RECLAMATION AND CLOSURE PLAN

KENO DISTRICT MINE OPERATIONS

KENO HILL SILVER DISTRICT

REVISION 6

NOVEMBER 2021

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1 INTRODUCTION

1.1 THIS DOCUMENT

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, Bermingham, and Flame & Moth mines and the Keno Hill District mill are currently licenced for production under Quartz Mining License QML-0009 and Water Licence QZ18-044. The Lucky Queen and Onek mines are only licenced under QML-0009.

This Keno Hill Mine Operations Reclamation and Closure Plan (RCP) Revision 6 represents an update to the currently approved RCP Revision 5 and is a condition of QML-0009 and Water Licence QZ18-044to be updated every two years. This RCP Revision 6 includes the mine plan outlined in the company's April 2021 Technical Report and includes production from Bellekeno, Flame & Moth, Bermingham and Lucky Queen over an eight-year period.

Figure 1-1 shows the project location within Yukon, while Figure 1-2 shows the site 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, Flame & Moth and Bermingham deposits, reclamation of existing disturbances at Lucky Queen and Onek, and for each mine all surface support infrastructure and activities, miners' dry area, offices, trailers, and portals;
- Conventional flotation mill & supporting infrastructure, warehouse, 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, Flame & 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.

1.2 ALEXCO'S PERMITS AND LICENCES IN THE KHSD

Alexco and its subsidiaries undertake a variety of activities within the Keno Hill Silver District including mine development and active operations, 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.

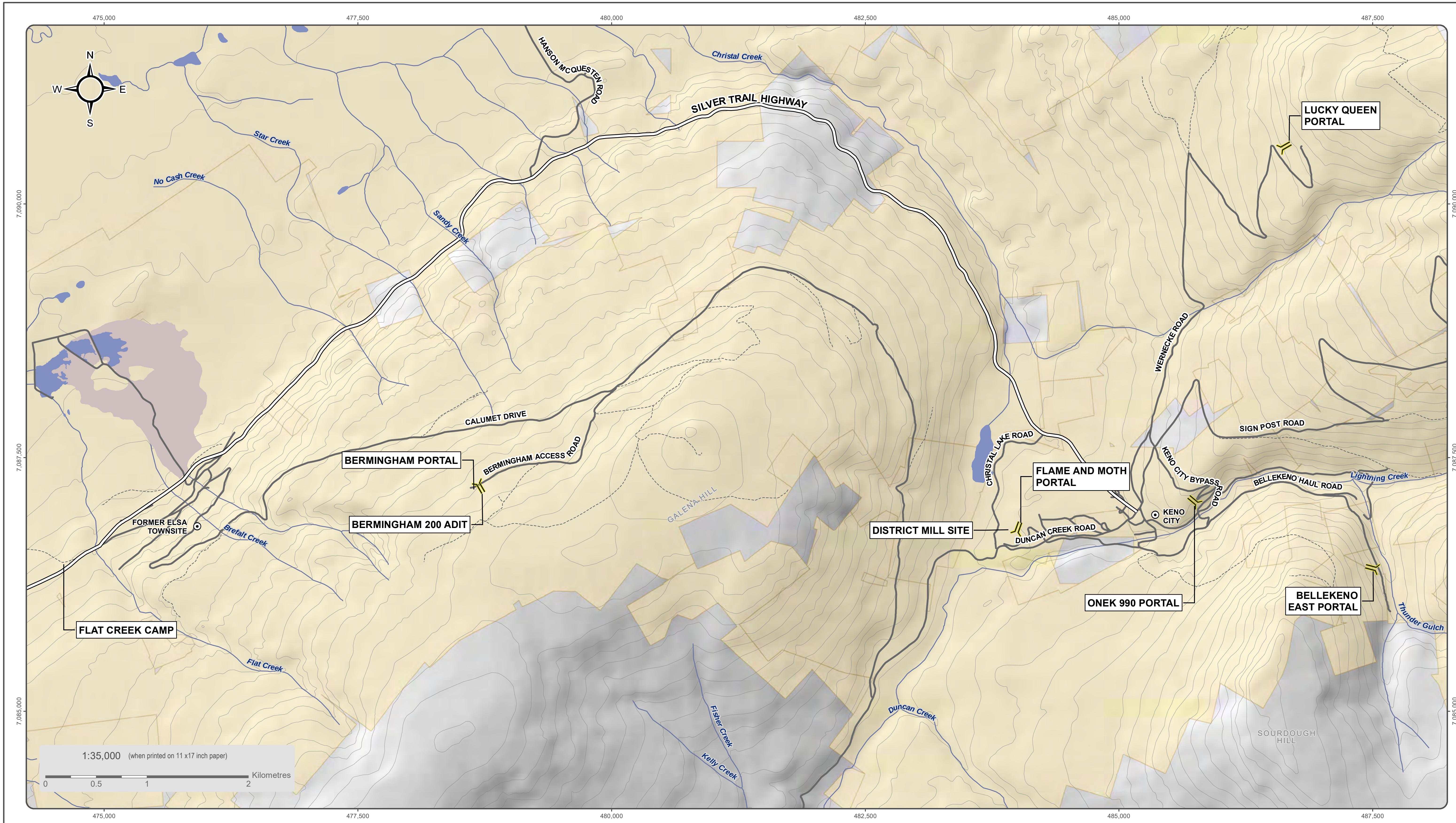
AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 1-1
PROJECT LOCATION

OCTOBER 2021

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\Project-Location\Project_Location_ESRI_LAYERS_20170612.mxd (*Last edited by: amatlashevska; 11/01/2018/14:18 PM*)



Satellite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on October 2021

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

- Place of Interest
- Adit
- Alexco/ERDC Quartz Claims
- Tailings Area
- Waterbody
- Watercourse
- Silver Trail Highway
- Road
- Limited-Use Road

AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 1-2
KENO HILL SILVER DISTRICT
MINING OPERATIONS OVERVIEW

OCTOBER 2021

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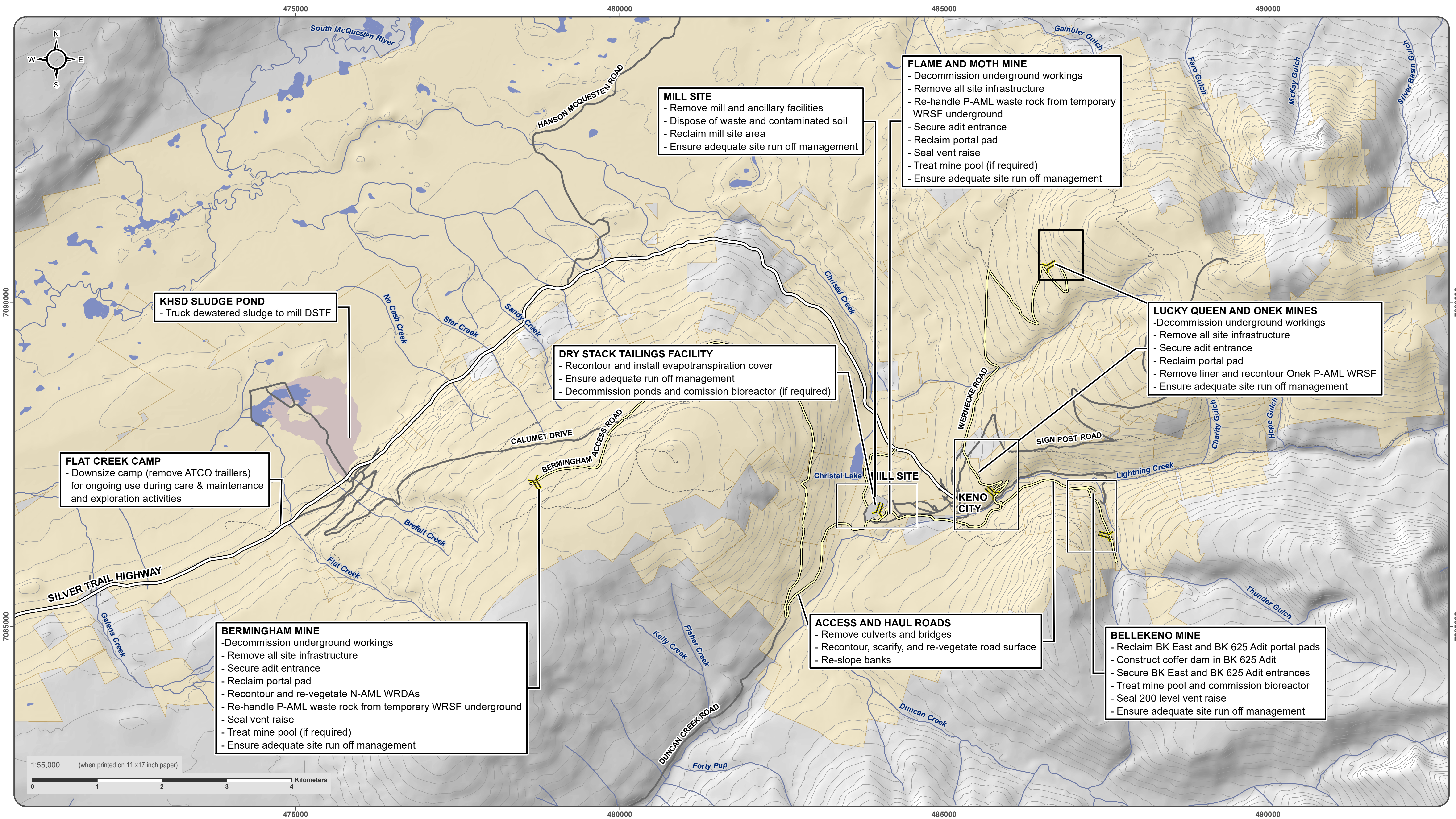
(*Last edited by: tosberg;10/27/2021/09:03 AM*)



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.

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

Adit
KHSD Mill
Waterbody
Watercourse
Contours (100 ft intervals)
Silver Trail Highway
Road
Limited-Use Road
Haul Road

AKHM

ALEXCO KENO HILL MINING CORP.
RECLAMATION AND CLOSURE PLAN

FIGURE 1-3

SITE RECLAMATION AND DECOMMISSIONING PLAN COMPONENTS

NOVEMBER 2021

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(*Last edited by: tosberg; 11/29/2021/09:12 AM*)

The Water Licence and Quartz Mining License have been amended and renewed and includes mining activities for Bellekeno, Flame & Moth, and Bermingham. The Lucky Queen and Onek deposits are not currently authorized for mine operations. Additional minor approvals will also be required.

Table 1-1 Relevant KHSD Assessment and Regulatory Approvals

Purpose	YESAA Approval	Quartz Mining Act Approval	Water Use Licence
Alexco Keno Hill Mining Permits			
Bellekeno Advanced Exploration	Project # 2008-0039 Decision Document	Class 4 Mining Land Use Approval (LQ00476, expires 2028)	Type B Water Use Licence QZ07- 078/Amendment 1 QZ10-060, licence cancelled in 2015 as authorizations moved to amended type A Water Licence in 2015[2]
Bermingham Advanced Exploration	Project#2017-0086 Decision Document	Class 4 Mining Land Use Approval (LQ00476, expires 2028)	Schedule 3 Notice of Water Use/Deposit of a Waste without a Licence
Bellekeno Mine Production	Project # 2009-0030 Decision Document	Quartz Mining Licence (QML-0009, amendment 2, expires 2037)[1]	Type A Water Use Licence QZ18-044 issued, , Expires 2037[2]
Onek and Lucky Queen Mine Production	Project#2011-0315 Decision Document	Quartz Mining Licence (QML-0009, amendment 2, expires 2037)[1]	Type A Water Use Licence QZ09-092, amendment 2 expired 2020[2]
Flame & Moth Mine Production	Project # 2013-0161 Decision Document	Quartz Mining Licence (QML-0009, Amendment 2, expires 2037)[1]	Type A Water Use Licence QZ18-044 issued, Expires 20372
Bermingham Mine Production	Project#2017-0176 Decision Document	Quartz Mining Licence (QML-0009, Amendment 2, expires 2037)[1]	Type A Water Use Licence QZ18-044 issued, Expires 2037[2]
Elsa Reclamation and Development Company Permits			
Care and Maintenance	Project # 2006-0293 and 2012-0141	N/A	Type B Water Use Licence QZ17-076 expires 2022[2]
Reclamation Plan	Project #2011-0187 Decision Document (construction and operation of land treatment facility) Project #2012-0077 Decision Document (building demolition) Project #2018-0169 Decision Document (Reclamation Plan implementation)	N/A	Submitted application QZ21-012 to Water Board following issuance of YESAB Decision Document for Project #2018-0169

Notes:

1. https://emr-ftp.gov.yk.ca/emrweb/COMM/major-mines/keno-hill/mml-keno-qml-0009-nov2019.pdf
2. http://www.yukonwaterboard.ca/waterline/

The reclamation plan for the historical liabilities (referred to as the UKHM Reclamation Plan) is currently being developed as required under the terms of the commercial agreement between Alexco and CIRNAC. The reclamation plan is current in the Water Board review process for water licencing. Once approved and permits received this plan will be implemented.

1.3 CONCORDANCE WITH WATER LICENCE AND QML REQUIREMENTS

The sections of the Reclamation Closure Plan that address the requirements listed in the Water Licence QZ18-044 and Quartz Mining License (QML-0009) are included in Table 1-2 and Table 1-3, respectively.

Table 1-2 Reclamation Closure Plan Requirements from Water Licence QZ18-044

Clause	Condition	Addressed in Section
134(a)	Detailed reclamation schedule for the period of active closure as per Section 8.1 of the Reclamation and Closure Planning for Quartz Mining Projects: Plan requirements and closure costing guidance – August 2013 (RCPQMP);	Sections 5.4 and 8.1
134(b)	A detailed execution strategy for the period of active closure including a personnel staffing chart as per Section 8.2 of the RCPQMP including the transportation, housing, planning, staffing and supervision requirements of the post-closure years as per Section 8.2 of the RCPQMP;	Section 8
134I	Updates on all DSTF engineered cover designs and modelling of expected cover performance, incorporating the results of ongoing research and data collection (geochemical characterization);	Appendix 1.1
134(d)	Results of reclamation research activities and a description of any revisions to the research program with rationale for those revisions;	Section 2.4
134(e)	Results of any closure planning studies or research completed since the previous RCP was submitted, account for any changes in environmental conditions arising from monitoring, any further development of the logistical execution of the plan, and must include any additional design details for closure measures that have been developed;	Section 2.4

134(f)	Updated and detailed closure cost estimates for all existing and proposed work, including, but not limited to, the following:
	i. all changes required by this license;
	ii. an Microsoft Excel security costing workbook, with all supporting spreadsheets including and describing all formulas and assumptions;
	iii. a detailed inventory of waste rock storage sites and their capacities, as well as a survey of all P-AML and ore temporarily stored on surface on the two-year anniversary of the RCP which includes:
	  i. location of material; and
	  ii. tonnages and volumes;
	iv. a detailed cost estimate to haul and place P-AML waste rock and ore permanently underground, which includes the following details:
	  i. equipment types and quantities;
	  ii. productivity assumptions for the haulage equipment;
	  iii. haulage distances to permanent disposal sites and the anticipated long-term groundwater characteristics of each site (saturated or dry);
	  iv. a detailed cost estimate for this activity including all equipment rental and operating costs and general mine expenses including adequate supervision; and
	  v. a demonstration of compliance with YWCB safety requirements for work inside any underground mine
		Section 9

134(g)	Descriptions, preliminary designs, and installation methodology for all mine closure facilities, including: i. all mine bulkheads and ventilation raise caps; and ii. the mine pool injection system;	Appendix 3.1
134(h)	A detailed description of water management and treatment activities planned for the post-closure years, including: i. the location of permanent mine effluents and any plans for collection, transportation, and/or treatment;	Section 7.4 Appendix 3.1, 3.7, 3.8

Clause	Condition	Addressed in Section
	ii. the installation, maintenance, or operation of any water collection or transfer systems, such as ditches, collection ponds, pumping systems, or truck haulage; iii. the operation and maintenance of any active or inactive water treatment facilities; iv. the operation and maintenance of the mine pool injection system; and v. the installation of any new water treatment facilities such as bio-reactors;	
134(i)	A detailed summary of findings or description of all planned additional kinetic testing including: i. saturated columns for backfill material at each mine; and ii. humidity cell(s) and saturated column(s) for tailings;	Appendix 3.3 and Section 5.9
134(j)	A detailed summary of findings or detailed description of seasonal water quality objectives including: i. the development of site specific WQO for arsenic; ii. details on how water quality objectives will be developed for KV-111 (upstream of KV-21 on No Cash Creek); and iii. an update on seepage chemistry predictions or investigations.	Section 5.9

Table 1-3 Reclamation Closure Plan Requirements from Quartz Mining License QML-0009 Schedule C

Clause	Condition	Addressed in Section
4.1(a)	Provide updated kinetic results and demonstrate how the results have been considered and addressed.	Appendix 3.3
4.1(b)	Provide updated data on the performances of the Silver King in-situ treatment, including: i. performance data up to 2019; I. a discussion about why metal concentrations appear to have increased and how the Licensee proposes to operate in-situ treatment, monitor treatment performances, identify triggers for if/when carbon addition is required and keep metal concentrations below EQS in a closure context; II. details regarding how often carbon addition would be required, what would trigger carbon addition need to be addressed - should carbon addition be required on a regular basis; and III. a discussion on how the updated data potentially impacts the design and planning of in situ treatment for Bellekeno and Bermingham.	Section 7.4.2, 7.4.4 Appendix 1.2, Appendix 3.7
4.1(c)	Construction, installation, implementation, and costing details for a contingency water treatment for the adit drainage if mine pool treatment does not achieve objectives; and	Section 7.4,
4.1(d)	Provide updated results on the DSTF cover performance in the Annual Report, including data up to 2019. In addition specifically addressing the following questions: v. were seeps collected from the toe of the DSTF and was the volume of the seeps monitored? vi. can the Licensee provide an estimate of the reduction in precipitation infiltration from the area of the DSTF that was covered?	Section 7.2.2

2 RECLAMATION AND CLOSURE PLANNING

2.1 RECLAMATION AND CLOSURE PLAN BASIS

A significant responsibility of Alexco is to develop and implement a closure plan for the historic environmental liabilities (District Closure Plan, also called the UKHM Reclamation Plan) addressing the historical mining practices in the Keno Hill Silver District. This is a public-private partnership between Alexco/CIRNAC/First Nation of Na-Cho Nyäk Dun (FNNND) provides for significant collaboration on closure objectives, applied reclamation research, and use of this information for 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 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 *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.

2.2 COMPREHENSIVE COOPERATION AND BENEFITS AGREEMENT

Since 2008, Alexco and FNNND have a Comprehensive Cooperation and Benefits Agreement (CCBA) that sets out the terms of Alexco's remediation, mineral exploration, and development and mining at Keno Hill. It is under the terms of this agreement that Alexco and FNNND have established a long-term relationship honoring the principles of economic sustainability, environmental stewardship, and self determination of FNNND in respect to the FNNND Lands and its resources.

Alexco is committed to:

- Maintaining a cooperative and respectful long-term relationship with the FNNND;
- Mitigating adverse impacts of its activities at Keno Hill;
- Providing business and employment opportunities related to Keno Hill's development and operation to FNNND citizens and businesses in order to promote their economic self-reliance;
- Establishing a role for FNNND in the assessment, permitting and environmental monitoring of Keno Hill and the promotion of environmental stewardship;
- Setting out financial provisions to enable FNNND to participate in the opportunities and benefits related to Keno Hill's development and operation; and
- Establishing a role for FNNND in the assessment, permitting and environmental monitoring of Keno Hill and the promotion of environmental stewardship.

As a result, FNNND is well informed about our applications, and their input is reflected in our project proposals. FNNND have long been active partners in the design of the District Reclamation planning as well as site operations and particularly environmental monitoring.

2.3 CONSULTATION AND ENGAGEMENT

Alexco conducts ongoing consultation and stakeholder engagement with respect to all of its 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.

The focus of the consultation events and topics varies, to address the relevant issues at the time and activities within the KHSD, including permitting of new mines, development of the ERDC Keno District Closure Plan or general updates on the mine development and production activities. There are no substantial changes in this revision of the AKHM Reclamation and Closure Plan and thus no specific consultation events completed.

2.4 RECLAMATION RESEARCH

Reclamation research and field validation of reclamation designs (hereafter collectively referred to as "research") can be a useful part of the closure planning process. The results are used to support site specific refinement of closure measure designs such as *in situ* water treatment.

There are currently a number of reclamation research and field validation programs underway as part of the ERDC 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. 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 and vegetation field trials – active monitoring was completed in 2019, observation of the physical conditions continues;
- Natural attenuation studies (Appendix 1.5 and 1.6); and
- In situ treatment demonstration at Silver King.

Summary reports of the results of the reclamation research programs are included in Appendix 1. Data Collection Programs for Reclamation and Closure Planning

The implementation of the reclamation measures for the temporary closure of the Bellekeno Mine provides an opportunity for applied reclamation research on the *in situ* water treatment in the underground mine. Data collection during flooding and as the natural biological processes are established will provide further information on the time to establish *in situ* treatment, reagent requirements to develop the biological community (the sulphate reducing organisms), and management requirements. The Bellekeno mine provides an excellent research site as the mine waters are contained and the system for conventional lime water treatment remains in place.

The Bellekeno reclamation also provides an opportunity to observe natural revegetation rate and extent. The area around the portal will be cleared of equipment and any infrastructure not currently required, and scarified to allow vegetation to establish. Observation of the growth will be added to the information collected at test plots noted above.

There is an extensive program of monitoring and data collection in the KHSD. These data are reported in the annual Water Licence and Quartz Mining License reports. The data programs that are particularly important to closure planning and monitoring include:

- Surface water quality and hydrology;
- Groundwater quality and quantity;
- Waste rock geochemistry;
- Tailings geochemistry; and
- Meteorology.

Extensive site characterization and data analysis programs continue to be completed to support the reclamation of the historical mines in the Keno Hill District (the former United Keno Hill Mines). This information is also applicable to the operation and closure of the Keno Hill Mine Operations. These data are documented in the annual Water Licence and Quartz Mining Licence reports. The data were also analyzed as part of the documentation for the recently completed environmental and socio-economic impact assessment under YESAA for the UKHM Reclamation Plan (file reference). Specific 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

3.1 DESIGN BASIS

Alexco's overall closure objective is to leave the site or the mine area in a safe and stable condition which requires little maintenance or management in the long term. To achieve this, each mine component is considered in terms of achieving the following at closure:

- Physical stability
- Chemical stability (particularly water quality);
- Minimal long-term active maintenance; and
- Future land use which considers the surrounding landscape, visual aesthetics, traditional values, and public safety.

These are consistent with YG's Reclamation and Closure policy and guidance *Reclamation and Closure Planning for Quartz Mining Projects August 2013 Guidance Document (YG and YWB, 2013)*. That guidance provides an excellent description of how specific closure objectives inform the design to attain the long-term condition, as shown in Table 3-1.

Table 3-1 Reclamation and Closure Objectives (YG and YWB 2013)

Value	Reclamation and Closure Objectives
Physical Stability	All mine-related structures and facilities are physically stable and performing in accordance with designs. All mine-related structures, facilities and processes can withstand severe climatic and seismic events.
Chemical Stability	Release of contaminants from mine related waste materials occurs at rates that do not cause unacceptable exposure in the receiving environment.
Health and Safety	Reclamation eliminates or minimizes existing hazards to the health and safety of the public, workers and area wildlife by achieving conditions similar to local area features. Reclamation and closure implementation avoids or minimizes adverse health and safety effects on the public, workers and area wildlife.
Ecological Conditions and Sustainability	Reclamation and closure activities protect the aquatic, terrestrial and atmospheric environments from mine-related degradation and restore environments that have been degraded by mine-related activities. The mine site supports a self-sustaining biological community that achieves land use objectives.
Land Use	Lands affected by mine-related activities (e.g., building sites, chemical and fuel storage sites, roads, sediment ponds, tailings storage facilities, waste rock storage areas, underground workings, etc.) are restored to conditions that enable and optimize productive long-term use of land. Conditions are typical of surrounding areas or provide for other land uses that meet community expectations. Site access is consistent with community land use expectations.
Aesthetics	Restoration outcomes are visually acceptable.
Socio-economic Expectations	Reclamation and closure implementation avoids or minimizes adverse socio-economic effects on local and Yukon communities, while maximizing socio-economic benefits. Reclamation and closure activities achieve outcomes that meet community and regulatory expectations.
Long-term Certainty	Minimize the need for long-term operations, maintenance and monitoring after reclamation activities are complete.
Financial Considerations	Minimize outstanding liability and risks after reclamation activities are complete.

These overall objectives are, in turn, used to develop specific design criteria for each component of the mine site as discussed in the following sections.

The effectiveness of closure measures implemented from this RCP will be the subject of review by regulatory agencies. Once the reclamation is complete, 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 integration of the District Closure Planning stakeholder objectives is discussed in Section 3.2.

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.

Table 3-2 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 7.1.3) Flame & Moth (Section 7.1.5) Bermingham (Section 7.1.7) Dry Stack Tailings Facility (Section 7.2) Waste Rock (Section 7.3) Mill and Infrastructure (Section 7.5.6) Camp (Section 7.5.7) Roads (Section 7.6.1.3)
(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 6.2
(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 4.3

Closure Plan Requirement	Document Location
(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;	Sections 6.4, Sections 7.2 and 7.4 (in situ treatment)
(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 6
(iv) a list of equipment required to be on-site to ensure that any unexpected water flows or levels or other contingencies are properly managed by the Licensee to protect the environment and human safety;	Bellekeno Mine (Section 7.1.2 Flame & Moth Mine (Section 7.1.4) Bermingham Mine (Section 7.1.6)
(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 7.10
(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 3-3 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; Mill Pond; Bellekeno East water storage ponds, Flame & Moth Treatment Pond and 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. In situ mine water treatment will be undertaken at Bellekeno and Bermingham mines. There is no discharge expected from F&M. (Section 7.4)
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 waste rock is being stored in a temporary lined storage facilities during operations, and will be rehandled back to the underground below the long-term static water level of the mine at closure. (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 limit 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 placed at the portal to block access to the Bellekeno East Adit (Section 7.1.3), Onek 990 adit (Section 7.1.9), Lucky Queen (Section 7.1.11) Bermingham (Section 7.1.7) and Flame & Moth adit (Section 7.1.5). A rock pile will be placed at the portal to block access to the Bellekeno East Adit (Section 7.1.3), Onek 990 adit (Section 7.1.9), Lucky Queen (Section 7.1.11) Bermingham (Section 7.1.7) and Flame & Moth adit (Section 7.1.5). A coffer dam will be installed at the Bellekeno 625 Adit to provide the ability to manage water discharge (Sections 7.4.2). An engineered cap will be placed at the Bellekeno 200 Level Vent Raise (Section 7.1.3), Flame & Moth vent raise (7.1.5) and Bermingham vent raise (7.1.7).
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	P-AML waste rock will be stored in approved, engineered facilities during operations and rehandled to underground at closure (see Section 7.3)

Technical Guideline #	Theme	Closure Objective	Document Reference
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 EMR's Yukon Mine Site and Reclamation Closure Policy (see Section 3) and that achieves the closure of objectives of aesthetics and reducing erosion (also see Section 7.9)
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

3.2 INTEGRATION WITH DISTRICT-WIDE CLOSURE PLANNING

The overall closure objectives were then used to develop specific Closure Objectives for the UKHM Reclamation Plan, through workshops with various stakeholders. These more specific closure objectives for the reclamation of the historical liabilities were agreed to by Alexco/ERDC, Canada (CIRNAC), FNNND, and Yukon to guide the development of that District Closure Plan.

These objectives were used to develop the UKHM Reclamation Plan and to inform the specific reclamation measures and design decisions. These project closure objectives are:

Protect Public and Worker Health and Safety

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

Protect and Restore the Environment

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

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

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

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

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

Minimize Project Related Liability and Risk

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

Minimize Cost

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

These objectives guided the selection of closure measures and design for the implementation of the UKHM District Reclamation Plan. The Reclamation Plan completed the Environmental Assessment process in July

2020 and is presently in the Yukon Water Licencing process. The implementation of the ESM Reclamation Plan is anticipated to commence in 2022.

These closure objectives are excellent guidance for all of Alexco's planning for new mine operations also. The intent of this Keno District Mine Operations RCP is to ensure that the site-specific objectives are aligned with the ESM Reclamation Plan objectives.

3.3 DESIGN CRITERIA

The design criteria for the existing facilities are defined in the design reports, and summarized in Chapter 5. The specific design basis for each reclamation measure are discussed in Chapter 7.

3.3.1 Physical Stability

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

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

3.3.2 Chemical Stability

The reclaimed mine sites within the Keno Hill District will be chemically stable. For reclamation measures, this means removing or controlling sources of leaching or other discharge e.g., contaminated soils, hazardous or special wastes, and acid rock drainage. Specially, 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.

The measurement of chemical stability will be water quality; both surface and groundwater. Wind erosion and transport are not significant mechanisms of contaminant dispersal for the active mining operations due to physical controls.

Aspects to be monitored closely will include short-term and long-term changes in underground mine discharge 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.

3.3.3 Biological Stability

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

3.4 COMPLETION CRITERIA FOR MINE COMPONENTS

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.

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.

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 3-4 provides a general overview of each Mine Area Component and the site conditions associated with meeting completion criteria.

Table 3-4 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 Bermingham Flame & Moth Onek Lucky Queen	Salvageable equipment removed. All other equipment cleaned of hydrocarbons Infilling of underground stopes with P-AML waste rock and tailings material Mine openings stabilized, barricaded, and free-flowing with respect to water, where applicable	All chemicals and contaminants remediated or removed	N/A
Waste Rock Storage Facilities and Disposal Areas			
Bellekeno Benched N-AML WRDA Bellekeno Temporary P-AML Facility Bermingham Temporary P-AML Bermingham N-AML WRDA Flame & Moth Temporary P-AML Facility Onek Temporary P-AML Facility	Stable slopes WRs 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 Pond	All impediments to normal hydrologic conditions broken down to re-establish hydrologic flow. BK 625 ponds converted to geotechnically-stable bioreactors; mill pond liner removed and stable	All chemicals and contaminants remediated or removed	Safe ingress/egress for wildlife
Water Diversion Structures			
DSTF diversion berms	No significant erosion along channel banks and banks of dam structures	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			

Reclamation Units		Completion Criteria Conditions		
		Physical Stability Requirements	Chemical Stability Requirements	Biological Stability Requirements
	Mill Building Mill Office and Dry Electrical Substation Crushing Plant, Fine Ore Stockpile Crusher MCC, Mill Motor Control Centre Assay Lab Fresh Water Tank, Mill Wastes Diesel Storage Tanks, Propane Tank 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 result in an adverse impact (i.e., WQO)	Wildlife access
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 Na-cho Nyäk 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 (KHSD) 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

Category	Description
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

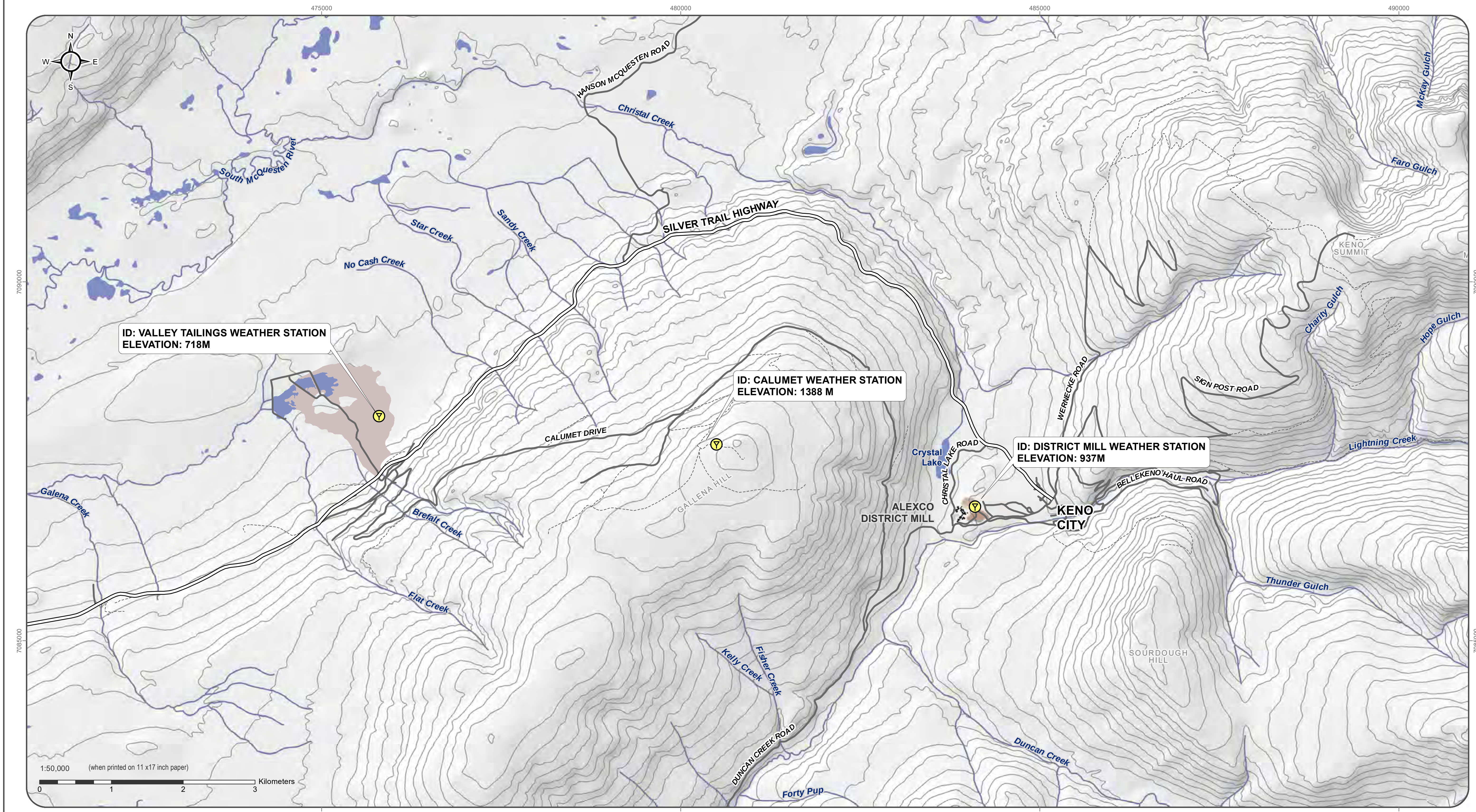
4.1 CLIMATE

The following provides a summary of the Climate information for the Site and additional details regarding Climate are presented in the QML-0009 Site Characterization Report (Appendix 2).

The KHSD falls in the subarctic clime of the Koppen climate classification. The closest current long-term climate record is at the Mayo Airport, which had an average daily temperature of -2.4°C and average annual precipitation of 313.5 mm, with 203.8 mm falling as rain for the 1981 to 2010 Climate Normal period. The wet season occurs in summer/fall with drier winters.

Meteorological data have been collected in the KHSD since 2007 at the Calumet weather station (as part of the development of the ESM Reclamation supporting studies), since 2011 at the Keno District Mill meteorological station (installed as part of Bellekeno mining operations) and since 2012 at the Valley Tailings meteorological station. The station locations are shown on Figure 4-1. All three stations collect air temperature, relative humidity, rainfall, solar radiation, wind speed and wind direction. In addition, the Keno District Mill station has a snowfall conversion adaptor and calculates evapotranspiration, while the Valley Tailings station collects barometric pressure and soil water content. The Calumet station collects soil temperature.

The region around the KHSD has been served by a network of climate monitoring stations over the years. At least three climate stations have been operated within the boundaries of the KHSD. Two of these stations were located in former Elsa town site and on the southern flank of Keno Hill. These two stations were maintained by the Atmospheric Environment Service (AES) until 1989 and 1982 respectively; AES is now known as the Meteorological service of Canada a branch of the Department of Environment. The third station was operated on a seasonal basis by the Department of Indian Affairs and Northern Development (DIAND) at a site in the Flat Creek catchment near the Elsa town site. In addition to these stations, the Meteorological Service of Canada operates a principal climate station at the Mayo Airport (Mayo A), located approximately 40 km southwest of Elsa. The data from the Mayo A station can be combined with that of two discontinued stations in the near vicinity of the airport (i.e., Mayo Landing and Mayo) to construct a long-term climate record. These stations have been active since 1953.



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Weather Station
Tailings Area
Waterbody
Silver Trail Highway
Road
Limited-Use Road
Contours (100 ft)
Watercourse

AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 4-1

KENO METEOROLOGICAL STATIONS

NOVEMBER 2021

4.1.1 Temperature

Table 4-2 presents monthly and annual mean temperatures, calculated for the entire period of record for the three local meteorological stations, as well as the 1981-2010 climate normal period for the Mayo A station; these are updated every 10 years. The monthly and annual temperatures are on average colder at the three KHSD stations than at Mayo A, which is expected given the higher site elevation. This pattern is not as clear during the winter months and could reflect the fact that the region experiences frequent temperature inversions.

Table 4-2 Mean Monthly and Annual Temperatures (°C)

	Calumet (2007–2020) Elev. 1,380 masl	District Mill (2011–2020) Elev. 936 masl	Valley Tailings Facility (2012–2020) Elev. 718 masl	Mayo A Normals (1981–2010) Elev. 504 masl
January	-15.1	-17.5	-19.5	-23.1
February	-13.5	-15.8	-18.6	-17.9
March	-12.5	-10.8	-11.0	-9.6
April	-4.5	-1.5	-0.9	1.0
May	3.6	7.8	8.9	8.8
June	9.0	12.4	13.7	14.5
July	9.9	13.6	15.4	16.1
August	8.2	11.0	11.8	13.1
September	3.2	5.2	5.9	6.4
October	-5.3	-4.0	-3.0	-2.7
November	-12.7	-15.5	-15.9	-15.3
December	-13.7	-16.0	-18.6	-19.9
Annual	**-3.6**	**-2.6**	**-2.7**	**-2.4**

The long-term climate record at Mayo A indicates a warming trend as can be observed in Figure 4-2. The rate of warming is greater for the minimum temperature than it is for the maximum temperature, consistent with observations made in other parts of Canada (EC, 2016).

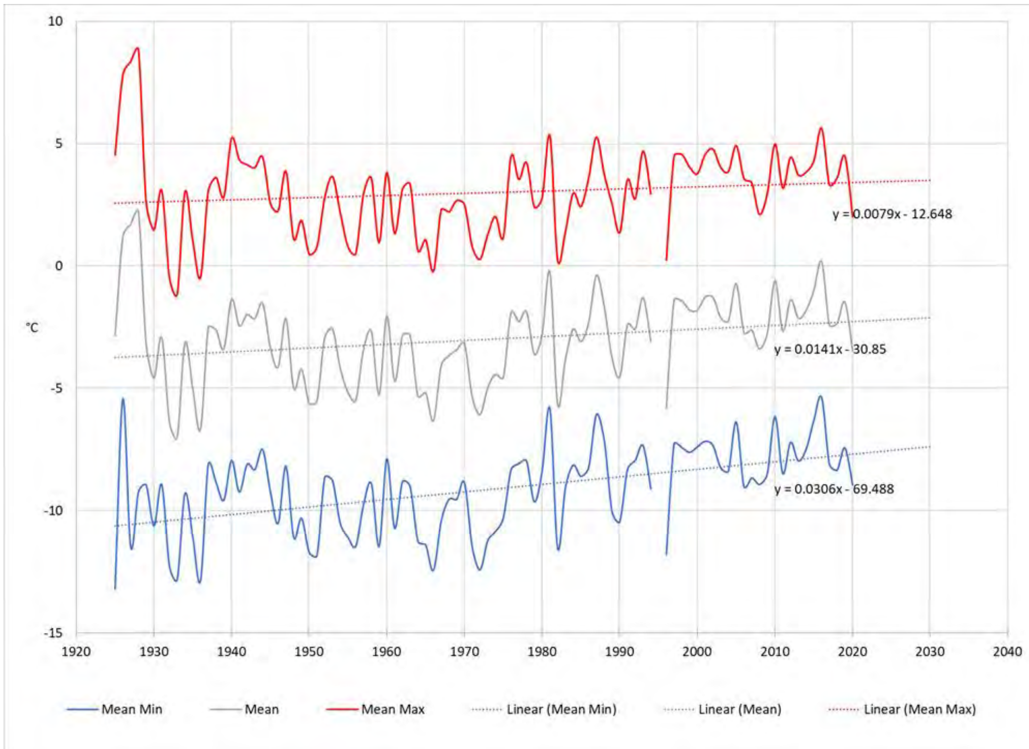


Figure 4-2 Mayo A Annual Temperatures, 1925–2020

SRK (2020) extended the local Calumet weather station record by correlating the data with the regional Mayo A station data (Figure 4-3). This allowed the extension of the local Calumet weather station to be extended to 95 years (October 1924 to July 2020). The monthly results are provided in Table 4-3.

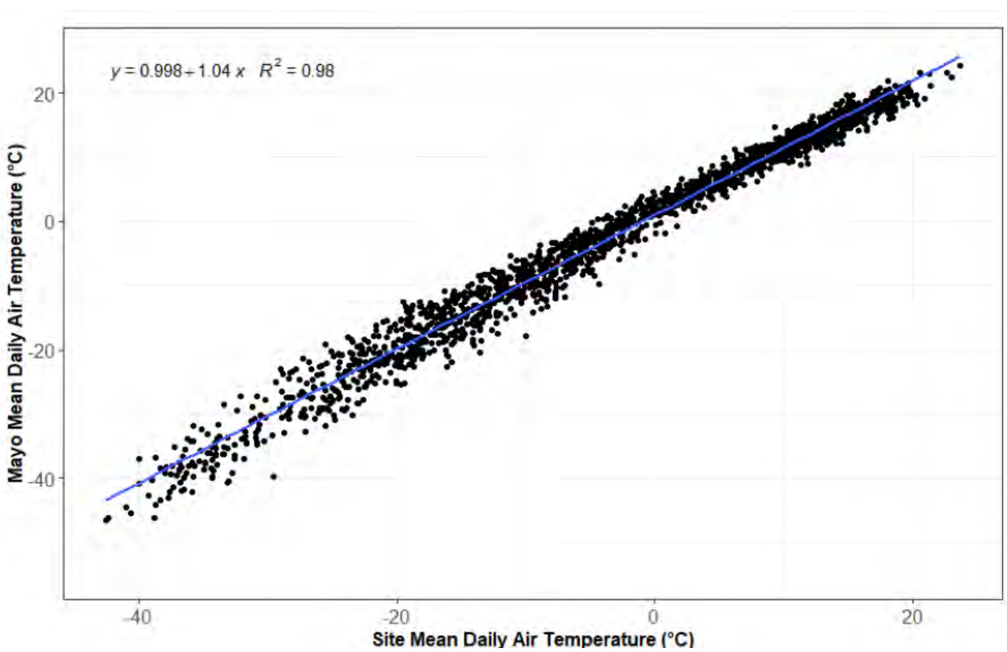


Figure 4-3 Daily Air Temperature - Mayo Airport vs. Calumet Weather Station (SRK, 2020)

Table 4-3 Extended Air Temperature Averages for 1990-2020 (SRK, 2020)

Month	Min. Temperature (°C)	Avg. Temperature (°C)	Max. Temperature (°C)
January	-58.3	-25.1	10.1
February	-62.2	-19.3	12.2
March	-48.9	-10.7	15.8
April	-41.1	0	22.8
May	-21.7	8.3	33.5
June	-3.9	13.8	36.1
July	-2.8	15.4	35.6
August	-10.6	12.6	32.6
September	-15.6	6.5	26.7
October	-36.7	-2.2	22.6
November	-50.6	-15.4	13.9
December	-57.2	-22.1	11.8

4.1.2 Precipitation

Of the three local meteorological stations, only the District Mill station measures total precipitation – since October 2013 - whereas the other two stations measure rainfall only. Analysis indicates that these data are not adequate for estimating precipitation trends on site, and as such the Mayo A station, before and after undercatch adjustment was used as a proxy.

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 1,472 masl. SRK (2020) derived a relationship between MAP and elevation, using the Mayo A data (not corrected for undercatch), Elsa, Keno, 7 regional stations (red points) and gridded precipitation from the Modern-Era Retrospective analysis for Research and Applications (MERRA2) dataset (black points), as shown on Figure 4-4. Using a linear relationship, as exhibited by the data, a line was fitted to the data of these stations. The slope of this line indicates that MAP increases by an average of 37.7 mm for every 100 m of ascent. Using this relationship, MAP values were developed for each design component based on its elevation:

- MAP for the VTF at a median elevation of 703 masl is 420 mm. This value was then adjusted for undercatch, resulting in an adjusted MAP for the VTF of 483 mm; and
- MAP for the upper hillslope region above the VTF, ranging in elevation from 704 to 1,400 masl (median elevation of 1,123 masl) is 577 mm. After corrections for undercatch, the MAP value for the upper hillslope region is 663 mm.

Table 4-4 presents mean monthly and annual rainfall, snowfall, total precipitation, and percentage of total precipitation falling as rain at the Mayo A station for the 1981-2010 climate normal period. Additionally, snow surveys have been conducted by Alexco and Yukon Government for sites within the KHSD and a summary of the data is provided in Appendix 2.

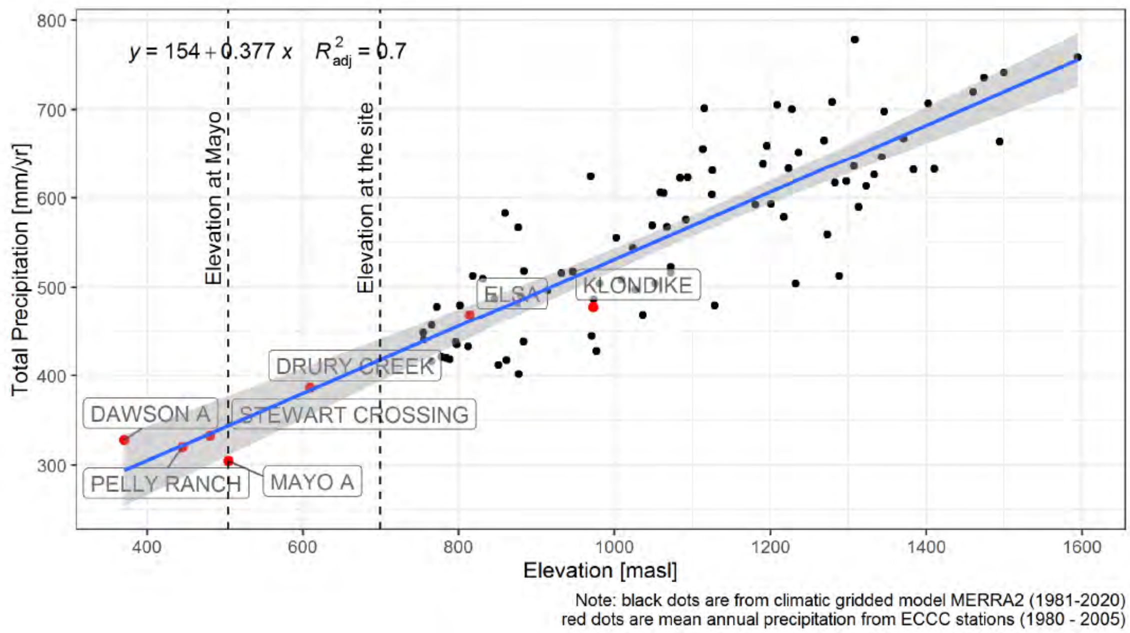


Figure 4-4 Map Annual Precipitation (MAP) – without undercatch - as a function of Elevation (SRK,2020)

Table 4-4 Mayo A Climate Normal (1981-2010) Average Precipitation

Month	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)	% Rain
January	0.3	28.3	18.3	1.6
February	0.0	20.2	13.0	0.0
March	0.1	14.5	9.9	1.0
April	2.9	7.8	8.8	33.0
May	22.2	1.0	23.2	95.7
June	38.9	0.1	39.0	99.7
July	50.2	0.0	50.2	100.0
August	44.5	0.3	44.6	99.8
September	34.8	3.9	38.7	89.9
October	9.4	23	27.0	34.8
November	0.3	31.8	21.1	1.4
December	0.3	29.8	19.8	1.5
Annual	**203.8**	**160.6**	**313.5**	**65.0**

4.1.3 Evaporation

No direct measurement of evaporation is carried out at Site. Estimates for lake evaporation and potential evapotranspiration were developed by SRK (2020). SRK based the Lake evaporation estimates on the Mayo A Climate Normals (1981-2010), and the Potential Evapotranspiration estimates were developed using Oudin's

(Oudin et al, 2005) temperature-index method. The estimated lake evaporation and potential evapotranspiration are presented in Table 4-5.

Table 4-5 Estimated Long-Term Monthly Evaporation

Month	Lake Evaporation [mm]	Potential Evapotranspiration [mm]
January	0	0
February	0	0
March	0	2
April	0	19
May	0	62
June	132	96
July	120.9	101
August	80.6	68
September	48	28
October	0	5
November	0	0
December	0	0
Annual	**381.5**	**383**

Notes:
Values in grey italics indicate a partial month
[1] ET code issues, code is under review

4.2 SURFACE WATER QUALITY

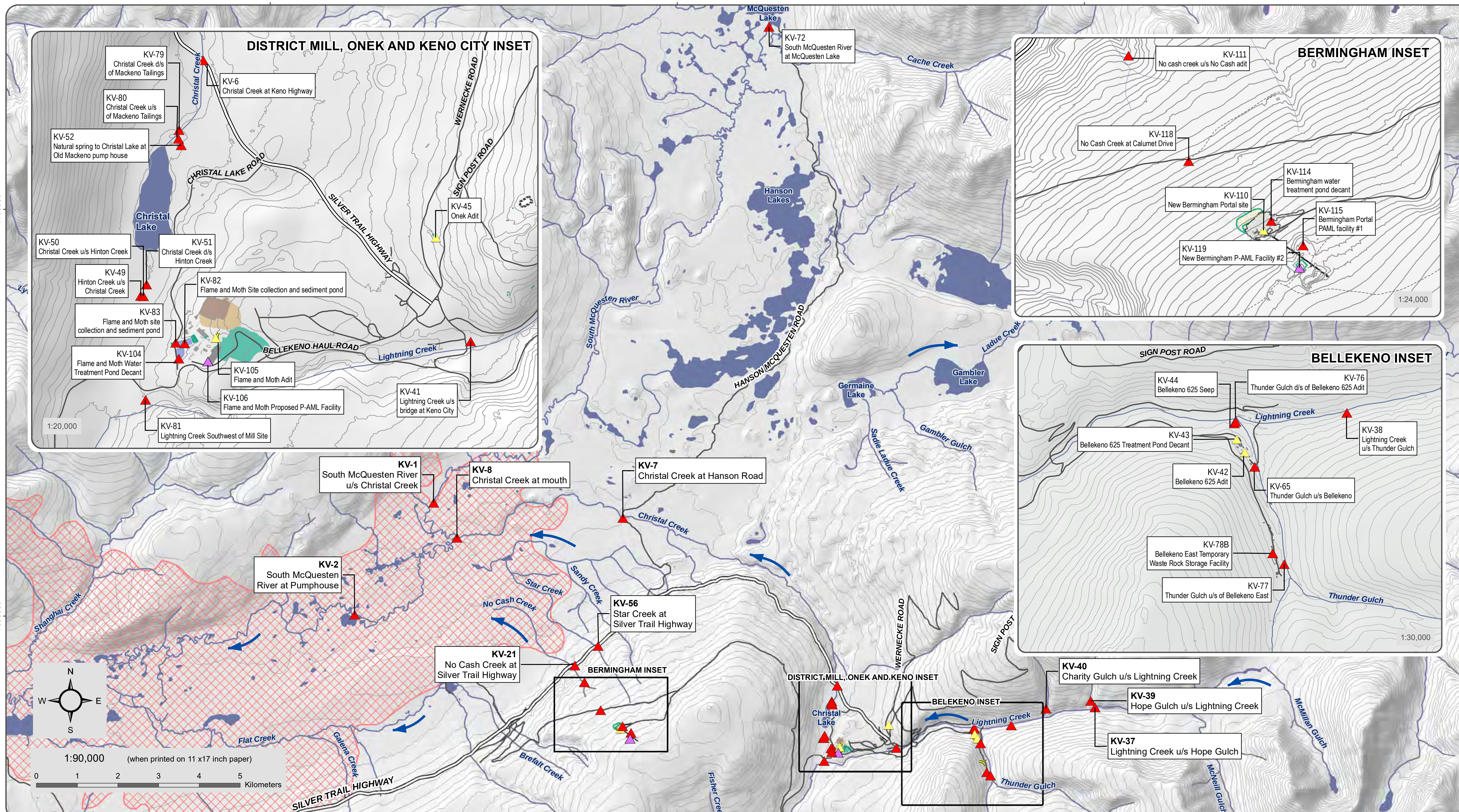
Surface water quality is monitored to assess and track changes in the condition of water of the various watersheds on the property. Through monitoring, AKHM can characterize waters and identify changes or trends in water quality over time, identify specific existing or emerging water quality problems and determine whether goals, including compliance with WL EQS and water quality objectives (WQO), are being met. The data are also used for building and maintaining site-wide and localized loading balances for closure planning purposes.

The comprehensive water quality monitoring program is outlined in Schedule B of WL QZ18-044 (see Figure 4-5 for station locations). The program is continuously reassessed for its effectiveness at canvassing the site and for its ability to help plan site activities.

The network of sampling stations has been established with the goal of addressing three main issues:

- Identify sources and sinks for contaminants along natural watercourses;
- Identify "reference" water chemistry (i.e., in areas unaffected by mining); and
- Determine what effect mine discharges may have on downstream water quality and aquatic life in the receiving environment.

In 2008, Minnow Environmental Inc. (Minnow) was contracted to analyze site wide water quality data to identify parameters and locations of concern within receiving waters relative to established guidelines and background water quality concentrations. Minnow identified two contaminants of concern (COCs) for the Keno Hill Property: zinc and cadmium (Minnow, 2008). Because of the limitations of the dataset, other 'potential' contaminants of concern were identified but not confirmed. In September 2013, Minnow revaluated the COCs and concluded that cadmium and zinc should remain and no additional COCs are warranted (Minnow, 2013). Subsequent assessments of receiving environment water quality have also indicated that cadmium and zinc remain the COCs for the receiving environment (Minnow, 2015; 2018; 2020). The focus of this section is on the COCs zinc and cadmium; however, additional results for other parameters are presented in the water quality summary tables provided in Water Licence annual report.



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- Adit Water Quality Station
- Surface Water Quality Station
- Pending Water Quality Stations
- Adit
- 2019 Forest Fire Extent
- Surface Water Flow Direction
- Silver Trail Highway
- Other Road
- Watercourse
- Infrastructure Footprint
- Waterbody
- DSTF 322k Tonnes Design
- Current DSTF
- To Be Constructed Mine Features

AKHM

ALEXCO KENO HILL MINING CORP.
WATER LICENCE QZ18-044

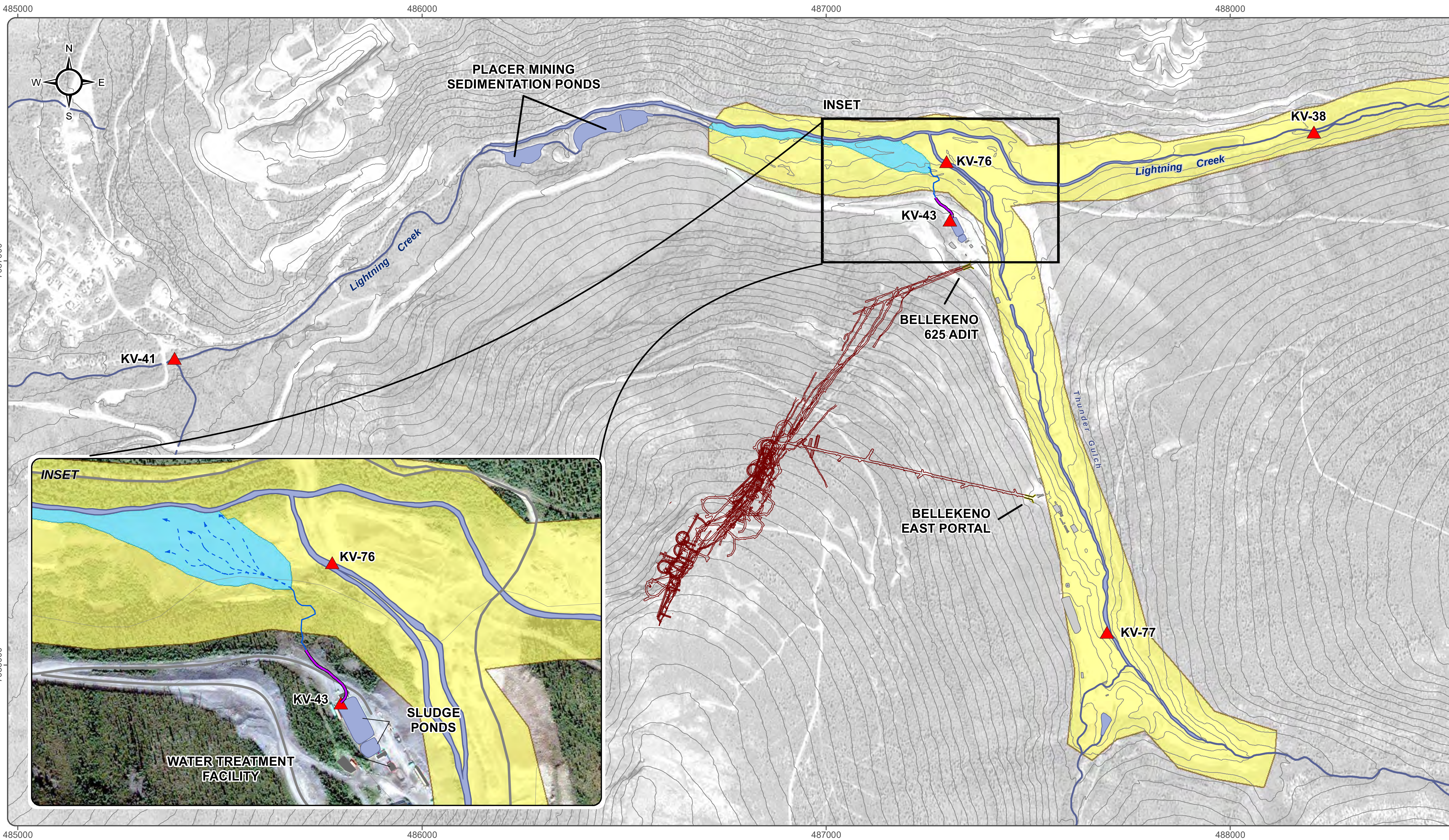
FIGURE 4-5
SURFACE WATER QUALITY STATIONS - QZ18-044

MARCH 2021

4.2.1 Bellekeno Mine

The Bellekeno mine site is near the confluence of Thunder Gulch with Lightning Creek, on the north side of Sourdough Hill. Thunder Gulch flows into Lightning Creek roughly 300 m down the hill from the Bellekeno Treatment Facility. Lightning Creek eventually converges with Duncan Creek, which then drains into the Mayo River. Bellekeno 625 treated decant water is discharged east of the treatment facility and reports to ground, flowing via a diffuse surface pathway into Lightning Creek, downstream of Thunder Gulch (Figure 4-6). This water eventually reports to placer mining sedimentation ponds located immediately downstream of the discharge point. The sedimentation ponds discharge into Lightning Creek farther downstream towards Keno City. Mining activities at Bellekeno resumed in September 2020.

Both Thunder Gulch and Lightning Creek have undergone extensive placer mining activities in the past; Thunder Gulch is a current site of active placer activities. This has an impact on aquatic conditions and can make it difficult to distinguish the effects of placer mining from the effects of underground mining. The Lightning Creek drainage is also affected by other historical mines in the district which continue to produce metals loading to the creek.



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

1:9,000 (when printed on 11 x17 inch paper)

0 125 250 500 Meters

- Water Quality Stations
- Bellekeno Adit
- Pipeline
- Underground Workings
- Placer Disturbed Area
- Bellekeno Effluent Discharge
- Waterbody
- Watercourse

AKHM

ALEXCO KENO HILL MINING CORP.
WATER LICENCE QZ18-044

FIGURE 4-6
BELLEKENO TREATED EFFLUENT DISCHARGE PATH AND PLACER MINING DISTURBANCES

FEBRUARY 2021

4.2.1.1 Bellekeno Adit Water Quality

Historical Data

Discharge at the Bellekeno portal has been monitored since at least 1984, with consistent records beginning in 2006. The frequency of monitoring increased with the Type B Water Licence issuance and advanced exploration activities at the Bellekeno mine in 2009.

Two periods of dewatering occurred in the history of the Bellekeno Mine: in 1994 during exploration activities and again in 2008 to 2009 during advanced exploration activities by Alexco.

During 1994 exploration, the flooded underground workings were dewatered and pumped. Water quality results prior to and during dewatering in this period show:

- No clear seasonal variations in either drainage chemistry or flow, indicating that there is little surface recharge to the workings;
- Consistently alkaline pH values, between 7 and 8;
- Variable conductivity values in the range of 700 µs/cm, but no clear and consistent change over time in conductivity, sulphate, or total dissolved solids;
- Iron concentrations were very low, consistent with the alkaline pH and lack of sulphide oxidation;
- Internal results showed cadmium values above detection, however analyses at independent laboratories consistently show total cadmium at <0.05 mg/L;
- Zinc was the only metal to show an apparent increase from 1990-1992 however the values in 1993/94 were comparable to those in the mid-1980s; and
- High lead and zinc during production in 1985 to 1988 (no settling pond).

The above indicates that Bellekeno underground workings and associated waste rock have not historically been of concern with respect to acid rock drainage (ARD). The chemistry of the drainage water appears to be reasonably constant with time and there are no parameters which indicate that ARD was developing. Leaching of zinc, probably from oxidation of zinc sulphides, was the only real concern from this adit.

Contemporary Data

Data collected since the 1994 dewatering are sparse following the shutdown of operations at KHSD; however, consistent data at Bellekeno collected from 2006 up to present day shows or confirms the following characteristics of Bellekeno underground water:

- No clear seasonal variations or trend in flow (Figure 4-7) or drainage chemistry (Figure 4-8) from the adit, implying that the impact of surface drainage to the underground workings is negligible. Discharge flows typically ranged between 2.0 and 5.0 L/s, while 2020 median flow was 2.3 L/s. In 2020, flow was generally lower from January until the end of July (average of 2.0 L/s), compared to the remainder of the year (4.4 L/s);
- Slightly alkaline pH values, typically between 7 and 8. In 2020, pH was between 6.32 and 8.81, with a median pH of 7.37 (Figure 4-8);

- Sulphate concentrations were typically high, generally more than 400 mg/L, and appeared to trend with zinc concentrations until temporary closure in September 2013 (Figure 4-9). During 2014 to 2020, the correlation between sulphate and zinc concentrations was not clearly discernable;
- Iron concentrations generally remained low with occasional cycles of increased iron in the adit discharge (Figure 4-10). Concentrations followed the same trend as zinc and cadmium, with a high correlation with both (see Figure 4-7 for zinc; R = 0.98) suggesting that dissolution of iron occurred in tandem with these other two parameters; and
- Cadmium concentrations were correlated with those of zinc (Figure 4-12).

The above summary generally indicates that the mine rock is non-acid generating and leaching of zinc continues to be the primary concern from this adit. Results from the Bellekeno Mine Wall Testing from 2010 to 2013 indicated that ARD was not developing in the mine walls underground. There is sufficient alkalizing material in Bellekeno rock to neutralize the mine water. The Bellekeno adit discharge pH was slightly alkaline with no correlation with metals concentrations in the water.

Conditions with respect to mine water have changed since the period of advanced exploration dewatering was begun in December 2008. Mine water discharge volume can vary from day to day and variability has also been seen in zinc concentrations (Figure 4-8); however, less variability was observed since mining operations temporarily ceased at the end of August 2013.

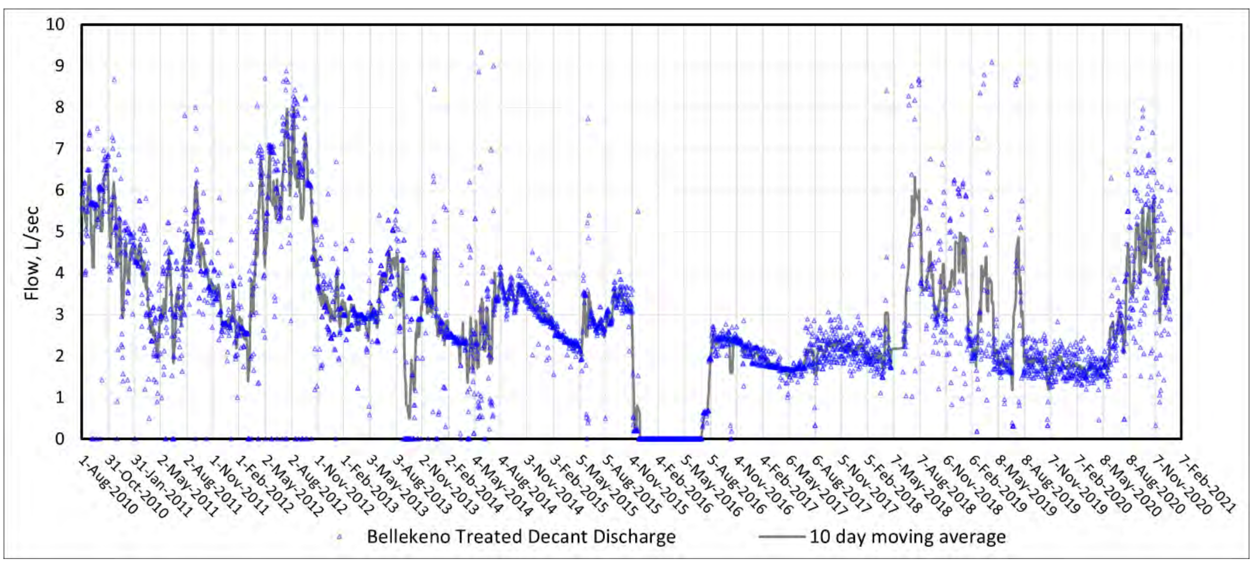


Figure 4-7 Bellekeno 625 Treatment System Flow through Discharge August 2010 to December 2020

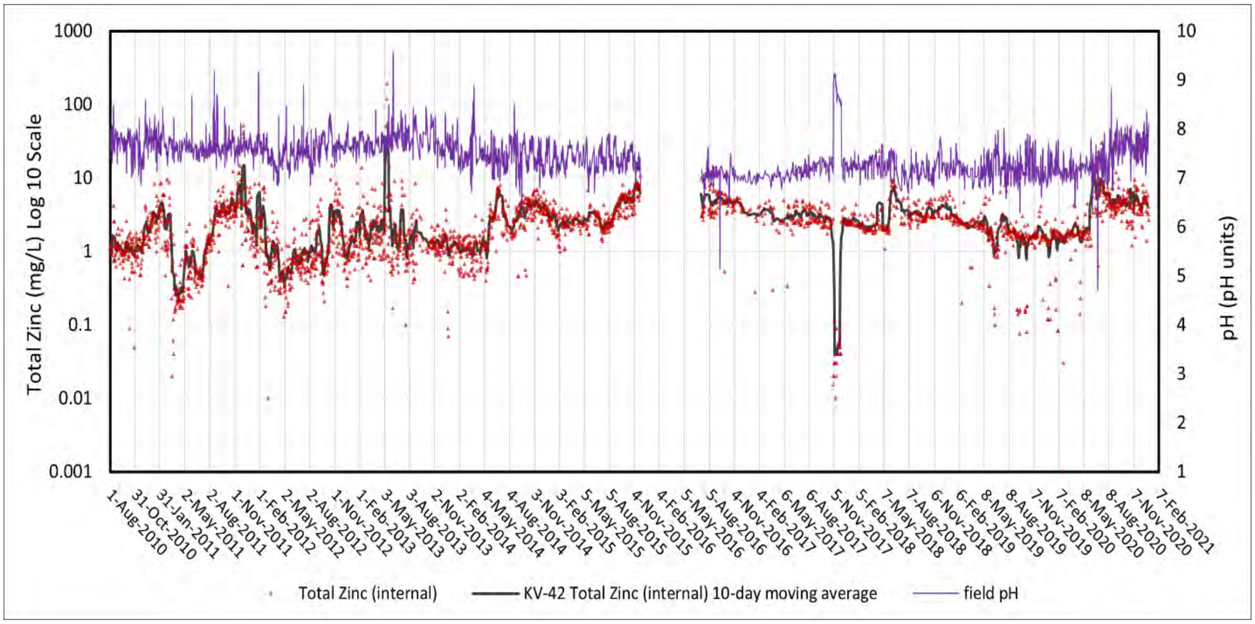


Figure 4-8 Bellekeno 625 Adit Total Zinc (Internal) and pH (field) August 2010 to December 2020

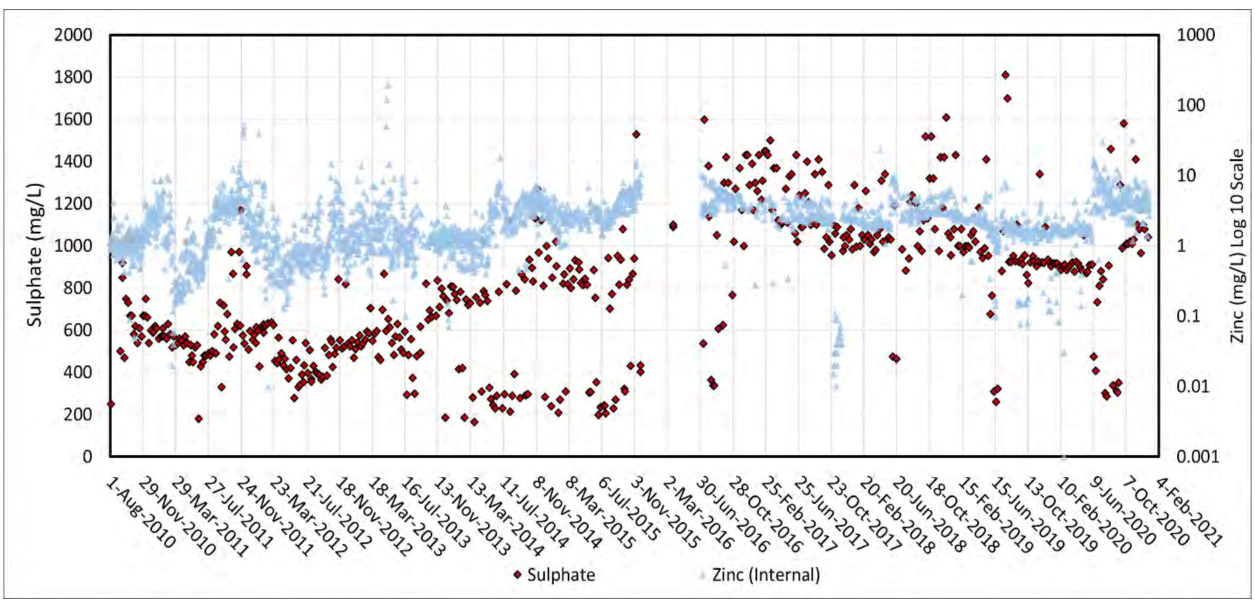


Figure 4-9 Bellekeno 625 Adit Sulphate and Internal Zinc, August 2010 to December 2020

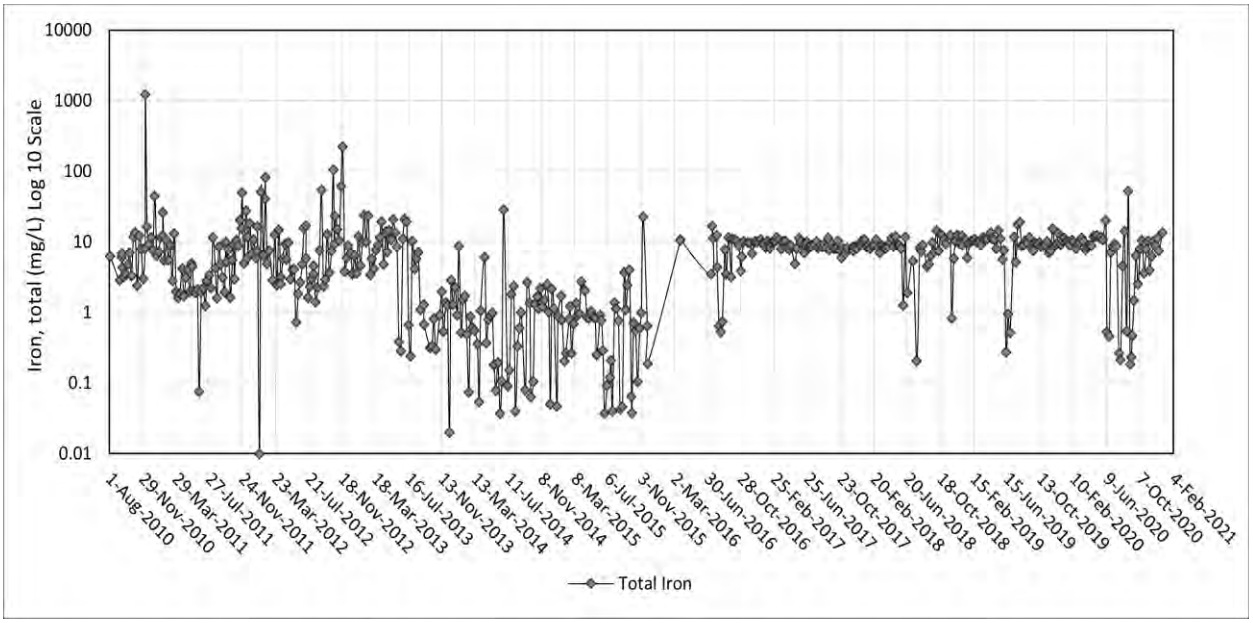


Figure 4-10 Bellekeno 625 Adit Iron Concentrations, August 2010 to December 2020

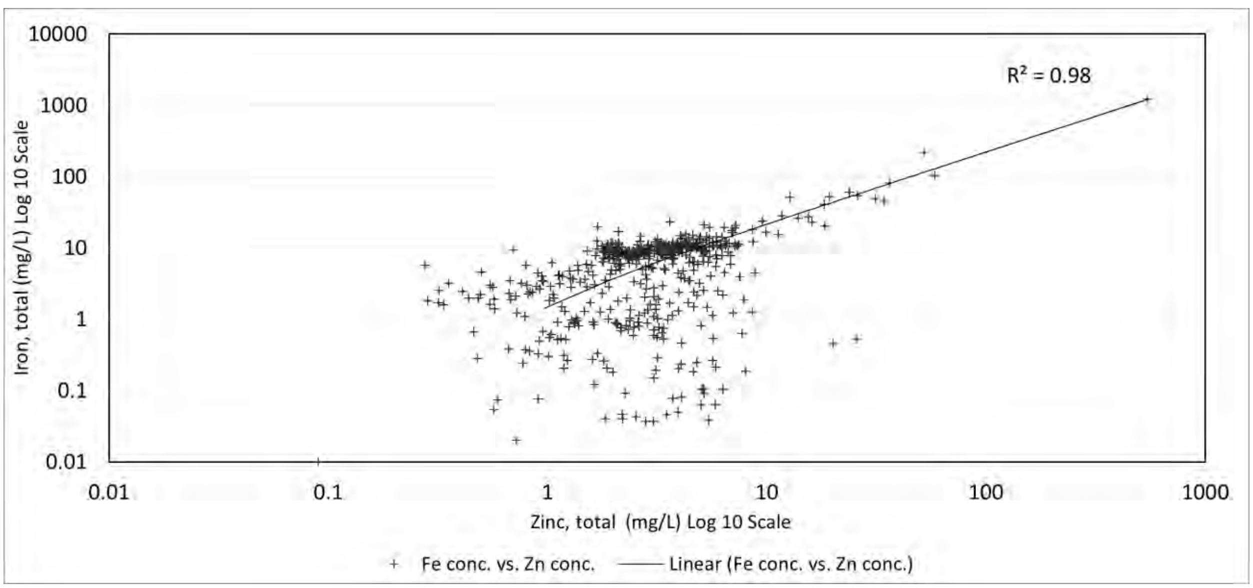


Figure 4-11 Bellekeno 625 Adit Iron and Zinc Concentration Correlation, August 2010 to December 2020

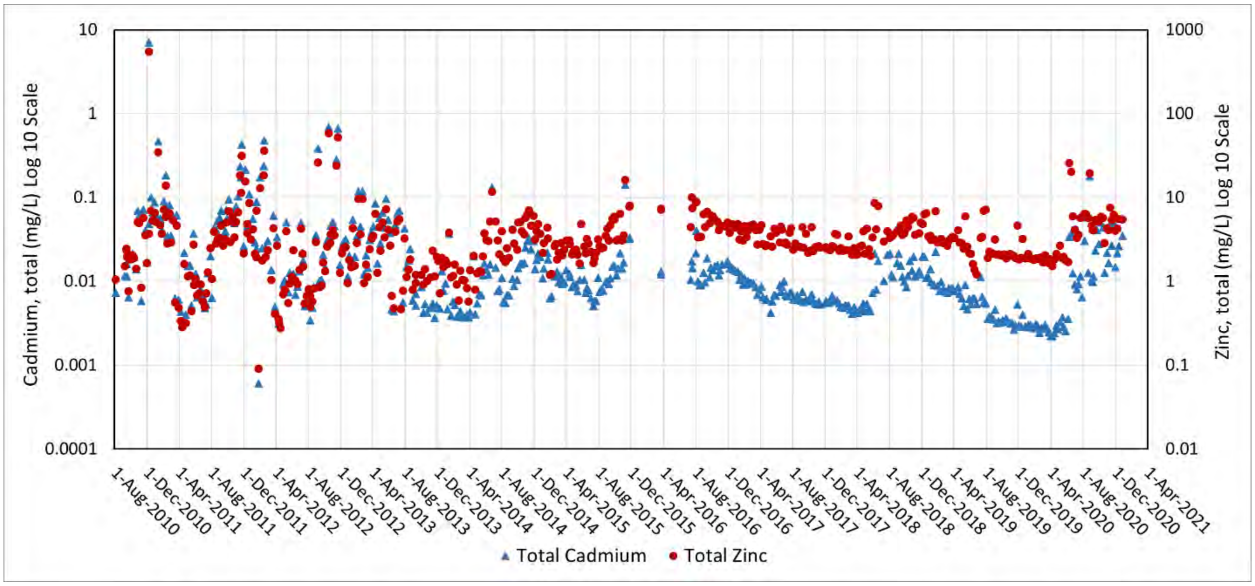


Figure 4-12 Bellekeno 625 Adit Total Cadmium and Zinc Concentrations, August 2010 to December 2020

4.2.1.2 Bellekeno Treatment Facility Water Quality

Total zinc concentrations and pH of the treated decant water at Bellekeno are shown in Figure 4-13. An exceedance of the WL EQS for zinc was observed on November 24, 2015 due to particulates in the sample. On January 17, 2017, a slightly elevated total zinc result was measured due to a power outage and the lime pump being shut off. On October 31, 2019, the external total zinc for KV-43 was 0.687 mg/L compared to the internal result of 0.38 mg/L. On September 8, 2020, the external total zinc for KV-43 was 1.45 mg/L compared to the internal result of 0.25 mg/L. Other WL EQS for the treated decant water at Bellekeno were also exceeded for total cadmium, lead, and silver on September 8, 2020. That the total concentration of these metals in the treated decant were higher than the untreated adit discharge suggests that foreign particles may have been introduced into the treated decant sample due to low-flow collection from the decant box at the time of sampling. Total lead concentrations also exceeded the EQS for the treated decant water at Bellekeno three more times in 2020, on May 15, August 25, and October 21. These exceedances were driven by elevated particulate-associated lead as dissolved lead concentrations were at least one order of magnitude lower and below the EQS.

