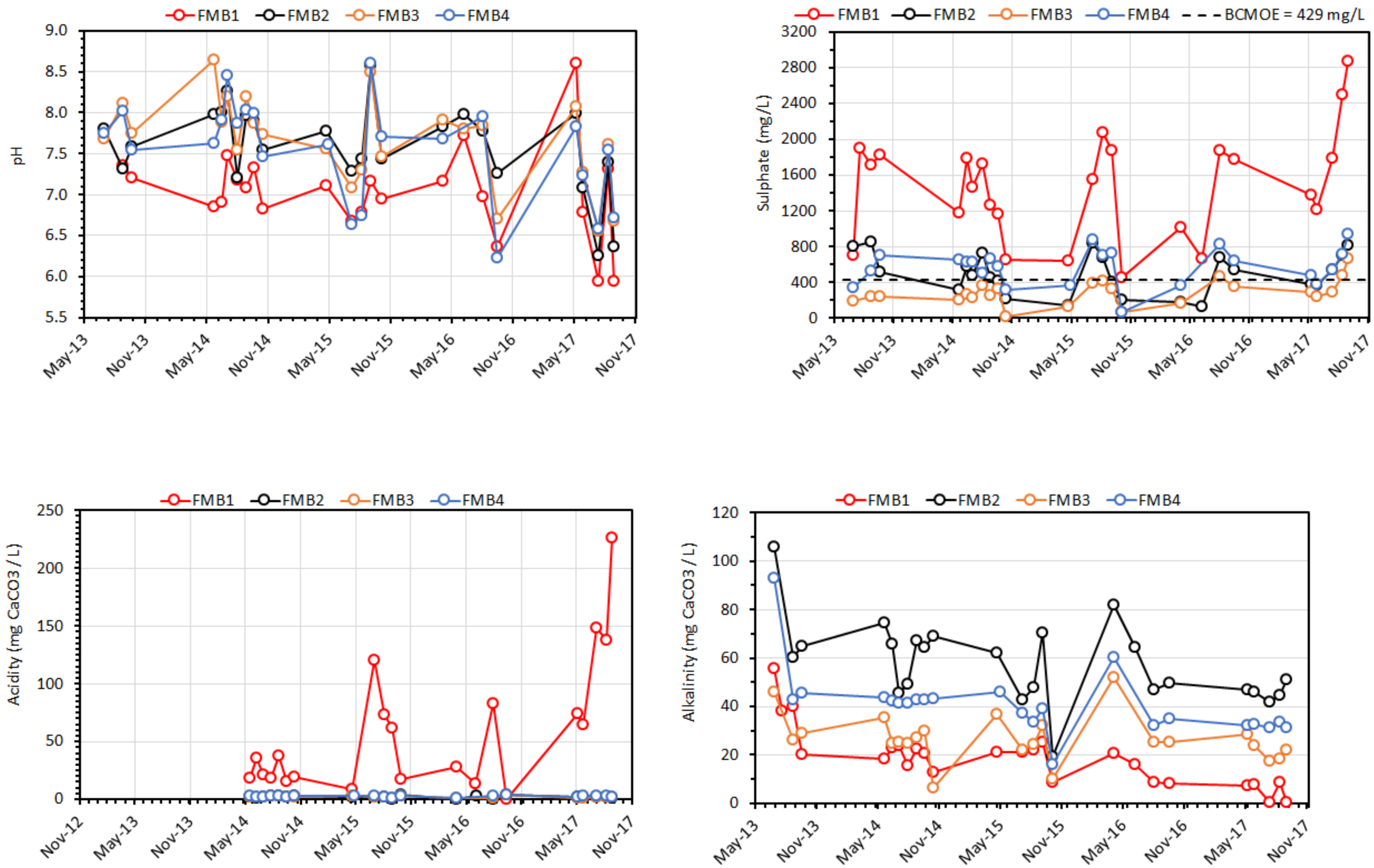


Figure 5-7: Trends in Flame & Moth Waste Rock Field Barrel pH, Sulphate, Alkalinity and Acidity Levels

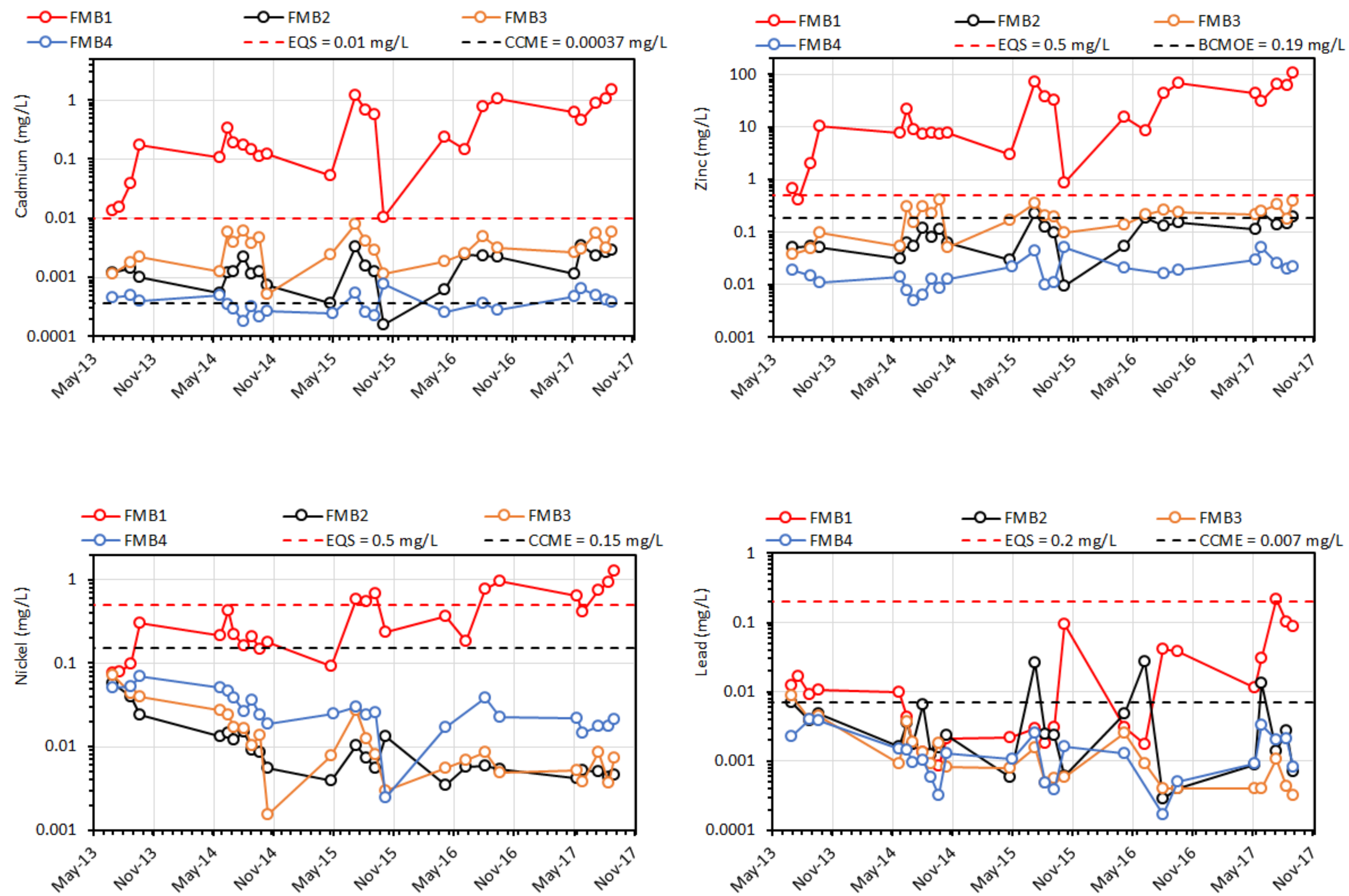


Figure 5-8: Trends in Flame & Moth Waste Rock Field Barrel Cadmium, Zinc, Nickel, and Lead Concentration

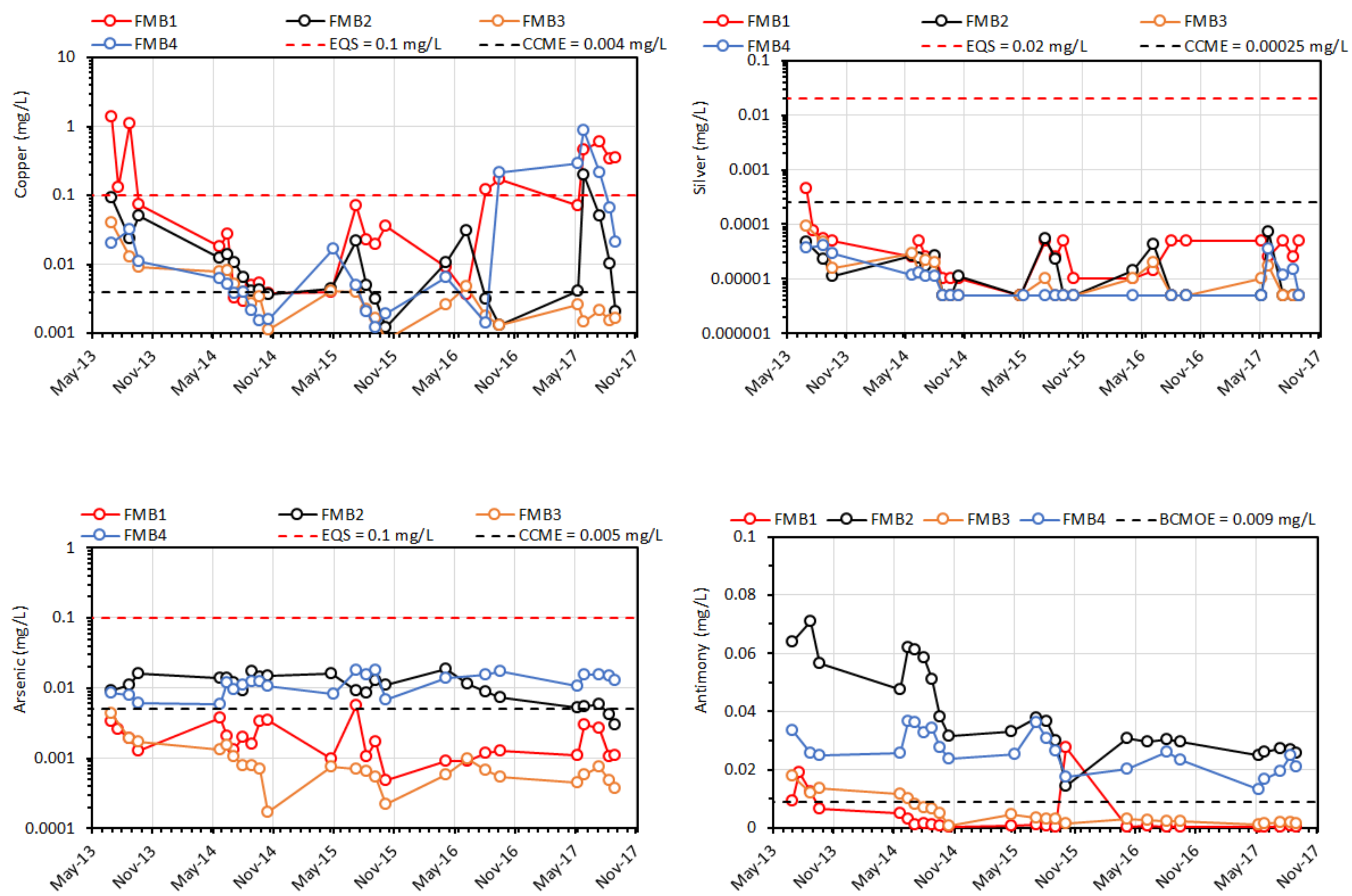


Figure 5-9: Trends in Flame & Moth Waste Rock Field Barrel Copper, Silver, Arsenic, and Antimony Concentrations

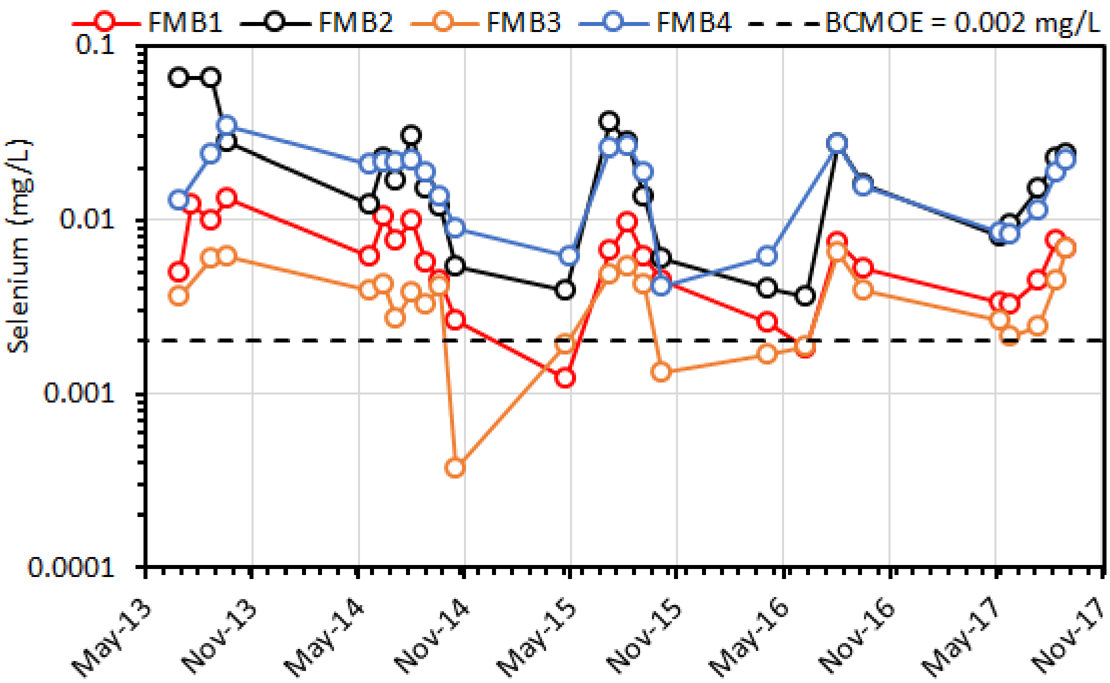


Figure 5-10: Trends in Flame & Moth Waste Rock Field Barrel Selenium Concentrations

Nickel

Nickel concentrations were highest in the leachate derived from the P-AML rock-bearing materials in FMB1 (Figure 5-8). The nickel level exceeded the CCME threshold (0.15 mg/L) for all FMB1 samples collected since June 2015, with the EQS threshold (0.5 mg/L) exceeded in three consecutive sampling events in the summer and fall of 2015, and the majority of sampling events since July 2016. Nickel concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. The nickel concentrations in the leachate collected from the three N-AML field barrels (FMB2, FMB3 and FMB4) have gradually declined over the monitoring period and did not exceed the CCME guideline or the EQS (Figure 5-8).

Lead

The leachate from FMB1 generally contained the highest lead concentrations (0.0013 – 0.22 mg/L), exceeding the CCME threshold (0.007 mg/L; Figure 5-8), and hence confirmed the P-AML nature of the rock materials used in this field barrel. Lead concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. Lead concentrations in the leachate from the three N-AML field barrels (FMB2, FMB3 and FMB4; 0.00017 – 0.027 mg/L) were typically below the CCME guideline (0.007 mg/L) except in a few instances for FMB2.

Copper

Copper concentrations followed a similar trend to those observed for lead. The P-AML rock-bearing field leach barrel FMB1 (0.003 – 1.4 mg/L) generally exhibited the highest copper concentrations over the monitoring period, exceeding the EQS (0.1 mg/L) in the first three monitoring events in 2013 and for the majority of the 2017 sampling events (Figure 5-9). Copper concentrations in leachate from N-AML FMB3 has remained below the EQS, and the CCME guideline (0.004 mg/L) for the majority of sampling events since late 2014. Conversely, FMB2 and FMB4 periodically exceeded the copper EQS in 2017 and exceeded the CCME threshold more often than not (Figure 5-9).

Silver

The P-AML FMB1 displayed the highest silver concentration in its leachate (<0.00005 – 0.00046 mg/L), although it was not particularly elevated compared to the other N-AML field barrels (<0.00001 - 0.0001 mg/L; Figure 5-9). Only the first FMB1 sampling event (0.00046 mg/L) exceeded the silver CCME guideline (0.00025 mg/L); silver levels in leachate from the other FMB1 sampling events and all the N-AML field barrels were below the CCME threshold and more than two orders of magnitude lower than the EQS (0.02 mg/L).

Arsenic

The leachate from FMB1 and FMB3 contained similar levels of arsenic (typically 0.0005 – 0.005 mg/L), which were below the CCME threshold (0.005 mg/L) for all but one sample collected to date (Figure 5-9). Arsenic concentrations in leachate from FMB2 and FMB4 were also comparable (0.006 – 0.016 mg/L), higher than FMB1 and FMB3, but exceeded the CCME limit for all the samples collected to date except for the final two 2017 sampling events for FMB2 (Figure 5-9). All the field barrel leachate was well below the EQS (0.1 mg/L).

Antimony

The antimony leaching behaviour was similar to that of arsenic. The lowest antimony concentrations were observed in leachate from FMB1 and FMB3 (0.0013 – 0.028 mg/L), in which the majority of the samples collected to date were at, or below the BCMOE working guideline (0.009 mg/L) (Figure 26). The antimony levels in the leachate from FMB4 and FMB2 were all above the BCMOE guideline, with the latter field barrel showing the highest antimony concentrations (0.014 – 0.071 mg/L). A declining trend in the leachate antimony concentration from the field barrels is broadly observed.

Selenium

The leachate selenium concentrations exceeded the BCMOE guideline (0.002 mg/L) for all samples collected to date from the FMB2 and FMB4 field barrels, and for the majority of samples collected from FMB1 and FMB3 (Figure 5-10). The lowest (FMB3: 0.00037 – 0.0069 mg/L) and highest (FMB2: 0.0037 – 0.065 mg/L; FMB4: 0.0041 – 0.034 mg/L) selenium concentrations were observed in the leachate from the N-AML field barrels, suggesting that the leaching behaviour of this element cannot be predicted based on AML classification.

The low concentrations of the of arsenic, antimony and selenium in the P-AML leach barrel FMB1 compared to the N-AML field barrels may suggest lower release rate of oxyanions from the predicted acidic water rock and a potentially elevated solubility under buffered conditions of material predicted non acid generating.

6 SUMMARY

- Waste rock generated from deposits of interest within the KHSD is expected to be predominantly non-acid generating. Only waste rock from Silver King and Bermingham is expected to have a sizeable (68% and 29 %, respectively) PAG component, perhaps reflecting a regional control on waste rock ARD potential;

- SFE testing suggested elevated soluble concentrations of fluoride, aluminum, antimony, arsenic, and selenium and potential exceedances of the CCME and BCMoE guidelines. Antimony predominantly exceed in samples from Flame & Moth, while the exceedances of arsenic are more recurrent at Bermingham; and

- Humidity cell testing indicates higher concentration release from the Flame & Moth compared to Bermingham waste rock with only antimony and selenium potentially exceeding the guidelines during early flushing events.

- Field kinetic testing of N-AML waste rock indicated that long-term metal leaching was expected to be low, although antimony, arsenic, and selenium concentrations in leachate from some Flame & Moth N-AML field barrels exceeded CCME and BCMOE guidelines by up to an order of magnitude. On the other hand, P-AML waste rock is expected to release elevated sulphate, cadmium, nickel, lead, copper and zinc in excess of water quality guidelines.

7 ONGOING WORK

At the time of writing, static ARD/ML characterization of waste rock from the Bermingham and Flame & Moth waste rock field barrels are ongoing and this technical memorandum will be updated as more data become available.

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APPENDIX 3.4

FLAME AND MOTH WASTE STORAGE FACILITY DESIGN

October 2, 2014

ISSUED FOR USE
FILE: W14103485
Via Email: kwoloshyn@alexcoresource.com

Alexco Resource Corp.
3-151 Industrial Road
Whitehorse, YT Y1A 2V3

Attention: Kai Woloshyn, Environmental Manager

Subject: Waste Storage Facility Design – Revision I
Flame & Moth Property, Keno City, Yukon

1.0 INTRODUCTION

Alexco Resource Corp. (Alexco) retained Tetra Tech EBA Inc. (Tetra Tech EBA) to provide a preliminary design for a waste containment facility for the storage of potentially acid metal leaching (P-AML) material at their Flame & Moth property west of Keno City, Yukon.

This letter summarizes the site specific foundation conditions, provides foundation preparation recommendations, and includes facility design drawings for two proposed facility locations. It also includes recommendations for the disposal of P-AML within the existing Dry Stacked Tailings Facility (DSTF). Tetra Tech EBA has reviewed the structural stability of the DSTF assuming co-mingling of produced tailings and P-AML waste rock. We have assumed the chemical implications of P-AML disposal in the DSTF will be reviewed by others. For additional information regarding the use of this report, please refer to Tetra Tech EBA's General Conditions included in Appendix A.

2.0 FLAME & MOTH WASTE STORAGE FACILITY

The Flame & Moth waste storage facility design is based on the previously completed "Typical Waste Containment Facility Design, Keno Hill Silver District, YT – Construction Specifications" (EBA 2008). The overall facility dimensions were determined based on the storage of 4,500 m^3 of waste material, as requested by Alexco.

2.1 Location I

Location I for the proposed Flame & Moth facility is southeast of the existing mill building between the Flame and Moth portal and the proposed Dry Stack Phase II Expansion. The proposed facility location and footprint are shown on the attached Figure 1.

Tetra Tech EBA has site specific historic subsurface information from a testpit excavated within the proposed footprint in 2009. W14101178.002-TP03 was excavated to a final depth of 4.0 m through roughly 3.5 m of frozen peat and SILT, over ice-poor SAND. The detailed testpit log is included in Appendix B.

2.1.1 Location I Waste Storage Facility Recommendations

Tetra Tech EBA considers Location I for the Flame & Moth waste storage facility suitable provided the following recommendations are adhered to and the facility is constructed to the dimensions and specifications in the attached Drawings.

- Tetra Tech EBA understands Alexco is currently excavating a pad for access to the Flame & Moth portal to an elevation of 907 m adjacent to the proposed waste storage facility footprint. The excavation will be about 2 m

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61 Wasson Place
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below existing grade, exposing frozen peat and silt in the upslope wall. The disturbance caused by the portal pad excavation increases the potential for thaw settlement in the ice rich peat and silt under the proposed facility – it should be removed.

- The portal pad excavation should be extended under the facility footprint to remove all frozen peat and silt, exposing the underlying sand. Any visible ice in the sand must also be removed.
- Subsequent to peat removal, 16 oz. non-woven geotextile should be placed over the entire footprint of the facility (including beneath perimeter berms and armoured slopes graded to meet original ground).
- 0.6 m of “Zone B” material should be placed and compacted over the frozen sand prior to facility construction.
- If thicker peat/silt deposits are encountered, additional “Zone B” material will be required to prepare a level working surface. The “Zone B” material should be placed in lifts no thicker than 0.5 m in uncompacted thickness and compacted to at least 95% of maximum dry density using standard effort (as per ASTM D698).
- The excavation walls beyond the footprint of the facility should be shaped at 1.5:1 (horizontal:vertical) to meet original ground, lined with non-woven geotextile as described above, and armoured with waste rock as shown on the attached Drawings.

2.2 Location II

Location II for the proposed Flame & Moth facility is east of the existing coarse ore stockpile concrete pads. The proposed facility location and footprint are shown on the attached Figure 1.

Tetra Tech EBA has site specific historic subsurface information from a testpit excavated near the proposed footprint in 2009. W14101178.002-TP07 was excavated to a final depth of 5.4 m through shallow frozen peat, 2.5 m of gravelly SAND, and 3 m SILT (till). The detailed testpit log is included in Appendix B.

2.2.1 Location II Waste Storage Facility Recommendations

Tetra Tech EBA considers Location II for the Flame & Moth waste storage facility suitable provided the following recommendations are adhered to and the facility is constructed to the dimensions and specifications in the attached Drawings.

- The existing organic cover should be left in place to reduce the risk of thaw related settlement of the facility after construction.
- A level surface for facility construction should be prepared by constructing a waste rock pad as shown on the attached Drawings.

3.0 DSTF WASTE STORAGE

The existing DSTF is a lined facility designed for the long term storage of tailings waste generated during the milling process. Tetra Tech EBA has reviewed the stability of the DSTF with respect to the storage of P-AML waste rock and determined that the calculated factors of safety increase slightly with its inclusion. This is expected as the waste rock has a larger angle of internal friction due to its angularity. Additionally, its placed weight is less than that of tailings due to its clast nature and the associated voids.

The calculated factors of safety in the most critical scenario (permafrost condition) originally presented in the “Dry Stacked Tailings Facility – Risk Assessment Stability Model Update” (EBA 2013) are compared with the calculated factors of safety when waste rock is co-mingled with tailings in the following Table 1. Detailed stability results, including critical failure surfaces, are available upon request.

Table 1: DSTF Slope Stability Factors of Safety – Fully Frozen Case

Stability Condition	Factor of Safety Suggested Minimum[1]	Calculated Factor of Safety		Calculated Factor of Safety (Waste Rock Included)	
		Alignment A	Alignment B	Alignment A	Alignment B
Stability of Surface					
Short-term (during construction – static)	1.0	2.0	2.2	2.1	2.3
Long-term (after construction – static)	1.1	2.0	2.3	2.1	2.3
Deep Seated Stability					
Short-term (during construction – static)	1.1-1.3	2.0	2.0	2.0	2.0
Short-term (during construction – pseudo-static)	1.0	1.4	1.4	1.4	1.5
Long-term (after closure – static)	1.3	1.5	1.4	1.5	1.4
Long-term (after closure – pseudo-static)	1.0	1.4	1.5	1.4	1.5

[1] Mined Rock and Overburden Piles Investigation and Design Manual (BC Mine Waste Rock Pile Research Committee, 1991)

3.1 DSTF Disposal Recommendations

Tetra Tech EBA considers the disposal of P-AML waste rock within the DSTF acceptable provided the following recommendations are adhered to:

- Waste rock should be placed in lifts no thicker than 1.0 m to limit the risk of void formation within the facility as tailings naturally filter into the voids within the placed rock during and after compaction.
- At least 0.5 m of tailings must be placed and compacted between subsequent waste rock lifts to reduce the risk of preferred pathways for water infiltration through the DSTF.
- Waste rock should not be placed within 1.0 m of the extents or final surface of the DSTF to allow for adequate encapsulation.
- Waste rock may be placed in isolated partial lifts at differing locations throughout the DSTF. In fact this approach is preferred to limit the regional variability of material used to construct the DSTF.

4.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Alexco Resource Corp and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Alexco Resource Corp, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

5.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

PROFESSIONAL ENGINEER
YUKON TERRITORY
JUSTIN PIGAGE
Oct.2/14

Justin Pigage, P.Eng.
Geotechnical Engineer, Arctic Region
Direct Line: 867.668.9213
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PERMIT TO PRACTICE
TETRA TECH EBA INC.
SIGNATURE ____
Date 04/2/2014
PERMIT NUMBER PP003
Association of Professional Engineers of Yukon

REVISION I SUMMARY:

Added recommendations for alternate facility location (Location II).