The licence also limits the effluent discharge rate from the mine to 864 m^3/day, or the equivalent of continuous discharge at 10 L/s. The discharge rate at the Bellekeno 625 decant has historically been <10 L/s (Figure 2-10), ranging between 0.3 and 8.0 L/sec in 2020. As flow from the mine fluctuated, so did concentrations for certain parameters. During temporary closure less fluctuation was observed compared to 2013 and previous years especially for TSS and ammonia, primarily due to no underground mining. Both TSS and ammonia varied widely during fluctuations in flow (Figure 4-15 and Figure 4-16). TSS concentrations in the adit water appeared slightly elevated since July 2016 when water was again pumped to surface, compared to TSS concentrations prior to November 2015 when pumping was discontinued (Figure 4-10). TSS remained consistent in Bellekeno adit water since fall 2016 until approximately August 2020, when the resumption of mining activities caused the flow rate and TSS to increase.

In previous years during operating, the use of bentonite in drilling muds to enhance drill core recovery is a source of fine-grained suspended solids in the mine adit discharge. There is a single pond for settling solid particles at Bellekeno 625, which normally has sufficient residence time for treatment. TSS concentrations exceeded the EQS for the treated decant water at Bellekeno on two occasions in 2020 (Figure 4-10) on October 21 and 29.

In Fall of 2020, mine development and blasting resumed at Bellekeno, which contributed ammonia to the underground water circuit. Due to the low quantities of blasting and the resulting underground ammonia concentrations no ammonia water treatment was required in 2020 (Figure 4-17).

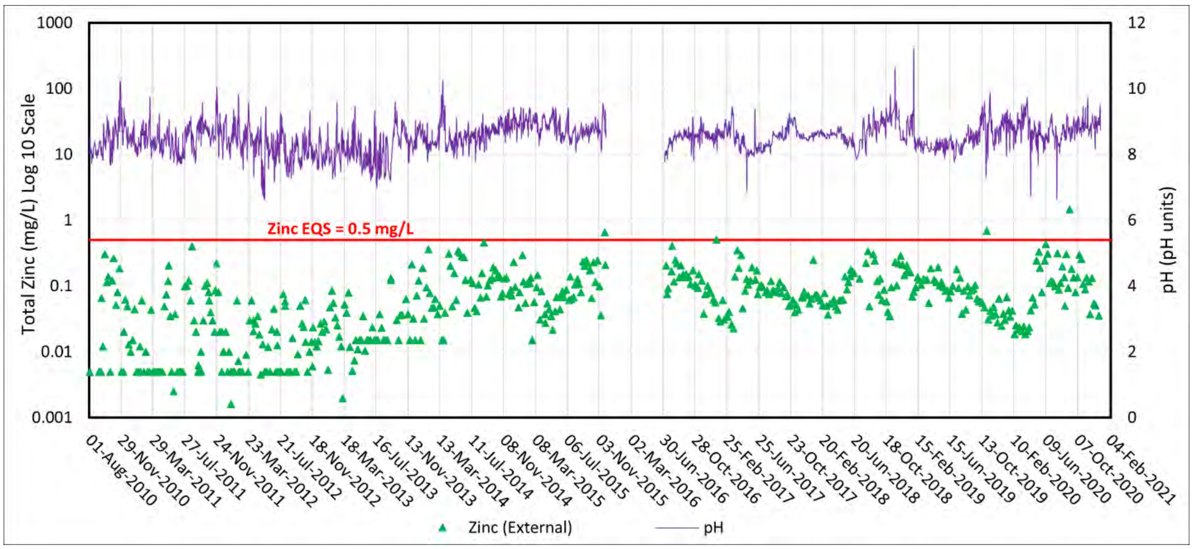


Figure 4-13 Bellekeno 625 Decant Internal Zinc and pH, August 2010 to December 2020

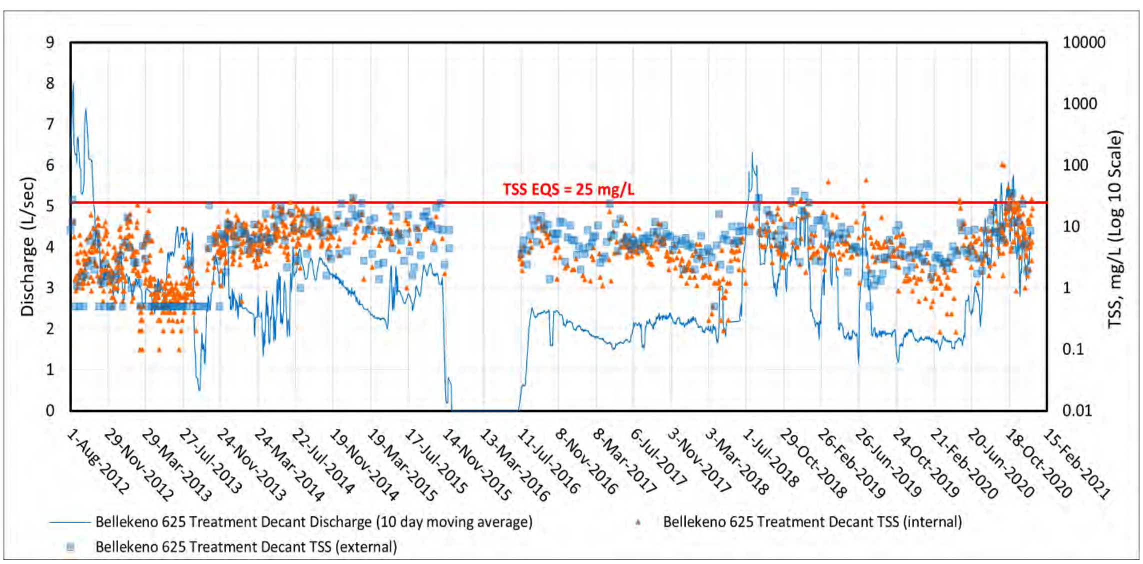


Figure 4-14 Bellekeno 625 Decant Flow and TSS August 2012 to December 2020

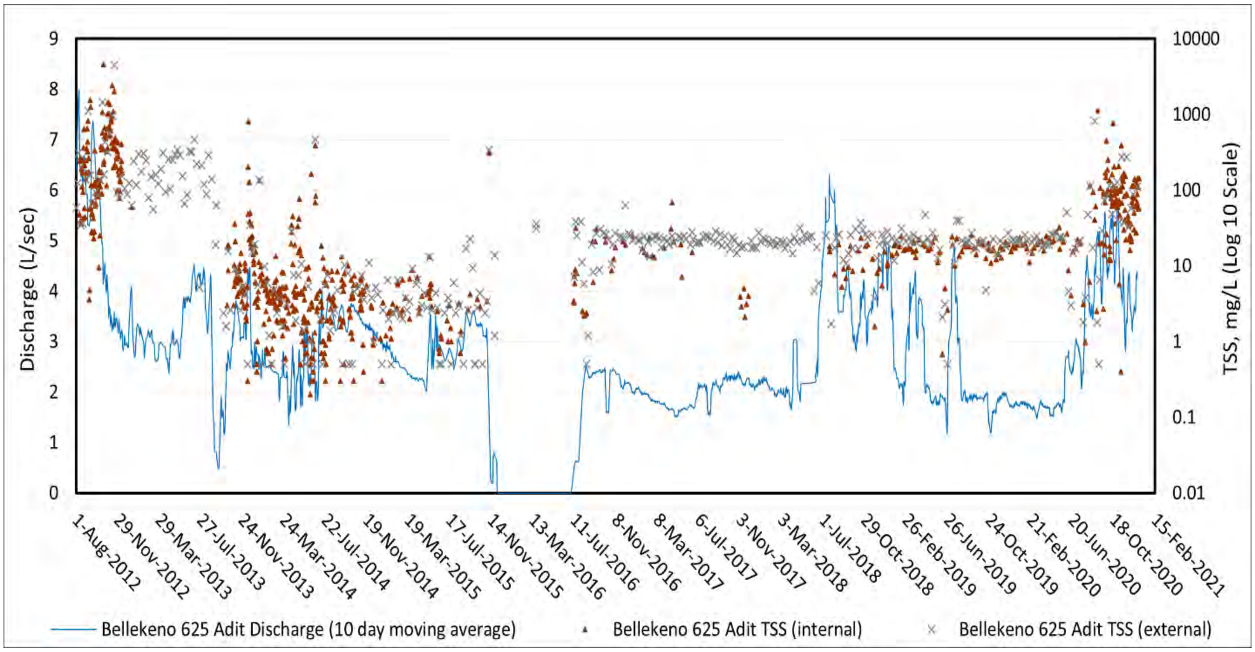


Figure 4-15 Bellekeno 625 Adit Flow and TSS August 2012 to December 2020

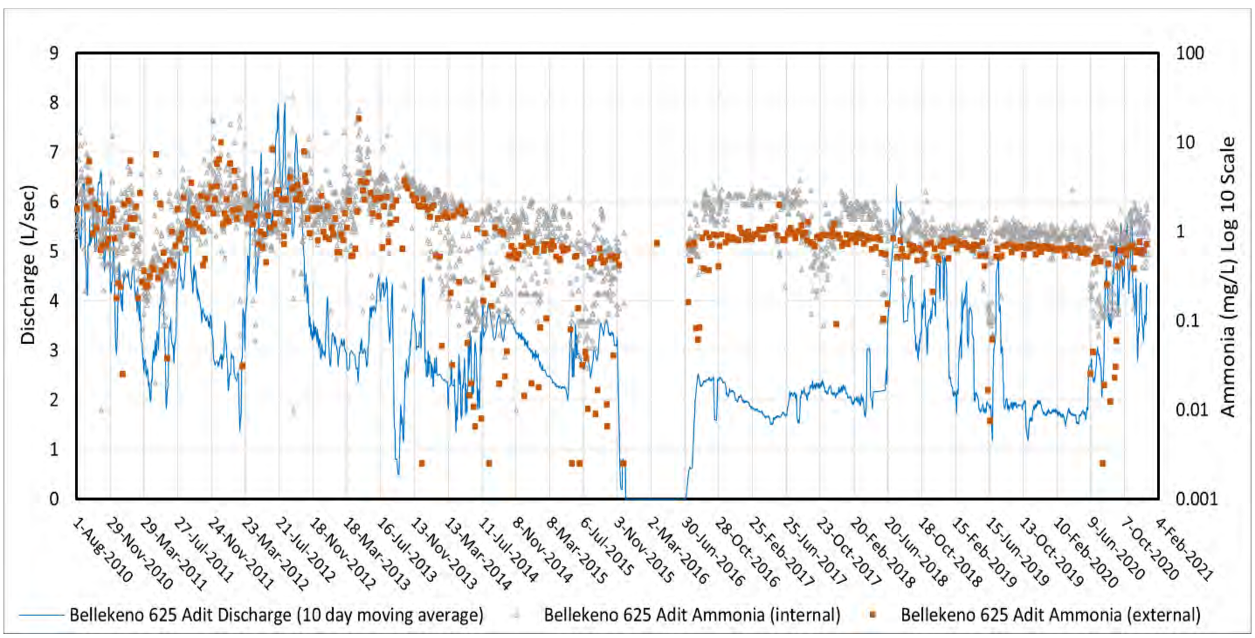


Figure 4-16 Bellekeno 625 Adit Flow and Ammonia August 2010 to December 2020

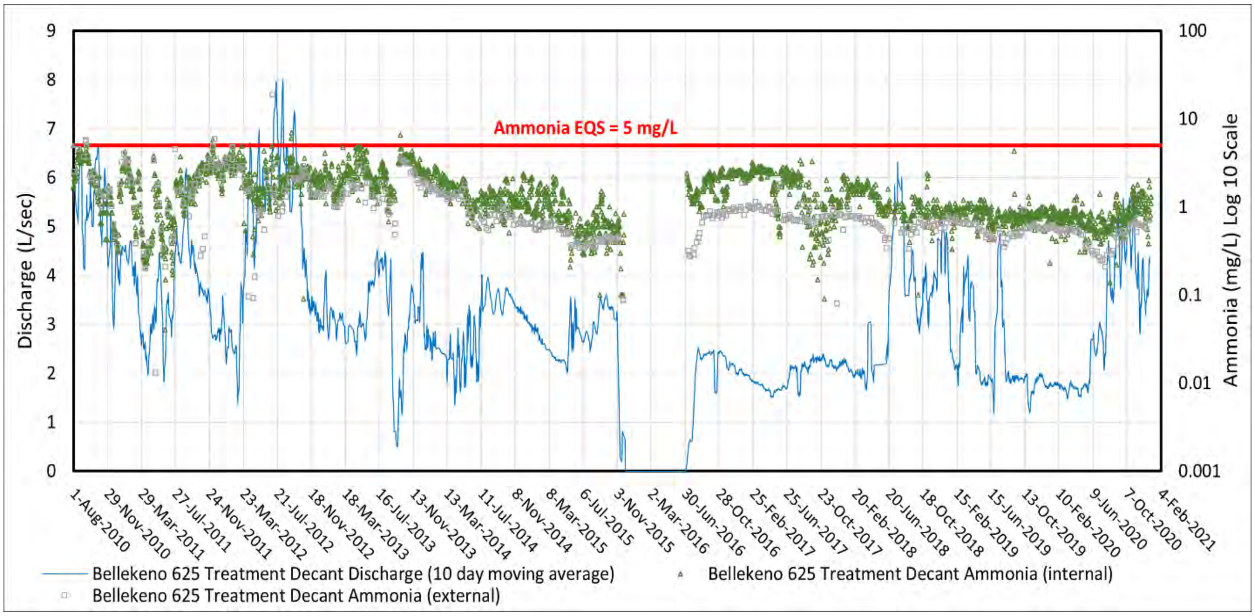


Figure 4-17 Bellekeno 625 Decant Flow and Ammonia August 2010 to December 2020

4.2.2 Flame & Moth Site

The Flame & Moth water treatment system can discharge to Christal Creek or Lightning Creek. The EQS for each watershed are further defined by the discharge rate, with four ranges identified in Part G, Clauses 65 and 66 of Water Licence QZ18-044. The licence also limits the effluent discharge rate from the mine to 3,024 m^3/day, or the equivalent of continuous discharge at 35 L/s.

In July and August 2018, the first Flame & Moth adit (KV-105) samples were collected with discharge going to the water management ponds. Effluent discharge occurred periodically to the Lightning Creek watershed (<10.5 L/s), with none directed to the Christal Creek watershed in 2018 to 2020.

Discharge measurements from the Flame & Moth adit and pond since 2018 are shown on Figures 4-14 and 4-15, respectively. Sample results from the Flame & Moth adit and pond for analytes with EQS are provided in Figures 4-16 to 4-25. Note that the EQS for metal(loid)s in the Flame & Moth treated water discharged to Lightning Creek apply to the dissolved fraction. Dissolved arsenic and TSS concentrations from the Flame & Moth adit dewatering were above the EQS while other analytes were typically below the EQS in the untreated adit discharge. In the case of dissolved copper, lead and silver, most results from the adit and decant were typically below or near to laboratory detection limits, except in 2020 when lead concentrations increased due to mining activity. Higher flows out of the Flame & Moth adit and pond from mid-August to December 2020 (Figures 4-14 and 4-15) reflect the advancement of the mine workings and associated requirement for greater groundwater dewatering. The higher TSS observed over this period also reflects mining activities (e.g., use of drilling muds and general disturbance in the underground workings). Similarly, ammonia, lead (mainly in the adit), and nickel concentrations were also higher during this time frame (Figure 4-27, Figure 4-23, and Figure 4-24). The majority of copper and silver concentrations from the adit during this period were at the detection limit (Figure 4-22 and Figure 4-24). No parameters were present at concentrations above the EQS for the Flame & Moth pond decant other than the one TSS excursion which occurred on November 24, 2020 (Figure 4-28).

As per Clause 100 of QZ18-044, a performance evaluation of the Bellekeno 625, Bermingham and Flame & Moth Treatment System was conducted. The report covers the period between January 1, 2020 and December 31, 2020 and is attached as Appendix A of the annual Water Licence Report.

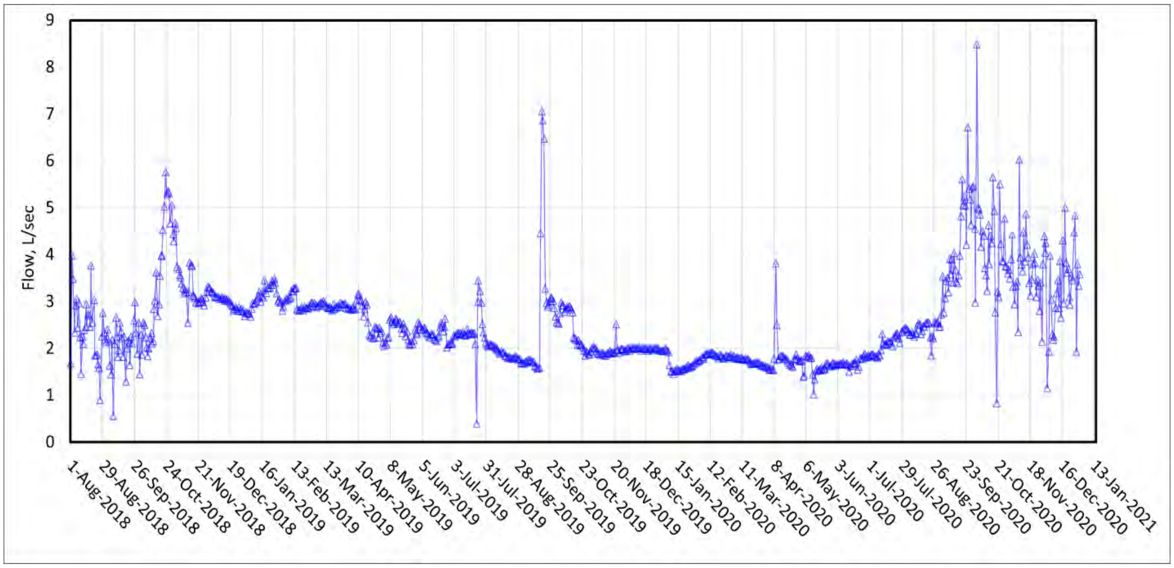


Figure 4-18 Flame & Moth Adit Discharge August 2018 to December 2020

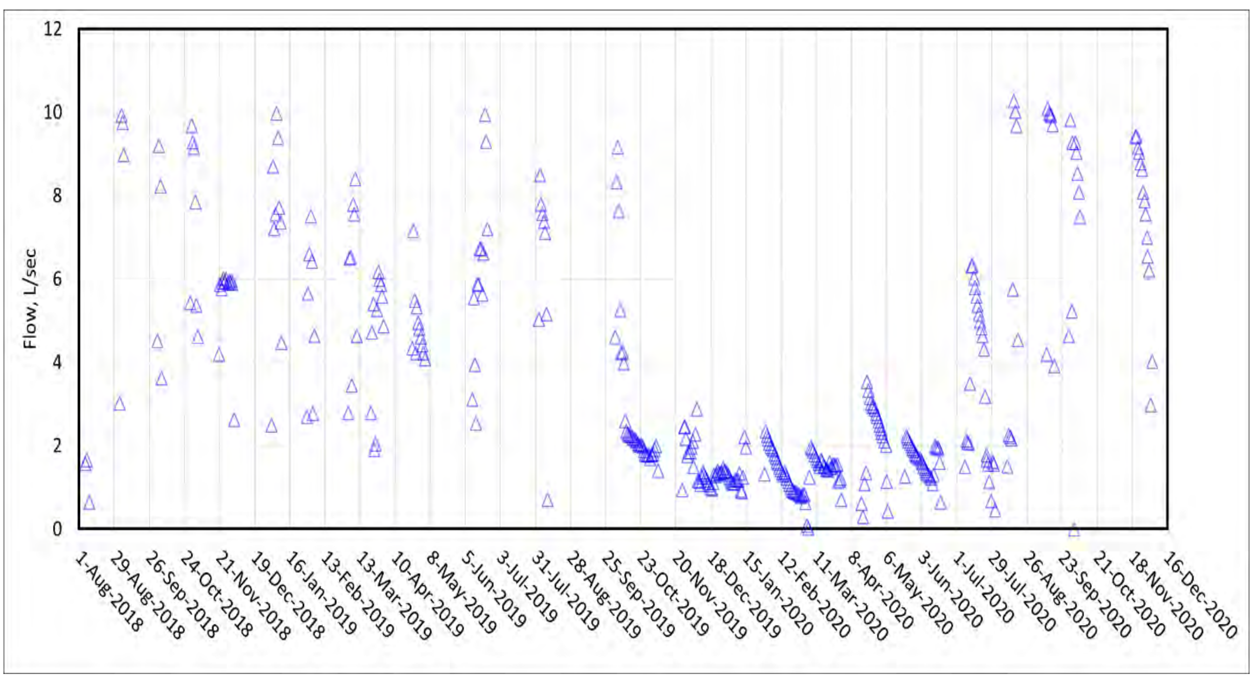


Figure 4-19 Flame & Moth Pond Discharge August 2018 to December 2020

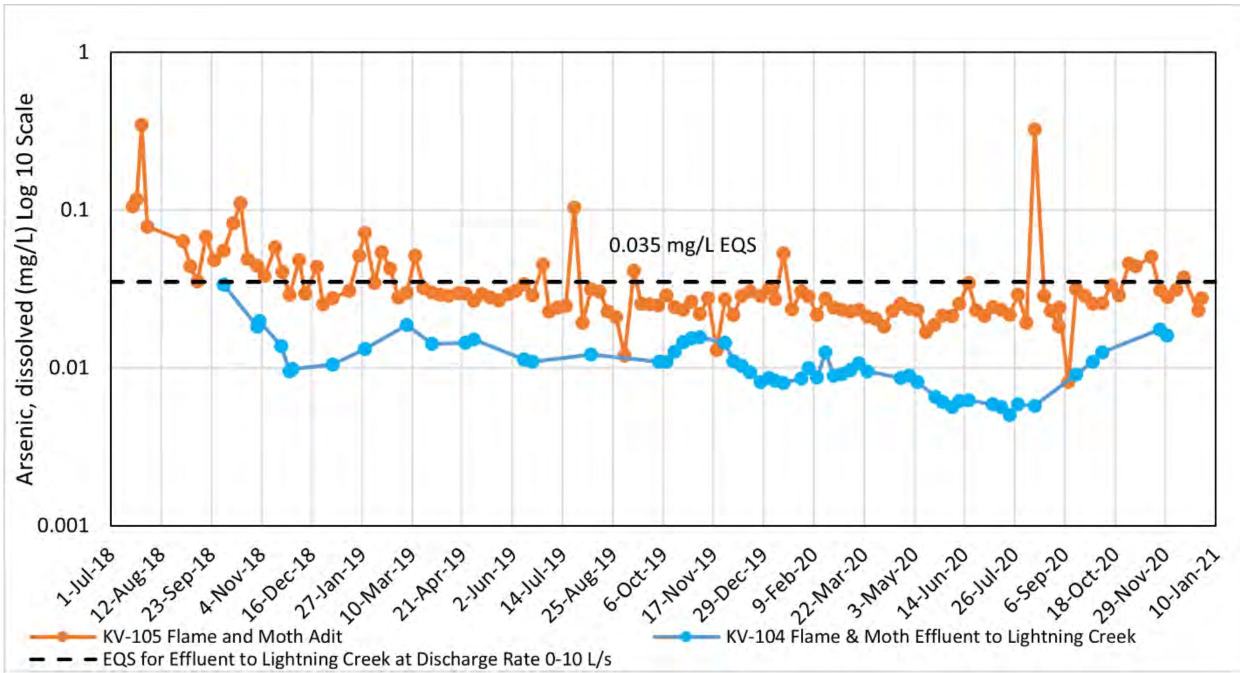


Figure 4-20 Flame & Moth Dissolved Arsenic, 2018 to 2020

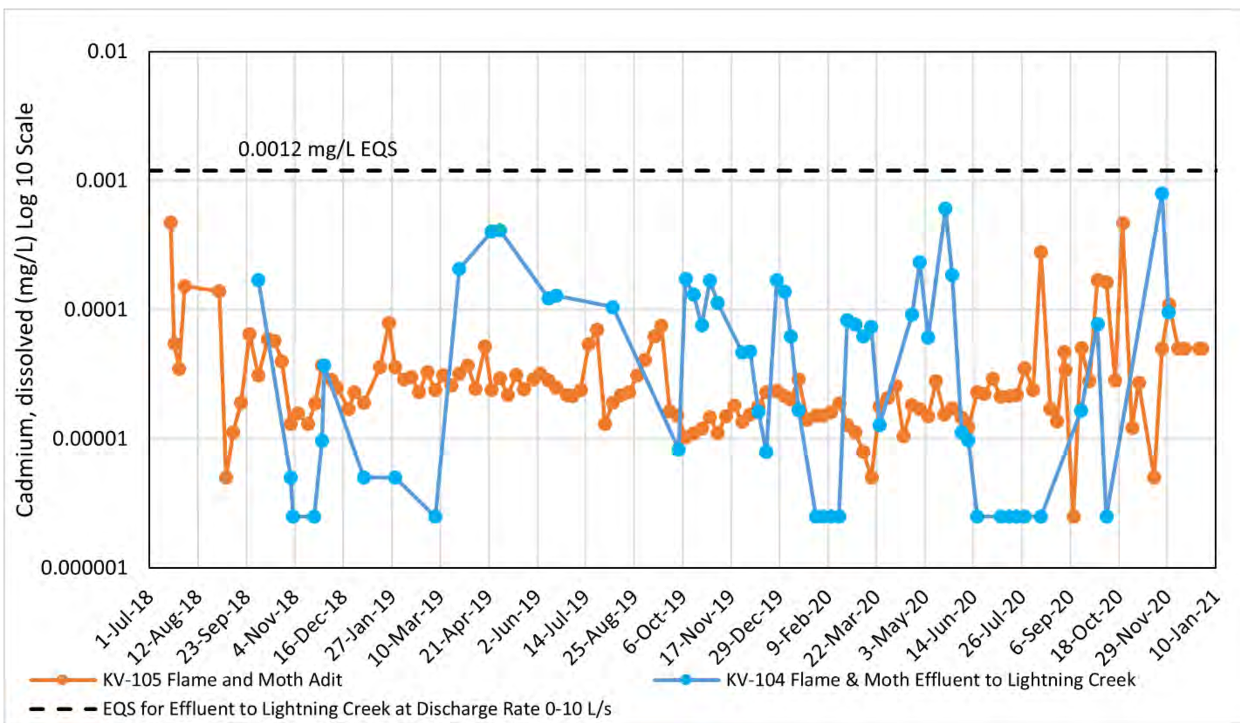


Figure 4-21 Flame & Moth Dissolved Cadmium, 2018 to 2020

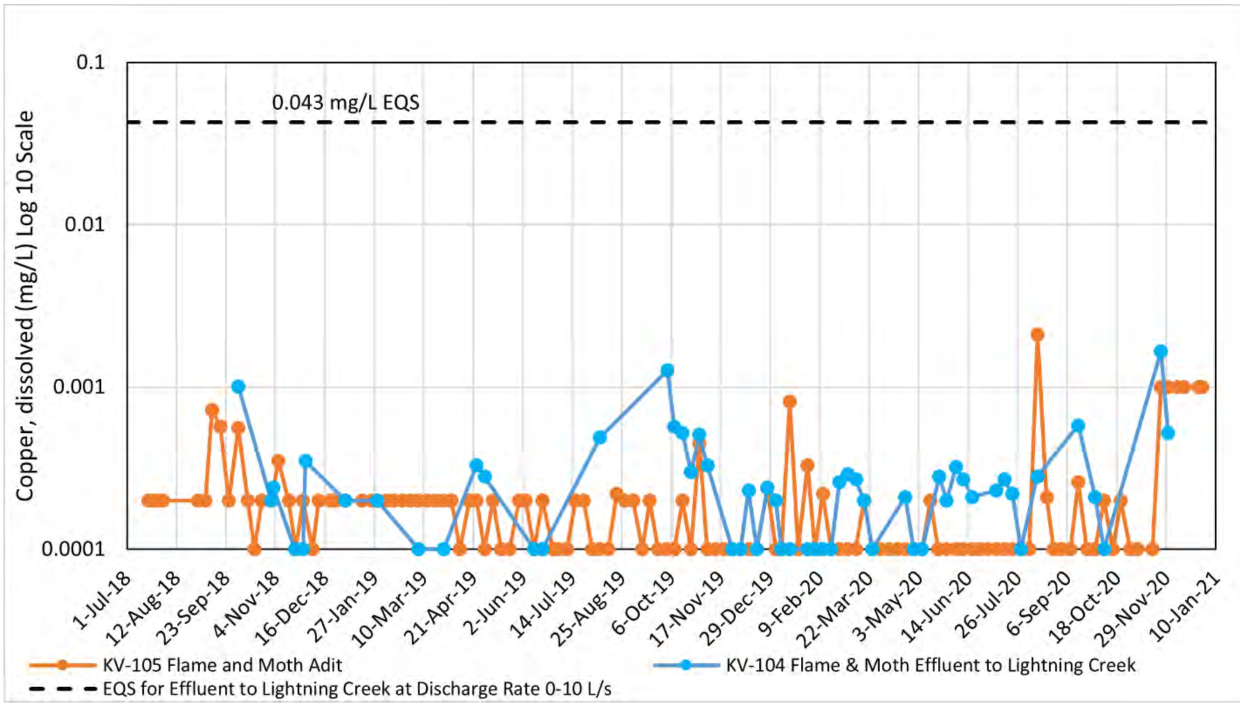


Figure 4-22 Flame & Moth Dissolved Copper, 2018 to 2020

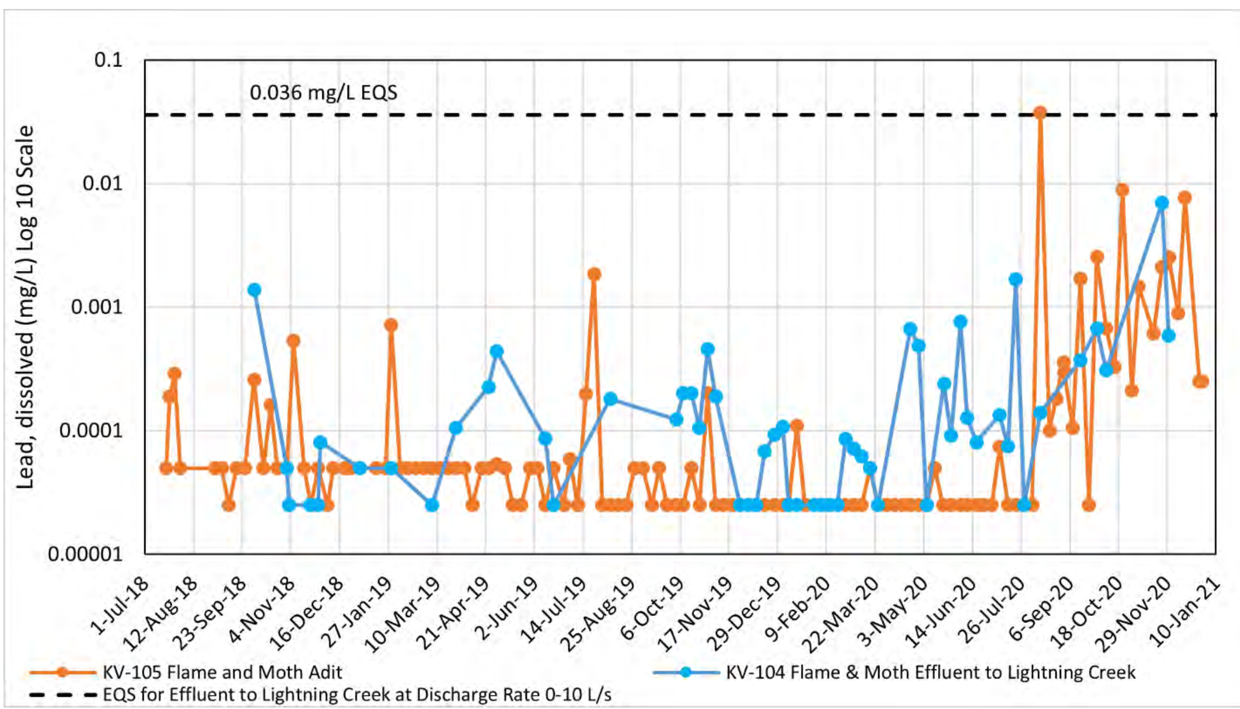


Figure 4-23 Flame & Moth Dissolved Lead, 2018 to 2020

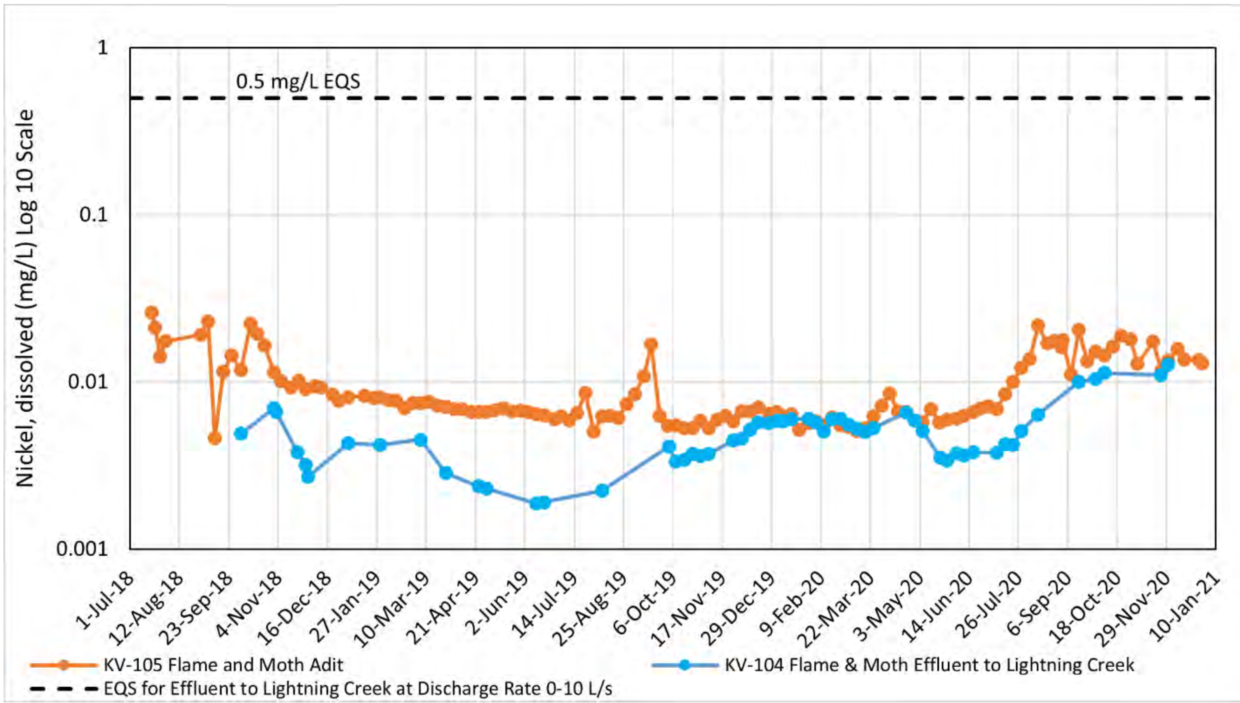


Figure 4-24 Flame & Moth Dissolved Nickel, 2018 to 2020

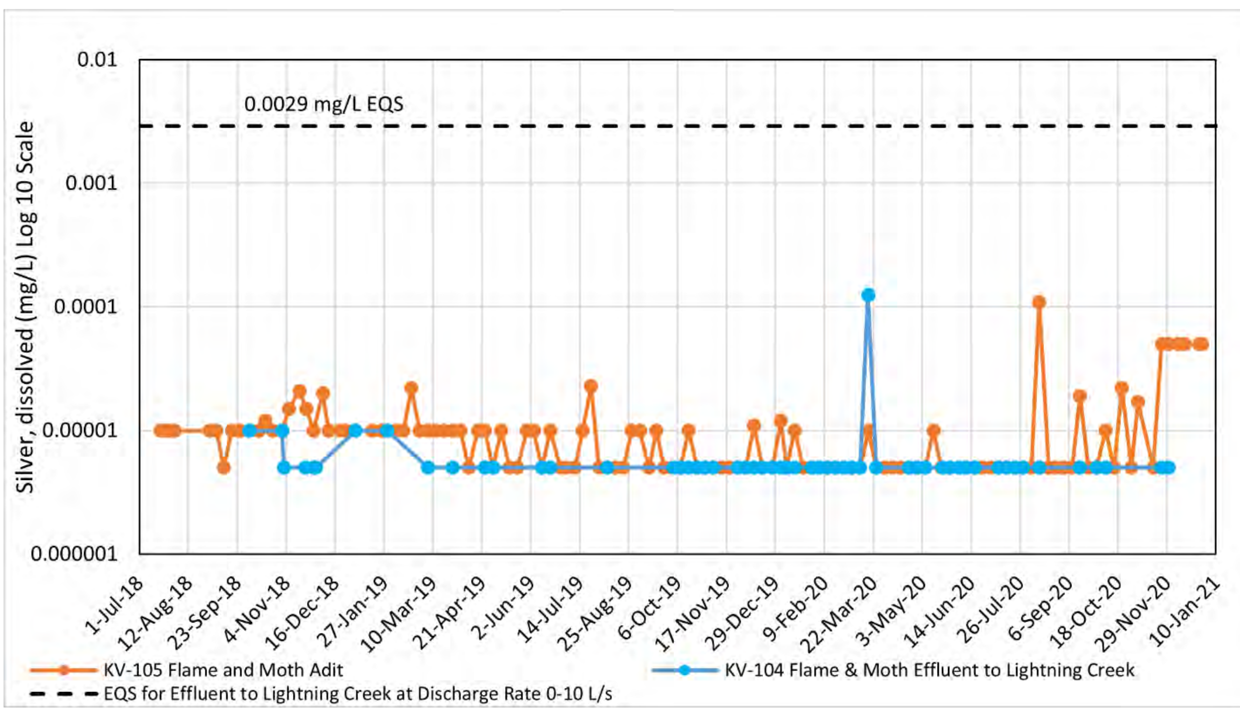


Figure 4-25 Flame & Moth Dissolved Silver, 2018 to 2020

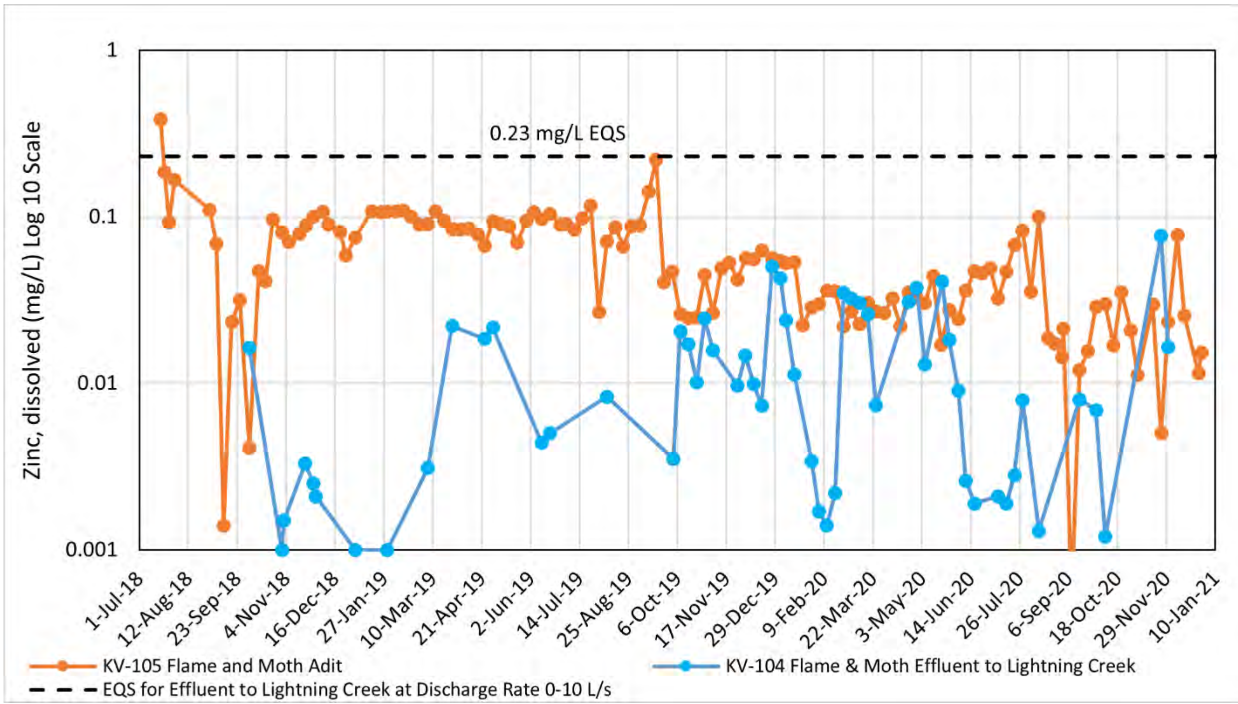


Figure 4-26 Flame & Moth Dissolved Zinc, 2018 to 2020

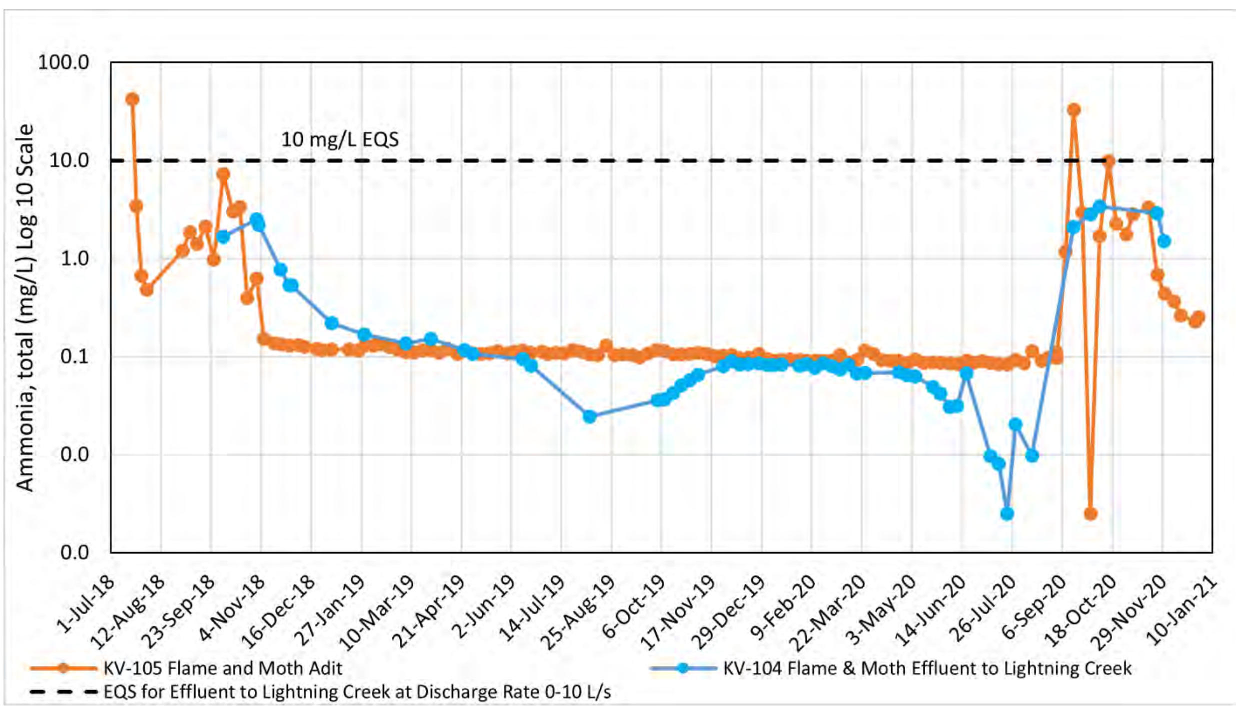


Figure 4-27 Flame & Moth Ammonia, 2018 to 2020

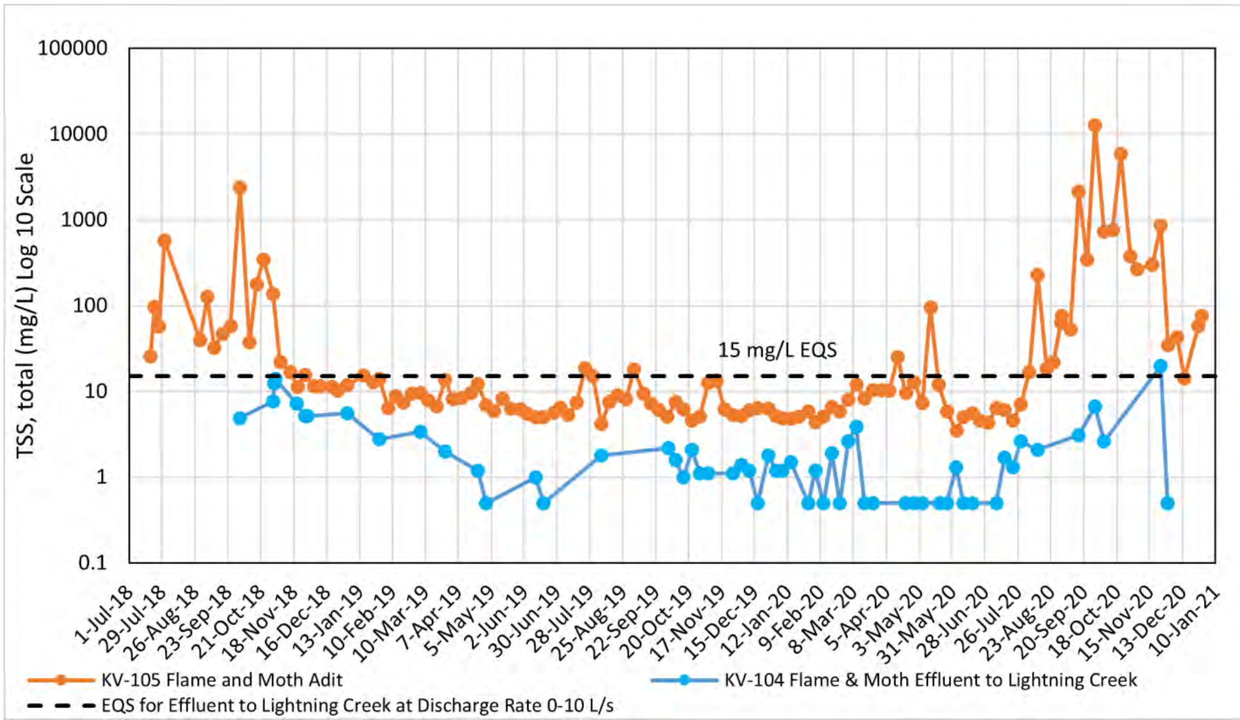


Figure 4-28 Flame & Moth Total Suspended Solids, 2018 to 2020

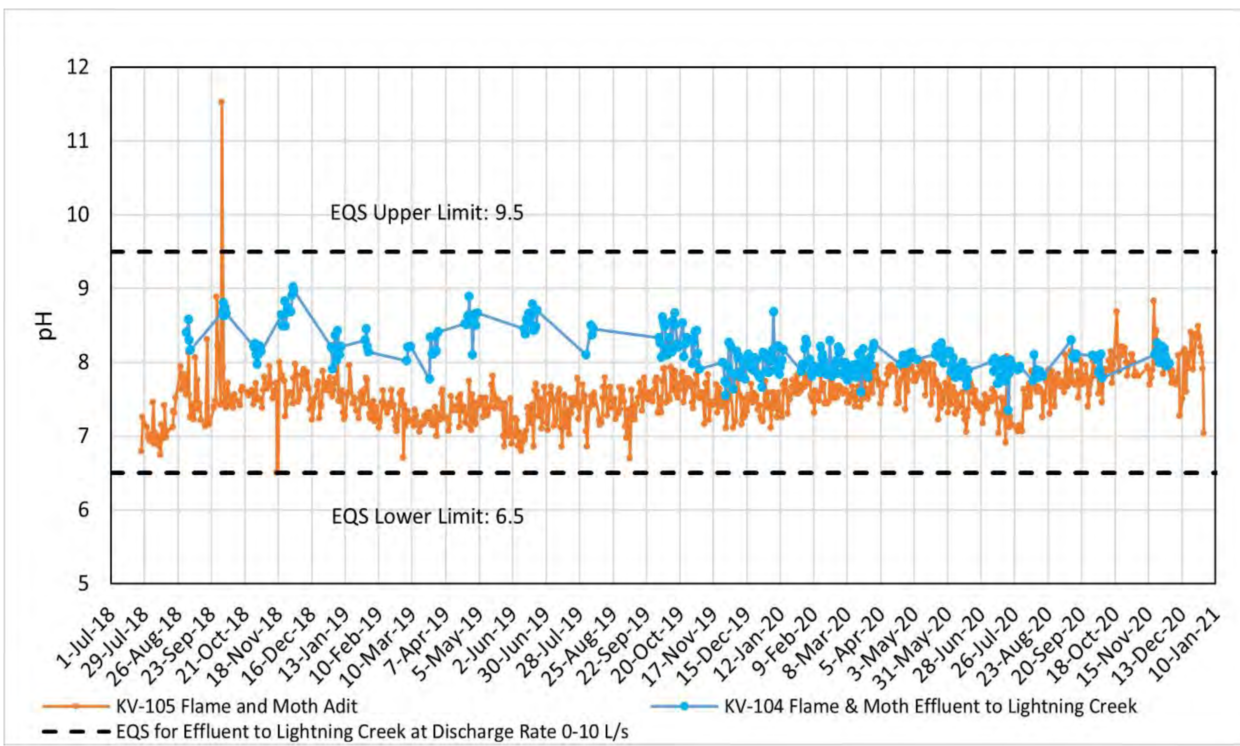


Figure 4-29 Flame & Moth pH, 2018 to 2020

4.2.3 Lightning Creek

Lightning Creek is a mountainous alpine stream flowing within a narrow valley with a steep gradient from the north side of Sourdough Hill into Duncan Creek, which drains into the Mayo River. Historically several mines have been in operation in the Lightning Creek watershed including: Keno 700, Bellekeno, Homestake, Demon, Bema, Divide, Comstock, Apex, Charity, Vanguard, Runner, Ironclad, Hogan and Gold Hill number 2. Placer mining in Lightning Creek and Thunder Gulch predate the Alexco Keno Hill Mining Corp. operations of the Bellekeno mine. The water treatment facility treats Bellekeno 625 adit discharge, with treated effluent discharged to ground up hill from the placer ponds, eventually reporting to Lightning Creek. Farther downstream, treated water from the Flame & Moth mine is discharged towards Lightning Creek.

Hope and Thunder Gulches flow into Lightning Creek within the bounds of the Keno Hill property. Lightning Creek and its tributaries have been the site of extensive placer mining in the vicinity of Keno City both historically and at present time.

Lightning Creek is one of only two creeks in the District not connected to the South McQuesten River (the other is the Sadie Ladue drainage, which reports to the Ladue River). There are nine regularly monitored surface water stations under QZ18-044 within the watershed from the reference station at KV-37 to the farthest downstream station KV-81, southwest of the District mill (Table 4-6).

Table 4-6 Lightning Creek Water Quality Monitoring Sites

Site	Site Description	WL QZ18-044 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	Monthly/Weekly while Flame & Moth treatment plant discharges to Lightning Creek

Figure 4-30 to Figure 4-35 show the temporal zinc and cadmium concentrations of stations located on Lightning Creek and Thunder Gulch. For comparative purposes, the graphs also show the Canadian Council of Ministers of the Environment (CCME) protection of aquatic life (PAL) dissolved zinc guideline calculated based on the lowest median hardness, pH and dissolved organic carbon of the sites within each plot. The total cadmium CCME-PAL guideline is based on a hardness of 100 mg/L within each plot. Summary statistics for the stations are presented in Table 4-7 and Table 4-4.

Reference water chemistry data on Lightning Creek is collected at station KV-37. Two creeks, Hope Gulch and Charity Gulch, flow from the south side of Keno Hill into Lightning Creek upstream of Thunder Gulch and the Bellekeno 625 treated effluent discharge. Hope Gulch and Charity Gulch are sampled upstream of the confluence with Lightning Creek (stations KV-39 and KV-40 respectively). Another water quality monitoring site on Lightning Creek (KV-38) is located downstream of Hope Gulch and Charity Gulch but upstream of Thunder Gulch. A water quality sampling site on Thunder Gulch upstream of all current mining activities (KV-77) also provides reference information on the quality of water flowing into Lightning Creek. Additional Thunder Gulch sites KV-76 and KV-65 monitor water quality along the watercourse and prior to the confluence with Lightning Creek. A third station on Lightning Creek (KV-41) downstream of the Bellekeno 625 adit flow, Thunder Gulch, and the placer operations gives an indication of the combined influence of these inputs and activities. The fourth station on Lightning Creek, KV-81 tracks water quality downstream of the District mill and Flame & Moth treated discharge.

There is only one historical mine site which drains to the Lightning Creek watershed – the Keno 700 adit and associated waste rock dump. The Keno 700 adit discharge drains over the Keno 700 waste rock dump and directly into Hope Gulch, which enters Lightning Creek upstream of station KV-38.

Median zinc and cadmium concentrations at the reference station on Lightning Creek at KV-37 were approximately one order of magnitude lower than those observed downstream at station KV-38 (Table 4-7 and Table 4-4). Although cadmium and zinc concentrations were elevated at KV-38 relative to KV-37, due to the contribution from the Keno 700 adit discharge, concentrations were typically below CCME-PAL guidelines (58% and 60% of samples collected between 2008 and 2020 were below CCME-PAL for total cadmium and dissolved zinc, respectively; Table 4-7 and Table 4-4). Cadmium and zinc concentrations at KV-38 were higher in 2020, with concentrations above the CCME-PAL guideline from May to October 2020 (Figure 4-30 and Figure 4-33).

Farther downstream on Lightning Creek, median cadmium and zinc concentrations at KV-41 were lower than those observed at KV-38 (Table 4-7 and Table 4-4), reflecting dilution from Thunder Gulch. Cadmium and zinc concentrations observed at KV-41 in 2020 were comparable with the historical record (Figure 4-31 and Figure 4-34). These observations indicate that zinc and cadmium contributions from Thunder Gulch and treated discharge from the Bellekeno mine are minimal relative to the effect of Hope Gulch (and the Keno 700 adit) on the overall chemistry in Lightning Creek. Median cadmium and zinc concentrations at KV-81 were similar to those observed upstream at KV-41 (Table 4-7 and Table 4-4), suggesting the treated discharge from the Flame & Month mine which enters Lightning Creek between these two stations does not materially affect downstream water quality. Cadmium and zinc concentrations observed at KV-81 in 2020 were also comparable with the historical record (Figure 4-31 and Figure 4-34).

Placer mining upstream of the District occurs or has occurred in Hope Gulch, Thunder Gulch, and Lightning Creek. Placer mining has a significant effect on water quality due to sediment released during operations, and the potential for increased TSS and metals concentrations associated with the suspended sediment. In recent years, Thunder Gulch has been the focus of placer mining activity, which is likely responsible for the elevated TSS levels observed in Thunder Gulch (e.g., KV-65) and downstream in Lighting Creek (KV-41). It can be reasonably assumed that water quality has been altered because of this activity, as it has taken place on both Lightning Creek and Thunder Gulch since at least the 1960s.

For example, KV-65 on Thunder Gulch had the highest and second highest total zinc and cadmium concentrations established on September 22, 2016 and July 10, 2018, respectively, which was due to extremely high TSS (2,360 and 3,110 mg/L, respectively). These dates are outside the flow peak during freshet when TSS is naturally elevated; rather placer mining activity is likely responsible for this behaviour. Dissolved zinc was below laboratory detection levels and dissolved cadmium was below the laboratory detection limit on September 22, 2016 and comprised 0.1% of the total cadmium concentration on July 10, 2018, indicating that the total metal concentrations are TSS-related. Dissolved zinc and cadmium concentrations from Thunder Gulch in 2020 were relatively consistent between KV-77, KV-65, and KV-76 with slight increases moving downstream (Table 4-7 and Table 4-8).

Zinc concentrations in the Upper Lightning Creek watershed at KV-39 displayed some seasonality with highs in February, while KV-37 showed little to no seasonality (Figure 4-30). Cadmium concentrations at KV-37 typically peaked in the spring (May or June) and/or in the fall (September or October), while there was no seasonality at KV-39 (Figure 4-33). Zinc and cadmium concentrations at KV-40 and in the Lower Lightning Creek watershed (KV-38, KV-41, KV-81) typically peaked in May, June or July and were influenced by the spring freshet (Figure 4-30, Figure 4-31, Figure 4-33, Figure 4-34). In Thunder Gulch (KV-65, KV-76, and KV-77) weak seasonality was observed for zinc and cadmium concentrations between 2008 and 2020 (Figure 4-32 and Figure 4-35). Zinc concentrations in Thunder Gulch typically peaked in the spring (May or June) and/or in the fall (September or October), whereas cadmium concentrations typically peaked in the spring (May) or summer (July).