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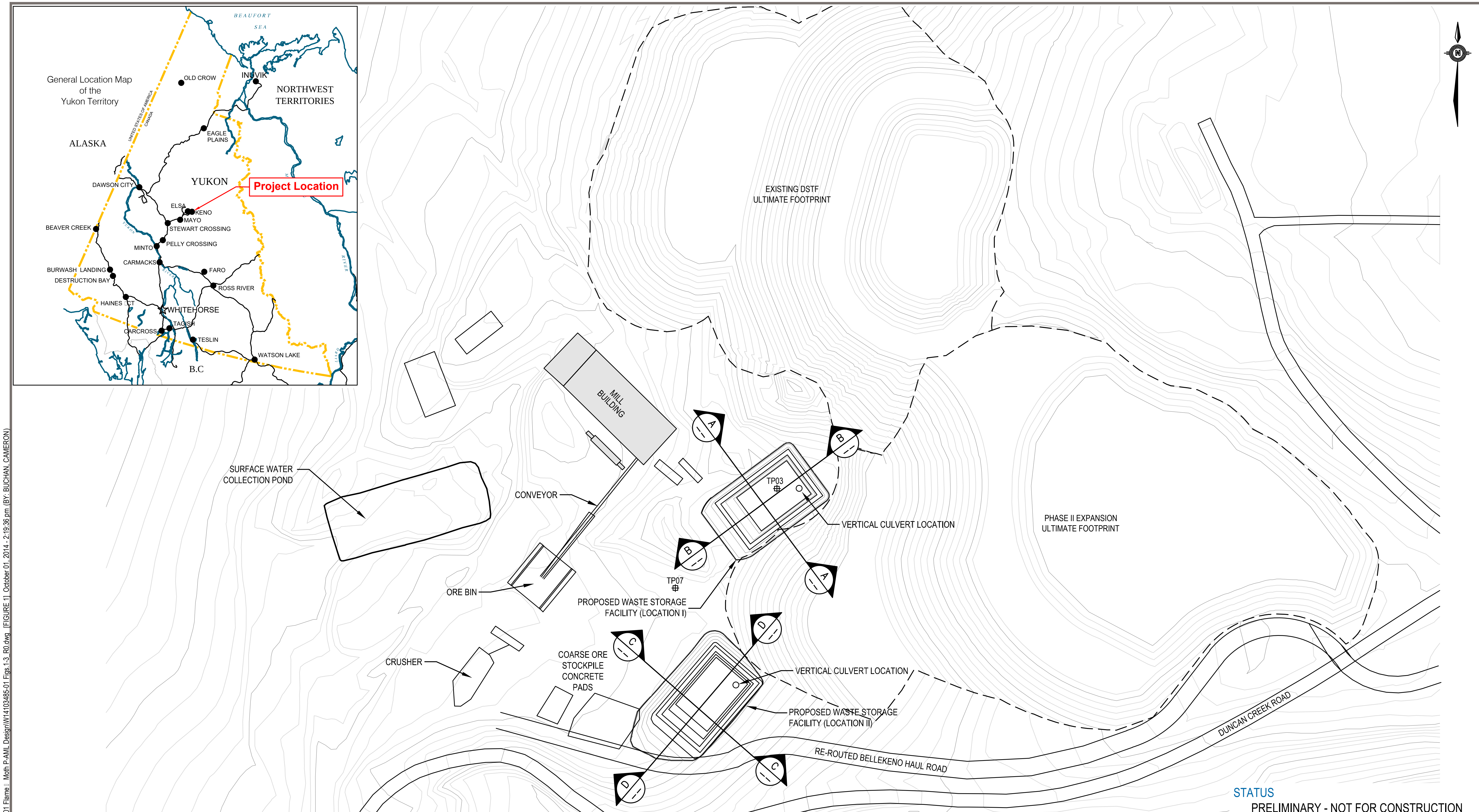
FIGURES



STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

LEGEND

⊕ - TESTPIT LOCATION (2009)

0 100 m

Scale: 1 : 1750 @ 11"x17"

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame - Moth P-AML Design\W14103485-01 Figs 1-3_R0.dwg [FIGURE 1] October 01, 2014 - 2:19:36 pm (BY: BUCHAN, CAMERON)

CLIENT

ALEXCO

TETRA TECH EBA

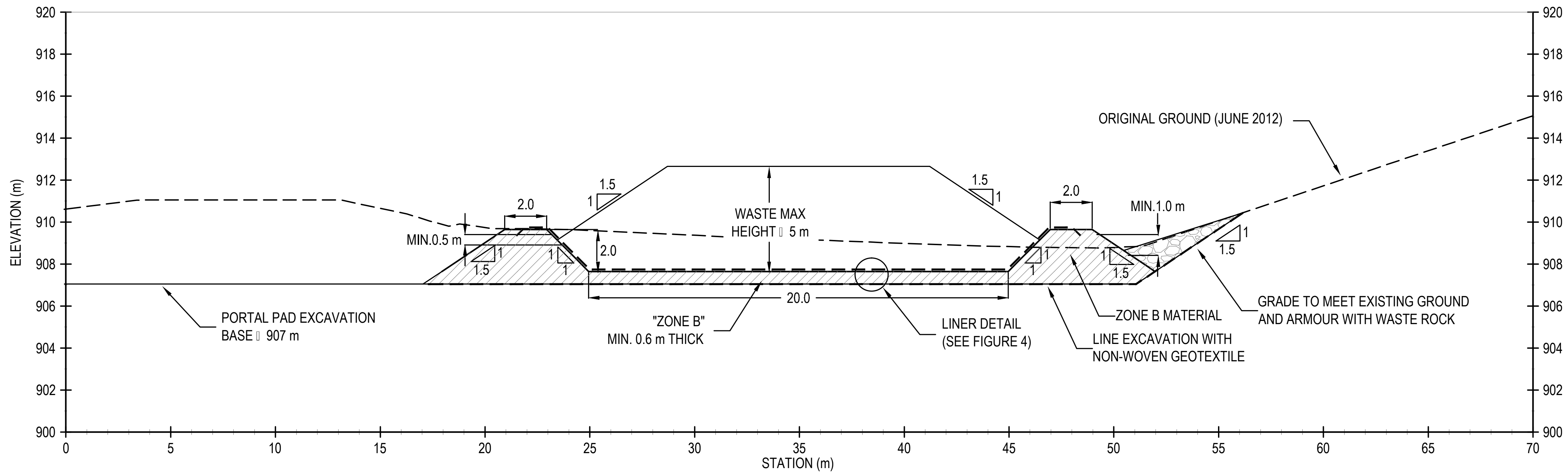
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

SITE PLAN

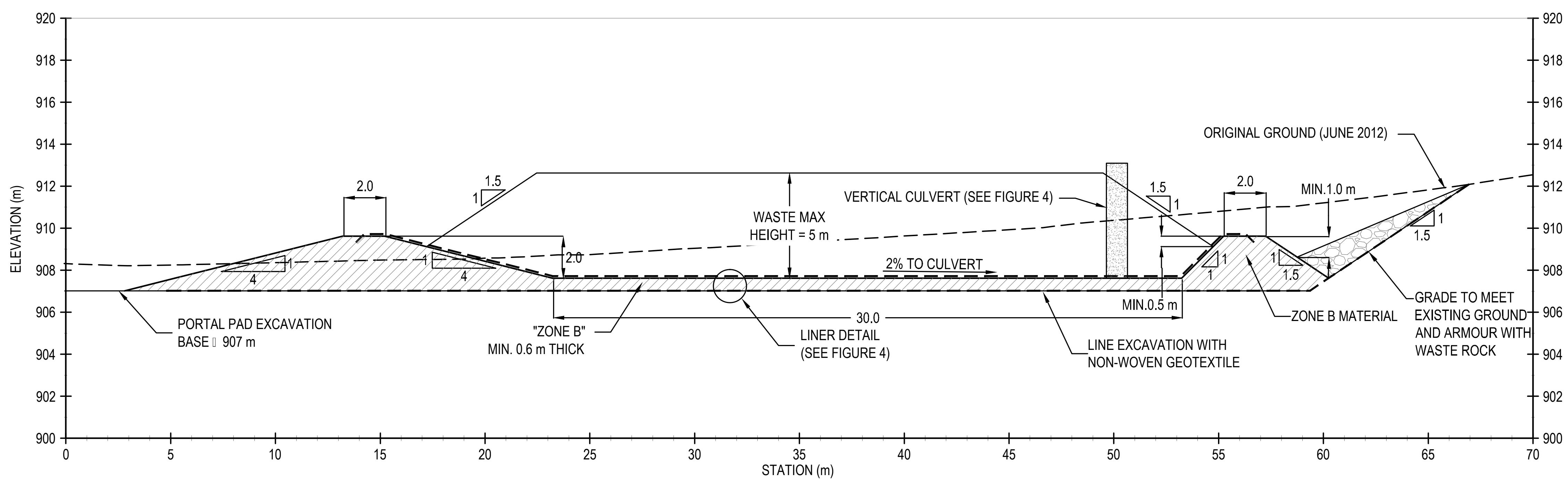
PROJECT NO.	DWN	CKD	REV
W141034□5-01	CB	□TP	0

OFFICE	DATE
EBA-WHSE	S□□□m□□r 25, 2014

F□□□r□ 1



SECTION A - A□



SECTION B - B□

STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

0 10 m

Scale: 1:250 @ 11"x17"

CLIENT

ALEXCO

TETRA TECH EBA

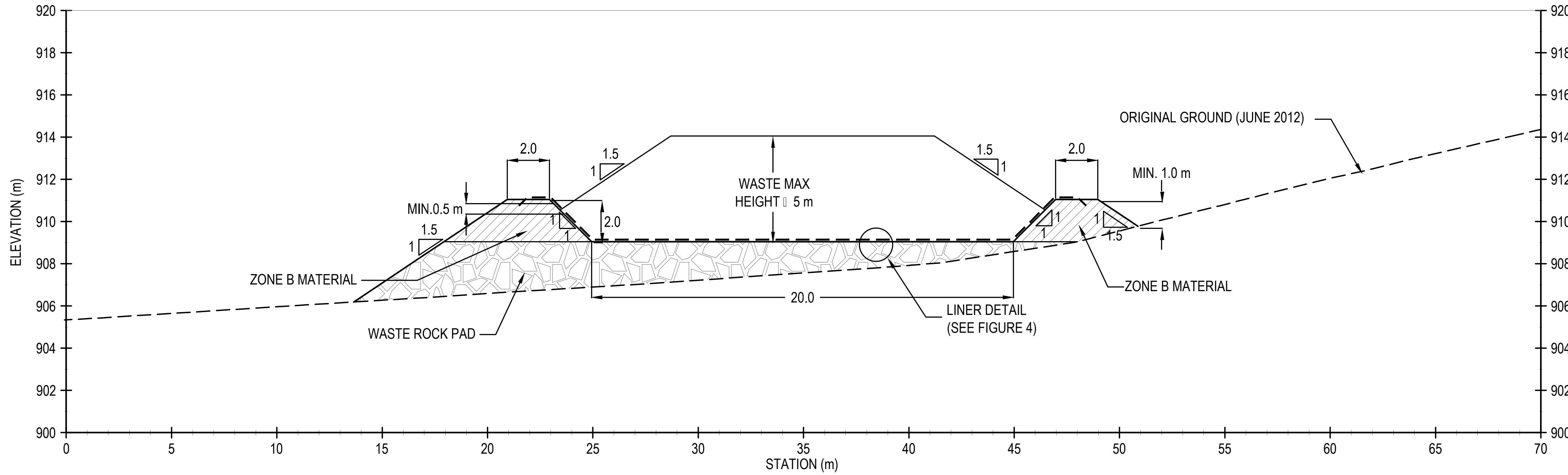
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

LOCATION I CROSS-SECTIONS

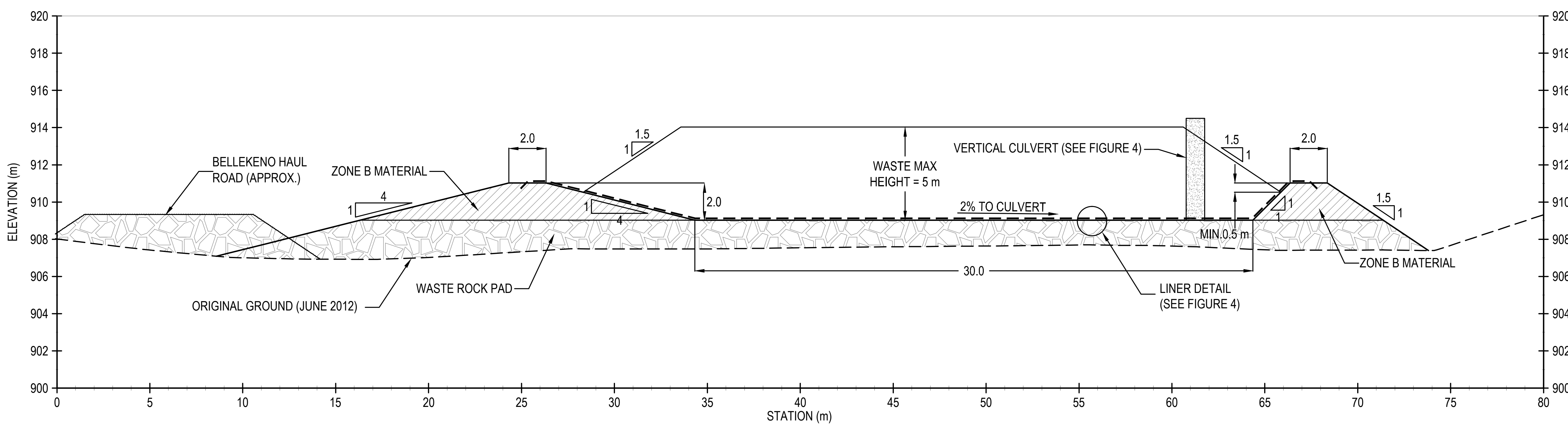
PROJECT NO.	DWN	CKD	REV
W141034□5-01	CB	□TP	0
OFFICE	DATE		
EBA-WHSE	S□□□m□□r 25, 2014		

F□□r□ □

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame□ Moth P-AML Design\W14103485-01 Figs 1-3_R0.dwg [FIGURE 2] October 01, 2014 - 2:20:40 pm (BY: BUCHAN, CAMERON)



SECTION C - C′



SECTION D - D′

0 10 m

Scale: 1:250 @ 11"x17"

STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

CLIENT: ALEXCO

TETRA TECH EBA

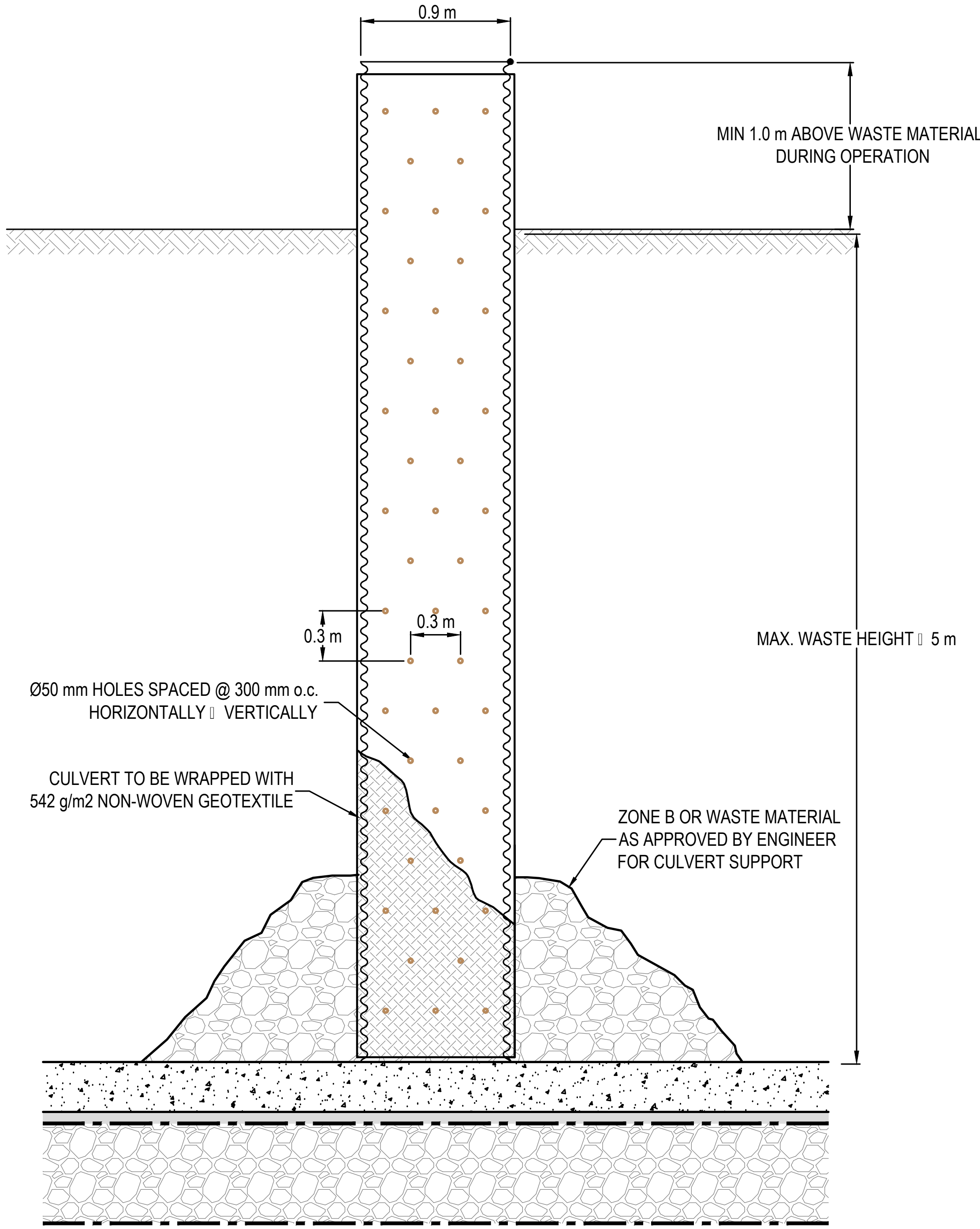
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

LOCATION II CROSS-SECTIONS

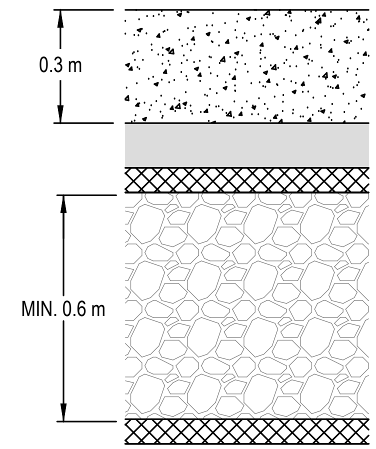
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	TP	0

OFFICE	DATE
EBA-WHSE	September 25, 2014

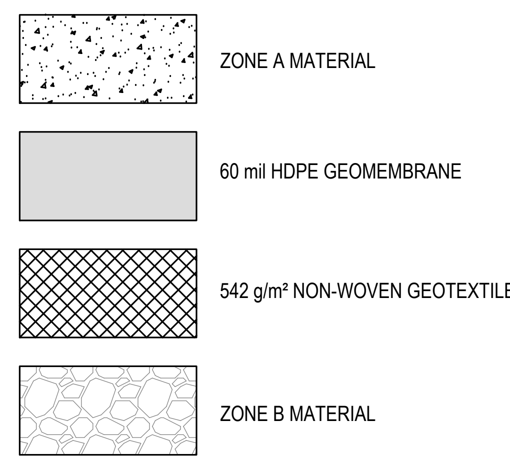
Figure 3



DETAIL 1 - VERTICAL SUMP CULVERT



DETAIL 2 - FACILITY FLOOR AND BERMS



LINER SYSTEM DETAIL KEY

NOTES :

These specifications, relevant to construction of the Flame Moth Waste Storage Facility, have been extracted from the Typical Waste Containment Facility Design Construction Specifications, Keno Hill Silver District, YT (EBA July 2008).

The Flame Moth Waste Storage Facility shall be constructed to the specifications below and the dimensions indicated on the Construction Drawings.

Water in the facility will flow towards and pond in the vertical culvert where it 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.

The facility has been sized based on containment of approximately 4,500 m3 of waste, when the ultimate capacity is reached a 0.5 m soil cover will be placed over the entire facility.

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 1, or as approved by the Engineer.

The Zone B 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 1, or as approved by the Engineer.

The fill materials shall be placed in lifts not exceeding 0.5 m in uncompacted thickness and compacted to at least 95% of maximum dry density using standard effort as per ASTM D698.

The non-woven geotextile shall be 542 g/m2 Layfield LP16 or equivalent approved by the Engineer.

The HDPE geomembrane shall be 1.6 mm (60 mil) thick Layfield HDPE 60 or equivalent approved by the Engineer.

The HDPE geomembrane seems shall be welded by a suitably qualified contractor. Trial seems shall be conducted prior to start-up each day and at approximately 4-hour intervals during seaming operations. During the trial seam, the minimum strength criteria set by the manufacturer for the geomembrane should be met.

No construction equipment shall be allowed to travel on the liner prior to the placement of the protective Zone A cover material.

Table 1: Particle Size Distribution Limits

Zone B Material		Zone A Material	
Particle Size (mm)	**% Passing by Mass**	**Particle Size (mm)**	**% Passing by Mass**
200	100		
100	85 – 100		
50	65 – 100		
25	40 – 100	10	100
5	20 – 55	5	80 – 100
2	0 – 20	2	55 – 100
		0.63	25 – 65
		0.25	10 – 40
		0.08	2 – 15

STATUS
PRELIMINARY - NOT FOR CONSTRUCTION

NOTE
- THIS PLAN IS NOT TO SCALE

CLIENT
ALEXCO

TETRA TECH EBA

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

DETAILS AND NOTES

PROJECT NO.	DWN	CKD	REV
W141034□5-01	CB	□TP	0
OFFICE	DATE		
EBA-WHSE	September 26, 2014		

Figure 4

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame Moth P-AML Design\W14103485-01 Fig 3_R0.dwg [FIGURE 3] September 30, 2014 - 3:02:12 pm (BY: BUCHAN, CAMERON)

APPENDIX A
TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA's Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B
HISTORIC TESTPIT LOGS

Flame and Moth Mill & DSTF	CLIENT: Alexco	PROJECT NO. - TESTPIT NO.
Mill Pad	EXCAVATOR: Hitachi 270 LC	W14101178.002-TP03
near Keno City, YT	7086760N; 484004E; Zone 8	ELEVATION: 907.4m

SAMPLE TYPE: DISTURBED, NO RECOVERY, SPT, A-CASING, SHELBY TUBE, CORE

BACKFILL TYPE: BENTONITE, PEA GRAVEL, SLOUGH, GROUT, DRILL CUTTINGS, SAND

Depth (m)	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NUMBER	TEMP (°C)	STANDARD PENETRATION (N) 20 40 60 80 / POCKET PEN. (kPa) 100 200 300 400 / PLASTIC M.C. LIQUID 20 40 60 80	GROUND ICE DESCRIPTION	Elevation (m)
0	PEAT - amorphous granular, roots, organics, black and brown, frozen					Frozen	907.0
1		Disturbed	SA01		354		
		Disturbed	SA02		1158		906.0
2							905.0
3	SILT - some sand, trace clay, soft (est.), low-plastic, massive, frozen, olive grey	Disturbed	SA03	-1.7		Vs (35%) ice lens up to 10cm thick	904.0
	SAND - silty, gravelly, trace clay, firm (est.), non-plastic, massive, frozen, olive grey	Disturbed	SA04			Vs and Vc (5%)	
4	EOH - target depth						903.0
5							902.0
6							

EBA Engineering Consultants Ltd.	LOGGED BY: CJD	COMPLETION DEPTH: 4m
	REVIEWED BY: JRT	COMPLETE: 5/6/2009
	DRAWING NO: Figure 2	Page 1 of 1

Flame and Moth Mill & DSTF	CLIENT: Alexco	PROJECT NO. - TESTPIT NO.
Mill Pad	EXCAVATOR: Hitachi 270 LC	W14101178.002-TP07
near Keno City, YT	7086712N; 483955E; Zone 8	ELEVATION: 906.7m

SAMPLE TYPE: DISTURBED, NO RECOVERY, SPT, A-CASING, SHELBY TUBE, CORE

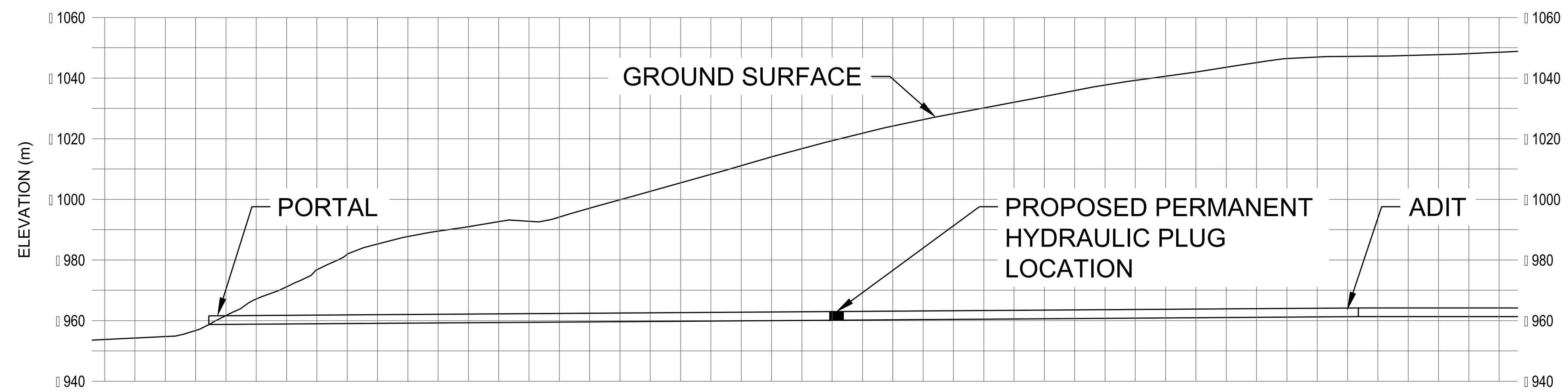
BACKFILL TYPE: BENTONITE, PEA GRAVEL, SLOUGH, GROUT, DRILL CUTTINGS, SAND

Depth (m)	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NUMBER	TEMP (°C)	STANDARD PENETRATION (N) 20 40 60 80 / POCKET PEN. (kPa) 100 200 300 400 / PLASTIC M.C. LIQUID 20 40 60 80	GROUND ICE DESCRIPTION	Elevation (m)
0	PEAT - some silt, woody, roots, black					Frozen	
	SILT - sandy, some gravel, medium, non-plastic, frozen, brown, organics, roots	Disturbed	SA01				
	SAND - gravelly, trace cobbles, trace silt,, compact (est.), medium grained, well graded, damp to moist, brown, sub-rounded						906.0
1		Disturbed	SA02				
						Unfrozen	905.0
2	- seepage					Frozen Nbn	
	SILT - sandy, some gravel, trace clay, stiff (est.), low plastic, massive, olive grey						904.0
3		Disturbed	SA03	-0.1		Vx, Vc (<5%)	
						Unfrozen	903.0
4							
		Disturbed	SA04	1.5			902.0
5							
	EOH - refusal at probable bedrock (quarzite)						901.0
6							

EBA Engineering Consultants Ltd.	LOGGED BY: CJD	COMPLETION DEPTH: 5.4m
	REVIEWED BY: JRT	COMPLETE: 5/6/2009
	DRAWING NO: Figure 2	Page 1 of 1

APPENDIX 3.5

PRELIMINARY SHAFTS AND ADITS BULKHEAD DESIGN



NO CASH 500 ADIT
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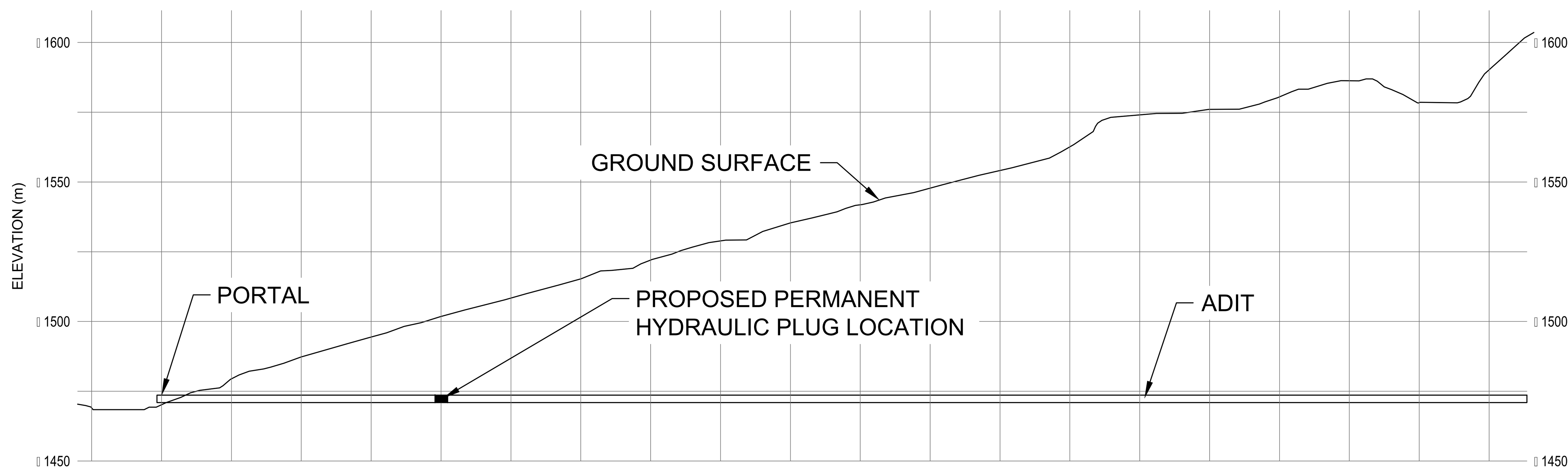
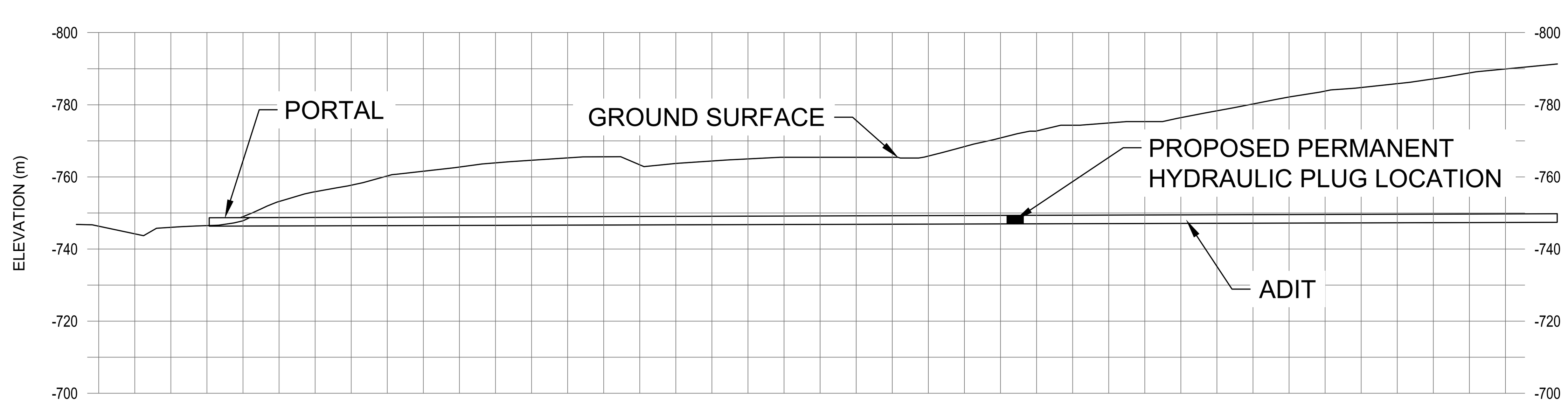


KENO 700 ADIT
SCALE 1:1500



SILVER KING 100 ADIT
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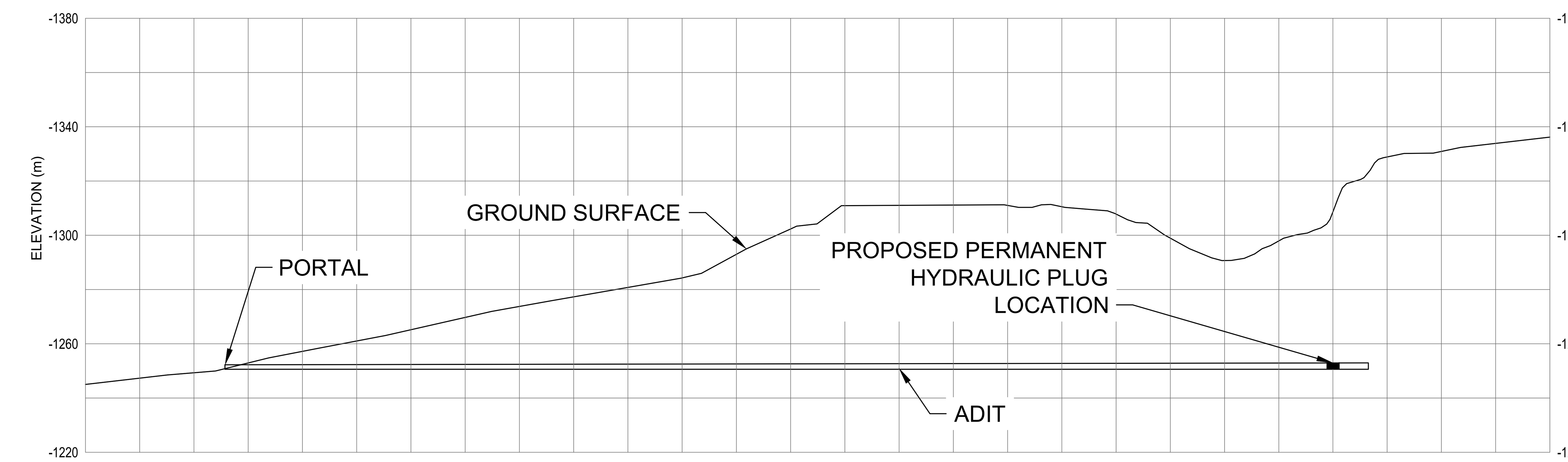
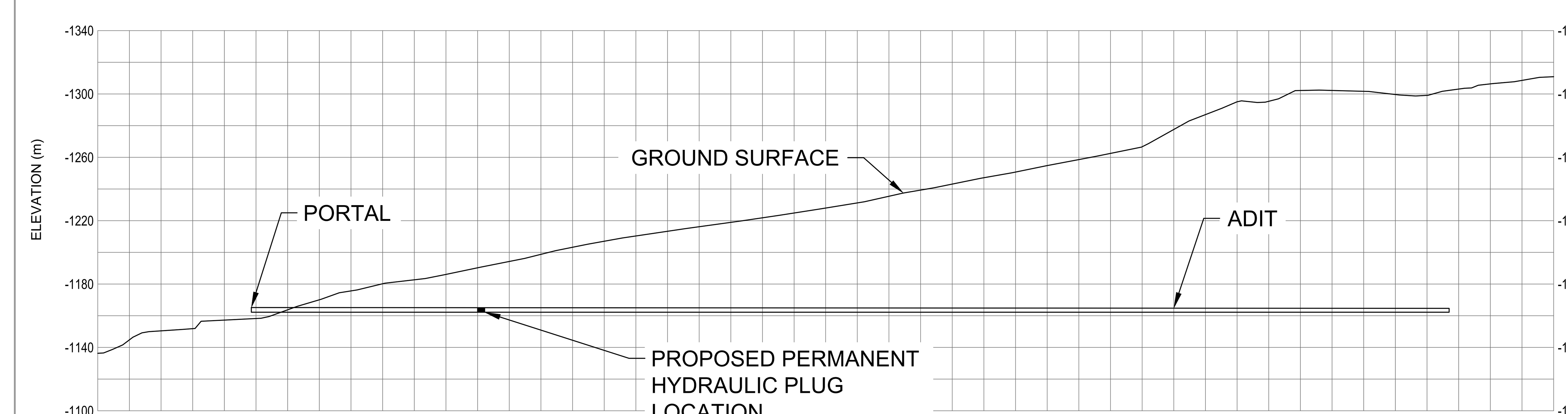


BERMINGHAM CROSS SECTION ALONG ADIT
SCALE 1:1500



RUBY CROSS SECTION ALONG ADIT
SCALE 1:2500

NOT ISSUED FOR CONSTRUCTION

LEGEND

NOTES

1. ALL UNITS ARE IN METERS UNLESS NOTED OTHERWISE.

NUM	DATE	DWN	CKD	APR	DESCRIPTION

REVISIONS

NUM	DATE	APR	DESCRIPTION

DRAWING STATUS

PERMIT

PROFESSIONAL SEAL

CLIENT

ERDC

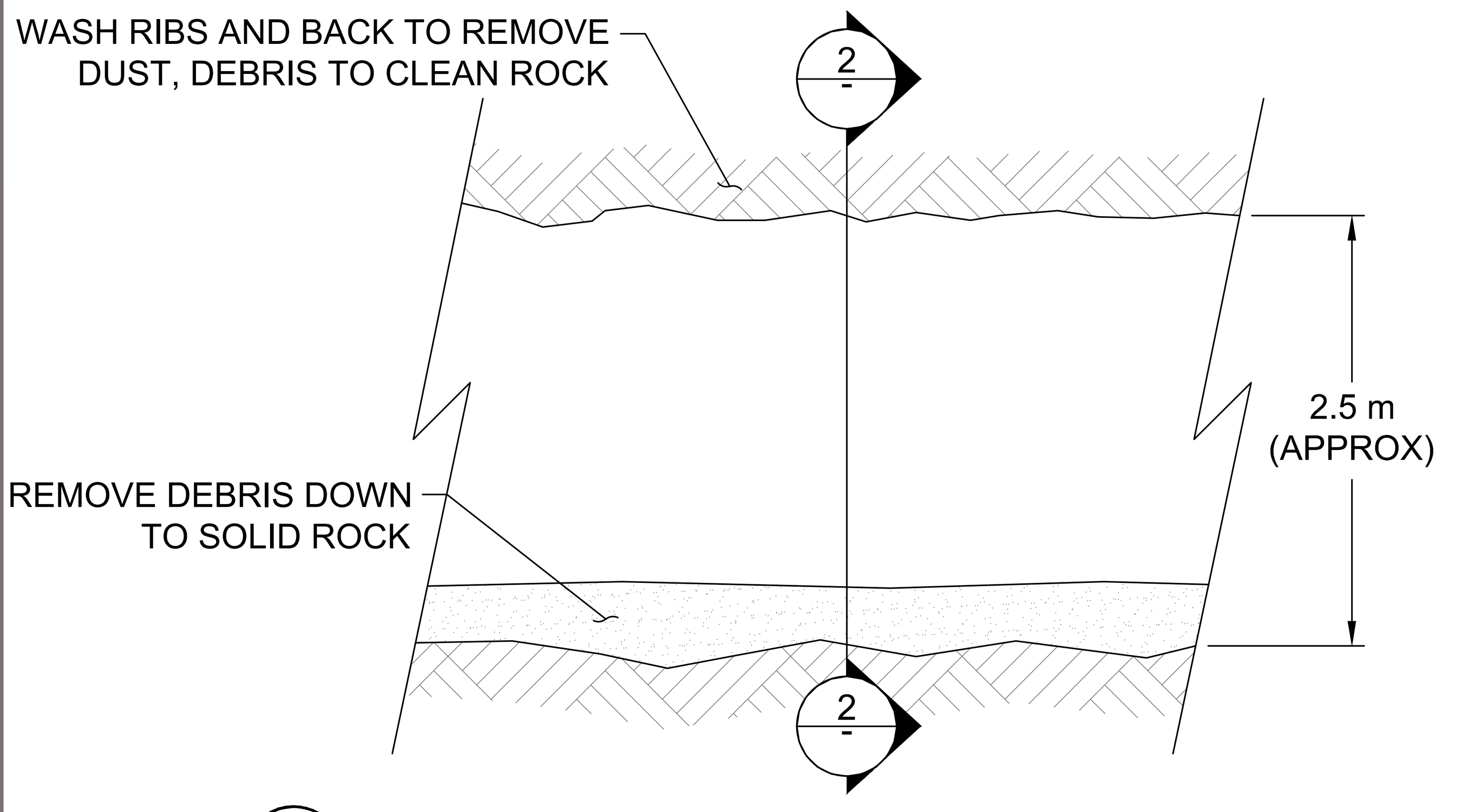
TETRA TECH EBA

ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

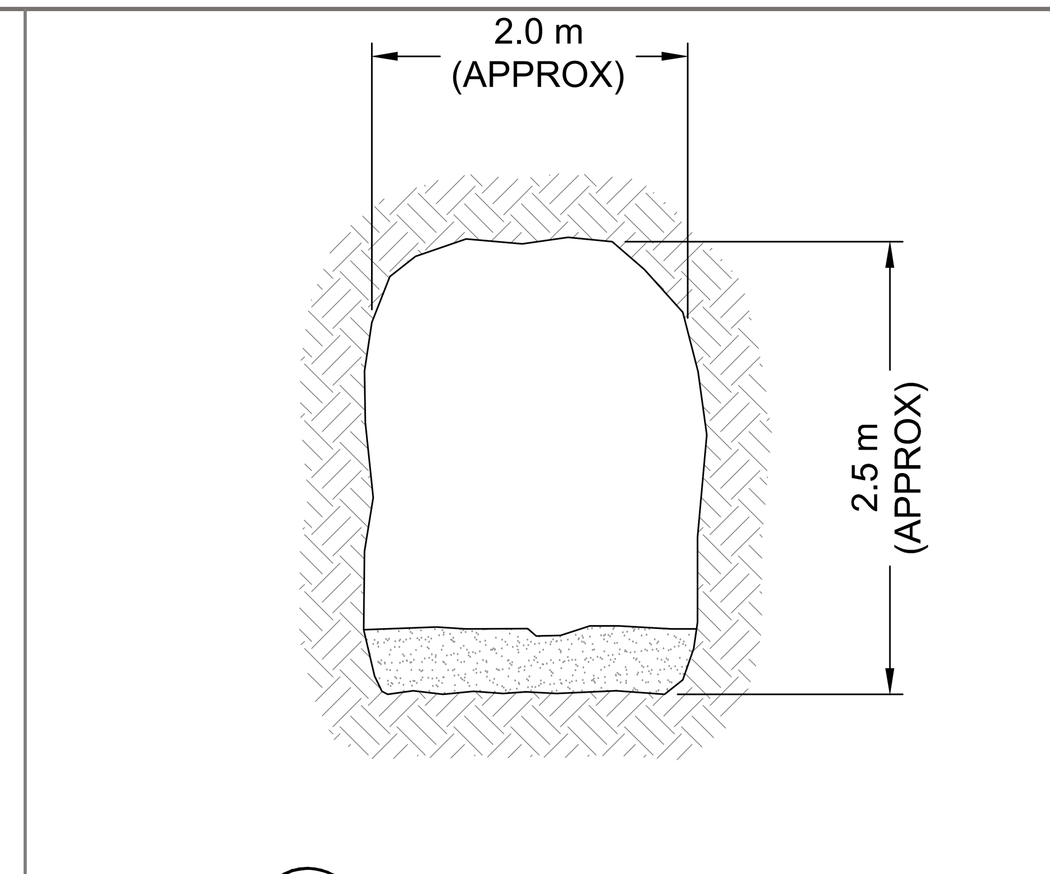
HYDRAULIC ADIT PLUG DETAILS
NO CASH ▯00, KENO ▯00, SILVER KING 100,
BERMINGHAM AND RUBY ADITS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D101▯
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	4 of 7	SF	MH	A	

C:\Users\Samuel.Fournier\Desktop\W14103428-01.003_D101a, 101b, 102b_R0.dwg [D101C] March 27, 2015 - 9:23:38 am (BY: FOURNIER, SAMUEL)



1 - PREPARE PLUG LOCATION - LONGITUDINAL SECTION VIEW
NOT TO SCALE



2 - ADIT CROSS SECTION
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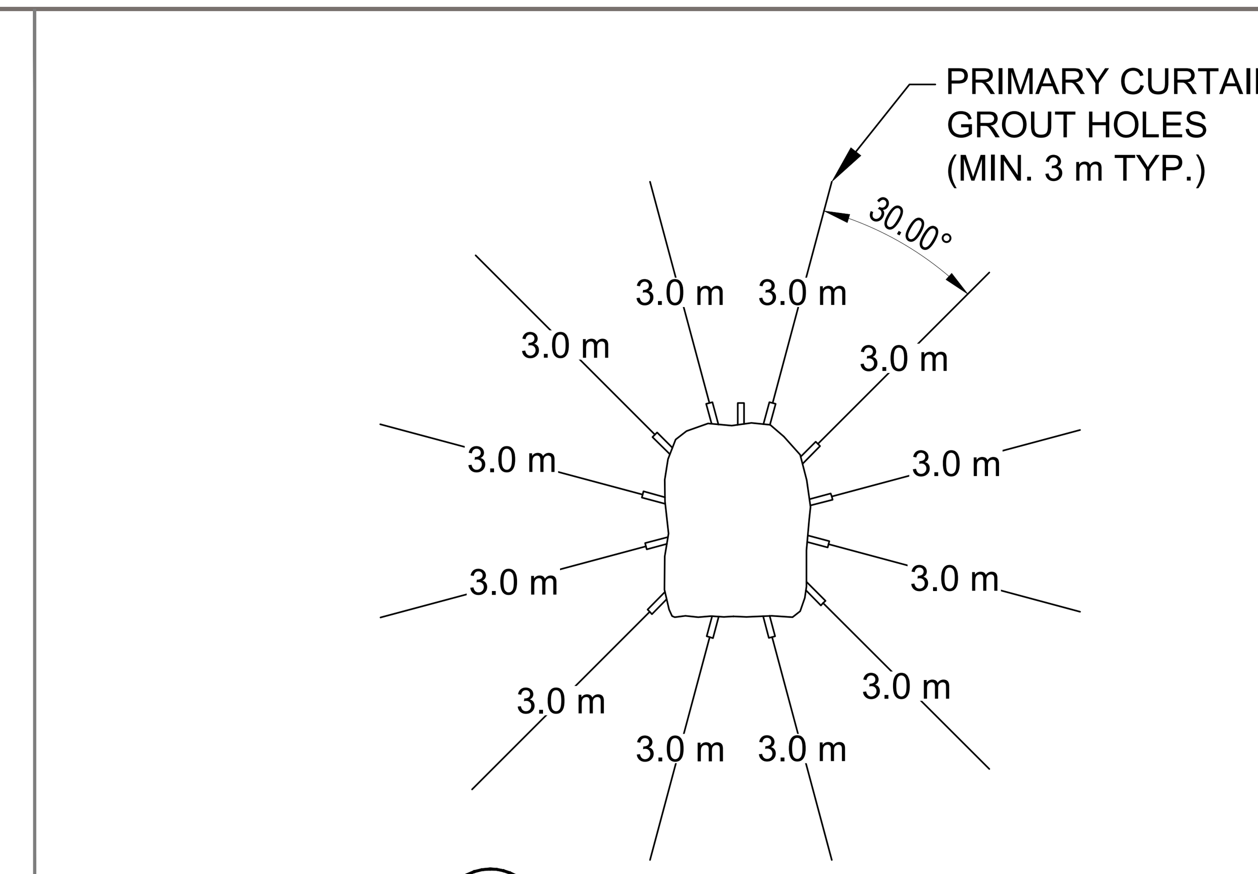
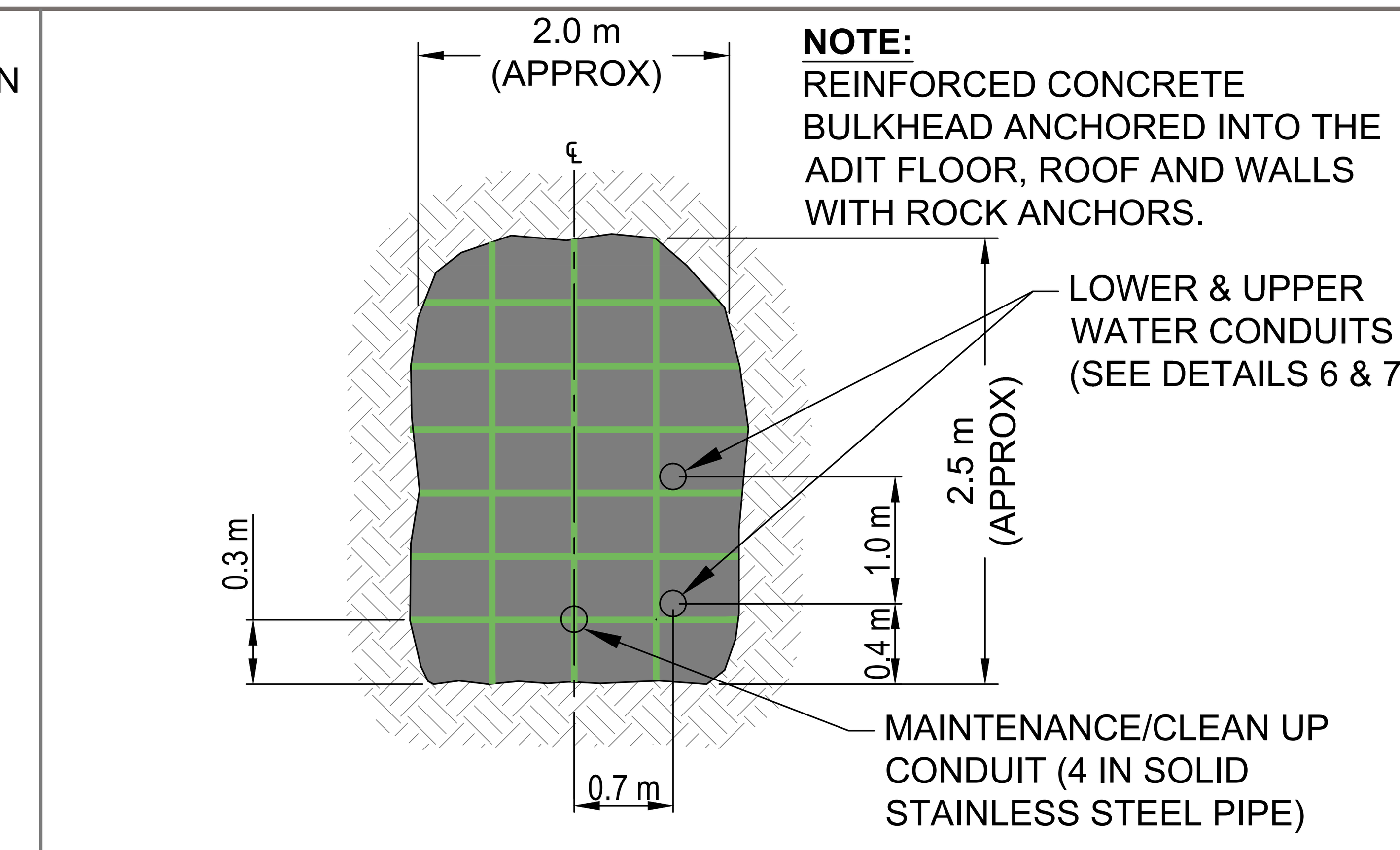
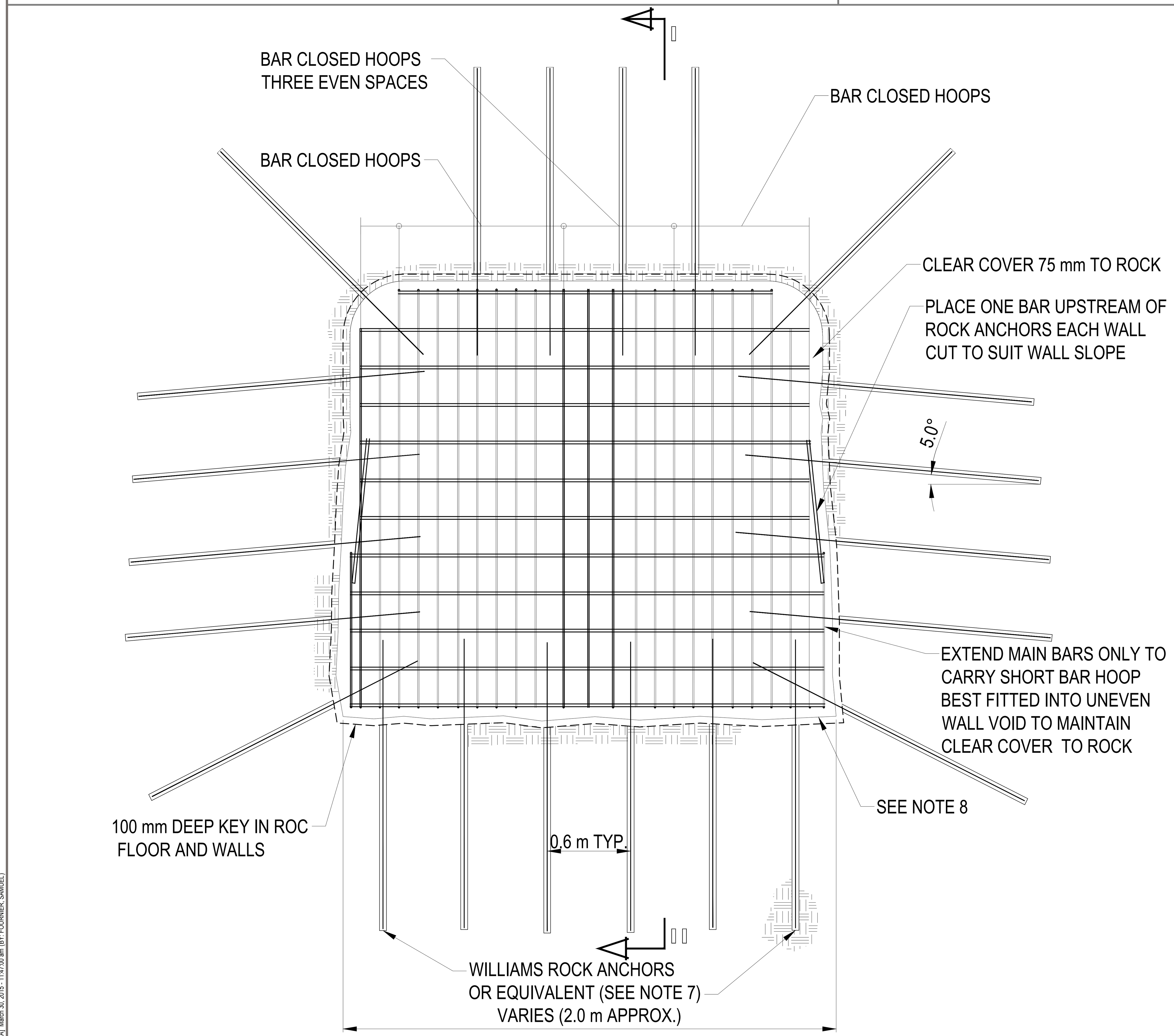


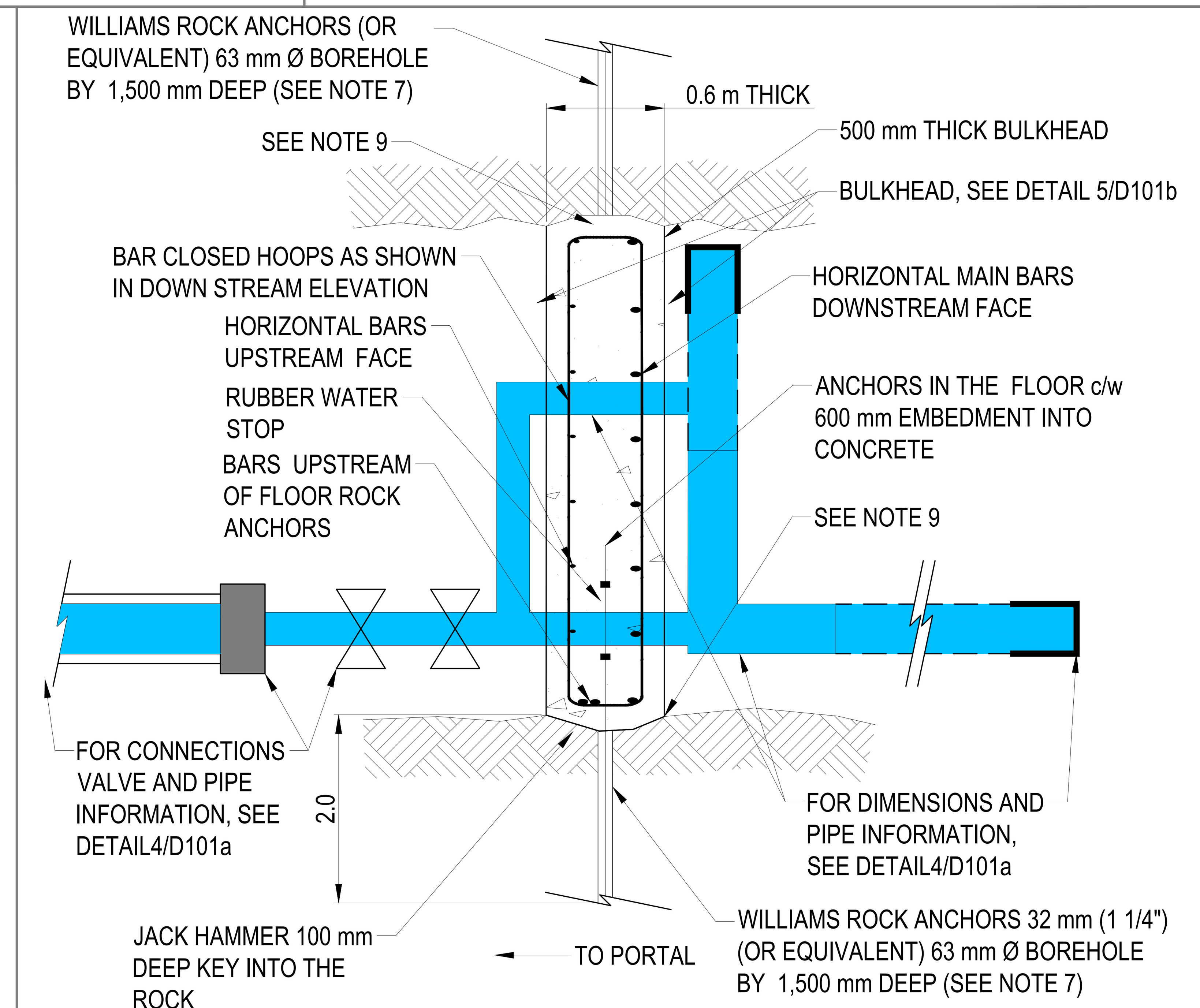
3 - PRESSURE GROUTING
NOT TO SCALE



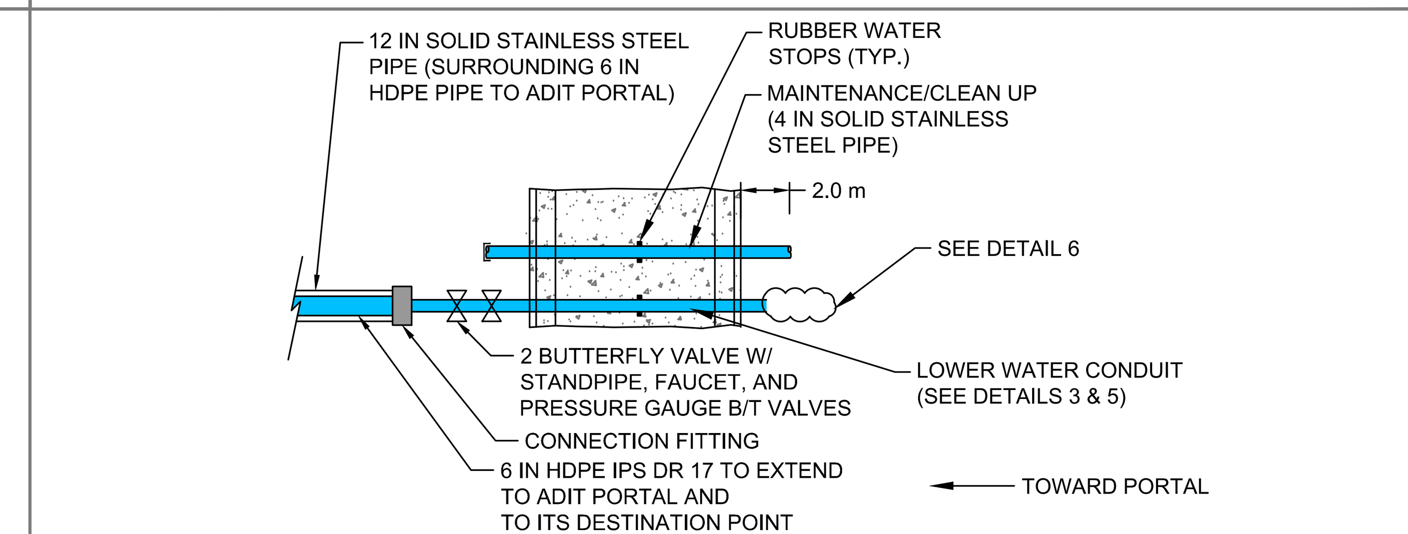
4 - BULKHEAD SITE - TRANSVERSAL SECTION VIEW
NOT TO SCALE



5 - BULKHEAD DOWNSTRAM ELEVATION
NOT TO SCALE



6 - BULKHEAD SITE - LONGITUDINAL SECTION VIEW
NOT TO SCALE



7 - BULKHEAD SITE - PLAN VIEW
NOT TO SCALE

NOTES

1. Bulkhead designed in accordance with CSA Standard A23.3-04 Design of Concrete Structures.
2. Bulkhead designed to retain 6.0 m of hydrostatic head of fresh water factored by 1.5 for Ultimate Strength Design
3. Consequence of failure is high.
4. Concrete shall have a minimum 40 MPa compressive strength at 28 days.
5. Steel reinforcement shall have a minimum yield strength of 415 MPa (60ksi) and be weldable type.
6. Site preparation shall remove loose rock and weathered rock from the walls, roof and invert of the adit from the footprint of the concrete bulkhead to a depth where the bulkhead will be in contact with and keyed into competent rock. This work shall be performed by hand using suitable scaling bars and may include scaling by compressed air in a controlled manner, or by means of hydraulic splitters. Competency of final rock face shall be reviewed by a professional engineer or geologist. Final rock face shall be fresh, unaltered (not faulty), and with a minimum intact compressive strength of 40 MPa.
7. Rock Anchors shall be hot dip galvanized 32 mm (1 1/4 inch) Ø Williams R-61-6R75 all thread (or equivalent). The boreholes shall be 63 mm Ø to a depth of 2000 mm below the surface on the walls, roof and floor. The wall anchors shall be drilled at 5 degrees from the horizontal, the floor and roof anchors shall be installed vertical.
8. The mine owner/operator shall seal any leaks immediately upon detection with approved quick seal grout on the downstream side or de-water and seal upstream.
9. Grout – Cemented Grout Bolts
   - Cement grout shall be used for all rock anchors installed as part of the water retention bulkhead.
   - Cement grouting for rock anchors shall be a non-shrink, non-sanded grout mixed with the proportion 0.4 water:cement by weight, capable of achieving a minimum compressive strength of 28 MPa at 7 days and 40 MPa at 28 days when tested in accordance with CAN/CSA A23.2-1B.
   - Equipment for mixing and pumping grout shall be capable of satisfactorily mixing and agitating grout and pumping it into the holes at the required water cement ratio.
10. Installation – Cemented Grout Bolts
   - Completely clean holes of all drill cuttings, sludge, debris and water using clean water and air.
   - Grout shall be placed in the hole from the bottom up using a grout tube extending to the lower end of the hole.
   - Rock bolts shall be fully encapsulated in grout to the drill hole collar.
   - If seepage of grout into cracks in the rock prevents the hole from being filled with grout, the hole shall be sealed with an approved grout material, and then redrilled. This sequence shall be repeated until the hole is sealed.
11. Grout and Concrete Testing
   - The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of grout and concrete to establish that minimum grout strength required for anchors and minimum concrete strength for bulkhead has been obtained.
   - The testing agent shall (i) Review and confirm that the grout mix submitted by the Contractor will provide the properties specified herein, (ii) take sample of grout from each continuous mix (Contractor can cast the grout samples under the directions of the testing agency) and (iii) test grout samples to determine compressive strength. The contractor shall provide a minimum of 48 hours notice to the testing agency.