Table 4-7 Lightning Creek Drainage Zinc Summary Statistics, 2008 to 2020

Zinc, total									
2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.0043	0.016	0.16	0.012	0.018	0.0077	0.015	0.013	0.014
Count	5	4	4	3	3	11	4	12	41
Minimum	<0.0030	0.0058	0.15	0.0072	0.0072	<0.0030	0.0070	<0.0030	0.0050
Maximum	0.014	0.019	0.17	0.015	0.030	0.027	0.040	0.043	0.042
Count <DL	3	0	0	0	0	2	0	1	0
Standard Deviation	0.0052	0.0065	0.011	0	0.011	0.0078	0.017	0.011	0.0097
1st Quartile	<0.0030	0.015	0.16	0.011	0.012	0.0033	0.0071	0.0068	0.0058
Median	<0.0030	0.019	0.16	0.014	0.018	0.0038	0.0072	0.0099	0.010
3rd Quartile	0.0035	0.019	0.17	0.015	0.024	0.0094	0.016	0.014	0.017
99 Percentile	0.013	0.019	0.17	0.015	0.030	0.026	0.039	0.041	0.041
2008 - 2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.0081	0.017	0.20	0.0076	0.11	0.034	0.065	0.017	0.015
Count	117	82	47	34	45	138	53	157	152
Minimum	<0.001	0.0037	0.095	0.0023	0.00040	0.0014	0.0015	<0.0030	0.0039
Maximum	0.24	0.10	0.47	0.027	3.2	1.1	0.83	0.14	0.062
Count <DL	46	0	0	1	8	6	1	1	1
Standard Deviation	0.031	0.014	0.077	0.0059	0.49	0.12	0.16	0.017	0.011
1st Quartile	<0.0030	0.0079	0.15	0.0034	<0.0030	0.0036	0.0071	0.0070	0.0077
Median	<0.0030	0.012	0.17	0.0053	0.0072	0.0057	0.015	0.012	0.011
3rd Quartile	0.0039	0.020	0.22	0.0092	0.040	0.016	0.039	0.020	0.016
99 Percentile	0.20	0.073	0.44	0.025	2.1	0.60	0.74	0.078	0.047
Zinc, dissolved									
2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.0051	0.015	0.16	0.0087	0.00080	0.0021	0.0060	0.011	0.0095
Count	5	4	4	3	3	11	4	12	41
Minimum	0.0011	0.0053	0.15	0.0073	<0.0010	<0.0010	0.0020	0.0039	0.0038
Maximum	0.016	0.019	0.17	0.0096	0.0014	0.0057	0.017	0.047	0.034
Count <DL	0	0	0	0	2	2	0	0	0
Standard Deviation	0.0061	0.0066	0.0080	0.0012	0.00052	0.0017	0.0075	0.012	0.0059
1st Quartile	0.0018	0.014	0.15	0.0082	0.00050	0.0012	0.0022	0.0049	0.0052
Median	0.0019	0.018	0.16	0.0091	<0.0010	0.0016	0.0024	0.0080	0.0080
3rd Quartile	0.0048	0.019	0.16	0.0094	0.0010	0.0020	0.0062	0.0089	0.012
99 Percentile	0.015	0.019	0.17	0.0096	0.0014	0.0056	0.017	0.043	0.028
Count > Guideline	0	2	4	0	0	0	0	1	2
% > Guideline	0	50	100	0	0	0	0	8	5
2008 - 2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.0077	0.015	0.19	0.0065	0.012	0.0034	0.0076	0.010	0.0090
Count	117	82	47	34	46	138	53	157	152
Minimum	<0.0010	0.0050	0.089	0.0024	<0.0010	<0.0010	<0.0010	0.0016	0.0026
Maximum	0.23	0.059	0.41	0.020	0.19	0.019	0.024	0.27	0.034
Count <DL	15	0	0	0	19	20	2	0	1
Standard Deviation	0.030	0.010	0.066	0.0046	0.040	0.0030	0.0059	0.021	0.0055
1st Quartile	0.0011	0.0079	0.15	0.0029	0.00050	0.0015	0.0032	0.0049	0.0054
Median	0.0021	0.011	0.17	0.0045	0.0014	0.0025	0.0055	0.0071	0.0077
3rd Quartile	0.0033	0.017	0.20	0.0091	0.0025	0.0043	0.011	0.011	0.011
99 Percentile	0.20	0.054	0.40	0.019	0.17	0.014	0.022	0.039	0.030
Count > Guideline	10	33	47	1	4	5	8	17	11
% > Guideline	9	40	100	3	9	4	15	11	7

Table 4-8 Lightning Creek Drainage Cadmium Summary Statistics, 2008 to 2020

Cadmium, total									
2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.000042	0.00016	0.0020	0.00015	0.00014	0.000063	0.00017	0.00011	0.00012
Count	5	4	4	3	3	11	4	12	41
Minimum	0.0000074	0.000047	0.0017	0.00010	0.000054	0.000021	0.000064	0.000029	0.000035
Maximum	0.00015	0.00020	0.0023	0.00018	0.00023	0.00023	0.00040	0.00035	0.00034
Count <DL	0	0	0	0	0	0	0	0	0
Standard Deviation	0.000059	0.000074	0.00025	0	0.000086	0.000060	0.00016	0.000095	0.000088
1st Quartile	0.0000081	0.00015	0.0019	0.00013	0.00010	0.000029	0.000070	0.000039	0.000051
Median	0.000022	0.00019	0.0020	0.00015	0.00015	0.000036	0.00011	0.000075	0.000093
3rd Quartile	0.000024	0.00020	0.0021	0.00017	0.00019	0.000068	0.00022	0.00014	0.00016
99 Percentile	0.00014	0.00020	0.0023	0.00018	0.00022	0.00021	0.00040	0.00033	0.00034
Count > Guideline	1	3	4	1	2	2	1	3	11
% > Guideline	20	75	100	33	67	18	25	25	27
2008 - 2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.000084	0.00018	0.0025	0.000081	0.0010	0.00026	0.00065	0.00015	0.00013
Count	117	82	47	34	45	138	53	157	152
Minimum	<0.0000050	0.000033	0.0014	0.000029	<0.000010	<0.00001	0.000020	0.0000070	0.000035
Maximum	0.0026	0.0012	0.0061	0.00033	0.026	0.0080	0.011	0.0011	0.00076
Count <DL	8	0	0	0	2	2	0	0	0
Standard Deviation	0.00033	0.00017	0.00086	0.000067	0.0040	0.00085	0.0018	0.00016	0.00011
1st Quartile	0.000012	0.000078	0.0020	0.000036	0.000020	0.000037	0.000079	0.000057	0.000069
Median	0.000017	0.00013	0.0024	0.000051	0.000054	0.000059	0.00013	0.00010	0.00010
3rd Quartile	0.000034	0.00021	0.0027	0.000099	0.00031	0.00014	0.00034	0.00017	0.00016
99 Percentile	0.0022	0.00086	0.0055	0.00029	0.019	0.0041	0.0087	0.00065	0.00047
Count > Guideline	14	34	47	4	17	34	24	48	36
% > Guideline	12	42	100	12	38	25	45	31	24
Cadmium, dissolved									
2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.000045	0.00015	0.0019	0.00014	0.000013	0.000028	0.000083	0.00013	0.000086
Count	5	4	4	3	3	11	4	12	41
Minimum	0.0000074	0.000047	0.0017	0.000092	0.0000071	0.000011	0.000029	0.000030	0.000033
Maximum	0.00017	0.00020	0.0022	0.00018	0.000019	0.000083	0.00024	0.00084	0.00027
Count <DL	0	0	0	0	0	0	0	0	0
Standard Deviation	0.000068	0.000068	0.00022	0	0.0000061	0.000022	0.00010	0.00023	0.000058
1st Quartile	0.000013	0.00014	0.0018	0.00012	0.000010	0.000017	0.000031	0.000040	0.000040
Median	0.000017	0.00017	0.0019	0.00015	0.000013	0.000021	0.000033	0.000061	0.000068
3rd Quartile	0.000020	0.00018	0.0020	0.00016	0.000016	0.000025	0.000085	0.000092	0.00011
99 Percentile	0.00016	0.00020	0.0022	0.00018	0.000019	0.000080	0.00023	0.00076	0.00026
2008 - 2020									
	KV-37	KV-38	KV-39	KV-40	KV-77	KV-65	KV-76	KV-41	KV-81
Average	0.000079	0.00015	0.0024	0.000075	0.00011	0.000041	0.00010	0.000083	0.000084
Count	117	82	47	34	46	138	53	157	152
Minimum	<0.0000050	0.000031	0.0013	0.000026	<0.000010	<0.00001	<0.0000050	0.000030	0.000032
Maximum	0.0028	0.00060	0.0046	0.00019	0.0014	0.00019	0.00056	0.00084	0.00037
Count <DL	9	0	0	0	5	4	2	0	0
Standard Deviation	0.00035	0.00011	0.00068	0.000053	0.00031	0.000036	0.00010	0.000077	0.000053
1st Quartile	0.000011	0.000075	0.0019	0.000034	0.000010	0.000017	0.000035	0.000046	0.000050
Median	0.000016	0.00010	0.0022	0.000048	0.000019	0.000028	0.000071	0.000064	0.000071
3rd Quartile	0.000026	0.00018	0.0026	0.00011	0.000026	0.000050	0.00014	0.000094	0.000097
99 Percentile	0.0022	0.00060	0.0044	0.00019	0.0013	0.00016	0.00043	0.00028	0.00029

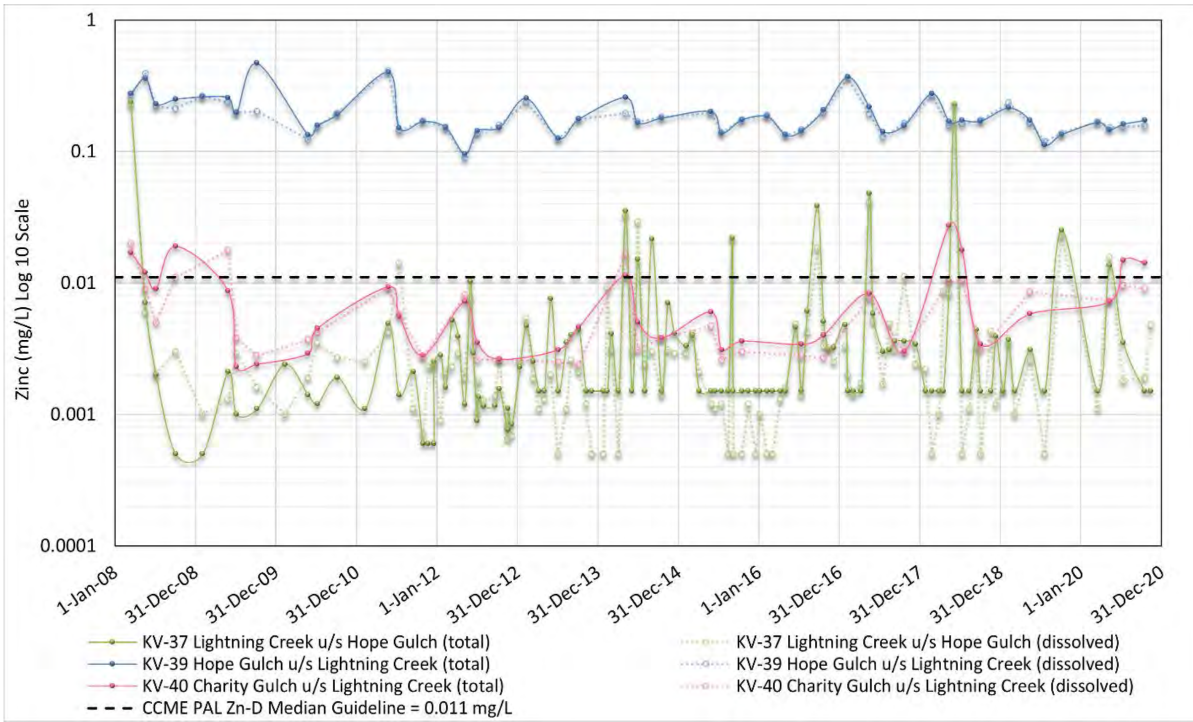


Figure 4-30 Upper Lightning Creek Total and Dissolved Zinc, 2008 to 2020

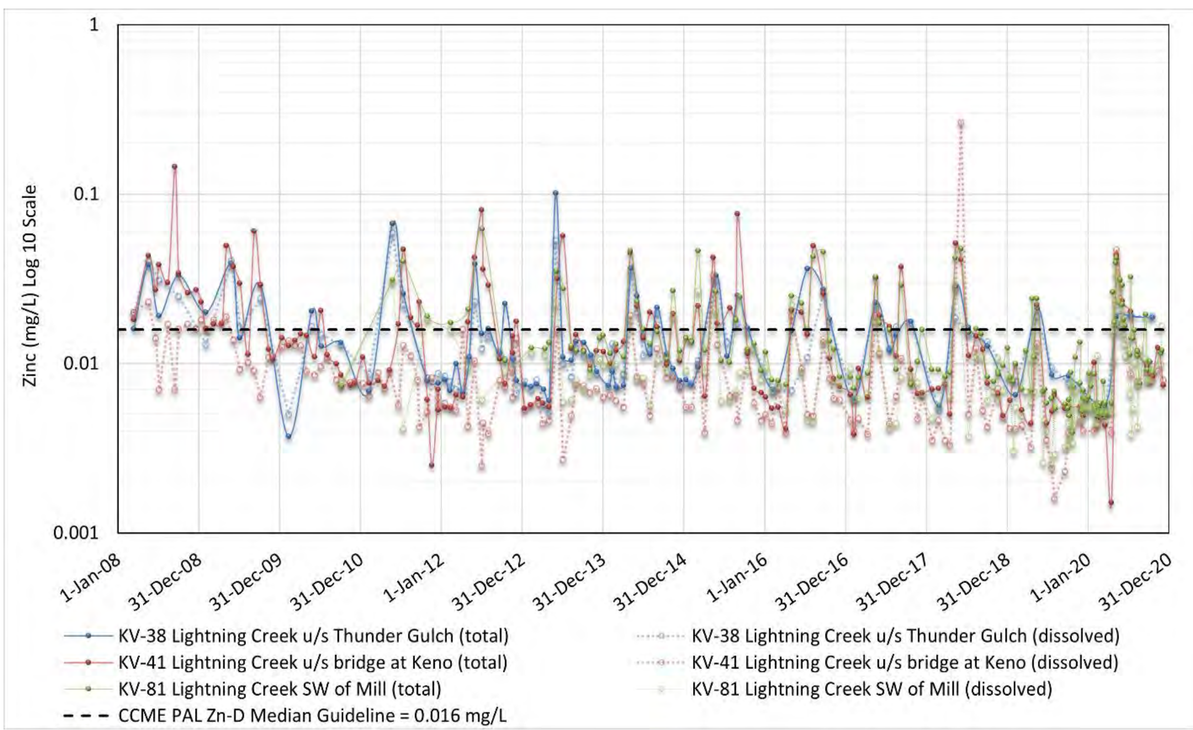


Figure 4-31 Lower Lightning Creek Total and Dissolved Zinc, 2008 to 2020

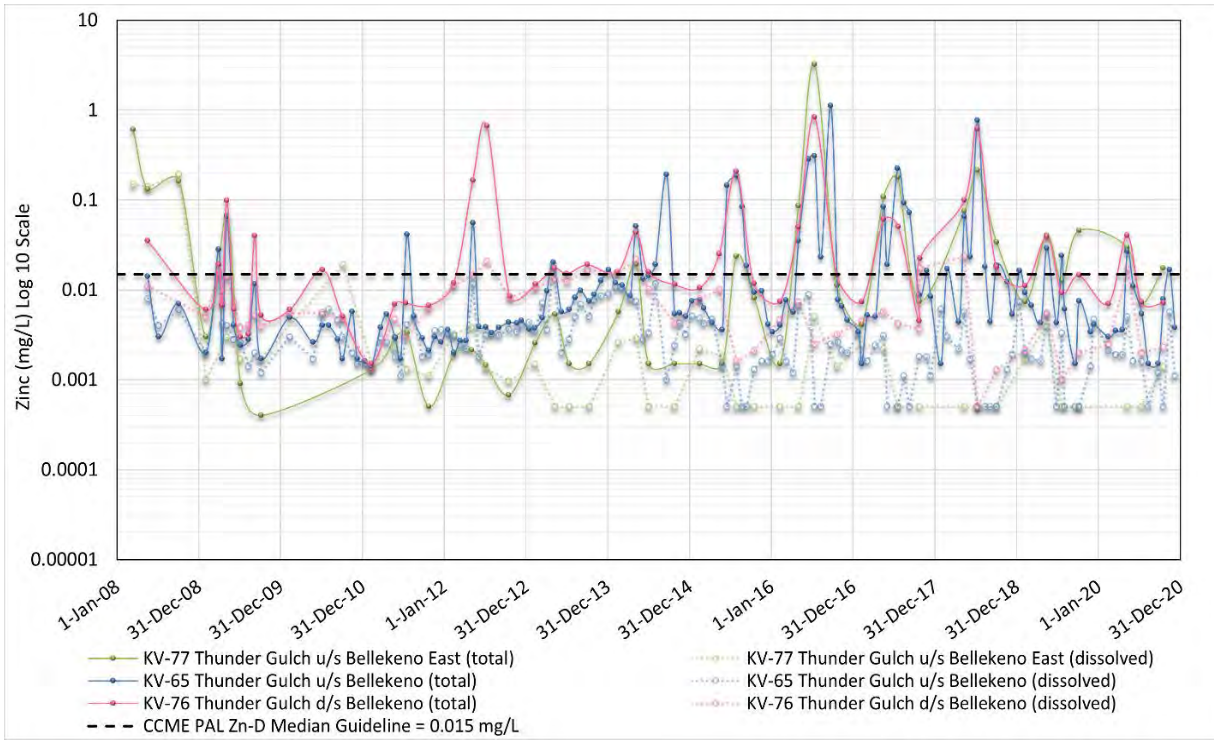


Figure 4-32 Thunder Gulch Total and Dissolved Zinc, 2008 to 2020

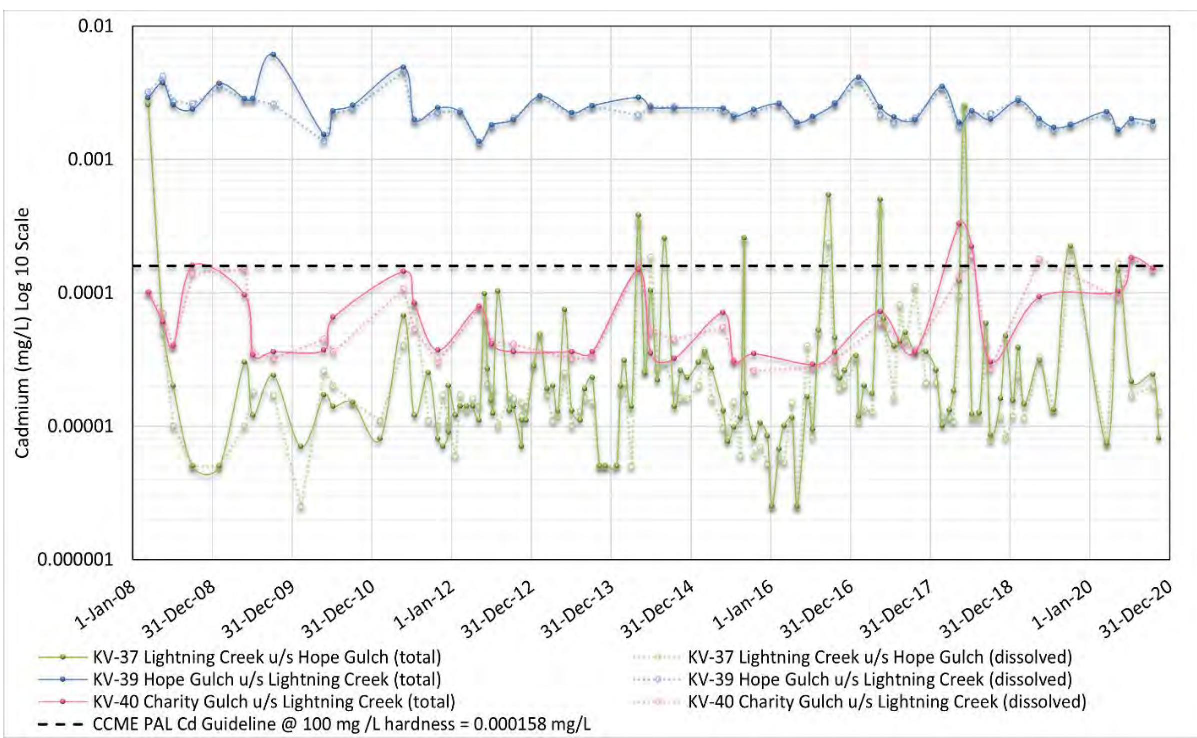


Figure 4-33 Upper Lightning Creek Total and Dissolved Cadmium, 2008 to 2020

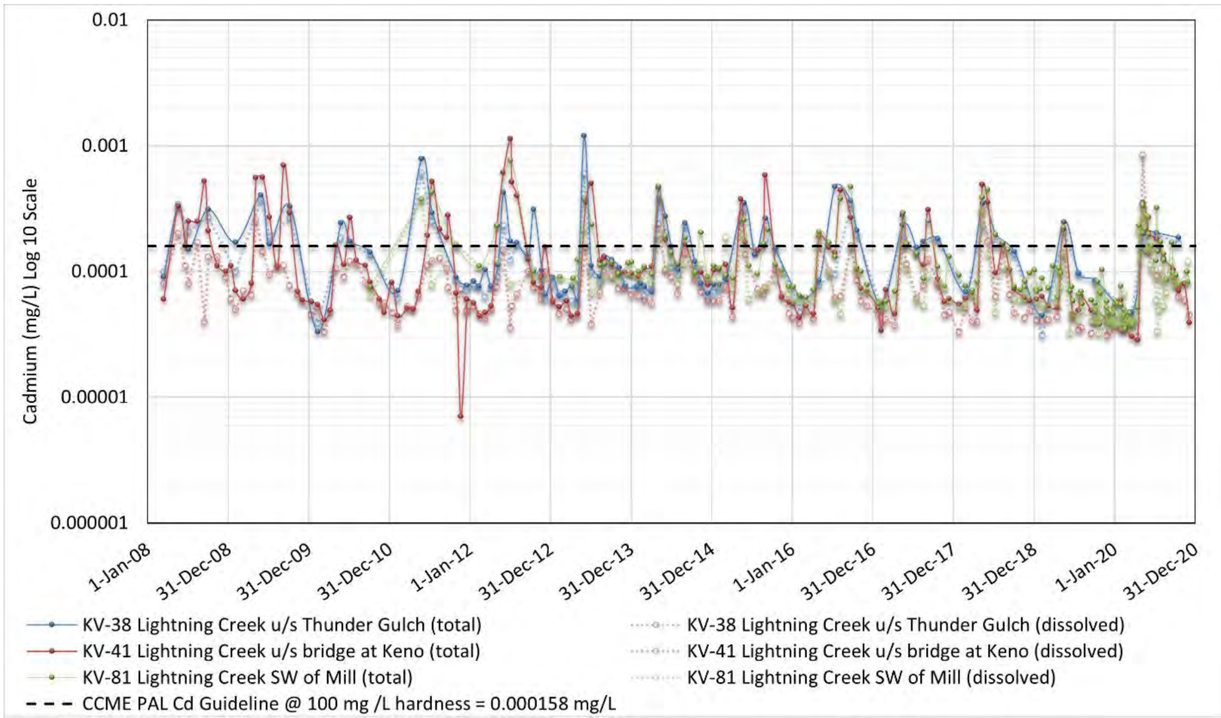


Figure 4-34 Lower Lightning Creek Total and Dissolved Cadmium, 2008 to 2020

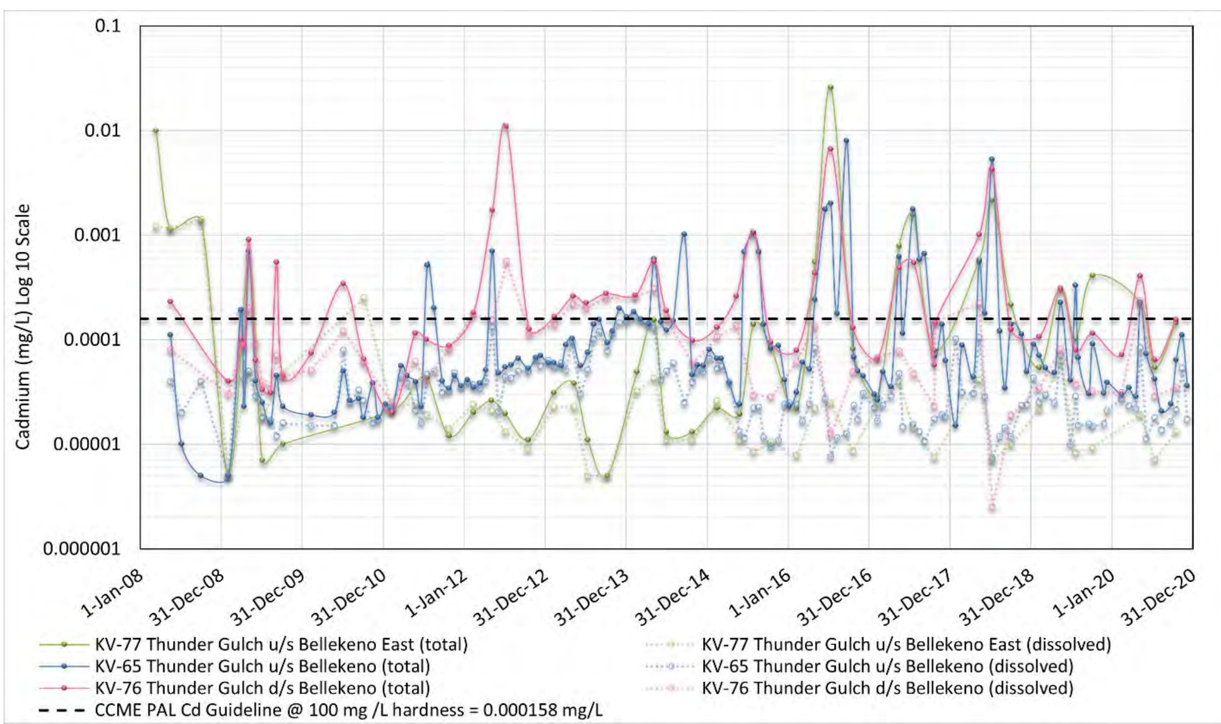


Figure 4-35 Thunder Gulch Total and Dissolved Cadmium, 2008 to 2020

4.2.4 District Mill Site

Construction of the DSTF was initiated in December 2010 during the commissioning of the mill. The District mill pond is located south of Christal Lake, and immediately north of Lightning Creek. The facilities are situated such that discharges will enter the Christal Creek watershed. Up to August 2015, the mill had not produced a discharge to the receiving environment. On August 24, 2015 water was released from the sedimentation pond with decanting discontinued by October 17, 2015 to lower the level within the mill pond. Water was discharged from the pond at about 0.5 L/s over approximately 50 days with a total effluent volume of 2,025 m^3 released in 2015.

Water was again released from the sedimentation pond starting June 26, 2016 with periodic discharges occurring through July to August 20, 2016. During September 10 to 20, 2016 additional water was pumped from the sedimentation pond for a total of 1,675 m^3 released in 2016. No water was released from the district mill pond in 2017. On June 18, 2018 water started being discharged from the sediment pond with periodic discharges occurring in July, August, October, and November 1. Discharge from the District Mill pond to the environment did not occur in 2019 and 2020. Discharge measurements from the mill pond between August 2015 and December 2020 are shown on Figure 4-36.

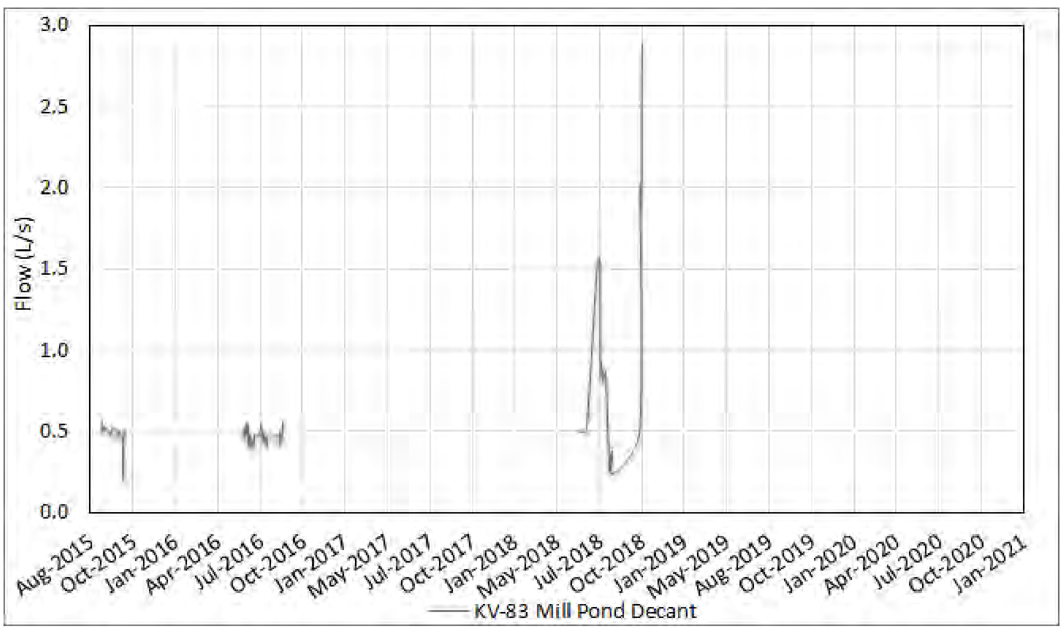


Figure 4-36 Mill Pond Discharge, 2015 to 2020

Mill pond concentrations of ammonia, total zinc, and cadmium in comparison to the EQS for the mill pond decant (KV-83) and the mill pond (KV-82) are shown on Figure 4-37 to Figure 4-39. In November 2020, the District Mill was recommissioned, which included water recycling water in the mill pond causing an increase in concentrations of metals and ammonia. No water was discharged from the mill pond in 2020.

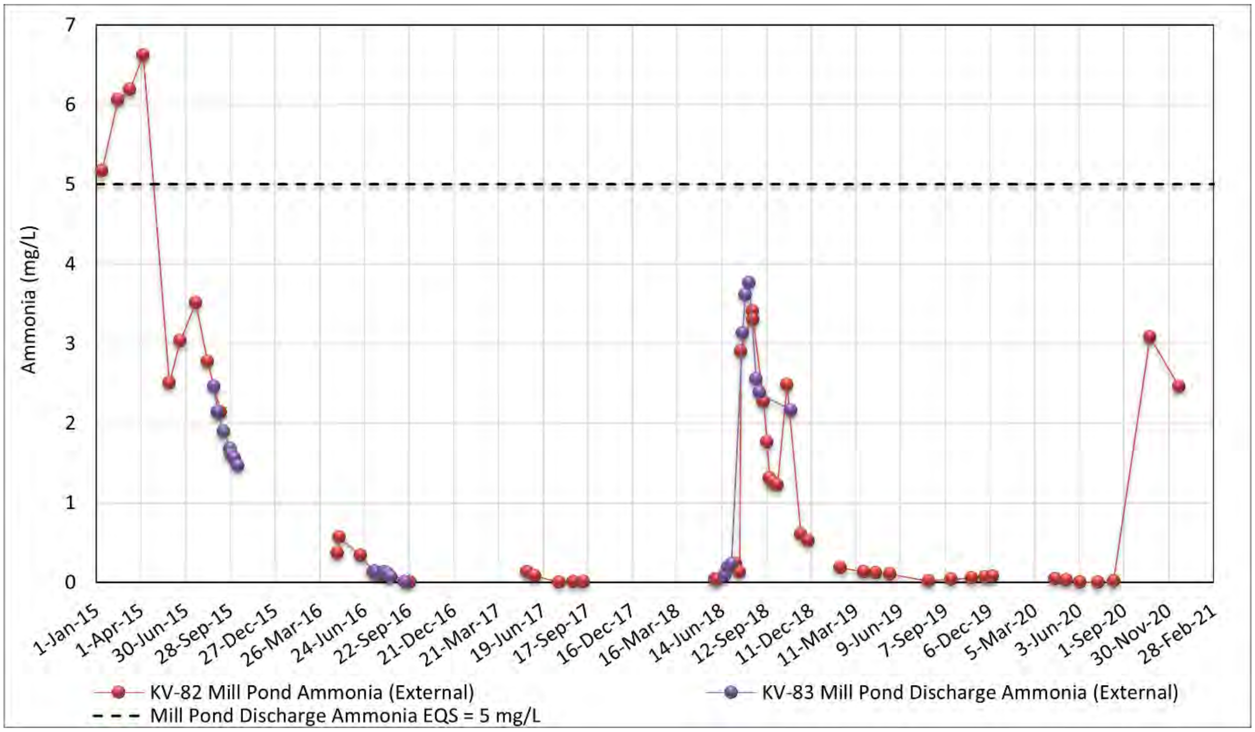


Figure 4-37 Mill Pond Ammonia, 2015 to 2020

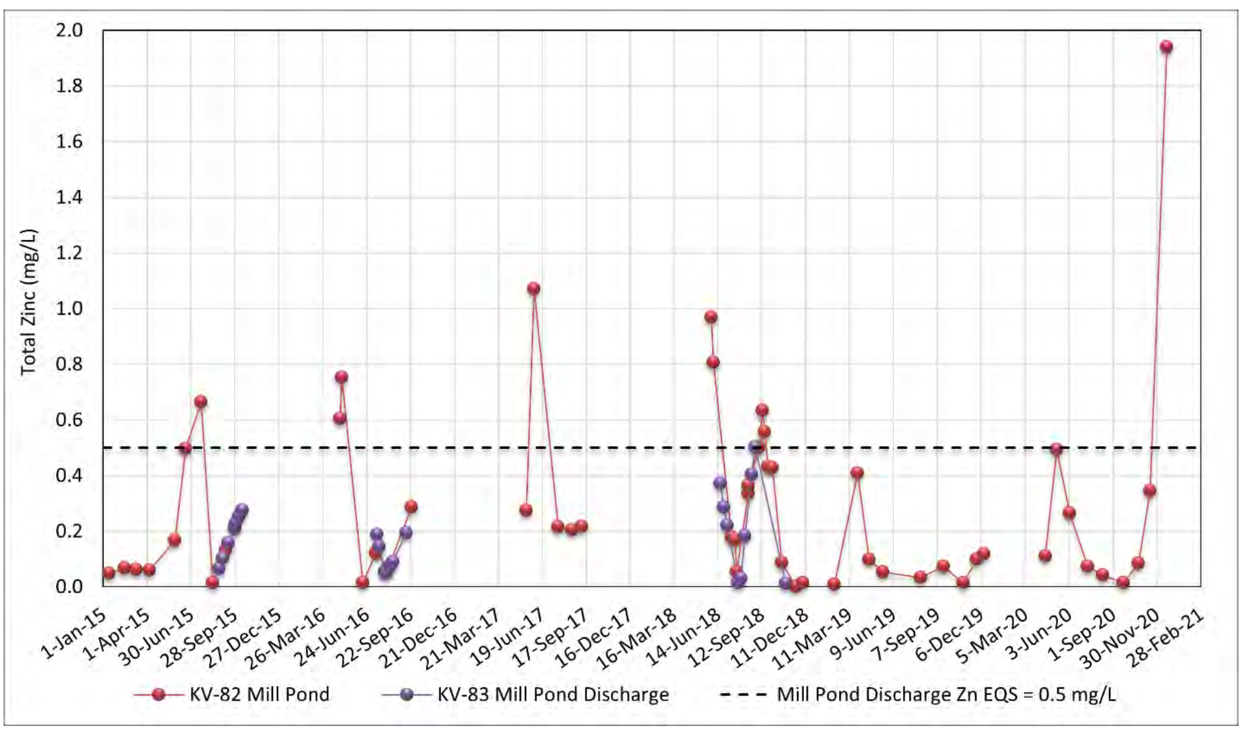


Figure 4-38 Mill Pond Total Zinc, 2015 to 2020

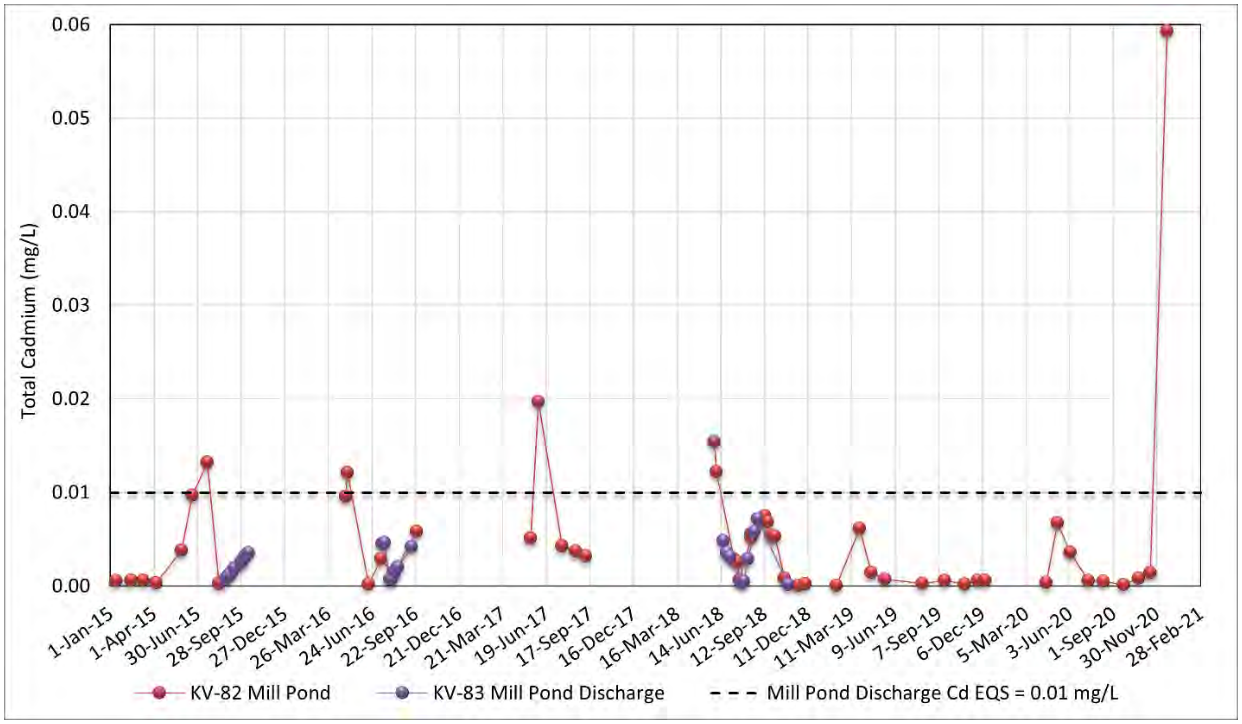


Figure 4-39 Mill Pond Total Cadmium, 2015 to 2020

4.2.5 Bermingham

Mining activities at the Bermingham mine started in Q4 2020. Mine dewatering was required during development activities at the Bermingham mine. The water discharged from the Bermingham mine was treated through the Bermingham WTP and discharged to ground in the upper No Cash Creek catchment.

The dissolved concentrations of constituents of potential interest (COPI) in surface waters sampled from the Bermingham pond decant (KV-114) for 2020 were compared with EQS for the Bermingham WTP. The EQS are defined in the Water Licence (QZ18-044) and those that apply to Bermingham pond decant came into effect on July 23, 2020 (YG, 2020). Although they do not apply to the untreated discharge, the EQS were also compared with data collected from the Bermingham adit discharge (KV-110) to provide a benchmark for comparison.

The licence also limits the effluent discharge rate from the mine to 1,200 m^3/day, or the equivalent of continuous discharge at 13.9 L/s. Flows ranged between 0.22 and 13.9 L/s since July 23, 2020 (average 4.4 L/s).

There were no exceedances of the EQS at KV-114 in 2020 for dissolved cadmium, copper, lead, silver, zinc, and total nickel, (Figure 4-40 to Figure 4-45). Additionally, there were no exceedances of the EQS for radium-226 at KV-114, with all values measured less than the detection limit in 2020. Sixty-four percent of the samples from KV-114 had dissolved arsenic higher than the EQS and coincided with increases in dissolved arsenic concentrations at KV-110 above the EQS and with the increase of field pH to alkaline levels (Figure 4-46). Eight of the 101 samples collected at KV-114 returned a field pH greater than EQS 9.5 and all of these were taken from late October to December 2020 (Figure 4-47). The ammonia-N concentration at KV-114 also increased similarly to KV-110 but marginally surpassed the EQS on one occasion (5.4 mg/L) on December 26, 2020 (Figure 4-48). There were three exceedances of TSS at KV-114 in December 2020, during which KV-110 returned TSS concentrations ranging from 161 to 1,730 mg/L (Figure 4-49).

The following upgrades to the Bermingham WTP will be made in early 2021:

- Installation of a reactor tank upstream of the clarifier to increase treatment residence time;
- Optimization of ferric sulphate addition for arsenic removal, informed by off-site laboratory testing;
- Addition of a multi-media filter to capture suspended solids; and
- Installation of a dedicated ammonia treatment system.

These measures are expected to improve treatment of TSS, arsenic, and ammonia in addition to the other EQS-regulated parameters.

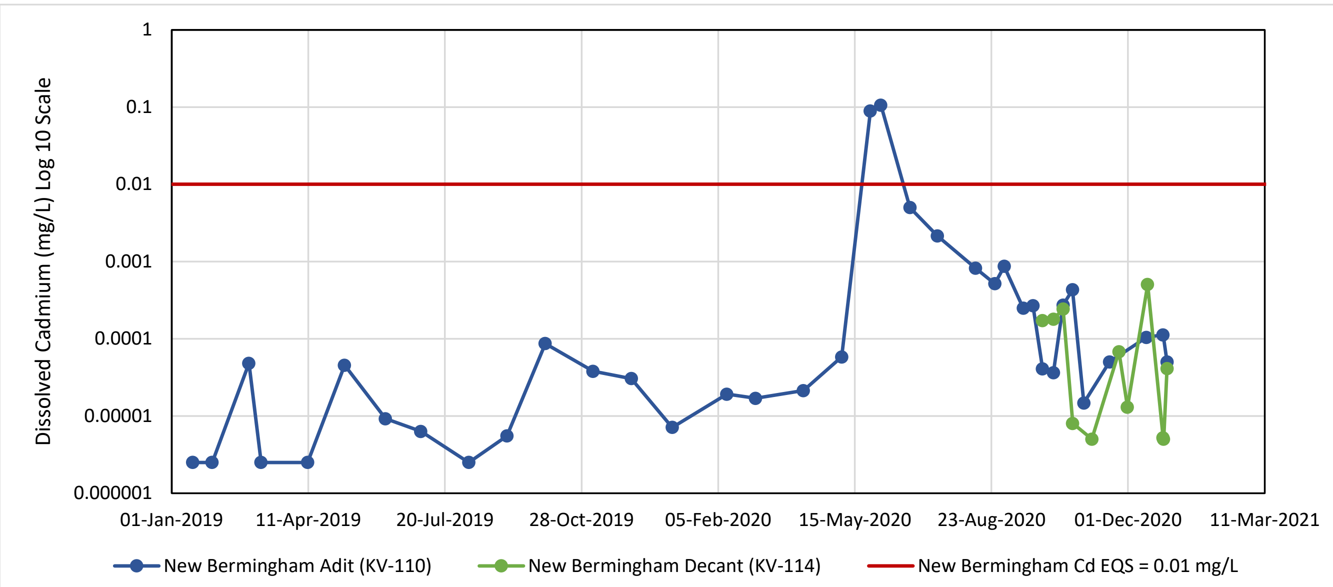


Figure 4-40 Bermingham Dissolved Cadmium, 2019 to 2020

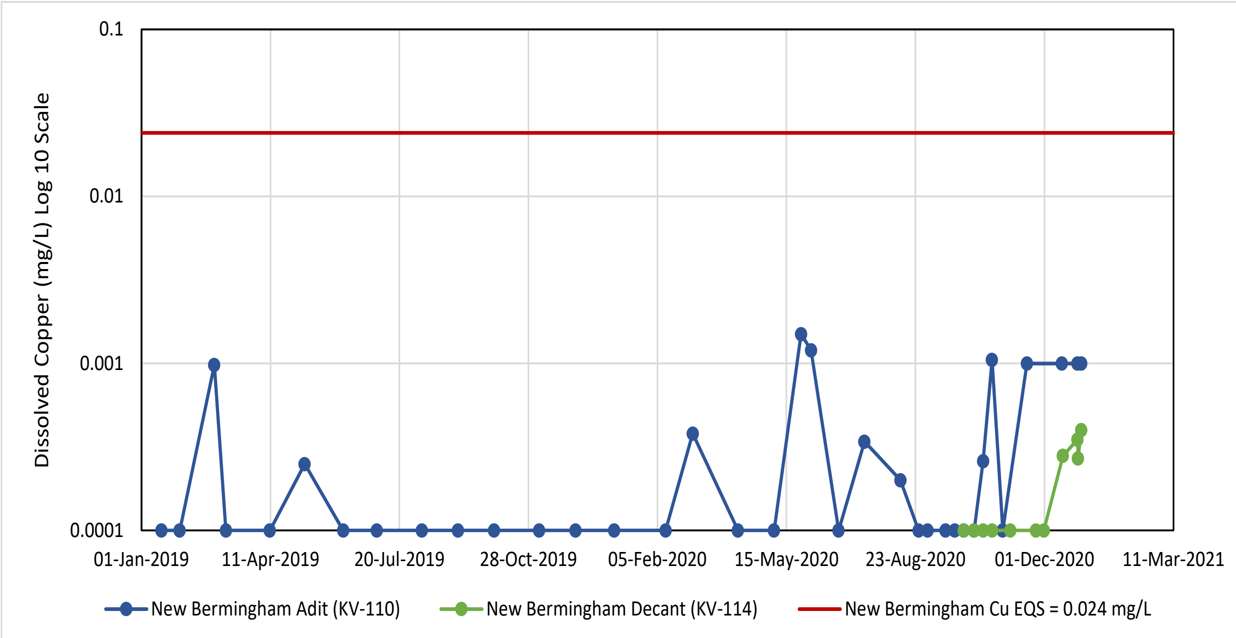


Figure 4-41 Bermingham Dissolved Copper, 2019 to 2020

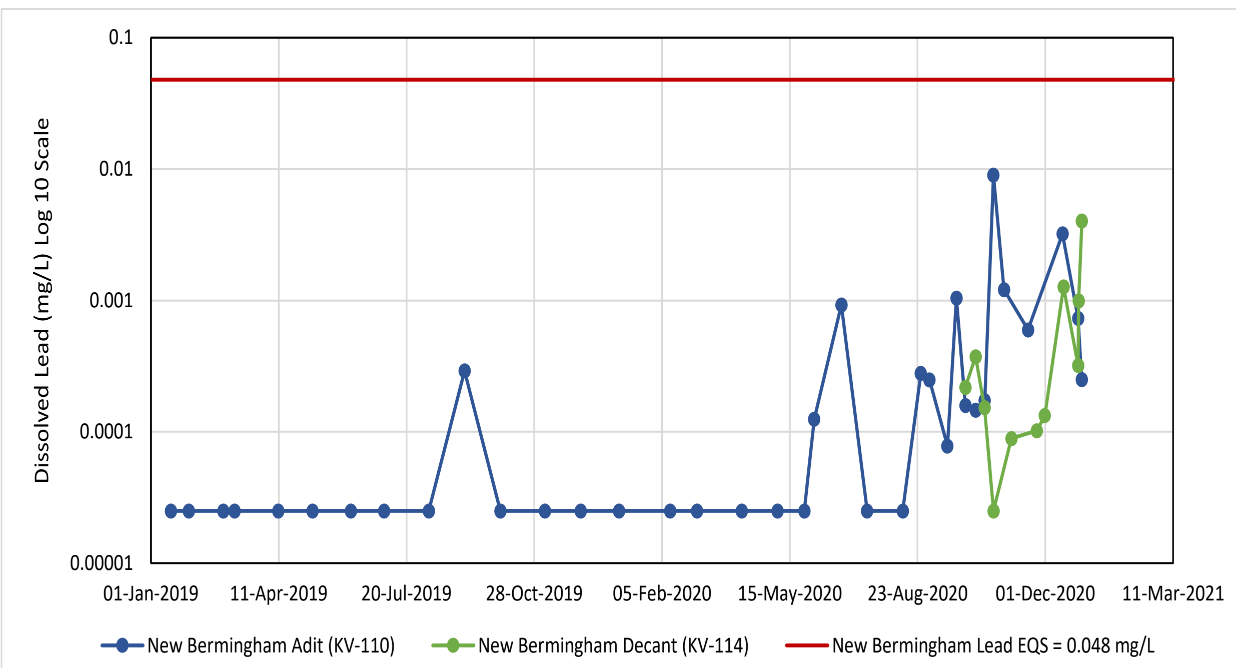


Figure 4-42 Bermingham Dissolved Lead, 2019 to 2020

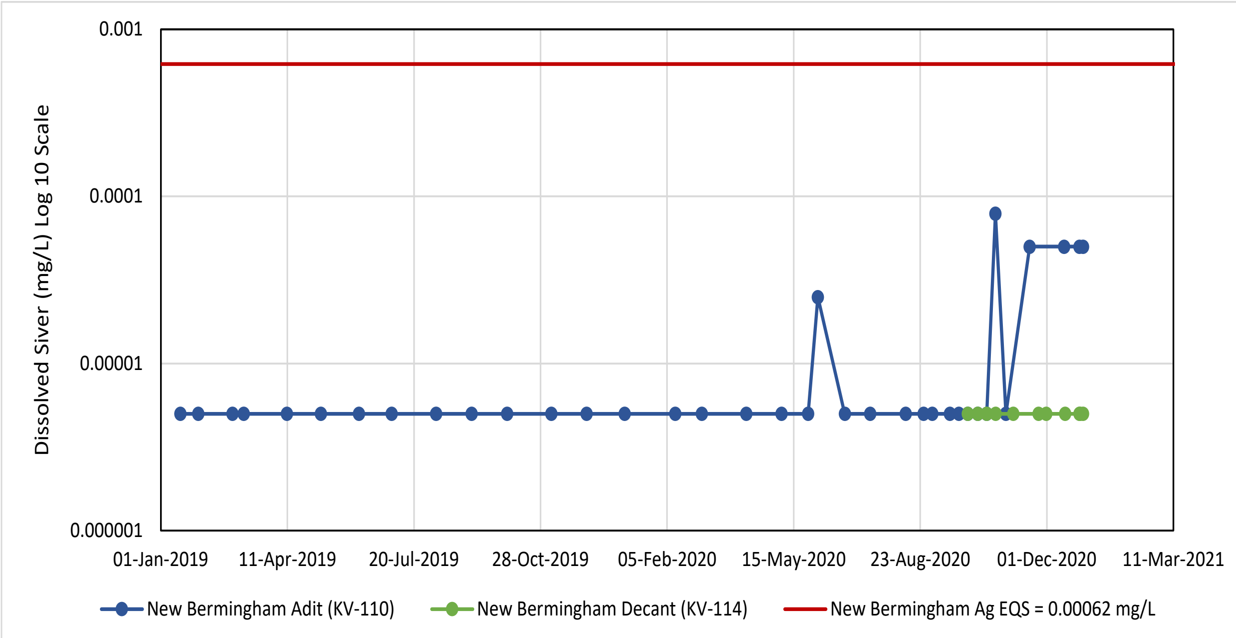


Figure 4-43 Bermingham Dissolved Silver, 2019 to 2020

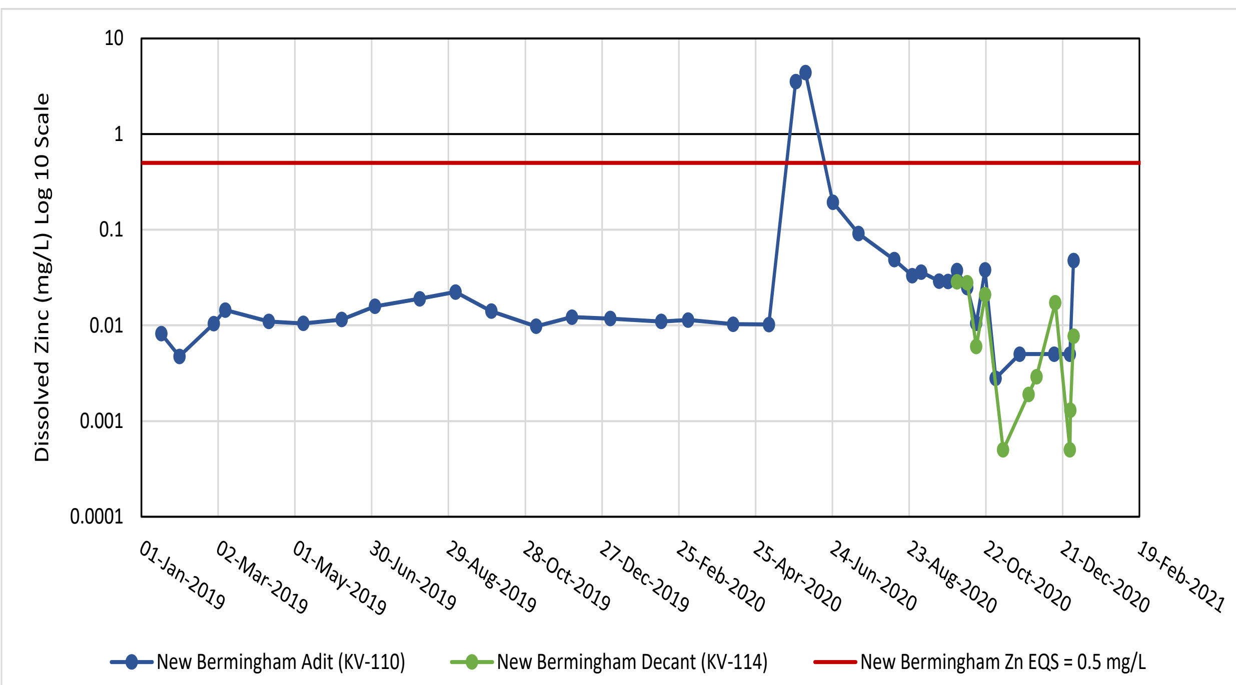


Figure 4-44 Bermingham Dissolved Zinc, 2019 to 2020

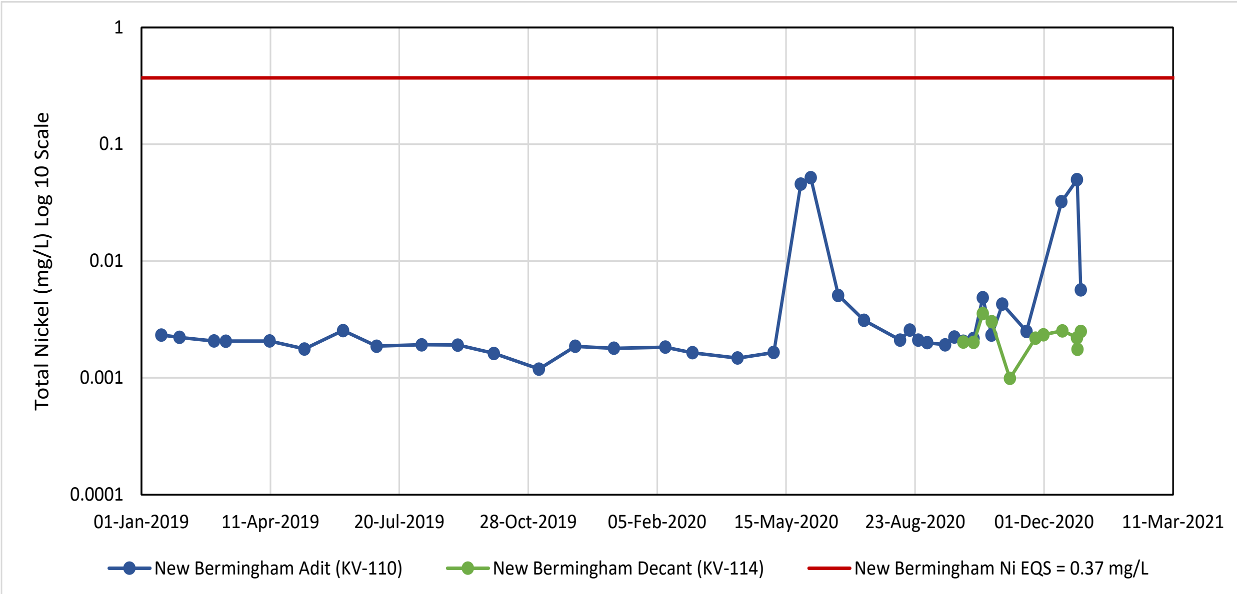


Figure 4-45 Bermingham Total Nickel, 2019 to 2020

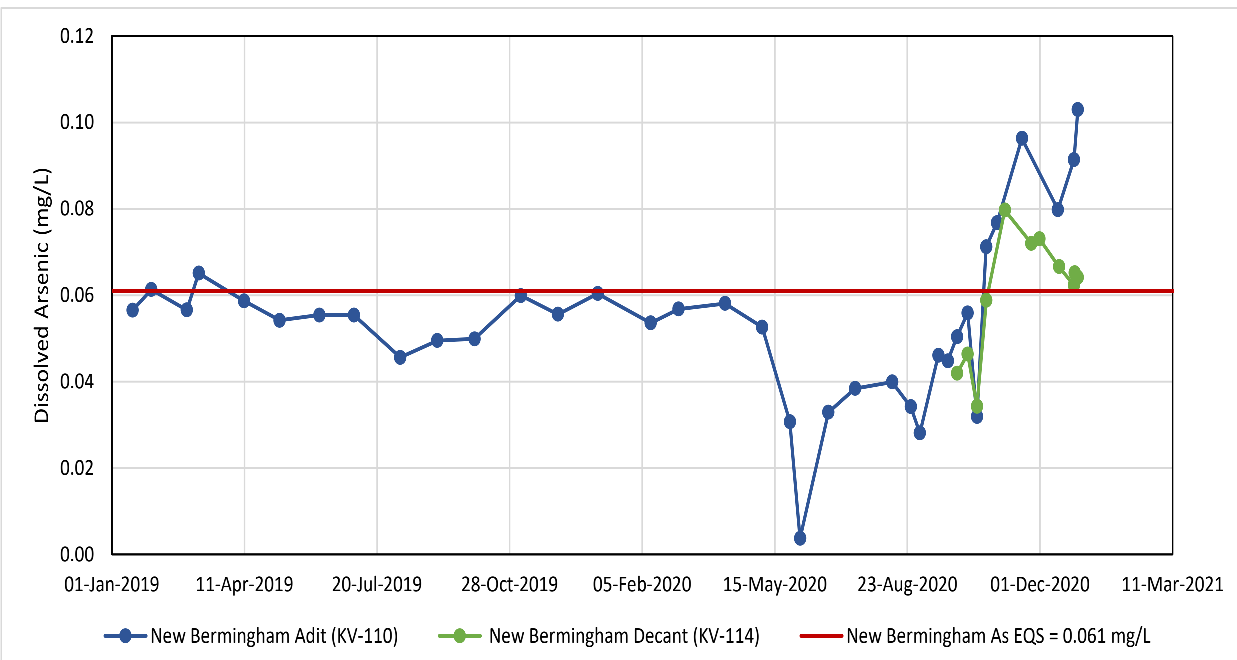


Figure 4-46 Bermingham Dissolved Arsenic, 2019 to 2020

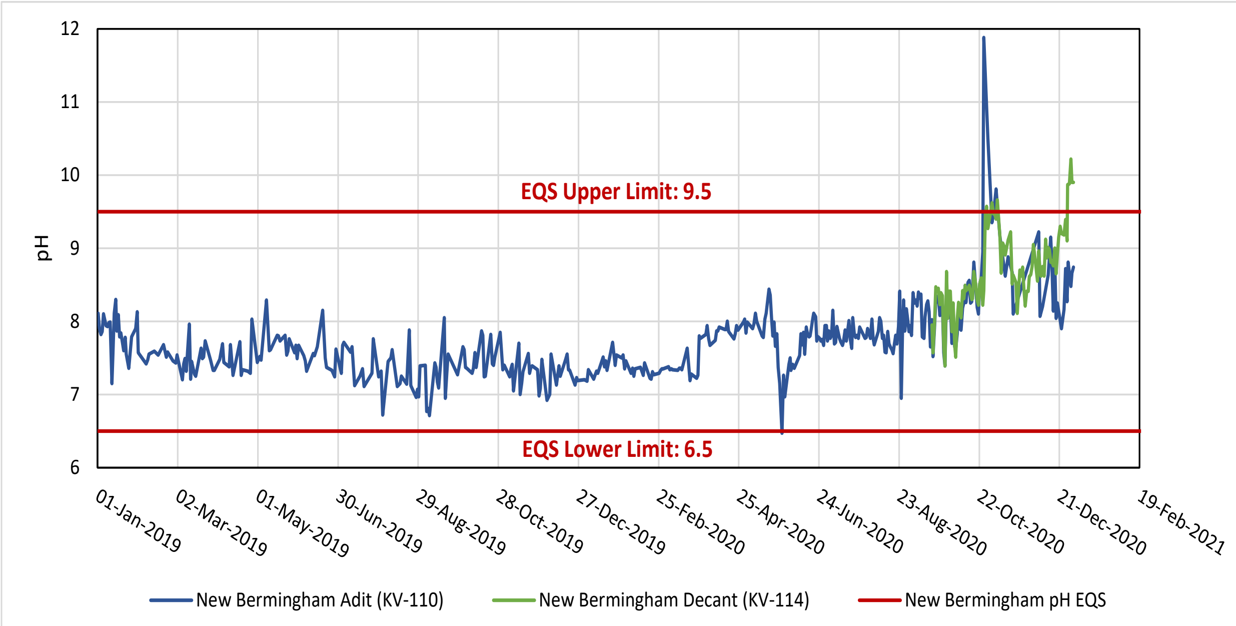


Figure 4-47 Bermingham Field pH, 2019 to 2020

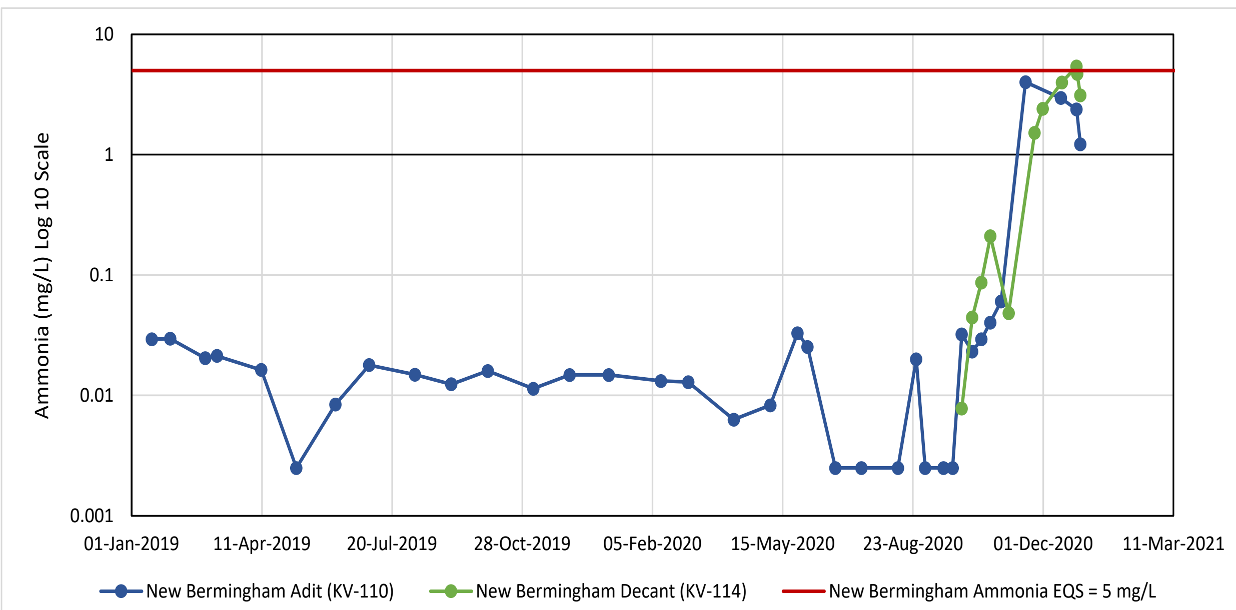


Figure 4-48 Bermingham Ammonia, 2019 to 2020

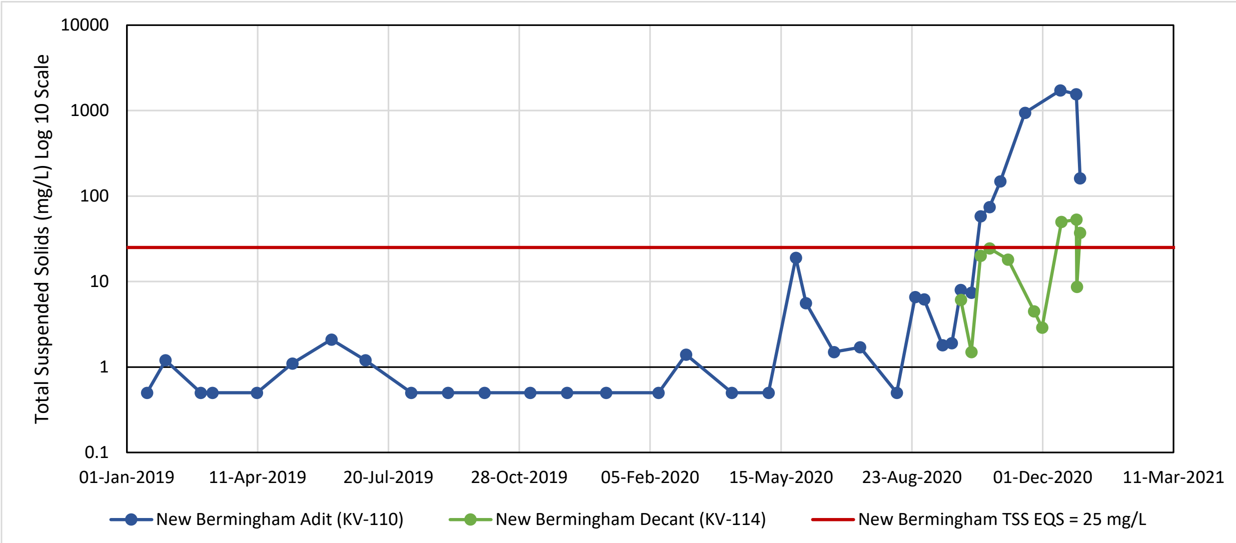


Figure 4-49 Bermingham Total Suspended Solids, 2019 to 2020

4.2.6 No Cash Creek Catchment

No Cash Creek is situated on the northwest slope of Galena Hill and flows down the hillside towards the wetlands northeast of the Valley Tailings Facility. From the headwaters on Galena Hill to dispersion in the bog, the distance is approximately 5.2 km. The No Cash Bog drainage includes the historical adit discharges from the No Cash 500 adit, the Ruby 400 adit, the historic Bermingham 200 adit and AKHM's Bermingham Mine. The No Cash Creek catchment is currently monitored by three water quality monitoring stations located on No Cash Creek; KV-21, KV-111, and KV-118. The water quality of station KV-21 is affected by the discharge from the historical No Cash 500 adit, located approximately 500 m upstream of station KV-21. Stations KV-111 and KV-118 are located upstream of the No Cash 500 adit and largely reflect background water quality. Similar to No Cash Creek, Star Creek (monitored at station KV-56) flows down the hillside towards the wetlands northeast of the Valley Tailings Facility. The flow path runs parallel to and between No Cash and Sandy Creeks. Star Creek originates near the No Cash mine at the 100 level adit (although no flow discharges from the No Cash 100 adit). The dissolved concentrations of COPI in surface waters sampled at KV-21 were compared with the No Cash Creek WQO listed in the AMP (Ensero & AKHM, 2020a). For hardness-, pH-, and temperature-dependent constituents (lead, nickel, and ammonia), the WQO was determined concurrently using these parameters. The WQOs for cadmium, copper, sulphate, and zinc were calculated using the background concentration procedure since existing water quality at KV-21 exceeded generic Canadian water quality guidelines (Ensero & AKHM, 2020a). In these cases, two WQOs are available – a short-term WQO that is compared on a sample-by-sample basis, and a long-term WQO which is compared against the average of the past 12 months of samples. Comparison to the WQOs was performed for samples collected since August 2020, after the Water Licence (QZ18-044) came into effect.

Temporal changes in dissolved cadmium and zinc concentrations between 2015 and 2020 are displayed in Figure 4-50 and Figure 4-51, respectively. Approximately 42% and 50% samples in 2020 exceeded the KV-21 short-term WQO for cadmium (0.0398 mg/L) and zinc (4.26 mg/L), respectively, and occurred between July and December 2020 when cadmium and zinc concentrations were elevated relative to the historical record. Additionally, 80% of dissolved cadmium and 60% of dissolved zinc 12-month moving average concentrations calculated since August 2020 exceeded the long-term WQO. Dissolved cadmium and zinc concentrations were elevated at KV-21 since July 2020. TSS concentrations also increased during this time. The higher TSS and metal concentrations observed at KV-21 are likely due to the greater flows noted in 2020 causing greater infiltration and flushing of the No Cash mine which supplies the bulk of cadmium and zinc to No Cash Creek. Cadmium and zinc concentrations at KV-21 typically peaked in the fall (October or November) with the lowest concentrations observed in late winter. There were no exceedances of the WQO for any other parameters since the Water Licence (QZ18-044) came into effect. Aside from a slight excursion above the short-term WQO for dissolved copper in May 2020 (0.00356 mg/L vs WQO of 0.00352 mg/L), all other parameters with a WQO at KV-21 (ammonia, nitrate, nitrite, sulphate, dissolved arsenic, lead, nickel, selenium, silver, and uranium) were below their respective WQO in 2020.

The dissolved cadmium concentrations in the Bermingham adit discharge (KV-110) were frequently lower than the EQS (0.01 mg/L) in 2020 with only two samples returning cadmium concentration higher than the EQS, which occurred in late May and June 2020 (Figure 4-40). No cadmium concentrations were higher than the EQS in the treated Bermingham Pond Decant (KV-114) where cadmium concentrations were one to three orders of magnitude lower than the EQS. The dissolved cadmium concentrations at KV-110 were orders of magnitude higher than in No Cash Creek above the No Cash 500 adit (KV-111) during early monitoring, became comparable in 2018, then decreased below KV-111 due to a significant decrease of cadmium at KV-110. While dissolved cadmium concentrations were generally lower at KV-110 than KV-111 in 2019 and into 2020, concentrations at KV-110 became several orders of magnitude higher in late May (Figure 4-50). The higher cadmium concentrations at KV-118 compared to the majority of KV-110 and KV-111 samples may suggest an influence from the historical Ruby 400 adit. KV-111 showed a seasonality marked by peak cadmium concentrations during freshet (April-May) followed by a decline and lowest concentration in the summer/fall (August through October).

Dissolved cadmium and zinc results for the No Cash Creek above the No Cash 500 adit (KV-111) for 2017 to 2020 are shown in Figure 4-50 and Figure 4-51, respectively. Dissolved concentrations were compared to the KV-111 WQOs (Ensero & AKHM, 2020a). The 12-month moving average (cadmium and zinc only) was calculated with limited data as KV-111 was only sampled between April and November in 2019 and May and October in 2020. There were no exceedances of the WQOs (for ammonia, nitrate, nitrite, sulphate, dissolved arsenic, cadmium, copper, lead, nickel, selenium, silver, uranium, and zinc) at KV-111 in 2020 or since the Water Licence (QZ18-044) came into effect. Concentrations of zinc and cadmium measured in the six 2020 KV-111 samples were similar to the historical record (Figure 4-50 and Figure 4-51).

The dissolved zinc concentrations at KV-110 and KV-114 were regularly lower than the EQS (0.5 mg/L). In 2020 two samples had dissolved zinc concentration that were above the EQS in the untreated Bermingham adit discharge (KV-110), which occurred in late May and June 2020 (Figure 4-44). Dissolved zinc concentrations at KV-110 declined more than two orders of magnitude from 0.6 mg/L in January 2018 to between 0.005 and 0.02 mg/L between late 2018 and April 2020. Dissolved zinc then increased sharply to 4.4 mg/L in June 2020 at KV-110, then sharply decreased to concentrations almost two orders of magnitude lower than the EQS over the remainder of 2020. The dissolved zinc concentrations at KV-118 were typically higher than at KV-110 for the same period (July 2018 onward) indicating an additional source of zinc, likely from the Ruby 400 adit (Figure 4-51). Dissolved zinc concentrations at KV-111 were generally lower or comparable to KV-110 between 2019 and 2020.

Total cadmium and zinc results for Star Creek (KV-56) for 2015 to 2020 are shown in Figure 4-52 and Figure 4-53, respectively; total concentrations are plotted since the KV-56 WQO apply to the total fraction (Ensero & AKHM, 2020a). The 12-month moving average (cadmium and zinc only) was calculated with limited data as KV-56 was only sampled between May and October in 2019 and 2020. There were no exceedances of the WQOs (for ammonia, nitrate, nitrite, sulphate, total arsenic, cadmium, lead, nickel, selenium, silver, uranium, and zinc) at KV-56 in 2020 or since the Water Licence (QZ18-044) came into effect, except for one marginal exceedance of total copper in August 2020. Concentrations of zinc and cadmium measured in the six 2020 Star Creek samples were similar to the historical record (Figure 4-52 and Figure 4-53).

No Cash Creek catchment concentrations of total zinc and cadmium in comparison to the WQO for the No Cash Creek catchment are shown on Figure 4-50 through Figure 4-51. Concentrations measured at the detection limited are plotted as half the value of the detection limit.

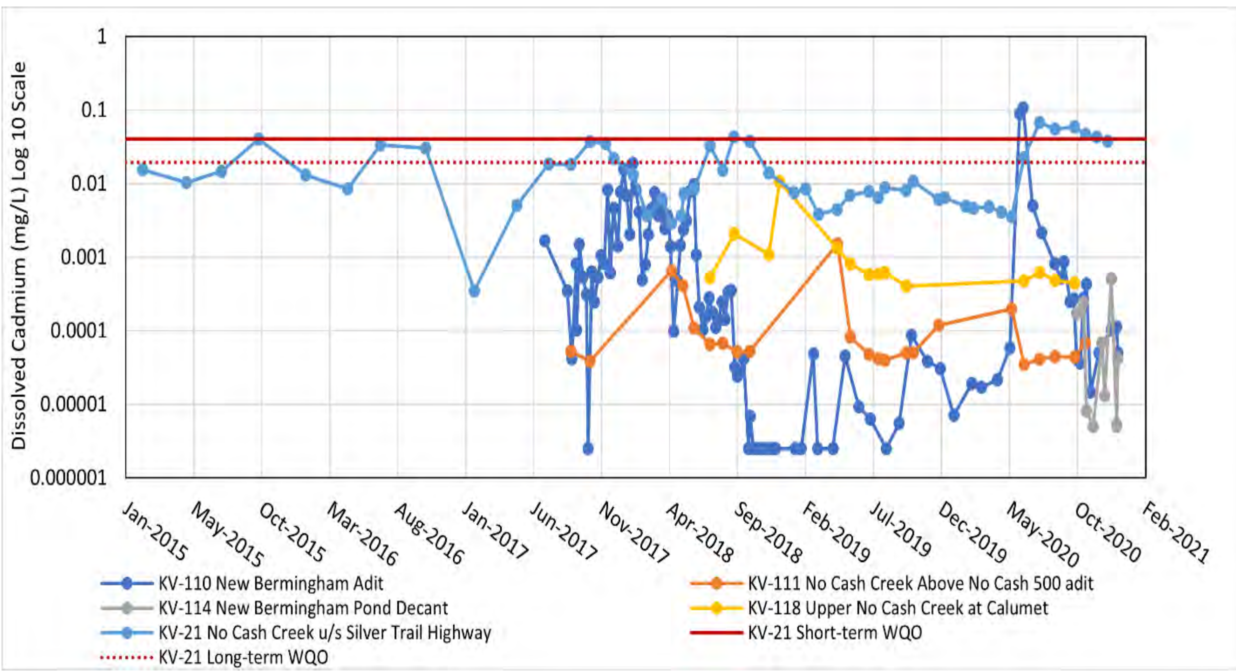


Figure 4-50 No Cash Creek Dissolved Cadmium, 2015 to 2020

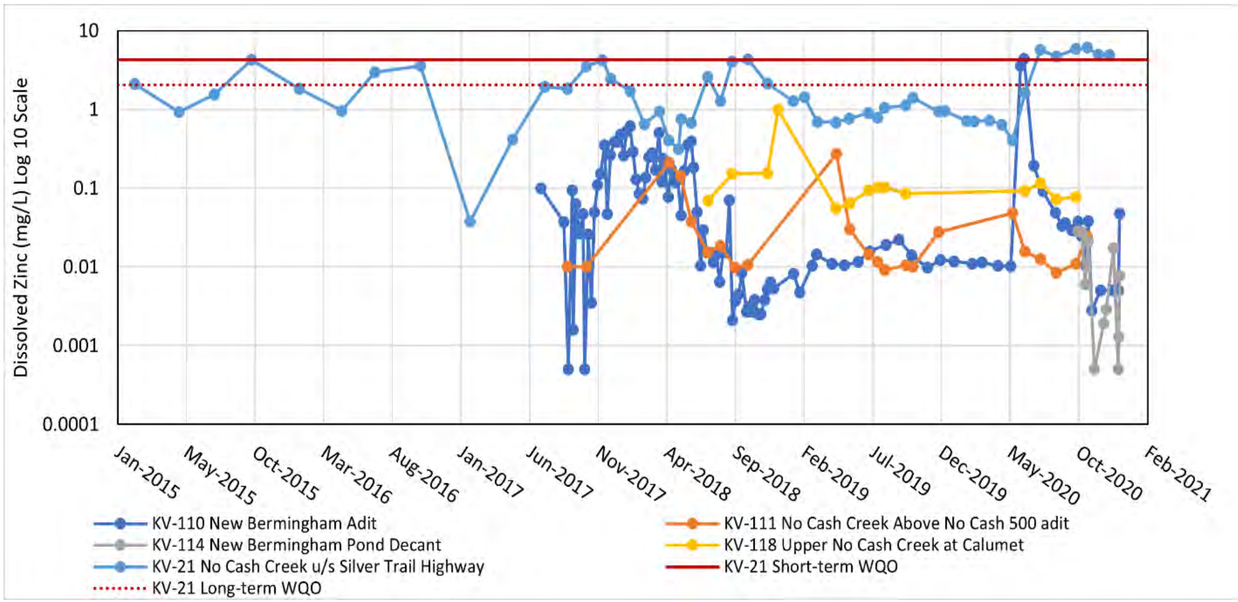


Figure 4-51 No Cash Creek Dissolved Zinc, 2015 to 2020

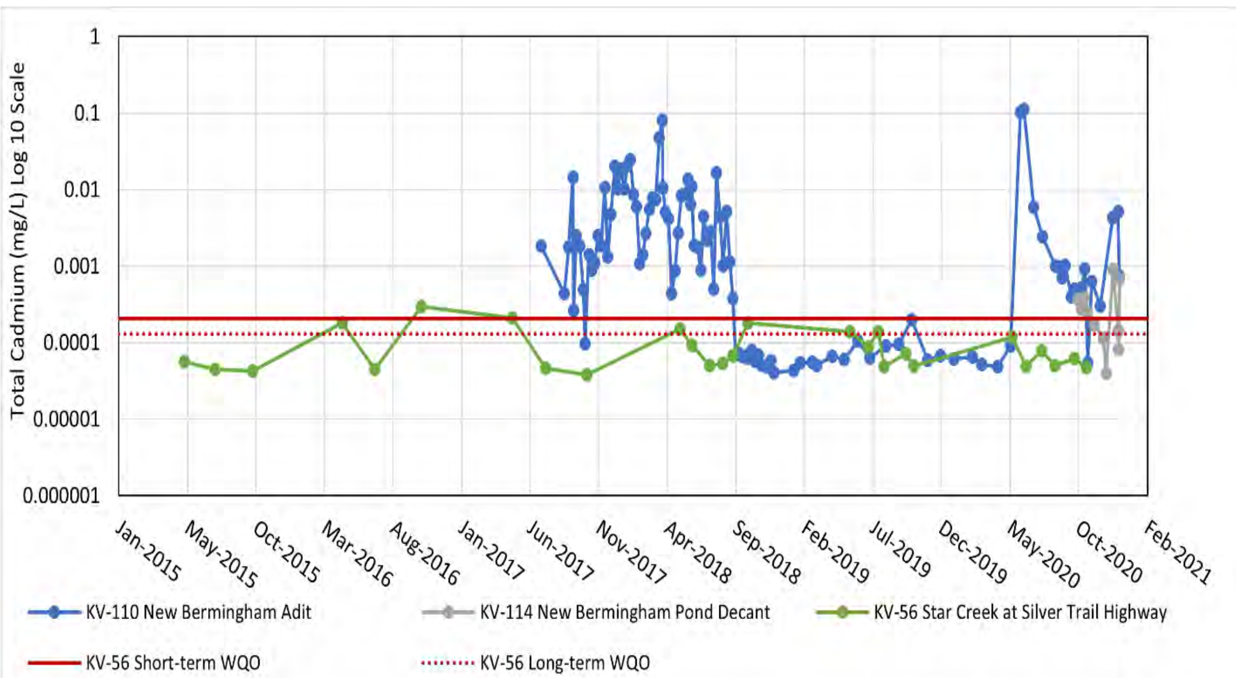


Figure 4-52 Star Creek Total Cadmium, 2015 to 2020

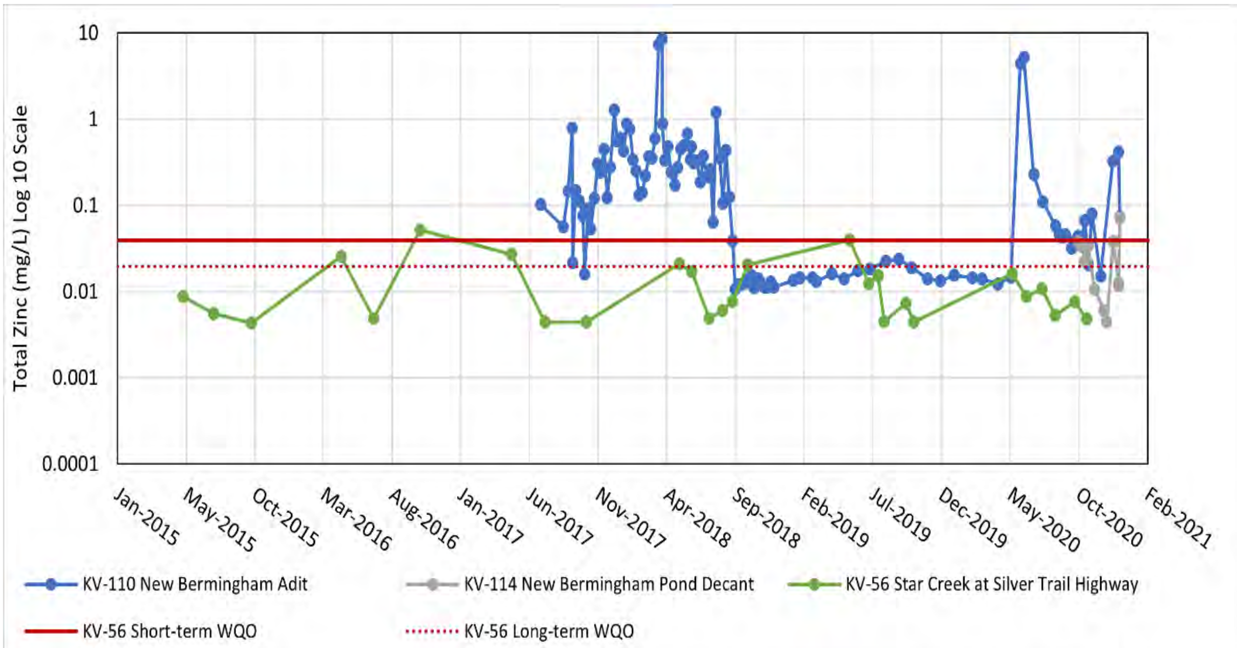


Figure 4-53 Star Creek Total Zinc, 2015 to 2020

4.3 GROUNDWATER

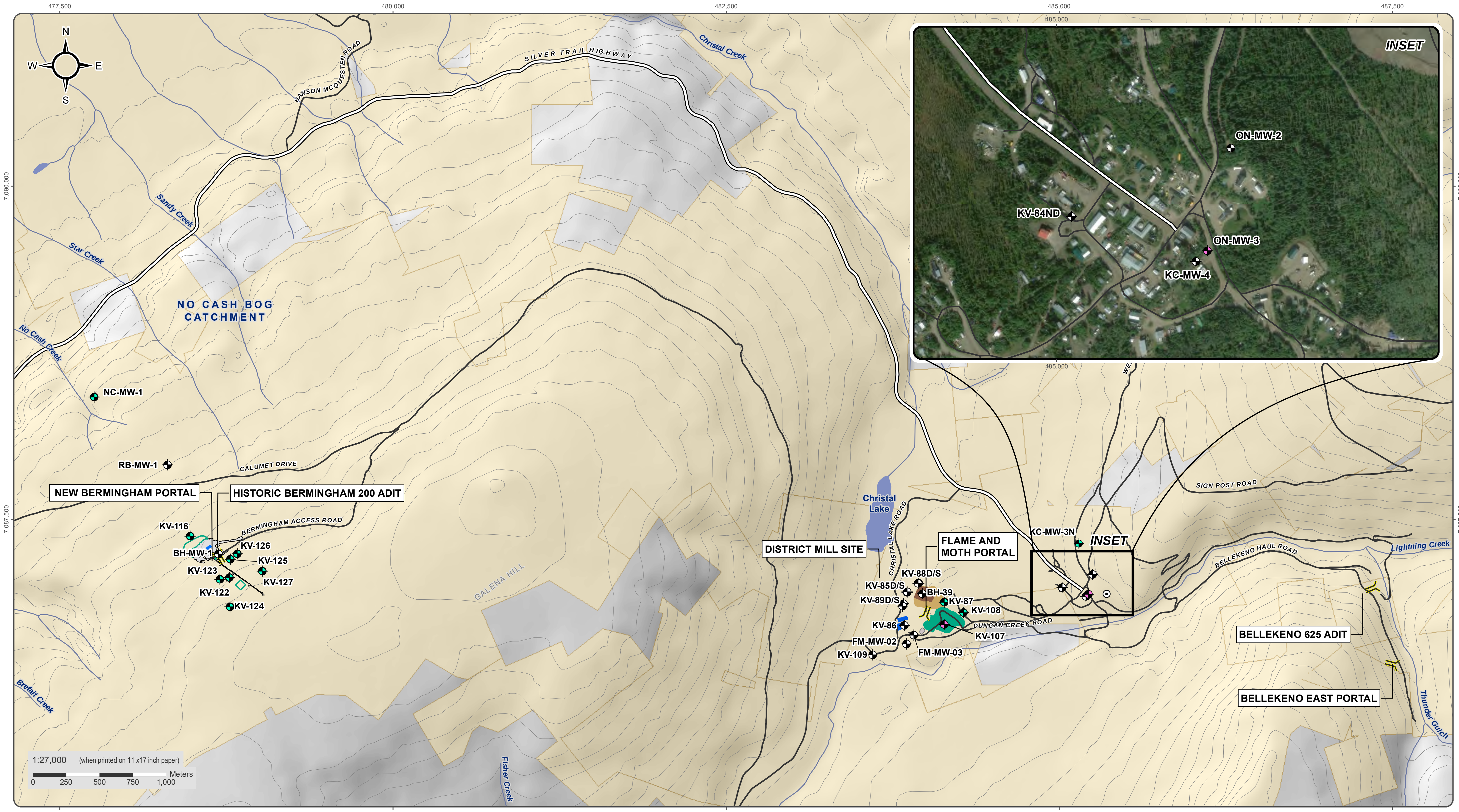
Groundwater monitoring is a critical component of the water-resource management program at the KHSD. The hydrologic connections between groundwater and surface water mandate that the monitoring program for all water resources be closely linked. By acknowledging this close hydrologic connection, groundwater monitoring can provide critical support to the surface monitoring program.

Groundwater quality monitoring is an integrated activity for obtaining and evaluating information on the physical, chemical, and biological characteristics of groundwater in relation to human health, a designated groundwater and surface water uses and receiving environment. In the case of the KHSD mining operations, this relates to the condition of groundwater within the No Cash Creek, Christal Creek and Lightning Creek watersheds, and the potential impacts to Keno City groundwater from activities relating to the Project. With accurate information, the current state of the project's groundwater resources can be assessed; water-resource protection, preservation, and abatement programs can be run more effectively; and trends in groundwater quality and the success of the management programs can be evaluated.

The full groundwater sampling program commenced during freshet 2011 after thaw of all groundwater wells installed in October 2010. Cold weather and frozen ground conditions makes the program challenging during winter. The groundwater monitoring program is detailed in Schedule B, QZ18-044, and the monitoring sites are shown in Figure 4-54, along with other wells in the area that are public or part of district closure studies underway. Keno City monitoring well KV-84 was removed from WL QZ18-044 in favor of KV-84ND, as it was not in an ideal location relative to Onek 400 mine and the Firehall well. In 2018, groundwater monitoring well KV-109 was installed near Lightning Creek as a requirement of the Water Licence for monitoring Flame & Moth.

A drilling program in late fall of 2020 replaced KC-MW-3 and KV-87 with new wells (called KC-MW-3-N and KV-87N, respectively) and a new well KV-108 was installed in the District Mill area upgradient of the phase 2 DSTF expansion area. In addition, seven new wells were installed in the vicinity of the Bermingham portal/historic Bermingham adit (KV-116, KV-122 through KV-127); one new well was installed at No Cash Creek (NC-MW-1) (Figure 4-54).

The results of the groundwater monitoring program are discussed below.



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

- Proposed Monitoring Well
- Monitoring Well
- Newly Installed Groundwater Monitoring Well
- Adit
- Infrastructure Footprint
- Pond
- DSTF 322k Tonnes Design
- Current DSTF
- To Be Constructed Mine Features
- Alexco/ERDC Quartz Claims
- Silver Trail Highway
- Other Road

AKHM

ALEXCO KENO HILL MINING CORP.
WATER LICENSE QZ18-044

FIGURE 4-54

KHSD GROUNDWATER MONITORING LOCATIONS

MARCH 2021

D:\Project\AllProjects\Keno_Area_Mines\ALL-SITES\02-Map\01_Overview\04-WQ\GW\District\GW_monitoring_locations_District_AMP_20210218.mxd
(Last edited by: amatlashevska;2021-03-17/09:17 AM)

4.3.1 Mill Area Groundwater Quality

The District Mill monitoring wells have been installed to collect baseline information on groundwater conditions, as well as information on the potential impacts of ancillary activities, construction and impacts from the DSTF. Precautions have been taken in the design and construction of the DSTF to prevent porewater seepage to groundwater by providing an impermeable basal layer to allow capture of any potential DSTF seepage and directing it to the mill pond.

Wells were installed at the District Mill site in October 2010 to monitor groundwater in Keno City and the District Mill/DSTF area. Shallow wells were installed into overburden and deep wells into the bedrock aquifer. Operation of the mill and placement of the first lift of tailings began on November 17, 2010.

As shown in Figure 4-54:

- Nested shallow and deep wells were installed down-gradient of the DSTF at KV-85 and KV-88;
- Nested shallow and deep wells were installed down-gradient of the mill at KV-89;
- A well was installed in overburden cross-gradient of the mill ore stockpiles at KV-86;
- KV-87 was installed in the bedrock up-gradient of the DSTF but cross-gradient from KV-86. A replacement well for KV-87 (labelled KV-87N) was drilled in November of 2020 near the location of the original well KV-87, and this well was sampled for the first time in December of 2020;
- KV-84 was installed north of the Fire Hall well in Keno City; in late 2013 KV-84ND was drilled to replace KV-84. KV-84ND is in a better location relative to the city supply Firehall well and has been replaced by KV-84 in WL QZ09-092 Amendment 2;
- Monitoring well ON-MW-2 (located between Onek 400 adit and Keno City, and upgradient of Christal Lake) and Lucky Queen Monitoring Well LQ-MW-1 were established in August of 2012; and
- A new well, KV-108, was installed in November of 2020 upgradient of the phase 2 DSTF expansion area.

Water Licence QZ18-044 Clauses 82 and 83 requires a comparison of groundwater quality with *Yukon Contaminated Sites Regulation* Schedule 3: Generic Numerical Water Standards (Aquatic Life) (YCSR-AL) and wells near Keno City are also to be compared with YCSR Drinking Water Standards (YCSR-DW). The groundwater monitoring plan was updated in October 2020.

Deviations to the Keno Hill Silver District Mill groundwater sampling program are as follows:

- KV-88S continues to be monitored quarterly however, only one sample was collected from it in June 2012 which was noted to be muddy;
- KV-85D monitoring well is not operational and no samples have been collected since June 2013;
- KC-MW-4 has not been sampled since May 2014 due to structural issues inhibiting sampling;
- KV-89D has not been sampled since 2017 due to structural issues inhibiting sampling;

- KV-87 has become compromised and was replaced; replacement well KV-87N was sampled for the first time in December of 2020;
- LQ-MW-1 has been sampled nine times since 2012 with the last sample collected in October 2018 as the well has been dry since; and
- Well FM-MW-01 was destroyed in 2020 with the advancement of the Flame and Moth Decline. Therefore, monthly water levels will be recorded at the adjacent mill well (KV-103) in its place.

The following sections provide graphical presentation and discussion of water quality analytical results of samples collected from the groundwater monitoring wells at the District Mill site, Keno City (KV-84ND and ON-MW-2) and Lightning Creek monitoring well KV-109. District Mill groundwater quality data are compared against the monitoring results collected in 2011 as these results largely represent background conditions in the District Mill area.

4.3.1.1 Arsenic

KV-88D, ON-MW-2, KV-85D, and KV-109 were consistently above YCSR-AL and YCSR-DW standards for arsenic (0.05 mg/L and 0.025 mg/L, respectively (see Figure 4-55). KV-88D and ON-MW-2 consistently exhibited the highest arsenic concentrations out of the District monitoring wells with median concentrations of 0.85 mg/L and 0.23 mg/L, respectively. The remaining monitoring wells had arsenic concentrations below the YCSR-AL standard, except for two excursions slightly above this standard at KV-87. Monitoring wells KV-84ND, KV-85S, KV-86, and KV-89S arsenic results were up to two orders of magnitude below the YCSR-DW standard except for four excursions above the standard at KV-89S prior to 2014.

KV-85S and KV-86 consistently exhibited the lowest arsenic concentrations with median concentrations of 0.00072 mg/L and 0.00056 mg/L, respectively. Monitoring wells KV-85D, KV-88D, and KV-89S exhibited marked variability in arsenic concentration values, while the arsenic concentration at KV-84ND, KV-86, and KV-89D have remained fairly stable.

The one measured arsenic concentration for the new well KV-108 from the December 2020 sampling event was 0.00002 mg/L, well below both YCSR-AL and YCSR-DW standards. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for arsenic.

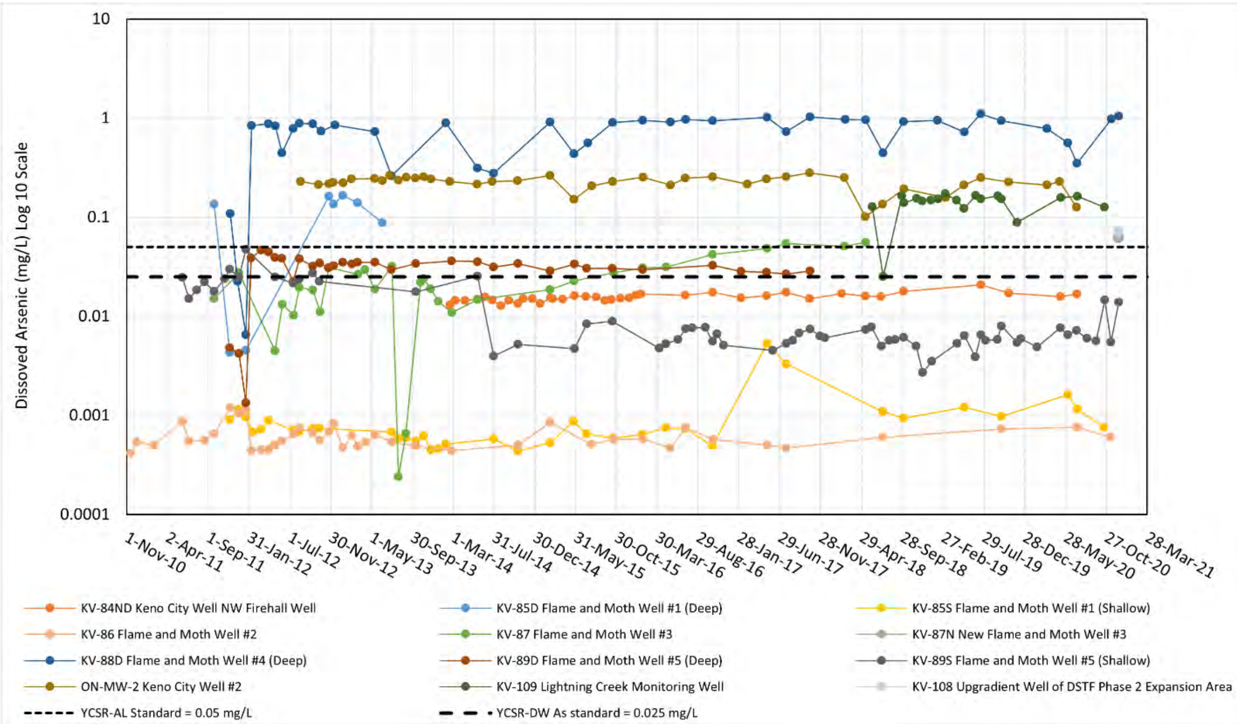


Figure 4-55 District Mill and Keno City Groundwater Monitoring, Dissolved Arsenic

4.3.1.2 Cadmium

Monitoring well KV-89S was consistently above YCSR-AL and YCSR-DW standards for cadmium (0.0006 mg/L [hardness ≥ 150 mg/L] and 0.005 mg/L, respectively (see Figure 4-56). KV-89S exhibited the highest concentration for cadmium of the District monitoring wells at a median concentration of 0.0093 mg/L.

The remaining monitoring wells had cadmium results below the YCSR-AL standard, except for three excursions above this standard by KV-88D in 2012. KV-86 was predominantly below the YCSR-DW standard for cadmium but had several excursions above the guideline (0.005 mg/L), with a median cadmium concentration of 0.00034 mg/L. The remaining monitoring wells in the District exhibited fairly consistent results below the YCSR-DW standard, except for occasional excursions above 0.005 mg/L by KV-85S, KV-87, and KV-89D with median concentrations of 0.000066 mg/L, 0.00001 mg/L, and 0.000053 mg/L, respectively.

All monitoring wells in the District exhibited marked variability in cadmium concentration values, during the monitoring period. The one measured concentration of cadmium for new well KV-108 from the December 2020 sampling event was 0.00002 mg/L, well below both YCSR-AL and YCSR-DW standards. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for cadmium.

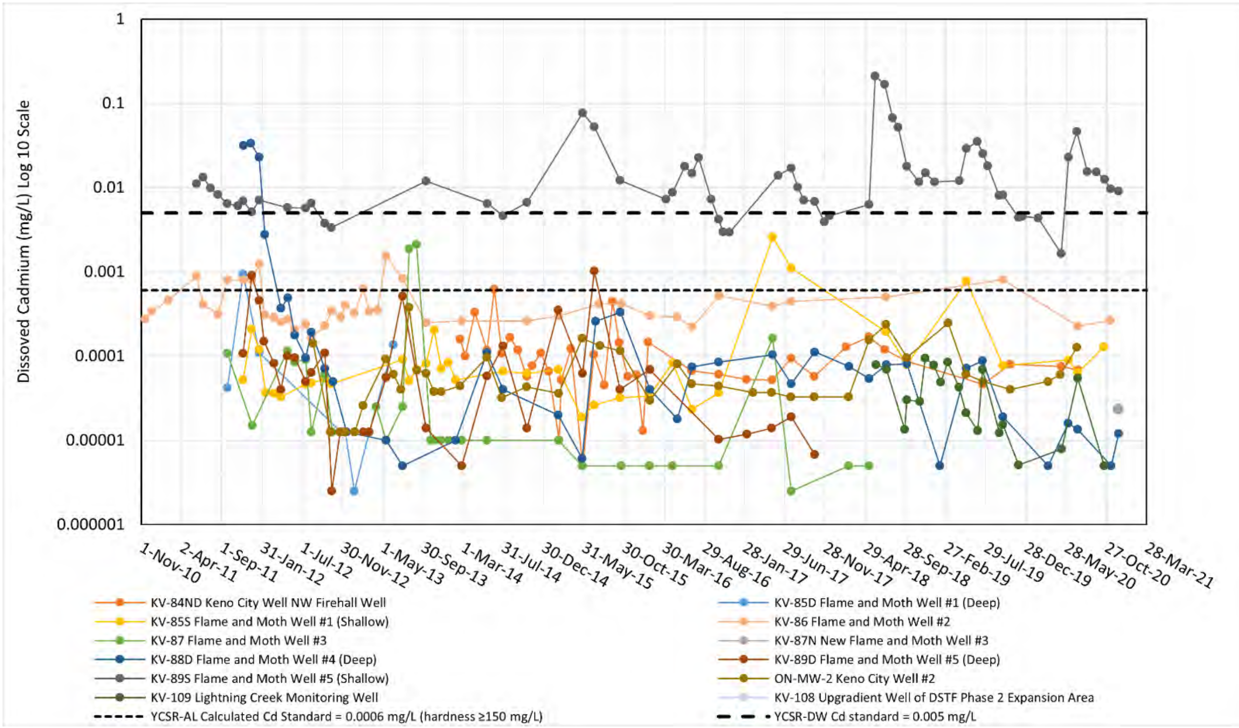


Figure 4-56 District Mill and Keno City Groundwater Monitoring, Dissolved Cadmium

4.3.1.3 Copper

All monitoring wells in the District returned copper concentrations below both YCSR-AL and YCSR-DW standards of 0.09 mg/L (hardness ≥ 200 mg/L) and 1 mg/L, respectively (see Figure 4-57). The majority of concentrations at KV-84ND, KV-89D, KV-109, and ON-MW-2 were below the detection limit for copper (0.0002 mg/L) with median concentrations of 0.0001 mg/L, 0.0002 mg/L, 0.00013 mg/L, and 0.0002 mg/L respectively. These four wells consistently exhibited the lowest concentrations of copper in the District. KV-89S often had the highest copper concentrations with a median concentration of 0.0024 mg/L.

Copper concentrations in wells KV-86, KV-89S, and KV-85S tend to be higher than KV-87, which typically returned copper concentrations below detection. All wells including the Keno City well KV-84ND have copper concentrations below the YCSR-AL standard (0.09 mg/L at hardness ≥ 200 mg/L). The YCSR-DW standard is much higher at 1 mg/L. The one measured concentration for new well KV-108 from the December 2020 sampling was below the detection limit. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for copper.

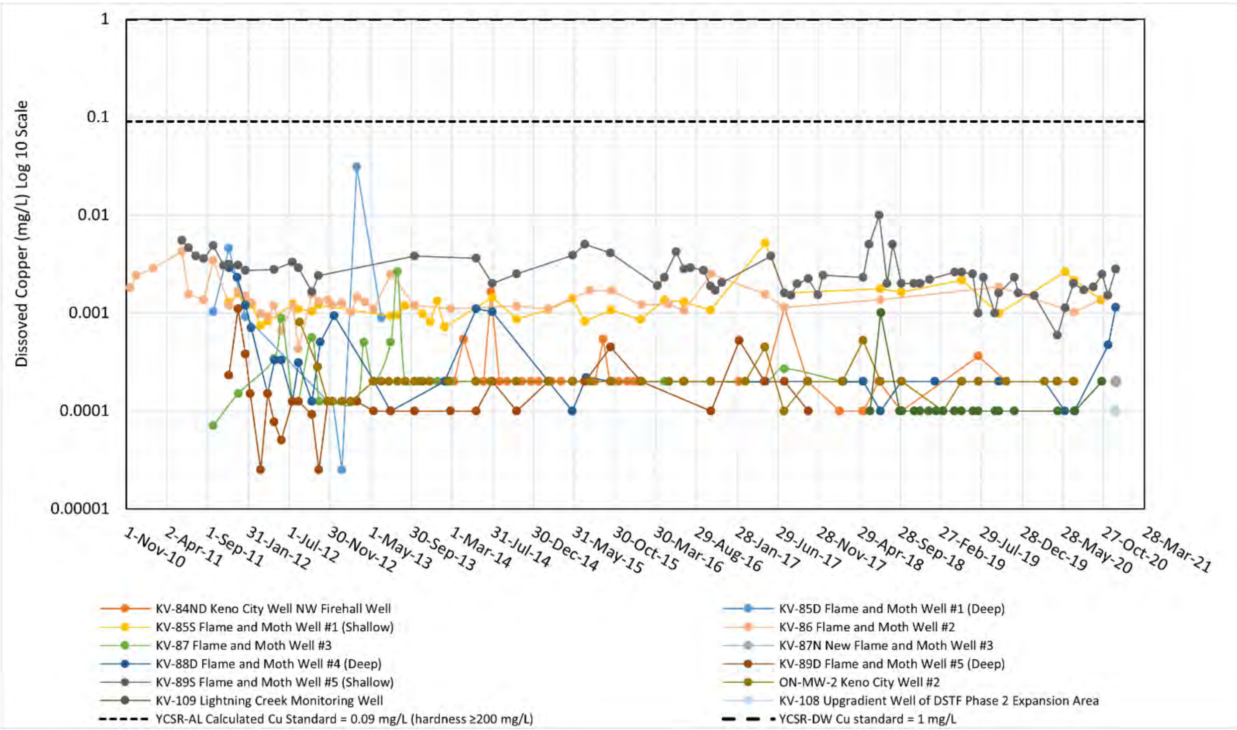


Figure 4-57 District Mill and Keno City Groundwater Monitoring, Dissolved Copper

4.3.1.4 Lead

All monitoring wells in the District show marked variability in lead concentrations across sampling events; no clear seasonal trends were discernible (See Figure 4-58). All monitoring wells in 2020 exhibited lead concentrations below both YCSR-AL and YCSR-DW standards of 0.11 mg/L (hardness 200 to < 300 mg/L) and 0.01 mg/L, respectively. KV-86 recurrently exhibited the highest lead concentrations, with a median concentration of 0.0017 mg/L. Monitoring wells that had several results under the detection limit for lead include KV-84ND (median 0.000099 mg/L), KV-87 (median 0.00013 mg/L), KV-88D (median 0.00084 mg/L), and ON-MW-2 (median 0.00014 mg/L). Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for lead.

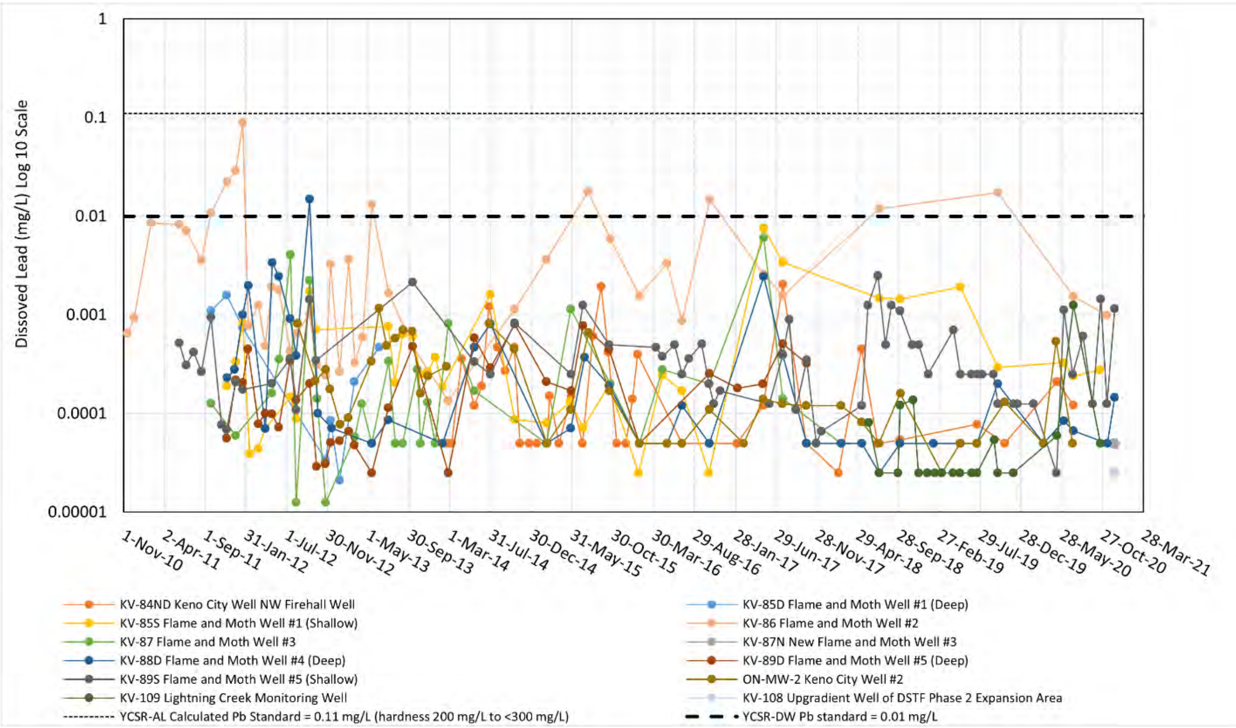


Figure 4-58 District Mill and Keno City Groundwater Monitoring, Dissolved Lead

4.3.1.5 Nickel

All District monitoring wells exhibited nickel concentrations below the YCSR-AL standard of 1.5 mg/L (hardness ≥180 mg/L) (see Figure 4-59). There is no applicable YCSR-DW standard for nickel. KV-88D and KV-89S exhibited the highest nickel concentrations with median values of 0.071 mg/L and 0.096 mg/L, respectively. KV-85S exhibited the lowest nickel concentrations with a median value of 0.00072 mg/L. KV-87, KV-88D, and KV-89S exhibited marked variability in nickel concentrations, and the other monitoring wells in the District show stable concentration levels across sampling events. The one measured nickel concentration for new well KV-108 from the December 2020 sampling event was 0.021 mg/L. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for nickel.

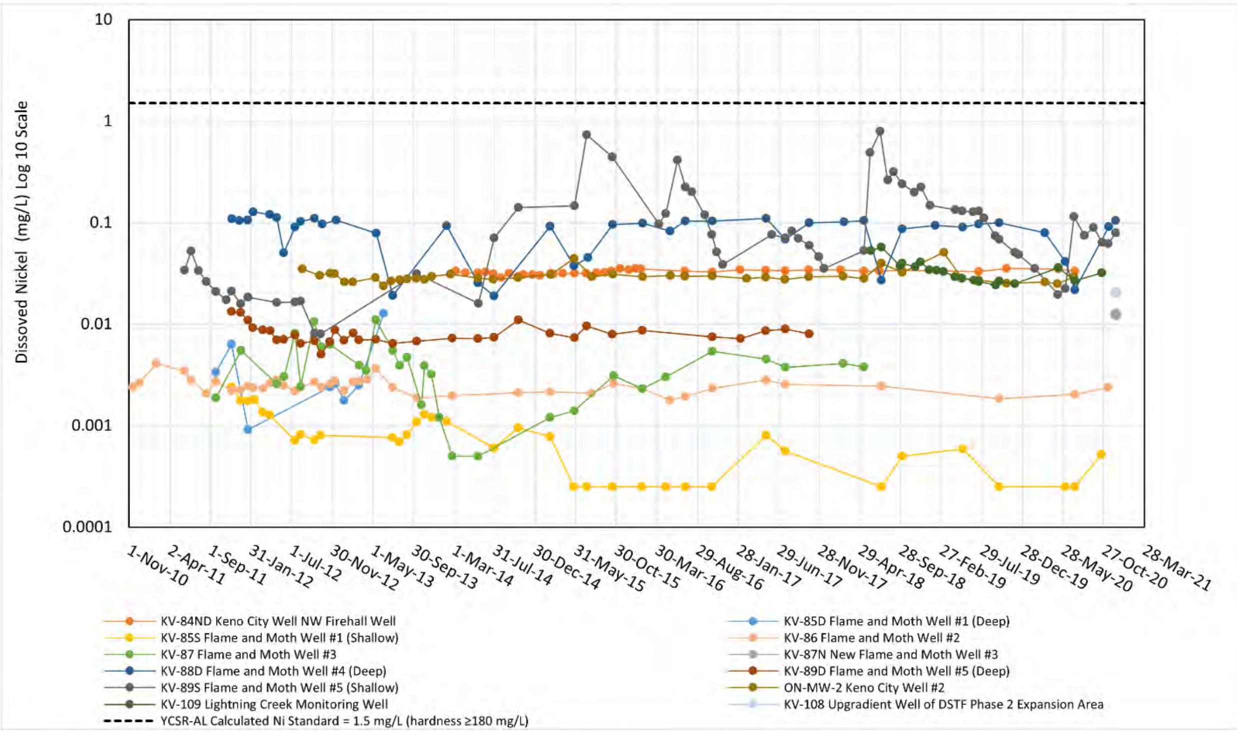


Figure 4-59 District Mill and Keno City Groundwater Monitoring, Dissolved Nickel

4.3.1.6 Silver

Silver concentrations for all District groundwater monitoring wells were below the YCSR-AL standard of 0.015 mg/L (hardness ≥ 100 mg/L) (Figure 4-60). Silver concentrations were mostly below detection levels for KV-84ND (median 0.00001 mg/L), KV-86 (median 0.000005 mg/L), KV-109 (median 0.000005 mg/L), and ON-MW-2 (median 0.00001 mg/L). KV-89S exhibited the highest silver concentrations of the District groundwater wells with a median value of 0.000027 mg/L and exhibited marked fluctuations in concentrations. The one measured silver concentration for new well KV-108 from the December 2020 sampling event was below the detection limit. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for silver.

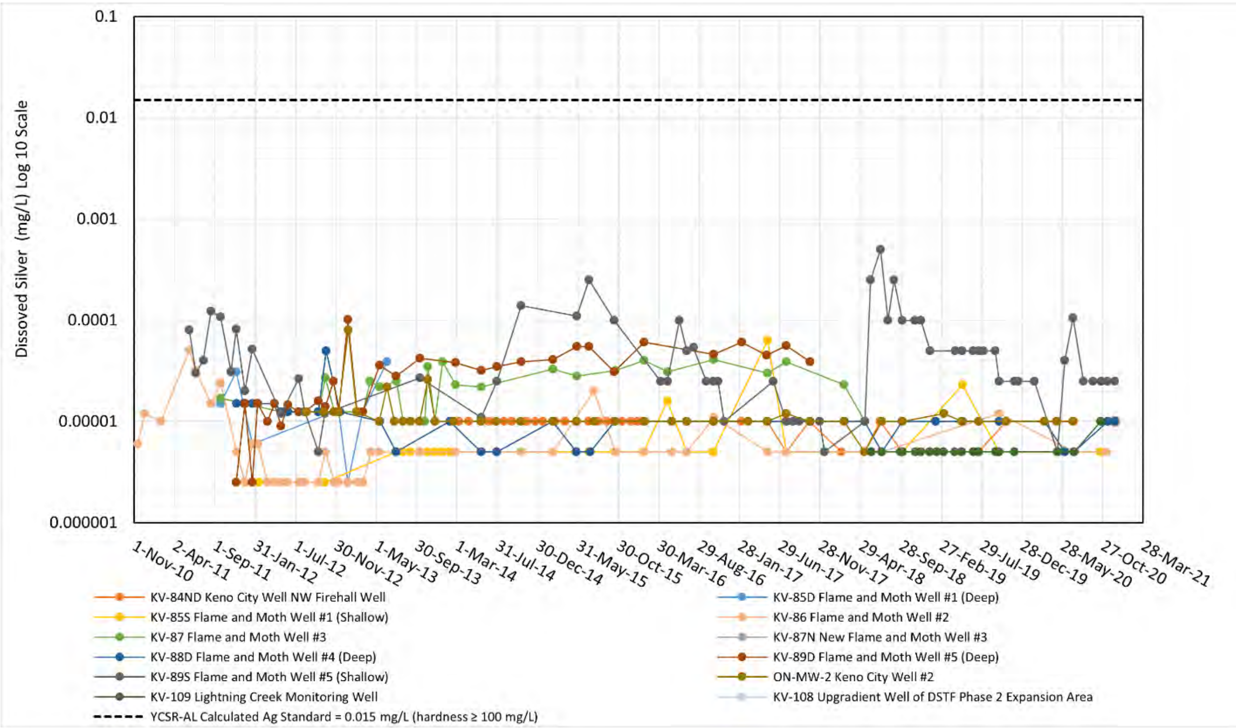


Figure 4-60 District Mill and Keno City Groundwater Monitoring, Dissolved Silver

4.3.1.7 Zinc

Zinc concentrations at KV-89S were consistently above the YCSR-DW and YCSR-AW standards of 5 mg/L and 1.65 mg/L (hardness 200 mg/L to <300 mg/L), respectively, except in 2012 (Figure 4-61). KV-89S also exhibited the highest concentrations of zinc of the District monitoring wells, with a median value of 19.5 mg/L. ON-MW-2 exhibited the second highest concentrations of zinc amongst District monitoring wells with a median value of 2.13 mg/L. The concentration was generally stable during the monitoring period and consistently below the YCSR-DW standard, but over the YCSR-AW standard.

KV-84ND, KV-86, KV-87, KV-85S, and KV-109 were all consistently below the YCSR-DW and YCSR-AW standards, with KV-85S and KV-87 exhibiting the lowest zinc concentrations of the District groundwater monitoring wells (median values of 0.0037 mg/L and 0.0043 mg/L, respectively). KV-84ND, KV-86, and KV-109 exhibited fairly stable concentrations across sampling events, and KV-89S exhibited marked variability in zinc concentrations. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for zinc.

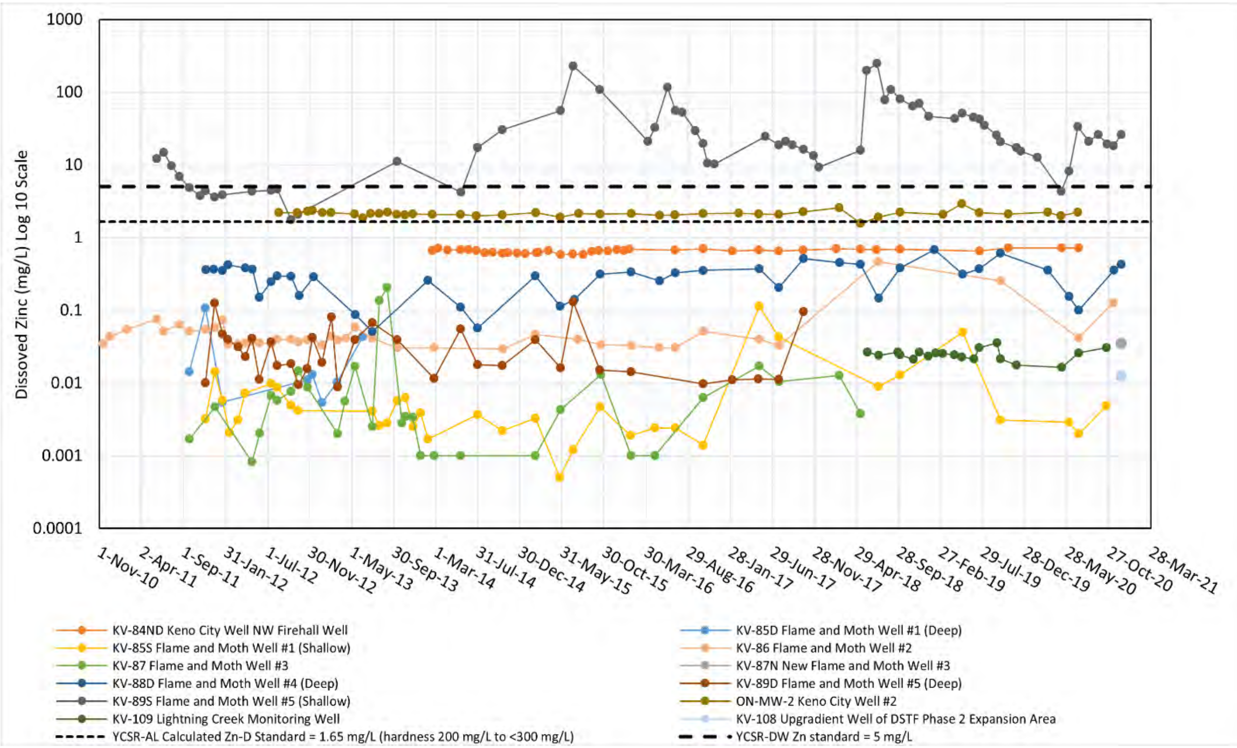


Figure 4-61 District Mill and Keno City Groundwater Monitoring, Dissolved Zinc

4.3.1.8 Sulphate

Monitoring wells KV-89S, KV-88D, and KV-87 exhibited elevated sulphate concentrations relative to YCSR-AL and YCSR-DW standards, which are 1,000 mg/L and 500 mg/L, respectively (Figure 4-62). KV-89S and KV-88D had the highest sulphate concentrations of the District monitoring wells, with median concentrations of 1,225 mg/L and 1,630 mg/L, respectively. These two monitoring wells also showed marked fluctuations in sulphate concentrations, while the remaining wells in the District had stable sulphate concentration levels.

Monitoring wells ON-MW-2, KV-84ND, KV-85D, KV-89D, and KV-109 had elevated concentrations relative to the YCSR-DW standard, but have remained under the YCSR-AL standard. KV-85S and KV-86 had the lowest sulphate concentrations of the District wells with median values of 67.5 mg/L and 214 mg/L, respectively, and were consistently below the YCSR-DW standard for sulphate. Data from the 2020 sampling events are consistent with the historical trends of the District groundwater monitoring wells for sulphate.

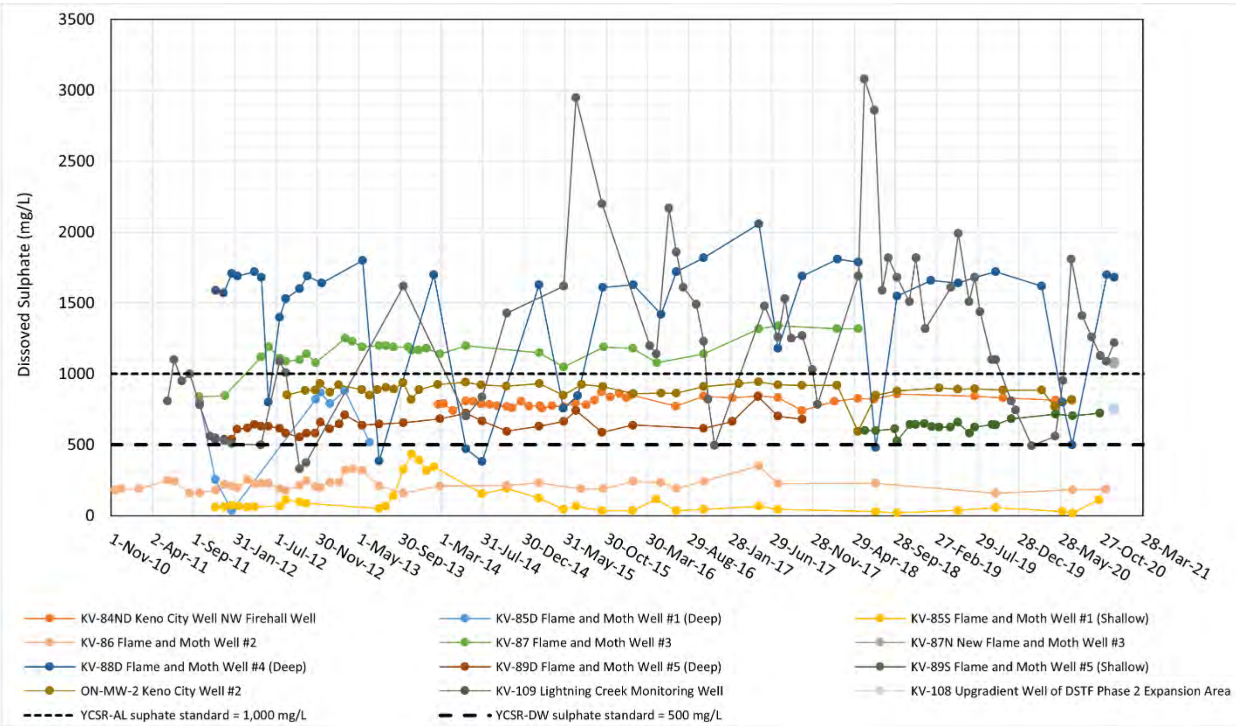


Figure 4-62 District Mill and Keno City Groundwater Monitoring, Sulphate

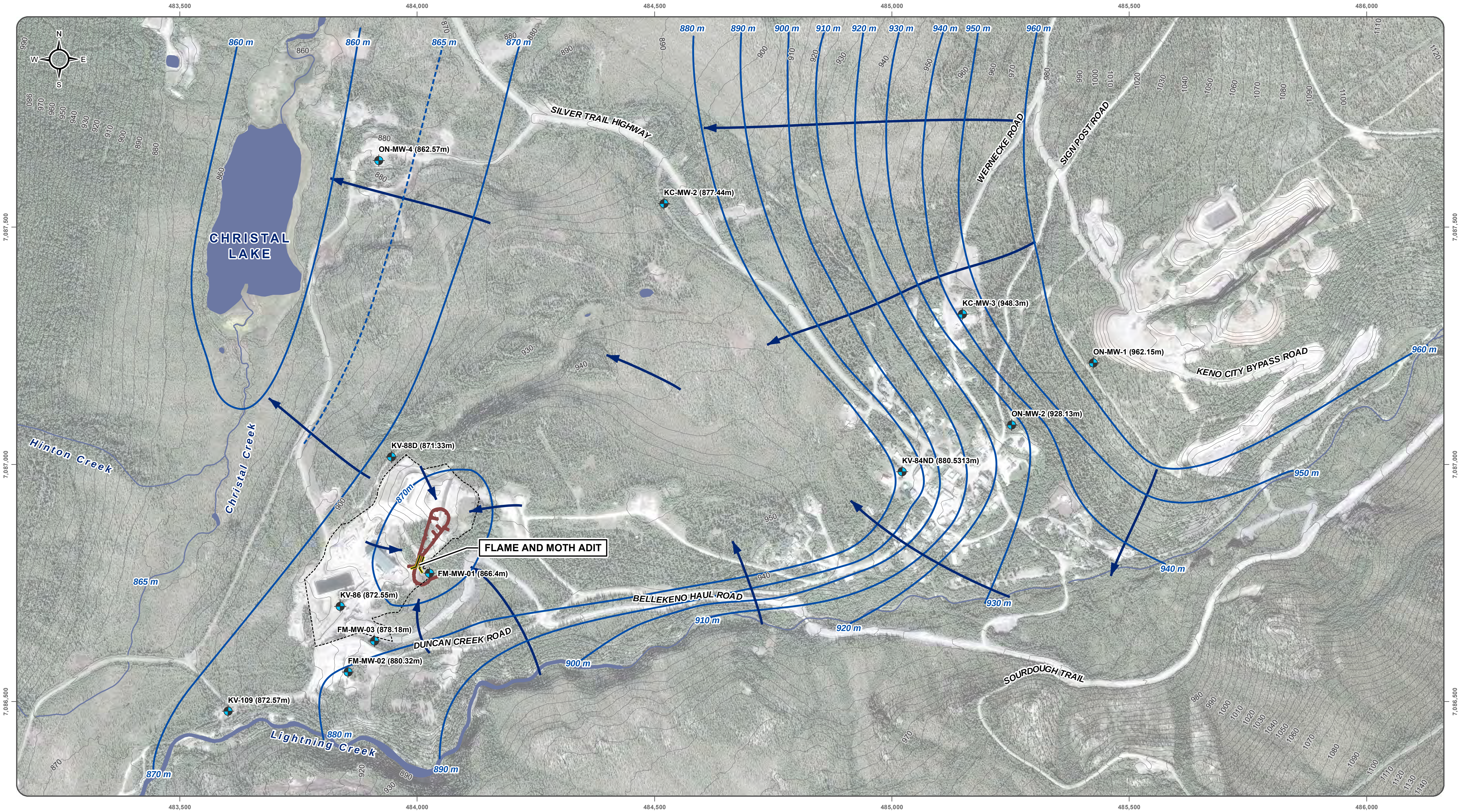
4.3.2 Mill Area Groundwater Flow

Across the KHSD, the groundwater table is a subdued reflection of the overlying topography, and natural groundwater flow paths tend to follow the surface topography from higher to lower elevations where the groundwater discharges to surface water. This general picture is modified by the presence of surface and underground mine workings, particularly when these features are actively dewatered or are drained by free-flowing adits. As such, active dewatering or free discharge from adit portals can create groundwater sinks that collect chemically affected groundwater within and adjacent to the mine workings and convey this flow to surface water. Groundwater can also flow through and be chemically affected by mine workings, after which, it continues to flow downgradient and merge with the natural groundwater system. In cases where an adit to the underground workings path is sealed (e.g., Galkeno 900), the workings have a smaller influence on groundwater flow paths.

Figure 4-59 is an interpreted groundwater elevation contour map extending from Keno City through the Mill Site and westward to Christal Creek/Lake based on geodetic groundwater level data from 2020. On the map, selected groundwater flowpaths are drawn to be perpendicular to the contours. Important features of the contour map are summarized below:

- The general groundwater flow direction is from east to west-northwest with natural groundwater discharge to Christal Lake and Christal Creek;

- Based on converging groundwater flow paths and the spacing of groundwater contours, it is postulated that a higher permeability zone extends from Keno City to the northwest;
- West of Keno City, surface water in Lightning Creek recharges the groundwater system north of the creek. This northward flowing recharge converges with the natural west-northwest flow of the regional groundwater system; and
- Dewatering of the Flame & Moth Decline has created a groundwater sink as expected. Groundwater flows radially to the deepest portion of the decline where it is removed by pumping. Some of the discharge to the sink may be derived from Lightning Creek surface water.



Satelite imagery obtained from ESRI Imagery map service http://goto.arcgisonline.com/maps/World_Imagery on October 2020

Datum: NAD 83; Projection: UTM Zone 8N

1:7,500 *(when printed on 11 x17 inch paper)*

0 100 200 300 400 Meters

Well (water levels measured June, 2020)
Adit
Groundwater Contour (10m)
Groundwater Contour (5m)
Groundwater Flow Direction
Flame and Moth Underground Workings
AKHM District Mill
Topo Contour (5m)
Watercourse
Waterbody

WATER ELEVATIONS ARE BASED ON GROUNDWATER DATA COLLECTED JUNE 2020

AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 4-63
JUNE 2020 KENO CITY GROUNDWATER LEVEL CONTOUR MAP

MARCH 2021

4.3.3 Results and Discussion: Mill Area

The groundwater elevation in the KHSD reflect the surface topography, and groundwater flow paths tend to follow topography from higher to lower elevations where the groundwater discharges to surface water. This flow pattern is modified by the dewatering of mine workings or by free-flowing adits. Dewatering can create groundwater sinks that collect groundwater within and adjacent to the mine workings and convey this flow to surface water. This groundwater may exhibit hydrogeochemical characteristics different from the general natural non-impacted groundwater. The groundwater monitoring program shows spatially variable water chemistry. The background well KV-87 generally had the lowest concentration of COPI typically below the YCSR-AL and YCSR-DW standards except for sulphate. The concentration of COPI in the majority of groundwater wells in the District returned concentrations below the YCSR-AL and YCSR-DW standards with the notable exception of arsenic, cadmium, zinc, and sulphate in a few wells. These elevated concentrations could be related to the mineralization of the District. Arsenic was elevated in the deep wells (KV-88D, ON-MW-2, KV-109, KV-89D and KV-85D) likely due to the reducing conditions in these wells which promote the dissolution of arsenic bearing minerals and amorphous phases. Cadmium and zinc were commonly elevated in the shallow well KV-89S and zinc in the shallow well ON-MW-2. Sulphate was elevated above YCSR-DW standard in several wells, but only KV-89S, KV-87 (background well), and KV-88D were higher than the YCSR-AL. The elevated sulphate concentrations in these wells, including the background well, indicate a generally elevated concentration of sulphate in the area. Fluctuations of the concentration of COPI in groundwater was noticeable at several wells but only KV-89S exhibited seasonality characterized by highest concentrations of COPI in May-July and the lowest concentration during the remainder of the year. Several wells also returned concentrations of cadmium, nickel, copper, lead, zinc, and silver below the detection limit.

4.3.4 Bermingham Area Groundwater Quality

In November of 2020, seven monitoring wells were installed in the Bermingham area of the KHSD (KV-116, KV-122, KV-123, KV-124, KV-125, KV-126 and KV-127), and one well was installed at No Cash (NC-MW-1) (Figure 4-50). Hydraulic conductivity testing for the new wells will be completed in summer of 2021. The purpose of these new wells is to monitor the groundwater quality upgradient and downgradient of the Bermingham Southwest open pit where water treatment sludge will be deposited and the Bermingham potentially acid metal leaching (P-AML) waste rock storage facility. KV-124 was drilled upgradient of Bermingham Southwest pit, and KV-122 and KV-123 were installed downgradient of this feature. KV-127 was installed upgradient of the Bermingham P-AML waste rock storage facility, and KV-125 and KV-126 were installed downgradient of this feature. KV-116 was installed downgradient of the non metal acid leaching (N-AML) waste rock disposal area in order to monitoring groundwater downgradient of the N-AML waste rock disposal area and the water treatment discharge location. NC-MW-1 was installed to monitor groundwater downgradient of the underground mine workings at Bermingham. No waste rock has been placed in the Bermingham P-AML facility, nor has water treatment sludge been placed in the Bermingham SW open pit and, therefore, the analytical results from the November and December 2020 monitoring events can be assumed to provide reference conditions for this area of the KHSD prior to AKHM mining operations.

The new wells were sampled in November shortly after the completion of the drilling and well installation program, and again in December of 2020; sampling of the newly installed groundwater monitoring wells will occur on a monthly basis for the first 12 months following installation and well development. The results of the two sampling events are summarized in Table 4-9 to Table 4-16, below. Results from the November and

December 2020 sampling events were compared against the YCSR-AL standards; since no drinking water wells exist within a 1.5 km radius of the Bermingham mine workings and open pits.

4.3.4.1 Arsenic

All monitoring wells had arsenic concentrations below the YCSR-AL standard of 0.05 mg/L. The highest concentration of arsenic observed during the December 2020 sampling event was at KV-126 (0.044 mg/L), which was slightly below the YCSR-AL standard (Table 4-9).

Table 4-9 Dissolved Arsenic Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
YCSR-AL (mg/L)	0.050						
November 2020 (mg/L)	0.0102	0.00090	0.00133	0.00038	-	0.00206	-
December 2020 (mg/L)	0.00949	0.00089	0.00149	-	0.0440	0.00136	0.00042

4.3.4.2 Cadmium

Most monitoring wells returned cadmium concentrations below the applicable YCSR-AL standards (hardness dependent), except KV-123 and KV-126. KV-123 retuned concentrations 21 to 28 fold higher than the YCSR-AL standard during the November and December sampling events, and KV-126 had a cadmium concentration just above the standard during the December sampling event (Table 4-10).

Table 4-10 Dissolved Cadmium Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	0.000080	0.00027	0.0127	0.000019	-	0.00024	-
November 2020 YCSR-AL (mg/L)	0.00050	0.00050	0.00060	0.00050	-	0.00030	-
December 2020 (mg/L)	0.000084	0.00032	0.0167	-	0.00085	0.000092	0.000043
December 2020 YCSR-AL (mg/L)	0.00050	0.00050	0.00060	-	0.00060	0.00030	0.00060

Notes: red value indicates exceedance of YCSR-AL standards. YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 samples.

4.3.4.3 Copper

All monitoring wells returned copper concentrations below the hardness-dependent YCSR-AL standards and below the detection limit during the December sampling events (Table 4-11).

Table 4-11 Dissolved Copper Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	0.00040	<0.00020	0.00023	0.0029	-	0.00021	-
November 2020 YCSR-AL (mg/L)	0.050	0.050	0.090	0.040	-	0.040	-
December 2020 (mg/L)	<0.00020	0.00031	<0.00020	-	<0.00020	<0.00020	<0.00020
December 2020 YCSR-AL (mg/L)	0.050	0.060	0.090	-	0.090	0.030	0.090

Note: YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 samples.

4.3.4.4 Lead

All monitoring wells except KV-124 and KV-126 had lead concentrations below the detection limit and all lead concentrations were below the hardness-dependent YCSR-AL standards (Table 4-12).

Table 4-12 Dissolved Lead Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	<0.000050	<0.000050	<0.000050	0.00012	-	<0.000050	-
November 2020 YCSR-AL (mg/L)	0.060	0.060	0.11	0.050	-	0.050	-
December 2020 (mg/L)	<0.000050	<0.000050	<0.000050	-	0.00043	<0.000050	<0.000050
December 2020 YCSR-AL (mg/L)	0.060	0.060	0.11	-	0.11	0.050	0.16

Note: YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 samples.

4.3.4.5 Nickel

All monitoring wells returned nickel concentrations two to three orders of magnitude below the hardness-dependent YCSR-AL standards (Table 4-13).

Table 4-13 Dissolved Nickel Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	0.00054	0.00084	0.0024	0.0016	-	0.013	-
November 2020 YCSR-AL (mg/L)	1.1	1.1	1.5	0.65	-	0.65	-
December 2020 (mg/L)	<0.00050	0.0012	0.0025	-	0.016	0.0015	0.0074
December 2020 YCSR-AL (mg/L)	0.65	1.1	1.5	-	1.5	0.65	1.5

Note: YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 samples.

4.3.4.6 Silver

All monitoring wells had silver concentrations orders of magnitude the hardness-dependent YCSR-AL standards. Also, all monitoring wells, except KV-127, returned results below the detection limit for silver during the 2020 sampling events (Table 4-14).

Table 4-14 Dissolved Silver Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	<0.00001	<0.00001	<0.00001	<0.00001	-	0.000016	-
November 2020 YCSR-AL (mg/L)	0.015	0.015	0.015	0.0005	-	0.0005	-
December 2020 (mg/L)	<0.00001	<0.00001	<0.00001	-	<0.00001	<0.00001	<0.00001
December 2020 YCSR-AL (mg/L)	0.015	0.015	0.015	-	0.015	0.0005	0.015

Note: YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 timepoints.

4.3.4.7 Zinc

All monitoring wells returned zinc concentrations below their respective hardness-dependent YCSR-AL standards. KV-123 had the highest zinc concentrations (1.14 to 1.28 mg/L compared to maximum of 0.018 mg/L in other wells; Table 4-15).

Table 4-15 Dissolved Zinc Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
November 2020 (mg/L)	0.0017	0.0151	1.14	0.0026	-	0.0051	-
November 2020 YCSR-AL (mg/L)	0.90	0.90	1.65	0.15	-	0.075	-
December 2020 (mg/L)	0.0013	0.018	1.28	-	0.043	0.0035	0.0059
December 2020 YCSR-AL (mg/L)	0.90	0.90	1.65	-	1.65	0.075	2.40

Note: YCSR-AL standards are hardness dependent; therefore, a standard is shown for both November and December 2020 timepoints.

4.3.4.8 Sulphate

All monitoring wells, except NC-MW-1, returned very low sulphate concentrations (3.1 to 77.4 mg/L) one to two orders of magnitude below the YCSR-AL standard of 1,000 mg/L. NC-MW-1 returned a much higher concentration (343 mg/L) compared to other wells including previously installed wells such as RB-MW-1 (maximum sulphate was 143 mg/L; Table 4-16).

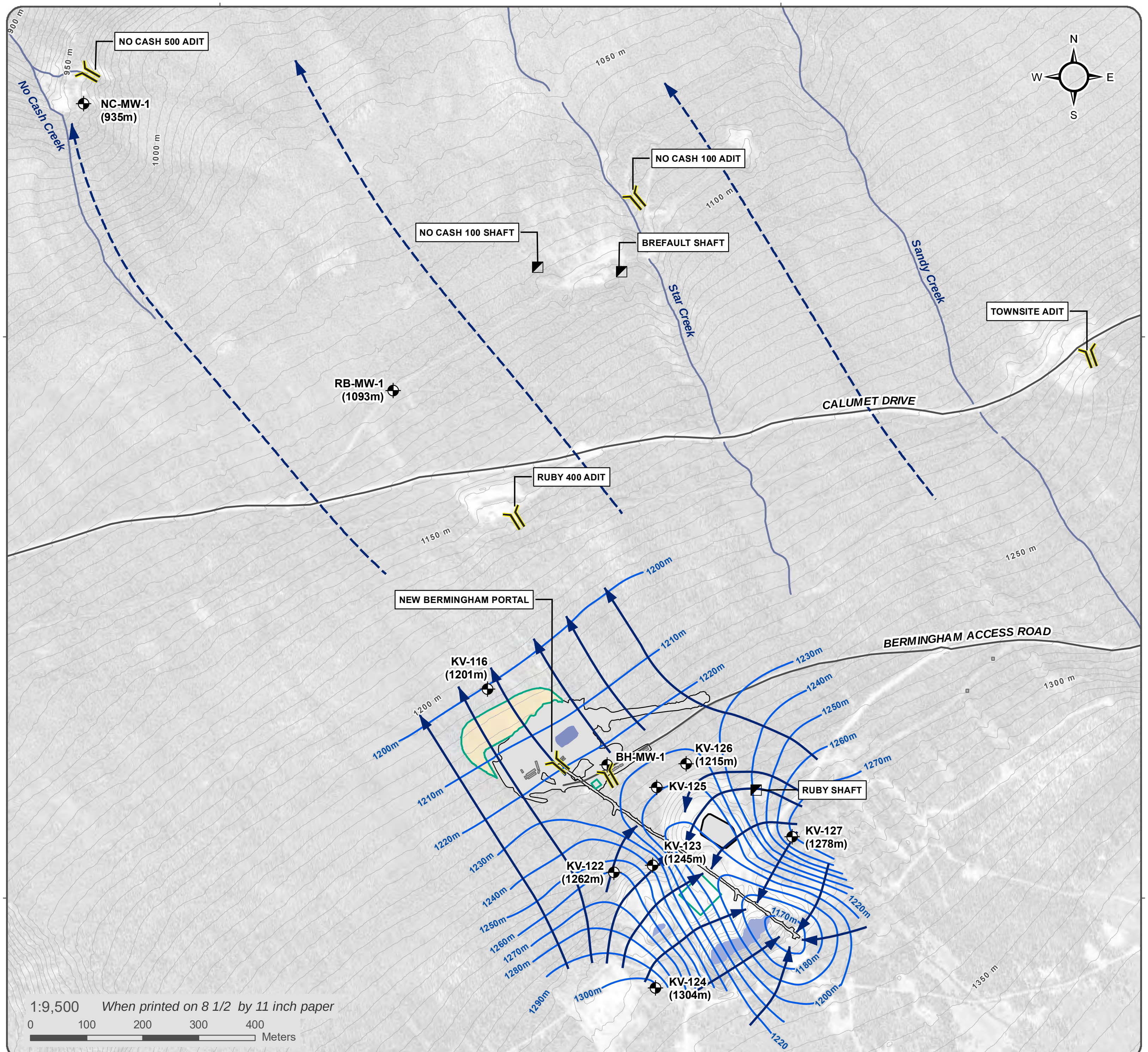
Table 4-16 Dissolved Sulphate Concentrations in Bermingham Monitoring Wells November-December 2020

Date	KV-116	KV-122	KV-123	KV-124	KV-126	KV-127	NC-MW-1
YCSR-AL (mg/L)	1,000						
November 2020 (mg/L)	52.0	39.4	77.4	8.69	-	4.94	-
December 2020 (mg/L)	48.2	38.4	73.4	-	58.5	3.06	343

4.3.5 Bermingham Area Groundwater Flow

Groundwater flow in the Bermingham area follows topography, so the general flow direction is from southeast to northwest. Construction and continued dewatering of the Bermingham decline has modified the flow patterns. Based on measured groundwater levels in wells and the expected hydrologic effect of the decline, Figure 4-64 is an interpreted groundwater elevation contour map of the Bermingham area. Shown on the map are interpreted groundwater flowpaths, which are generally drawn perpendicular to the contours. The map shows flow lines converging along the decline, which operates as a groundwater sink. Groundwater inflows in the decline are collected by a sump system and pumped via pipeline to the portal where the mine water is discharged at ground surface. The groundwater effects (drawdowns) are most pronounced at the far end of the portal where the depth of excavation below the natural (preconstruction) water table is the greatest. As one proceeds away from the decline, the effects diminish, and groundwater becomes more similar to the natural regional system characterized by southeast to northwest flow. The groundwater contours are anticipated per the groundwater model submitted as part of Water Licence application

Another area of interest is the hydrogeological effect of the pond in the historic main Bermingham open pit, and if this is an expression of the groundwater system. It is our current interpretation that the pond comes from the collection of surface water (particularly snowmelt during freshet) and is not a feature that is groundwater fed. As such, the water in the pit is interpreted to not have a direct affect on the groundwater system, except perhaps providing some amount of annual recharge. Additional groundwater monitoring performed during 2021 will be used to refine our understanding of this area.



ALEXCO KENO HILL MINING CORP.

FIGURE 4-64

BERMINGHAM MONITORING LOCATIONS AND GROUNDWATER LEVEL CONTOUR MAP

MARCH 2021

- Adit/Portal
- Shaft
- Groundwater Quality Monitoring, Existing
- Groundwater Contour
- Estimated Groundwater Flow Direction
- Inferred Groundwater Flow Direction
- Waterbody
- As Built Mine Structure
- Permitted To Be Constructed Mine Features
- Contour (5m interval)

Water Elevations are based on Groundwater Data Collected in December 2020

Water Elevation for RB-MW-1 was collected in October 2020

National Topographic Data Base (NTDB) compiled by Natural Resources Canada at a scale of 1:50,000. Cadastral data compiled by Natural Resources Canada. Reproduced under license from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.
Satellite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on March 2021

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

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4.3.6 Results and Discussion: Bermingham Area

Groundwater flow in the Bermingham area follows topography resulting in a general flow direction southeast – northwest. The flow near the decline converges toward the decline, which operates as a groundwater sink. Groundwater inflows in the decline are collected by a sump system and pumped to the discharge portal. The groundwater drawdowns are most pronounced at the far end of the portal where the depth of excavation below the natural (preconstruction) water table is the greatest.

Early results of the groundwater quality monitoring of wells newly constructed upstream and downstream of the Bermingham mine and related structures (e.g., Bermingham SW open pit, P-AML facility, N-AML disposal area, water treatment discharge) indicate low concentration of COPI. The wells returned concentrations of COPI well below the YCSR-AL standards and commonly below the detection limit. The only exception was cadmium which was elevated in KV-123 and KV-126 with respect to the YCSR-AL standards and zinc in KV-123, which was near the YCSR-AL standard.

4.4 VEGETATION

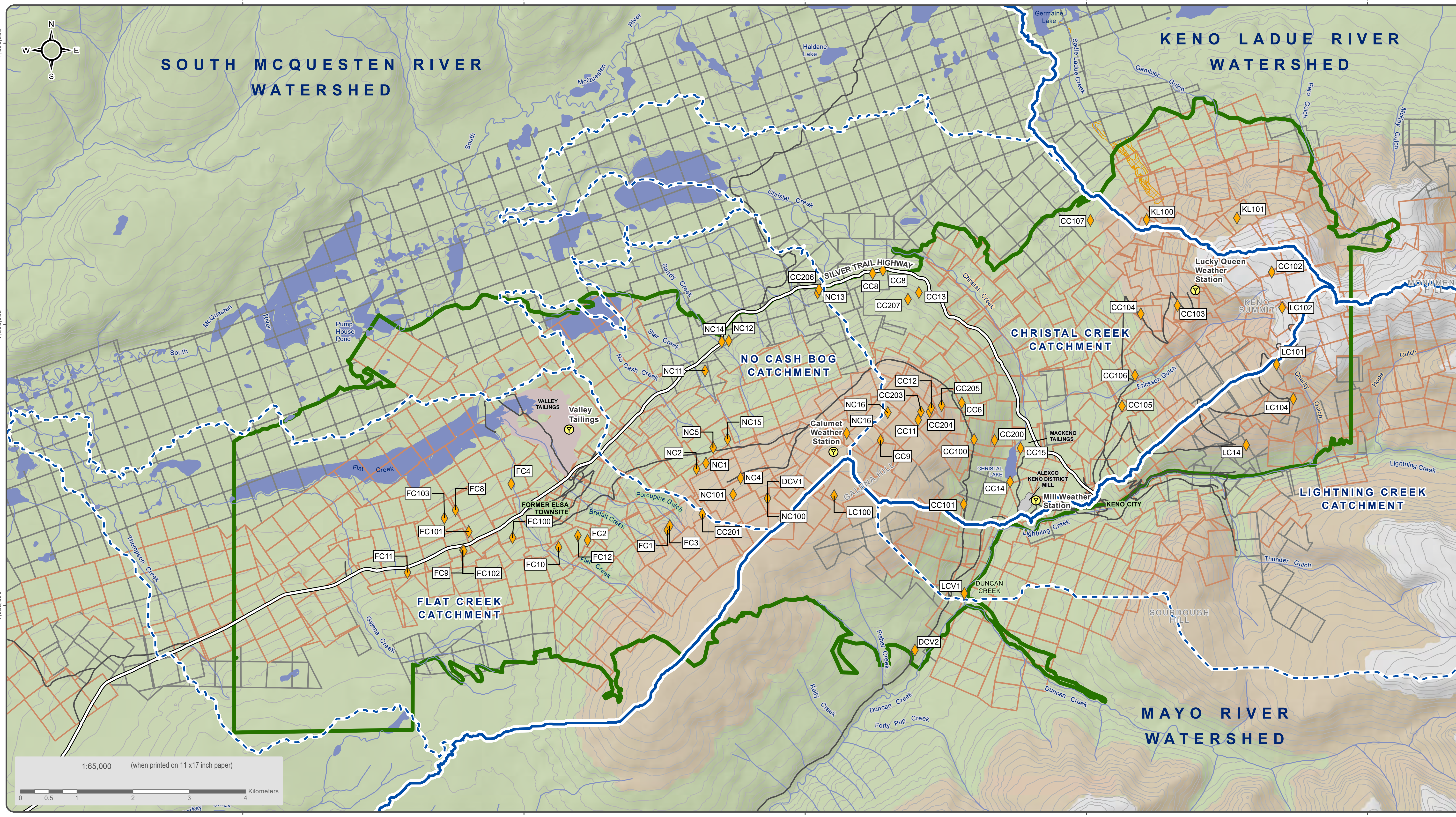
The following sections summarize the vegetation and monitoring programs for the KHSD and additional information is provided in the Site Characterization Plan (Appendix 2).

4.4.1 Biophysical Background

Details of vegetation in the KHSD can be found in the *2013 KHSD ecosystem mapping report* (ACG, 2013a), *2011-2013 Soil and Vegetation Baseline Study and Analysis* (ACG, 2011b, 2012b, 2013b) and *Site Characterization Report* (AMC, 1996).

The District lies within the Stewart Plateau region of the Yukon Plateau – North Ecoregion. The area is characterized by a series of table lands divided by broad deep cut valleys which are dominated by widespread discontinuous permafrost (Smith et al, 2004). The South McQuesten River valley bounds the property to the north, while the Lightning Creek watershed confines the property to the south-east and the Keno Ladue drainage system to the north-east of the property. The climate is characterized by hot dry summers, while winters are cold with minimal snowfall. Many valleys include peatlands, palsas, fens and meadows of sedge tussocks. Upper slopes may be covered with scree material, with treeline occurring at 1,300 masl on northern aspects and up to 1,360 masl on southern aspects.

The District comprises three bioclimatic zones which are summarized in Table 4-17 and shown in Figure 4-65. The predominant bioclimatic zone is the Boreal High, making up two thirds of the KHSD, followed by the Subalpine zone (one quarter of the area), with the Alpine zone occupying a confined area on Keno Hill, in the eastern extent of the claims.



Topographic Data (CANVEC) data at a scale of 1:50,000 and crown grant (land parcels and mineral survey claims) data compiled by the Department of Natural Resources Canada. Quartz claim boundaires and ownership are current as of March[th] 2017; obtained from Geomatics Yukon, Government of Yukon.
Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on March 2017

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

BIOCLIMATIC ZONES

- Boreal Low (< 500m) 0%
- Boreal High (500 - 1225m) 62.6%
- Subalpine (1225 - 1450m) 32.0%
- Alpine (> 1450m) 5.4%
- Vegetation Classification Outline
- Ecosystem Plot Location
- Weather Station
- Watershed
- Catchment
- ERDC Owned Quartz Claims or Crown Grants
- Tailings Area
- Waterbody
- Watercourse
- Silver Trail Highway
- Other Road
- Contours (100 ft intervals)

AKHM

FIGURE 4-65

BIOCLIMATE ZONES OF THE KHSD

REVISION 5	NOVEMBER 2021	JOB:007-4
DRAWN BY GIS	DESIGNED BY GIS	REVIEWED BY: LB

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Table 4-17 Bioclimatic Zones in the Keno Hill Silver District

Bioclimatic Zone (elevation range)	Definition
Boreal High (BOH) (500 – 1,225 masl)	The boreal high forested areas are predominantly a mix of white and black spruce, with a shrub, lichen, and moss understory. The higher elevation extents of this bioclimatic zone support a mix of subalpine fir, scrub birch and willow as it approaches the subalpine zone. The boreal high tends to have more of an open canopy then Boreal low and a moderate to well-developed shrub layer. Non forested areas include wetlands, riparian areas, avalanche tracks, exposed soil/rock and anthropogenic disturbances.
Subalpine (SUB) (1,225 – 1,450 masl)	Open to sparse forest canopy cover where the main tree species are Sub-alpine fir and White spruce which become less frequent at the higher elevations. The shrub layer is well-developed and composed mainly of scrub birch, willow species and vaccinium species. At the higher extent of this zone small woody shrubs, Dryas, mosses and lichen replace the forest cover with only a few krummholtz subalpine fir scattered amongst the landscape.
Alpine (ALP) (1,450 masl+)	Alpine communities include dwarf ericaceous shrubs, scrub birch, willow species, grass/sedges, forbs, lichen and bare bedrock at elevations above the tree line. Trees if present are low growing krummholtz that exist in small microsites where they can receive enough moisture and nutrients to grow. This bioclimatic zone is only present on Keno Hill.