BULKHEAD LOCATIONS AND DETAILS

MINE SITE	APPROX. DIST. FROM PORTAL (m)	ROCK TYPE	BULKEAD WIDTH, W (m)	APPROX. VOLUME (m^3)	DESIGN HYDRAULIC HEAD[1] (m)	GROUTING RING	AIM	ADIT ICE PLUG PREVENTION
GALKENO 300	AT 110 m (±10)	QUARTZITE	0.5	2.5	2	YES	DIRECT WATER IN A CONTROLLED MANNER TO WATER TREATMENT PLANT	AT ONEK 400 AND GALKENO 300, INSTALL HEAT TRACING ALONG PIPE FROM PLUG LOCATION TO PORTAL FOR ADIT ICE PLUG PREVENTION
GALKENO 900	AT 75 m (±10)	QUARTZITE	0.5	2.5	2	YES		
ONEK 400	AT 105 m (±10)	QUARTZITE	0.5	2.5	2	YES		

[1] DESIGN HYDRAULIC HEAD ABOVE ADIT ROOF (APPROXIMATELY 4.5 m ABOVE ADIT INVERT)

NOT ISSUED FOR CONSTRUCTION

LEGEND

NOTES
1. ALL UNITS ARE IN METERS UNLESS NOTED OTHERWISE.

NUM	DATE	DWN	CKD	APR	DESCRIPTION

REVISIONS

NUM	DATE	APR	DESCRIPTION

DRAWING STATUS

PERMIT

PROFESSIONAL SEAL

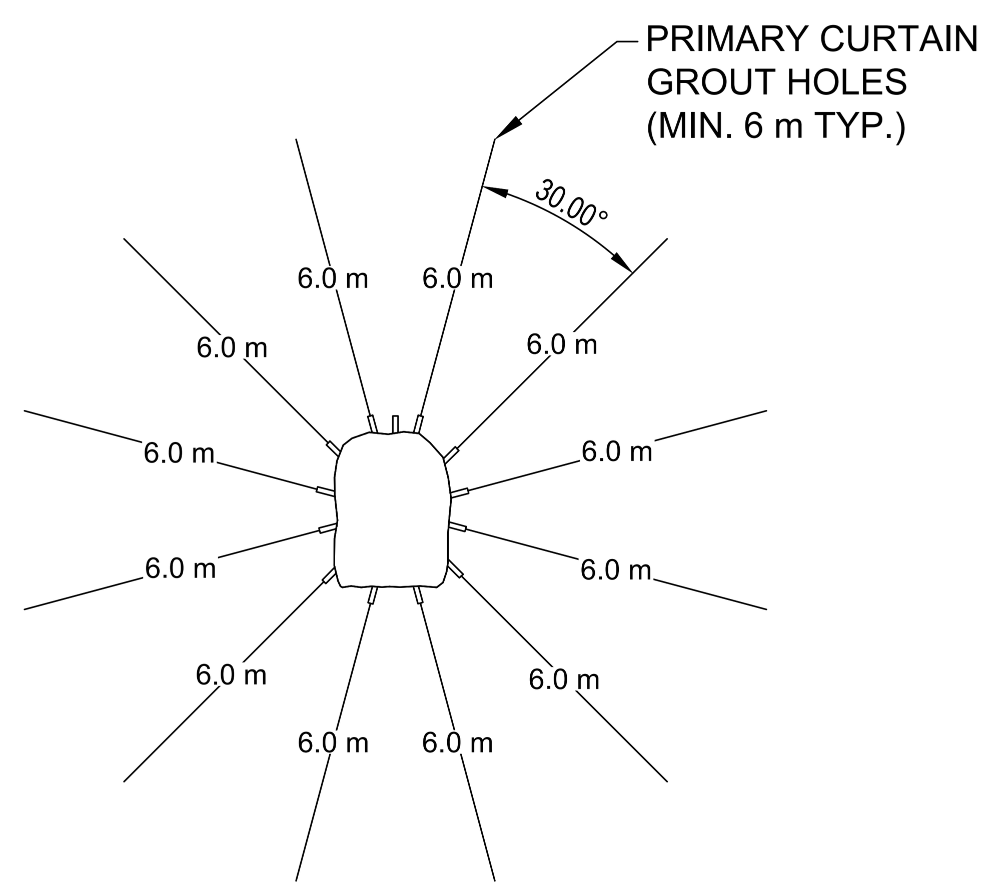
CLIENT
ERDC

TETRA TECH EBA

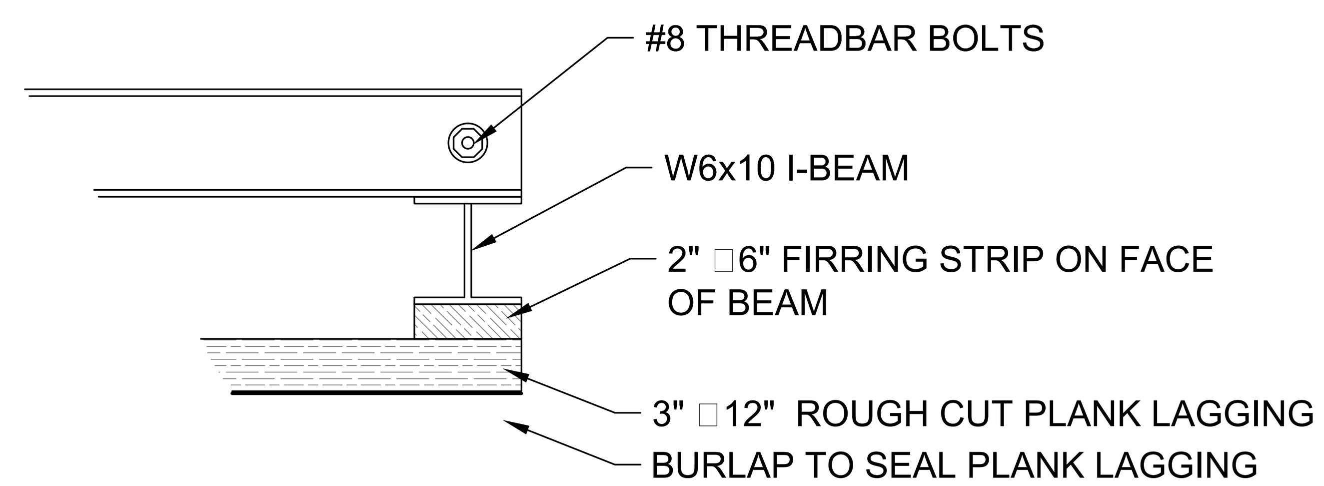
ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

**CONCRETE BULKHEAD
GALKENO 300, GALKENO [illegible]00 AND
OVER [illegible]00 ADITS**

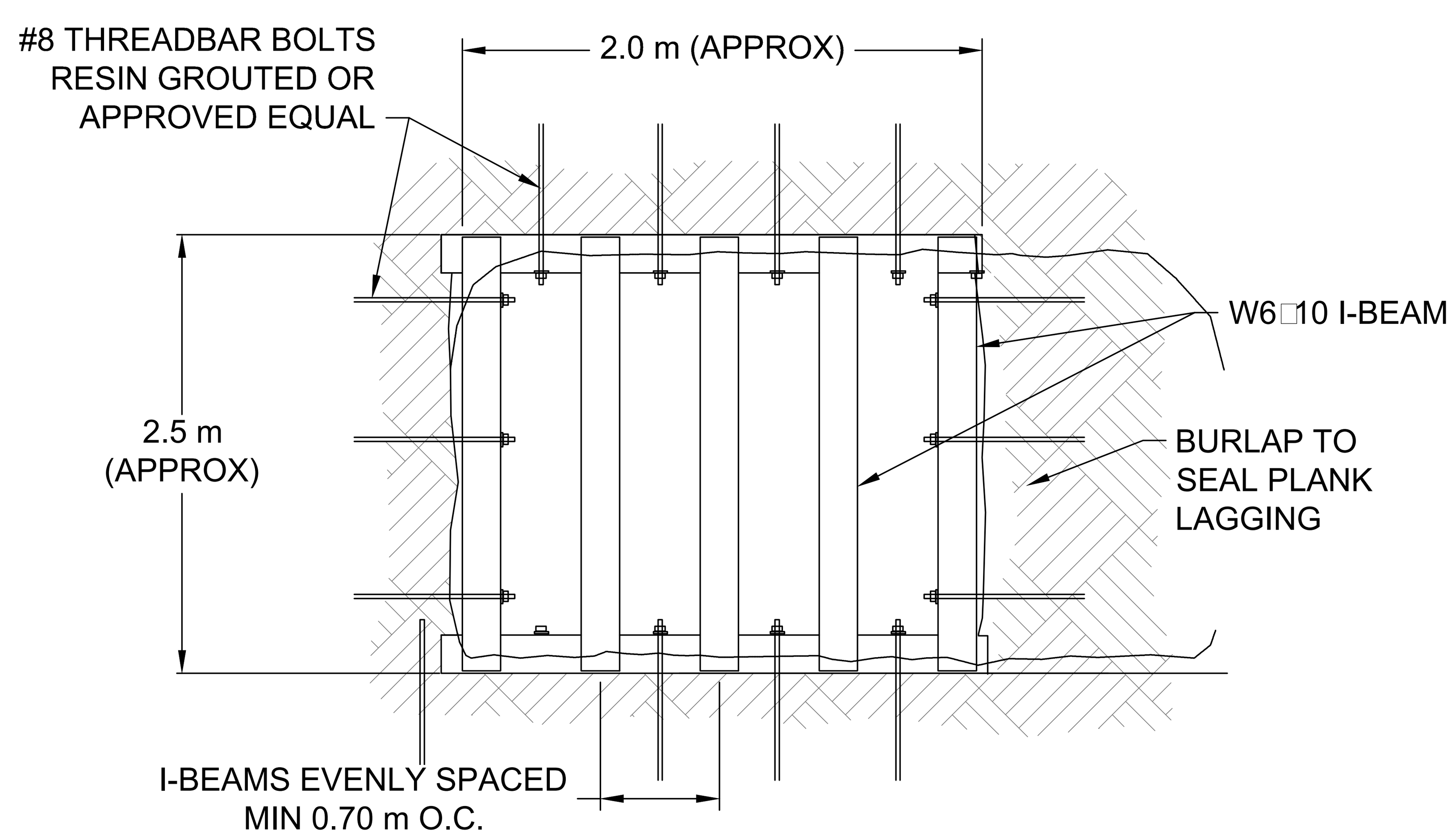
PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D10[illegible]
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	5 of 7	SF	MH	A	



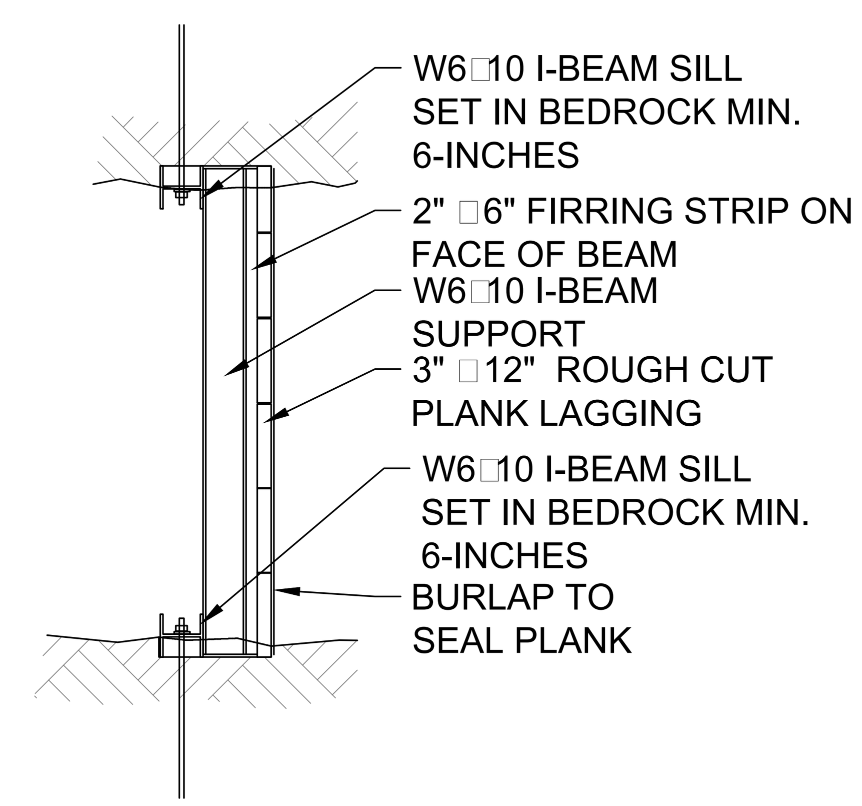
PRESSURE GROUTING
NOT TO SCALE



TOP VIEW



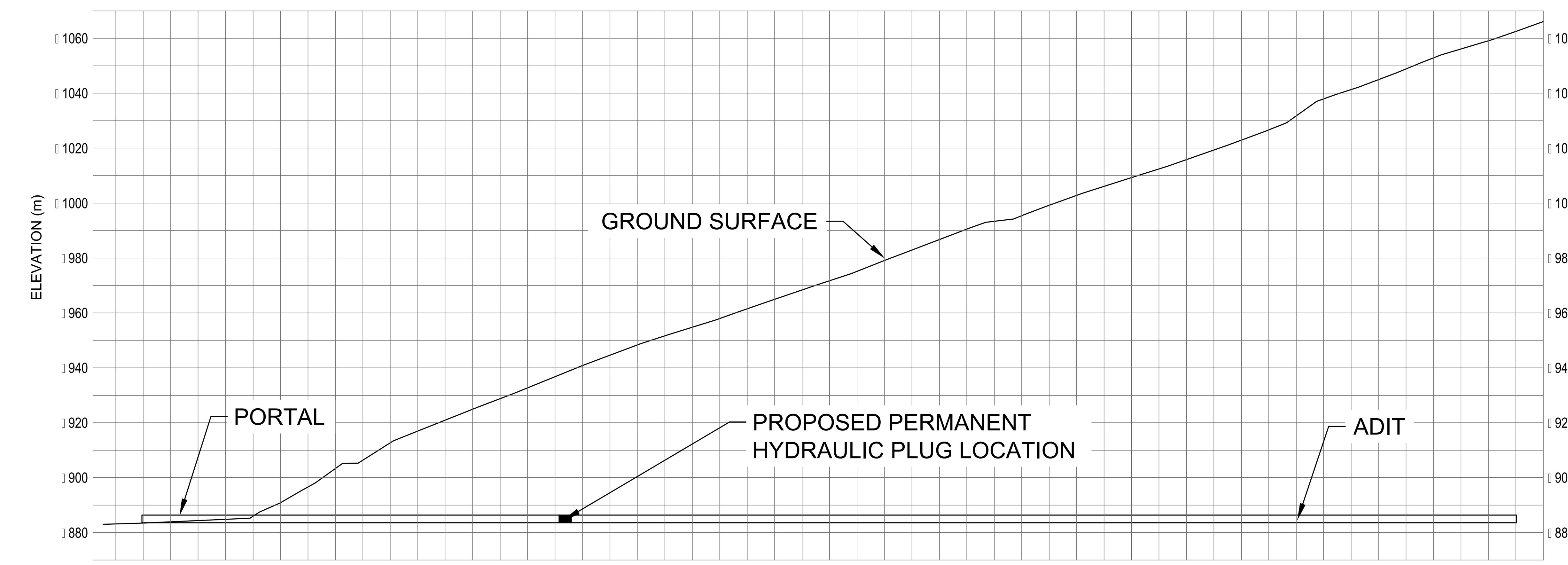
FRONT VIEW



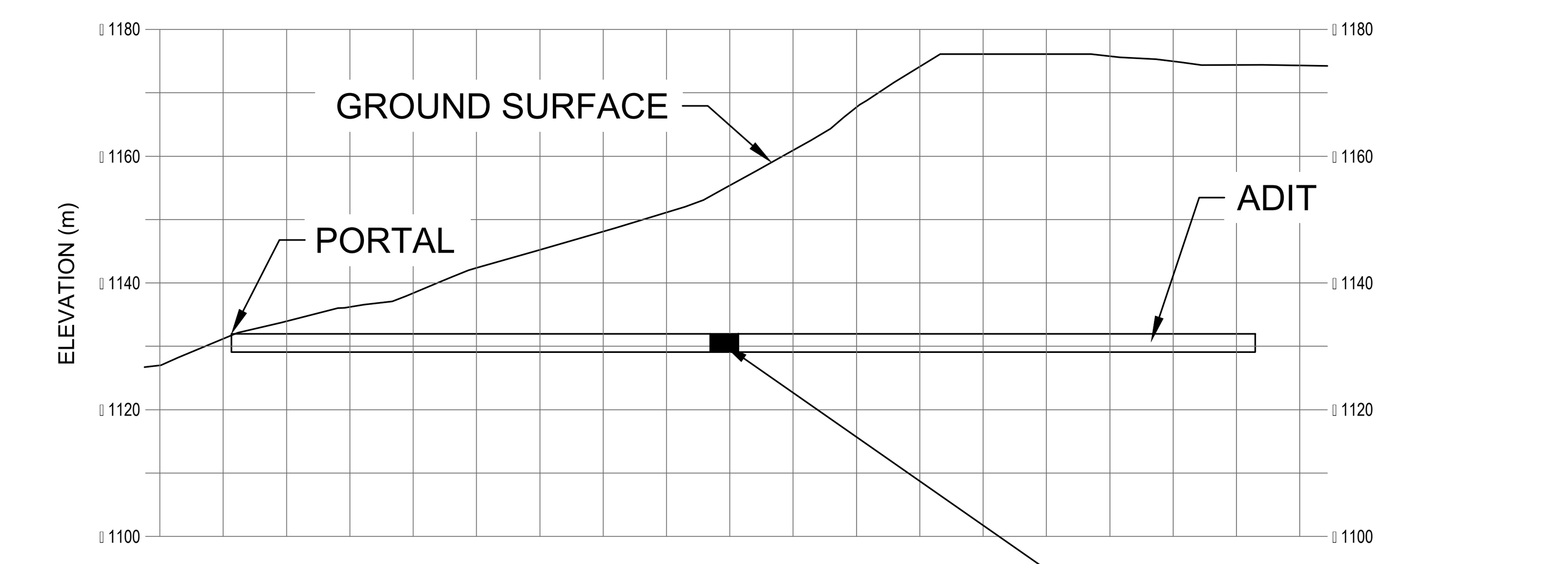
SIDE VIEW

9 TEMPORARY BULKHEAD DETAIL
NOT TO SCALE

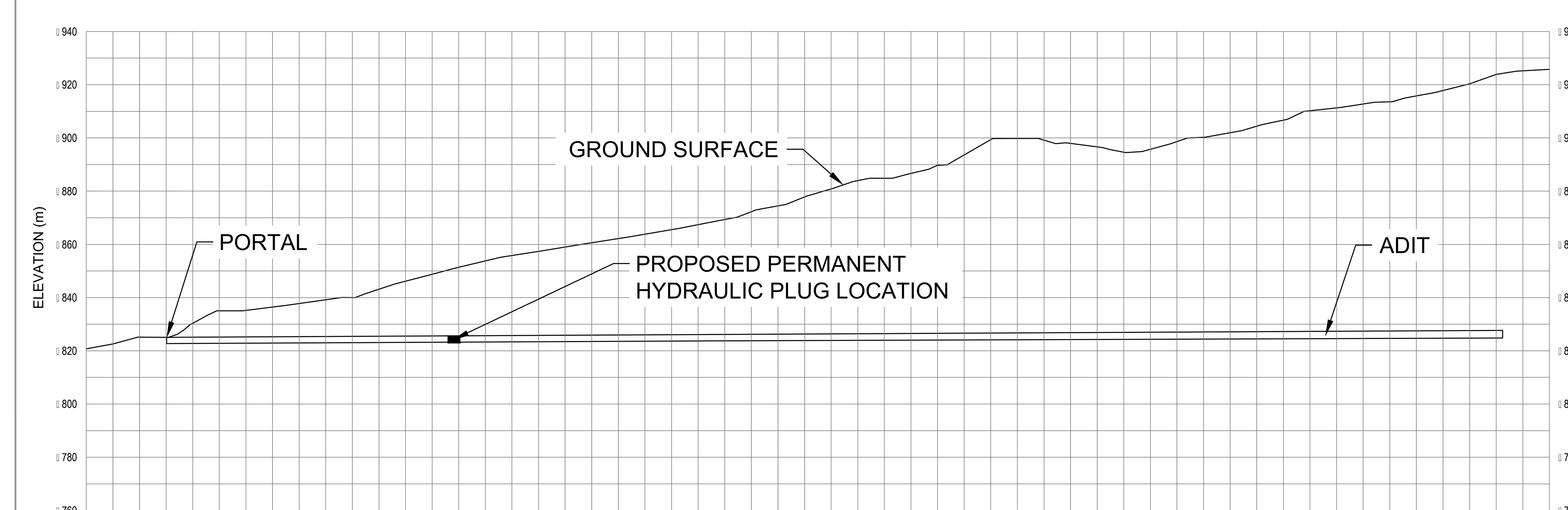
NOTES
1. TOP AND BOTTOM BEAMS INSET IN BEDROCK
2. EMBEDMENT DISTANCE FOR ROCK BOLTS IS 6-FT



GALKENO 300 ADIT
SCALE 1:1500



GALKENO 900 ADIT
SCALE 1:1000



ONEK 400 ADIT
SCALE 1□1500

NOT ISSUED FOR CONSTRUCTION

LEGEND

NOTES
1. ALL UNITS ARE IN METERS UNLESS NOTED OTHERWISE.

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ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

CONCRETE BULKHEAD
GALKENO 300, GALKENO □00 AND
OVER □00 ADITS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D10□ b
DATE: March 27, 2015	SHEET No. 6 of 7	DWN SF	APP MH	STATUS A	

Shaft Closure Methods

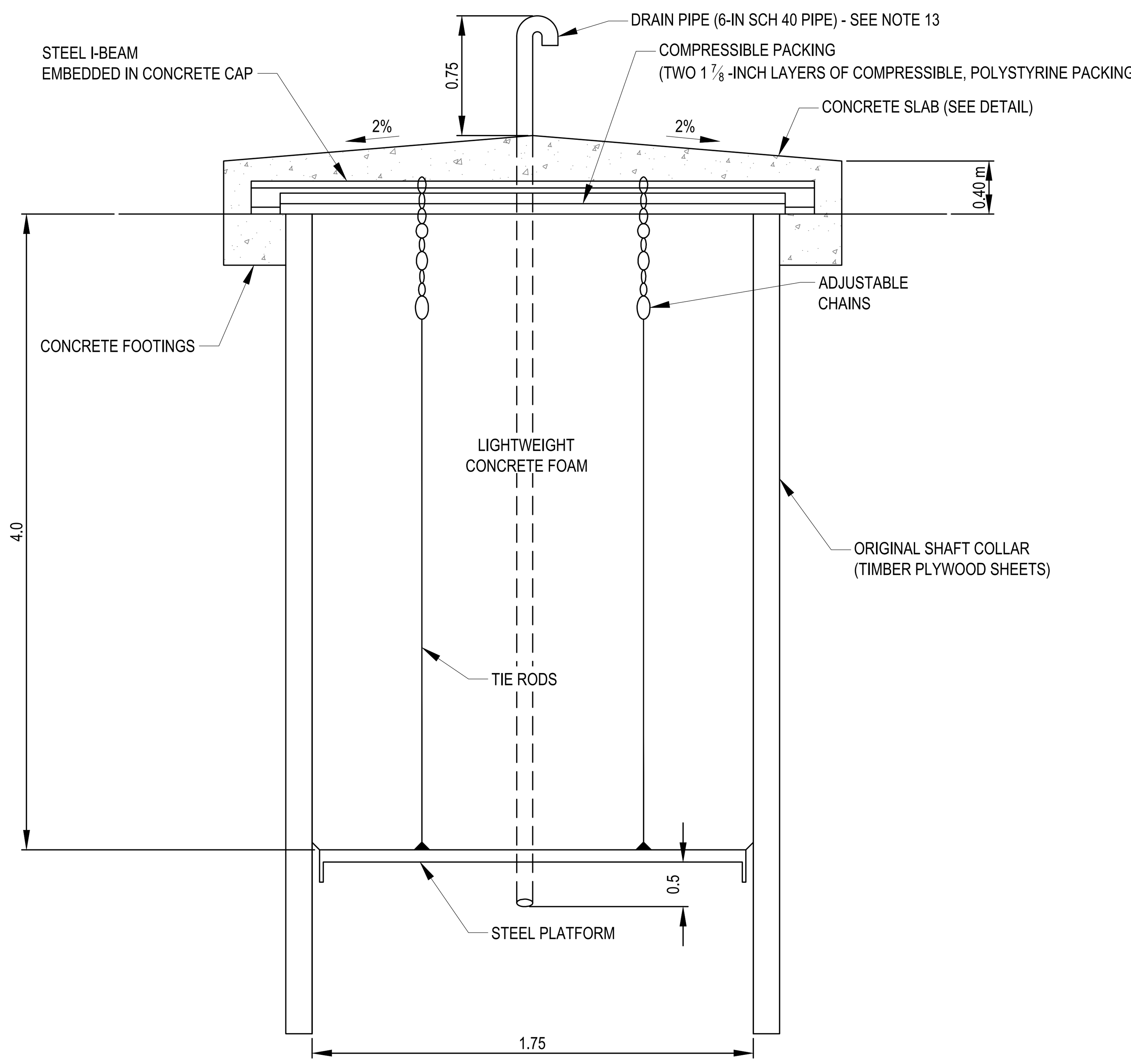
SHAFT NAME	PWGSC REF SITE	SHAFT CLOSURE METHOD [3]
Silver King Vent Raise	Silver King	Light concrete with concrete slab cap [1]
Silver King Shaft #1 (Open Pit Shaft)	Silver King	Light concrete with concrete slab cap [1]
Silver King Shaft #2	Silver King	Shaft Backfill (Dry Seal) [4]
Silver King Raise #1	Silver King	Shaft Backfill (Dry Seal) [4]
Husky Raise	Husky #2	Light concrete with concrete slab cap [1]
Husky Shaft	Husky #2	Light concrete with concrete slab cap [1]
Husky SW Shaft	Husky SW	Light concrete with concrete slab cap [1]
Ruby Shaft	Bermingham & Ruby	Light concrete with concrete slab cap [2]
McLeod shaft	Galkeno Mine	Shaft PUF with Concrete Cap[3]
Shafts SW of Gravel Level Adit	Elsa Mine	Shaft PUF with Concrete Cap[3]
Dixie Shaft	Dixie	Light concrete with concrete slab cap [1]
Brefalt Shaft	No Cash Mine	Light concrete with concrete slab cap [1]
Jock Shaft	Hector-Caulmet	Shaft PUF with Concrete Cap[3]
Coral and Wigwam Shaft #1	Coral and Wigwam	Shaft Backfill (Dry Seal) [4]
Coral and Wigwam Shaft #2	Coral and Wigwam	Shaft Backfill (Dry Seal) [4]
Betty shafts	Betty	Shaft Backfill (Dry Seal) [4]
Tin Can Shaft #1	Tin Can	Shaft Backfill (Dry Seal) [4]
Tin Can Shaft #2	Tin Can	Shaft Backfill (Dry Seal) [4]
Rico Shaft	Rico	Shaft Backfill (Dry Seal) [4]
Sadie Ladue Shaft (No. 1 Shaft)	Sadie Ladue - Wernecke	Light concrete with concrete slab cap [1]
Lucky Queen Shaft #1	Lucky Queen	Light concrete with concrete slab cap [1]
Lucky Queen Shaft #2	Lucky Queen	Shaft PUF with Concrete Cap[3]
Shamrock J18 Raise	Keno No. 9	Shaft PUF with Concrete Cap[3]
Prospect Shaft	Shamrock (Original)	Shaft Backfill (Dry Seal) [4]
Porcupine Shaft	Porcupine Comstock	Shaft Backfill (Dry Seal) [4]
Unknown Shaft near 5-2 Adit	Keno	Shaft PUF with Concrete Cap[3]
Lower Lake Shaft	Lake	Shaft Backfill (Dry Seal) [4]
Upper Lake Shaft	Lake	Shaft Backfill (Dry Seal) [4]
Silver Basin Hand Shafts (Shaft #1)	Silver Basin	Shaft Backfill (Dry Seal) [4]
APEX Shaft	APEX	Shaft Backfill (Dry Seal) [4]
Christal Shaft #1	Christal	Shaft Backfill (Dry Seal) [4]
Christal Shaft #2	Christal	Shaft Backfill (Dry Seal) [4]