Plant communities specific to KHSD are discussed in the QML-0009 Site Characterization Report (Appendix 2).

4.4.2 Vegetation Monitoring

Revegetation monitoring have been conducted for the KHSD since 2007 when the Galena Hill revegetation trials began. Cover systems and natural succession trials have also been done and are monitored regularly (Section 4.4.2.1). Studies to determine contaminant levels in vegetation have been conducted by Microbial Technologies (included in AMC, 1996) and by Environmental Dynamics Inc. (Section 4.4.2.2; EDI 2008, 2009).

4.4.2.1 Vegetation Monitoring

Ensero Solutions (formerly Alexco Environmental Group Ltd.) conducted five vegetation monitoring trials in 2019 (AEG, 2020), to document the continued development of vegetation on different applied surface treatments. Monitoring focused on percent cover of vegetation, general observations of species diversity, and chronosequencing observations. The site visit in 2019 included the following programs:

1. the 2007 revegetation trials on Galena Hill waste rock storage areas;
2. the 2014 cover systems and vegetation field trials;
3. the 2015 operational trials; and
4. No Cash 100 chronosequence trials.

Overall, natural succession and recolonization has been observed across the site and at the various vegetation trial sites. The chronosequence monitoring at No Cash 100 show that natural succession initially occurs at a slower rate (vegetation was sparse for the first 30 years), but once sufficient vegetation has established, the rate of natural revegetation increases. At locations being monitored for active revegetation work on newly disturbed waste rock it was found that vegetation coverage benefitted from a second application of fertilizer and seed, particularly the year immediately following the second application. The reapplication of seed and fertilizer seemed to have less of an impact the second year after application. Establishing significant vegetation cover will need time similar to natural revegetation.

Visual inspections of the lysimeter covers indicated that the covers appeared largely stable since installation in 2015; however, the thickest covers were showing slightly more erosion at edges than the thinnest covers, suggesting that 0.25 m of Husky SW till is sufficient and stable cover. The water quality results from the Husky and Valley Tailings cover system field trials indicate that cover thickness does not appear to affect the water quality, but solely the volume of water percolating through the materials. It is understood that the lysimeter cover trials are expected to be finished next year, but should they be continued, maintenance would be required on the connections to each on the tanks. The limited collection of water quality samples from most of the tanks indicates a potential problem with piping connections that feed the percolated lysimeter water to the collection tanks.

In 2012 reclamation was initiated on the DSTF 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. Details regarding this program are included in Appendix 1.1.

4.4.2.2 Contaminants in Vegetation

Access Mining Consultants Ltd. investigated the concentration of metals in local wetland plant species tissue and found that although the sediments in the wetland sampling areas were enriched in metals compared to reference sites, metal concentrations in plant tissue, were similar to reported values for reference sites. There was no evidence of metal uptake in plants in these wetland areas. Results from this study were reported in the "Design of a Passive System for Treatment of Discharges for the Galkeno 900 Adit at the United Keno Hill Mine Camp" prepared by Microbial Technologies in 1995 and included in the report by Access Mining Consultants Ltd. (AMC, 1996).

EDI conducted three terrestrial effects study in the KHSD, from 2007 to 2009. They first investigated the area of the VTF, to determine if aerial dispersion of metals in dust had occurred and the extent of dispersion (EDI, 2008, 2009). Results concluded metals contamination were present in the eastern portion of the VTF. The second study investigate the extent of metals uptake in plants from the original sample sites, as well as areas used for traditional harvest by the local First Nation. The study concluded there was heavy metals uptake in some of the traditional medicinal plants gathered. The last study found greater concentrations of heavy metals in plants growing in the VTF compared to those growing near to adit discharge. EDI also noted that metals uptake differed between species. For example, willow samples had greater concentrations per weight than Labrador tea samples. There was no correlation made between metals concentration in the soil, and metals concentration in plant tissue.

4.5 WILDLIFE

The following sections summarize wildlife study results in the KHSD and additional information is provided in the QML-0009 Site Characterization Report (Appendix 2).

4.5.1 General

The KHSD lies between the Stewart and South McQuesten Rivers, which is located entirely within the Yukon Plateau – North Ecoregion and supports a variety of wildlife including ungulates, bears, furbearers, small mammals, upland game birds and waterfowl. A general descriptive overview of biophysical properties is found within *Ecoregions of the Yukon Territory* (Smith et al., 2004), while detailed biophysical information is found within *Heart of the Yukon—A Natural and Cultural History of the Mayo Area* (Bleiler et al., 2006). The following summary on wildlife use in the area has been adapted from *The Current State of Wildlife in the Keno Hill Silver District* (Lortie, 2009).

There are several species of ecological, economic, and cultural importance in the KHSD. Of these. Moose (*Alces alces*) are highly valued to a subsistence and commercial lifestyle for the peoples in this area, including the FNNND. Repeated survey work over the last 15 years has indicated a healthy, stable moose population that depend on the KHSD for important habitat. For example, the subalpine zones on the Keno Hill, Bunker Hill and Sourdough Hill uplands are key rutting and post rutting aggregation areas (O'Donoghue, pers. comm. as cited in Lortie, 2009). Further, the wetlands associated with and above Pumphouse Pond, the South McQuesten River and the Elsa tailings areas are important calving and post calving areas (O'Donoghue, pers. comm. as cited in Lortie, 2009). In 2011, Environment Yukon noted in their draft report that the moose population in the Mayo-Elsa-Keno area are experiencing a slight decline in population numbers compared to previous surveys. It is suspected that overharvesting may have been the main cause for lower numbers of moose. A late winter survey was conducted in 2014 for the Mayo Moose Management Unit, which includes the project area (O'Donoghue et al., 2016). This survey found that the highest densities of moose were found in areas with abundant willows along rivers and creeks and in lowland burns, especially in the lowland burns near Keno. Recruitment rate (i.e., the ratio of calves to cows) was found to be at or slightly below average.

Other species of importance are Thinhorn sheep (*Ovis dalli*) were formerly present on Keno Hill but hunted to extinction in the early 20th century. Heart of the Yukon (Bleiler et al., 2006) indicates that sheep are not present in the KHSD, and the nearest population of about 70 animals inhabits the Ddhaw Ghro Habitat Protection Area south of Ethel Lake. Black bear (*Ursus americanus*) and grizzly bear (*Ursus arct*os) are common in the area (Bleiler et al., 2006). COSEWIC lists the status of grizzly bears as 'Special Concern'.

Several furbearers are known to use the project area including gray wolves (*Canis lupus*), coyotes (*Canis latrans*), foxes (*Vulpes vulpes*), marten (*Martes Americana)*, mink (*Neovison vison)*, Canada lynx (*Lynx canadensis*), wolverine (*Gulo gulo*) and river otter (*Lontra canadensis*). A number of these species are culturally and economically important to trappers in the area and the FNNND. Beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) are also economically important and common in aquatic habitats in the region. Wolverine are listed as a species of special concern (COSEWIC, 2014). Rogue River Outfitters has an outfitting concession in the area but have a voluntary "No Hunt" agreement with the Mayo Regional Resources Council. There is a no hunting policy for AKHM mine workers within the KHSD.

There are five registered traplines summarized as follows:

1. Concession 85: Active. Minor portions including Galena Creek and Williams Creek and a small piece south of Mt. Hinton;
2. Concession 82: Activity unknown. This concession is reserved for the Mayo First Nation and covers most of the central and western study area;
3. Concession 81: Active. Only a minor portion on the western limit of the study area;
4. Concession 83: Inactive. Eastern limit of the study area, including Keno Hill, Beauvette Hill, Upper Lightning and Faith Creeks; and

5. Concession 43: Intermittently Active. Marginally peripheral on the northwest corner of the study area.

A thorough and comprehensive narrative of birds in the area can be found within *Heart of the Yukon* (Bleiler et al., 2006). Additionally, a report on the recent site specific waterbird use of the Christal Creek area jointly produced by Ducks Unlimited and the FNNND was conducted in 2004 (Leach and Hogan, 2005). Three species of birds are COSEWIC listed:

1. Common Nighthawk (Chordeiles minor) – Threatened;
2. Rusty Blackbird (Euphagus carolinus) – Special Concern; and
3. Olive-Sided Flycatcher (Contopus cooperi) – Special Concern.

Other small mammals common to the area include ground squirrel, red squirrel, varying hare, weasel, vole, and shrew. Less common are porcupine and chipmunk. Alpine areas have local populations of hoary marmot and collared pika (*Ochotona collaris*). The collared pika is listed as a species of special concern (COSEWIC, 2011).

4.5.2 Community-Based Fish and Wildlife Work Plan

A Community-Based Fish and Wildlife Work Plan for the FNNND Traditional Territory was developed using a cooperative approach by the First Nation, the Mayo District Renewable Resources Council, and Environment Yukon (FNNND et al, 2003). The plan documents concerns and potential solutions expressed about fish and wildlife management in the FNNND Traditional Territory and intended to be implemented over the five-year period. "The plan addresses community concerns about moose, caribou, bear, wolf, and fish populations, along with habitat, harvest, wildlife viewing and other wildlife and land issues, and suggests opportunities for public participation and ways to better inform area residents about management activities." (FNNND, 2008).

AKHM created a Wildlife Protection Plan in 2012, which was updated in 2018 (AKHM, 2018) to provide general wildlife management objectives and protocols for all employees in the KHSD mining operations. This plan reflects considerations of current work activities, anticipated developments, and a better understanding regarding wildlife usage of the area from three years of observations and maintaining records of wildlife sightings. Table 4-18 lists wildlife species that are recognized by the federal or territorial government as needing extra protection or monitoring and may be found in KHSD.

Table 4-18 Yukon Wildlife Species with Conservation Status

Species	Status	Source
Short eared owl (*Asio flammeus*)	Special Concern	COSEWIC
Common nighthawk (*Chordeiles minor*)	Threatened	COSEWIC (2007)
Olive-sided fly catcher (*Contopus cooperi*)	Threatened	COSEWIC (2007)
Rusty blackbird (*Euphagus carolinus*)	Special Concern	COSEWIC
Gyrfalcon (*Falco rusticolus*)	Specially Protected	Yukon Wildlife Act (2019)
Trumpeter swan (*Cygnus buccinator*)	Specially Protected	Yukon Wildlife Act (2019)
Barn swallow (*Hirundo rustica*)	Threatened	COSEWIC (2011)
Bank swallow (*Riparia riparia*)	Conservation Concern	Yukon Environment
Canada warbler (*Wilsonia canadensis*)	Threatened	COSEWIC
Northern shrike (*Lanius excubitor*)	Conservation Concern	Yukon Environment
Little Brown Bat (*Myotis lucifugus*)	Endangered	COSEWIC (2012)
Northern Long-eared Bat (*Myotis septentrionalis*)	Endangered	COSEWIC
Wolverine (*Gulo gulo*)	Special Concern	COSEWIC
Grizzly bear (*Ursus arctos*)	Special Concern	COSEWIC
Woodland caribou (*Rangifer tarandus caribou*)	Special Concern	COSEWIC (2002), SARA (2002)
Mule deer (*Odocoileus hemionus*)	Specially Protected	Yukon Wildlife Act (2019)
*Cougar (*Puma concolor*)	Specially Protected	Yukon Wildlife Act (2019)
Collared pika (*Ochotona collaris*)	Special Concern	COSEWIC (2011)

Note: Not all species listed in this table have been observed in the project area.

4.5.3 Recent Wildlife Surveys

Wildlife studies were completed in 2018 to obtain additional wildlife information to support the AKHM ERDC Reclamation Project. The objectives of the work conducted in 2018 were to:

- Determine what waterfowl species are using the ponds within the Valley Tailings, Germaine Lake and Christal Lake;
- Complete wildlife transects to identify what wildlife are using the area during the summer construction season in each habitat type around the proposed reclamation areas;
- Determine if bats are using adits or portals as habitat; and
- Collect knowledge of the wildlife presence around the site by interviewing long time workers for Alexco Keno Hill Mines.

Identified objectives were met by following standardized protocols for wildlife detection. Waterfowl surveys included Breeding Pair and Brood Count surveys. The methods used were based on the British Columbia waterfowl survey protocols (BC RIC, 1999). Wildlife transects were completed by walking a specified distance in varying habitats and recording any wildlife seen or heard. Bat surveys were completed by monitoring bat movement at adits through visual confirmation. Interviews were conducted with two long-time AKHM employees to determine species presence in the area through personal observations and experience.

The waterfowl survey confirmed the presence of breeding birds on all three sites sampled, with higher abundance on the third pond of the Valley Tailings. None of the waterfowl species identified during the survey are species of conservation concern. However, mitigations should still be implemented to avoid disturbance during the nesting season. One endangered species, the olive-sided flycatcher, was identified at Germaine Lake in the Keno-Ladue area. This species was noticed during two surveys, as the birds were constantly audible across the lake from the tailing's delta (suitable tree habitat available).

The transect survey confirmed the presence of species known to be in the Keno area. The collared pika was the only mammal observed during the survey and is rated as vulnerable in the Yukon. Therefore, protective measures identified in the Wildlife Protection Plan should be implemented.

The wood frog has been identified in the lower valley close to the VTF, mitigations should be considered before disturbing habitat areas. Although no wood frogs were identified in the VTF ponds during the summer surveys, potential breeding habitat is present. Breeding sites are the most important habitat for this species. The surveys did not identify any other potential species that would require additional or different mitigations measures to be included in the Wildlife Protection Plan.

Little brown bats are known to live in the area around Keno but have not been observed by any workers on the Keno mine property. The survey at Onek 400 indicate that little brown bats are not likely using abandoned adits in the Keno area.

Based on these results it was determined that:

1. No species at risk were found in the areas where reclamation will take place; and
2. No critical habitat has been identified within the footprint of disturbance in the project area.

Ensero Solutions conducted two waterfowl surveys in 2019 (June and July), to assess and document waterfowl breeding and rearing habitat for Germaine Lake (Keno-Ladue drainage), the Valley Tailings Ponds, and Christal Lake (AEG, 2019b).

At Germaine Lake, a total of 33 waterfowl were observed during the Breeding Pair Survey, representing seven species. During the Brood Survey, 61 waterfowl were observed representing five species. Moose and wolf tracks were also observed in the area.

At the Valley Tailings, a total of 54 waterfowl were observed during the Breeding Pair Survey, representing 12 species. Moose and wolf tracks were also observed in the area. The survey crew was not able to conduct the Brood Survey due to an active fire in the area.

At Christal Lake, a total of 16 waterfowl were observed during the Breeding Pair Survey, representing six species. During the Brood Survey, 68 waterfowl were observed representing five species. A muskrat was also observed during this survey.

Three Species at Risk, as listed through the Federal *Species at Risk Act*, by the Committee on the Status of Endangered Wildlife in Canada or under the *Yukon Wildlife Act*, were observed during the surveys.

Trumpeter Swans and Horned Grebe were observed nesting in Germaine Lake and the Valley Tailings Ponds. The Trumpeter Swan is listed under the *Yukon Wildlife Act* as Specially Protected (Government of Yukon, 2019). The Horned Grebe and Red-necked Phalarope are both listed as species of Special Concern by COSEWIC (2009 and 2014, respectively; COSEWIC 2019). Lesser Yellowlegs were observed in Germaine Lake, the Valley Tailings and Christal Lake and is listed as a Species under Review by COSEWIC (COSEWIC, 2019).

At this point, unless warranted by new information or changes to reclamation plans, no further wildlife assessments are recommended until reclamation activities commence.

4.6 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.

4.7 SOCIO-ECONOMIC

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

Keno City is a small community situated at the end of the Silver Trail Highway with a population of approximately 12 permanent residents. The community was originally established to support mining operations in the area and the community's population has fluctuated over the last hundred years in response to local mineral development activity. Today, Keno City is a small community with residences, a few small and growing businesses, the Keno City Mining Museum, and the Keno City Alpine Interpretive Centre.

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

4.7.1 Land and Resource Use

The regional land use within the KHSD has evolved from a long history of occupation and development. Significant development activity and local population fluctuations have historically occurred in the area. As such, land and resource use was selected as a Valued Component.

The general area is utilized for several purposes by a variety of users. Regional land use has been influenced by the following activities:

- the area has been utilized by First Nations for thousands of years;
- a variety of anthropogenic activities have occurred throughout the region including both hard rock and placer mining, forestry, hunting and gathering, transportation, recreation and residential;
- the project footprint overlaps with Registered Trapline Concession (RTC) #82;
- the sites lie within Rogue River Outfitters Ltd. (Duncan, BC) Registered Outfitting Concession (ROC#7), reported to operate near the KHSD;
- numerous historic mining related structures exist in the general area and are of interest to local community groups and government; and
- the area is known and used for recreational pursuits and has potential for tourism development.

4.7.1.1 Recreation and Tourism

Recreation and tourism are important in the Keno area and concerns have been raised by stakeholders about potential impacts on these values from mining activities in the KHSD.

Consistent with the trend in most small Yukon communities, tourism in the region has decreased over the past five years, as indicated by decreasing visitor numbers to the Mayo and Keno Visitor Information Centres (Derome & Associates, 2013). Fluctuations in visitor numbers in Keno City are consistent with the same trends in other communities within the Yukon.

4.7.1.2 Sport/Commercial Hunting, Fishing and Trapping

Very limited sport/commercial hunting or trapping is conducted in the KHSD, likely because of the high level of historic and present mineral development activity and general use of the area.

The project sites lie within RTC#82, which is currently unassigned (though FNNND have expressed interest in the trapline), and near RTC#83, assigned to Christine Hager. Alexco is aware of some trapping on Galena Hill, but otherwise trapping in the district is limited. Alexco personnel will continue to be instructed not to disturb trapping equipment or activities.

The KHSD lies within hunting outfitting concession #7, operated by Rogue River Outfitters. Hunting in the KHSD is not allowed due to employee safety concerns and its close proximity to current operations.

4.7.2 Local Economy and Human Resources

The economy of Keno City is based on tourism and mining. Consistent with the trend in most small Yukon communities, tourism in the region has decreased over the past five years, indicated by decreasing visitor numbers to the Mayo and Keno Visitor Information Centres (Derome & Associates, 2013). In addition to the Keno City Mining Museum, which provides excellent historical perspective on the KHSD, a population of butterflies also exists in the region and attracts interested individuals. The Signpost Viewpoint on Keno Hill Summit also attracts numerous tourists throughout the summer months.

Tourism in the Mayo area is an important industry. Accommodations, food services, recreation services (i.e., guiding and outfitting) and retail cater to tourists and provide employment for local residents. Tourist attractions in the area are linked with the history of mining around Mayo and Keno City. Camping and hiking, hunting and fishing, and other outdoor pursuits comprise the activities undertaken by tourists in the area.

The economy of Mayo is linked to the provision of services to the people of Mayo and the surrounding areas. One third of the jobs in the community are related to government services, including First Nation and territorial administration. Placer mining and mineral exploration and development also provide an economic base for the community. Construction also provides considerable employment to Mayo residents.

The Mayo Official Community Plan (OCP) outlines local economic conditions and describes community priorities: "Mayo's economy is presently based on its role as a regional administrative and service centre, mineral exploration and placer mining and tourism. In addition, traditional activities play a large role in the community's economic life. Diversification and stabilization of the regional economy remains a community priority" (Mayo OCP, 2006, p. 11). The Mayo Official Community Plan recognizes opportunities for local economic diversification in terms of supporting mineral exploration and development, expanding the local service sector, maximizing the use of the local labour force and reducing dependence on outsiders to fill local employment opportunities.

In cooperation with industry (developers/companies), the FNNND Development Corporation is establishing a number of training, work, and apprenticeship programs in the community. The First Nation works toward participation in land and resource development in their traditional territory and employs many FNNND citizens.

4.7.2.1 Heritage Resources

The KHSD has rich historical significance and is characterized by numerous historic and heritage resources, largely related to past mineral development. As part of the KHSD Closure Plan, ERDC is developing a district-wide heritage plan in consultation with stakeholders, including YG Heritage Resources, FNNND, the Silver Trail Tourism Association, the Binet House Museum, the Village of Mayo, Keno City Mining Museum, Keno City and Indigenous and Northern Affairs Canada (INAC).

Heritage Resources in the KHSD in general are known and, in many cases, documented. The extent of new footprint associated with the KHSD is limited and no heritage resources are known to exist in that area. In order to mitigate potential significant effects of the project on heritage resources, Alexco implements the Heritage Resources Protection Plan developed under QML-0009.

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 1-1shows 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, UKHM 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 PriceWaterhouse Coopers 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 (Table 5-1).

Table 5-1 Keno District Mine Timeline

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 & 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 – 2020:	Permitting and development of Flame & Moth and Bermingham mines. Continued surface exploration, advanced underground exploration decline at Bermingham deposit. Decline development at Flame & Moth and Bermingham mines. Care and maintenance and water treatment.
2021:	Ore production from Bellekeno. Camp, surface facilities, mill upgrades, mine development at Flame & Moth and Bermingham, ore production from Bermingham

5.2 MINING AND MILLING OPERATIONS

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 & Moth and Bermingham.

The RCP incorporates underground mines and deposits that are in a variety of phases including active mines (Bellekeno, Flame & Moth, and Bermingham), and the current disturbance at the two mines which are permitted under the QML but not in the Water Licence. Table 5-2 presents a summary of the current Keno Hill Mine Operations. This RCP also includes reclamation of existing disturbance from the two mines which are permitted but not licenced (Onek and Lucky Queen).

Table 5-2 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 & 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) Flame & Moth, Bermingham (in development and production) Lucky Queen, Onek (permitted but not licenced and not active)
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 (Bellekeno, Flame & Moth, Bermingham) for a total of ~1,38 M tonnes of ore
Mine Waste Rock	796,400 tonnes of waste rock from underground development, of which 768,300 is required for structural backfill 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 & 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 & Moth, Bermingham. Ammonia treatment via breakpoint chlorination at Flame & Moth and Bermingham.
First Nations	First Nation of Na-Cho Nyak Dun

5.3 MINE OPERATIONS PLAN

Active mining and milling operations are currently underway at the Keno Hill Mine Operations. Table 5-3 summarizes the mine operations schedule and history over the last 10 years from its current status through the completion of the current Life of Mine (LOM) plan. A more detailed project schedule is included as Table 5-3.

Table 5-3 Mine Development Timeline

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 & Moth YESAB assessment and decision document • Surface exploration • District care and maintenance
2015	• Surface exploration, Flame & Moth, Bermingham • District care and maintenance
2016	• QML-0009 amended for Flame & Moth development • Begin development of Flame & Moth underground portal, surface facilities construction • Surface exploration Bermingham • District care and maintenance
2017	• WL QZ12-053 amended for Flame & 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 & Moth decline, completed initial development in Q4 2018 • District care and maintenance
2019	• QML-0009 amended for Bermingham development • District care and maintenance
2020	• WL QZ18-044 amended for Bermingham production • District care and maintenance
2021	• Commence and complete mining of Bellekeno • Commence mining of Bermingham and Flame & Moth ore
2022-2027	• Operate Bermingham and Flame & Moth mines
2027	• Complete mining of Bermingham
2028	• Complete mining at Flame & Moth • Commence closure plan activities • District care and maintenance
2029 - 2037	• Care and Maintenance of AKHM mines for term of Water Licence

5.4 MINE PRODUCTION

The Keno Hill Mine Operations comprise a series of small underground mines which a centralized mill (Keno District Mill). The Keno District Mill is designed for 400 tpd. The current LOM mine plan includes a combination of Bellekeno, Flame & Moth, and Bermingham operating over an 8 year period.

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. Depending on the various parameters, mines may come in and out of the LOM plan as factors change.

Table 5-4 presents the current LOM plan that is the basis for the RCP. The LOM plan was based on mine development and operations beginning in 2021.

Table 5-4 Keno Hill Mine Operations LOM Plan (Bellekeno, Flame & Moth and Bermingham)

Consolidated Mine Plan	Total	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Mill Feed Tonnes	1,367,700	67,100	132,400	180,500	201,400	202,000	202,200	189,200	158,600	34,300
Waste Tonnes	796,400	99,500	160,200	187,600	193,500	98,900	44,600	12,100	0	0
Total Tonnes	2,164,100	166,600	292,600	368,100	395,000	300,900	246,700	201,300	158,600	34,300
MCF (Tonnes)	656,500	50,900	100,700	122,000	138,600	118,900	60,300	49,300	15,800	0
LHOS (Tonnes)	707,800	12,800	31,600	58,500	62,900	83,100	141,800	139,900	142,800	34,300
MCF Backfill Tonnes	473,400	38,500	81,500	83,400	120,300	66,200	37,800	30,500	15,300	0
LHOS Backfill Tonnes	294,900	0	0	0	0	33,800	70,200	80,800	80,000	30,100
Total Backfill Tonnes	768,300	38,500	81,500	83,400	120,300	100,000	108,000	111,300	95,300	30,100
Development (m)	18,600	2,400	3,600	4,400	4,600	2,400	1,000	300	0	0

Notes:

1. Development (m) are lateral and vertical metres
2. Mill feed tonnes are all Probable Mineral Reserves calculated from current Alexco Technical Report (Alexco, 2021).
3. Rounding as required by reporting guidelines may result in apparent summation differences between tonnes;
4. Tonnages are diluted and recovered
5. Tonnage are in metric units.

Table 5-5 LOM Plans for Individual Mines Currently Licenced

Bellekeno	Total	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Mill Feed Tonnes	**16,206**	16,206	-	-	-	-	-	-	-	-
Ag(g/t)	**981**	981	-	-	-	-	-	-	-	-
Au(g/t)	-	-	-	-	-	-	-	-	-	-
Pb (%)	**15**	14.82	-	-	-	-	-	-	-	-
Zn (%)	**7**	6.72	-	-	-	-	-	-	-	-
Waste Tonnes	-	-	-	-	-	-	-	-	-	-
Total Tonnes	**16,206**	16,206	-	-	-	-	-	-	-	-
MCF Tonnes	-	-	-	-	-	-	-	-	-	-
LHOS Tonnes	**12,809**	12,809	-	-	-	-	-	-	-	-
MCF Backfill Tonnes	-	-	-	-	-	-	-	-	-	-
LHOS Backfill Tonnes	-	-	-	-	-	-	-	-	-	-
Total Backfill Tonnes	-	-	-	-	-	-	-	-	-	-
Development (m)	-	-	-	-	-	-	-	-	-	-

Flame & Moth	Total	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Mill Feed Tonnes	**721,322**	25,684	64,406	76,761	82,458	82,038	82,308	114,704	158,646	34,315
Ag(g/t)	**672**	648	698	751	961	802	674	550	537	489
Au(g/t)	**0.49**	0.34	0.43	0.44	0.66	0.64	0.59	0.46	0.38	0.38
Pb (%)	**2.69**	2.6	2.8	3.13	5.84	3.85	2.09	1.79	1.53	1.09
Zn (%)	**6.21**	6.72	7.98	5.93	5.05	7.27	5.95	5.8	5.96	6.64
Waste Tonnes	**385,709**	47,779	81,247	93,359	102,387	45,943	8,957	6,037	-	-
Total Tonnes	**1,107,031**	73,463	145,653	170,120	184,846	127,981	91,266	120,741	158,646	34,315
MCF Tonnes	**356,198**	25,684	42,101	42,438	81,299	69,646	45,050	34,158	15,821	-

Flame & Moth	Total	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
LHOS Tonnes	**365,124**	-	22,306	34,323	1,159	12,391	37,258	80,546	142,826	34,315
MCF Backfill Tonnes	**239,514**	20,352	29,915	28,812	52,472	51,722	24,103	16,873	15,265	-
LHOS Backfill Tonnes	**153,116**	-	-	-	-	-	-	42,996	79,989	30,131
Total Backfill Tonnes	**392,630**	20,352	29,915	28,812	52,472	51,722	24,103	59,868	95,254	30,131
Development (m)	**8,939**	1,127.76	1,740.53	2,228.38	2,333.22	1,099.23	245.62	163.88	-	-

Bermingham	Total	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Mill Feed Tonnes	**630,173**	25,220	67,984	103,692	118,977	119,965	119,849	74,487	-	-
Ag(g/t)	**899**	1,218	1,450	1,011	806	645	844	775	-	-
Au(g/t)	**0.13**	0.1	0.16	0.14	0.13	0.12	0.13	0.11	-	-
Pb (%)	**2.26**	3.02	3.05	2.69	1.78	1.54	2.37	2.47	-	-
Zn (%)	**1.3**	1.74	1.44	1.2	1.27	1.08	1.49	1.24	-	-
Waste Tonnes	**410,652**	51,676	78,945	94,268	91,132	52,921	35,626	6,083	-	-
Total Tonnes	**1,040,825**	76,896	146,929	197,960	210,109	172,886	155,475	80,570	-	-
MCF Tonnes	**300,344**	25,220	58,645	79,528	57,253	49,274	15,280	15,144	-	-
LHOS Tonnes	**329,829**	0	9339	24164	61723	70690	104570	59343	-	-
MCF Backfill Tonnes	**233,934**	18,166	51,590	54,544	67,827	14,451	13,708	13,648	-	-
LHOS Backfill Tonnes	**141,768**	0	0	0	0	33825	70162	37781	-	-
Total Backfill Tonnes	**375,702**	18,166	51,590	54,544	67,827	48,276	83,870	51,429	-	-
Development (m)	**9,707**	1,247	1,846	2,200	2,257	1,251	741	166	-	-

Table 5-6 Keno Hill Mine Operations LOM Plan & Decommissioning and Reclamation Plan Schedule

Phase / Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030 → 2039
	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	
	Mine Development/Operations/Progressive Reclamation								Final Closure		Post Closure Monitoring and Maintenance
Bellekeno Production Unit Area											
- Underground Development/Operations											
- Reclaim Bellekeno East Portal Site											
- Reclaim Bellekeno 625 Adit Site											
- 625 Coffer Dam Installation											
- Bellekeno Mine Flooding and Insitu Treatment											
- Bellekeno 625 Bioreactor Construction											
- Backhaul P-AML Underground											
- Reclaim N-AML Facility											
- 200 Level Vent Raise											
Flame and Moth Production Unit Area											
- Underground Development/Operations											
- Underground Backfill											
- Portal Closure											
- Mine Flooding											
- Backhaul P-AML Underground											
- Reclaim N-AML Facility											
- Vent Raise											
Bermingham Production Unit Area											
- Underground Development/Operations											
- Underground Backfill											
- Portal Closure											
- Mine Flooding/In Situ Treatment											
- Backhaul P-AML Underground											
- Reclaim N-AML Facility											
- Vent Raise											
Lucky Queen Production Unit Area											
- Underground Development Operations											
- Underground Backfill											
- Reclaim Lucky Queen 500 Level Portal Site											
- Reclaim N-AML Facility											
- Vent Raise											
Onek Production Unit Area											
- Underground Development Operations											
- Reclaim Onek 990 Portal Area											
- Vent Raise											
Roads											
- Access Road Extension Bellekeno East to Bellekeno 625											
- Bellekeno Haul Road											
- Keno City Bypass											
- Mill Site Access Including Christal Lake Road											
- Lucky Queen Bypass Road											
- Bermingham Mine Road											
- Other Roads and Trails											
Mill & Facilities											
- Active Milling Operations											
- Mill and Ancillary Facilities											
- Mill Pad											
- Ore/Tailings Stockpile Pads											
- Runoff Collection Pond(s)											
- Diversion Ditches to Collection Pond											
Dry Stack Tailings Facility Cover											
Tailings to Phase 1											
Tailings to Phase 2											
- Progressive Reclamation											
- Final Cover Reclamation											
Camp Downsize											
Post Closure Site Management (monitoring & maintenance)											

Active Operations
Reclamation and Closure
Water Management

5.5 MINING

5.5.1 Mining Methods

The mining methods employed at the underground mines associated with the Keno Hill Mine Operations are common and well proven mining methods. Mine methods are selected based on deposit geometries, geotechnical conditions, production rates, and other constraints. The mining methods are predominantly longhole open stoping and mechanized cut and fill. A brief description of each follows.

Mechanized Cut and Fill (MCF) mining is a method of short hole mining used in a wide range of deposit geometries and will be the dominant mining method for Flame & Moth and Bermingham. In MCF method, an attack ramp is developed from the main ramp at a gradient of -15%. Upon reaching the orebody, an intersection is developed and a lift is developed in both directions along strike, following the geological contact of the orebody. At the end of the lens, the void is backfilled using either unconsolidated rock fill or cemented rockfill (CRF) with a Load Haul Dump (LHD) machine. The LHD utilizes a rammer-jammer plate (a dozer plate modified to be attached to a scoop to push waste tight to the back) to ensure that the backfill is placed tight to the back of the drift.

Once the level has been completely backfilled, the next lift above the previously mined lift is accessed by slashing down the back of the attack ramp and working off the muck pile/horizon. Figure 5-1 illustrates the sequence of activities with MCF mining.

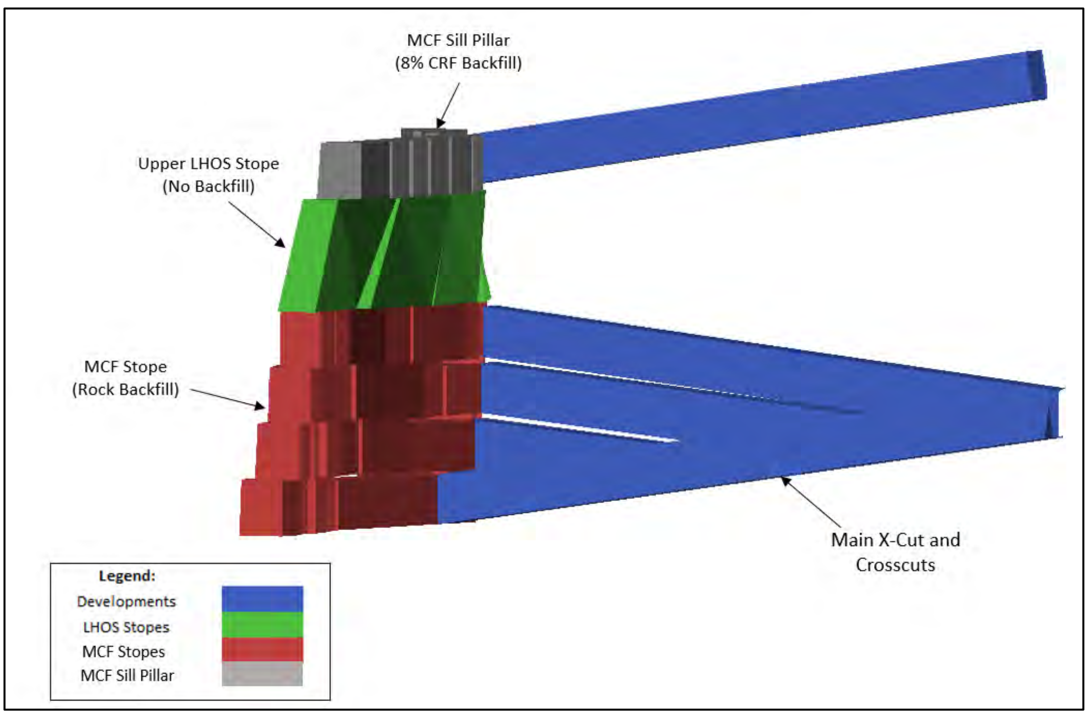


Figure 5-1 MCF lifts with Uphole Stopes Section

MCF drift are on average 4.0 m high with varying widths, based on the deposit geology. For areas wider than development equipment is capable of mining or supporting, a second parallel drift will be mined beside the backfilled drift to fully extract the orebody width prior to accessing the lift above. In this situation, the first drift will be completely backfilled with cemented rock fill to ensure a stable wall to allow adjacent mining activity.

For the Bermingham and Flame & Moth deposits, the lifts are sequenced bottom up within each panel; however, to maximize productivity the panels are mined from the top down as they are accessed by the ramp spiraling down. As such, a pillar will remain between the top lift of one panel and the bottom lift of the panel above. These pillars will be extracted using an uphole drill and blast method discussed later in this Section.

Long hole open stoping ("LHOS") is the preferred mining method when the ground conditions and the lens geometry allow. In LHOS, two drifts are developed along the strike of the orebody at a vertical spacing selected based on geotechnical constraints for that zone. After development is completed, blasting rings are drilled in parallel from the top level to the bottom level. Hole diameter and blast design follow industry best practice and are detailed in Alexco's standard operating procedures. Several rows will also typically be pre-loaded to minimize the loading crew's exposure to the open stope brow.

An initial slot is developed by drilling and blasting a drop raise made up of multiple holes in close spacing. Hole diameter and blast design follow industry best practice and are detailed in Alexco's standard operating procedures. Once this initial slot has been blasted (retaining a minimum pillar below the top drift) the entire stope is blasted and mucked using a LHD. All remote mucking will be carried out using a LHD equipped with a remote package.

Stope strike lengths are based on the geotechnical analysis that has been performed and is detailed in the sites' Ground Management Control Plan (AKHM 2021a, 2021b). Typical stope lengths vary from approximately 8 m to 20 m.

Once the stope is empty, the stope is backfilled with Cemented Rock Fill (CRF). Cemented rockfill mix design and curing times to achieve required strengths were determined by an independent consultant and are detailed in Alexco's standard operating procedures. Figure 5-2 illustrates the LHOS Method. LHOS will be used in the Flame & Moth deposit at Christal and Lightning zones, as well as NE and Arctic zones of the Bermingham deposit.

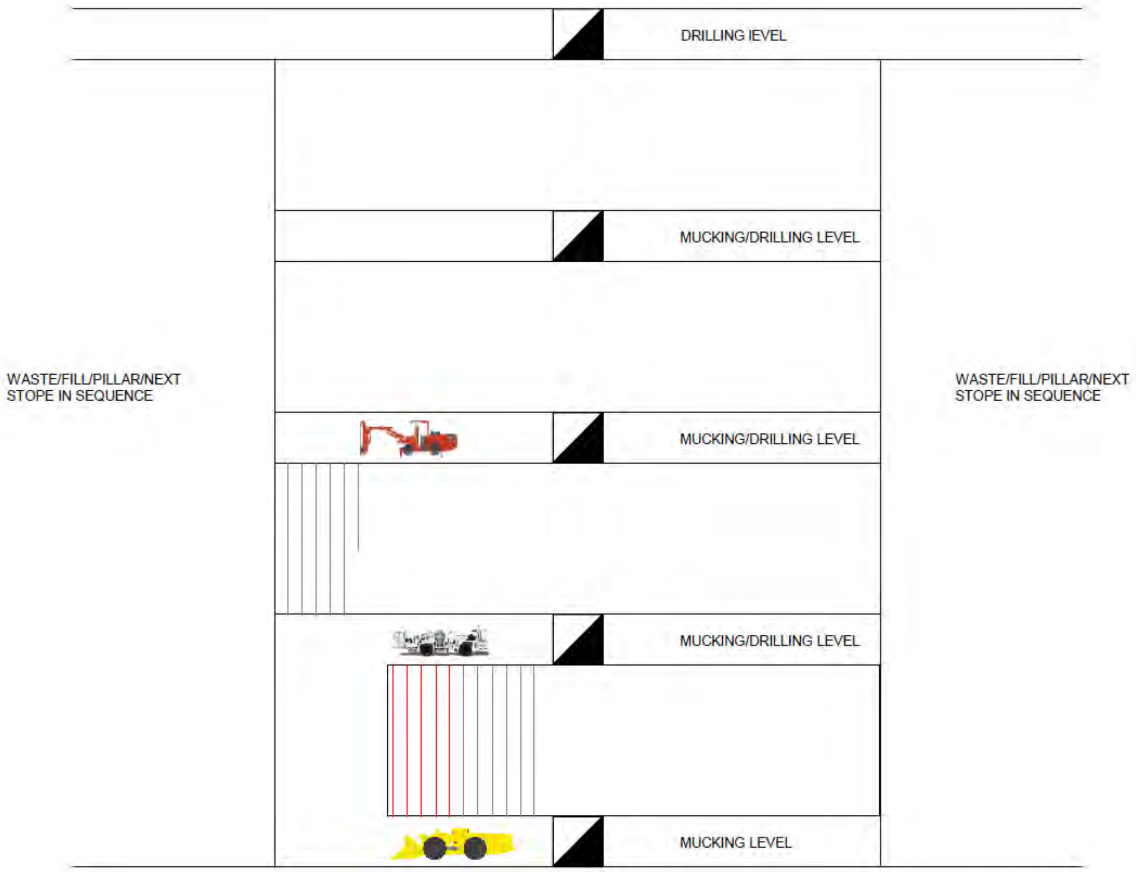


Figure 5-2 (Downhole) Longhole Stoping

A modified version of LHOS will be used at the top of a MCF level to extract the sill pillar between MCF panel and the panel above, or in areas where there is no access for a top drift. Cemented rockfill mix design and curing times to achieve required strengths for the CRF pillar above the uphole stope were determined by an independent consultant and are detailed in Alexco's standard operating procedures. In uphole stoping, a series of parallel rings are drilled from the bottom drift into the back, to the limit of the lens. An inverse raise is drilled and blasted on the extremity of the stope. The longhole rings are then blasted into the void created by the raise and mucked using a remote-operated LHD. No backfill is necessary in this method. Figure 5-3 illustrates the uphole stoping method.

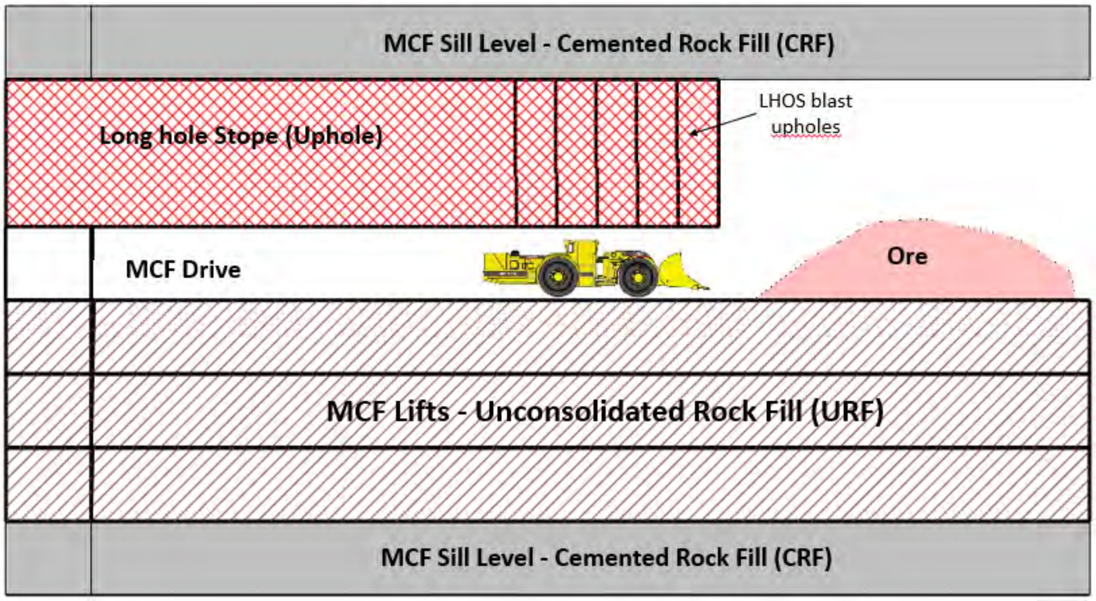


Figure 5-3 Uphole Longhole Stoping

The only mining method used at Bellekeno Mine will continue to be uphole LHOS to extract a mostly developed panel at the beginning of mine production. Uphole LHOS will also be used to extract sill pillars in the Bermingham and Flame & Moth mines. LHOS method will not be used at Lucky Queen Mine.

5.5.2 Backfill

Backfill materials consisting of development waste rock (N-AML and P-AML) and dry filtered tailings will be placed into empty stopes by Load Haul Dump (LHD) or 15-tonne trucks. The mix of these materials was determined based on geotechnical requirements and characteristics of backfill materials available (Minefill, 2021). Backfill mix design will also aim to minimize the surface environmental impact while optimizing the most efficient and cost-effective back filling sequence.

Based on the planned stopes geometry, the required strength for each stope, with a factor of safety of 1.3, was determined. Material samples sourced from Flame & Moth and the mill were sent to an independent laboratory to determine the optimal mix design to achieve the required strength. Refer to the Laboratory Test Report (Minefill, 2021) for detailed required strengths, mix design for each type of placement, and curing times.

Cemented backfill with the same cement by weight will be used in longhole and cut and fill stopes, except for the first lift of cut and fill stopes, where cement contentment will be higher. 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.

For cut and fill stopes, the backfill will be pushed up tight to the back using an LHD equipped with a rammer jammer. For long hole stopes, the backfill procedures vary depending on stoping methods. For conventional downhole stopes, the backfill will be placed by dumping rockfill or cemented rockfill from the top access using

LHDs or underground trucks. For pillar recovery (up hole stopes), no backfill is necessary. They will be filled with P-AML and N-AML as needed for waste management.

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. These materials should be placed into headings as tight to the back as possible. An increased cement content 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.

Quality assurance and quality control (QA/QC) procedures are in place to ensure backfill procedures are appropriate for short and long-term stability requirements.

5.5.2.1 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 three 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.

5.5.3 Ground Control

A third party geotechnical ground control management plan (GCMP) has been developed for each mine that governs the ground support methodology (AKHM 2021a, 2021b). 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.

5.5.4 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. The mill was constructed in 2009 and 2010. The mill achieved commercial production in January 2011 using Bellekeno ore, and operated until 2013. The mill was then put into Care and Maintenance, which lasted until 2021. In 2020 and 2021 minor modifications were made to the mill to improve throughput and recovery. Further improvements are planned to be completed in Q3 2023 to increase the throughput from 400 to 550 tpd. Recommissioning of the mill commenced in 2021. An overview of the District Mill and supporting infrastructure is shown in Figure 5-4.

Figure 5-4 District Mill Infrastructure Overview

5.5.4.1 Mill Design Criteria

The overall mill site layout is shown in Figure 5-5. Design criteria for the mill operations are summarized in Table 5-7.

Table 5-7 District Mill Design Criteria

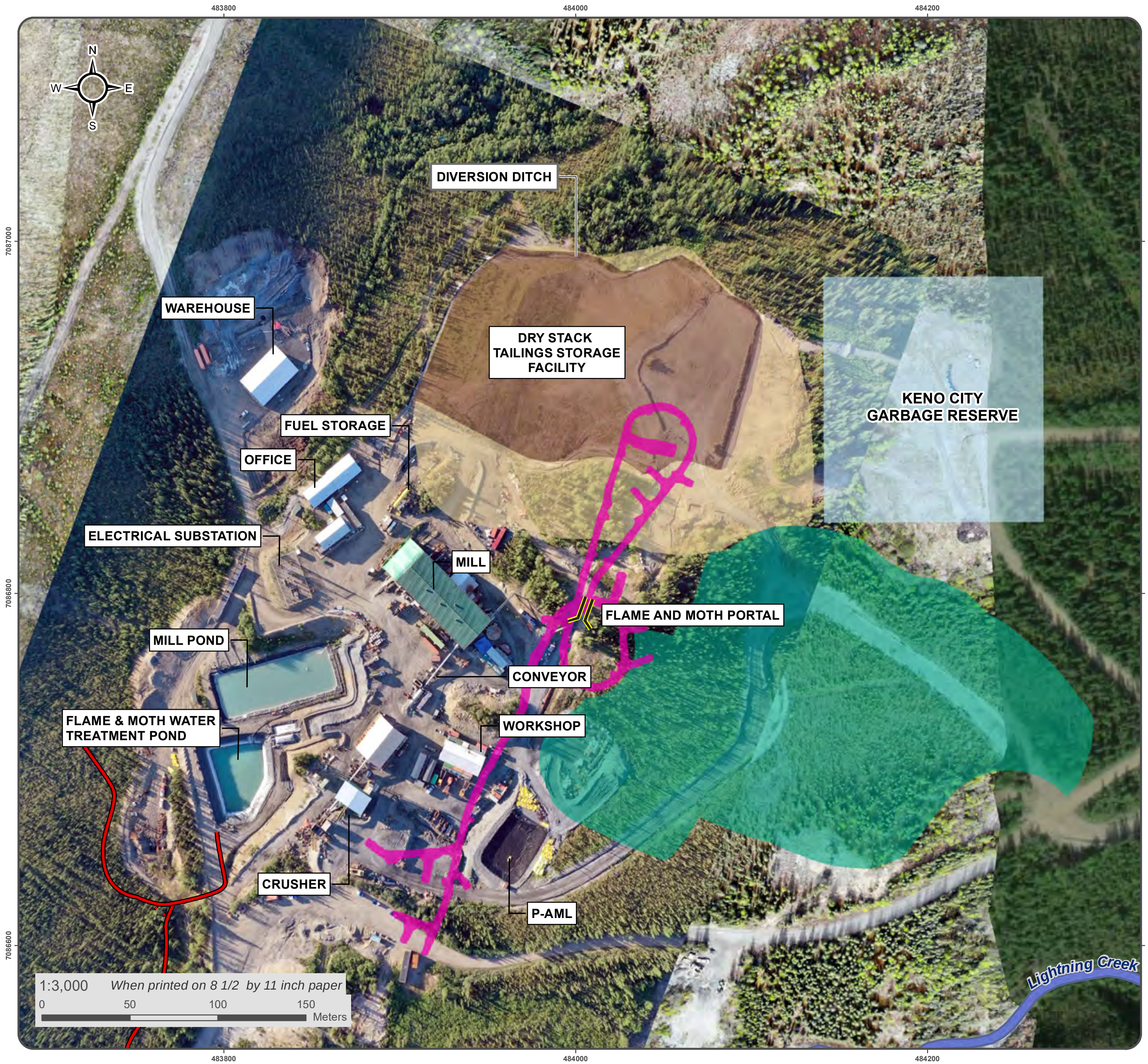
Descriptions	Unit	Values
Daily Processing Rate	tpd	400
Annual Operating Days	d/y	365
Operating Schedule – Crushing		1 shift per day (12 h/shift)
Operating Schedule – Grinding/Flotation		2 shifts per day (12 h/shift)
Crushing Availability	%	75
Grinding/Flotation Availability	%	92
Head Grades, LOM Average		
Ag Grade	g/t	805
Au Grade	g/t	0.34
Pb Grade	%	2.98
Zn Grade	%	4.13
Bond Ball Mill Work Index	kWh/t	10.5
Grinding		
Feed Particle Size P80	µm	12,000
Product Particle Size P80	µm	100 to 120
Regrinding		
Lead Rougher Concentrate Particle Size P80	µm	30
Zinc Rougher Concentrate Particle Size P80	µm	30
Flotation Stages		Pb Ro/3-stage Cleaner flotation followed by Zn Ro/3-stage Cleaner flotation
Tailings Management:		
Tailings		Surface Dry Stack, with portion of F&M tailings used for underground backfill

ALEXCO KENO HILL MINING CORP.

FIGURE 5-5

DISTRICT MILL AND FLAME AND MOTH LAYOUT

NOVEMBER 2021



- Adit
- Pipeline
- Decline
- Waterbody
- Land Disposition
- DSTF 322k Tonnes Design
- Current DSTF
- Permitted To Be Constructed Features

Aerial Imagery aquired on August, 2020.

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

AKHM

D:\Project\AllProjects\Keno_Area_Mines\ALL-SITES\02-Map\01_Overview\02-District Mill\District_Mill_20211118.mxd
(Last edited by: tosberg;11/22/2021/11:37 AM)

5.5.5 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 cyclones to produce a grinding product of 80% passing 110 µm;
- the cyclone overflow feeding to lead rougher scavenger flotation circuit to recover lead and silver minerals; the lead rougher flotation concentrate regrind followed by being upgraded in three stages of cleaner flotation;
- the zinc rougher flotation concentrate regrind followed by 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 5-6.

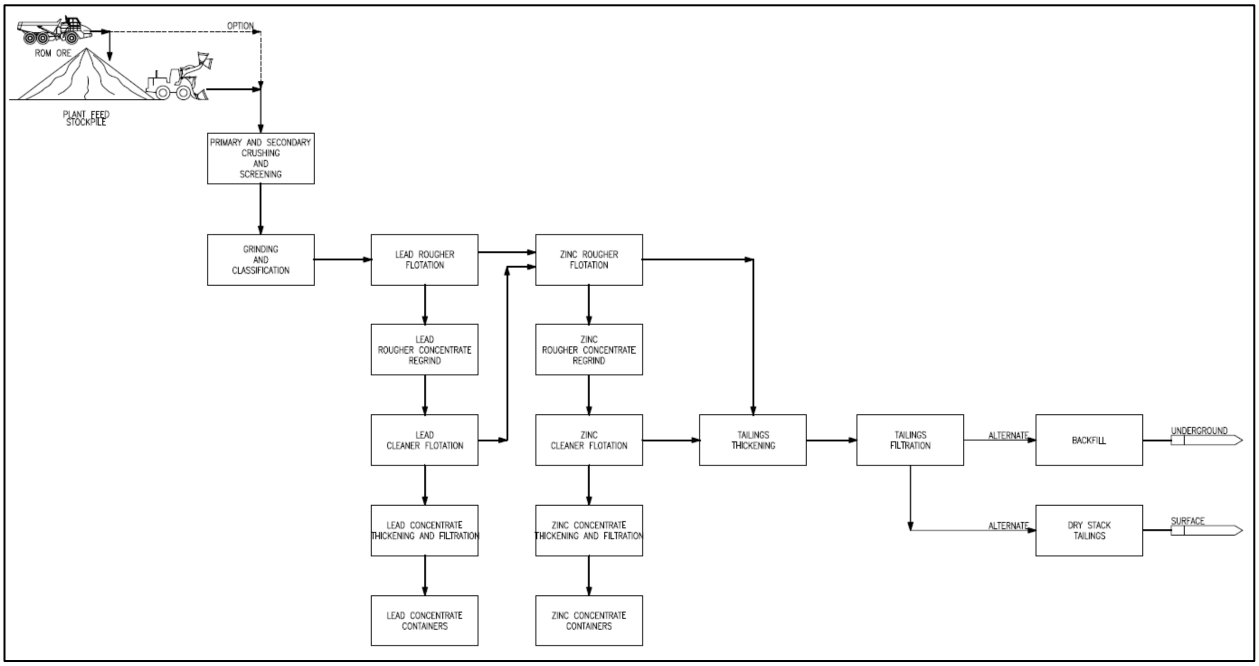


Figure 5-6 District Mill Process Flowchart

5.6 DRY STACK TAILINGS FACILITY

Alexco employs Dry Stack Tailings technology for management and long term 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 5-7. The detailed design of the DSTF phase I is presented in Figure 5-8 and Figure 5-9.

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 5-7 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 of which approximately half has been filled in the previous mine operation. The DSTF phase 2 is located immediately adjacent to the current Phase 1 DSTF and has a design capacity of 585,000 t. It is expected that the DSTF will be expanded to Phase 2.

The Phase 2 expansion will be constructed using the same foundation systems, tailings placement techniques and geometry (side slopes and bench elevations) as the current DSTF design. All other conditions regarding placement and compaction of the tailings is detailed in the DSTF Operation, Maintenance, and Surveillance Manual (EBA, 2010) are assumed to remain the same as the those used in the current facility. The subsurface conditions within the footprint of the expansion are assumed to be generally similar to those under the existing approved footprint, but will be investigated as part of the detailed design. The design for Phase 2 is shown in Figure 5-10.

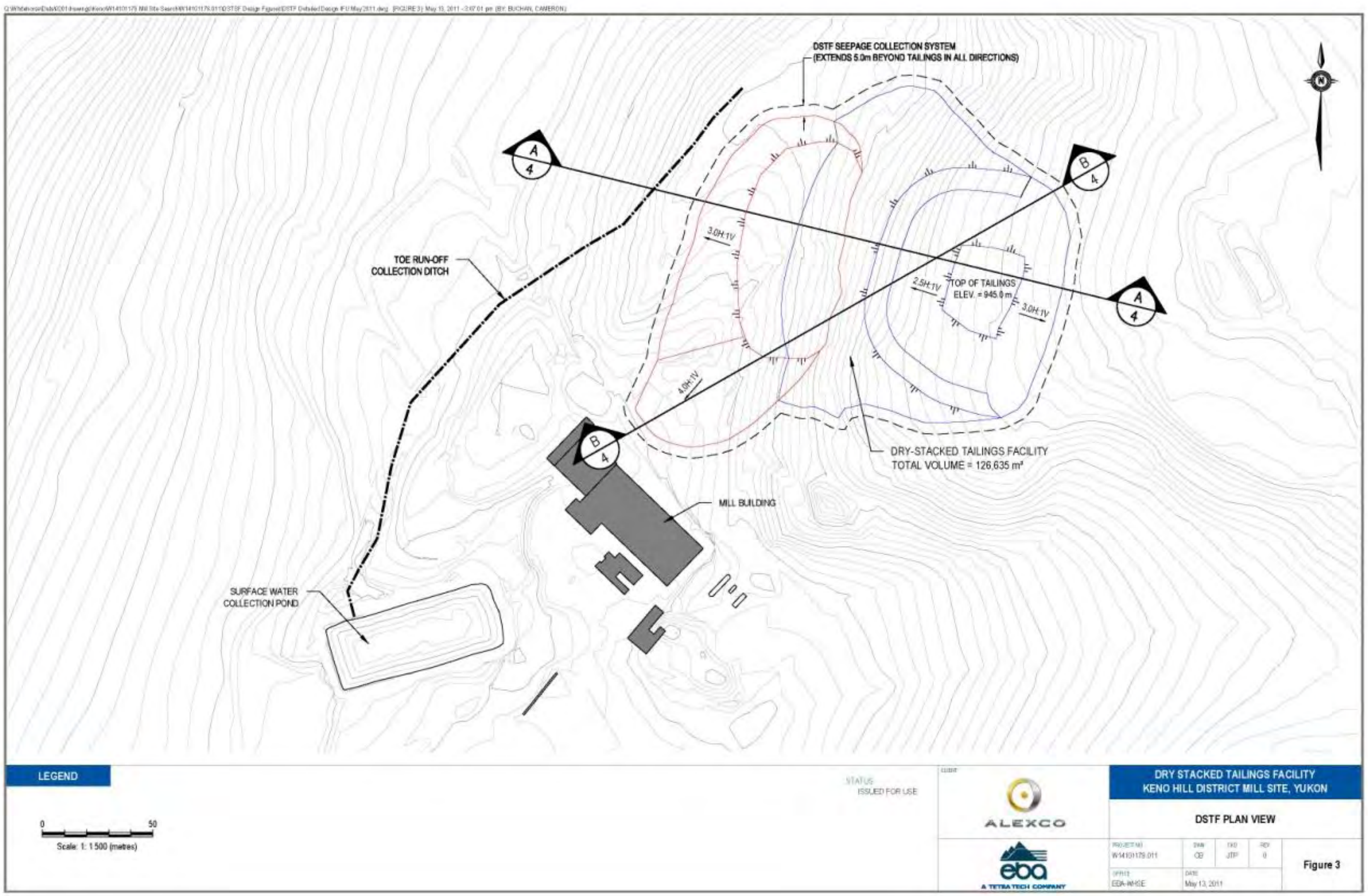


Figure 5-8 DSTF Phase I Plan View

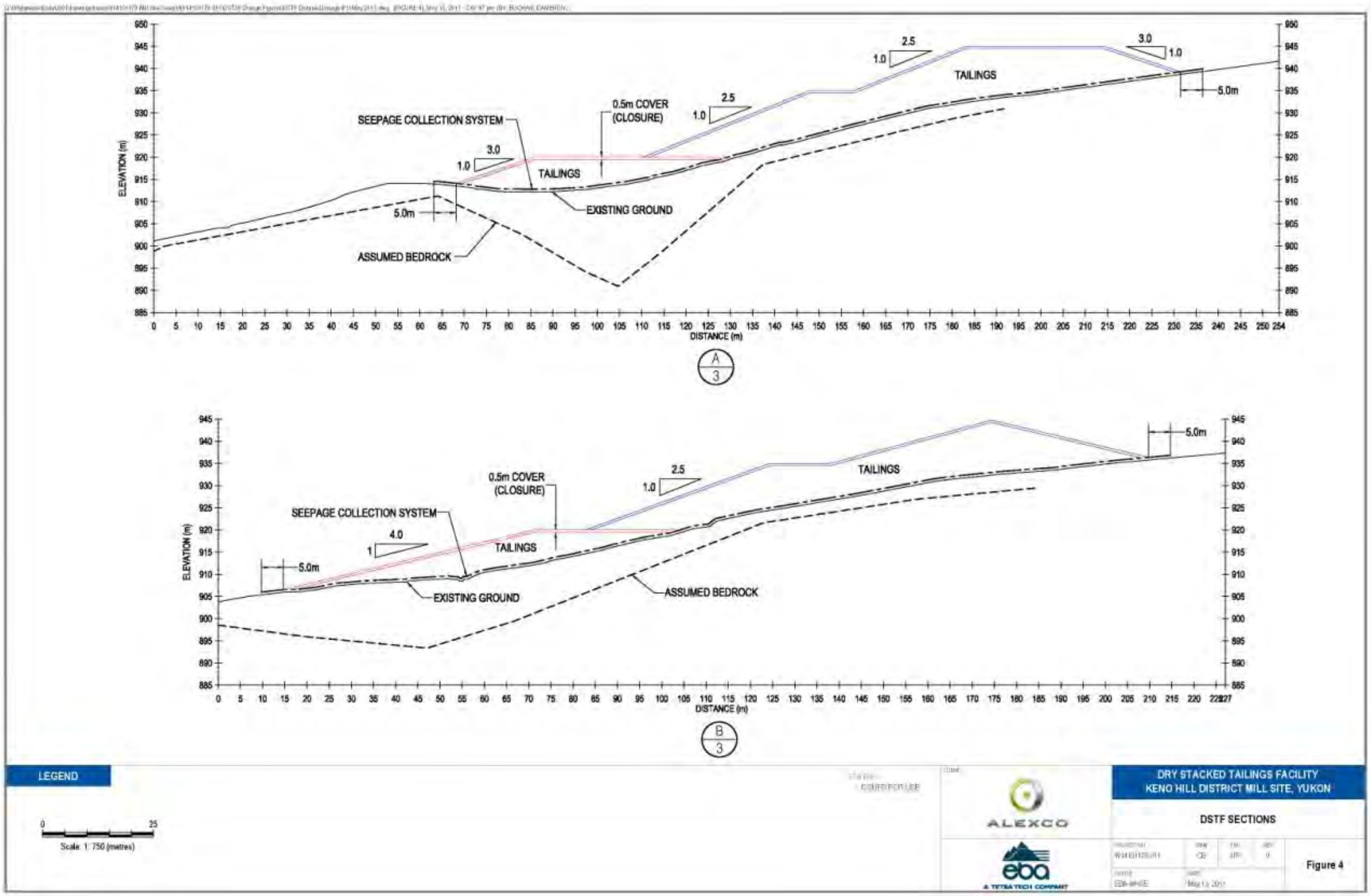
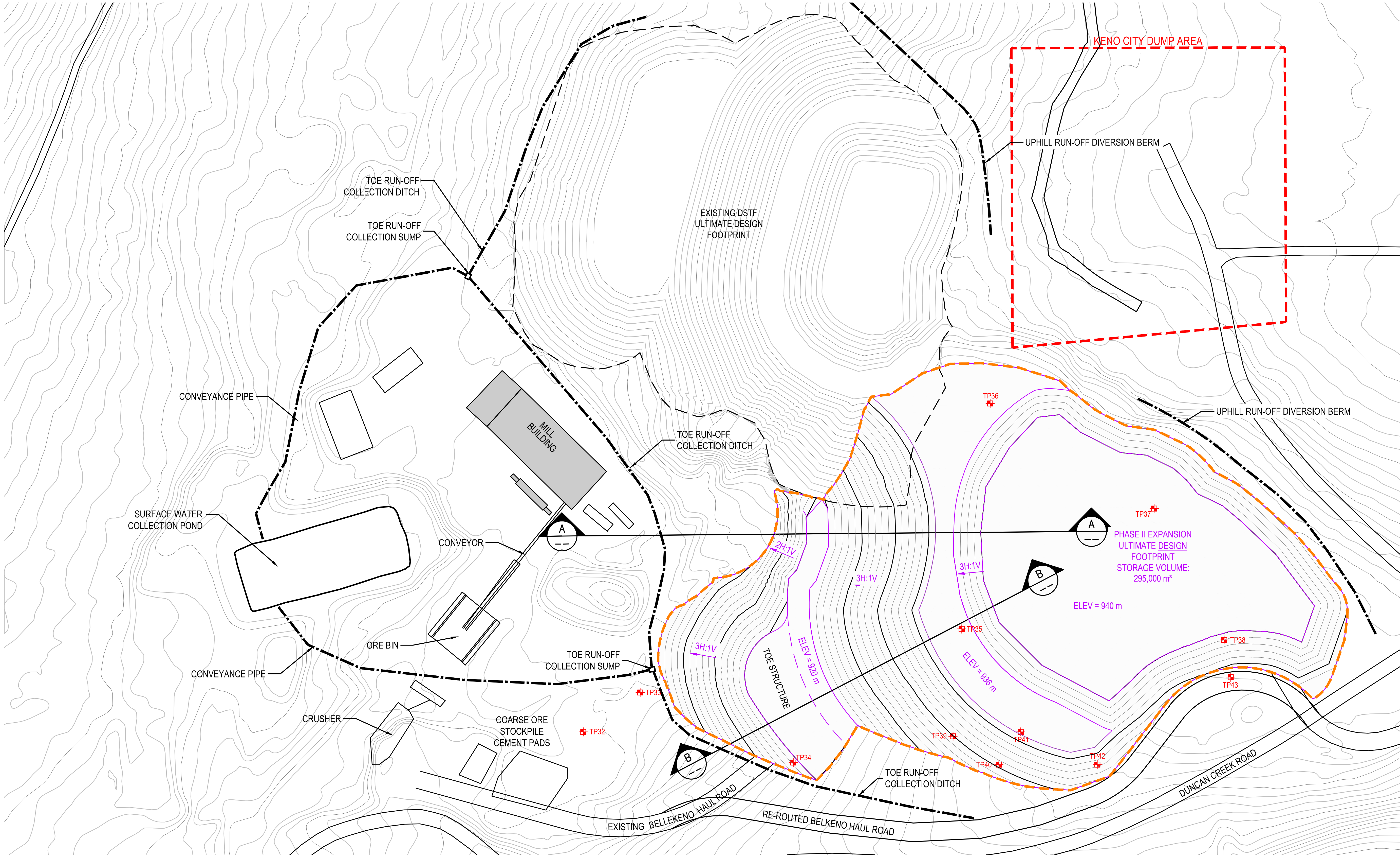


Figure 5-9 DSTF Phase I Sections



LEGEND:

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

0 — 100

Scale: 1 : 1750 (metres)

CLIENT

ALEXCO

TETRA TECH EBA

DRY STACKED TAILINGS FACILITY E ANSION HASE II
KENO HILL DISTRICT MILL SITE, YUKON

DSTF PHASE II EXPANSION

PROJECT NO.	DWN	CKD	REV
W14103548-01	CB	JTP	1

OFFICE	DATE
EBA-WHSE	May 15, 2015

Figure 5-10

Q:\Whitehorse\Data\0201drawings\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)

5.7 OPERATIONS WATER MANAGEMENT

The Water Management Plan (Ensero & AKHM, 2020c) describes protocols for decision making on water management for each of Bellekeno, Flame & Moth and Bellekeno mines. Storage and settling ponds have been constructed at each site and include berms built up around all sides to ensure no surface runoff enters the ponds. All water management pond designs have a freeboard of 0.5 m to ensure collection of the 1 in 100 year 24 hour maximum rain event.

Mass load model for No Cash Creek, Christal Creek and Lightning Creek were developed by Ensero and Interralogic, Inc./ Hatch using the GoldSim simulation framework. The load models calculated metal loadings for three phases of the project: pre-mining development, operations, and reclamation and post-closure. The largest proposed loading source, Flame & Moth Mine discharge, is only of short duration and will cease at the end of the mine life. These load models formed the basis for the EQS defined within Water Licence QZ18-044.

The water management is focused on ensuring all water discharged from site is compliant with the EQS. The main features of water management include and are discussed in more detail in the following sections:

- Lime water treatment plants are used to remove dissolved metals from adit drainages at Flame & Moth, Bermingham and Bellekeno;
- A breakpoint chlorination system was constructed and commissioned in 2021 to remove ammonia from the Bermingham adit drainage when required;
- Water storage in ponds near each of the adits for use within the mill, and for underground development;
- Water management structures, including berms, ditches, and temporary water storage ponds, have been established to convey water around N-AML WRDA and P-AML waste rock storage facilities and direct water to appropriate locations to be discharged to ground. Any runoff from N-AML WRDA is conveyed to the environment. At Bermingham the diversion ditch is located upgradient of the Bermingham portal, and diverts clean water around surface facilities to a point approximately 0.65 km uphill of the No Cash Creek headwaters. If water accumulates within the P-AML facilities this water is collected and treated at a water treatment plant prior to discharge; and
- Tailings produced is deposited in the permitted existing lined Phase 1 DSTF, which will be expanded into the Phase 2 footprint when required. The DSTF is a lined and bermed facility that conveys any runoff from the DSTF area to the Mill pond.

5.7.1 Bellekeno

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 to allow precipitation of zinc hydroxide sludge along with other hydroxide based metal precipitates. The water then flows into two sequential HDPE lined ponds that have a combined storage capacity of 1,830 m^3. The water treatment plant at Bellekeno has operated successfully for over 10 years and is well demonstrated and proven, as is shown in Figure 5-11.

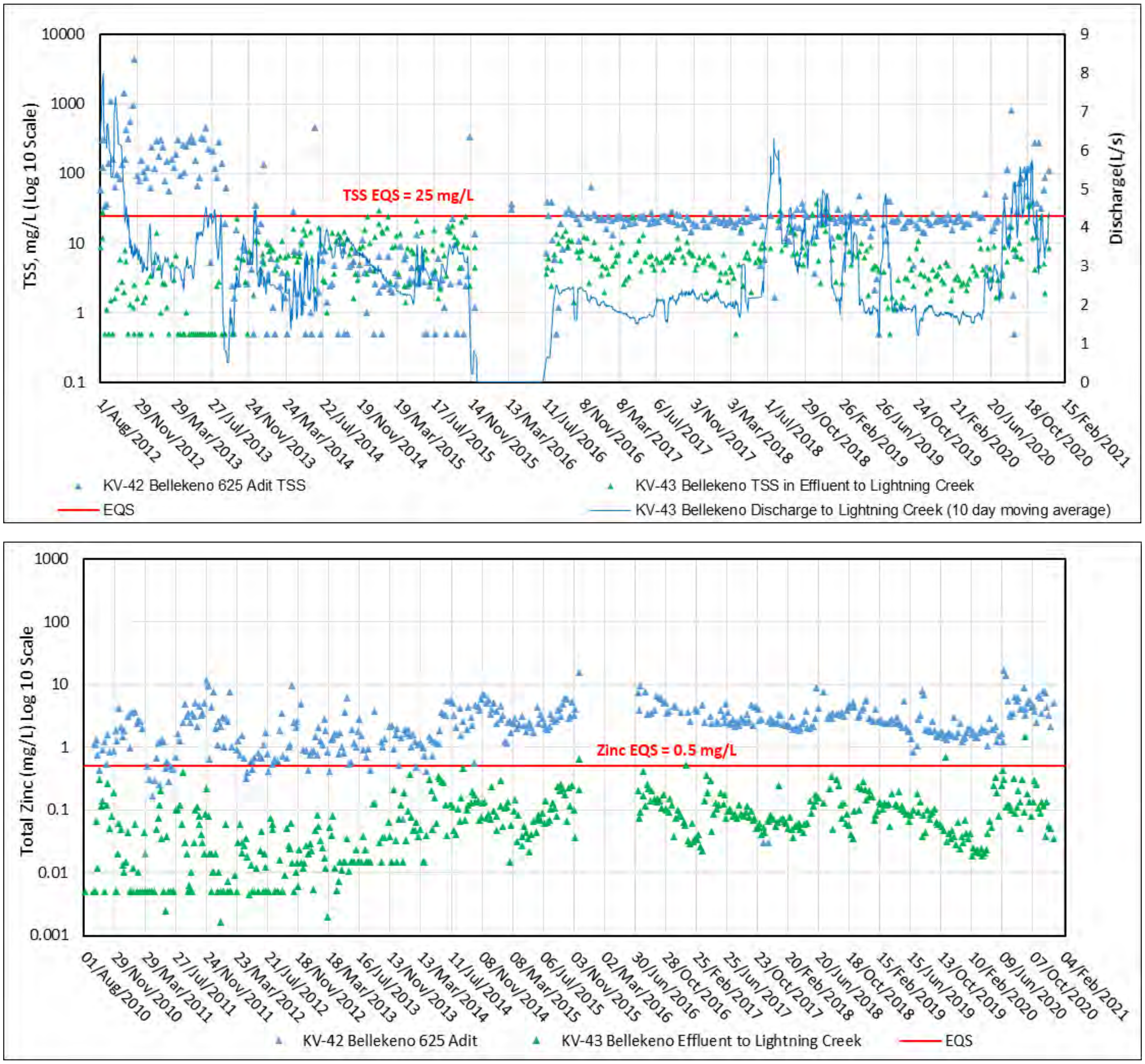


Figure 5-11 Bellekeno Water Treatment Plant Performance - TSS, Flow Rate (top) and Zinc (bottom)

Water use requirements for the Bellekeno Mine are currently supplied from the recharge to the underground mine water. Makeup water is also available and permitted for withdrawal from Lightning Creek and Thunder Gulch as well as Bellekeno 625 treatment facility decant water at a rate of up to 245.5 m^3/day. All water use sources are fitted with a totaliser to collect daily withdrawal rates. Groundwater seepage through bedrock and vein fractures is collected in the Bellekeno Mine and is pumped to surface for treatment and release. A certain portion of the underground mine water is used for various mine development and operations requirements including equipment operation and paste backfill. The Bellekeno water balance is shown in Figure 5-12.