[1] Remove steel pits, cables wihin the shaft to bottom of further light concrete

[2] Presently filled with waste dump fill; remove waste material to bottom of further light concrete

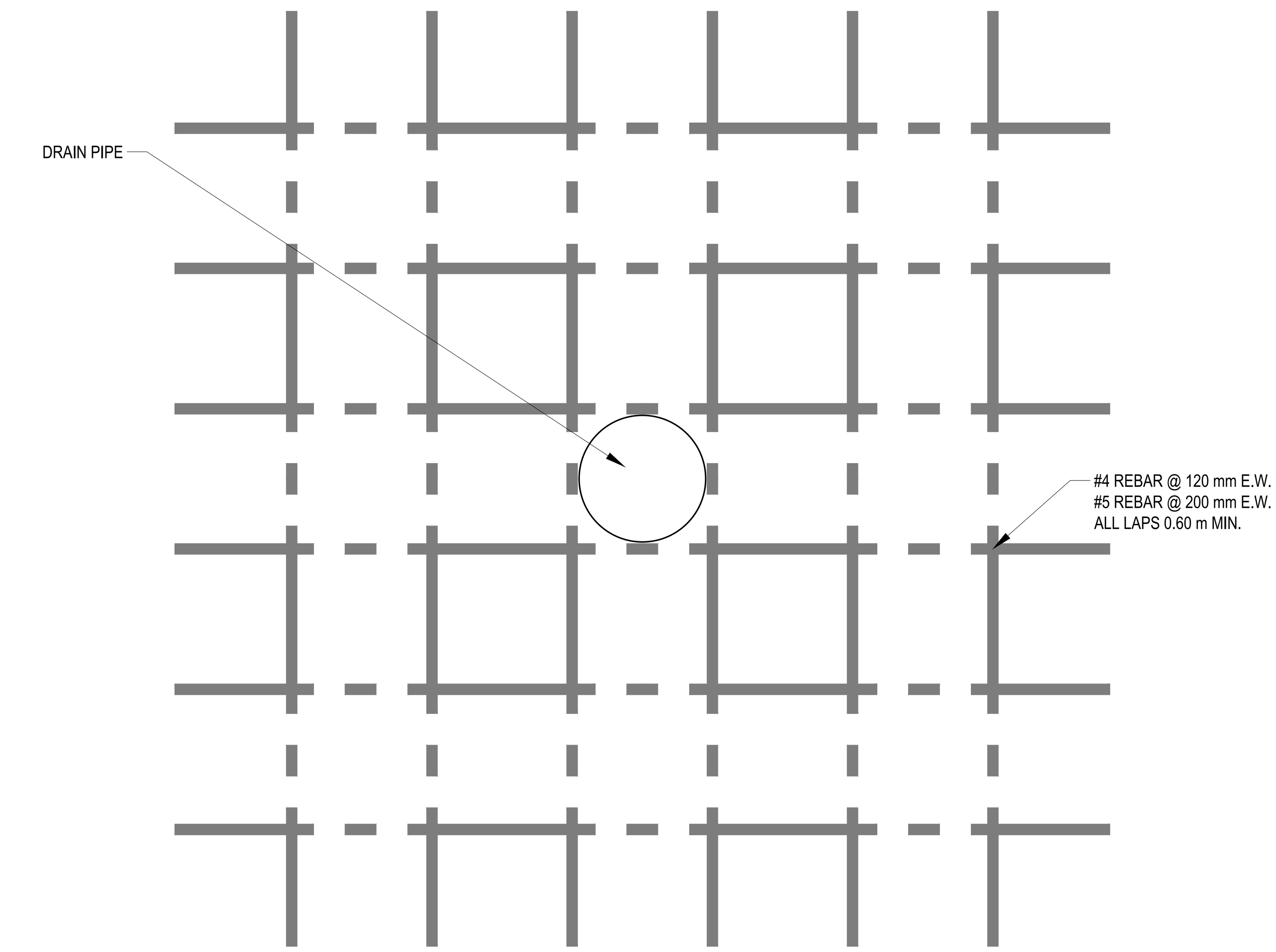
[3] If presentely backfilled, remove backfill material to bottom of further further PUF

[4] If presentely backfilled, complete backfilling (if needed) and make ground surface to conform as presented in this drawing.



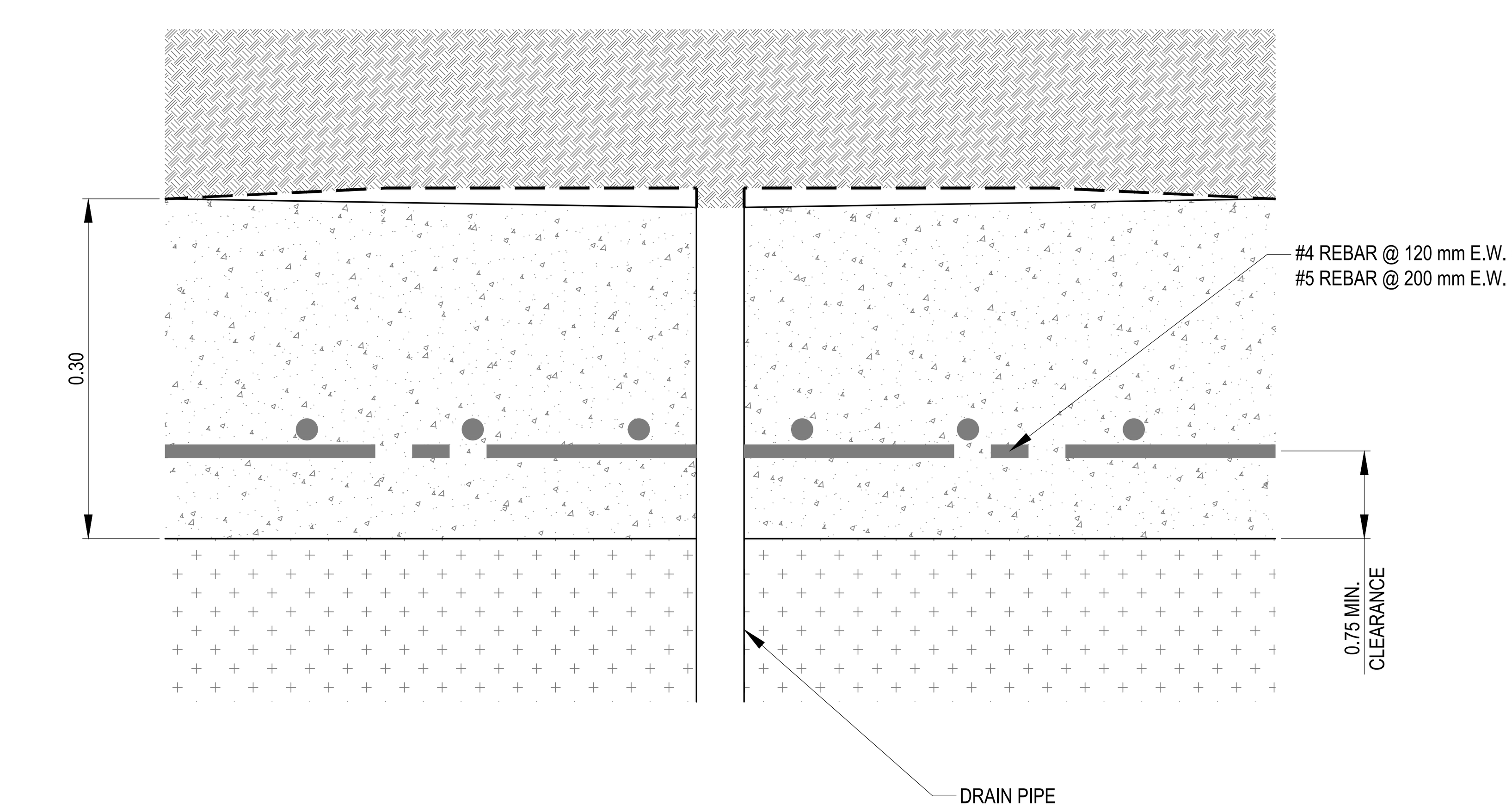
LIGHTWEIGHT CONCRETE WITH CONCRETE SLAB CAP CLOSURE

NOT TO SCALE



NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. A Geotechnical Engineer should assess the ground conditions at the site to determine the bearing capacity of the ground for footing design. Footing design should be completed by a qualified Geotechnical Engineer.
3. Existing steel pipe, cables and other utilities and materials inside the shaft shall be removed to the depth of the lightweight concrete foam
4. Clean the shaft walls to a minimum depth of 300 mm below the base of the steel platform by power-washing to provide a suitable construction surface.
5. All construction surfaces and material should have a water proofing sealant applied. Cover the steel platform and shaft walls with a geomembrane prior to placing concrete.
6. The reinforced concrete cap designed for a 20 KPa (3 psi) live load not designated to resist hydrolic uplift loads..
7. Install a layer of compressible packing (Styrofoam polystyrene or similar) between the lightweight concrete and the concrete cap to allow for differential movement.
8. Install a 6 in SC 40 PVC drain pipe extending from below the steel platform, through the lightweight concrete, to above the concrete cap. Use an 8 inch SC 40 PVC as a sleeve pipe between 1 m below the bottom of concrete slab to 0.2 m above the top of the concrete slab.
9. Concrete shall have a minimum 20 MPa compressive strength at 28 days
10. The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of concrete to establish that minimum strength required for concrete slab has been obtained.
11. Concrete mix for lightweight (foam) concrete:
    - Type II cement..........326.6 kg (720 lb)
    - Water..........134.8 L (35.62 gal)
    - Foaming Agent..........0.5 m3 (18.62 ft3)
    - Superplasticizer..........0.81 L/m3 (1 qt per yd3)
    - Silica fume (6.5% by weight)..........0.5 kg/m (50lb/yd)
    - Water/Cement Ratio..........0.41
    - Calculated Wet Density..........714.4 kg/m3 (44.6 lbs/ft3)
    - 28-day compressive strength (average)..........1.6 MPa (226 psi)
    -
12. Concrete mix for the footings and concrete cap:
    - Type II cement..........213.2 kg (470 lb)
    - Fly Ash..........31.8 kg (70 lb)
    - Water..........104.5 L (27.6 gal)
    - Sand..........600.6 kg (1324 lb)
    - No. 57 limestone..........807.4 kg (1780 lb)
    - Water-reducing admixture..........2.8 g/kg (5 ozs/cwt)
    - Air-entraining agent..........0.6 g/kg (1.10 ozs/cwt)
    - Design Unit Weight..........2298.3 kg/m3 (143.48 lb/ft3)
    - Slump..........76 mm (3in)
    - Air Content..........7.5%
    - Water/Cement Ratio..........0.426
    - 28-day compressive strength (average)..........1.6 MPa (226 psi)
13. Capture water at exit of drain pipe and route it to the assigned destination.



CONCRETE SLAB DETAILS

NOT TO SCALE

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GENERAL NOTES
ALL UNITS ARE IN METERS IN UNLESS NOTED OTHERWISE.

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ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

SHAFT CLOSURE METHODS AND DETAILS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
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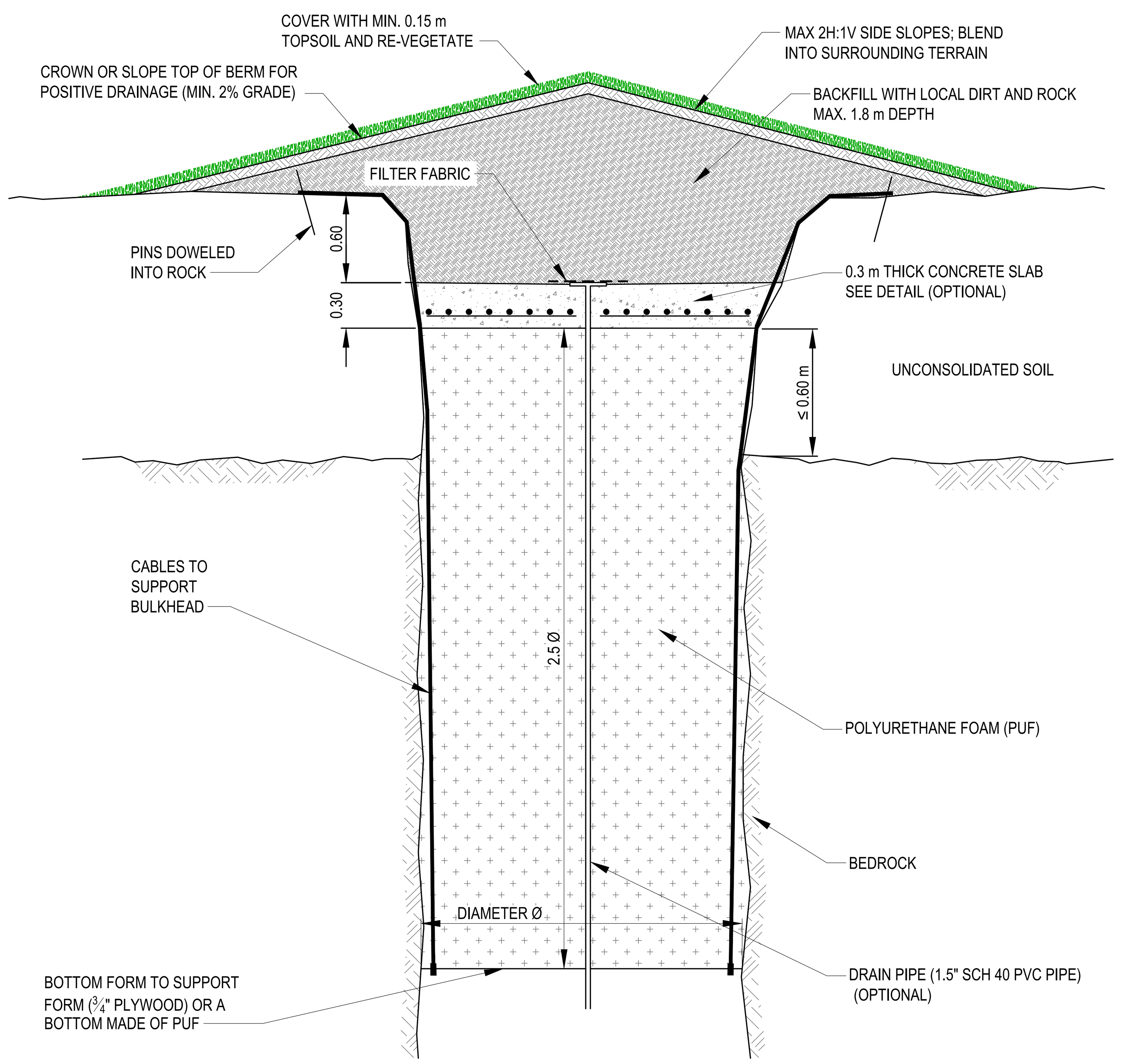
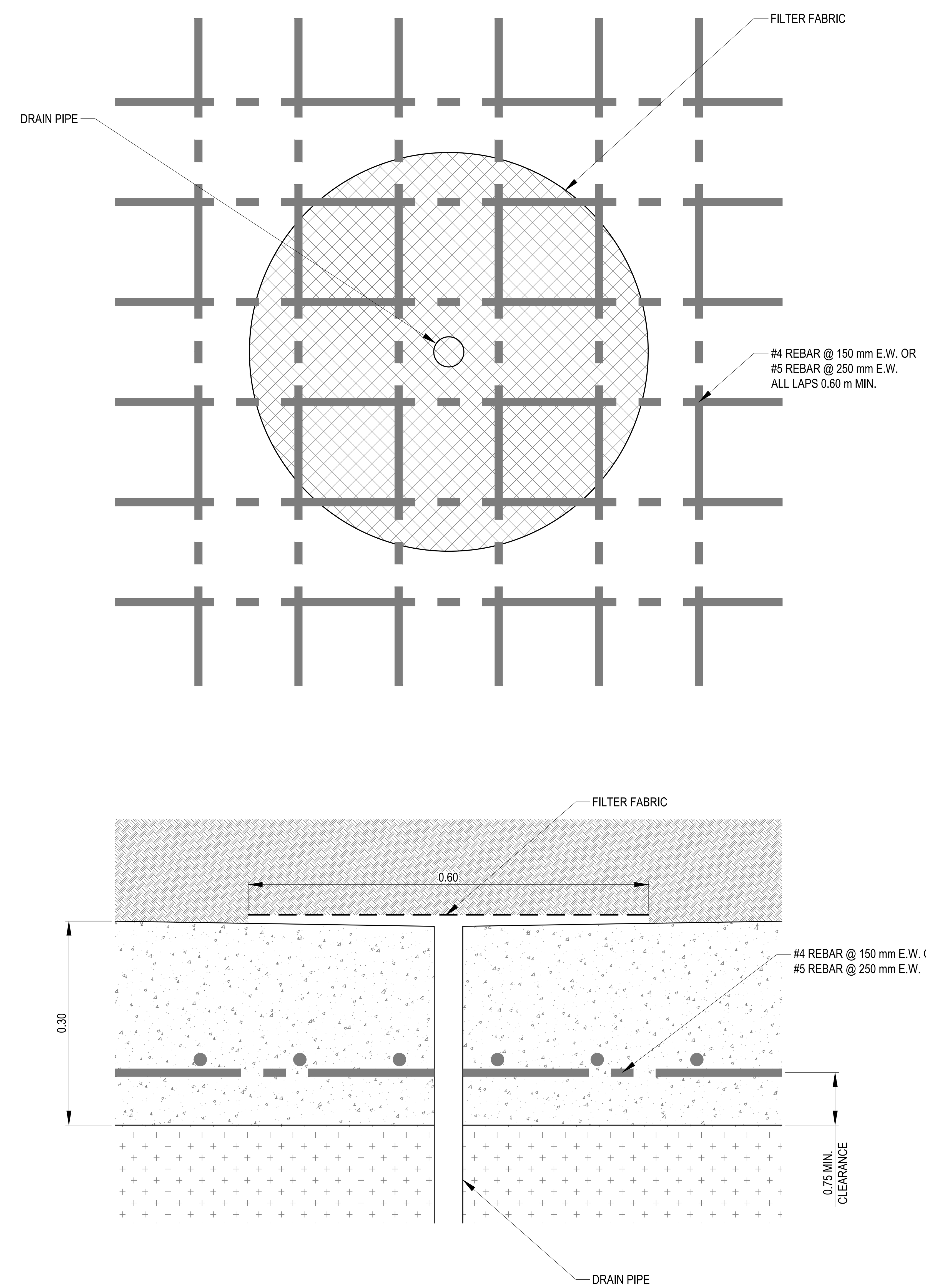


SHAFT PUF WITH CONCRETE SLAB CLOSURE

NOT TO SCALE

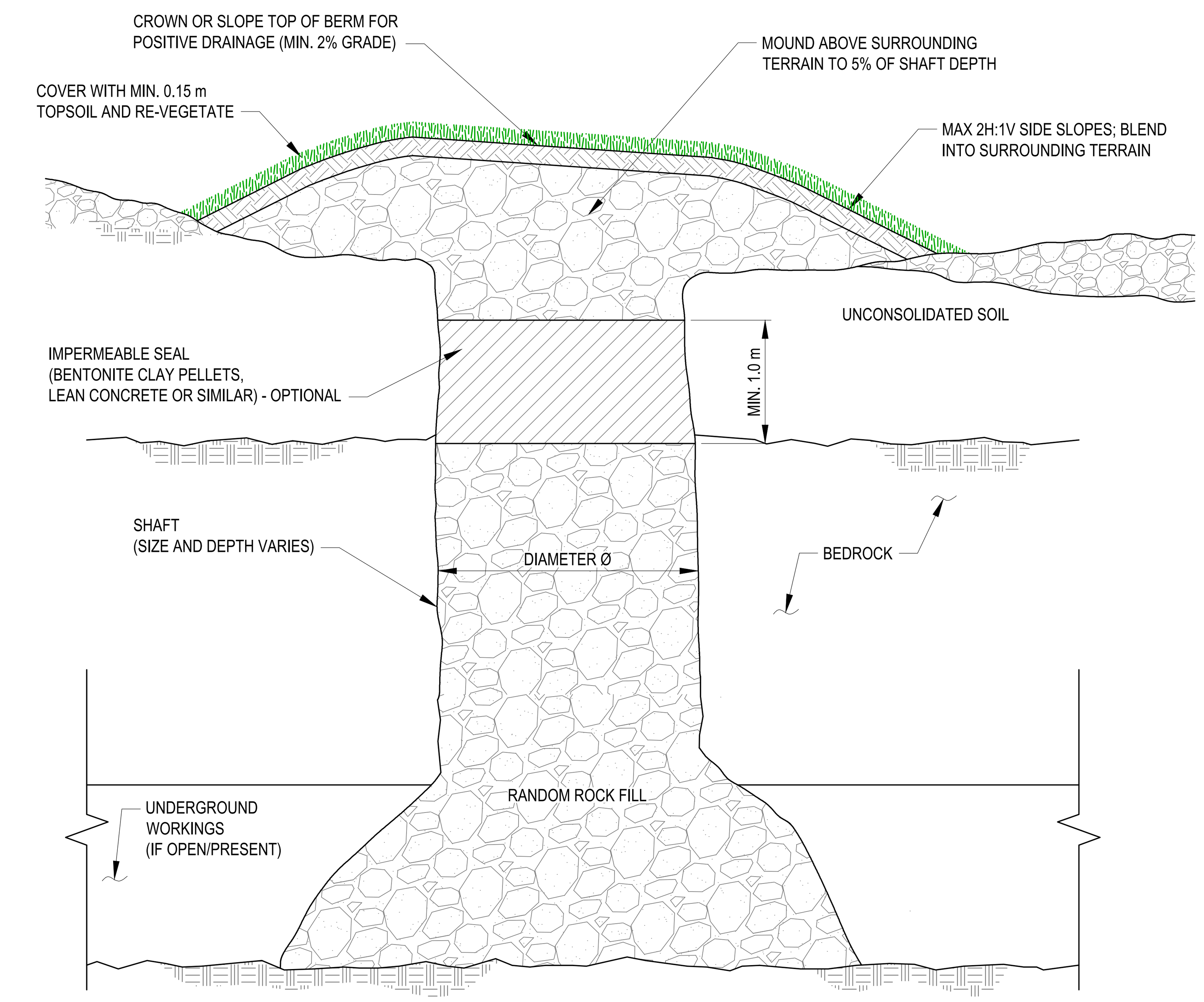
NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Lower the bottom form into the shaft to the final depth of the Polyurethane foam (PUF)
3. Install drain pipe (1.5 " SC 40 PVC) extending from below the bottom form to planned top of concrete cap.
4. Place seals into the cracks between the edges of the bottom form to prevent foam from falling down the shaft.
5. Pour the mixed PUF foam onto the bottom form to form the plug.
6. Construct the 0.3 m concrete slab. Concrete slab sloped outwards to drain (2%)
7. Back fill on top of the concrete slab with local dirt and rock.
8. Concrete shall have a minimum 20 MPa compressive strength at 28 days
9. The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of concrete to establish that minimum strength required for concrete slab has been obtained.



CONCRETE SLAB DETAILS

NOT TO SCALE



SHAFT BACKFILL (DRY SEAL) CLOSURE

NOT TO SCALE

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Quantities will vary with shaft depth, connection to underground workings, and other conditions.
3. Mobile equipment must never operate on ground that shows signs of subsidence without taking adequate precautions.
4. Remove as practical, if present, 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.
5. Existing steel pipe, concrete rubble (if present) should be removed or incorporated into backfill as directed by engineer.
6. Random rock fill must be:
   a. Non-acid generating rock fill
   b. Sized to contain no rocks greater than 1/4 the diameter of the shaft.
7. Every effort should be made to keep all debris other than rock fill from going underground.

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GENERAL NOTES

1. All units are in meters unless noted otherwise.

NUM	DATE	DWN	CKD	APR	DESCRIPTION	NUM	DATE	APR	DESCRIPTION

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ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

SHAFT CLOSURE CAPPING METHODS AND DETAILS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
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APPENDIX A
HYDRAULIC PLUG AND BULKHEAD CLOSURE – CONSTRUCTION STEPS

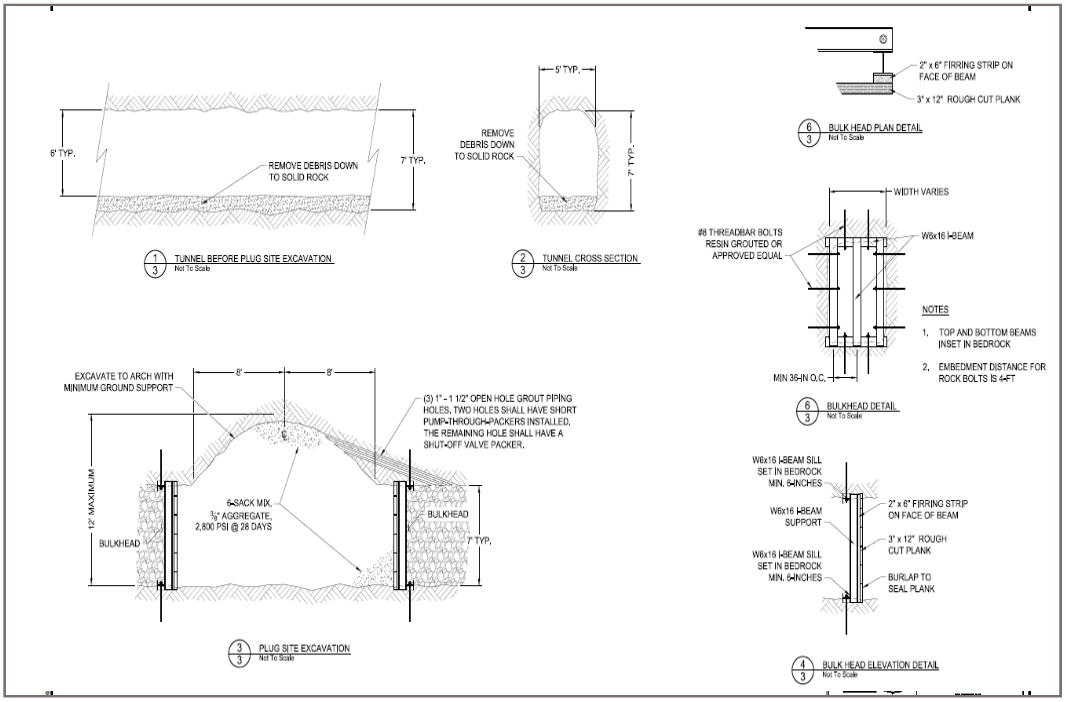

Photo 1: Hydraulic Adit Details

Photo 2: Geotechnical mapping of adit to determine plug site suitability. All ribs (walls) and back (roof) are to be removed of existing electrical and mechanical appurtenances, if present shall be removed from the plug footprint.

Photo 3: Intersected location of the workings is located and installation of grout and cement pumping lines.

Photo 4: Installation of grout rings All walls and roof should be cleaned and washed free of dust and debris. Grouting rings are installed around the hydraulic plugs and proposed bulk head location.

Photo 5: Building of the temporary bulkheads.
6 Inch Steel High beams installed in preparation for lower seal.

Photo 6: Temporary bulkhead
Braced timber sets for back end of the plug.

Photo 7: Jimmy window allows for access and installation and inspection of cement and grout pumping lines.

Photo 8: Pumping of grout / cement in several stages

Photo 9: Temporary Bulkhead - Perimeter of lagging packed with burlap and grouted

Photo 12: Water tight temporary Bulkhead

APPENDIX B
HYDRAULIC PLUG AND BULKHEAD CLOSURE – GEOTECHNICAL ASSESSMENT AND CALCULATIONS

1.0 ROCK MASS CHARACTERIZATION AND PERMANENT HYDRAULIC PLUGS AND BULKHEADS PRELIMINARY DESIGN

Two important parameters relating to bulkhead design are rock mass strength, which in part will control the position and length of the hydraulic plugs and bulkheads, and rock mass permeability, which will control the risk of leakage past the bulkhead. These parameters are both functions of rock mass quality.

Section 2.0 presents the rock mass classification methods used to assess the quality of the rock mass. Section 3.0 a preliminary geotechnical characterization of the adits based on available information, and Section 4.0 the preliminary design of the permanent hydraulic plugs and bulkheads.

2.0 ROCK MASS CLASSIFICATION

As described in Section 4.0 of the report the geotechnical information was obtained from:

- Tetra Tech's site visit in September 2014. During the site visit, only the first 30 m of the Galkeno 300 adit, the first 50 m of the Silver King 100 and the first 100 m of the Ruby adit (from their portals) were accessed for inspection.
- Rock Quality Designation (RQD) data included in the logs of boreholes drilled between 2006 and 2014.

Rock mass classification systems to estimate rock mass properties (rock quality) constitute an integral part for decision making for design. These systems are used to group areas of similar geomechanical characteristics, based on ratings of three principal properties: the intact rock strength, the frictional properties of the discontinuities, and the geometry of intact blocks of rock defined by the discontinuities.

Table B-1 provides comparison of RMR and NGI-Q ratings to the quality of rock. Sections 2.1 and 2.2 below present an overview of the classification systems. Table B-2 presents the Rock Quality Designation (RQD) ratings to the quality of the rock, and Section 2.3 presents an overview of the RQD classification system.

Table B-1: Summary RMR and Q Rating Values

RMR Value	RMR Rating	Q Value	Q Rating
0	Very Poor Rock	0.001-0.01	Exceptionally Poor
<20	Very Poor Rock	0.01-0.1	Extremely Poor
21-40	Poor Rock	0.1-1	Very Poor
41-60	Fair Rock	1-4	Poor
		4-10	Fair
61-80	Good Rock	10-40	Good
		40-100	Very Good
81-100	Very Good Rock	100-400	Extremely Good
		400-1000	Exceptionally Good

Table B-2: Summary of RQD Rating Values

RDQ (%)	Rock Quality
<25	Very Poor

25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

2.1 Overview of Rock Mass Rating System

The RMR system is a geomechanical classification system for rocks, developed by Z.T. Bieniawski (1989). The following six parameters are used to classify a rock mass using the RMR system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (RQD).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

Each of the six parameters is assigned a value corresponding to the characteristics of the rock. The sum of the six parameters is the “RMR value”, which ranges between 0 and 100.

2.2 Overview of NGI Q-System

The NGI Q-system is an empirically based system developed by Barton, Lien, and Lund (1974) through analysis (initially) of over 200 case studies. Further development since the initial publication of the paper has refined the system based on over 1,000 case studies.

The NGI Q-system uses six parameters to determine a numerical value (Q) which represents the quality of a given rock mass. The parameters assign numerical values to various features of the rock mass, including RQD, number of joint sets, joint alteration, joint surface roughness, stress conditions, and water inflow intensity. These are combined in a simple formula to derive a “Q-value”, which is indicative of the overall quality of the rock mass for the purpose of underground excavation and support design. This formula can be thought of as the function of three geomechanical rock properties:

- Block size given by RQD/Jn.
- Inter-block shear strength given by Jr/Ja.
- Active stress given by Jw/SRF.

The formula for determining Q is as follows:

$$Q = \left(\frac{RQD}{Jn}\right) \cdot \left(\frac{Jr}{Ja}\right) \cdot \left(\frac{Jw}{SRF}\right)$$

Where: *RQD* = rock quality designation.

Jn = joint set number.

Jr = joint roughness number.

Ja = joint alteration number.

Jw = joint water reduction number.

SRF = stress reduction factor.

The description of the six parameters can be found in the report by Barton et al. (1974). The numerical value of Q ranges from 0.001 (for exceptionally poor quality, squeezing ground) to 1000 (for exceptionally good quality, massive rock).

The formula for determining Q is as follows:

$$Q = \left(\frac{RQD}{Jn}\right) \cdot \left(\frac{Jr}{Ja}\right) \cdot \left(\frac{Jw}{SRF}\right)$$

2.3 Overview of Rock Quality Designation (RQD)

RQD was introduced by D.U. Deere (1964) as an index of assessing rock quality quantitatively. It is a more sensitive index of core quality than the core recovery.

The RQD is a modified percent core recovery which incorporates only sound pieces of core that are 100 mm (4 inches) or greater in length along the core axis,

RQD (%) = ((Sum of core pieces ≥ 10cm)/(total drill run))* 100

3.0 GEOTECHNICAL CHARACTERIZATION

Geotechnical characterization was based on the data collected during the Tetra Tech's site visit in September 2014, and the RQD data recorded on logs of boreholes drilled between 2006 and 2014..

3.1 September Site Visit

As described in Section 4.0 of the report, Tetra Tech's visited the project site in September 2014. During the site visit, only the first 30 m of the Galkeno 300 adit, the first 50 m of the Silver King 100 and the first 100 m of the Ruby adit (from their portals) were accessed for inspection.

3.1.1 Intact Rock Strength

The ISRM (1981) divides the rock strengths from R0 to R6 according to the UCS of the intact rock. R0 has UCS<1 MPa, R1: 1≤UCS1≤5 (very weak), R2: 5≤UCS1≤25 (weak), R3:25≤UCS1≤50 (medium strong), R4:50≤UCS1≤100 (strong), R5:1005≤UCS1≤250 (very strong), R6:> 250 (extremely strong),

Intact rock strength was estimated from field identification using a geological hammer. The rock at the adit location described above required more than one blow of geological hammer to fracture, and in occasions required many blows. This indicate the uniaxial compressive strength varies between strong and very strong rocks.

3.1.2 Material Properties - Strength

The permanent hydraulic plugs and bulkheads and the surrounding rock can be regarded as a discontinuum consisting of a series of blocks of intact rock and concrete, separated by various planes of weakness. The behavior of this system will be controlled by both the strength and deformation moduli of the intact material and the strength and stiffness along the planes of weakness.

The rock mass quality was estimated from field observations and measurements carried out during the September 2014 site visit. Tables B-3, B-4 and B-5 presents the estimated rock mass quality based on the RQD, RMR and NGI-Q classification systems, respectively.

Table B-3: RQD Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist
Rock Quality Designation (RQD).	50-60%	50-60%	50-60%

Table B-4: RMR89 Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist
Strength of intact rock (Uniaxial compressive strength of rock material)	12	12	7
Rock Quality Designation (RQD).	13	13	13
Spacing of discontinuities.	10	10	10
Condition of discontinuities.	20	20	20
Groundwater conditions.	10-15	10-15	10-15
Adjustment for Joint Orientation	-5	-5	-6
Total RMR Rating	60-65	60-65	55-60

Table B-5: NGI Q Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist

RQD	55	50	55
Number of Discontinuity Sets	4	4	5
Roughness of Most Unfavorable Discontinuity	2	2	2
Degree of Alteration of Filling along the Weakest Discontinuity	1	1	1
Water Inflow	0.66	0.66	0.66
Stress Condition	2.5	2.5	2.5
Total NGI Q Rating	7.2	6.6	5.8

From Tables B-3, B-4 and B-5, the quality of the rock mass according to the RQD, RMR89 and NGI-Q designations, is 'fair' for all the rock mass classifications.

It should be emphasized that the ratings presented in Tables B-3, B-4 and B-5 are from data collected within 100 m from the portal. The rock mass quality further into the adits is expected to improve as the adits are deeper in relation to the ground surface.

3.2 RQD from Boreholes

Tetra Tech EBA received spread sheets with RQD records for 180 boreholes drilled between 2006 and 2014. Tetra Tech reviewed the RQD data and split it by its lithology. The depths of the boreholes varies mostly from 100 to 400 m.

Tables B-6 through B-10 presents the average of the RQD for each lithology unit for each boreholes. Also presents the average RQD of all the boreholes at the same location. The RQD data is not in agreement with the data presented in Section 3.1. The RQD data from boreholes are much lower. Tetra Tech believes that one of the main reasons of this is that the drill holes were targeting the vein zones where the rock quality is of poorer conditions. Also, in Tetra Tech EBA's experience when RQD data is collected as part of a geological investigation, the measurements also considers mechanical fractures which should not be part of the RQD ratings.

It is important the dedicated geotechnical boreholes be drilled to investigate it further.

4.0 PRELIMINARY DESIGN

Two important parameters relating to bulkhead design are rock mass strength, which in part will control the position and length of the hydraulic plugs and bulkheads, and rock mass permeability, which will control the risk of leakage past the bulkhead. These parameters are both functions of rock mass quality.

This section presents the preliminary design of the permanent hydraulic plugs and bulkheads.

TABLE B-6: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-06-0028			9.8	16.7		2.6												BERMINGHAM
K-06-0029			0.0															BERMINGHAM
K-06-0031			28.1															BERMINGHAM
K-09-0219			38.5	33.4	56.4						24.4							BERMINGHAM
K-09-0220			39.9	32.9	49.8													BERMINGHAM
K-10-0287	0.0		42.3	29.5	48.7		30.6				51.0	36.9		48.0	0.0	60.9		BERMINGHAM
K-10-0290	0.0		48.0	22.3	40.8							46.1		43.9	8.4	82.0		BERMINGHAM
K-10-0293			40.4	39.1	35.6		57.8				70.1	52.9		38.7	5.7			BERMINGHAM
K-10-0301			51.2		46.7		86.2					49.2		38.1	19.6	44.3	62.9	BERMINGHAM
K-10-0307	7.4		37.8	28.9	28.1							35.4		31.2	24.4		47.9	BERMINGHAM
K-10-0310			40.6	40.1	45.7		51.3				60.1	32.6		35.3	10.7	13.2	51.2	BERMINGHAM
K-10-0315	20.9		40.7	10.2	64.6		90.2				27.1	37.0		38.7	27.6	23.9	54.7	BERMINGHAM
K-10-0319			60.3	65.6	37.0	59.6	67.2					43.9		35.6	12.2		42.4	BERMINGHAM
K-11-0358	6.0		52.6	32.6	38.1							39.7			16.3	13.0		BERMINGHAM
K-11-0359	0.0		49.2	56.3	35.3		17.3					40.7			16.0	39.5		BERMINGHAM
K-11-0360	0.0		65.6	43.3	9.3							42.6				52.2	47.9	BERMINGHAM
K-11-0361	0.0		45.2	17.6	50.2	52.8						51.2			29.2		50.6	BERMINGHAM
K-11-0363	0.0		43.6	39.6								49.3			0.0	40.7		BERMINGHAM
K-11-0364	5.0		26.6	22.1	20.4		7.5								2.7	19.7	10.0	BERMINGHAM
K-11-0366	6.0		11.5	16.3	6.3							3.2			1.0	69.7		BERMINGHAM
K-11-0368	28.0		21.2	15.8	38.4	3.6	15.8					24.9			0.0	37.0		BERMINGHAM
K-11-0369	22.1		48.4	36.6	29.1		72.2					28.5				40.0	41.3	BERMINGHAM
K-11-0370	42.2		29.0	3.3								20.9			2.5			BERMINGHAM
K-11-0372	0.0		54.8	36.5			49.3				11.3	22.3			18.5		45.1	BERMINGHAM
K-11-0373	0.8		40.9	34.5	34.5		63.9					14.7			26.3			BERMINGHAM
K-11-0376	0.0		56.7	39.7	35.6		74.5					32.1			12.6	45.2		BERMINGHAM
K-11-0378	1.4		40.6	33.7			46.9								16.2			BERMINGHAM
K-11-0380	0.0		29.6	19.2								26.3			6.5			BERMINGHAM
K-11-0381	0.0		54.9	40.2		63.4	72.3	64.5				49.4			23.9		27.3	BERMINGHAM
K-11-0385			49.2	30.9	6.3		56.3					30.3			10.5			BERMINGHAM
K-11-0388			66.0	48.2	12.3							41.7				47.3	46.5	BERMINGHAM

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TABLE B-6: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-11-0389	5.0		52.8	40.7	43.9		64.3				45.3	53.7			22.4	38.3	64.9	BERMINGHAM
K-11-0390	0.0		26.6	21.8	37.1		47.3					38.9			14.3	41.0	44.0	BERMINGHAM
K-11-0392	6.9		40.9	25.8	71.7		87.1					45.5			15.3	66.4		BERMINGHAM
K-11-0393	3.6		47.0	25.0	56.3							35.7			16.0			BERMINGHAM
K-11-0394			66.3	37.5	44.1							55.2				69.9		BERMINGHAM
K-11-0395	6.0		51.2	35.4	49.2		85.1					61.6			15.0	68.7		BERMINGHAM
K-12-0403	11.8		21.6	0.0	38.2		23.0					31.7			7.7			BERMINGHAM
K-12-0408	5.4		25.4	29.8	29.4		83.6					7.3			58.2		13.7	BERMINGHAM
K-12-0412			24.8	41.0	48.0	37.8	31.1				3.3	33.9						BERMINGHAM
K-12-0415	0.0		40.5	29.5	45.3		75.7				83.3	32.7			11.5		18.7	BERMINGHAM
K-12-0422	0.0		42.2	27.1	51.9		15.8	57.2				36.7			9.3		41.9	BERMINGHAM
K-12-0426	0.0		37.8	37.9	29.7		37.5	38.6			33.0	40.1			29.7		20.8	BERMINGHAM
K-12-0434	11.5		59.6	41.7	58.3		79.7					47.1			26.8			BERMINGHAM
K-12-0440	3.8		31.6	36.5	28.9		53.8				48.0	30.6			31.0		57.3	BERMINGHAM
K-12-0444	0.0		33.3	22.9		11.5	39.5				33.7	25.1			12.7		20.3	BERMINGHAM
K-12-0446	0.0		39.3	28.1	17.3		48.3	21.0			38.7	32.9			25.0		64.4	BERMINGHAM
K-12-0449	0.0		35.6	32.5			40.8				38.7	29.3			31.1			BERMINGHAM
K-12-0452	1.8		42.5	37.8	47.0		42.4	45.0			35.0	24.8			18.0		56.0	BERMINGHAM
K-12-0459	0.0		39.0	20.8	30.7		46.7	44.0				33.7			28.0	74.7	46.7	BERMINGHAM
K-12-0465	0.0		37.9	28.6	21.8		42.4	12.0			40.1	34.1			29.3		29.6	BERMINGHAM
K-12-0473	0.0		29.7	20.9	31.2		34.9					22.7			34.1			BERMINGHAM
K-14-0524			14.2	20.4			16.7				6.3				1.3	56.7		BERMINGHAM
K-14-0529	0.0		20.0	22.1	26.3		7.9								4.1	25.3		BERMINGHAM
K-14-0531	225.0		26.1	16.8	7.1		66.8				33.3				20.4	44.7	43.8	BERMINGHAM
K-14-0535	0.0		48.0	10.9	62.7		33.7					26.1			4.0		43.5	BERMINGHAM
K-14-0537			10.4	14.2	24.1		31.0					133.4			0.0	25.3		BERMINGHAM
K-14-0538	2.5		26.3	9.3	3.8		22.4					12.8			3.0		8.3	BERMINGHAM
K-14-0539	8.3		88.2	5.5	8.1		48.0				3.9	10.8			2.2		451.7	BERMINGHAM
K-14-0542			93.4	21.1	188.3		47.8					32.3			8.3	33.0		BERMINGHAM
Average RQD	**9.8**		**40.2**	**28.5**	**39.0**	**33.1**	**49.1**	**40.3**			**36.1**	**36.4**		**38.7**	**15.4**	**45.1**	**55.5**	
Standard Deviation	**33.9**		**17.9**	**13.1**	**27.8**	**27.4**	**24.1**	**22.4**			**22.4**	**19.3**		**13.8**	**11.9**	**20.7**	**78.6**	

TABLE B-7: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-11-0389	41.0		54.2	11.1				50.3				36.0		36.7				GALKENO
K-10-0292			47.4	32.4		30.8		72.1				32.5		35.0	0.0	5.9	52.6	GALKENO
K-10-0297	2.2		56.5	0.0	2.3							42.9		44.5	0.0			GALKENO
K-12-0439	0.0		32.5	21.6				40.8			14.7				17.4			GALKENO
K-12-0447	0.0		37.1	22.4	56.3		77.3	53.6							10.3		15.2	GALKENO
K-14-0522	5.0		47.2	22.0				22.0			32.7	25.1			5.6			GALKENO
Average RQD	**9.6**		**45.8**	**18.2**	**29.3**	**30.8**	**77.3**	**47.7**			**23.7**	**34.1**		**38.7**	**6.7**	**5.9**	**33.9**	
Standard Deviation	**17.7**		**9.4**	**11.2**	**38.2**			**18.3**			**12.7**	**7.4**		**5.1**	**7.4**		**26.5**	

TABLE B-8: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-08-0160			31.5	15.1	39.3		57.6		32.1	0.0								KENO
K-08-0162				35.9			67.5											KENO
K-08-0163	4.1		37.7	13.8	15.5	26.3	60.2											KENO
K-08-0165	0.0	25.3	35.6		14.0	17.8	68.6											KENO
Average RQD	**2.0**	**25.3**	**34.9**	**21.6**	**22.9**	**22.1**	**63.5**		**32.1**	**0.0**								
Standard Deviation	**2.9**		**3.1**	**12.4**	**14.2**	**6.0**	**5.4**											

TABLE B-9: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-07-0069	2.3	31.2	46.7		23.8													ONEK
K-07-0072		37.2	42.3		30.5	18.7	61.6											ONEK
K-07-0074			53.2	25.7	42.8													ONEK
K-07-0116		31.4	36.0				49.8	62.4	27.7									ONEK
K-07-0118			40.6	39.5	33.2		66.9			0.0								ONEK
K-07-0119		40.6	35.5	26.8	32.8		60.0	40.7										ONEK
K-07-0120			39.8	24.9	45.9		42.1											ONEK
K-07-0121		26.1	32.7	44.7			54.2											ONEK
K-07-0122		51.8	30.9	31.3	25.4		65.1											ONEK
K-07-0123	0.0		33.0	28.5		21.6	64.1											ONEK
K-07-0124			38.7	41.9		73.1	64.5	51.8										ONEK
K-07-0125		19.9	20.8			31.8	45.9											ONEK
K-07-0126	0.0		21.5	9.5		5.3												ONEK
K-08-0129			55.3	32.6				60.3	64.3									ONEK
K-08-0134			54.8	64.0	79.4	86.1	86.6			0.0								ONEK
K-08-0135		21.0	26.4	27.6	61.4		35.8	31.4	17.5	0.0								ONEK
K-08-0136			44.6	41.8			60.3	56.4										ONEK
K-08-0137	0.0		30.9	28.5		47.5	76.1											ONEK
K-08-0138		41.6	42.3	41.4	65.5		60.8	53.2										ONEK
K-08-0139		34.6	28.6	18.4			47.2	29.4		0.0								ONEK
K-08-0140			43.2	40.2	55.9		35.3	71.8		0.0								ONEK
K-08-0141			49.3	45.1		60.9	68.0			0.0								ONEK
K-08-0142			42.3	28.1	63.9	56.9	65.6	43.6										ONEK
K-08-0143		31.8	45.7	22.2	52.5		69.9	44.9		0.0								ONEK
K-08-0144	0.0			73.6			73.1	37.6										ONEK
K-08-0145	0.0	75.4	40.3	10.2		36.9	62.3											ONEK
K-08-0146			46.4	40.5			63.9	71.2		0.0								ONEK

TABLE B-9: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-08-0147	0.0		45.2	56.3	88.2		26.5	27.7										ONEK
K-08-0148		45.6	47.0	17.7			27.6	62.4	75.7	4.8								ONEK
K-08-0149			51.7	54.9	53.0					0.0								ONEK
K-08-0150	0.0	87.5	33.8	40.2	39.5		51.2	20.0										ONEK
K-08-0151			46.4	15.0		24.8	49.9	41.2		0.0								ONEK
K-08-0152			59.6	61.1	88.6		77.6	75.0										ONEK
K-08-0153		54.0	72.6			91.4	89.7			0.0								ONEK
K-08-0154	0.0	77.3	70.8		87.1		91.1		83.6									ONEK
K-08-0155			70.3	47.1	89.6		92.5			0.0								ONEK
K-08-0156	0.0		69.1	70.0														ONEK
K-08-0157			68.0	55.6					49.2	0.0								ONEK
K-08-0158	0.0		62.9	70.0	56.0													ONEK
K-08-0175			40.6	38.6		63.9	94.0	60.4										ONEK
K-08-0177			56.6	52.1		58.4	76.3		56.7									ONEK
K-10-0237			21.2									26.6		6.4				ONEK
K-10-0239			12.2											5.1		26.9		ONEK
K-10-0240			49.3											9.7		49.6		ONEK
K-10-0241	12.8		46.5	16.6								30.7		15.0		34.9		ONEK
K-10-0244			30.2	12.5	17.2							30.5		24.8		53.1		ONEK
K-10-0245			28.0	48.2	50.8							41.1		34.1		69.6		ONEK
K-10-0247	5.1		72.6		10.7		63.2					31.1		36.4		45.7		ONEK
K-10-0248			50.2	24.7	15.1							40.2		16.7	20.3	54.5		ONEK
K-10-0249	5.1		40.2	41.9	36.7		52.9					36.1		30.1		61.1		ONEK
K-10-0250	3.8		76.7	65.2	80.4		82.8					67.7		75.5		77.1		ONEK
K-10-0251			51.4		71.2		84.1					50.4		65.1	66.9			ONEK
K-10-0252	6.4		40.3		70.0		82.6					61.0		21.9				ONEK
K-10-0253	0.0		34.4		61.2		67.4					34.6		12.0	6.8	27.5		ONEK
K-10-0254	0.0		74.8		52.5		85.0					42.9		10.0	31.8	78.7		ONEK
K-10-0255	28.7		39.5	15.1			57.1					36.3		23.4		0.0		ONEK
K-10-0256	0.0		54.7				41.7					30.5		26.9		49.2		ONEK

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TABLE B-9: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-10-0262			44.8		45.1		62.6					30.7		26.4		78.4		ONEK
K-10-0263			25.0		37.5	15.3	41.9					20.6		3.3				ONEK
K-10-0265	0.0		28.1			42.7	43.4					36.6		44.4		28.0		ONEK
K-10-0267			70.3	35.8			92.4					61.8		45.5		44.3		ONEK
K-10-0306	12.4		16.9		25.6		57.9					21.5		16.2	25.3	56.9		ONEK
K-10-0308			41.2	34.4		56.7	64.4					35.2		29.0	43.3	51.5	62.1	ONEK
K-10-0309	0.0		42.1		61.0		46.6					37.9		34.9		46.1	42.8	ONEK
K-10-0311	0.0		50.9				40.3					50.0		36.2		57.6	55.7	ONEK
K-11-0324	0.0		54.4				35.4					29.8		0.0	15.5			ONEK
K-11-0325	0.0		41.4		41.5		87.6					28.2		17.9	26.2	9.2		ONEK
K-11-0326	0.0		52.2	47.6	33.3		86.9					41.1		18.3		93.4	66.6	ONEK
K-11-0327	5.6		55.7	36.1	77.1		92.2					31.6		23.5		29.0		ONEK
K-11-0328			40.0	15.6			51.4					28.6		47.3				ONEK
K-11-0329			51.7	35.1	47.7		61.1					36.3		25.7			35.4	ONEK
K-11-0330			49.8	24.4	34.4		63.3					49.7		33.7	29.5			ONEK
K-11-0331			33.2	27.6			31.8					38.8		28.0	28.3	51.5		ONEK
K-11-0332			52.9				58.6					36.6		21.2		53.6	25.9	ONEK
K-11-0333			44.7	30.1			54.1	51.0				42.2		44.9				ONEK
K-11-0334			46.2	4.3			62.4					36.9		22.8	52.7	50.8		ONEK
K-11-0335			58.8	51.1	26.1		40.8					54.5		36.2				ONEK
K-11-0337			42.5	7.7		56.7	59.3					27.8	28.8	43.8				ONEK
K-11-0339			52.1	25.2			60.3					42.8		43.6	23.5	36.5		ONEK
K-12-0488	0.0		39.7	30.1	7.7		76.6	29.3										ONEK
K-12-0491	34.3		38.8	39.9	46.7		68.2	65.3										ONEK
Average RQD	**3.9**	**44.2**	**45.2**	**35.7**	**49.2**	**47.2**	**62.3**	**49.4**	**53.5**	**0.3**		**38.3**	**28.8**	**27.8**	**30.8**	**48.7**	**48.1**	
Standard Deviation	**8.1**	**23.9**	**15.4**	**17.7**	**24.1**	**27.2**	**20.2**	**20.6**	**31.6**	**1.2**		**13.7**		**17.0**	**18.8**	**23.8**	**26.0**	

TABLE B-10: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-06-0001	0.0	26.1	51.5	28.4	33.8													SK
K-06-0002	0.0		54.4	28.9		38.7												SK
K-06-0003	0.0		43.4	30.5														SK
K-06-0004	0.0		46.2	26.5			0.0											SK
K-06-0006	0.0		42.8	32.2	46.3													SK
K-06-0007	0.0	20.1	53.9	18.8	56.1		23.3											SK
K-06-0009	0.0		48.0	41.7	75.5													SK
K-07-0112		81.0	75.2	15.0	85.4													SK
K-07-0113		43.1	48.0		18.4		34.1											SK
K-09-0218	0.0		54.4	47.1	61.1		82.3											SK
K-10-0221			39.3	9.7	54.9					15.8		53.4	17.7	53.0				SK
K-10-0222			61.7	19.9	45.1		85.6			0.0		52.8	0.0	42.9	0.0			SK
K-10-0223	33.9		59.4	38.2	45.8		59.0					46.7	48.5	31.2	16.4			SK
K-10-0224			53.8	23.6	23.6		35.2			1.4		38.7	0.0	40.1				SK
K-10-0225	54.3		60.8	37.8	74.0							48.7	17.1	44.2	8.5			SK
K-10-0226	28.9		25.7	8.0								37.2	32.8	33.2				SK
K-10-0227	3.2		45.5	22.7			51.6					33.5		32.7				SK
K-10-0228	35.8		45.5	15.9			31.4					60.4		27.7				SK
K-10-0229	5.4		69.6	4.8								58.4	56.4	42.4				SK
K-10-0230	0.0		50.6	10.8	62.3		61.6					41.2		48.3		10.9		SK
K-10-0231	0.0		28.1	54.0	32.2		52.8					29.2		39.1		28.2		SK
K-10-0232	1.2		50.6	18.7	47.7		71.2					38.4	41.8	36.2	0.0			SK
K-10-0233			52.9	14.8			46.7					44.4	37.7	19.7	57.4			SK
K-10-0234	2.1		50.9	41.0	20.0							38.9		35.0	60.9			SK
K-10-0236	15.7		67.0	0.0	56.9							45.6		55.5	13.9	73.4		SK
K-10-0238	4.3		45.2	19.9	11.8					4.9		40.8		32.7		42.3		SK
K-10-0242	1.9		17.6	1.4	0.0		56.1					29.0	72.8	16.0		38.7		SK
K-10-0243	8.1		54.6		18.7		59.2					39.4		21.8	0.0			SK
K-10-0246	3.0		71.4	0.0								40.5		30.6				SK
Average RQD	**8.6**	**42.6**	**50.6**	**22.6**	**43.5**	**38.7**	**50.0**			**5.5**		**43.0**	**32.5**	**35.9**	**19.6**	**38.7**		
Standard Deviation	**14.9**	**27.4**	**12.8**	**14.6**	**23.2**		**22.6**			**7.2**		**8.8**	**23.9**	**10.6**	**25.2**	**22.9**		

Lithology Codes 2012

BX	Hydrothermal Breccia	Typically zones of monomictic breccia typically composed of angular rock and/or vein clasts cementedby later quartz, carbonate (calcite, dolomite, siderite) with pyrite, galena or sphalerite.
CHSCH	Chlorite Schist	Light green to green-grey, or silvery green chlorite - sericite schist (phyllite), locally containing siliceous laminations. May have prominent lineation. Possible meta-tuffaceous rock. If rock makes up less than 5% of unit the chloritic modifier "chl" can be used.
CQTZT	Calcareous Quartzite	Quartzite characterized by brownish speckled texture or banding of primary carbonate that reacts to acid test. If rock makes up less than 5% of unit the calcareous modifier "c" can be used.
CSCH	Calcareous Schist	Light coloured schist, with carbonate as a major constituent. If rock makes up less than 5% of unit, the calcareous modifier "c" can be used.
DM	Disseminated Mineralization	Zone of disseminated galena or sphalerite (excluding pyrite), shown in Lith_2
FLT	Fault	Always placed in Lith_1 except where VM or VL occupies the same interval, when it is placed in Lith_2. Use Lith_2 if the rubbled or gouged rock type can be determined, but do not show it asa > 49% as the presence of the fault is more important. Includes Fault Breccia.
GNST	Greenstone	Generally massive greyish green to dark green, chlorite - actinolite - calcite sills locally with relict phaneritic texture and sometimes schistose particularly on margins.
GRIT	Gritty Schist	Schist containing clear, grey, and/or blue quartz grains (to 1mm) in a quartz-mica schist matrix. The quartz grains can generally only be seen on a freshly broken surface and not on the drill core surface. Petrology suggests these rocks may be meta-felsic volcanics.
GSCH	Graphitic Schist	Grey to dark grey to black schist (phyllite) with graphite as a major constituent, with well developed foliation, comprising > about 80%, with common quartzite bands generally < 1cm thick. A soft, Weak rock that breaks along foliation. Commonly contain plications, wrinkle laminations, small drag folds and crenulations. Most contain irregular masses of quartz as stringers or boudins. If rock makes up less than 5% of unit the graphite modifier "g" can be used.
LMST	Limestone	Light - medium grey to black crystalline limestone, sometimes banded with irregular lens-like layers of white or buff carbonate, or schistose (phyllitic) limestone.
NR	No Recovery	Loss of core, record in the Lith_2 field if VM or VL is present as these must show in Lith_1. Outside of mineralized zones, the % of the interval that NR represents determines its placement in Lith_1 or Lith_2, because core loss commonly represents faults.
OVB	Overburden	Quartenary alluvium, colluvium comprising interbeded sandy to bouldery fluvio-glacial beds.
QFP	Quartz Feldspar Porphyry	Fine to medium grained, brown to pinkish, quartz porphyritic ± biotite-bearing, felsic (dyke) intrusive.