There may be instances and operational requirements to use water from other permitted sources (i.e., Lightning Creek, Thunder Gulch, Bellekeno 625 treated decant) instead of or in addition to the primary source of the underground mine water. Alternative sources may be required if water quality in the underground mine water is not suitable (e.g., high suspended solids could damage mechanical equipment) or if it is temporarily not available (e.g. during sump construction).

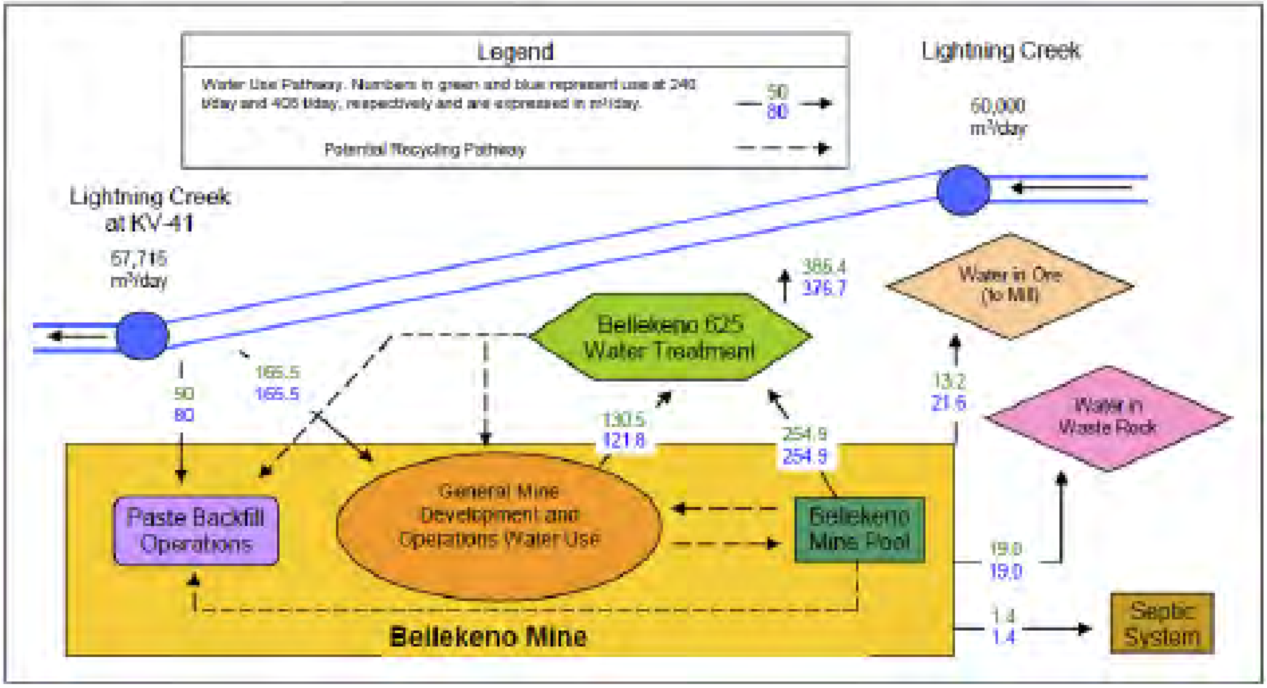


Figure 5-12 Bellekeno Water Balance Schematic

5.7.2 Flame & Moth

The Flame & Moth Mine is licenced to discharge up to 35 L/s (3,024 m^3/day) to both Lightning and Christal Creek. The water encountered during the development and operation of the Flame & Moth underground workings will either be utilized in the milling process as makeup water or discharged. The milling process requires up to 81 m^3/day, while the underground development requires up to 140.1 m^3/day (includes 25% contingency) when production is at 400 tpd. The balance of this flow will be treated in a lime water treatment plant that has been constructed in the District Mill building. The treated effluent is conveyed to the Flame & Moth settling pond and discharged via pipeline to Christal or Lightning Creeks. Figure 5-13 shows the portal location, ponds and mill building. To date the majority of the Flame & Moth treated water has been discharged to Lightning Creek

The Flame & Moth water treatment system operates as follows:

- Once primary settling of solids has occurred in the sumps, water is pumped to surface via a submersible pump in the sump through an 8" pipeline to a flash mixing tank on the clarifier. Lime and ferric are added into the flash mixing tank and mixed. The dissolved metals will begin to react with lime and form precipitates. Ferric sulphate is also added as a coagulant, and to assist with arsenic removal;

- Water flows into the lamella clarifier, which contains a series of inclined plates. Polymer is added to the stream at the beginning of the clarifier to accelerate settling of solid particles. The solids then settle on the plates and accumulate into a cone located at the bottom of the clarifier. The sludge is drawn off at the bottom and the clarified liquid exits the top by weir. The clean clarifier overflow flows into a pipeline and is conveyed to the settling pond;
- Sludge and heavier particles from the clarifier then gravity flow into geotextile dewatering bags. The bags densify the sludge by filtering the water from the solids. The water flows into a pipeline and is conveyed to the settling pond. The sludges in the geotextile bags are disposed of in the DSTF once the bags have been filled;
- Once water enters the settling pond, residence time will allow for final particle removal and polishing of the treated water; and
- Water can then be decanted from the pond for discharge or reused within the Flame & Moth underground activities if required.

The mine development is still advancing towards the mineralized vein material, so the water chemistry from the adit has typically only contained elevated TSS thus far. The plant has been in operation since October 2018 and its performance is summarized in Figure 5-14. The as-built pond and process flowsheet are shown in Figure 5-15 and Figure 5-16, respectively.

Figure 5-13 Flame & Moth Portal Location

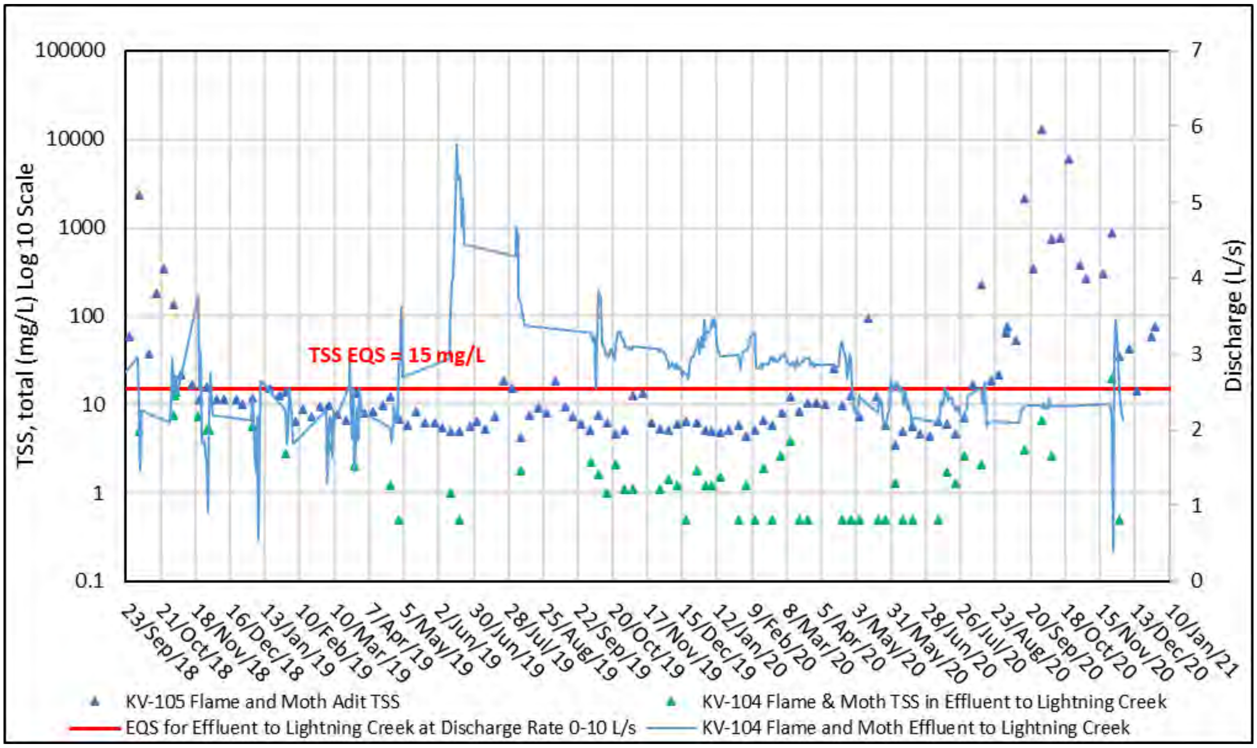
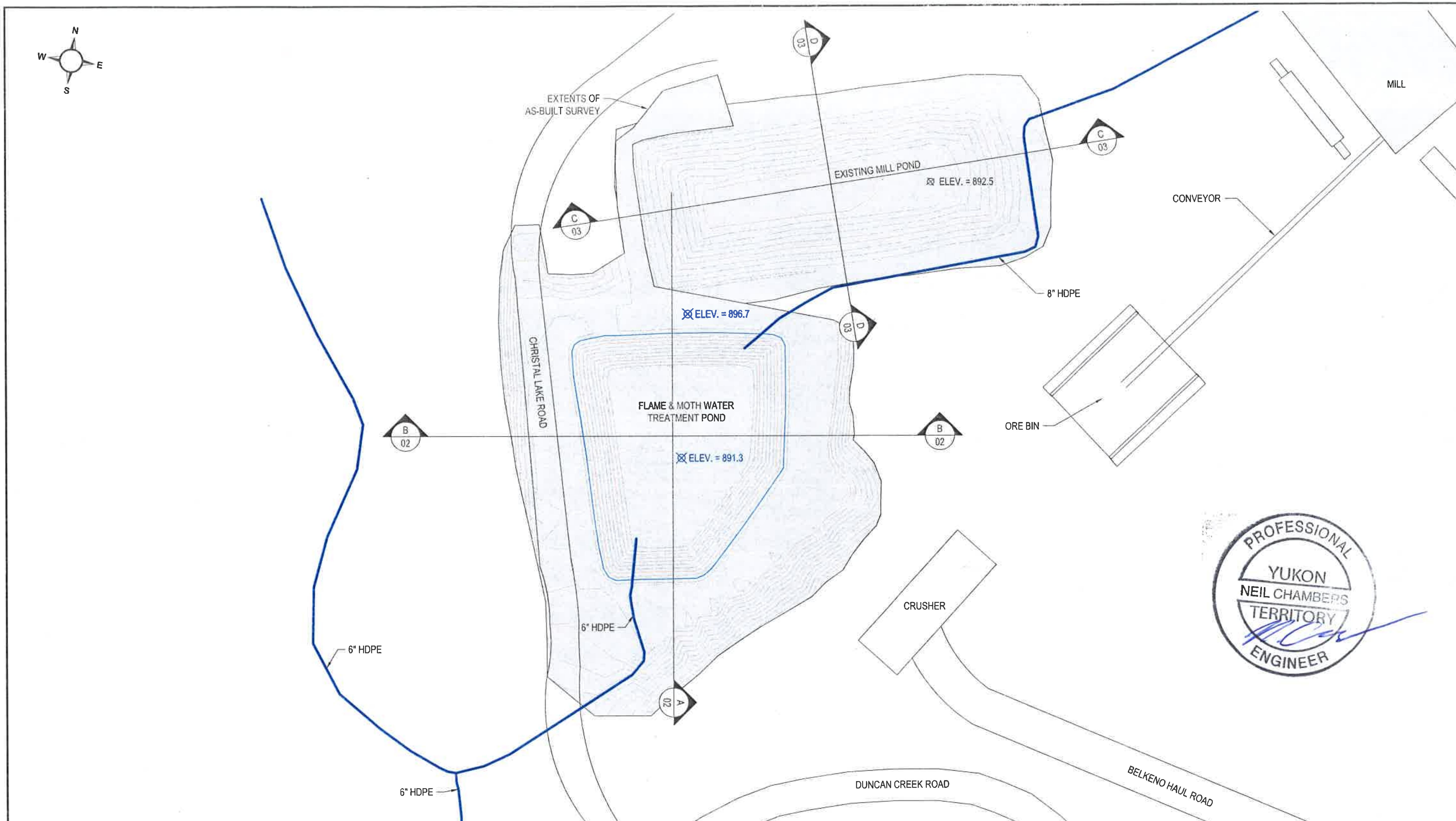


Figure 5-14 Flame & Moth Water Treatment Plant Performance



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)

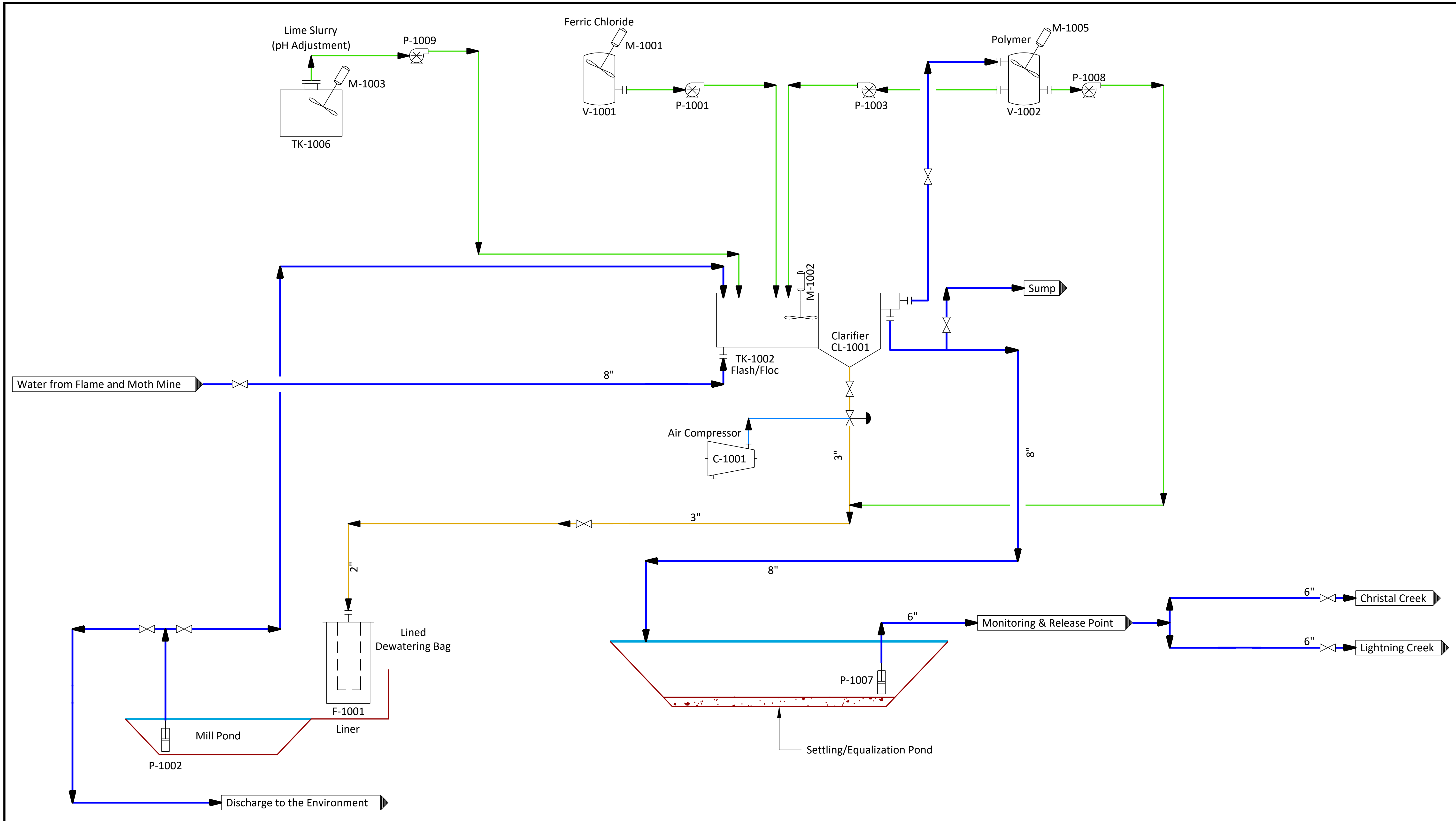
ALEXCO

Flame & Moth
Water Use License

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

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



DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-10-23	As-Built	B	KAB	--
2018-01-31	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

Flame & Moth IWTP
Phase I
Drawing No.: ALEX-13-NMP-02-1DI601

Figure 5-16
Flame & Moth Water Treatment Plant Process Flow Sheet As-built

REVISION B	2018-10-23	PROJECT No.: ALEX-13-NMP-02
DRAWN BY: KB	DESIGNED BY: EL	REVIEWED BY: BT

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\1-Flame and Moth\Flame & Moth WTP\PID DWG\ALEX-13-NMP-02-1DI602.dwg (last edited by: KBoldt; 2018/10/23 - 9:46 AM

5.7.3 Bermingham

The new Bermingham underground development and production requires up to 140.1 m^3/day (includes a contingency of 25%) and will discharge up to 13.9 L/s (1,200 m^3/day) to the No Cash Creek catchment, following water treatment. Daily water usage during ongoing underground mine development and operation is estimated at 112.5 m^3/day when mining at an estimated maximum rate of 400 tpd. This water is used to support activities including percussion drilling, dust suppression, equipment cooling and minor use for sanitation. As part of advanced exploration, water was pumped from the face of the underground development to a series of underground sumps before being conveyed to the surface pond, which then discharged to ground.

Reused process water from the underground workings will be the primary source of water for Bermingham. The underground water will be supplemented if needed by water sourced from the new Bermingham water treatment pond and from a groundwater source as contingency. These contingency sources may be required if water quality in the underground mine water is not suitable (e.g., high suspended solids could damage mechanical equipment) or if it is temporarily not available (e.g., during sump construction).

The Bermingham mine requires continual dewatering, with discharge flows dependent on mine depth. It is estimated that flow rates may reach a maximum of 13.9 L/s 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 is located near the Bermingham portal.

As part of mine operations at Bermingham, a water treatment plant similar to Flame & Moth has been constructed. All of the systems and technology used in this WTP are proven technologies operating at Keno Hill or elsewhere in the industry. The system operates as follows:

- Once primary settling of solids has occurred in the sumps, water is pumped to surface via a submersible pump in the sump through a 4" pipeline line to a reactor tank. Lime and ferric are added into the reactor tank and aggressively mixed. The reactor tank provides sufficient residence time for the dissolved metals to react with lime being added to this tank. Ferric sulphate is also added as a coagulant, and assisting with arsenic removal;
- Water flows from the reactor tank into the lamella clarifier, which contains a series of inclined plates. Polymer is added to the stream at the beginning of the clarifier to accelerate settling of solid particles. The solids then settle on the plates and accumulate into a cone located at the bottom of the clarifier. The sludge is drawn off at the bottom and the clarified liquid exits the top by weir. The clean clarifier overflow flows into a pipeline and is conveyed to the settling pond;
- Sludge and heavier particles from the clarifier then gravity flow into geotextile dewatering bags. The bags densify the sludge by filtering the water from the solids. The water flows into a pipeline and is conveyed to the settling pond. The sludges in the geotextile bags are disposed of in the Bermingham SW pit once the bags have been filled. At closure the sludge in the pit will be covered with waste rock and till material;
- Once water enters the settling pond, 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 ammonia treatment system if required; and

- The ammonia treatment system utilizes breakpoint chlorination to convert the ammonia into nitrate, nitrogen gas and low concentrations of nitrous oxide. Sodium hypochlorite is dosed based on the ammonia concentration, and the pH is tightly controlled using sulphuric acid and pH probes. A series of reactor vessels ensure complete reaction and then the treated water flows via gravity back to the settling pond.

The as-built pond and process flowsheet are shown in Figure 5-17 and Figure 5-18.

PROFESSIONAL
YUKON
NEIL CHAMBERS
TERRITORY
ENGINEER

VRT SECTION

Asbuilt water treatment pond storage capacity of 1,205m3 with 0.5m freeboard

PLAN VIEW

Rev:	Rev. Date:	Description:	Drwn	Chkd	Geo	Apvd

MINING PLUS

ALEXCO

Area:
Rev No:
Drawing Title: Bermingham Water Treatment Pond Asbuilt
Client:
Project: BERMINGHAM
Originator: NC
Figure/Drawing No.:
Date Drawn: 20 AUG 2019
Scale: 1:250
Paper Size:

Figure 5-17

REVISION HISTORY				
D	As-Built	2021-06-26	DS	
C	Revised per client request	2021-02-09	KB	KC
B	Issued for Report	2020-08-07	KB	KC
A	Draft for Review	2020-08-06	KB	--
REV No.	ISSUE/REVISION	DATE	DRWN	APP

STAMP/SEAL

Notes:

1. If the Ammonia Treatment System is required to be used on the Project, the System process design details (including expected treatment performance), system construction details, and operational details (including required chemical reagents and secondary waste products), shall be developed, reviewed, and approved by a Licensed Professional Engineer in the Yukon.

ISSUED FOR REPORT

ENSERO solutions

PROJECT NO.	DESIGNED BY	DRAWN BY	DATE
ECA20YT00030-222	PJ	KB	2021-06-26

Bermingham Water Treatment Plant Water Licence Support

Figure 5-18
Bermingham Water Treatment Plant
Process Flowsheet As-Built

DRAWING NO.	REVISION
ECA20YT00030-222-D1001	D

5.8 MONITORING

The Monitoring, Surveillance and Reporting Plan (Ensero & AKHM, 2021a) 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 monitoring 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 surveillance networks were already in place as per care and maintenance activities (Water Licence QZ17-076), advanced exploration and preliminary development activities at the Bellekeno, Flame & Moth and Bermingham mines (Water Licence QZ18-044) 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 & Moth and Bermingham mines are presented in the Monitoring, Surveillance and Reporting Plan (Ensero and AKHM, 2021a).

Alexco provides regular monitoring data, analysis, and discussion of trends in our monthly and annual reports submitted as a condition of QZ18-044 and QML-0009.

5.9 RISK AND ADAPTIVE MANAGEMENT

This is documented in the Adaptive Management Plan (AEG 2018) the updated plan (Ensero & AKHM 2021d) is currently under review by YG and includes the water quality objectives (WQO) for the project (Table 5-8). This includes the development of a WQO for KV-111 and the schedule (2020-2024) for the development of as site specific WQO for arsenic. Should that research indicate that a more sensitive arsenic WQO be appropriate, it will be incorporated into the AMP by December 31, 2024.

Additionally, as part of risk management for the project the seepage source terms will be updated as the Flame and Moth and Bermingham mines produce waste rock and tailings and are characterized through the static and kinetic testing requirements outlined in the Tailings Characterization Plan and Waste Rock Management Plan. These include humidity cells and saturated kinetic tests for backfilled tailings and waste rock, and will commence once the materials are available. These revised source terms are not currently available as mining operations focused on Bellekeno in 2021 and mine development is still ongoing at Flame and Moth and Bermingham. Once these data are available, they will be incorporated into a revised water quality model.

Table 5-8 Water Quality Objectives for Christal Creek, Lightning Creek, No Cash Creek, Star Creek, and South McQuesten River (mg/L)

	KV-50	KV-6	KV-7	KV-81[a]	KV-21[a]	KV-56	KV-111[a]	KV-2
Ammonia-N	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Nitrate-N	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Nitrite-N	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Arsenic	0.0432[b], 0.0277[c]	0.0167[b], 0.0098[c]	0.0102[b], 0.0043[c]	CCME	0.025[f]	CCME	CCME	CCME
Cadmium	BCMoE	0.00218[b], 0.00142[c]	0.00251[b], 0.000945[c]	BCMoE	0.0445[d], 0.0209[e]	0.000297[d], 0.000132[e]	0.000541[b], 0.000258[c]	0.000941[b], 0.000647[c]
Copper	0.00602[b], 0.00280[c]	0.0321[b], 0.00115[c]	0.00726[b], 0.00216[c]	0.00148[b], 0.00070[c]	0.00359[d], 0.00193[e]	BCMoE	BCMoE	0.00651[b], 0.00376[c]
Lead	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE
Nickel	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Silver	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Uranium	CCME	CCME	CCME	CCME	CCME	CCME	CCME	CCME
Zinc	0.271[b], 0.205[c]	0.367[b], 0.207[c]	0.220[b], 0.120[c]	CCME	4.94[d], 2.28[e]	CCME	0.179[b], 0.0602[c]	0.152[b], 0.103[c]
Sulphate	544[b], 409[c]	BCMoE	BCMoE	BCMoE	539[d], 349[e]	BCMoE	BCMoE	BCMoE
Selenium	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE	BCMoE
Radium	-	0.037 Bq/L	-	0.037 Bq/L	-	-	0.037 Bq/L	-

a) Objectives for KV-81, KV-21, and KV-111 metals are dissolved
b) 95th percentile from July 2011 to August 2021 data set, except for KV-111 which ranges from September 2017 to August 2021
c) Upper confidence level mean from July 2011 to August 2021 data set, except for KV-111 which ranges from September 2017 to August 2021
d) 95th percentile from July 2017 and June 2018 to August 2021 data set for KV-21 and KV-56, respectively
e) Upper confidence level mean from July 2017 and June 2018 to August 2021 data set for KV-21 and KV-56, respectively
f) Site specific based on Golder (2013) presented in Bermingham Water Quality Model (AEG, 2019)

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 SITE SECURITY, MONITORING AND MAINTENANCE

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 (Ensero & AKHM 2020a, 2021a, 2021b) 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.

6.2 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 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.

6.3 REPORTING

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

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
Flame & Moth Mine	Water Management	Maintain Flame & Moth 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
Bermingham Mine	Water Management	Maintain Bermingham 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
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	Remove all P-AML WRSFs and place underground Monitor WRSF & WRDA for water collection or seepage, respectively.	WL Water Quality Surveillance Program	Care & Maintenance Crew	As per WL
Roads	Physical Stability	Grade surface and scarify, 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:	Care & Maintenance Monitoring of all infrastructure and site elements	Care & Maintenance Crew	Daily: Inspection Sheets included in Annual Reporting
		· precautionary signage			
		· security gates – installed to restrict access to the mill			
	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

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)
    - Flame & 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)
    - Onek existing workings and infrastructure
    - Lucky Queen existing workings and infrastructure – including consideration of existing waste rock disposal areas/ storage facilities; water management; and surface facilities.
      (Appendix 3.1, Drawings: C-3401, B-3101, B-3301)
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 (2021)	Year 2 LOM Plan	End of LOM Plan
Mill Facilities				
Ore Mined/Milled	tonnes	274,208	440,824	907,715
Dry Stack Tailings Facility	tonnes	200,296	282,112	553,692
Dry Stack Tailings Facility Area (unreclaimed)	ha	0.8	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	0.33	0.33	0.33
Temporary P-AML WRSF	tonnes	0	0	0
Temporary P-AML WRSF	m^3	0	0	0
Flame & Moth				
Yards/Portal/Laydown Areas	ha	0	0	0
N-AML WRDA	tonnes	0	0	0
N-AML WRDA	ha	0	0	0
P-AML WRSF	tonnes	0	18,000	18,000
P-AML WRSF	ha	0.23	0.23	0.23
P-AML WRSF	m^3	0	6,000	6,000
Bermingham				
Yards/Portal/Laydown Areas	ha	2.61	3.0	3.0
N-AML WRDA	tonnes	18,000	70,000	190,000
N-AML WRDA	ha	0.34	0.68	0.68
P-AML WRSF	tonnes	0	8,000	24,000
P-AML WRSF	ha	0.19	0.19	0.32
P-AML WRSF	m^3	0	2667	8,000
Roads and Other				
Camp Accommodations	ha	1.8	2.2	2.2
Sludge Volume	m^3	200	250	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	1,979	1,979	1,979
Onek (existing, no planned mining)				
Yards/Portal/Laydown Areas	ha	0.83	0.83	0.83
N-AML WRDA	tonnes	0	0	0

Mine Component	Units	Current (2021)	Year 2 LOM Plan	End of LOM Plan
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 (existing, no planned mining)				
Yards/Portal/Laydown Areas	ha	0.64	0.64	0.64
N-AML WRDA	tonnes	0	0	0
N-AML WRDA	ha	0	0	0
P-AML WRSF	tonnes	0	0	0
P-AML WRSF	ha	0	0	0
P-AML WRSF	m^3	0	0	0

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
- Flame & Moth Mine
  - Flame & Moth Portal
  - Flame & Moth Decline and Underground Workings
  - Flame & Moth Vent Raise/Secondary Escape
- Bermingham Deposit
  - Bermingham Portal
  - Bermingham Decline and Underground Workings
  - Bermingham Vent Raise/Secondary Escape
- Lucky Queen Mine
  - Lucky Queen Portal
- Onek Mine
  - Onek Portal

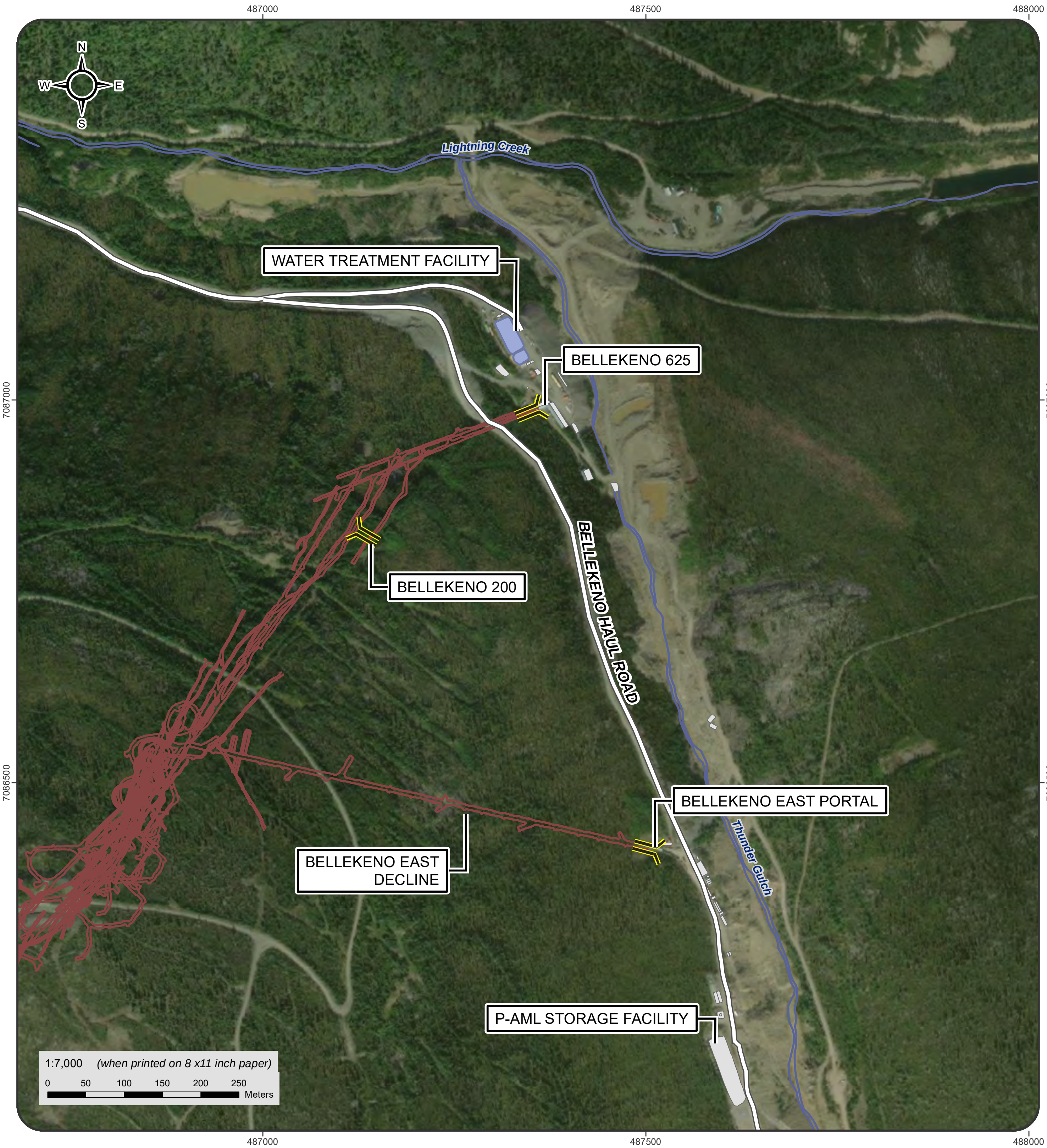
7.1.1 Closure Objectives

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 (control or prevent access); 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 at the end of the LOM is shown in Figure 7-4. 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

As Built Mine Feature

Pond

Underground Workings

Haul Road

Watercourse

ALEXCO KENO HILL MINING CORP.

FIGURE 7-1

BELLEKENO MINE OVERVIEW

OCTOBER 2021

Satellite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on October 27 2021.

Datum: NAD 83; Projection: UTM Zone 8N

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(Last edited by: tosberg; 10/27/2021/09:38 AM)

Figure 7-2 Bellekeno East Portal and Site Facilities

Figure 7-3 Bellekeno East Portal

Figure 7-4 Bellekeno Mine As-Built at EOM

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.
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.

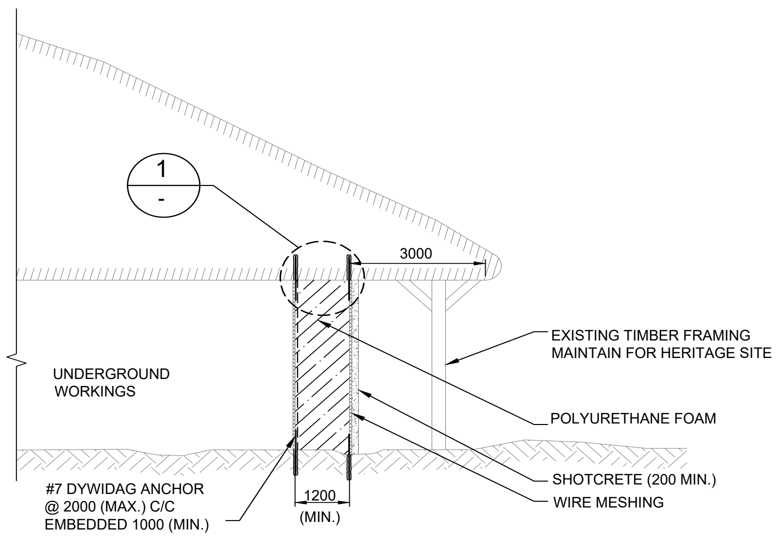
The mine pool will be managed by transitioning from actively treating adit discharge to managing the discharge with a concrete coffer dam, implementing *in situ* mine pool treatment, and installing a passive treatment system (bioreactor). Further discussion on the closure measures associated with long-term 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 7-5). 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.

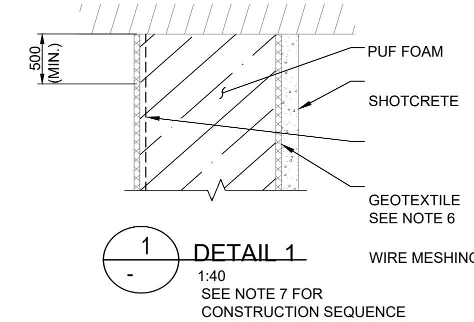
Reclamation measures for the Bellekeno East, and Bellekeno 625 adit areas are described on Drawings C-2401 and C-2402 respectively located in Appendix 3.1.

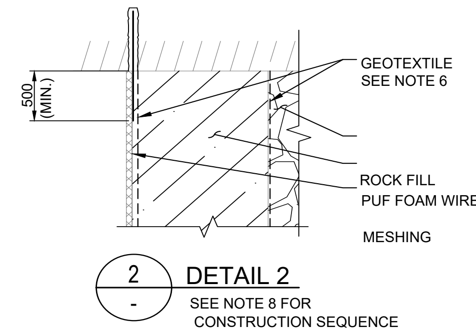
7.1.3.1 200 Level Vent Raise

The 200 level vent raise is a 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 polyurethan (PUF) cap similar to what is used at mines elsewhere in Canada. This plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A design for a PUF cap is included in Figure 7-6.



TYPICAL ADIT CLOSURE TYPE 1

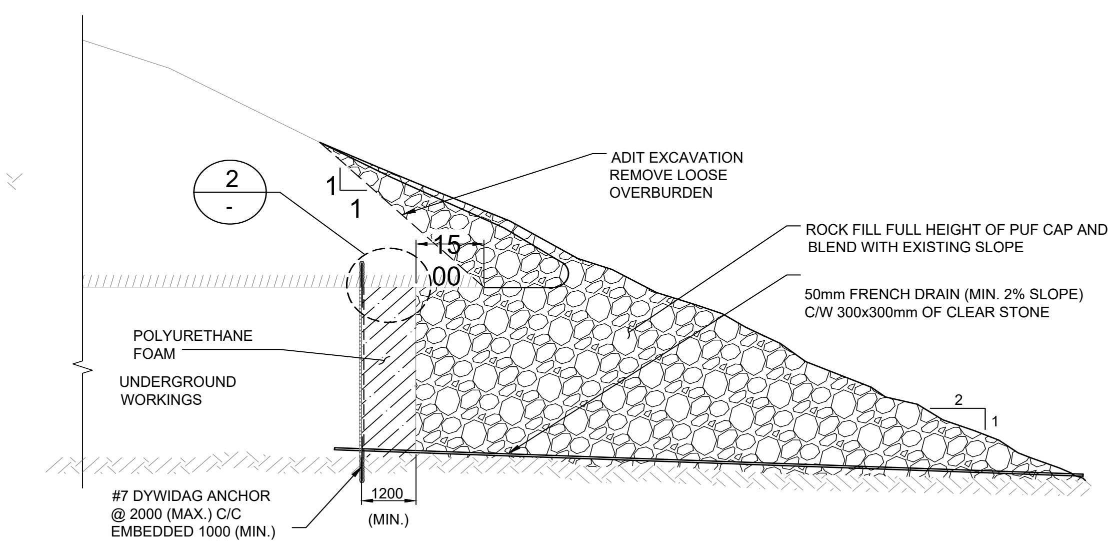




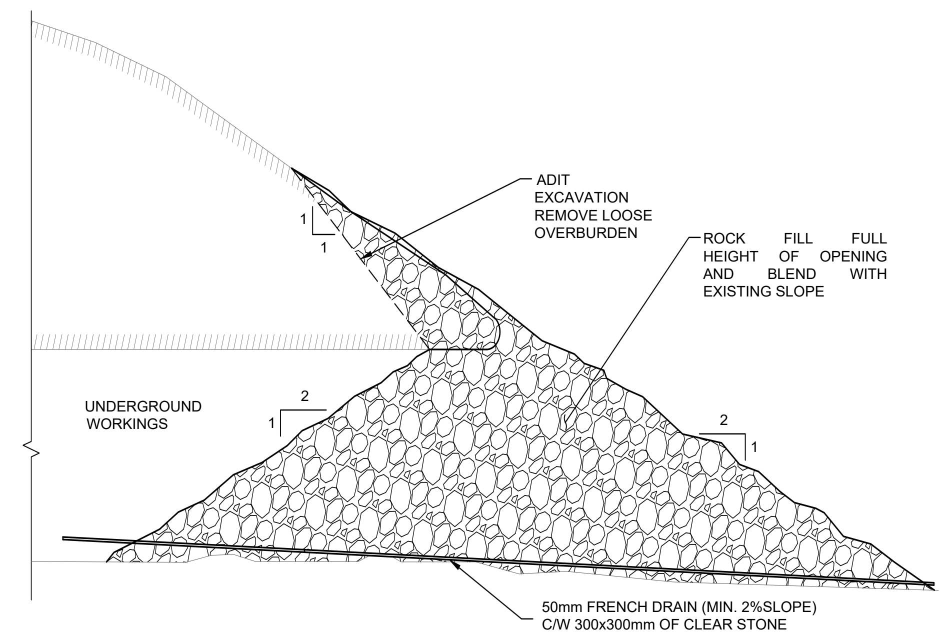
NOTES:

1. SEE DRAWING AKHM-13-01-S-0303 FOR GENERAL NOTES.
2. SEE DRAWING AKHM-13-01-S-0303 FOR CONCRETE NOTES
3. SEE DRAWING AKHM-13-01-S-0303 FOR PUF NOTES
4. VERIFY ADIT DIMENSIONS ARE CONSISTENT WITH DRAWING.

   ALL DEVIATIONS MUST BE REPORTED TO THE PROJECT ENGINEER BEFORE COMMENCING CONSTRUCTION.
5. ALL DIMENSIONS IN MILLIMETERS U.N.O.
6. GEOTEXTILE TO BE ARMTEC 835 WOVEN GEOTEXTILE OR APPROVED ALTERNATE WITH MINIMUM OVERLAP OF 300mm.
7. CONSTRUCTION SEQUENCE TYPE 1:
   - 7.1. INSTALL DYWIDAG ANCHORS ALONG WITH WIRE MESHING AND GEOTEXTILE ON FAR SIDE OF PUF PLUG LOCATION.
   - 7.2. SPRAY PUF PLUG TO DESIRED THICKNESS.
   - 7.3. INSTALL DYWIDAG ANCHORS ON NEAR SIDE OF PLUG.
   - 7.4. INSTALL WIRE MESH AND SPRAY SHOTCRETE OVER ENTIRE AREA OF THE PLUG.
8. CONSTRUCTION SEQUENCE TYPE 2:
   - 8.1. INSTALL DYWIDAG ANCHORS ALONG WITH WIRE MESHING AND GEOTEXTILE ON FAR SIDE OF PUF PLUG LOCATION.
   - 8.2. SPRAY PUF PLUG TO DESIRED THICKNESS.
   - 8.3. FASTEN GEOTEXTILE TO PUFAND BACKFILL TO THE FULL HEIGHT OF THE ADIT WITH ROCKFILL.



TYPICAL ADIT CLOSURE TYPE 2



TYPICAL ADIT CLOSURE TYPE 3

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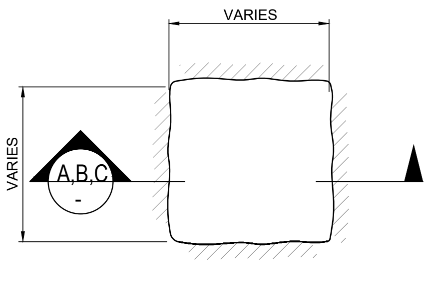
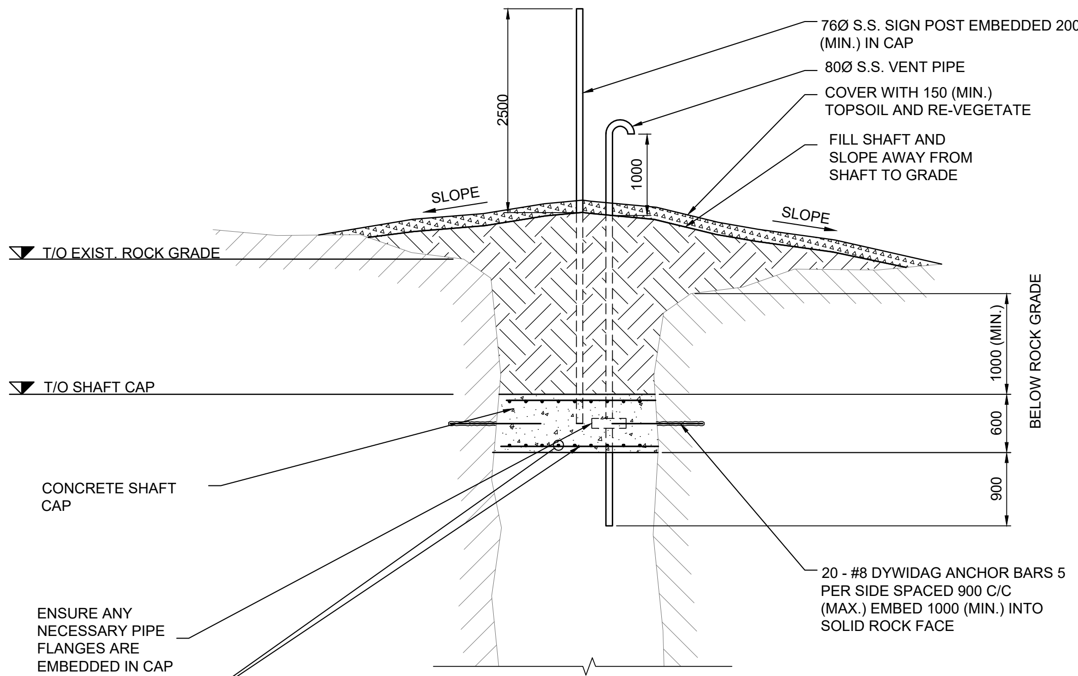
Drawing No:
AKHM-13-01-S-0301

Figure 7-5
Portal Closure
Typical Adit Closure Design

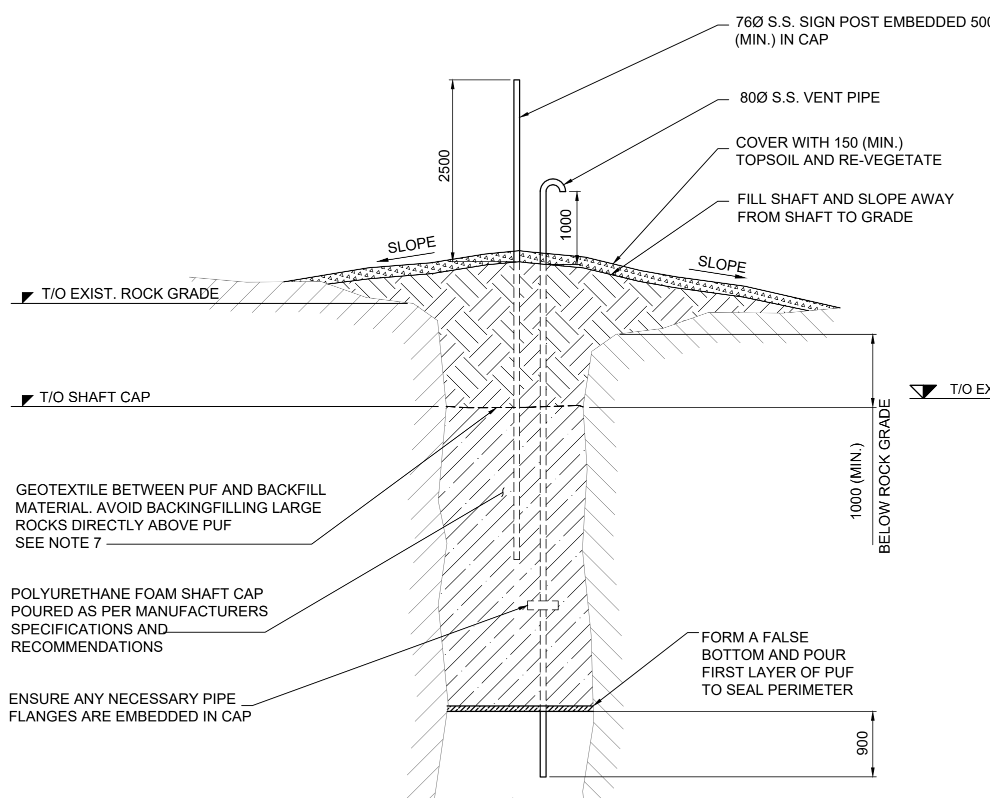
REVISION: 0A	2021-04-23	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW



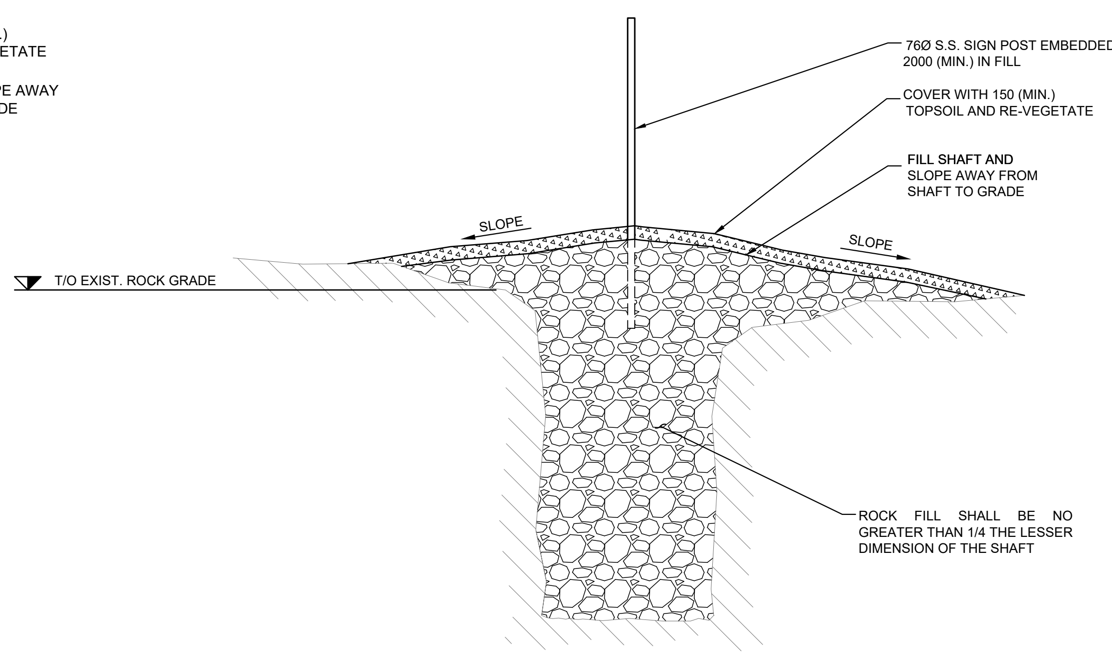
EXISTING SHAFT PLAN VIEW



A - SECTION THROUGH SHAFT TYPE 6



B - SECTION THROUGH SHAFT TYPE 4 & 5



C - SECTION THROUGH SHAFT TYPE 2 & 3

CLOSURE TYPE	DESCRIPTION
1	LEVEL AS IS, OR FILL IN MINOR INDENT IN GROUND WHERE PREVIOUS SHAFT WAS BACKFILLED
2	FOR SHALLOW SHAFTS, DEPOSIT ROCK INTO SHAFT UNIT REFUSAL
3	FOR DEEPER SHAFTS, EXTENSIVE AMOUNTS OF ROCK PUSHED INTO SHAFT UNTIL REFUSAL
4	POLYURETHANE FOAM PLUG FOR SMALL SHAFTS (LESS THAN OR EQUAL TO 2 x 2m). FORM AND POUR PUF. MINOR BACKFILL REQUIRED.
5	POLYURETHANE FOAM PLUG FOR LARGER SHAFTS (GREATER THAN 2 x 2m) THAT REQUIRE EXTENSIVE FORMWORK FOR PLACEMENT. FORM AND POUR PUF. MINOR BACKFILL
6	FORM, REINFORCE AND POUR CONCRETE CAP TO PLUG SHAFT. MINOR BACKFILL REQUIRED.

GENERAL NOTES:

1. ALL SUPPORTS TO BE FOUNDED ON SOUND ROCK. THE DESIGN IS BASED ON A MINIMUM BEARING VALUE OF GOOD QUALITY SEDIMENTARY ROCK (e.g., SHALE) = 600 kPa.
2. COMPETENCY OF THE ROCK AT THE SUPPORTS SHALL BE EXAMINED AND APPROVED BY A QUALIFIED PROFESSIONAL ENGINEER PRIOR TO CONSTRUCTION.
3. ALL LOOSE ROCK SHALL BE REMOVED FROM THE ROCK ANCHORAGES TO COMPETENT ROCK. VERIFY SHAFT DIMENSIONS ARE CONSISTENT WITH DRAWING.
4. ALL DEVIATIONS MUST BE REPORTED TO THE PROJECT ENGINEER BEFORE COMMENCING CONSTRUCTION.
5. THOROUGHLY COMPACT ALL CONCRETE USING VIBRATORS OR OTHER SUITABLE TOOLS DURING THE PLACING OPERATION. THOROUGHLY WORK THE CONCRETE INTO THE CORNERS OF THE FORMS AND ROCK SURFACES AND AROUND THE REINFORCEMENT.
6. SHAFT CAP SHALL NOT BE LOADED UNTIL THE 28-DAY CONCRETE STRENGTH HAS BEEN VERIFIED BY CYLINDER TESTS IN ACCORDANCE WITH CAN/CSA-A23.2.
7. GEOTEXTILE TO BE ARMTEC 835 WOVEN GEOTEXTILE OR APPROVED ALTERNATE WITH MINIMUM OVERLAP OF 300mm.

DESIGN LOADS:

6. LIVE LOAD = 2.0 METERS OF SATURATED SOIL COVER AT 19 kN/cu.m. + THE GREATER EFFECT OF A SPECIFIED 12 kPa UNIFORMLY DISTRIBUTED LOAD, OR 24 kN CONCENTRATED LOAD OVER AN AREA 0.3 m by 0.3 m, ANYWHERE ON THE SLAB.
7. DEAD LOAD = WEIGHT OF CAP

CAST-IN-PLACE CONCRETE:

1. ALL CONCRETE WORK, MIXES, PLACING, CURING, AND TESTING TO BE IN ACCORDANCE WITH CSA-A23.1-19/A23.2-19 "CONCRETE MATERIALS AND METHODS OF CONCRETE CONSTRUCTION/TEST METHODS AND STANDARD PRACTICES FOR CONCRETE".
2. CONCRETE ADMIXTURES CONFORM TO CSA A3000-18 "CEMENTITOUS MATERIALS COMPENDIUM."
3. CONCRETE MIXES TO BE IN ACCORDANCE WITH CSA-A23.1-19 ALTERNATIVE 1.
4. USE COLD WEATHER CONCRETING METHODS WHEN THE MEAN AMBIENT TEMPERATURE FALLS BELOW 41°F (+5°C). ADDITIONAL TEST CYLINDERS WILL BE PREPARED DURING COLD WEATHER CONCRETING
5. TEST CYLINDERS TO BE FIELD CURED UNDER THE SAME CONDITIONS AS THE CONCRETE WHICH THEY REPRESENT.
6. FORMWORK TO BE IN ACCORDANCE WITH CAN/CSA S269.1-16 "FALSEWORK AND FORMWORK". NO COLUMN OR WALL FORMS SHALL BE REMOVED BEFORE CONCRETE HAS REACHED 8MPa.
7. FORM OIL TO BE NON-STAINING, NON-TOXIC AND NON-VOLATILE.
8. BEFORE CONCRETE IS PLACED, REVIEW SHOP DRAWINGS FOR EQUIPMENT, OPENINGS, ANCHOR BOLTS, EMBEDS, INSERTS, ETC. TO ENSURE COMPLETENESS.
9. ALL PIPES, CONDUITS, AND SLEEVES EMBEDDED IN CONCRETE SHALL BE INSTALLED IN ACCORDANCE WITH CSA A23.1-19.
10. TESTING:
    A) QUALITY CONTROL TO BE UNDERTAKEN BY AN INDEPENDENT TESTING AGENCY OBTAINED BY THE CONTRACTOR, RESULTS OF FIELD TESTING WILL BE REPORTED IMMEDIATELY TO THE CONTRACTOR AND ERDC. ERDC MAY ENGAGE AN INDEPENDENT INSPECTION/ TESTING AGENCY TO CONDUCT TESTING; HOWEVER INSPECTION AND TESTING BY ERDC DOES NOT RELIEVE THE CONTRACTOR OF RESPONSIBILITY FOR QUALITY CONTROL AND CONTRACTUAL OBLIGATIONS.
    B) TEST PROCEDURE SHALL INCLUDE, BUT NOT LIMITED TO, THREE TEST CYLINDERS FROM EACH 50m3 OF CONCRETE, OR FRACTION THEREOF, FOR EACH DAY, TYPE OF CONCRETE, OR TYPE OF STRUCTURAL COMPONENT. ONE SLUMP TEST AND ONE ENTRAINED AIR TEST FOR EACH SET OF CYLINDERS.
11. ACCESSORIES SUCH AS HI-CHAIRS, SPACERS ETC., WILL BE SUPPORTED USING PADS OF PLYWOOD OR TEMPERED FIBREBOARD TO PREVENT PUNCTURING. POLYSTYRENE IS NOT AN ACCEPTABLE FORM MATERIAL

CONCRETE REINFORCING:

1. ALL REINFORCING STEEL TO MEET CAN/CSA-G30.18-09 (R2019) "CARBON STEEL BARS FOR CONCRETE REINFORCEMENT", 400 MPa DEFORMED BARS EXCEPT 10M TIES MAY BE 300 MPa.
2. ALL STEEL TO BE DETAILED IN ACCORDANCE WITH CSA A23.1-19 "CONCRETE MATERIALS AND METHODS OF CONCRETE CONSTRUCTION", A23.3-19 "DESIGN OF CONCRETE STRUCTURES" AND THE LATEST EDITION OF THE REINFORCING STEEL MANUAL OF STANDARD PRACTICE BY THE REINFORCING INSTITUTE OF CANADA.

CONCRETE REINFORCING (CONT'D):

3. CLEAR COVER TO REINFORCING WILL BE:
   - CONCRETE CAST AGAINST EARTH -
     - ALL BARS.. 75mm
   - CONCRETE PLACED IN FORMS -
     - 20M OR LARGER.................................. 50mm
     - 10M & 15M... 40mm
4. PROVIDE LAPS TO CSA A23.3 OR THE FOLLOWING MINIMUMS:
   - 10M - 700mm
   - 15M - 1000mm
   - 20M - 1200mm
   - 25M - 1900mm
5. ALL REINFORCING TO BE HELD IN PLACE AND TIED WITH PROPER ACCESSORIES, HI-CHAIRS AND SPACERS. DETAIL, SUPPLY AND INSTALL ALL ACCESSORIES. HI-CHAIRS TO HAVE 4 LEGS AND TO BE STAPLED OR NAILED TO THE FORMWORK.
6. REINFORCING STEEL SHALL HAVE ADEQUATE SUPPORTS SPACED NOT MORE THAN 1200mm APART IN ANY DIRECTION AND SHALL BE FIRMLY ANCHORED BEFORE CONCRETE IS POURED.
7. ALL REQUIRED OPENINGS NOT SHOWN ON STRUCTURAL DRAWINGS SHALL BE APPROVED BY THE CONSULTANT PRIOR TO CONSTRUCTION.
8. REINFORCING STEEL SHALL BE CLEAN AND FREE OF ALL DIRT, GREASE AND OTHER DELETERIOUS MATERIALS PRIOR TO PLACING CONCRETE.
9. FOR OPENINGS OR INSERTS LESS THAN 450mm, THE REINFORCING STEEL SHALL BE DEFLECTED, NOT CUT.
10. REINFORCING STEEL SHALL NOT BE WELDED, HEATED OR BENT ON-SITE WITHOUT PRIOR APPROVAL OF THE CONSULTANT.
11. DOWELS TO CONCRETE SLABS AND WALLS TO MATCH SLAB REINFORCING UNLESS NOTED OTHERWISE.

ROCK ANCHORS:

1. ROCK BOLTS AND ACCESSORIES TO BE IN ACCORDANCE WITH CAN/CSA M430-90 (R2016) "ROOF AND ROCK BOLTS, AND ACCESSORIES".
2. ROCK ANCHORS TO BE: 'DYWIDAG' THREADBAR, GRADE 75 (517 MPa) OR APPROVED ALTERNATIVE.
3. MINIMUM EMBEDMENT TO BE 2000mm INTO SOUND ROCK UNLESS NOTED OTHERWISE. GROUT FULL DEPTH.
4. INSTALL RESIN AS PER MANUFACTURER'S RECOMMENDATIONS AND INSTRUCTIONS.
5. SCALE ROCK THOROUGHLY PRIOR TO DRILLING ANCHOR HOLES.
6. ANCHOR HOLES SHALL BE CLEAN AND DRY PRIOR TO INSTALLING RESIN.

POLYURETHANE FOAM (PUF) STORAGE AND APPLICATION:

THE CURED PUF MUST MEET THE FOLLOWING SPECIFICATION(S):

COMPRESSIVE STRENGTH 140 kPa

4. PERFORM ALL POLYURETHANE FOAM (PUF) WORK INCLUDING STORAGE AND PLACEMENT TO THE MANUFACTURERS SPECIFICATIONS AND RECOMMENDATIONS.
5. PUF CONTAINERS SHALL BE STORED IN A DRY TEMPERATE LOCATION OUT OF THE SUNLIGHT AND BELOW 30 °C.
6. THE APPLICATION AND MIXTURE OF 2-PART PUF PRODUCTS SHALL BE ACCURATELY METERED AND MIXED TO COMPLY WITH THE MANUFACTURERS SPECIFICATIONS.
7. FORMWORK FOR PUF SHOULD BE SUFFICIENT TO PREVENT THE LEAKAGE OF THE LIQUID DOWN THE SHAFT. THE FIRST LAYER OF PUFF SHOULD BE POURED TO SEAL THE PERIMETER OF THE FORM AND THE VENT. METHOD MAY VARY DEPENDING ON SHAFT CROSS SECTION.
8. ENSURE EACH LAYER OF PUF IS EVENLY APPLIED ACROSS SHAFT OPENING. NO LAYER OF PUF SHALL EXCEED THE LESSER OF THE MANUFACTURERS SPECIFICATIONS OR 450mm.
9. A MINIMUM TIME OF 20 MINUTES SHOULD BE ALLOWED BETWEEN THE POURING OF EACH LAYER OF PUF. THE LAYER SHOULD BE COOL AND REACH A TACK FREE TEXTURE BEFORE POURING THE NEXT LAYER.
10. BACKFILL SHOULD BE COMPLETED NO SOONER THAN 60 MINUTES AFTER THE COOLING OF THE LAST PUF LAYER. THE BACKFILL SHOULD BE NO LESS THAN 1M OF DIRT OVER THE TOP OF THE PUF CAP. THE GRADE SHOULD SLOPE AWAY FROM THE SHAFT CENTER.

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AKHM-13-01-S-0303

Figure 7-6
Shaft/Raise to Surface
Typical Concrete, PUF and Backfilled Caps

REVISION: 0A	2021-04-23	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW

7.1.4 Flame & Moth Mine

The Flame & Moth deposit was outlined by surface exploration drilling in 2010 through 2013 with ongoing surface exploration. The Flame & 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 & Moth mine in relation to the District mill and the ore zones is shown in Figure, the portal in Figure 7-8, and in the as built in Figure 5-5. The Flame & Moth underground workings design is shown in Figure 7-9.

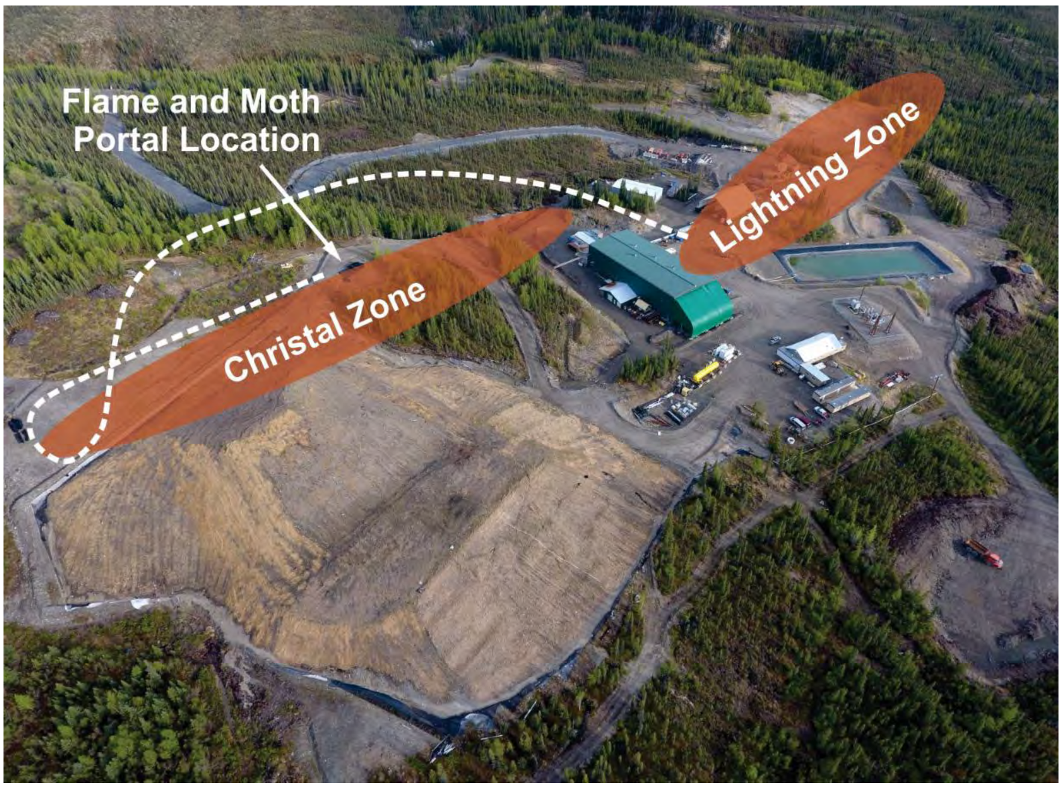


Figure 7-7 Flame & Moth Plan View Showing Ore Zones To Be Mined

Figure 7-8 Flame & Moth Adit During Developments

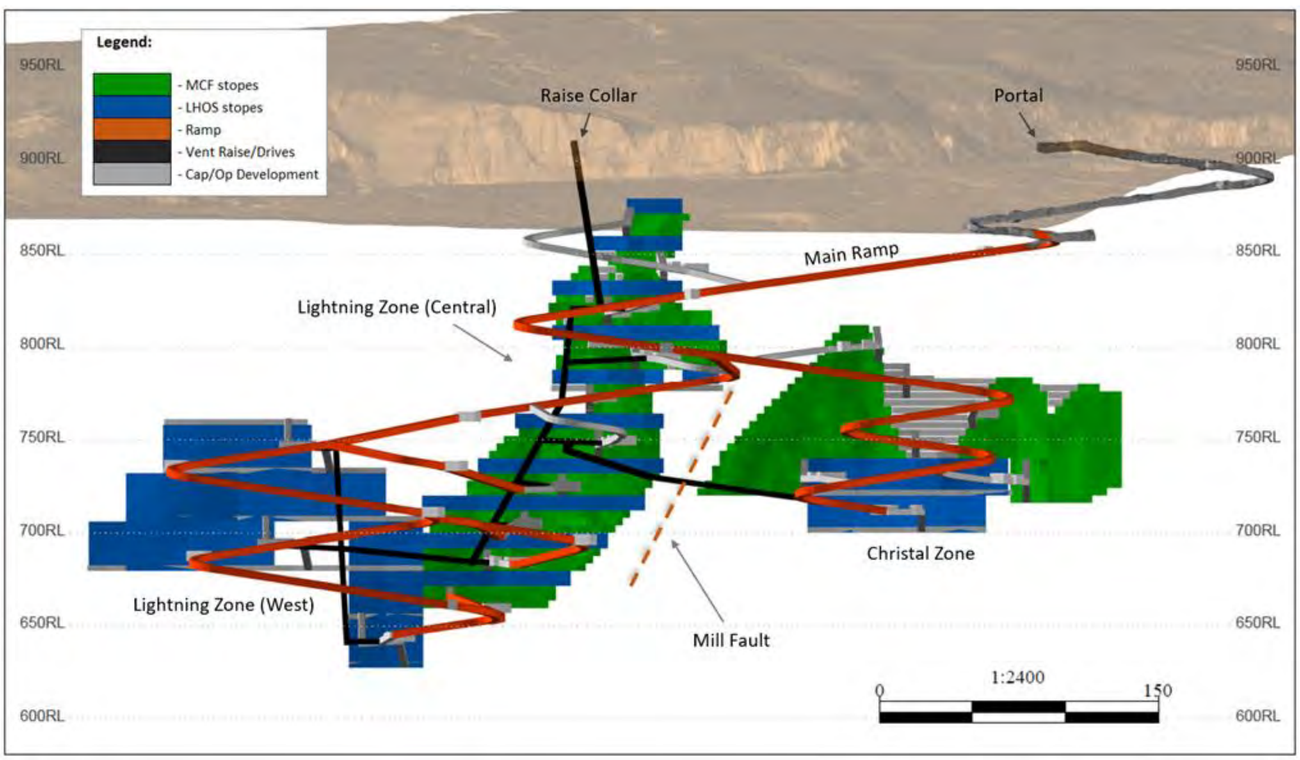


Figure 7-9 Flame & Moth LOM Plan

7.1.5 Flame & Moth Mine Closure Measures

The steps and measures required for closure of the Flame & 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;
5. Install PUF or concrete cap on vent raise; and
6. Install rock pile portal cover.

During operations, the Flame & Moth mine is expected to produce up to 35 L/s at the deepest level of the mine. The current static water elevation of groundwater table within the Flame & 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 & Moth portal (906 masl) and therefore no water is expected to discharge the Flame & Moth mine requiring any ongoing water management at closure.

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

7.1.6 Bermingham Mine

Various surface facilities and infrastructure were constructed in 2017 and 2020 to support the new Bermingham underground exploration decline including include a dedicated mine office, dry/lunch room, maintenance shop, water treatment plant, diesel power generation, fuel storage tanks and laydown yard. The surface infrastructure that was constructed for the advanced exploration decline will remain in place and be expanded to facilitate development and production at the new Bermingham mine. A lined water management pond already constructed will be used as part of the water treatment system required during active mine operations.

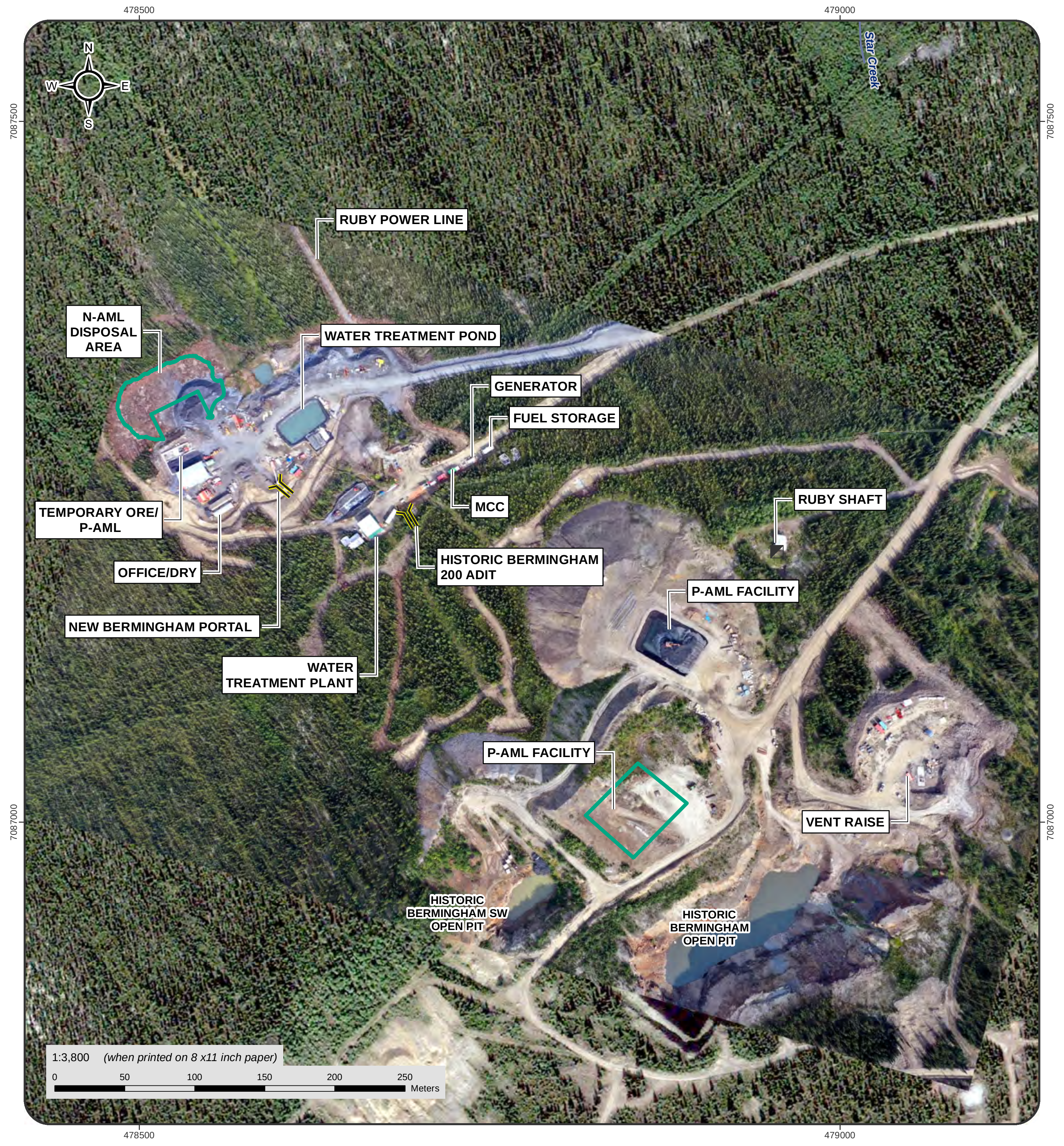
An aerial photo with Bermingham infrastructure and portal location is provided in Figure 7-10 and Figure 7-11.

Non-acid metal leaching (N-AML) waste rock generated from development and mining at Bermingham will be deposited in a new N-AML waste rock disposal area, which will be built as an extension to the current waste rock disposal area at Bermingham. P-AML waste rock is expected to be deposited in a P-AML waste rock storage facility constructed nearby.

The site receives explosives deliveries by truck and the explosives will initially be stored in licensed and permitted surface magazines. A second powder and detonator magazine will be constructed underground during pre-production using existing remucks off the main decline.

The current underground mine workings as-built is provided in Figure 7-12.

Figure 7-10 Bermingham Portal Area – August 2020



Permitted To Be Constructed Mine Features

Surface Watercourse

Adit/Portal

Shaft

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FIGURE 7-11

BERMINGHAM MINE PROJECT LAYOUT AS-BUILT

NOVEMBER 2021

Satellite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on November 29 2021.

Datum: NAD 83; Projection: UTM Zone 8N

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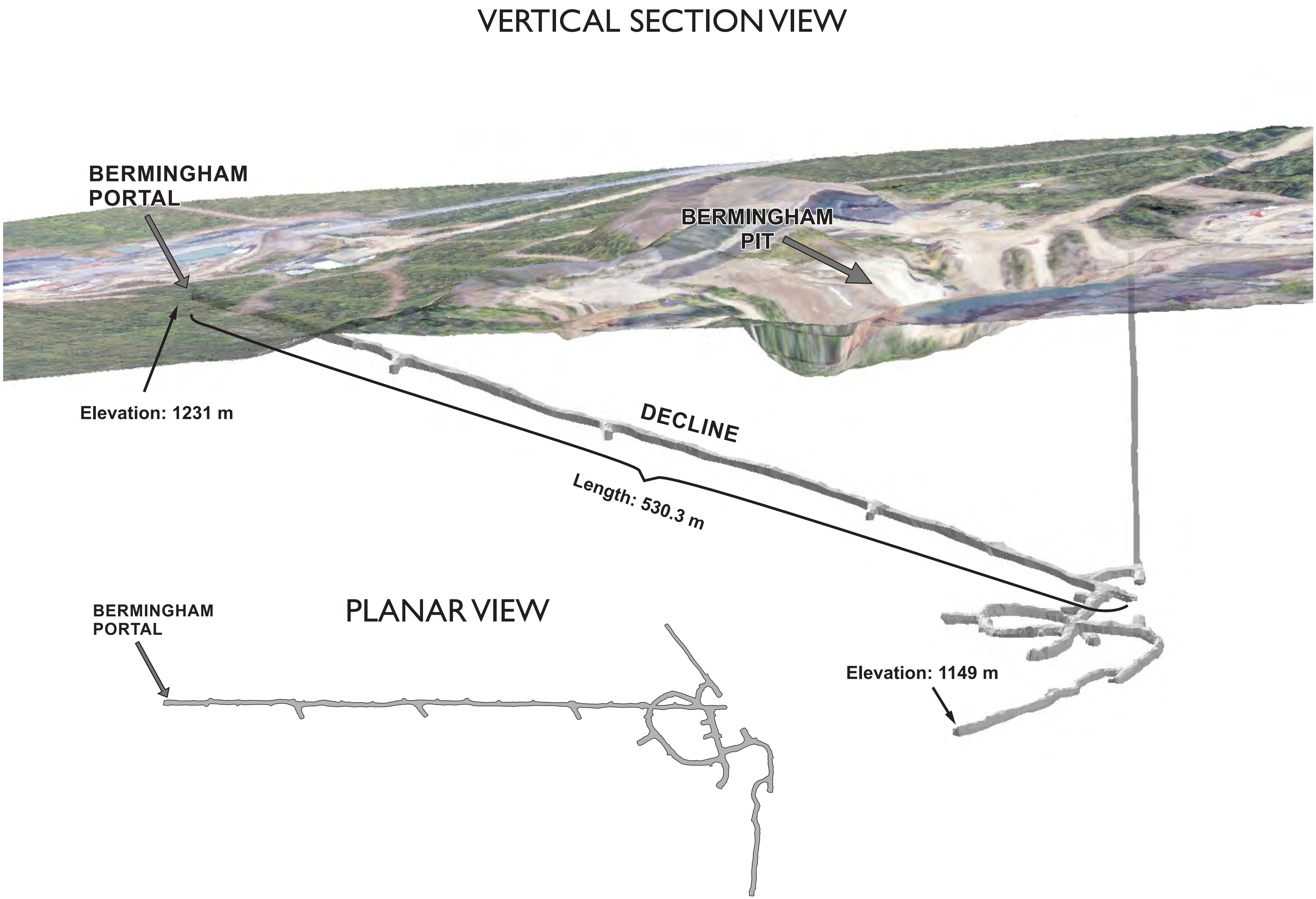

CONCEPTUAL DRAWING; FEATURES ARE NOT TO SCALE

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FIGURE 7-12
BERMINGHAM DECLINE AS BUILT

NOVEMBER 2021

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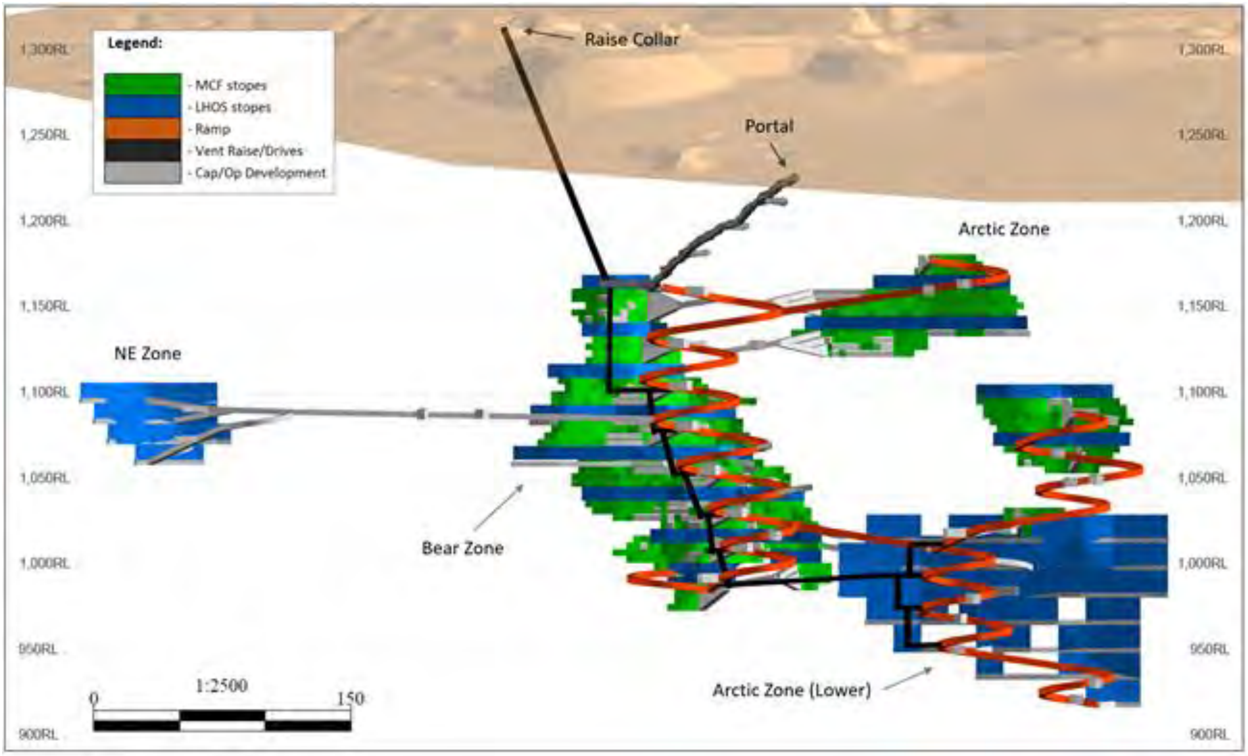

Figure 7-13 Bermingham LOM Plan

7.1.7 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 *in situ* mine pool treatment;
7. Install PUF or concrete cap on vent raise; and
8. Install rock pile portal cover.

During operations, the Bermingham mine is expected to produce up to 13.9 L/s 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 or creating a PUF plug and then laying rockfill in front of it. A french drain would penetrate through the rockfill or PUF plug to ensure drainage (Figure 7-5 Type 2 or Type 3). These measures will protect human 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.

7.1.8 Onek Mine

The Onek mine was developed in 2012 and currently consists of 220 meters of a primary decline. Surface facilities (office building, storage containers, and ventilation fan) have already been removed. The N-AML WRDAs, and the vent raise have not yet been constructed. The P-AML WRSF has been constructed, but no material placed in it. 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 7-14 and Figure 7-15. An as built of the Onek mine underground workings is shown in Figure 7-16.

Figure 7-14 Onek Mine Surface Overview

As Built Mine Feature

Permitted To Be Completed Mine Features

Underground Workings Footprint

Adit

Secondary Road

Limited-Use Road

Watercourse

Aerial Imagery aquired on August 2017

Datum: NAD 83; Projection: UTM Zone 8N

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FIGURE 7-15
ONEK 990 MINE LAYOUT

OCTOBER 2021

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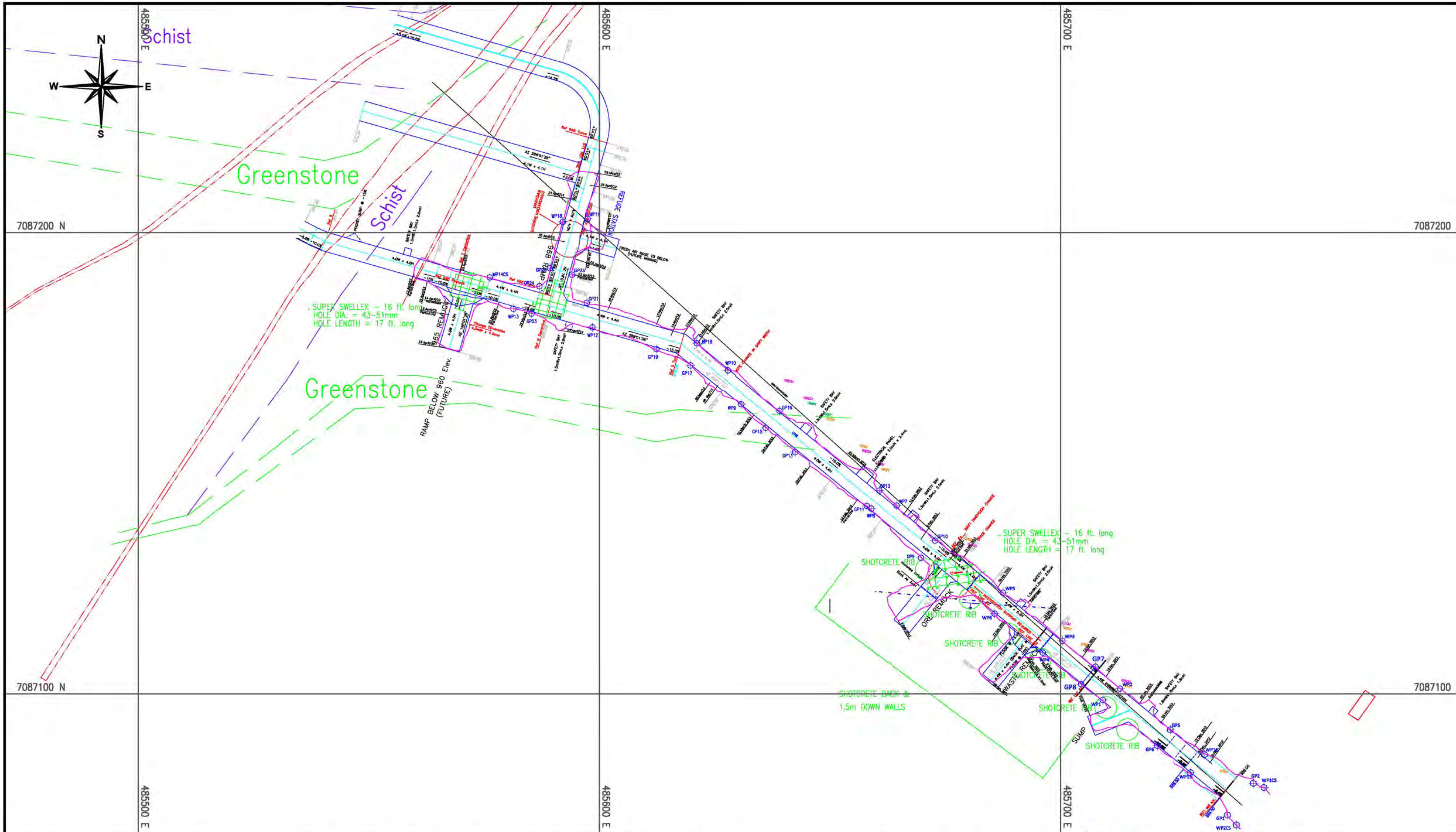

ALEXCO RESOURCE CORP BELLEKENO MINE	DEPT.	APPROVED BY	DATE	COMMENTS
	SURVEY			
	ENGINEERING			
	GEOLOGY			
	ALEXCO MANAGER			
	PROCON SUPER			

TITLE: **ONEK**
ASBUILT 30 May 2013

Figure 7-16

Drawn by: DARIN BAKER
Scale: 1:750
Date: 05/30/2013
Approval:
Date:
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7.1.9 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 including P-AML facility; 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 9 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.

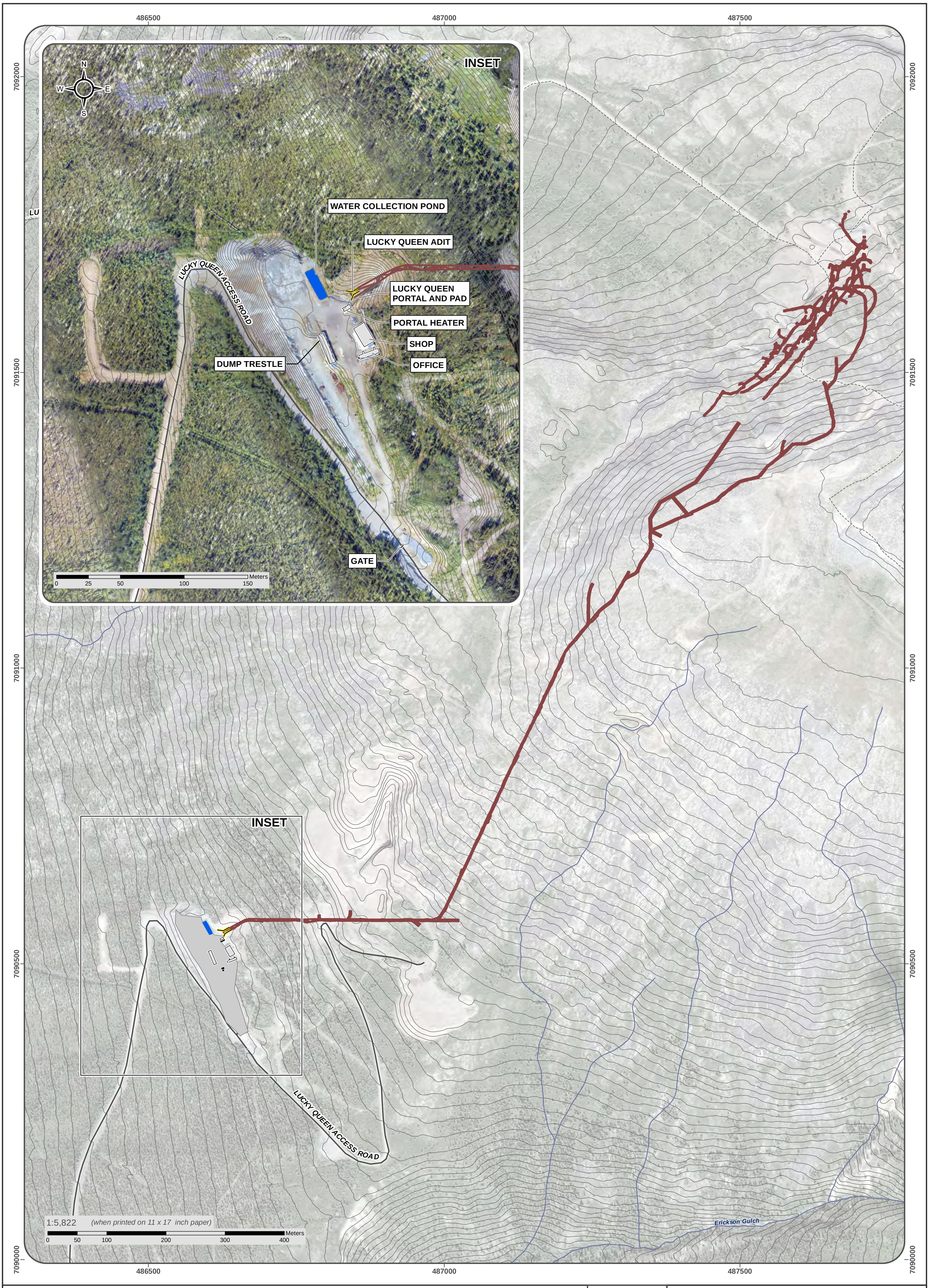
A rock pile cover similar to Bellekeno East (Figure 7-5) will be constructed to close the Onek 990 portal face and prevent inadvertent access from wildlife or people.

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.

7.1.10 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 provides primary ingress/egress to the Lucky Queen mine (**Figure 7-17 Lucky Queen Mine Layout**).

The current status of the Lucky Queen mine includes the portal, a shop maintenance building, and a storage building Figure 7-18 An unlined settling pond is in place to manage water flowing from the Lucky Queen mine. An as built of the Lucky Queen underground workings is shown in Figure 7-19.



Adit

As Built Mine Features

Pond

Historic Underground Workings

Watercourse

Other Road

Limited-Use Road

Contour (5 m interval)

AKHM

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FIGURE 7-17
LUCKY QUEEN MINE LAYOUT

NOVEMBER 2021

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on November 2021

Datum: NAD 83; Projection: UTM Zone 8N

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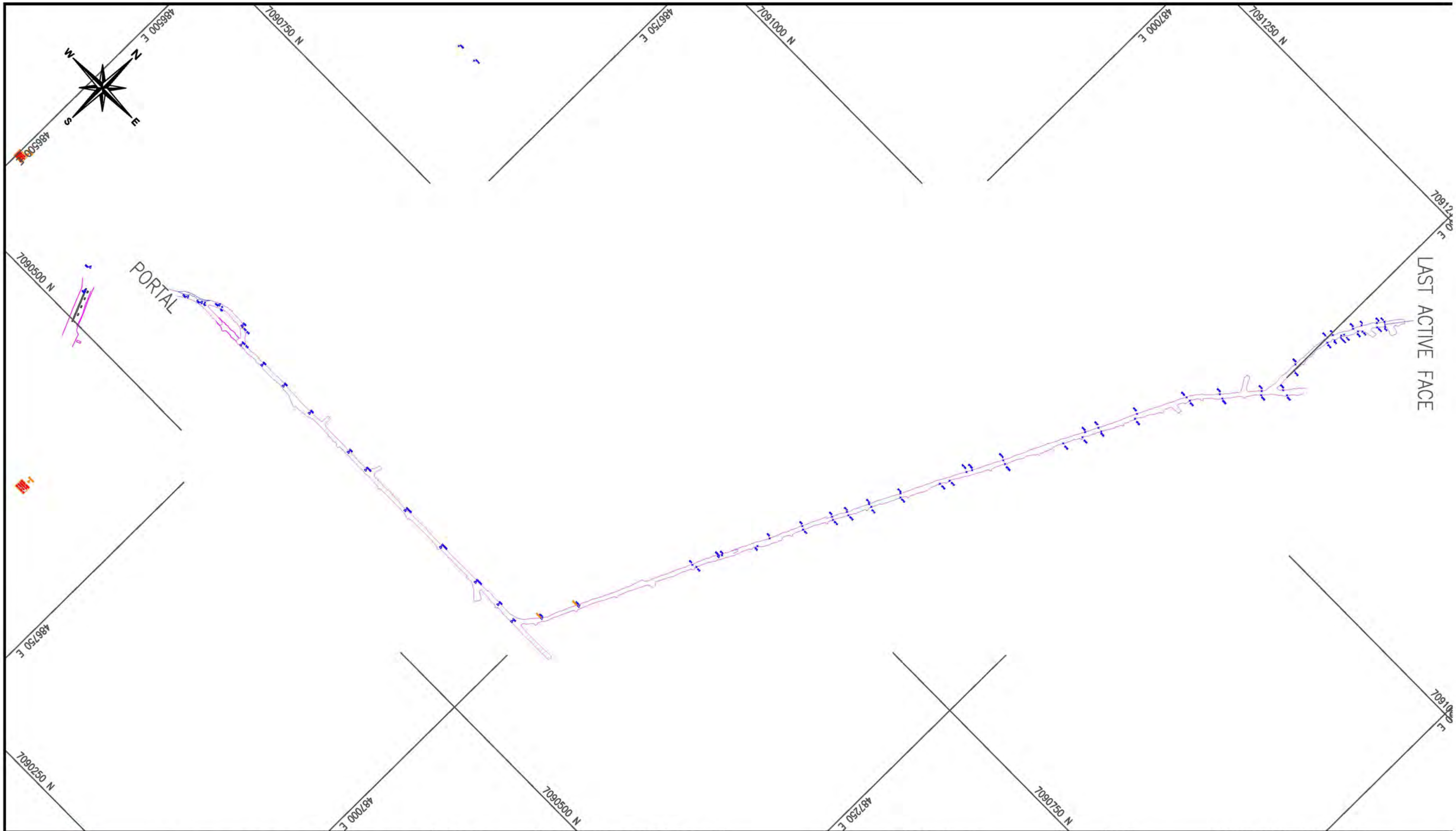
(Last edited by: tosberg;11/29/2021/09:57 AM)

Figure 7-18 Lucky Queen Portal



ALEXCO RESOURCE CORP BELLKENO MINE	DEPT.	APPROVED BY	DATE	COMMENTS	TITLE: LUCK QUEEN MINE Asbuilt March 8, 2013 Figure 7-19	
	SURVEY					
	ENGINEERING					
	GEOLOGY				Drawn by: DARIN BAKER	Scale: 1:2500
	ALEXCO MANAGER				Date: 03/08/2013	Approval: Date:
ALEXCO	PROCON SUPER				File: C:\Users\Darin Baker\Documents\Drawing1.dwg	

7.1.11 Lucky Queen Mine Closure Measures

Only the closure measures for the existing infrastructure at Lucky Queen are included as this time since this mine is not currently licenced. 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. Remove/salvage underground assets and equipment;
3. Remove/salvage surface facilities and infrastructure;
4. Backfill the adit and install French drain with pipe; and
5. Remove any hazardous materials.

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

The grading plan and the reclamation measures for the Lucky Queen mine are described and presented on Drawings S-0301, B-3101, B-3301 and C-3401 located in Appendix 3.1.

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 7-20.

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 November 2021, approximately 200,000 tonnes of tailings have been placed on the DSTF. 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 Tailings Characterization Plan which was submitted in October 2020 as a requirement under Water Licence QZ18-044 and QML-0009. 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 & Moth and Bermingham 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 7-21 shows the reclamation underway on the DSTF during June 2012. The second phase of progressive reclamation was completed in August 2013 (Figure 7-) 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 7-23.

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.

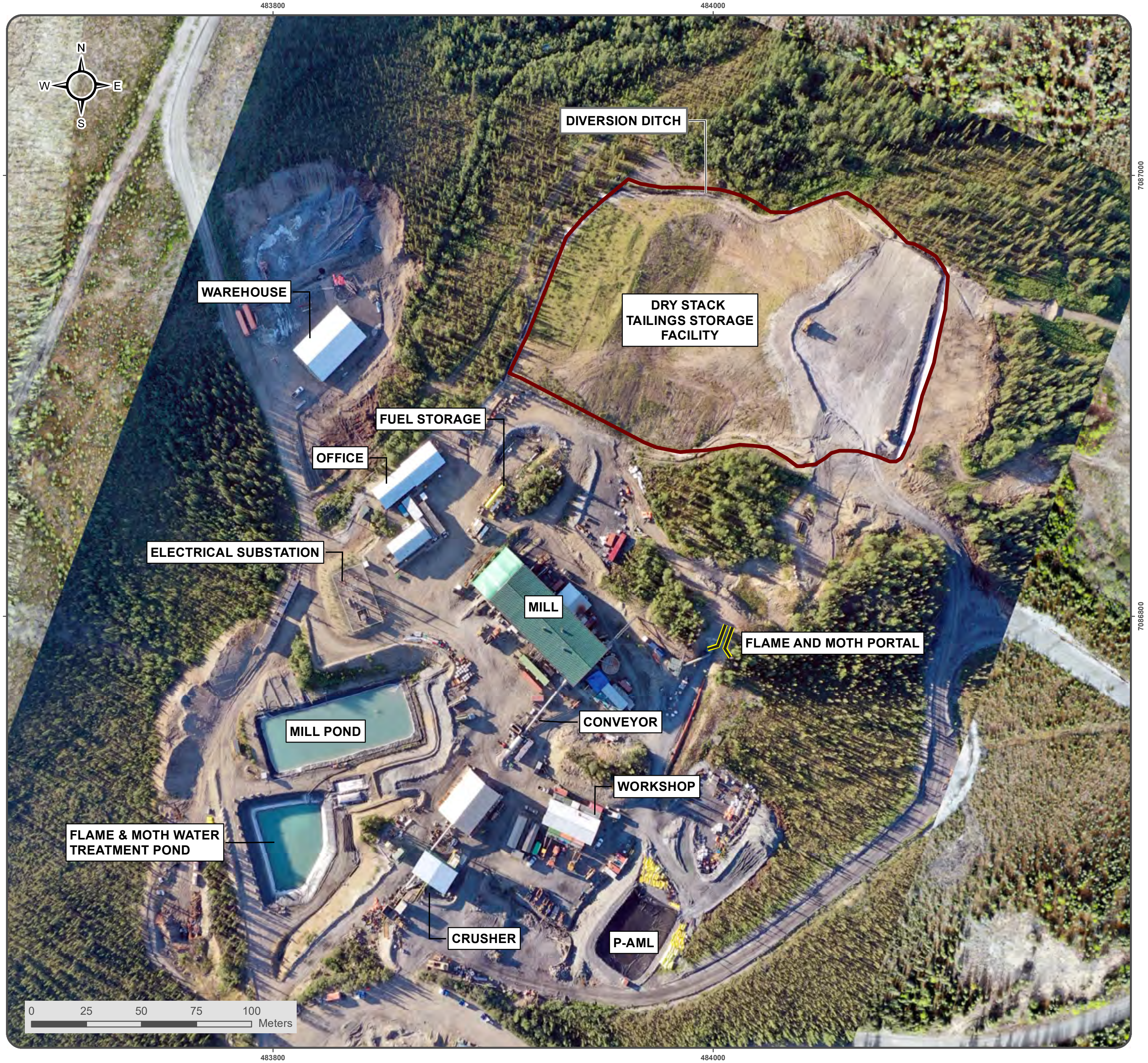
The DSTF cover performance to date has shown no seepage from the toe of the dry stack facilities. Additional, groundwater well BH39 located in the dry stack tailings facility remains dry since installation. Runoff during snow melt and runoff from large rain events is captured and conveyed to the mill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

ALEXCO KENO HILL MINING CORP.

FIGURE 7-20

DRY STACK TAILINGS FACILITY LAYOUT CURRENT CONDITIONS

NOVEMBER 2021



Adit

Waterbody

Current DSTF

Aerial Imagery aquired on August, 2020.

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

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(*Last edited by: tosberg;11/19/2021/15:24 PM*)

Figure 7-21 DSTF Progressive Reclamation, June 2012

Figure 7-22 DSTF Progressive Reclamation, August 2013

Figure 7-23 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 – 2020 demonstrate that the soil cover has been effective in doing so and has established vegetative cover as shown in Figure 7-23.

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 QZ18-044. 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.

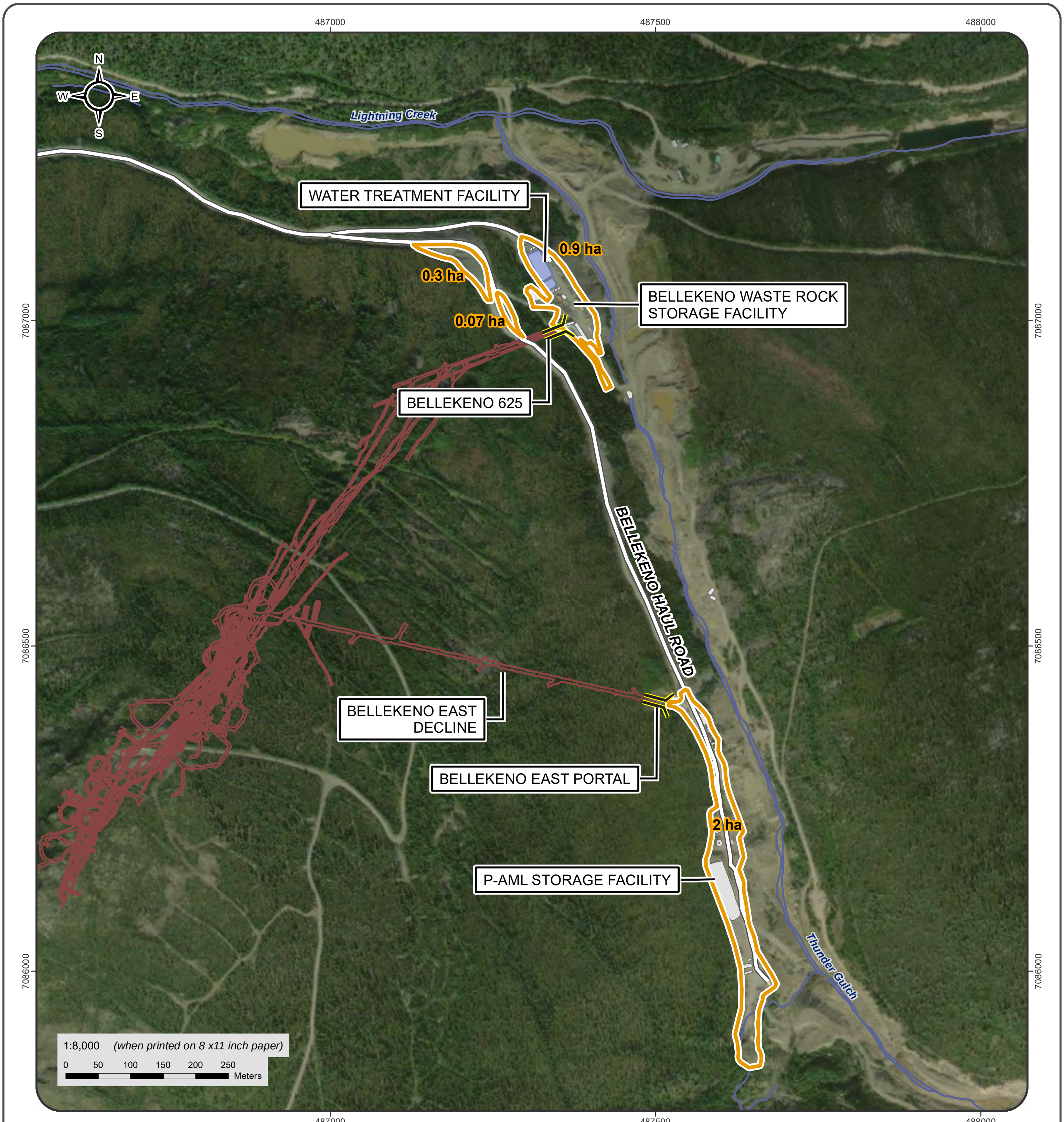
7.3.1 Bellekeno Waste Rock Storage Facilities/Disposal Areas

7.3.1.1 P-AML Waste Rock Storage Facilities

P-AML waste rock previously mined from the Bellekeno mine was placed in a lined temporary Waste Rock Storage Facility (WRSF) located south of the Bellekeno East portal (Figure 7-24). The facility was designed according to the approved generic design (EBA, 2008) Appendix 3.2. At temporary closure of Bellekeno, this P-AML waste rock stored has been transported underground. The temporary WRSF liner has been removed and placed underground in 2021. Recontouring and revegetation will take place with appropriate growth media and seed mixes.

7.3.1.2 N-AML Waste Rock Disposal Area

A Waste Rock Disposal Area (WRDA) was proposed to be constructed along the northeast flank of Sourdough Hill, northwest of the current Bellekeno 625 waste rock storage areas. 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.



Satellite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on October 27 2021.

Datum: NAD 83; Projection: UTM Zone 8N

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FIGURE 7-24

LOCATION OF EXISTING BELLEKENO WASTE ROCK STORAGE FACILITY

OCTOBER 2021

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(Last edited by: tosberg; 10/27/2021/13:58 PM)

7.3.1.3 Bellekeno 625 Waste Rock Dump

The Bellekeno 625 waste rock dump (Figure 7-24) 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 Flame & Moth Waste Rock Storage/Disposal Areas

7.3.2.1 Flame & Moth P-AML Waste Rock Storage Facilities

A lined temporary P-AML storage facility has been constructed near the portal entrance (up to 12,000 tonnes) (Figure 5-4 and Appendix 3.4). 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.

7.3.2.2 Flame & Moth N-AML Waste Rock Storage Facilities

A N-AML waste rock disposal area will not be built for Flame & 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.

7.3.3 Bermingham Waste Rock Storage/Disposal Areas

7.3.3.1 Bermingham P-AML Waste Rock Storage Facilities

A temporary P-AML storage facility has been constructed on the historic Bermingham waste rock dump. This and a secondary P-AML WRSF (if required) 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.

7.3.3.2 Bermingham N-AML Waste Rock Storage Facilities

A N-AML waste rock disposal area will be built for the Bermingham Mine (Figure 7-11) 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.

7.3.4 Onek Waste Rock Storage Facilities/Disposal Areas

7.3.4.1 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 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.

7.3.4.2 N-AML Waste Rock Disposal Area

N-AML will be used for general construction and access road repairs and surface capping, or placed into onsite N-AML WRDAs (Figure 7-15). 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.

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

7.3.4.3 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.

7.3.5 Lucky Queen Waste Rock Storage/Disposal Areas

7.3.5.1 P-AML Waste Rock Storage Facilities

This is not yet licenced and therefore not constructed, so no reclamation required at this time.

7.3.5.2 N-AML Waste Rock Disposal Area

N-AML will be used for general construction and access road repairs and surface capping, or placed into the onsite N-AML WRDA. N-AML material may also be placed underground as mine backfill, as required. The existing disturbance at 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.

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

7.3.5.3 Lucky Queen Historic Waste Rock Dumps

Terrestrial reclamation of historic liabilities at Lucky Queen is currently under the scope of the District Closure Plan.

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:

- Prevent, minimize, or mitigate adverse effects on the aquatic environment by removing constituents of concern prior to discharge to the aquatic or terrestrial environment.
- Minimize effects on the terrestrial environment by reducing sources of metals that could affect soil quality.
- 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 coffer dam (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 Rock fill in front of adit
Onek	No water discharges from Onek 990 portal Rock fill in front of adit
Flame & Moth	Mine floods and reaches pre-mining static groundwater elevation (20 metres below surface and portal elevation, no portal discharge) Modification of Mill Pond to function as bioreactor if required 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 or PUF plug in front of adit

7.4.2 Bellekeno 625

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. At closure, reagents will be added to the mine as it floods to promote the natural biological conditions for *in situ* mine water treatment. Water management will be constructed to control the discharge and to allow reagent injection if required.

The water quality monitoring collected by AKHM over the life of the Bellekeno mine, which includes both periods of operation as well as several years of temporary closure, provides a sound basis for designing the *in situ* treatment reagent addition and water management requirements. Targeted campaigns of water sampling throughout the underground are planned immediately following cessation of mining, while there is still safe access to the underground. Reagent addition will begin as the mine floods. Water sampling with analysis of both water chemistry and indicators of biological activity will be done periodically. This will contribute to the body of knowledge for reclamation research about this type of mine specific semi-passive treatment.

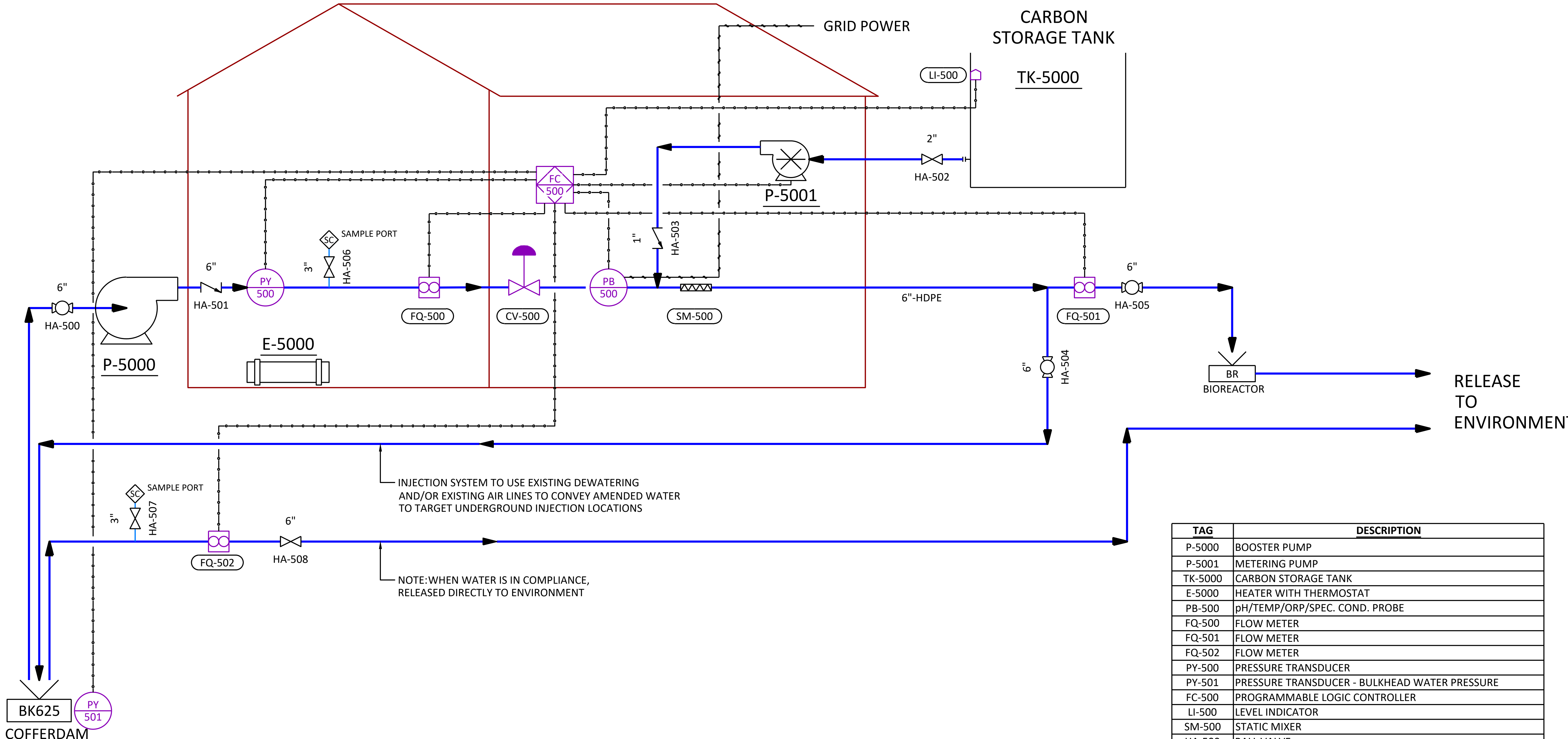
A concrete coffer dam will be constructed to allow management of the underground mine water in the long term. The coffer dam is not designed to withhold water to allow flooding above the 625 elevation, but rather as a water management tool and feature that will allow consistent flow to the secondary bioreactor contingency treatment system if it is required for treatment. A preliminary design for the Bellekeno 625 adit concrete coffer dam is shown in Figure 7-26. The size of the Bellekeno 625 adit opening is approximately 2.5 m x 2.5 m.

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

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

- A hydrogeological study of the Bellekeno Mine is on-going during mine operations and is required to confirm 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 ~2.9 L/s. 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.
- A preliminary design for the coffer dam is shown in Figure 7-26 (Appendix 3.1, Drawing S-0302). The coffer dam 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 Silver King and has proven highly successful in reducing soluble metal loading. 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 to meet discharge criteria. A process and instrumentation diagram for this system is included in Figure 7-25. 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.
- Bellekeno will have a 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. As a contingency, 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.
- 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.

Additional details for the *in situ* treatment system can be found in Appendix 3.7.



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.
2021-11-25	Draft for review	B	KAB	--
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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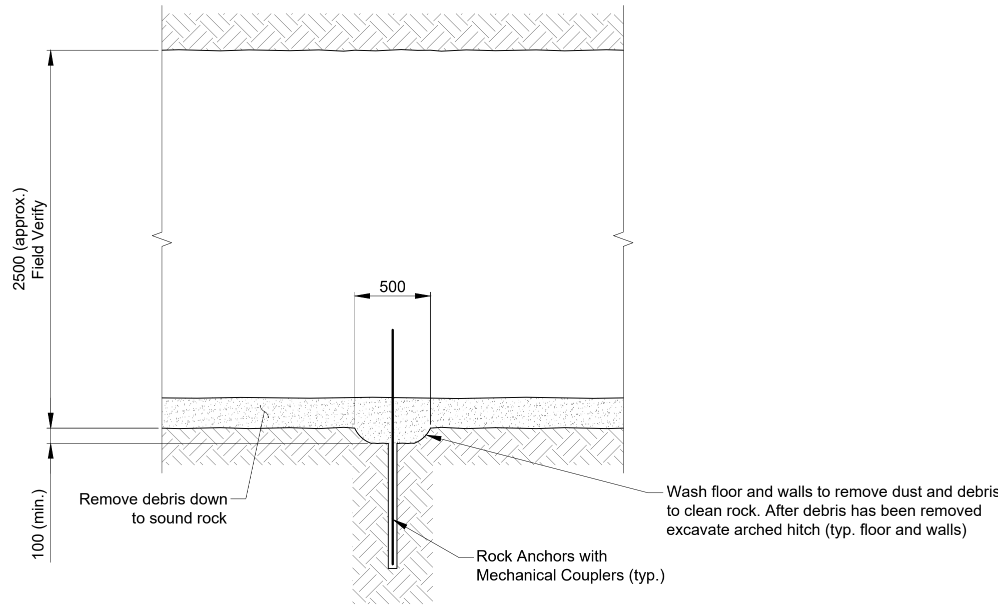
Keno District Mine Operations
Reclamation and Closure Plan
Drawing No.: AKHM-13-01-D2601

Figure 7-25

Bellekeno 625 In Situ Treatment Process Flow and Instrumentation Diagram

REVISION B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: EJL	REVIEWED BY: JMH



1 COFFERDAM PREPARATION - LONGITUDINAL SECTION
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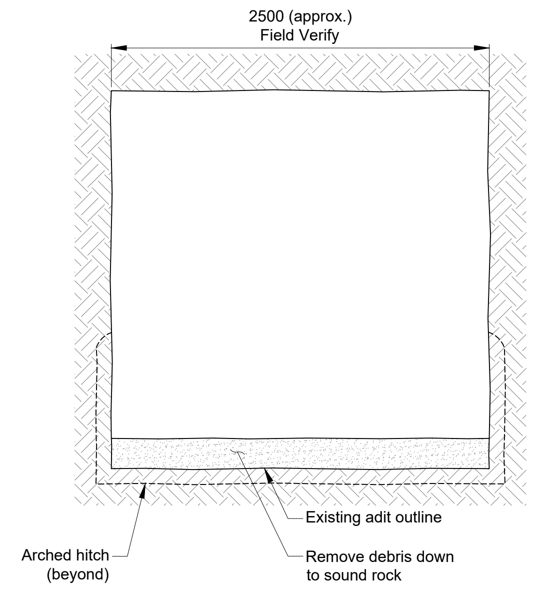
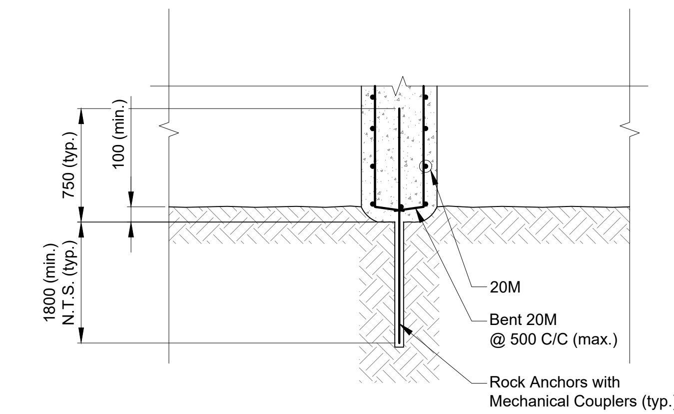


A ADIT CROSS SECTION
Scale: 1:50
*Rock anchors not shown for clarity



3 ARCHED HITCH DETAIL (TYP. ALL SIDES)
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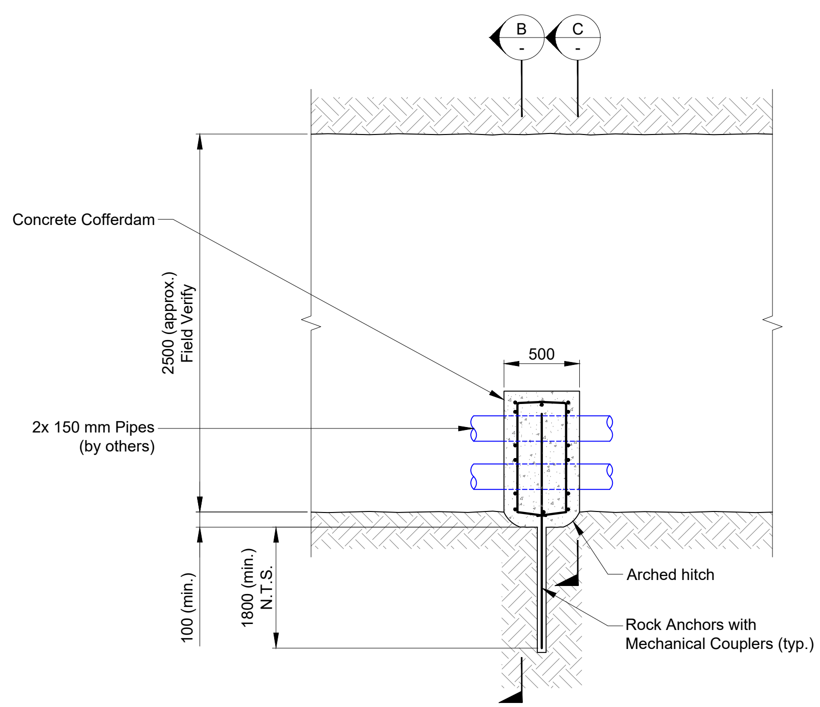

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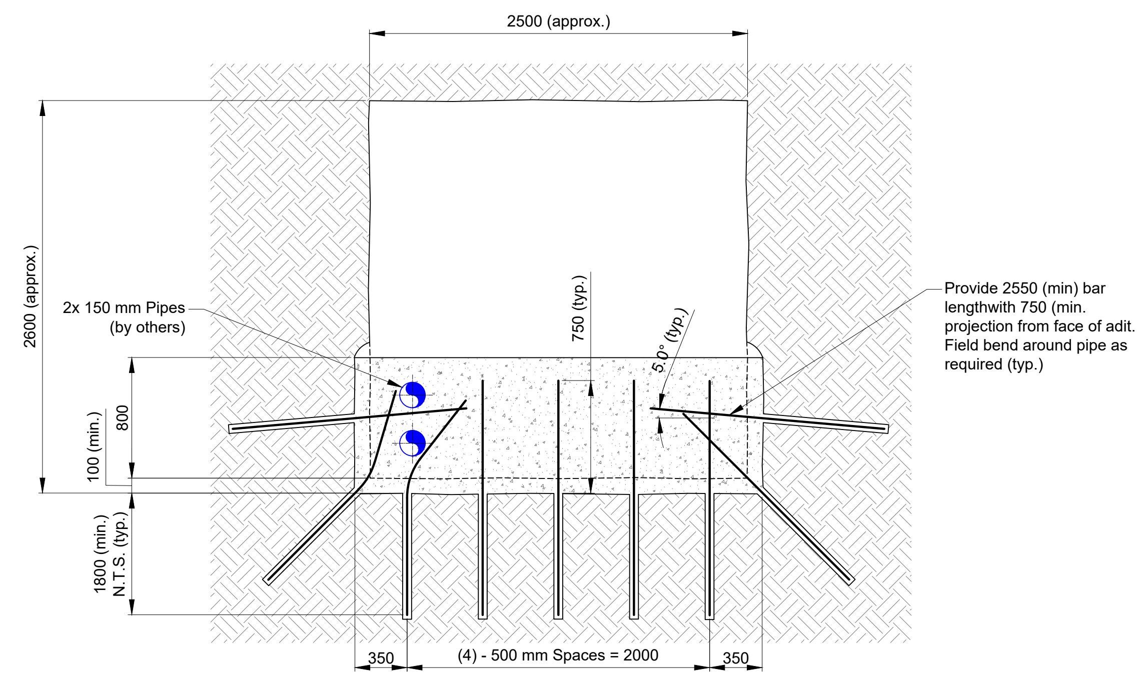

B COFFERDAM - TRANSVERSE SECTION
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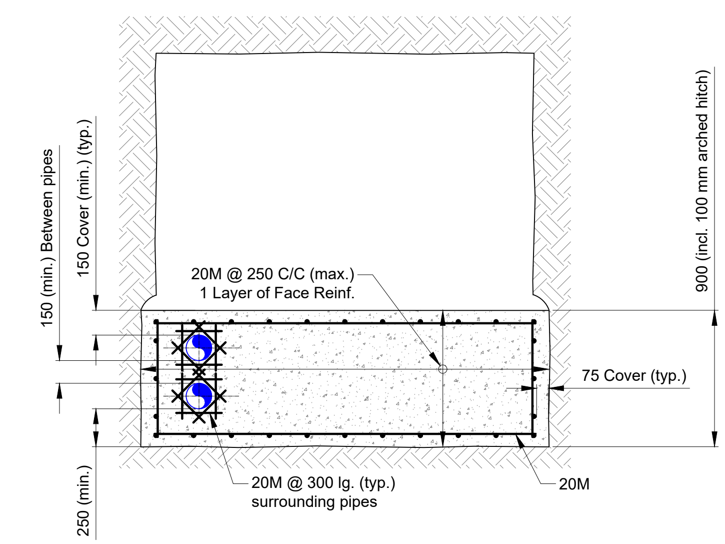
*Reinforcing steel not shown for clarity



C COFFERDAM - TRANSVERSE SECTION
Scale: 1:50
*Rock anchors not shown for clarity

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2021-11-18	Draft for review	A	KAB	--

DRAFT
NOT FOR
CONSTRUCTION

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AKHM

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

Figure 7-26
Sections and Details Concrete Cofferdam
Adit Closure

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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7.4.2.1 Bellekeno 625 Existing Water Treatment Facility

The Bellekeno 625 Water Treatment Facility (WTF) (Figure 7-27) 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 7-27 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 or placed in the DSTF.

The discharge criteria currently authorized in Water Licence QZ18-044 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.

7.4.2.2 Bellekeno 625 Bioreactor

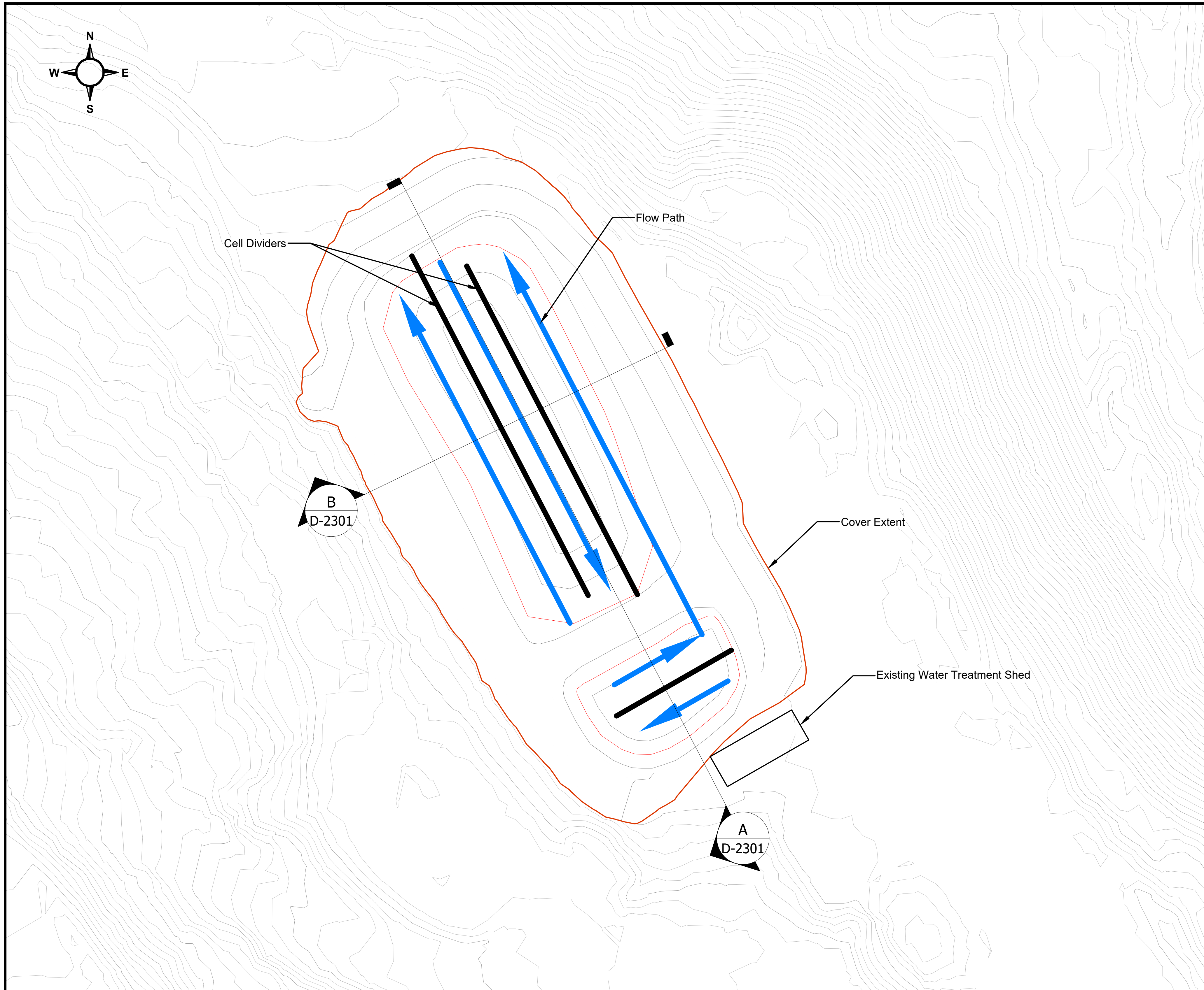
A preliminary design of the bioreactor at 625 is shown in Figure 7-28 and Figure 7-29.

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 compliant water, an additional contingency treatment system in the form of a bioreactor adds further 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.



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

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2018-02-01	Draft for review	A	KAB	--

ENSERO solutions

AKHM

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

Figure 7-28
Bellekeno 625
Bioreactor Design

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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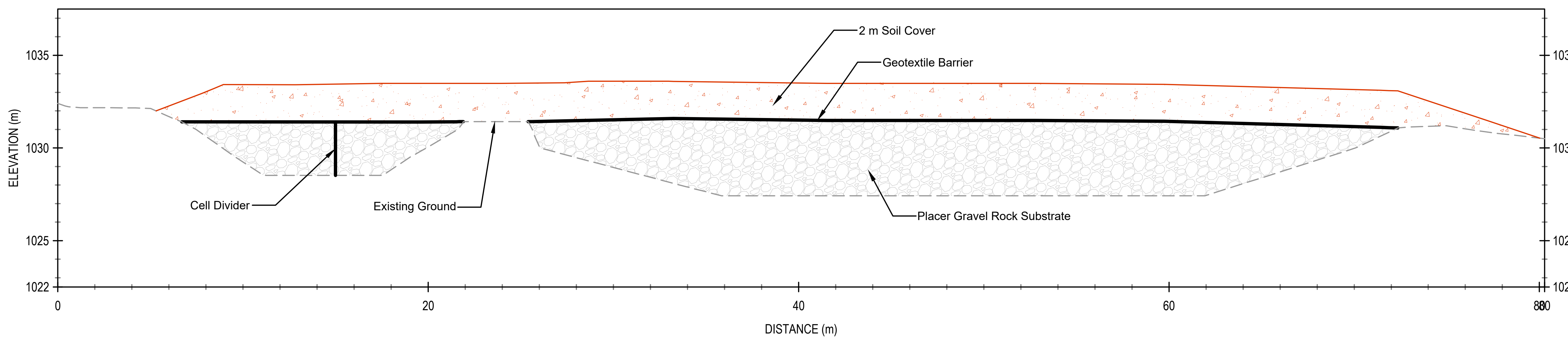
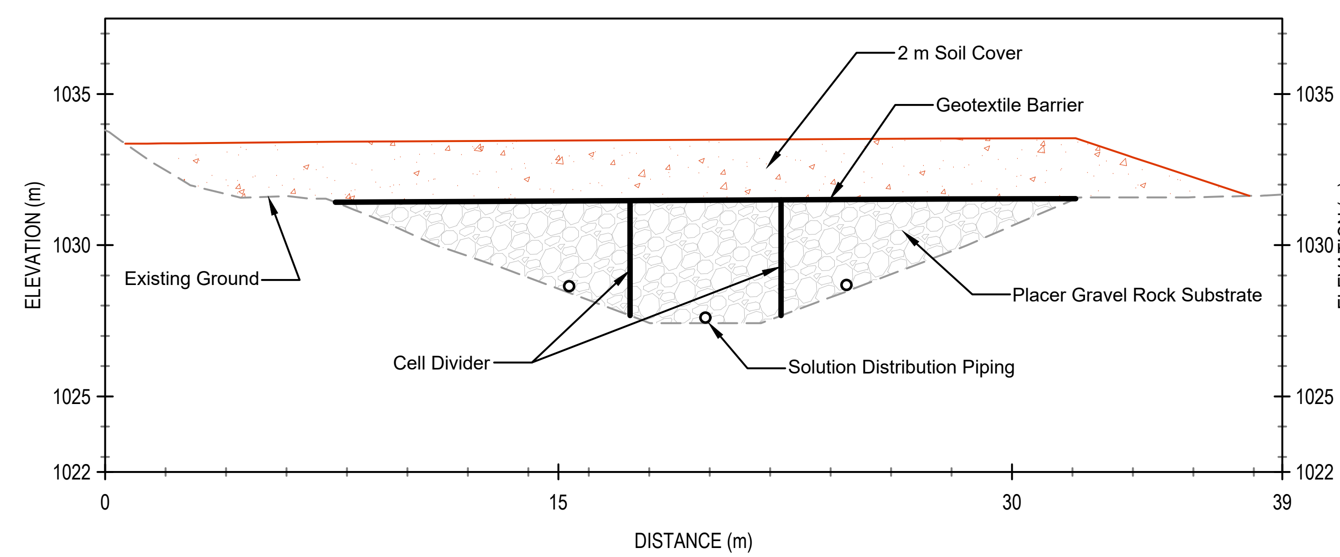


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2018-02-01	Draft for review	A	KAB	--

ENSERO solutions

AKHM

Keno District Mine Operations Reclamation and Closure Plan

Drawing No: AKHM-13-01-D-2301

Figure 7-29
Bellekeno 625
Bioreactor Design Sections

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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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																
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							■	■	■	■	■	■	■	■	■	■	■

7.4.3 Flame & Moth

7.4.3.1 Flame & Moth Pond

The F&M pond is located adjacent to the mill pond and serves as a final polishing step for effluent from the water treatment plant. The clarifier overflow water from inside the mill building gravity flows via a 6" HDPE pipe into the pond. The water is then pumped from the pond to either the Lightning Creek or Christal Creek discharge points.

The F&M pond was constructed with an engineered fill embankment. The closure of the pond consists of removing and burying the HDPE liner, backfilling and recontouring the pond to limit ponding, scarification of the final surface and revegetation.

7.4.3.2 Mill 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. 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 excavated and 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. An overflow spillway will be constructed at closure to allow the pond to serve as a sedimentation pond during closure. It would capture 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.

7.4.4 Bermingham

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. A rockfill or PUF adit closure with a drain will be installed at the adit entrance to restrict access by humans or wildlife (Figure 7-5 – Type 2 or 3). At closure, discharge from the flooded Bermingham mine (up to 2.5 L/s) will infiltrate to ground.

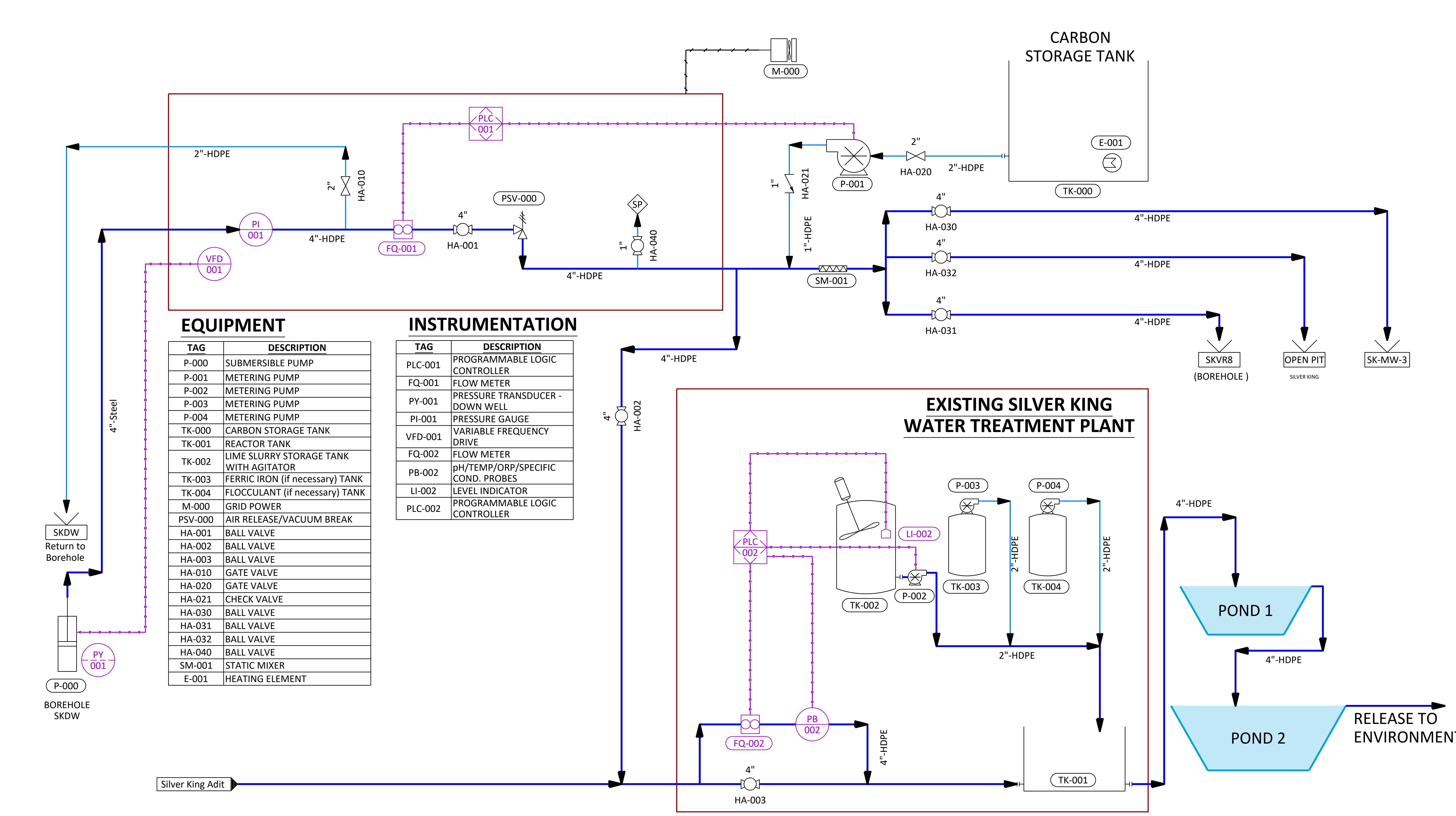
The adit discharge chemistry is expected to be similar to that of the nearby historical Bermingham 200 adit, which has an average total zinc concentration of 2.2 mg/L.

The long term water management and treatment approach for the Bermingham Mine is summarized as follows:

- Once active treatment and pumping of the mine pool ceases, the mine workings are allowed to flood and *in situ* treatment begins. A conceptual in situ treatment design, similar to that currently in place at Silver King, is envisaged for the Bermingham mine. Water from the Bermingham adit discharge will be amended with soluble organic carbon (e.g., alcohol and/or molasses) and pumped 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. 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.

- 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.
- The conceptual hydrogeologic model for the underground mine flow will be evaluated as the mine is developed. The flow volumes and pathways will be confirmed, which will then inform the *in situ* treatment design for finalizing carbon addition locations and whether water recirculation is require.
- The water quality monitoring data from both Bermingham, as well as the Bellekeno and Silver King *in situ* treatment will be used to refine the design, particularly the commissioning period requirements. To date, the data do not indicate any changes are required to the current plans.
- The lime water treatment plant constructed for the mine operations phase will remain in place as a contingency measure until the *in situ* treatment system has demonstrated stability and effectiveness.

The Silver King in situ treatment as-built is provided in Figure 7-30 and is representative of what would be constructed at Bermingham. Additional details describing typical operations and maintenance of this type of system can be found in the In Situ System Operations Plan (Appendix 3.7)



EQUIPMENT

TAG	DESCRIPTION
P-000	SUBMERSIBLE PUMP
P-001	METERING PUMP
P-002	METERING PUMP
P-003	METERING PUMP
P-004	METERING PUMP
TK-000	CARBON STORAGE TANK
TK-001	REACTOR TANK
TK-002	LIME SLURRY STORAGE TANK WITH AGITATOR
TK-003	FERRIC IRON (if necessary) TANK
TK-004	FLOCCULANT (if necessary) TANK
M-000	GRID POWER
PSV-000	AIR RELEASE/VACUUM BREAK
HA-001	BALL VALVE
HA-002	BALL VALVE
HA-003	BALL VALVE
HA-010	GATE VALVE
HA-020	GATE VALVE
HA-021	CHECK VALVE
HA-030	BALL VALVE
HA-031	BALL VALVE
HA-032	BALL VALVE
HA-040	BALL VALVE
SM-001	STATIC MIXER
E-001	HEATING ELEMENT

INSTRUMENTATION

TAG	DESCRIPTION
PLC-001	PROGRAMMABLE LOGIC CONTROLLER
FQ-001	FLOW METER
PY-001	PRESSURE TRANSDUCER - DOWN WELL
PI-001	PRESSURE GAUGE
VFD-001	VARIABLE FREQUENCY DRIVE
FQ-002	FLOW METER
PB-002	pH/TEMP/ORP/SPECIFIC COND. PROBES
LI-002	LEVEL INDICATOR
PLC-002	PROGRAMMABLE LOGIC CONTROLLER

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-11-28	Updated for pilot system	C	KAB	EJL
2017-03-22	Updated Borehole IDs	B	KAB	EJL
2015-07-16	Initial issue	A	KAB	EJL

ERDC

UKHM-*In Situ*
ESM Reclamation Plan - *In Situ* Treatment Design Report
Figure 7-30

Silver King In Situ Treatment As Built

REVISION C	2018-11-28	PROJECT No.: 007-4
DRAWN BY: KAB	DESIGNED BY: EJL	REVIEWED BY: JMH

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Figure 7-31 Mill Process Pond

7.4.5 Onek

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.

7.4.6 Lucky Queen

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.

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

7.5.1.1 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:

- Sea container storage units (5 each);
- Skid mounted washroom trailer;
- Skid mounted miners dry/lunchroom;
- 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.

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 is in the process of being permitted 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.

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

7.5.1.2 Bellekeno 625 Adit Surface Facilities

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

- Historic loadout and snow shed facility;
- Compressor shack;
- Ventilation fan;
- Water treatment buildings (will be converted to treat shed for in situ see Section 7.4.2);
- Sea container storage units; and
- Electrical substation (will remain until power not required at Bellekeno in situ).

7.5.2 Flame & Moth Surface Infrastructure

The Flame & 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 5-5 and Figure 7-32 shows the location of the Flame and Moth portal in relation to the mill. Figure 5-5 and Figure 7-32 shows the location of the Flame & Moth portal in relation to the mill. Surface infrastructure that is new to Flame & Moth and not already included in the mill facilities and infrastructure includes:

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

Figure 7-32 Flame and Moth Surface Facilities

An overview of the layout of the Flame and Moth mine surface infrastructure is shown in Figure 5-5. An overview of the layout of the Flame & Moth mine surface infrastructure is shown in Figure 5-5. The water treatment plant (WTP) for the Flame & 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 & Moth will be installed inside the portal to reduce noise emissions.

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

7.5.3 Bermingham Surface Infrastructure

The Bermingham mine 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;
- Substation from Ruby and power lines; and
- Compressor, ventilation containers.

A view of the Bermingham surface facilities (current and proposed) and layout is shown in Figure 7-10, Figure 7-11 and Figure 7-12. The existing infrastructure as of September 2021 is shown in Figure 7-33

All of the above infrastructure will be removed and repurposed or disposed of. The substation at Ruby will be removed. 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 assessed near Elsa 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. Compacted areas will be scarified to promote natural revegetation or selected areas will be reseeded with native vegetation.

Figure 7-33 Existing Bermingham Surface Infrastructure (September 2021)

7.5.4 Onek Surface Infrastructure

All buildings and facilities at Onek have been removed and the area only requires minimal final recontouring and reclamation of the surface disturbance and closure of the portal.

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 assessed near Elsa 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.

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

7.5.5 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 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 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.

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

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 5-5 and Figure 7-34.

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 5-5 and Figure 7-34):

- Mill building;
- Mill office and dry;
- Electrical substation;
- Crusher plant and building;
- Crusher MCC;
- Fine ore stockpile;
- Mill feed conveyor;
- Mill MCC;
- Assay lab;
- Process water tank;
- Diesel storage tank;

- Warehouse;
- Propane tank; and
- Lightning Creek bridge.