QTZT	Quartzite	Massive buff, light to medium grey to white or bluish grey, may have a weak schistosity defined by sericite. Some are very fine grained, white and resemble re-crystallized cherts. Bedding may be visible throughout. Some are very fine grained, with a sugary texture and resemble re-crystallized cherts. Minor GSCH (to about 5%) is generally present as very narrow bands.
SCH	Undifferentiated Schist (Phyllite)	Fine grained, light to dark greyish - black or green depending on the dominant mineral content. Fracture surfaces generally have a distinctive sheen and show well developed foliation. Generally plications, wrinkle laminations, small drag folds and crenulations. Most contain irregular masses of quartz as stringers or boudins. Siliceous schist may be interbedded throughout, but must comprise less than 10% of the unit.
SM	Stringer Mineralization	Zone of stringers (< 1 cm true width) that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_2 field unless they comprise > 25% of the interval in which case put in Lith_1.
SSCH	Sericite Schist	Light green or mottled greenish yellow fine grained schist (phyllite), commonly with a silvery luster. Commonly show marked schistosity, plications, crenulations and contain numerous stringers, masses and boudins of white quartz. If rock makes up less than 5% of unit the sericite modifier "s" can be used.
TQTZT	Thin Bedded Quartzite	Grey quartzite bands 5 - >10 cm in thickness, with mud/graphitic schist bands up to about 20% (ONLY TO BE USED IN MSQ)
VL	Mineralized Veinlet	Zone of veinlets (1 - 10 cm true width) comprising > 25% of interval, that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_1 field.
VM	Mineralized Vein	Zone of veins (> 10 cm true width) that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_1 field.
VN	Unmineralized Vein	Veins, veinlets and stringers lacking hypogene mineralization, but usually containing quartz, calcite or dolomite

Lithology Modifiers	
a	argillaceous
c	calcareous
chl	chloritic
cty	cherty
g	graphitic
m	massive (quartzite or schist)
s	sericitic
tnb	Thin bedded <30 cm bands QTZT, GSCH
mb	Medium bedded 30-120 cm bands QTZT, GSCH
tkb	Thick bedded >120 cm bands QTZT, GSCH

TETRA TECH EBA

		Job Number	W14103428-01.003
		Sheet No.	1 of 2
Contract/Client	Alexco Environmental Group	Made by	JV
Design Topic	Plug DimensionDesign	Date	17/03/2015
	10 m Hydraulic Head	Reviewed by	CC

NELPCO NND-EBA LAND PROTECTION CORP.

1.) Punching Shear Design

Shear Strength for unreinforced concrete

$f'_s =$ 107.7 psi concrete shear strength
742.2 Kpa

Inputs

where $f'_c =$ 2900.75476 concrete compressive strength **(psi)**

NOTES:

* **Changing from kPa to to psi**

$f'_c =$ 20000 (kPa)

$f'_c =$ 2900.8 (psi)

Shear Strength of the rock mass (U)

Use the fair rock in the table on the right

This corresponds to U = 600 kPa

Therefore, punchiing shear failure is controlled by the shear strenght of the rock mass.

Recommended design shear strengths and hydraulic gradients for tunnel plugs (after Lang, 2012)

Rock Condition CSIR Rock Mass Rating	Design Shear Strength (kPa)	Allowable Hydraulic Gradient*
Very Good Rock Massive, hard, widely jointed 81<RMR<100	1500	15-30
Good Rock Hard to Moderately hard, moderately jointed 61<RMR<80	900	10-14
Fair Rock Moderate to Weak, Moderately jointed 41<RMR<60	600	7-9
Poor Rock Weak, closely jointed or sheared 21<RMR<40	300	5-6
Poor Rock Very weak, possible erodible RMR<20	150	3-4

*Allowable gradients can be higher if formation grouting is performed.

2.) Plug length for static loading

L = 0.0908 Length without considering F.S

L = 0.2725 **Final length considering F.S.**

		Inputs	
where	**h**	2.5	Adit height **(m)**
	w	2	Adit width **(m)**
	U	600000	**(Pa)** Allowable shear strength rock mass, **U** should be substituted for ***f's*** if ***f's*** is lower
	H	10	Head of fluid on plug **(m)**
	ρ	1000	Density of fluid **(kg/m^3)**
	g	9.81	Gravitational constant **(9.81 m/s^2)**
	FS	3	Factor of Safety

3.) Additional Pressure (Seismic)

PH 144 (kPa) considering Vmax

		Inputs		
where	**c**	1437	acoustic velocity of water **(1437 m/s)**	1437
	v		ground velocity **(m/s)**	
	ρ	1000	Density of fluid **(kg/m^3)**	1000
	V_{max}	0.1001	**m/s**	0
	a_{max}	0.182	**g**	0.182

The relationship between Vmax and amax is given approximately by Seed and Idriss (1983) as

$$\frac{V_{max}}{a_{max}} = \frac{55\,\frac{cm}{seg}}{g}\,(for\ rock)$$

* $V_{max}/a_{max}=$ 55 cm/seg/g

NOTES:

*notice V_{max} is dependent on a_{max}

TETRA TECH EBA

		Job Number	W14103428-01.003
		Sheet No.	2 of 2
Contract/Client	Alexco Environmental Group	Made by	JV
Design Topic	Plug DimensionDesign	Date	17/03/2015
	10 m Hydraulic Head	Reviewed by	CC

NELPCO NND-EBA LAND PROTECTION CORP

4.) Hydraulic Jacking

CRM = minimum rock cover measured to the nearest point on the ground surface

CRM	5.3209	m	Condition met

		Inputs	Inputs	
where	h_s		10	**(m)** static design water head
	γ_w		1000	**(kg/m^3)**unit weight of water
	γ_r		2600	**(Kg/m^3)**unit weight of rock
	β (°)	**20**	0.3491	slope angle of topography
	F		1.3	FoS (**between 1.1 and 1.3** Bergh-Christiansen and Dannevig, 1971)

NOTES:

C_{RM} = minimum rock cover measured to the nearest point on the ground surface

* **β (°)** **degree**: enter value in degrees on green celd

5.) Allowable Hydraulic Gradient

The length of the plug is reviewed by the allowable hydraulic gradient for the rock condtitions that will prevent piping and downstream erosion of the adit walls or by maximum accetable seepage

$$\text{Hydraulic Gradient} = \frac{\text{Design head of water [m]}}{\text{Lengh of the plug [m]}}$$

$$\text{Length of Plug [m]} = \frac{\text{Design head of water [m]}}{\text{Hydraulic Gradient}}$$

Hydraulic gradient = 8 Based on a fair rock (from table on previous page)

Design of head water = 10 m

Then length of Plug = 1.3 m However, 3 m long is recommended to meet conditions of plug length > adit width or height

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX 3.6
DSTF RISK ASSESSMENT

Bellekeno Mine - Dry Stack Failure Modes and Effects Analysis
Final Draft

Prepared for

Alexco Resource Corp.

Prepared by

srk consulting

SRK Consulting (Canada) Inc.
1CA009.006
July 2013

Bellekeno Mine - Dry Stack Failure Modes and Effects Analysis Final Draft

July 2013

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[illegible]

[illegible]

1 Introduction

Alexco Resource Corp. entered into a contract with SRK Consulting (Canada) Inc. to perform a Failure Modes and Effects Analysis (FMEA) for the Ken District Mill Dry Stack Tailings Facility. Alexco owns and operates the Bellekeno Mine (silver, lead and zinc) in the Keno Hill Silver District of the central Yukon.

Based on concerns raised by technical staff and consultants of Na-cho Nyak Dun regarding the suitability and long-term stability of the DSTF and ice rich permafrost in foundation soils, Alexco commissioned the FMEA workshop to address these concerns using an objective risk-based approach. Following some preparatory work, the FMEA for the DSTF was completed in a workshop on September 24, 2012 at the Whitehorse, Yukon office of Alexco. This report describes the approach to the project and the results.

2 Objectives

The overall objective of the FMEA for the Bellekeno Dry Stack Tailings Facility is to evaluate the risks associated with the presence of permafrost in the foundation materials adjacent to the dry stack facility. The objectives of the workshop were to evaluate the likelihood of occurrence and consequences associated with a series of failure modes for the dry stack at the site and to identify high concern issues.

3 [illegible]

The physical boundaries of the FMEA were the immediate surroundings of the dry stack, however; surface water impacts on facilities downstream of the facility, e.g. Christal Lake, were included. The temporal boundaries included operations as well as long-term considerations, assumed to be about 50 years.

4 FMEA Process

4.1 Preparation

Preparation for the workshop included the following activities:

- Review of site information;
- Identification of workshop participants; and
- Circulation of failure likelihood and severity of consequence descriptions for review by the participants.

4 [illegible]

The FMEA workshop was held on September 24, 2012 at the Alexco's office in Whitehorse, Yukon. The workshop participants and their affiliations were:

- Brad Thrall, Alexco Resource Corp.;
- Richard Trimble, EBA, a Tetra Tech Company;
- Justin Pigage, EBA, a Tetra Tech Company;
- Kim Winnicky, consultant to First Nation of Na-cho Nyak Dun (NND);
- Bill Slater, consultant to First Nation of Na-cho Nyak Dun (NND);
- Rob McIntyre, Alexco Resource Corp.; and
- Dirk van Zyl, SRK Consulting (Canada) Inc. (facilitator).

As an introduction to the workshop, EBA made a presentation of site conditions. The presentation is provided in Appendix A.

Failure modes were identified, described and discussed during the workshop. A participant described the failure mode and its effect (or manifestation of the failure mode). During this discussion, descriptions were added in the FMEA table for the columns labelled ID, Failure Mode and Consequence Type.

There was open discussion amongst the workshop participants to review and agree on the description of the failure mode and its effects, i.e. reach consensus on the description in the FMEA table for the columns above. Based on this discussion, initial suggestions for the following columns in the FMEA table were made: Likelihood (using the descriptions in Table 1 as guidance) and Consequence Severity (using the descriptions in Table 2 as guidance).

Participants discussed the initial ratings with a view to obtaining consensus on the likelihood, severity, and notes for further consideration. The Risk Rating Descriptive Column was completed using the Risk Matrix in Table 3.

[illegible]

In total, 15 failure modes were identified and discussed at the workshop. The FMEA outcome for the workshop is presented in Table 4.

The cells in Table 4 describing the risks are shaded using the colors in the attached Risk Table (Table 3). The colors indicate the various risks posed by a combination of the likelihood of a failure occurring and the consequence severity of the failure mode if it should occur. For example, dark orange to red correspond to high to very high risk failure modes while the green colors correspond to a low risk failure mode. None of the failure modes identified in the workshop received a high or very high risk rating.

Twelve of the fifteen failure modes identified resulted in a low risk rating (refer to Table 4). Two resulted in medium risk and one in a moderately high risk rating. The failure modes resulting in medium risk ratings are:

- Large differential settlement in the long-term (~50 years) leading to tailings exposure on the surface from compromised covers (environmental consequence).
- Large precipitation event erodes through the surface cover, exposes the tailings resulting in transport of tailings into natural environment (special considerations consequence).

The moderately high risk rating was linked to large differential settlement in the long-term (~50 years) leading to tailings exposure on the surface from compromised cover (special considerations consequence).

The special considerations consequences were identified as being of specific concern to the NND and comments are provided in Table 4 for the further evaluation and mitigation of these, as well as the medium risk associated with the environmental consequences.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Happens often	High frequency (more than once every 5 years)	98%	17.8%
[illegible]	Could easily happen	Event does occur, has a history, once every 15 years	75%	6.7%
[illegible]	Could happen and has happened elsewhere	Occurs once every 40 years	40%	2.5%
[illegible]	Hasn't happened yet but could	Occurs once every 200 years	10%	0.5%
[illegible]	Conceivable, but only in extreme circumstances	Occurs once every 1000 years	2%	0.1%

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	No impact.	Minor localized or short-term impacts.	Significant impact on valued ecosystem component.	Significant impact on valued ecosystem component and medium-term impairment of ecosystem function.	Serious long-term impairment of ecosystem function.
[illegible]	Some disturbance but no impact to traditional land use.	Minor or perceived impact to traditional land use.	Some mitigable impact to traditional land use.	Significant temporary impact to traditional land use.	Significant permanent impact on traditional land use.
[illegible]	Informal advice from a regulatory agency.	Technical/Administrative non-compliance with permit, approval or regulatory requirement. Warning letter issued.	Breach of regulations, permits, or approvals (e.g. 1 day violation of discharge limits). Order or direction issued.	Substantive breach of regulations, permits or approvals (e.g. multi-day violation of discharge limits). Prosecution.	Major breach of regulation – wilful violation. Court order issued.
[illegible]	< $100,000	$100,000 - $500,000	$500,000 - $2.5 Million	$2.5-$10 Million	>$10 Million
[illegible]	Local concerns, but no local complaints or adverse press coverage.	Public concern restricted to local complaints or local adverse press coverage.	Heightened concern by local community, criticism by NGOs or adverse local /regional media attention.	Significant adverse national public, NGO or media attention.	Serious public outcry/demonstrations or adverse International NGO attention or media coverage.
[illegible]	Low-level short-term subjective symptoms. No measurable physical effect. No medical treatment.	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization.	Moderate irreversible disability or impairment to one or more people.	Single fatality and /or severe irreversible disability or impairment to one or more people.	Multiple fatalities.

[illegible]

[illegible]	[illegible]				
	[illegible]	Minor	Moderate	Major	Critical
[illegible]	Moderate	Moderate [illegible]	High	Very High	Very High
[illegible]	Moderate	Moderate	Moderate [illegible]	High	Very High
[illegible]	Low	Moderate	Moderate [illegible]	High	High
[illegible]	Low	Low	Moderate	Moderate [illegible]	Moderate [illegible]
[illegible]	Low	Low	Low	Moderate	Moderate [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Large differential settlement in the long-term (~50 years) leading to tailings exposure on surface from compromised cover.	Env. Imp.	Minor	Likely	Moderate	Check for other examples in the district for settling. Look at additional modeling with real data.
2	Large differential settlement in the long-term (~50 years) leading to tailings exposure on surface from compromised cover.	Spec. Cons.	Moderate	Likely	Moderately High	Check for other examples in the district for settling. Look at additional modeling with real data. Cover maintenance.
3	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in contamination of localized GW from tailings porewater.	Env. Imp.	Minor	Unlikely	Low	
4	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in upwelling of GW/melt water into the tailings resulting in slope instability	Env. Imp.	Minor	Very Unlikely	Low	
5	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in contamination of surface water (i.e. Christal Lake)	Env. Imp.	Minor	Very Unlikely	Low	Took into account present state of Christal Lake.
6	Large precipitation event erodes through surface cover, exposes tailings resulting in transport of tailings into natural environment	Env. Imp.	Minor	Unlikely	Low	
7	Large precipitation event erodes through surface cover, exposes tailings resulting in transport of tailings into natural environment	Spec. Cons.	Moderate	Unlikely	Moderate	Mitigate by cleaning up the tailings released during the large precipitation event.
8	Poor cover performance (vegetation, other) leads to increased infiltration and increased pore water transport resulting in metals migration	Env. Imp.	Minor	Unlikely	Low	
9	Metals uptake in soil cover vegetation leads to introduction into food chain and human health impacts	Human H&S	Low	Unlikely	Low	Used guidance from Env. Impact to rate.
10	Metals uptake in soil cover vegetation leads to introduction into food chain and human health impacts	Spec. Cons.	Minor	Unlikely	Low	
11	Earthquake larger than design event leads to slope failure resulting in exposure of tailings long-term	Env. Imp.	Minor	Very Unlikely	Low	
12	Earthquake larger than design event leads to slope failure resulting in exposure of tailings long-term	Spec. Cons.	Moderate	Very Unlikely	Low	
13	Modeling has underestimated the foundation pore pressures leading to slope failure and exposure of tailings long-term	Env. Imp.	Minor	Very Unlikely	Low	
14	Failure to follow OMS manual leads to stack not performing to design, resulting in environmental impacts	Env. Imp.	Minor	Unlikely	Low	OMS in place, 3rd party QA/QC every 6 weeks.
15	Dust migration from DSTF leads to (i.e. temporary closure, construction, not following OMS) environmental impacts	Env. Imp.	Minor	Unlikely	Low	OMS in place, 3rd party QA/QC every 6 weeks.

This final draft report, “Bellekeno Mine - Failure Modes and Effects Analysis”, was prepared by SRK Consulting (Canada) Inc.

Dirk van Zyl, Ph.D., P.E.
Principal Consultant (Associate)

and reviewed by

Cam Scott, P.Eng.
Principal Consultant

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

Disclaimer—SRK Consulting (Canada) Inc. has prepared this document for Alexco Resource Corp.. Any use or decisions by which a third party makes of this document are the responsibility of such third parties. In no circumstance does SRK accept any consequential liability arising from commercial decisions or actions resulting from the use of this report by a third party.

The opinions expressed in this report have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

Appendix A: Introductory PowerPoint Presentations

DSTF Risk Assessment

ALEXCO

- Introductions
- Participants
- Objectives
- Risk Assessment Process Overview
- DSTF Overview
- DSTF Risk Assessment

Keno District Timeline

ALEXCO

- **2005** Company Founded
- **2006** Acquired Keno Hill Silver District, Care maintenance change over
- **2007** District wide closure plan studies begins
- **2008** Advanced exploration/development Bellekeno
- **2009** QML Granted - Bellekeno Construction Begins
- **2010** Comprehensive Cooperation Agreement with FNNND
- **2010** Water License Granted – mill/DSTF commissioned
- **2011** Commercial Production – Bellekeno mine/mill
- **2012** Lucky Queen/ Onek new mine development, YESAB/QML

Dry Stack Tailings Technology

ALEXCO

- **Advantages**
  - Reduced makeup water – increased recycle
  - Progressive reclamation enhanced
  - Decreased footprint from higher compaction, stack heights
  - Higher geotechnical stability if constructed appropriately
  - Pore water seepage significantly reduced – groundwater contamination eliminated if operated appropriately

Dry Stack Tailings Technology

ALEXCO

- **Disadvantages**
  - Increased capital and operating costs
  - Increased process bottlenecks – decreased operating flexibility
  - Potential dust migration due to lower moisture content

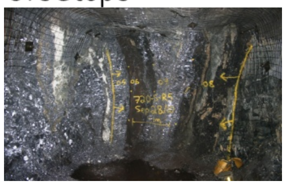
Mill Area Layout

ALEXCO

Mill Process Flowsheet

ALEXCO

Underground
Ore Stope



Drill/Blast
Ore

Load Ore

Ore Haulage

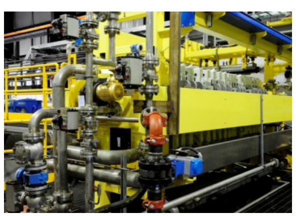
ing

Crushing

Grinding

Classification

Thickening/Filtration

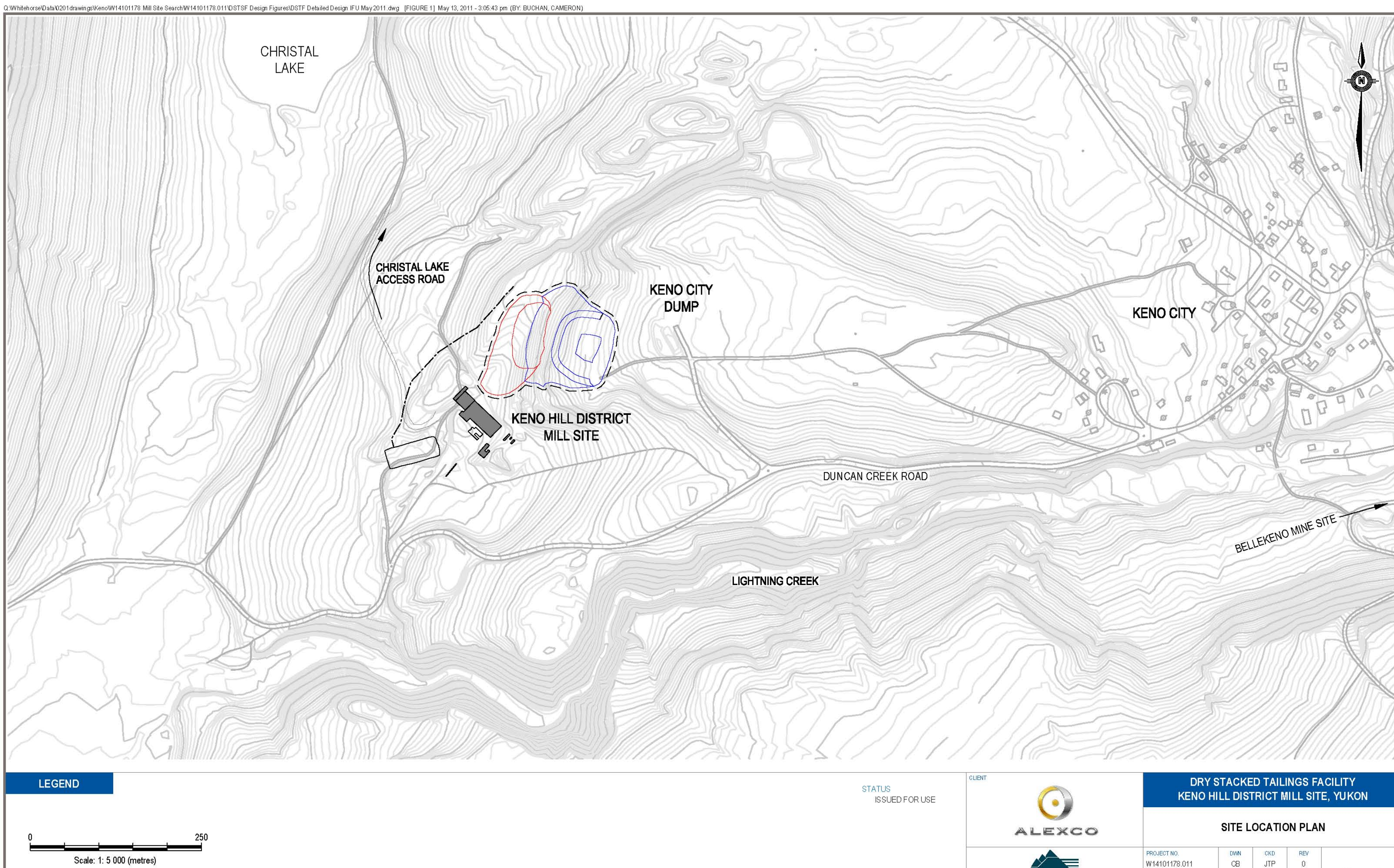


Concentrate Storage

Concentrate Shipment
(Ag, Pb, Zn)

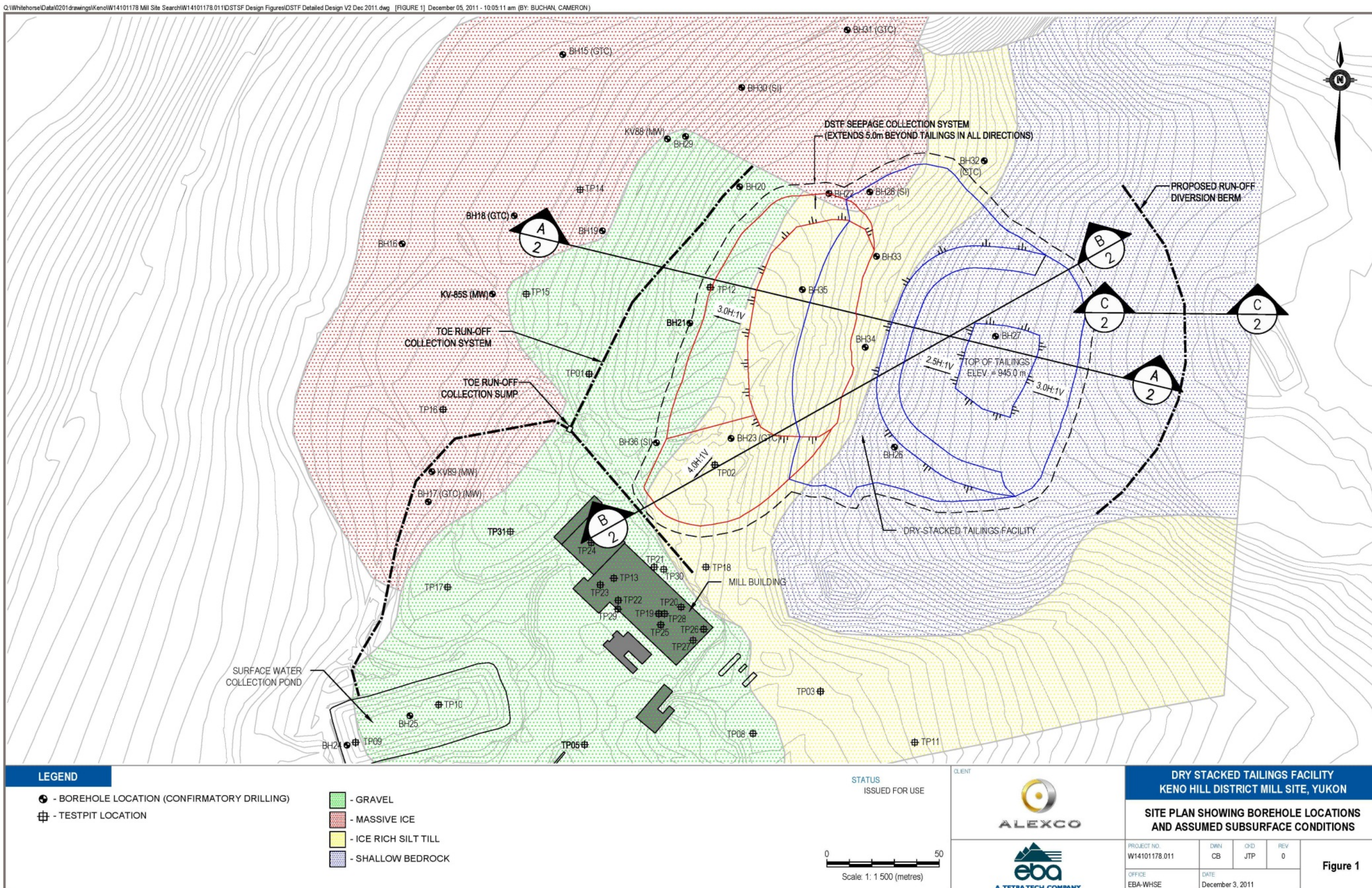
Dry Stack Tailings
Storage

DSTF Design

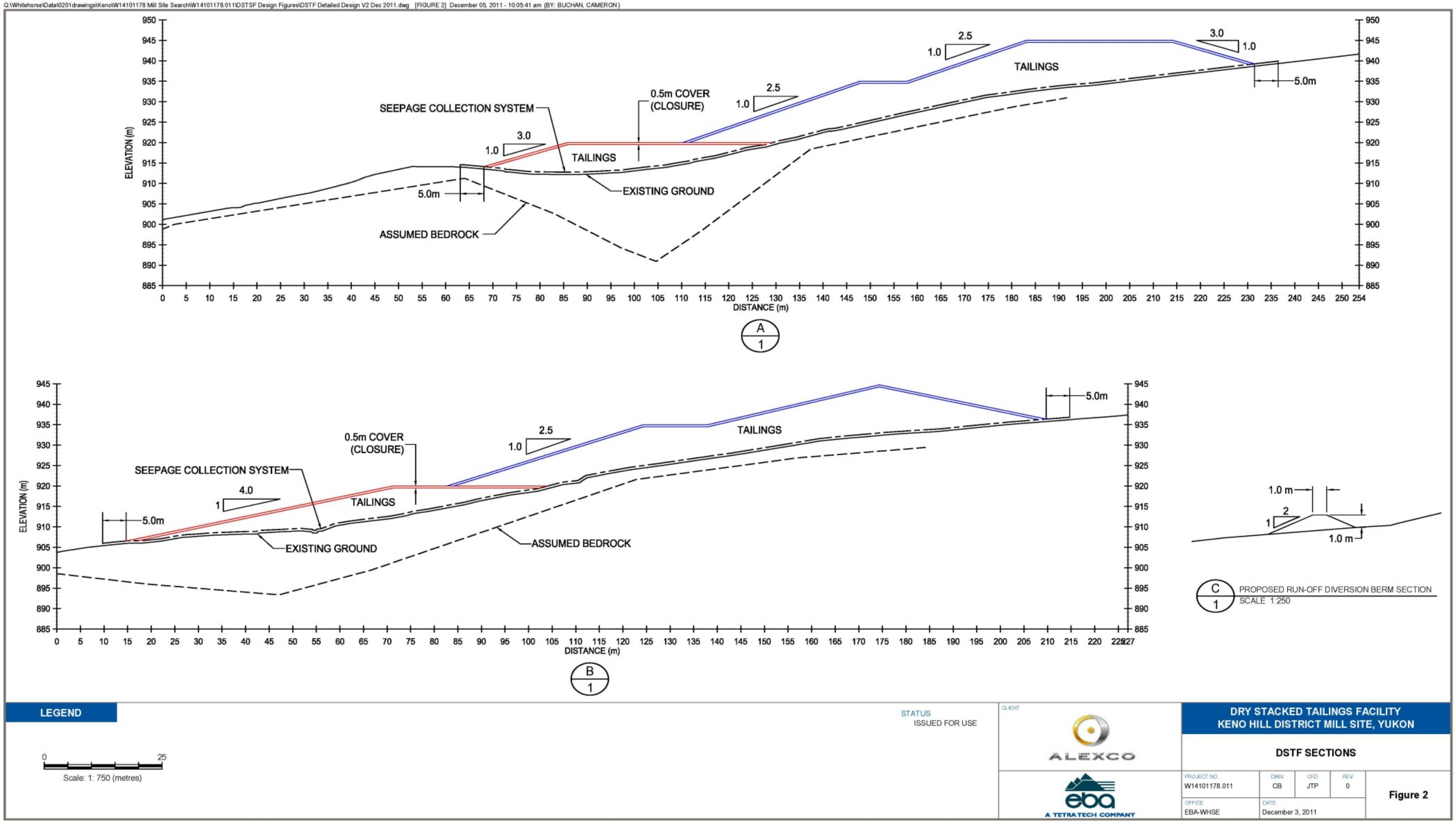


Q:\Whitehorse\Data\0201drawings\Keno\W14101178 Mill Site Search\W14101178.011\DSTSF Design Figures\DSTF Detailed Design IFU May2011.dwg [FIGURE 1] May 13, 2011 - 3:05:43 pm (BY: BUCHAN, CAMERON)
CHRISTAL LAKE
CHRISTAL LAKE ACCESS ROAD
KENO CITY DUMP
KENO CITY
KENO HILL DISTRICT MILL SITE
DUNCAN CREEK ROAD
BELLEKENO MINE SITE
LIGHTNING CREEK
N
LEGEND
0
250
Scale: 1: 5 000 (metres)
STATUS
ISSUED FOR USE
CLIENT
ALEXCO
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
SITE LOCATION PLAN
PROJECT NO.
W14101178.011
DWN
CB
CKD
JTP
REV
0

DSTF Design

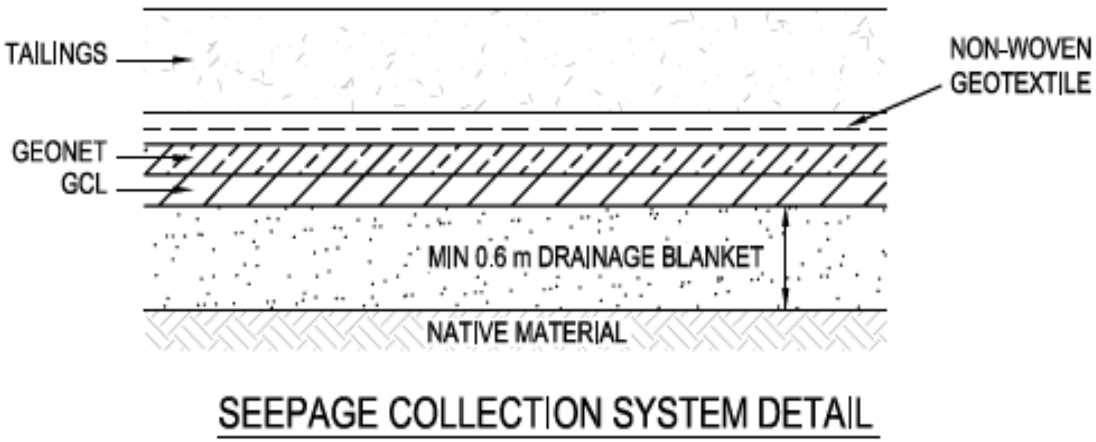

DSTF SEEPAGE COLLECTION SYSTEM
(EXTENDS 5.0m BEYOND TAILINGS IN ALL DIRECTIONS)
PROPOSED RUN-OFF DIVERSION BERM
TOE RUN-OFF COLLECTION SYSTEM
TOE RUN-OFF COLLECTION SUMP
TOP OF TAILINGS ELEV. = 945.0 m
3.0H:1V
2.5H:1V
4.0H:1V
DRY-STACKED TAILINGS FACILITY
MILL BUILDING
SURFACE WATER COLLECTION POND
LEGEND
- BOREHOLE LOCATION (CONFIRMATORY DRILLING)
- TESTPIT LOCATION
- GRAVEL
- MASSIVE ICE
- ICE RICH SILT TILL
- SHALLOW BEDROCK
STATUS
ISSUED FOR USE
Scale: 1: 1 500 (metres)
ALEXCO
eba
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
SITE PLAN SHOWING BOREHOLE LOCATIONS AND ASSUMED SUBSURFACE CONDITIONS
PROJECT NO. W14101178.011
DWN CB
CKD JTP
REV 0
OFFICE EBA-WHSE
DATE December 3, 2011
Figure 1

DSTF Design

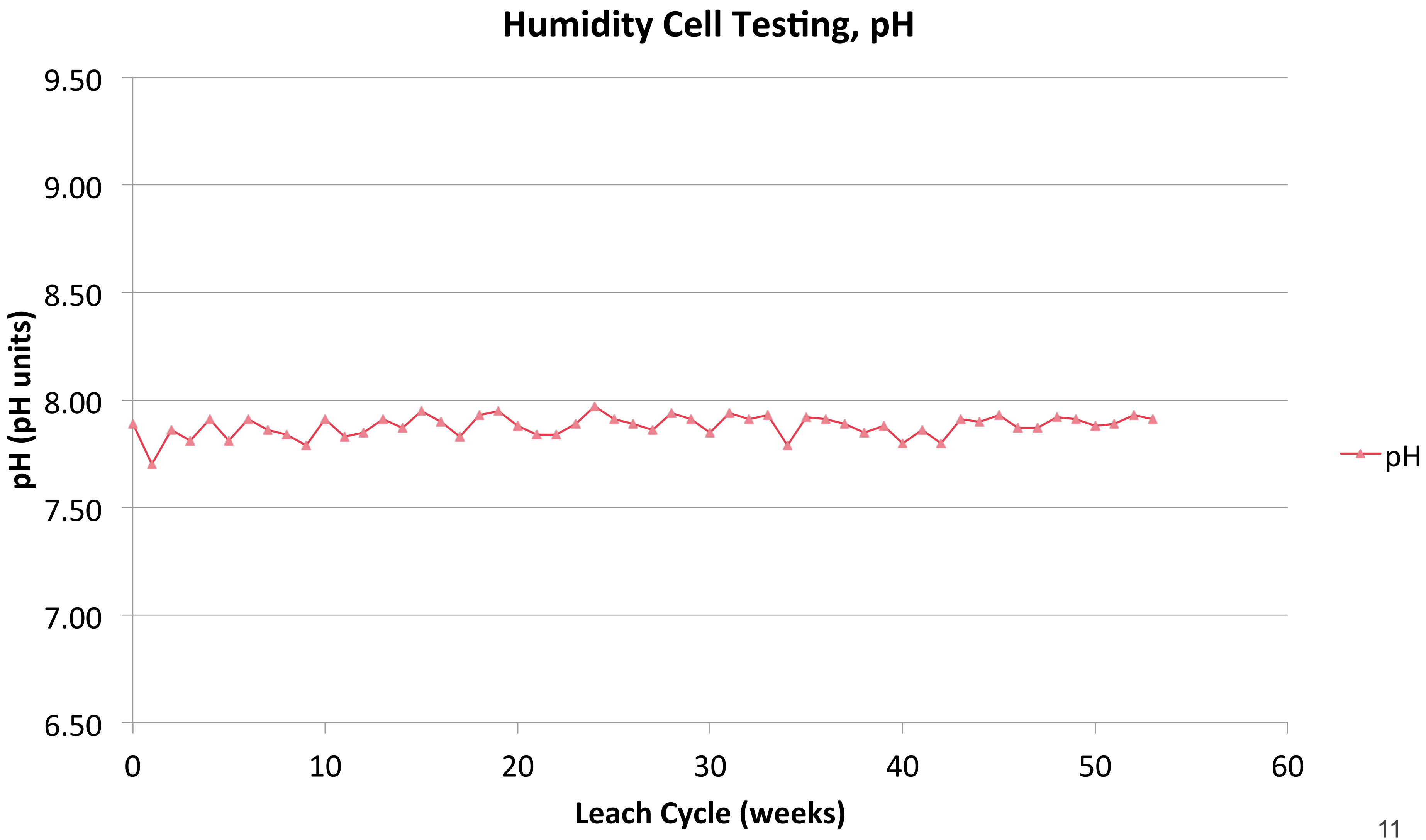


SEEPAGE COLLECTION SYSTEM
0.5m COVER (CLOSURE)
TAILINGS
EXISTING GROUND
ASSUMED BEDROCK
ELEVATION (m)
DISTANCE (m)
5.0m
A
1
B
1
C
1
PROPOSED RUN-OFF DIVERSION BERM SECTION
SCALE 1:250
LEGEND
Scale: 1: 750 (metres)
STATUS
ISSUED FOR USE
ALEXCO
eba
A TETRA TECH COMPANY
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
DSTF SECTIONS
PROJECT NO. W14101178.011
DWN CB
CKD JTP
REV 0
OFFICE EBA-WHSE
DATE December 3, 2011
Figure 2

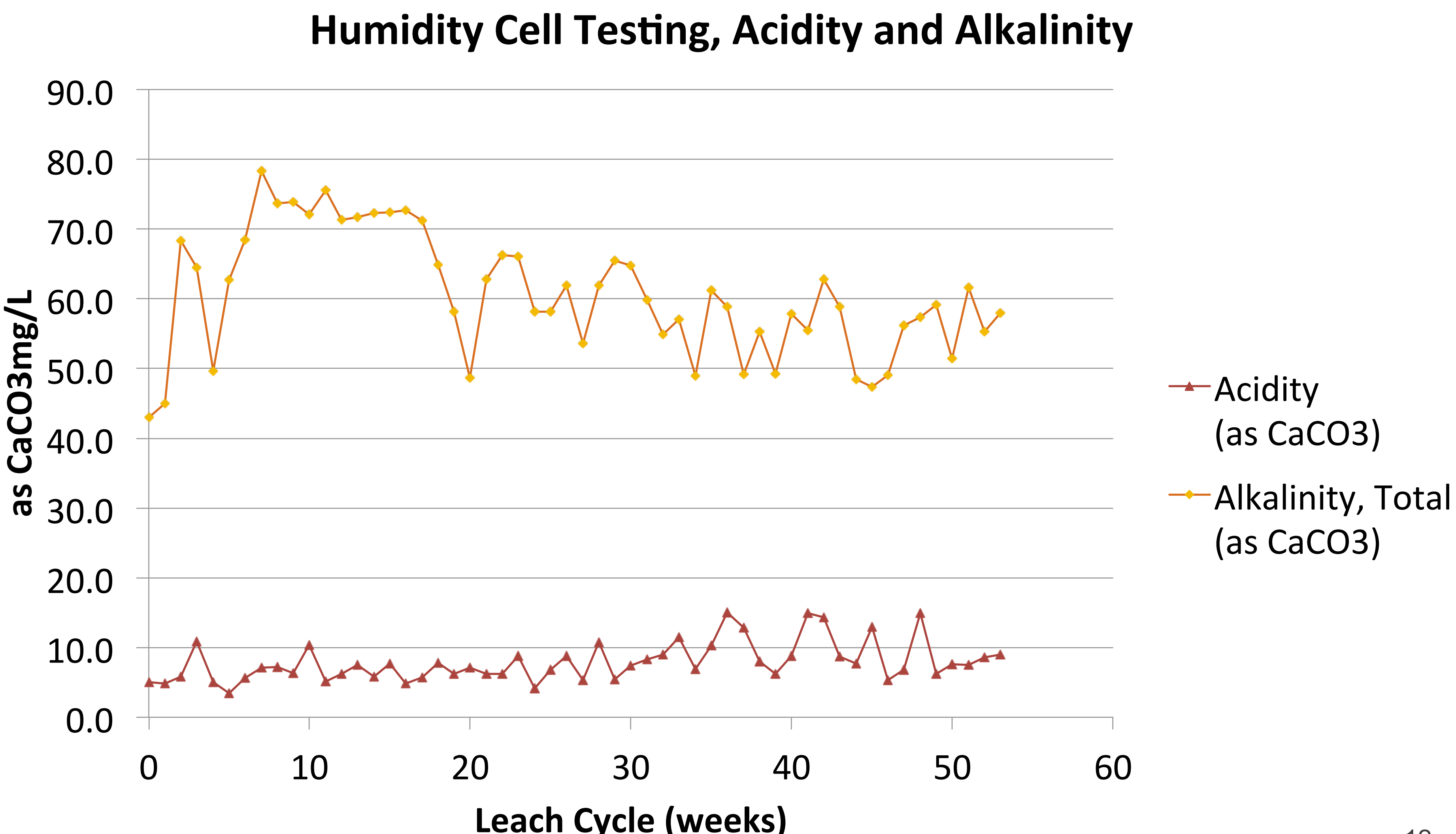
DSTF Design


TAILINGS
NON-WOVEN GEOTEXTILE
GEONET
GCL
MIN 0.6 m DRAINAGE BLANKET
NATIVE MATERIAL
SEEPAGE COLLECTION SYSTEM DETAIL

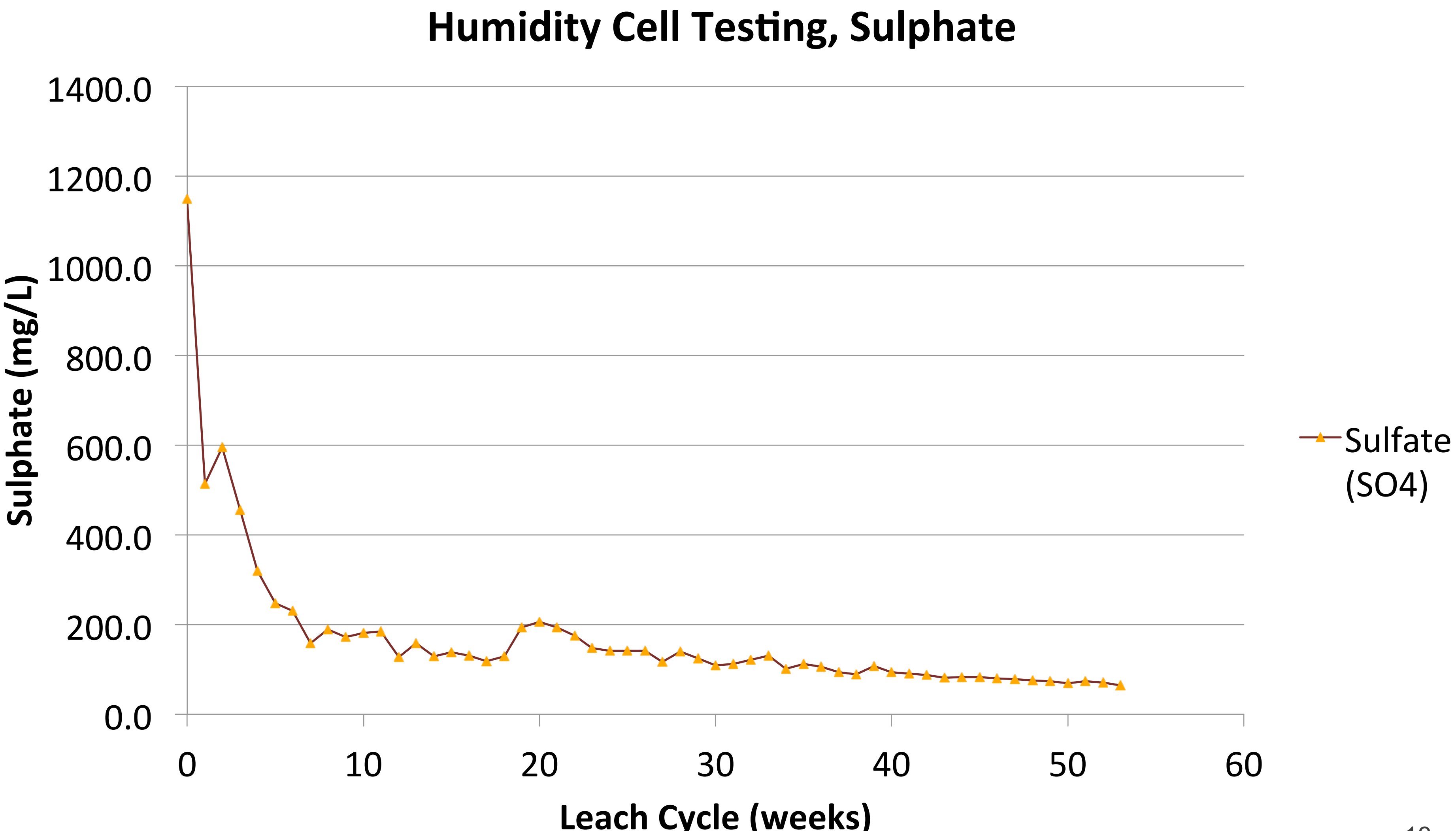
DSTF Performance



DSTF Performance

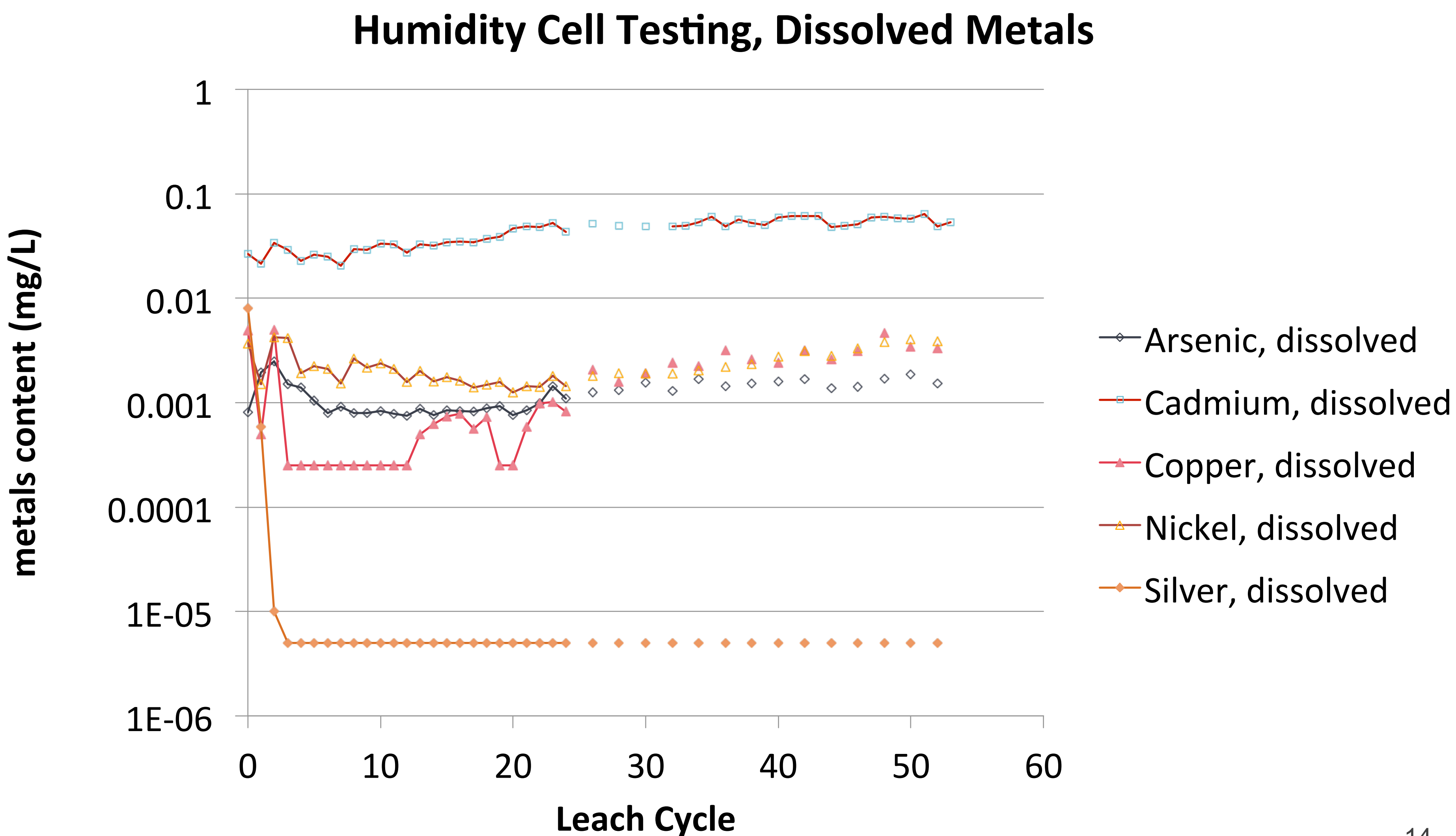


DSTF Performance



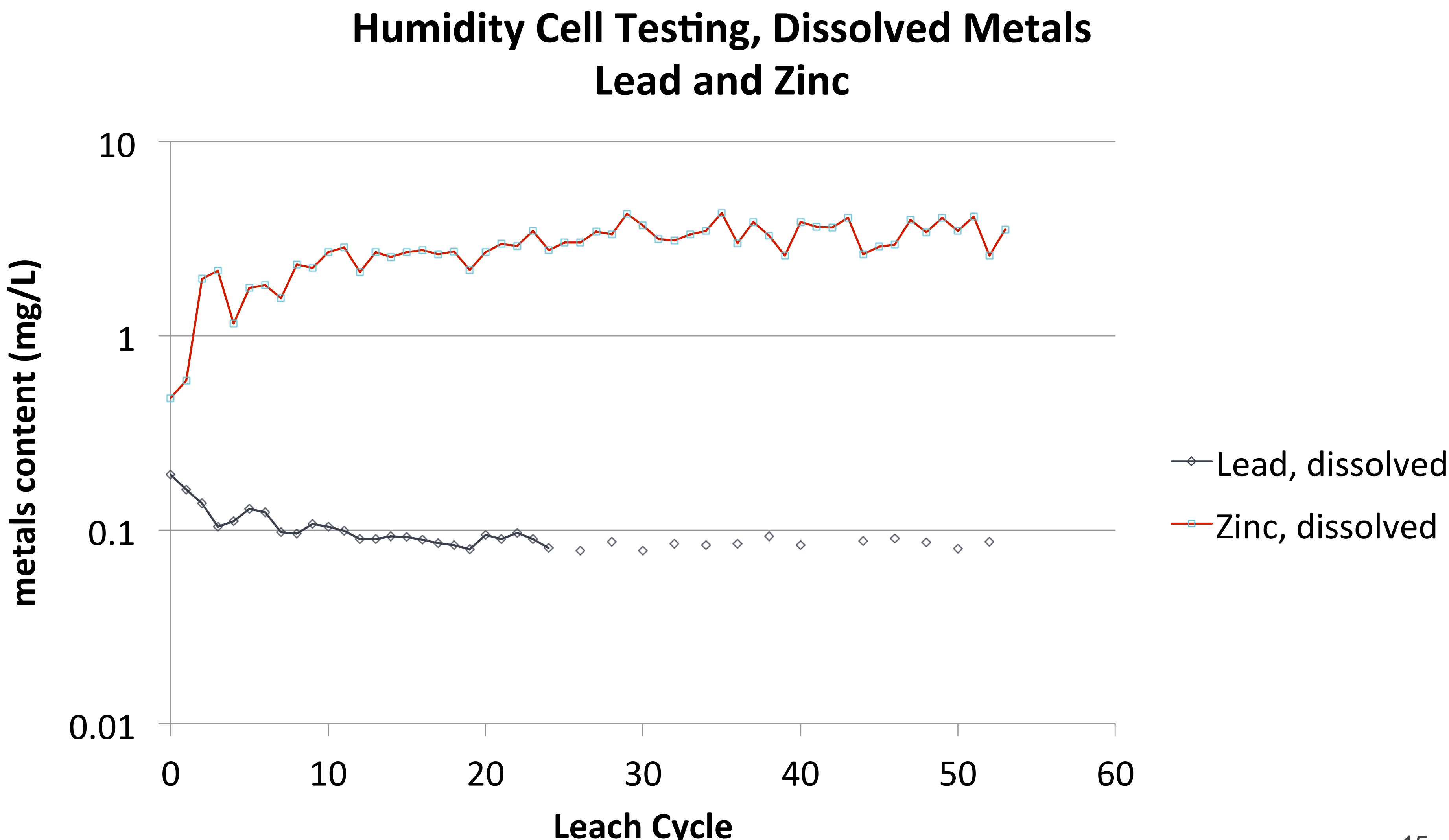
DSTF Performance

ALEXCO



DSTF Performance

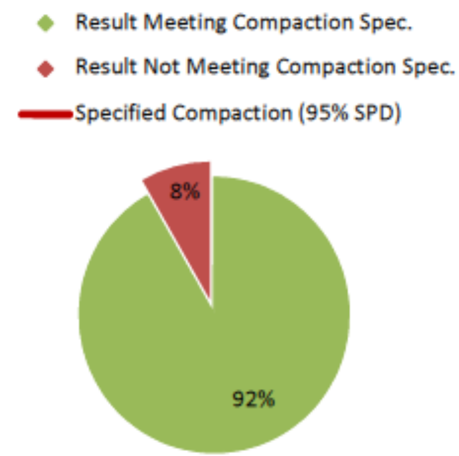
ALEXCO



DSTF Performance - Compaction

ALEXCO

Summary of DSTF Compaction Results



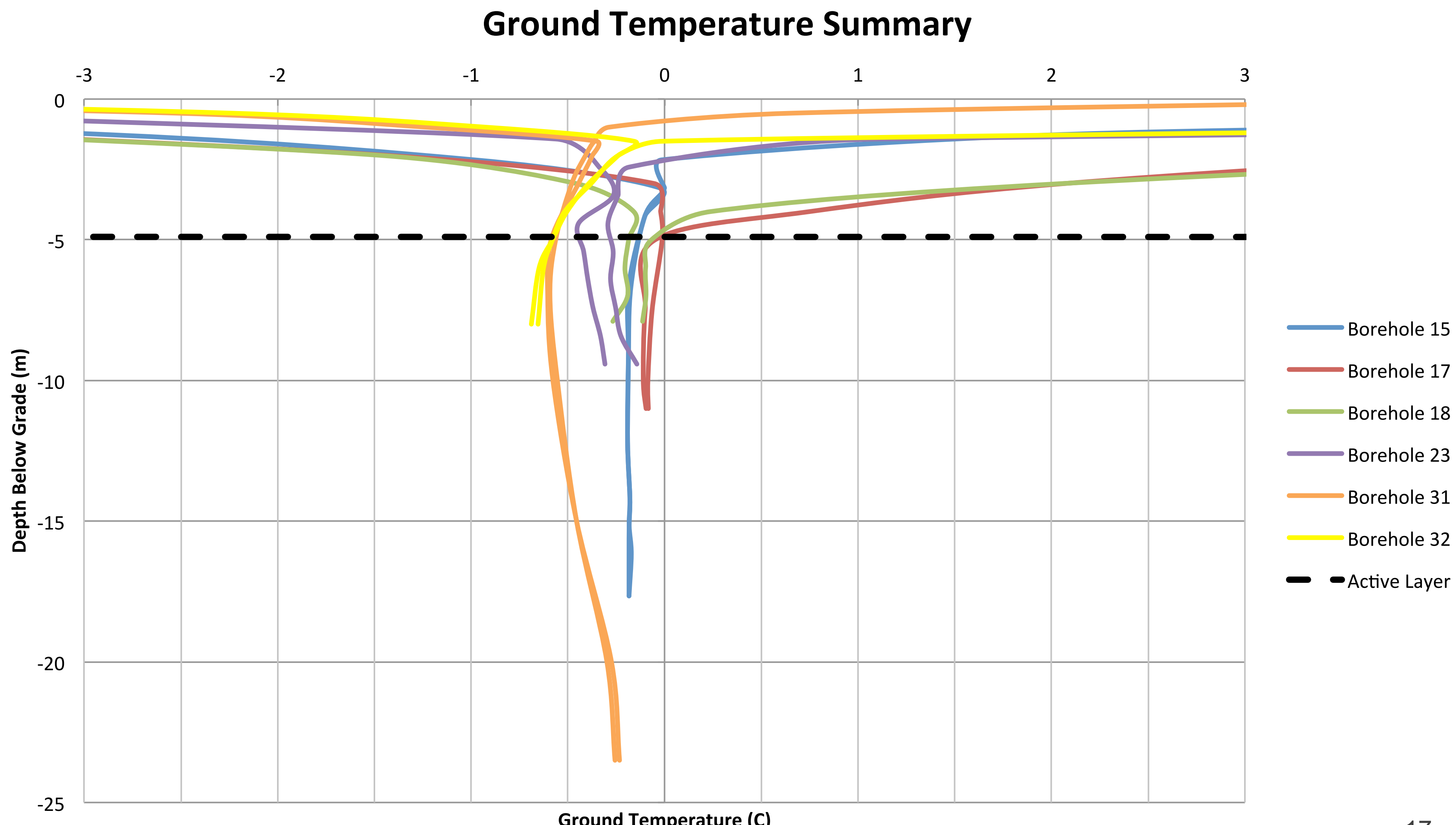
120 Compaction Tests To Date

Notes

Compaction based on maximum dry density for tailings of 2080 kg/m³ determined using ASTM D698 (Standard Proctor)

Specified compaction from DSTF "Preliminary Engineering Design and

DSTF Performance - Temperature



DSTF Progressive Reclamation

DSTF Progressive Reclamation

ALEXCO

DSTF Progressive Reclamation