7.5.6.1 Mill Buildings and Infrastructure

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

- modular, prefabricated trailer style buildings, such as the offices and dry;
- rigid, steel frame construction buildings with steel wall sheeting, such as the mill building; 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 7-34 Aerial View of Mill Site Infrastructure and Layout

7.5.6.2 Mill Building

The mill building is a pre-engineered steel building containing all of the processing equipment used for the milling, flotation and recovery of Ag, Pb and Zn from the Bellekeno mine underground ore. The mill building is 22.5 x 54 meters in dimension (Figure 7-35).

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 7-35 Mill Building

7.5.6.3 Mill Office and Dry

The mill office and dry facility is comprised of two skid mounted trailer units and one skid mounted wash car with a wooden truss constructed over the top of the 3 units. The four office units are 3.05 x 8.3 meters in dimension and the dry/shower facility is 3.35 x 11.58 meters (Figure 7-36).

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 7-36 Mill Office and Dry

7.5.6.4 Electrical Substation

An electrical substation is located adjacent to the mill office/dry facility and houses a primary 69 KV – 600 V step down transformer and electrical distribution infrastructure. The substation is enclosed by a 28 m x 15.5 m fence (Figure 7-37). 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 7-37 Electrical Substation

7.5.6.5 Crushing Plant

Coarse ore from the Bellekeno, Bermingham, Onek, Lucky Queen and Flame & Moth underground mines is transported to a crushing plant (Figure 7-38 Crushing Plant) 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.

The crusher retaining wall is constructed of 6 stacked sea- containers that likewise can be removed and salvaged.

Figure 7-38 Crushing Plant

7.5.6.6 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 7-39). 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 7-39 Fine Ore Stockpile

7.5.6.7 Crusher MCC

A Motor Control Centre (MCC) for the crusher (Figure 7-40) 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 7-40 Crusher MCC

7.5.6.8 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 7-41). 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 7-41 Assay Lab

7.5.6.9 Mill Motor Control Centre

A Motor Control Centre (MCC) for the mill building (Figure 7-42) is located immediately adjacent to the mill and contains the motor control starters and distribution for the mill equipment. The main electrical substation distributes 600 V electrical power to the mill MCC. The mill MCC is a skid mounted unit mounted on a steel support structure and has a dimension of 15.24 x 3.04 meters.

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

7.5.6.10 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 7-42 Mill MCC

7.5.6.11 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.

7.5.6.12 Propane Tank

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

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

7.5.6.13 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 7-43). Some personnel and camp accommodation requirements will be required in the longer term for the Lucky Queen, Onek, and other deposits as well as for 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, Bermingham, and Flame & Moth deposits production closure plan and requirement.

Closure measures include dismantling and removal of the excess trailer units off site. 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 7-43 Flat Creek Camp

7.6 HAZARDOUS MATERIALS

7.6.1.1 Mill Wastes

Any remaining reagents or chemicals will be returned to the supplier where possible. Concrete footings will be demolished and buried *in situ*. Demolition debris will also be removed for reuse, salvage, recycle, 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.

7.6.1.2 Contaminated Soils

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 areas would be regraded re-graded to prevent water ponding, and the surface will be scarified and reseeded to promote vegetative cover. There is currently no onsite deposit for (metals) contaminated soils; any metal contaminated soils in the vicinity of the mine workings will be placed underground with any remaining PAML or other waste rock.

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 lined rehandling pads will be demolished and buried once cleaned of all metal contaminants.

7.6.1.3 Landfills

Alexco has a number of permitted locations per Waste Management Permit 81-067 for safe disposal of demolition debris including:

- Bellekeno;
- Mill;
- Sign Post Portal; and
- Permitted but not yet built at Lucky Queen and Bermingham.

There is sufficient capacity for the demolition materials planned for disposal on site.

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 7-45):

- 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 7-45). 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. It has been assumed existing public roads will remain in place post closure. Figure 7-44 illustrates a typical section of the haul road between the mine and mill and shows the bridge crossing at Lightning Creek.

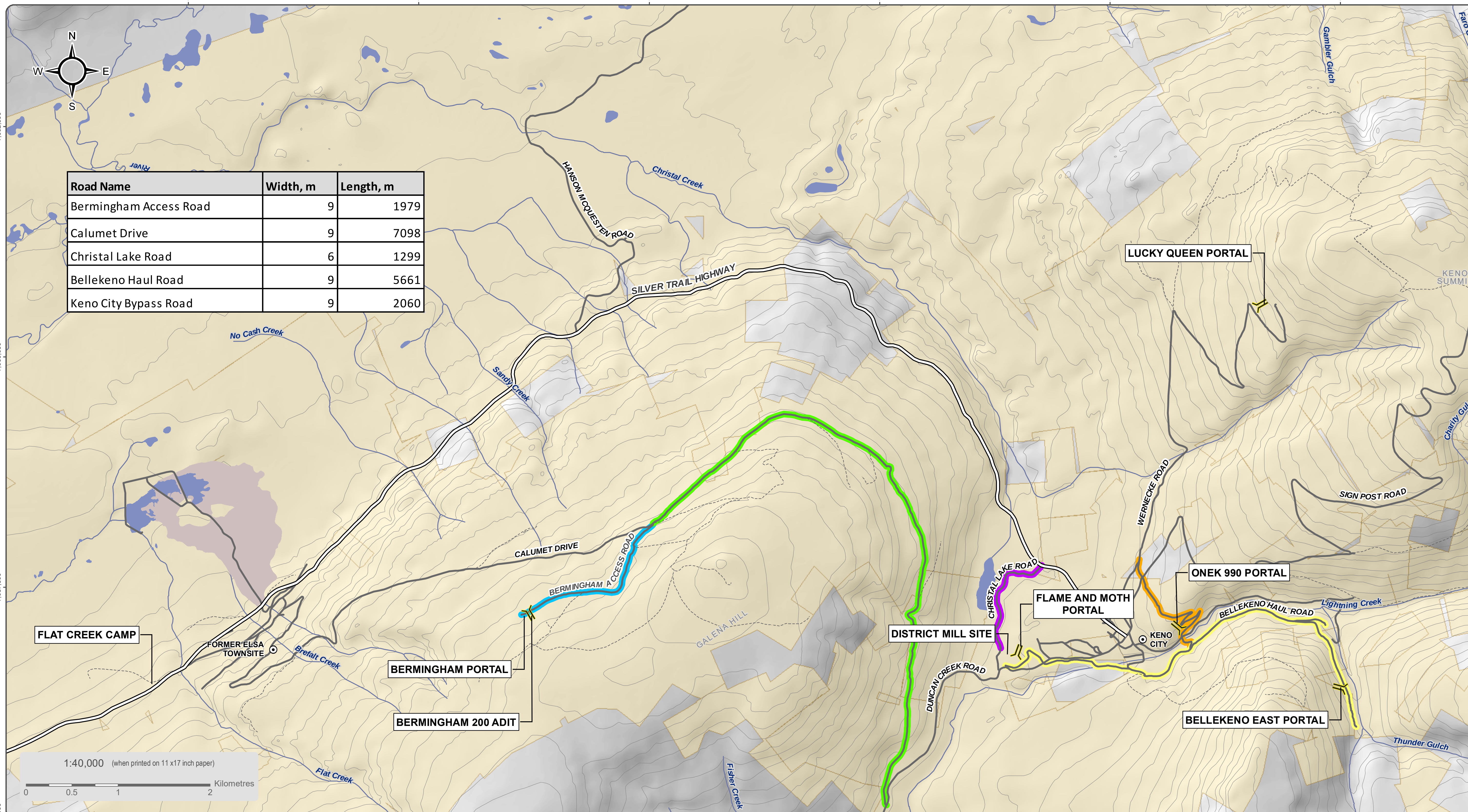
A typical cross-section of road reclamation is described in Drawing B-0301, located in Appendix 3.1.

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.

Figure 7-44 Lightning Creek Bridge and Typical Bellekeno Haul Road Section

7.7.2 Transmission Lines

Transmission lines constructed or to be constructed include the Mill/F&M, Bellekeno, Bermingham, and in future the 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.



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.

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

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Chistal Lake Road
Bellekno Haul Road
Keno City ByPass
Calumet Drive
Bermingham Access Road

Place of Interest
Adit
Alexco/ERDC Quartz Claims

Tailings Area
Waterbody
Silver Trail Highway
Road
Limited-Use Road

AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 7-45

ROADS SUBJECT TO STANDARD DECOMISSIONING AND RECLAMATION

OCTOBER 2021

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 7-46) 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 7-46 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; and
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.

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; and
- 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. Progressive reclamation has taken place on the DSTF and a summary report on the activities completed in 2012 are included in Appendix 1.1

Appropriate diversions will be in place to meet erosion prevention objectives. Alexco's revegetation program includes contouring and resloping, 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, Bermingham and Flame & Moth Production Unit Areas closure is commensurate with the overall plan for the district.

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.

7.9.3.1 Cover Modelling

This reclamation plan does not require any covers to function as "low permeability" covers to prevent infiltration. There will be no reactive (P-AML) waste rock left on surface nor reactive tailings. Therefore, conventional cover modelling which evaluates design and performance of covers in terms of reduction of net percolation etc is not required.

The cover on the DSTF facility is designed to reduce erosion, enhance runoff and facilitate a vegetated surface after closure. The DSTF cover is an additional control on infiltration, as well as providing erosion control and a vegetated surface. The demonstration of the cover performance is tracked during operation by both observations of surface conditions (saturation, cracking etc) and monitoring of any seepage from the DSTF which would be collected through the existing system of ditching and piping at the toe of the facility.

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.

ALEXCO KENO HILL MINING CORP.

FIGURE 7-46

GROWTH MEDIA SITES
IN DISTRICT AREA

NOVEMBER 2021

Adit
Growth Media Stockpiles
Waterbody
Current DSTF

Aerial Imagery aquired on August, 2020.

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

AKHM

D:\Project\AllProjects\Keno_Area_Mines\ALL-SITES\02-Map\01_Overview\02-District Mill\Growth_Stockpiles_District_MIll_20211025_20211025.mxd
(*Last edited by: tosberg;11/19/2021/14:42 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 already in place for care and maintenance activities and for advanced exploration and preliminary development activities at the KHSD. These programs include physical inspections, effluent treatment systems and flow monitoring, a water quality surveillance network, old mine workings monitoring, aquatic effects monitoring for benthic invertebrate populations, sediment monitoring, waste rock and mine wall sampling and the Adaptive Management Plan.

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

a) Surface water quality monitoring (as per Table 7-4);

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 7-4 Keno Hill Silver District Mining Operations Water Monitoring Program Summary

		WATER LICENCE	INSITU MEASUREMENTS / INTERNAL ANALYSIS									EXTERNAL LAB ANALYSIS															
SITE	SITE DESCRIPTION	QZ18-044 Monitoring Status	Level	Synoptic Levels	Flow	pH	Temperature	Conductivity	Total Zn	Ammonia	Turbidity	Total Metals	Dissolved Metals	Hardness	pH	Conductivity	TSS	Alkalinity	Sulphate	Nitrate	Nitrite	Ammonia-N	DOC	Total Phosphorous	Total and Free Chlorine	Radium 226	Acute Lethality LC50 Rainbow Trout 96 Hour
Mine Treatment / Effluent Discharge Sites																											
KV-42	Bellekeno 625 Adit	Existing	-		C	D	D	D	D	D	D	W	W	W	W	W	W	W	W	W	W	W	M	W		-	-
KV-43	Bellekeno 625 Settling Pond Decant	Existing	-		C	D	D	D	D	D	D	W	W	W	W	W	W	W	W	W	W	W	W	W		W/Q	M
KV-82	Flame and Moth Mill Site Collection and Sediment Pond	Existing	D		-	D	D	D	D	D	D	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-83	Flame and Moth Mill Treatment Plant Discharge	Existing	-		C-WD	D-WD	D-WD	D-WD	D-WD	D-WD	D-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	Q-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD		W/Q	M
KV-105	Flame and Moth Adit Discharge	Existing	-		C	D-WD	D-WD	D-WD	D-WD	D-WD	D-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD		-	-
KV-104L	Flame and Moth Settling Pond Decant discharge to Lightning Cree	Existing	D		C-WD	D	D	D	D	D	D	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD		W/Q	M
KV-104C	Flame and Moth Settling Pond Decant discharge to Christal Creek	Existing	D		C-WD	D	D	D	D	D	D	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD		W/Q	M
KV-110	New Bermingham Portal	Existing	-		C-WD	D-WD	D-WD	D-WD	D-WD	D-WD	D-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	D-WD*	-	-
KV-114	New Bermingham Pond Decant	Existing	D		C-WD	D	D	D	D	D	D	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	W-WD	D-WD*	W/Q	M
Mine Surface Water Surveillance Sites																											
KV-1	South McQuesten River u/s Christal Creek	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-2	South McQuesten River @ Pumphouse	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-6	Christal Creek @ Keno Highway	Existing	-		C	M-WD	M-WD	M-WD	-	-	-	W-WD/M	W-WD/M	W-WD/M	W-WD	W-WD	W-WD	W-WD	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M		-	-
KV-7	Christal Creek @ Hanson Road	Existing	-		M	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-8	Christal Creek @ mouth	Existing	-		Q	M	M	M	-	-	-	M	M	M	M	M	M	M	M	-	-	-	M	M		-	-
KV-21	No Cash Creek at Silver Trail Highway	Existing	-		C	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-37	Lightning Creek u/s Hope Gulch	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-38	Lightning Creek u/s Thunder Gulch	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-39	Hope Gulch u/s Lightning Creek	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-40	Charity Gulch u/s Lightning Creek	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-41	Lightning Creek u/s Bridge @ Keno City	Existing	-		C	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-44	Bellekeno 625 Seep	Existing	-		Ms	Ms	Ms	Ms	Ms	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	Q
KV-45	Onek 400 Adit	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-49	Hinton Creek u/s Christal Creek	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-50	Christal Creek u/s Hinton Creek	Existing	-		M-WD	M-WD	M-WD	M-WD	-	-	-	W-WD/M	W-WD/M	W-WD/M	W-WD	W-WD	W-WD	W-WD	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M		-	-
KV-51	Christal Creek d/s Hinton Creek	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-52	Natural spring to Christal Lake @ Old Mackeno Pumphouse	Existing	-		M	M	M	M	-	-	-	M	M	M	M	M	M	M	M	-	-	-	M	M		-	-
KV-56	Star Creek at Silver Trail Highway	Existing	-		M	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-65	Thunder Gulch u/s of Bellekeno 625	Existing	-		Q	Q	Q	Q	-	-	-	M	M	M	M	M	M	M	M	-	-	-	M	M		-	-
KV-72	South McQuesten River at McQuesten Lake	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q				Q	Q			
KV-76	Thunder Gulch d/s Bellekeno 625	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-77	Thunder Gulch u/s Bellekeno East	Existing	-		Q	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-78B	Bellekeno East Temporary Waste Rock Storage Facility	Existing	Ms		-	Ms	Ms	Ms	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-79	Christal Creek d/s MacKeno Tailings	Existing	-		-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-80	Christal Creek u/s Mackeno Tailings	Existing	-		-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-81	Lightning Creek Southwest of Mill Site	Existing	-		M-WD	M-WD	M-WD	M-WD	-	-	-	W-WD/M	W-WD/M	W-WD/M	W-WD	W-WD	W-WD	W-WD	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M	W-WD/M		-	-
KV-106	Flame and Moth Temporary P-AML Waste Rock Storage Facility	Existing	Q		-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-111	No Cash Creek above No Cash 500 Adit	Existing	-		M	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
KV-115	Bermingham P-AML Facility #1	Existing	Ms		-	Ms	Ms	Ms	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-119	Bermingham P-AML Facility #2	Pending	Ms		-	Ms	Ms	Ms	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	-	-	-	Q	Q		-	-
KV-118	No Cash Creek at Calumet Drive	Existing	-		M	M	M	M	-	-	-	M	M	M	M	M	M	M	M	M	M	M	M	M		-	-
Mine Groundwater Monitoring Wells																											
KV-84Nd	Keno City Well #1	Existing	Q	-	-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-85D	Keno Hill Silver Distirict Mill Site Groundwater Well #1 (PH2) Deep	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-85S	Keno Hill Silver Distirict Mill Site Groundwater Well #2 (Shallow)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-86	Keno Hill Silver Distirict Mill Site Groundwater Well #3 (PH5)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-87	Keno Hill Silver Distirict Mill Site Groundwater Well #4 (PH6)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-88D	Keno Hill Silver Distirict Mill Site Groundwater Well #5 (Deep)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-88S	Keno Hill Silver Distirict Mill Site Groundwater Well #6 (Shallow)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-89D	Keno Hill Silver Distirict Mill Site Groundwater Well #7 (Deep)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-89S	Keno Hill Silver Distirict Mill Site Groundwater Well #8 (Shallow)	Existing	Q		-	Q	Q	Q	-	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
KV-122	Bermingham - downgradient of BH SW pit well #1	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-123	Bermingham - downgradient of BH SW pit well #2	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-124	Bermingham - upgradient of BH SW pit	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q			
KV-125	Bermingham - downgradient of BH P-AML well #1	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q			
KV-126	Bermingham - downgradient of BH P-AML well #2	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-127	Bermingham - upgradient of BH P-AML	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KC-MW-4	Keno City Well #3 (Well south of Onek 400 adit)	Existing	Q	-	-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
ON-MW-2	Keno City Well #2 (Onek Monitoring Well d/g Project Facilities)	Existing	Q	-	-	Q	Q	Q	-	-	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		-	-
ON-MW-3	Keno City Well (Well south of Onek 400 adit)	Pending	M/Q	-	-	M/Q	M/Q	M/Q	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
FM-MW-01	Flame and Moth Well #1 (KAR-01)	Existing	M	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
FM-MW-02	Flame and Moth Well #2 (KAR-02)	Existing	M	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
FM-MW-03	Flame and Moth Well #3 (KAR-03)	Existing	M	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
BH39	DSTF phase 1 area	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-107	DSTF phase II expansion area	Pending	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-108	Upgradient of DSTF Phase 2 Expansion Area	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q			
RB-MW-1	Ruby 400 adit Monitoring Well	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
BH-MW-1	Historical Bermingham 200 adit monitoring well	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-116	Bermingham Waste Rock Disposal Area Well	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
NC-MW-1	No Cash 500	Existing	M/Q		-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-109	Lightning Creek near KV-81	Existing	M/Q	-	-	M/Q	M/Q	M/Q	-	-	-	-	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q	M/Q		-	-
KV-103	District Mill Supply Well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
KV-84	Overburden Monitoring Well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
KC-MW-1B	Bedrock Groundwater Monitoring Well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
KC-MW-2	Overburden Groundwater Monitoring Well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
KC-MW-3	Bedrock Groundwater Monitoring Well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ON-MW-1	Onek Monitoring Well #1 d/g Project Facilities	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ON-MW-4	Bedrock monitoring well	Existing	Q	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-

Pending Stations to be established

C = Continuous
C-WD = Continuous While Discharging
D = Daily
D-WD = Daily While Discharging
D-WD* = Daily While Discharging from breakpoint chlorination system
W = Weekly
W-WD = Weekly While Discharging

W/Q = Weekly migrating to quarterly to accord with monitoring frequency pursuant to MDMER
M = Monthly
Ms = Monthly (May - Oct)
M/Q = Monitoring to occur monthly for first 12 months, reverting to quarterly thereafter.
Q = Quarterly
A = Annually

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 7-47:

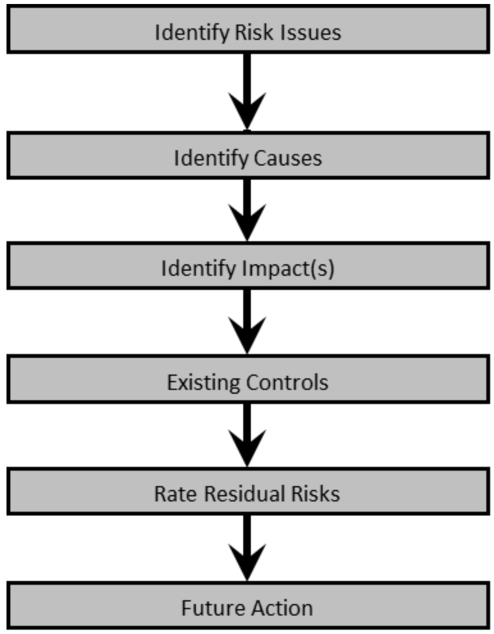


Figure 7-47 Risk Assessment Process Flow Chart

Alexco uses standard tools for risk assessments of activities. For technical risk assessments, an "FMEA" (failure modes and effects analysis) approach is used. These are conducted with appropriate technical experts to inform both the risk characterization (consequence, likelihood) as well as the mitigating measures and/or design changes.

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, Bermingham, 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 (or temporary 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, and Flame & Moth is shown in Table 7-3 and Table 5-6 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 Reclamation and Closure Plan assumes the use of third-party contractors and Yukon Government implementation. The closure cost estimate is consistent with the plan requirements and closure costing guidance as per the **August 2013 Reclamation and Closure Planning for Quartz Mining Projects**. 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 $8,623,484. Alexco also has estimated the reclamation and closure costs for the current operations at $7,424,632 and after two years of operations for the current mine plan at $7,969,688. The amount of security currently held by YG for reclamation and closure of the Keno Hill Mine Operations is $10,232,955. 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. 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 Alexco's operational and professional experience and with other closure program costing estimates prepared for Yukon Government. The following summarizes the scope within each cost sheet.

T1 Cost Summary: The summary table provides an overview of all costs required for the closure and reclamation of the Mine and links to the costs calculated in the other costing tables. Each individual costing table (Tables T2 to T15) is described separately.

T2 Unit Costs: This table lists the unit rates for equipment, personnel, materials, and other rates, which are used repeatedly throughout the cost estimate. Unit rates are based on input received during previous review processes, updated labour rates based on the Yukon Government Fair Wage Schedule (effective February 20, 2020), the Yukon Third Party Equipment Rental Rates (effective February 8, 2019), developed custom rates based on the configuration of the Mine and estimates based on current site contractors conducting similar work at Keno Hill.

T3 General and Administrative: This task accounts for typical G&A costs that are not directly associated with individual reclamation and closure tasks. Line items include general project management during the implementation period as well as pre closure planning, light vehicles, power and heat, miscellaneous G&A expenses, employee transport, mobilization/demobilization of contractor equipment and camp accommodations. Contractor costs such as profit, and insurance are included in the specific unit rate for equipment.

T4 Exploration Disturbances: No costs are included for this task as exploration disturbance is bonded for under the Class IV Mining Land Use ApprovalLQ00476 and security is held under a separate bond held by the Yukon

T5 Closure Planning: Costs for closure planning include an update to the closure plan every 2 years, ongoing kinetic testing of tailings and waste rock, adaptive management plan updates, contaminated site assessment plans, reclamation research plans and passive treatment design.

T6 Underground Mines: Reclamation tasks for the underground mines include removal of any remaining salvageable or hazardous equipment, demolition or removal of surface buildings and facilities, removal of pond sludges and remediation of lined ponds, construction of rip-rap in portal entrances, recontouring and revegetation of yard areas and remediation of any contaminated soils. Provisions for unique underground requirements such as underground supervisor oversight and air ventilation for any underground access are included. Equipment hours for these tasks are based on experience and costs realized during active mine operations.

T7 Waste Rock Dumps: The primary tasks associated with closure and reclamation of the waste rock dumps include the recontouring of the crests, scarification of the surface of NAML waste rock storage facilities followed by revegetation. Closure of P-AML facilities at Flame & Moth and Bellekeno include backhauling remaining P-AML underground followed by liner removal and closure of the P-AML storage facility. Rock stored in the P-AML facility at Bermingham is planned for rehandling and hauling and placement underground at Bermingham. Borrow areas and coarse ore pads are included in the waste rock dumps cost category. A custom rate has been calculated for haulage and placement of cover material.

T8 Mill & Facilities: Demolition costs for the mill and surface facilities are calculated based on the assumption that no salvage value is credited against the cost of demolition. The majority of the costs for demolition is based on the amount of general and skilled labour along with the type of support equipment (crane, excavators, etc.). It is likely that significant salvage value will be realized in the facilities however no value, or credit, for salvage has been included within the security estimates.

T9 DSTF: Reclamation and closure of the DSTF includes recontouring the side slopes to a 3:1 angle followed by compaction of the tailings to reduce water infiltration and then load, haul, place and spread a 0.25 m soil cover and final revegetation. The productivities associated with these tasks are based on actual performance during progressive reclamation already completed on the DSTF Phase 1.

T10 Waste Disposal and Remediation: Costs associated with this task include offsite hazardous material disposal and the management of hydrocarbon contaminated soils from sources such as around the fuel storage facilities and equipment maintenance shop. It is assumed that contaminated soils will be transported offsite given its minimal volume.

T11 Landfills: Costs to close out the AKHM landfills are included in this sheet.

T12 Roads and Trails: Closure costs for the roads and trails account for both present and future roads on site, and consider the equipment and labour costs to recontour road crests, scarify the surface and revegetate. Costs for removal of culverts are included along with standard erosion control measures.

T13 Water and Solutions Management: The scope of work and costs for this task include the decommissioning of water storage ponds which include discharge of remaining solution, removal of sludges, removal, and burial of the HDPE liners and recontouring. The Bellekeno 625 treatment pond is planned to be converted into a biological treatment cell as a contingency treatment system in addition to the in-situ treatment of the mine pool. Removal of pipelines and rip rap discharge channels are included in this closure task.

T16 Interim Care and Maintenance: This cost sheet provides the cost basis for 2 years of interim care and maintenance during the time period between an unanticipated shutdown (presumed to be from the company's inability to carry out operations or closure) and the time for government to initiate and implement the closure plan through third party contractors. The activities associated with this period include ongoing monitoring as per license requirements and site presence and care and maintenance activities.

T15 Post Closure Compliance Monitoring and Reporting: This table includes costs for long-term monitoring and maintenance of the site over a 10-year post closure period once the active closure activities have been completed. Costs to maintain and operate the contingency bio reactor at Bellekeno are included. Onsite management, employee transport, ongoing water treatment operating and capital replacement costs, long term funding of reclamation and closure research, monitoring and reporting, and site maintenance are also within this category. A breakdown of water treatment operating and capital replacement costs are provided. The annual costs and full costs for each of these tasks are presented in this table, along with the Net Present Value (NPV) of the costs as they occur in the future. The NPV costs are calculated in separate tables. NPV is described further below.

NPV Calculations: YG security costing provides for discounting the future long-term monitoring and maintenance costs associated with the closure cost estimate. The discount rate used in the NPV calculation is the long-term government of Canada benchmark bond yield as of October 1, 2021 which is 1.96%.

Table 9- 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.

Basis of Cost Estimate

The basis of the cost estimate for the RCP assumes the use of third-party contractors and equipment for implementation of major earthworks and terrestrial tasks. Many of the reclamation tasks may be implemented in house but the assumption of third-party contractors is consistent with the YG costing guidance document. It is also noted that the company currently owns all of the equipment that is included in the cost estimate and this equipment is currently on site and operational. For the basis of the current cost estimate, standard equipment types are included that are locally available (i.e. D-7 dozer, CAT 235 excavator).

Equipment and Personnel Rates: Labour rates are based on experience and current third party contractor rates for similar positions. These rates are higher than the Yukon Government Fair Wage Schedule, effective February 2020. Camp costs are based on current site contract variable rates for a small camp population. Custom haul rates are based on site-specific information.

Lump Sum Values: Some costs are presented as a lump sum which could be either a one-time expenditure, repeating periodic cost or specific equipment costs. Many lump sum costs have been derived based on experience with similar tasks at other Yukon mine sites or have been developed in consultation with knowledgeable vendors.

Indirect Costs: Indirect costs are related to the planning, design, contracting, administration and or actual performance of the reclamation tasks. Indirect costs in the RCP have been included in two approaches. The YG closure costing guidance identifies several categories associated with indirect costs including reclamation research, engineering design, mobilization/demobilization, contractors' costs, permitting and assessment costs, contingencies, inflation, and government project management. Where applicable, these indirect unit costs categories have been costed individually. In addition, a further 15% provision of direct costs is included. Table 9-1 below summarizes the indirect costs associated with the RCP.

Table 9-1

Summary Table of Estimated Closure Costs - Keno Hill Mine Operations

Description of Cost	Proposed Cost Current - AKHM 2021	Proposed Cost Year 2 - AKHM 2021	Proposed Cost EOM - AKHM 2021
Closure Implementation			
T3 General & Administration	$927,890	$927,890	$927,890
T4 Exploration Disturbances	$0	$0	$0
T5 Closure Planning	$107,500	$162,500	$340,000
T6 Mine Workings - Underground	$567,280	$653,362	$710,459
T7 Waste Dumps	$94,932	$235,154	$308,028
T8 Mill and Surface Facilities	$648,455	$648,455	$648,455
T9 DSTF	$22,268	$105,574	$330,207
T10 Waste Disposal/Remediation	$49,288	$49,288	$49,288
T11 Landfills	$12,084	$12,084	$12,084
T12 Roads and Trails	$181,696	$181,696	$160,303
T13 Water and Solutions Management	$284,332	$327,332	$327,332
T14 Interim Care and Maintenance	$1,326,948	$1,326,948	$1,326,948
Sub-total Direct Cosets	$4,222,671	$4,630,282	$5,140,993
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$633,401	$694,542	$771,149
Contingency Costs (%)	18%	18%	18%
Contingency Costs	$760,081	$833,451	$925,379
Cost Inflation [1]	$203,955	$223,643	$248,310
Total Closure Implementation Costs	**$5,820,108**	**$6,381,917**	**$7,085,830**
T15 Long Term Monitoring and Maintenance			
Onsite Management	$128,700	$128,700	$128,700
Transport Costs	$75,000	$75,000	$75,000
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	$110,000	$110,000	$110,000
Operation and Maintenance Costs	$77,500	$77,500	$77,500
Reclamation & Closure Research Plan (Post Closure)	$0	$0	$0
Monitoring & Reporting	$912,240	$912,240	$912,240
Sub-Total	$1,303,440	$1,303,440	$1,303,440
Sub-Total NPV (1.0198% DROR)	$1,234,250	$1,221,362	$1,182,811
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$185,137	$183,204	$177,422
Contingency Costs (%)	15%	15%	15%
Contingency Costs	$185,137	$183,204	$177,422
Total (NPV)	$1,604,525	$1,587,771	$1,537,654
Total Financial Security (incl. Indirect Costs)	**$7,424,632**	**$7,969,688**	**$8,623,484**

Table 9-2

Keno Hill Mine Operations Unit Rates

Equipment Rates		
Equipment	**Unit Rates**	**Per Unit**
D7 Dozer	$275	per hr
A30 Haul Truck	$300	per hr
Cat 235 Excavator	$240	per hr
Cat 235 Excavator w hammer	$275	per hr
Cat 14H grader	$270	per hr
966 Loader	$250	per hr
Tractor Trailer (lowbed)	$225	per hr
Vacuum Truck	$150	per hr
30 ton Crane	$190	per hr
3 yd Underground LHD	$220	per hr
15 tonne Underground Truck	$200	per hr
Vibratory Packer	$200	per hr
Pickup Truck	$2,500	per mo

Personnel Rates		
Personnel	**Unit Rates**	**Per Unit**
General Labourer	$55	per hr
Equipment Operator	$65	per hr
Trades Labourer	$100	per hr
Site Supervisor	$700	per day
Design Engineer	$150	per hr
Project Manager	$1,000	per day
Site Caretaker, Operator	$500	per day
Field Engineer, QA/QC	$110	per hr
Environmental Monitor	$75	per hr

Revegetation Rates		**Per Unit**
Revegetation Seed Mix	$18.38	per kg
Revegetation Seed Mix - 50kg/ha	$919	per ha
Fertilizer	$1.16	per kg
Fertilizer - 250kg/ha	$275	per ha
Tree Seedlings (1,000 seedlings per ha)	$2,100	per ha
Seed/Fertilizer Application	$1,785	per ha
Erosion Barrier	$3.15	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
Produce Rip-Rap	$15.75	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	$1,250	per load
Camp Cost	$82	per day per person
Power and Heat	$5,500	per month
Employee Transport Costs	$3,500	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 (Pre-closure planning and organization)	Project Manager	days	65	$1,000	$64,950	$64,950	$64,950
	Project Management (on site Active Closure 6 months per year, 2 years)	Project Manager	days	180	$1,000	$180,000	$180,000	$180,000
	Site Supervisor (on site Active Closure 6 months per year, 2 years)	Site Supervisor	days	180	$700	$126,000	$126,000	$126,000
	Pickup truck (2 trucks, 6 months per year, 2 years)	Pickup Truck	monthly	24	$2,500	$60,000	$60,000	$60,000
	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 (6 months per year, 2 years)	Power and Heat	monthly	12	$5,500	$66,000	$66,000	$66,000
	General Administrative expenses (6 months per year, 2 years)	Unit Cost Basis	monthly	12	$2,000	$24,000	$24,000	$24,000
	Geotechnical Inspections (included in T16)		annually	-		$0	$0	$0
	Reclamation Inspections (Active Closure 1 time)		annually	1	$10,000	$10,000	$10,000	$10,000
	Camp Costs (Average 7 people, 6 months/season, 2 seasons)	Camp Cost	man-day	2,520	$82	$206,640	$206,640	$206,640
					Sub-Total	**$762,590**	**$762,590**	**$762,590**
3.2	**Transport Costs**							
	Employee transport costs (7 months per year, 2 years)	Employee Transport Costs	monthly	14	$3,500	$49,000	$49,000	$49,000
	Commercial flights		monthly	14	$3,000	$42,000	$42,000	$42,000
					Sub-Total	**$91,000**	**$91,000**	**$91,000**
3.3	**Contractor/Third Party Costs**							
	Contractor Profit & Home Office Overhead	Contractor profit and insurance included in the all in wet rates						
	Insurance							
	Bonding	Included in Indirect Costs calculated in Summary tab						
	Taxes							
	Government Bond Costs							
	Property Holding Costs							
	General freight allowance	Elsa- Whitehorse	loads	6	$2,500	$15,000	$15,000	$15,000
					Sub-Total	**$15,000**	**$15,000**	**$15,000**
3.4	**Mobilize Equipment & Fuel**							
	Heavy Equipment							
	D7 Dozer	Equipment	hrs	10	$275	$2,750	$2,750	$2,750
	A30 Haul Truck	Equipment	hrs	10	$300	$3,000	$3,000	$3,000
	Cat 235 Excavator	Equipment	hrs	10	$240	$2,400	$2,400	$2,400
	Cat 235 Excavator w hammer	Equipment	hrs	10	$275	$2,750	$2,750	$2,750
	Cat 14H grader	Equipment	hrs	10	$270	$2,700	$2,700	$2,700
	966 Loader	Equipment	hrs	10	$250	$2,500	$2,500	$2,500
	Tractor Trailer (lowbed)	Equipment	hrs	10	$225	$2,250	$2,250	$2,250
	Vacuum Truck	Equipment	hrs	10	$150	$1,500	$1,500	$1,500
	30 ton Crane	Equipment	hrs	10	$190	$1,900	$1,900	$1,900
	3 yd Underground LHD	Equipment	hrs	10	$220	$2,200	$2,200	$2,200
	Vibratory Packer	Equipment	hrs	11	$200	$2,200	$2,200	$2,200
	15 tonne Underground Truck	Equipment	hrs	10	$200	$2,000	$2,000	$2,000
					Sub-Total	**$28,150**	**$28,150**	**$28,150**
3.5	**Demobilize Equipment**							
	Heavy Equipment							
	D7 Dozer	Equipment	hrs	10	$275	$2,750	$2,750	$2,750
	A30 Haul Truck	Equipment	hrs	10	$300	$3,000	$3,000	$3,000
	Cat 235 Excavator	Equipment	hrs	10	$240	$2,400	$2,400	$2,400
	Cat 235 Excavator w hammer	Equipment	hrs	10	$275	$2,750	$2,750	$2,750
	Cat 14H grader	Equipment	hrs	10	$270	$2,700	$2,700	$2,700
	966 Loader	Equipment	hrs	10	$250	$2,500	$2,500	$2,500
	Tractor Trailer (lowbed)	Equipment	hrs	10	$225	$2,250	$2,250	$2,250
	Vacuum Truck	Equipment	hrs	10	$150	$1,500	$1,500	$1,500
	30 ton Crane	Equipment	hrs	10	$190	$1,900	$1,900	$1,900
	3 yd Underground LHD	Equipment	hrs	10	$220	$2,200	$2,200	$2,200
	15 tonne Underground Truck	Equipment	hrs	10	$200	$2,000	$2,000	$2,000
	Vibratory Packer	Equipment	hrs	11	$200	$2,200	$2,200	$2,200
	Sea Containers (supplies, mobile offices)	Other	hrs	60	$50	$3,000	$3,000	$3,000
					Sub-Total	**$31,150**	**$31,150**	**$31,150**
Total Estimated Cost for General & Administration During Closure						**$927,890**	**$927,890**	**$927,890**

Table 9-4

Exploration Disturbances

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	**Exploration Disturbances**										
	Exploration disturbances secured by a separate security bond				Cat 235 Excavator	hrs					
					General Labourer	hrs					
					D7 Dozer	hrs					
					Revegetation cost per ha. Including application cost	ha					
					% of Direct Costs	%					
								Sub-Total	**$0**	**$0**	**$0**
Total Estimated Cost in Reclaiming Exploration Disturbances									**$0**	**$0**	**$0**

Note:

Table 9-5

Closure Planning

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
5.1	**Reclamation & Closure Planning**							
	Update closure plan every two years	Misc.	l.s.	1	$15,000	$0	$15,000	$45,000
	Permitting and Assessmnent (RCP is already assessed and licensed)	Misc.	l.s.	1	$0	$0	$0	$0
	FN and Community Consultation	Misc.	l.s.	1	$15,000	$5,000	$10,000	$30,000
					Sub-Total	**$5,000**	**$25,000**	**$75,000**
5.2	**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	$5,000	$15,000	$15,000	$30,000
					Sub-Total	**$27,500**	**$27,500**	**$55,000**
5.3	**Other Adaptive Management Plans Required**							
	Inclusion of additional triggers and updating of overall plan as per directives (YWB, YESAB	Misc.	l.s.	1	$10,000	$10,000	$20,000	$20,000
					Sub-Total	**$10,000**	**$20,000**	**$20,000**
5.4	**Contaminated Site Assessment Plan**							
	Develop Plan	Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Site Reportng	Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
					Sub-Total	**$10,000**	**$10,000**	**$10,000**
5.5	**Reclamation & Closure Research Plan**							
	Resesarch to finalize closure plan ($25K per year)	Misc.	l.s.	1	$25,000	$25,000	$50,000	$150,000
					Sub-Total	**$25,000**	**$50,000**	**$150,000**
5.6	**Passive Treatment Design**							
	Design for mill pond bioreactor	Misc.	l.s.	1	$30,000	$30,000	$30,000	$30,000
					Sub-Total	**$30,000**	**$30,000**	**$30,000**
Total Estimated Cost for Closure Planning						**$107,500**	**$162,500**	**$340,000**

Table 9-6

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
6.1	**Bellekeno East Portal and Underground**	**7.1.3, 7.5.1.1**	**7-1, 7-2**	**1.71**							
	Remove underground equipment (already complete)				3 yd Underground LHD	hrs		$220	$0	$0	$0
					A30 Haul Truck	hrs		$300	$0	$0	$0
					Trades Labourer	hrs		$100	$0	$0	$0
					General Labourer	hrs		$55	$0	$0	$0
	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	$55	$2,200	$2,200	$2,200
	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	$55	$330	$330	$330
	Remove settling ponds liners to landfill				A30 Haul Truck	hrs	2	$300	$600	$600	$600
					Cat 235 Excavator	hrs	4	$240	$960	$960	$960
					General Labourer	hrs	8	$55	$440	$440	$440
	Clean out fuel tank residue					lump sum	1	$1,000	$1,000	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill				Cat 235 Excavator	hrs	6	$240	$1,440	$1,440	$1,440
					A30 Haul Truck	hrs	6	$300	$1,800	$1,800	$1,800
					General Labourer	hrs	16	$55	$880	$880	$880
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					A30 Haul Truck	hrs	20	$300	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Test area soils for contamination				Environmental Monitor	days	2	$75	$150	$150	$150
	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	$240	$3,840	$3,840	$3,840
					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		D7 Dozer	hrs	20	$275	$5,400	$5,400	$5,400
			C-2401, B-2101		Cat 14H grader	hrs	2	$270	$540	$540	$540
	Revegetation		C-2401	1.71 ha	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
	Certified Underground Supervisor				Site Supervisor	days	5	$700	$3,500	$3,500	$3,500
	Underground safety equipment				Misc.	lump sum	1	$5,000	$5,000	$5,000	$5,000
	Engineering Design				% of Direct Costs	%	8%		$6,049	$6,049	$6,049
								Sub-Total	**$86,702**	**$86,702**	**$86,702**
6.2	**Bellekeno 625 Adit Area**	**7.1.3, 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	$30,000	$30,000	$30,000	$30,000
	Remove ammonia treatment plant trailers				Misc.	lump sum	1	$10,000	$10,000	$10,000	$10,000
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					A30 Haul Truck	hrs	20	$300	$6,000	$6,000	$6,000
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Test area soils for contamination				Environmental Monitor	hrs	8	$75	$600	$600	$600
	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	$240	$3,840	$3,840	$3,840
					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		D7 Dozer	hrs	8	$275	$2,206	$2,206	$2,206
			C-2402, B-2102		Cat 14H grader	hrs	2	$270	$540	$540	$540
	Revegetation		C-2402	1.29 ha	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
	Engineering Design				% of Direct Costs	%	8%		$8,232	$8,232	$8,232
								Sub-Total	**$117,994**	**$117,994**	**$117,994**
6.3	**Bellekeno 200 Level Vent Raise**	**7.1.3.1**	**7-6**								
	Engineering for Expansion foam cap		S-0303		Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
	Expansion foam				Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
					966 loader	hrs	12	$250	$3,000	$3,000	$3,000
					Tractor Trailer (lowbed)	hrs	48	$225	$10,800	$10,800	$10,800
	Labour for cap				General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Engineering Design				% of Direct Costs	%	8%		$2,700	$2,700	$2,700
								Sub-Total	**$38,700**	**$38,700**	**$38,700**
6.4	**Onek 990 Portal and Underground**	**7.1.9**									
	Remove underground equipment (no material underground after suspension)				3 yd Underground LHD	hrs					
					A30 Haul Truck	hrs					
					Trades Labourer	hrs					
					General Labourer	hrs					
	Engineering Design				% of Direct Costs	%	8%		$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**

Table 9-6

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
6.5	**Onek 990 Portal Site and Infrastructure**	**7.5.4**	**7-16**	**0.35**							
	Remove shop and other buildings (already completed)				Misc.	l.s.	1		$0	$0	$0
	Supply rockfill for portal barrier		S-0301		Load and Haul and Place Rip Rap	m3	700	$13	$9,100	$9,100	$9,100
	Labour for portal barrier				General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	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	10	$240	$2,400	$2,400	$2,400
					A30 Haul Truck	hrs	8	$300	$2,400	$2,400	$2,400
					General Labourer	hrs	20	$55	$1,100	$1,100	$1,100
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$75	$600	$600	$600
	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	$240	$1,920	$3,840	$3,840
					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		D7 Dozer	hrs	5	$275	$1,504	$1,504	$1,504
			C-4401, B-4101		Cat 14H grader	hrs	1	$270	$270	$270	$270
	Recontour crests of pad		C-4401, B-4101		Cat 235 Excavator	hrs	1	$240	$267	$267	$267
	Install Signage				Misc.	l.s.	1	$500	$500	$500	$500
	Remove electrical substation (not yet constructed, not part of LOM Plan)				Misc.	l.s.					
	Remove electrical transmission line (not yet constructed, not part of LOM Plan)				Misc.	l.s.					
	Characterize settling pond sediments/sludge (not yet constructed, not part of LOM Plan)				Analytical Costs	Unit Cost					
	Remove sludge from settling pond (not yet constructed, not part of LOM Plan)				Vacuum Truck	hrs					
					General Labourer	hrs					
	Remove settling ponds liners to landfill (not yet constructed, not part of LOM Plan)				A30 Haul Truck	hrs					
					General Labourer	hrs					
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$240	$1,920	$1,920	$1,920
					A30 Haul Truck	hrs	12	$300	$3,600	$3,600	$3,600
	Revegetation		C-4401	0.35 ha	Revegetation cost per ha. Including ap	ha	0.35	$2,850	$998	$998	$998
	Engineering Design				% of Direct Costs	%	8%		$2,428	$2,752	$2,752
								Sub-Total	**$34,807**	**$39,451**	**$39,451**
6.6	**Onek 990 Vent Raise**	**7.5.4**									
					Misc.	l.s.					
					Misc.	l.s.					
	Not constructed and not licensed for production				Cat 966 loader	hrs					
					Tractor Trailer (lowbed)	hrs					
					General Labourer	hrs					
					% of Direct Costs	%	8%		$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**
6.7	**Lucky Queen Underground/Laydown Areas**	**7.1.11**	**7-18**	**0.63**							
	Remove shop and other buildings				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	$55	$2,200	$2,200	$2,200
	Clean out fuel tank residue				Misc.	l.s.					
	Haul fuel tank and liner for reuse or landfill				Cat 235 Excavator	hrs		$240	$0	$0	$0
					A30 Haul Truck	hrs		$300	$0	$0	$0
					General Labourer	hrs		$55	$0	$0	$0
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$240	$2,400	$2,400	$4,800
					A30 Haul Truck	hrs	20	$300	$3,000	$3,000	$6,000
					General Labourer	hrs	40	$55	$1,100	$1,100	$2,200
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$75	$600	$600	$600
	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	$240	$1,920	$1,920	$3,840
					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		D7 Dozer	hrs	5	$275	$1,328	$1,328	$1,328
			C-3401, B-3101		Cat 14H grader	hrs	1	$270	$270	$270	$270
	Recontour crests		C-3401, B-3101		Cat 235 Excavator	hrs	4	$240	$1,036	$1,036	$1,036
	Remove electrical substation (not yet upgraded)				Misc.	l.s.					
	Remove electrical transmission cable (not yet constructed)				Misc.	l.s.					
	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	$75	$600	$600	$600
	Remove sludge from settling pond				Vacuum Truck	hrs	40	$150	$1,500	$3,000	$6,000
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Remove settling ponds liners to landfill (not yet constructed)				A30 Haul Truck	hrs		$300			
	Scrap hauled to solid waste facility				Cat 235 Excavator	hrs	8	$240	$1,920	$1,920	$1,920
					A30 Haul Truck	hrs	12	$300	$3,600	$3,600	$3,600
	Revegetation		C-3401	0.63 ha	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
	Engineering Design				% of Direct Costs	%	8%		$4,085	$4,378	$5,234
								Sub-Total	**$58,555**	**$62,747**	**$75,024**

Table 9-6

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
6.8	**Lucky Queen Vent Raise**	**7.1.10**									
	Not constructed and not licensed for production				Misc.	l.s.					
					966 loader	hrs					
					Tractor Trailer (lowbed)	hrs					
					General Labourer	hrs					
					% of Direct Costs	%	8%		$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**
6.9	**Flame and Moth Underground**	**7.1.5**									
	Remove underground equipment				3 yd Underground LHD	hrs	60	$220	$3,300	$6,600	$13,200
					A30 Haul Truck	hrs	60	$300	$4,500	$9,000	$18,000
					Trades Labourer	hrs	120	$100	$3,000	$6,000	$12,000
					General Labourer	hrs	120	$55	$6,600	$6,600	$6,600
	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	$55	$2,200	$2,200	$2,200
	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	$240	$1,440	$1,440	$1,440
					A30 Haul Truck	hrs	6	$300	$1,800	$1,800	$1,800
					General Labourer	hrs	16	$55	$880	$880	$880
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	10	$240	$2,400	$2,400	$2,400
					A30 Haul Truck	hrs	10	$300	$3,000	$3,000	$3,000
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Sample and test area soils for contamination				Environmental Monitor	hrs	8	$75	$600	$600	$600
	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	$240	$1,920	$3,840	$3,840
					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-6401, C-6101		D7 Dozer	hrs		$275	$0	$0	$0
			C-6401, C-6101		Cat 14H grader	hrs		$270	$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	$55		$1,650	$1,650
	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	$240	$960	$1,920	$1,920
					A30 Haul Truck	hrs	12	$300		$3,600	$3,600
	Certified Underground Supervisor				Site Supervisor	days	5	$700	$3,500	$3,500	$3,500
	Underground safety equipment				Misc.	lump sum	1	$5,000	$5,000	$5,000	$5,000
	Misc. Supplies & Tools				Misc.	l.s.	1	$7,500	$7,500	$7,500	$7,500
	Engineering Design				% of Direct Costs	%	8%		$3,945	$5,207	$5,207
								Sub-Total	**$73,945**	**$102,837**	**$124,437**
6.10	**Flame and Moth Vent Raise**	**7.1.5**	**S-0303**								
	Concrete Batch (may use PUF alternatively) (not constructed)				Misc.	m3	7	$1,500		$10,500	$10,500
					966 loader	hrs	12	$250		$3,000	$3,000
					Tractor Trailer (lowbed)	hrs	48	$225		$10,800	$10,800
	Labour for cap				Trades Labourer	hrs	40	$100		$4,000	$4,000
	Engineering Design				% of Direct Costs	%	8%		$0	$2,123	$2,123
								Sub-Total	**$0**	**$30,423**	**$30,423**
6.11	**Bermingham Underground Portal and Surface Site**	**7.1.7 & 7.5.3**		**2.36**							
	Remove underground equipment				3 yd Underground LHD	hrs	60	$220	$3,300	$6,600	$13,200
					A30 Haul Truck	hrs	60	$300	$4,500	$9,000	$18,000
					Trades Labourer	hrs	120	$100	$3,000	$6,000	$12,000
					General Labourer	hrs	120	$55	$6,600	$6,600	$6,600
	Remove electrical substation located at Ruby				Misc.	lump sum	1	$15,000	$15,000	$15,000	$15,000
	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	$55	$2,200	$2,200	$2,200
	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	$240	$1,920	$1,920	$1,920
					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				966 Loader	hrs	6	$250	$1,500	$1,500	$1,500
					Tractor Trailer (lowbed)	hrs	6	$225	$1,350	$1,350	$1,350
					General Labourer	hrs	16	$55	$880	$1,760	$1,760
	Area cleanup and haul debris to landfill				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					A30 Haul Truck	Unit Cost	40	$300	$12,000	$12,000	$12,000
					Cat 235 Excavator	hrs	16	$240	$3,840	$3,840	$3,840
	Test area for soils for contamination				Environmental Monitor	hrs	8	$75	$600	$600	$600
	Laboratory analysis for soils testing					unit cost	2	$300	$600	$600	$600
	Haul contaminated soils to LTF				Cat 235 Excavator	hrs	16	$240	$3,840	$3,840	$3,840
					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		D7 Dozer	hrs	1	$275	$387	$387	$387
			C-5401, B-5101		Cat 14H grader	hrs	3	$270	$810	$810	$810
	Revegetation		C-5401	2.36	Revegetation cost per ha. Including ap	ha	2.36	$2,850	$6,726	$6,726	$6,726
	Install signage				Misc.	lump sum	1	$500	$500	$500	$500
	Certified Underground Supervisor				Site Supervisor	days	5	$700	$3,500	$3,500	$3,500
	Underground safety equipment				Misc.	lump sum	1	$5,000	$5,000	$5,000	$5,000
	Misc. Supplies & Tools				Misc.	l.s.	1	$7,500	$7,500	$7,500	$7,500
	Engineering Design				% of Direct Costs	%	8%		$8,801	$10,052	$11,672
								Sub-Total	**$126,154**	**$144,085**	**$167,305**

Table 9-6

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
6.12	**Bermingham Vent Raise**	**7.1.7**	**S-0303**								
	Concrete Batch (may use PUF alternatively)				Misc.	m3	7	$1,500	$10,500	$10,500	$10,500
					966 loader	hrs	12	$250	$3,000	$3,000	$3,000
					Tractor Trailer (lowbed)	hrs	48	$225	$10,800	$10,800	$10,800
	Labour for cap				Trades Labourer	hrs	40	$100	$4,000	$4,000	$4,000
	Engineering Design				% of Direct Costs	%	8%		$2,123	$2,123	$2,123
								Sub-Total	**$30,423**	**$30,423**	**$30,423**
Total Estimated Cost in Reclaiming Underground Mines									**$567,280**	**$653,362**	**$710,459**

Table 9-7

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
7.1	**Bellekeno East Temporary P-AML WRSF**	**7.3.1.1**	**7-24**	**0.33**							
	Rehandle PAML underground (complete)										
					3 yd Underground LHD	hrs.		$220	$0	$0	$0
					A30 Haul Truck	hrs		$300	$0	$0	$0
					Cat 235 Excavator	hrs		$240	$0	$0	$0
					General Labourer	hrs		$55	$0	$0	$0
	Site Recontouring		C-2401, B-2101		D7 Dozer	hrs	10	$275	$2,764	$2,764	$2,764
			C-2401, B-2101		Cat 235 Excavator	hrs	9	$240	$2,195	$2,195	$2,195
	Revegetation		C-2401		Revegetation cost per ha. Including application cost	ha	0.3	$2,850	$941	$941	$941
	Engineering Design				% of Direct Costs	%	8%		$443	$443	$443
								Sub-Total	**$6,343**	**$6,343**	**$6,343**
7.2	**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**
7.3	**Bellekeno Historic WRDAs**	**7.3.1.3**	**7-24**	**1.29**							
	Recontour crests 625 WRDA		C-2402, B-2102		Cat 235 Excavator	hrs	7	$240	$1,752	$1,752	$1,752
	Up-slope Diversion Ditch-no lining specified				Cat 235 Excavator	hrs	4	$240	$960	$960	$960
	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	1	$2,850	$3,677	$3,677	$3,677
	Engineering Design				% of Direct Costs	%	8%		$479	$479	$479
								Sub-Total	**$6,867**	**$6,867**	**$6,867**
7.4	**Onek P-AML WRSF**	**7.3.4**	**7-15**	**0.48**							
	Remove impounded water (no water liner not complete)				Vacuum Truck	hrs	2	$150	$0	$0	$0
					General Labourer	hrs	4	$55	$0	$0	$220.0
	Remove P-AML rock and place underground at Onek				D7 Dozer	hrs	-	$275	$0	$0	$0
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	2	$300	$600	$600	$600
					Cat 235 Excavator	hrs	4	$240	$960	$960	$960
					General Labourer	hrs.	8	$55	$440	$440	$440
	Recontour for drainage		C-4401, B-4101		D7 Dozer	hrs	15	$275	$4,111	$4,111	$4,110.7
	Revegetation		C-4401	0.48 ha	Revegetation cost per ha. Including application cost	ha	0.48	$2,850	$1,368	$1,368	$1,368.0
	Engineering Design				% of Direct Costs	%	8%		$561	$561	$577
								Sub-Total	**$8,040**	**$8,040**	**$8,276**
7.5	**Onek N-AML WRDA**	**7.3.4**									
	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**	**$0**
7.6	**Lucky Queen P-AML WRSF**	**7.3.5**									
	Not constructed and not licensed for production				Vacuum Truck	hrs					
					General Labourer	hrs					
			C-3401, B-3101		D7 Dozer	hrs					
					Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	cu.m.					
			C-3401		Revegetation cost per ha. Including application cost	ha					
	Engineering Design				% of Direct Costs	%	8%		$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**
7.7	**Lucky Queen N-AML WRDA**	**7.3.5**									
	Not constructed and not licensed for production		C-3401, B-3101		Cat 235 Excavator	hrs					
			C-3401		D7 Dozer	hrs					
			C-3401		Revegetation cost per ha. Including application cost	ha					
	Engineering Design				% of Direct Costs	%	8%		$0	$0	$0
								Sub-Total	**$0**	**$0**	**$0**
7.8	**Flame and Moth Temporary P-AML WRSF**	**7.3.2**		**0.23**							
	Rehandle underground										
	6000 m3 @ 24m3/hr cycle time to underground (vol estimate based on maximum capacity assuming full)				3 yd Underground LHD	hrs.	250	$220		$55,000	$55,000
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	8	$300		$2,400	$2,400
					Cat 235 Excavator	hrs	48	$240		$11,520	$11,520
					General Labourer	hrs	24	$55		$1,320	$1,320
	Certified Underground Supervisor				Site Supervisor	days	12	$700	$8,400	$8,400	$8,400
	Underground safety equipment				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Site Recontouring		C-1401, B6101		D7 Dozer	hrs	7	$275	$1,919	$1,919	$1,919
	Revegetation		C-1401		Revegetation cost per ha. Including application cost	ha	0.23	$2,850	$656	$656	$656
	Engineering Design				% of Direct Costs	%	8%		$1,198	$6,466	$6,466
								Sub-Total	**$17,173**	**$92,681**	**$92,681**
7.9	**Flame and Moth N-AML WRDA**	**7.3.2**									
	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.					
					% of Direct Costs	%	8%		$0	$0	$0
7.10	**Bermingham N-AML WRDA**	**7.3.3**		**0.68**							
	Recontour crests		C-5401, B-5101		Cat 235 Excavator	hrs.	20	$240	$4,800	$4,800	$4,800
	Scarify surface		C-5401		D7 Dozer	hrs.	11	$275	$1,450	$2,900	$2,900
	Revegetation		C-5401		Revegetation cost per ha. Including application cost	ha	1	$2,850.00	$969	$1,938	$1,938
	Engineering Design				% of Direct Costs	%	8%		$541	$723	$723
								Sub-Total	**$7,761**	**$10,361**	**$10,361**
7.11	**Bermingham P-AML WRSF**	**7.3.3**		**0.32**							
	Rehandle underground										
	8000 m3 @ 16m3/hr cycle time to underground (vol estimate based on maximum capacity assuming full)				3 yd Underground LHD	hrs.	500	$220		$36,667	$110,000
	Remove liner and haul to solid waste facility				A30 Haul Truck	hrs	24	$300		$7,200	$7,200
					Cat 235 Excavator	hrs	48	$240		$11,520	$11,520
					General Labourer	hrs	24	$55		$1,320	$1,320
	Certified Underground Supervisor				Site Supervisor	days	12	$700	$8,400	$8,400	$8,400
	Underground safety equipment				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Site Recontouring		C-5401, B-5101		D7 Dozer	hrs	8	$275		$770	$2,309
	Revegetation		C-5401		Revegetation cost per ha. Including application cost	ha	0.32	$2,850		$304	$912
	Engineering Design				% of Direct Costs	%	8%		$1,005	$5,339	$11,000
								Sub-Total	**$14,405**	**$76,519**	**$157,660**
7.12	**Borrow Areas (2ha currently, 3ha by EOM)**	**7.8.1**		**2.00**							
	Stabilize slopes				Cat 235 Excavator	hrs	12	$240	$1,901	$1,901	$2,880
					D7 Dozer	hrs	8	$275	$1,452	$1,452	$2,200
	Revegetation				Revegetation cost per ha. Including application cost	ha	2.0	$2,850	$5,700	$5,700	$5,700
	Engineering Design				% of Direct Costs	%	8%		$679	$679	$809
								Sub-Total	**$9,732**	**$9,732**	**$11,589**
7.13	**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
					D7 Dozer	hrs	16	$275	$4,400	$4,400	$4,400
	Dismantle Sprung Structure over fine ore stockpile				Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
	Haul contaminated soils/materials to DSTF or underground				Cat 235 Excavator	hrs	6	$240	$1,440	$1,440	$1,440
					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
	Engineering Design				% of Direct Costs	%	8%		$1,717	$1,717	$1,717
								Sub-Total	**$24,612**	**$24,612**	**$24,612**
Total Estimated Cost in Reclaiming Overburden and Waste Rock Dumps									**$94,932**	**$235,154**	**$308,028**

Note:

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**	**7.5.6**									
	Remove equipment (crusher, conveyors, mill equipment, trailer units, other ancillary facilities - fine ore bin)				General Labourer	hrs	600	$55	$33,000	$33,000	$33,000
					Trades Labourer	hrs	400	$100	$40,000	$40,000	$40,000
					966 loader	hrs	150	$250	$37,500	$37,500	$37,500
					Cat 235 Excavator	hrs	50	$240	$12,000	$12,000	$12,000
					Tractor Trailer (lowbed)	hrs	120	$225	$27,000	$27,000	$27,000
	Load and return extra chemicals/reagents				General Labourer	hrs	75	$55	$4,125	$4,125	$4,125
					Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
	Dismantle Mill Building				966 loader	hrs	70	$250	$17,500	$17,500	$17,500
					Tractor Trailer (lowbed)	hrs	70	$225	$15,750	$15,750	$15,750
					Trades Labourer	hrs	300	$100	$30,000	$30,000	$30,000
					General Labourer	hrs	1000	$55	$55,000	$55,000	$55,000
	Removal and burial of outside pipelines				General Labourer	hrs	80	$55	$4,400	$4,400	$4,400
					966 loader	hrs	40	$250	$10,000	$10,000	$10,000
	Concrete Demolition				Cat 235 Excavator w hammer	hrs	40	$275	$11,000	$11,000	$11,000
					D7 Dozer	hrs	40	$275	$11,000	$11,000	$11,000
	Elec. Substation (disconnect, remove from site)				Misc.	Unit Cost	1	$20,000	$20,000	$20,000	$20,000
	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	$2,000	$8,000	$8,000	$8,000
	Decommission buried infrastructure				Misc.	Misc.	1	$5,000	$5,000	$5,000	$5,000
	Dismantle/remove fresh water tank				Misc.	Misc.	1	$10,000	$10,000	$10,000	$10,000
	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	$240	$12,000	$12,000	$12,000
					A30 Haul Truck	hrs	100	$300	$30,000	$30,000	$30,000
	Misc. Supplies and Tools				Misc.	hrs	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering				% of Direct Costs	%	8%		$35,496	$35,496	$35,496
								Sub-Total	**$508,771**	**$508,771**	**$508,771**
8.2	**Warehouse**										
	Dismantle Mill Building				966 loader	hrs	30	$250	$7,500	$7,500	$7,500
					Tractor Trailer (lowbed)	hrs	30	$225	$6,750	$6,750	$6,750
					Trades Labourer	hrs	100	$100	$10,000	$10,000	$10,000
					General Labourer	hrs	250	$55	$13,750	$13,750	$13,750
	Concrete Demolition				Cat 235 Excavator w hammer	hrs	20	$275	$5,500	$5,500	$5,500
					D7 Dozer	hrs	20	$275	$5,500	$5,500	$5,500
	Haul Scrap to Solid Waste Facility				Cat 235 Excavator	hrs	15	$240	$3,600	$3,600	$3,600
					A30 Haul Truck	hrs	10	$300	$3,000	$3,000	$3,000
	Misc. Supplies and Tools				Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Engineering Design				% of Direct Costs	%	8%		$4,545	$4,545	$4,545
								Sub-Total	**$65,145**	**$65,145**	**$65,145**
8.3	**Mill Pad**	**7.5.6**		**4.8**							
	Regrade embankment shoulders		C-6401, B-6101		D7 Dozer	hrs	7	$275	$2,005	$2,005	$2,005
	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		D7 Dozer	hrs	75	$275	$20,582	$20,582	$20,582
	Revegetate		C-6401		Revegetation cost per ha. Including application cost	ha	4.8	$2,850	$13,652	$13,652	$13,652
	Engineering Design				% of Direct Costs	%	8%		$3,325	$3,325	$3,325
								Sub-Total	**$47,664**	**$47,664**	**$47,664**
8.4	**Camp Downsize**	**7.5.7**									
	Dismantle 5 trailer units and transport to Lot 960				Misc.	l.s.	1	$25,000	$25,000	$25,000	$25,000
	Engineering Design				% of Direct Costs	%	8%		$1,875	$1,875	$1,875
								Sub-Total	**$26,875**	**$26,875**	**$26,875**
Total Estimated Cost in Reclaiming Mill and Ancillary Facilities									**$648,455**	**$648,455**	**$648,455**

Table 9-9

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
9.1	**DSTF - Current**	**7.2**		**0.75**							
	Recontour slopes to final design and compact				D7 Dozer	hrs	16	$275	$4,400		
				Equipment	Vibratory Packer	hrs	10	$200	$2,000		
	Place soil cover and spread			hours and	A30 Haul Truck	hrs	16	$300	$4,800		
				productivities	Cat 235 Excavator	hrs	12	$240	$2,880		
				from 2014	D7 Dozer	hrs	16	$275	$4,400		
	Revegetation			progressive	Revegetation Seed Mix - 50kg/ha	ha	0.8	$919	$689		
				reclamation	Fertilizer - 250kg/ha	ha	0.8	$275	$206		
				tracking	Seed/Fertilizer Application	ha	0.8	$1,785	$1,339		
	Engineering Design				% of Direct Costs	%	8%		$1,554	$0	$0
								Sub-Total	**$22,268**		
9.2	**DSTF - Year 2**	**7.2**		**2.0**							
	Recontour slopes to final design and compact				D7 Dozer	hrs	40	$275		$11,000	
					Vibratory Packer	hrs	16	$200		$3,200	
	Place soil cover and spread				A30 Haul Truck	hrs	100	$300		$30,000	
					Cat 235 Excavator	hrs	120	$240		$28,800	
					D7 Dozer	hrs	70	$275		$19,250	
	Revegetation				Revegetation Seed Mix - 50kg/ha	ha	2.0	$919		$1,838	
					Fertilizer - 250kg/ha	ha	2.0	$275		$550	
					Seed/Fertilizer Application	ha	2.0	$1,785		$3,570	
	Engineering Design				% of Direct Costs	%	8%		$0	$7,366	$0
								Sub-Total		**$105,574**	
9.3	**DSTF - EOM**	**7.2**		**7.2**							
	Recontour slopes to final design and compact		C-7401		D7 Dozer	hrs	115	$275			$31,496
					Vibratory Packer	hrs	57	$200			$11,440
	Place soil cover and spread		C-7401		A30 Haul Truck	hrs	358	$300			$107,250
					Cat 235 Excavator	hrs	429	$240			$102,960
					D7 Dozer	hrs	119	$275			$32,723
	Revegetation		C-7401		Revegetation Seed Mix - 50kg/ha	ha	7.2	$919			$6,571
					Fertilizer - 250kg/ha	ha	7.2	$275			$1,966
					Seed/Fertilizer Application	ha	7.2	$1,785			$12,763
	Engineering Design				% of Direct Costs	%	8%		$0	$0	$23,038
								Sub-Total			**$330,207**
Total Estimated Cost in Reclaiming DSTF									**$22,268**	**$105,574**	**$330,207**

Table 9-10

Waste Disposal/Remediation

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
10.1	**Solid Waste Disposal**	**7.6**									
10.2	**Hazardous Materials Disposal**	**7.6**									
	Consolidation of onsite materials, packaging					l.s.	1	$15,000	$15,000	$15,000	$15,000
	Off-site disposal					l.s.	1	$7,500	$7,500	$7,500	$7,500
	Engineering Design				% of Direct Costs	%	8%		$1,688	$1,688	$1,688
								Sub-Total	**$24,188**	**$24,188**	**$24,188**
10.3	**Contaminated Soils**	**7,6**									
	Test area soils for contamination				Environmental Monitor	hrs	16	$75	$1,200	$1,200	$1,200
	Laboratory Analysis for soils testing				Analytical Costs	Unit Cost	20	$300	$6,000	$6,000	$6,000
	Excavation and packaging of contamined soils				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Haul any contaminated soils to nearest Land Treatment Facility					l.s.	1	$10,000	$10,000	$10,000	$10,000
	Engineering Design				% of Direct Costs	%	8%		$900	$900	$900
								Sub-Total	**$25,100**	**$25,100**	**$25,100**
Total Estimated Cost in Reclaiming Waste Disposal and Remediation									**$49,288**	**$49,288**	**$49,288**

Note:

Table 9-11

Landfills

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
11.1	**Landfill Final Closure**	**7.6**		**0.33**							
	Valley Tailings Landfill is an ERDC permitted facility										
	Final Closure of AKHM landfills				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
	Site Recontouring				D7 Dozer	hrs	12	$275	$3,300	$3,300	$3,300
	Revegetation				Revegetation cost per ha. Including application cost	ha	0.3	$2,850	$941	$941	$941
	Engineering Design				% of Direct Costs	%	8%		$843	$843	$843
								Sub-Total	**$12,084**	**$12,084**	**$12,084**
Total Estimated Cost in Reclaiming Landfills									**$12,084**	**$12,084**	**$12,084**

Note:

Table 9-12

Roads & Trails

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
12.1	**Bellekeno East Portal to Upper Laydown**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	10	$240	$2,400	$2,400	$2,400
					General Labourer	hrs	10	$55	$550	$550	$550
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	16	$240	$3,840	$3,840	$3,840
	Scarify road surface			0.5	Cat 14H grader	hrs	16	$270	$4,320	$4,320	$4,320
	Erosion barrier (50% of length)				Erosion Barrier	m2	500	$3	$1,575	$1,575	$1,575
	Engineering Design				% of Direct Costs	%	8%		$951	$951	$951
								Sub-Total	**$13,636**	**$13,636**	**$13,636**
12.2	**Bellekeno 625 Access**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (3 ea)				Cat 235 Excavator	hrs	12	$240	$2,880	$2,880	$2,880
					General Labourer	hrs	12	$55	$660	$660	$660
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	12	$240	$2,880	$2,880	$2,880
	Scarify road surface			0.25	Cat 14H grader	hrs	16	$270	$4,320	$4,320	$4,320
	Erosion barrier (50% of length)				Erosion Barrier	m2	250	$3	$788	$788	$788
	Engineering Design				% of Direct Costs	%	8%		$865	$865	$865
								Sub-Total	**$12,392**	**$12,392**	**$12,392**
12.3	**Bellekeno Haul Road**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (15 ea)				Cat 235 Excavator	hrs	60	$240	$14,400	$14,400	$14,400
					General Labourer	hrs	60	$55	$3,300	$3,300	$3,300
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	40	$240	$9,600	$9,600	$9,600
	Scarify road surface			5.7	Cat 14H grader	hrs	30	$270	$8,100	$8,100	$8,100
	Erosion barrier (50% of length)				Erosion Barrier	m2	5,700	$3	$17,955	$17,955	$17,955
	Engineering Design				% of Direct Costs	%	8%		$4,002	$4,002	$4,002
								Sub-Total	**$57,357**	**$57,357**	**$57,357**
12.4	**Keno City Bypass Road**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (5 ea)				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					General Labourer		20	$55	$1,100	$1,100	$1,100
	Reslope banks/remove safety berms				Cat 235 Excavator		24	$240	$5,760	$5,760	$5,760
	Scarify road surface			2.1	Cat 14H grader	hrs	16	$270	$4,320	$4,320	$4,320
	Erosion barrier (50% of length)				Erosion Barrier	hrs	12	$3	$38	$38	$38
	Remove Lightning Creek Bridge (Bellekeno)				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					Tractor Trailer (lowbed)	hrs	12	$225	$2,700	$2,700	$2,700
	Erosion barrier (50% of length)				Erosion Barrier	m2	2,100	$3	$6,615	$6,615	$6,615
	Engineering Design				% of Direct Costs	%	8%		$2,260	$2,260	$2,260
								Sub-Total	**$32,393**	**$32,393**	**$32,393**
12.5	**Christal Lake Road**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (5 ea)				Cat 235 Excavator	hrs	20	$240	$4,800	$4,800	$4,800
					General Labourer	hrs	30	$55	$1,650	$1,650	$1,650
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	12	$240	$2,880	$2,880	$2,880
	Scarify road surface			1.3	Cat 14H grader	hrs	16	$270	$4,320	$4,320	$4,320
	Erosion barrier (50% of length)				Erosion Barrier	m2	1,300	$3	$4,095	$4,095	$4,095
	Engineering Design				% of Direct Costs	%	8%		$1,331	$1,331	$1,331
								Sub-Total	**$19,076**	**$19,076**	**$19,076**
12.6	**Lucky Queen Haul and Access Road**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	40	$240	$9,600	$9,600	$9,600
					General Labourer	hrs	16	$55	$880	$880	$880
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	10	$240	$2,400	$2,400	$2,400
	Scarify road surface			1.2	Cat 14H grader	hrs	12	$270	$3,240	$3,240	$3,240
	Erosion barrier (50% of length)				Erosion Barrier	m2	1,200	$3	$3,780	$3,780	$3,780
	Engineering Design				% of Direct Costs	%	8%		$1,493	$1,493	$1,493
									$21,393	**$21,393**	**$21,393**
12.7	**Bermingham Haul and Access Road**	**7.7**	**B-0301 & Fig 7-46**								
	Culvert Excavation and install swales (2 ea)				Cat 235 Excavator	hrs	32	$240	$7,680	$7,680	$7,680
					General Labourer	hrs	16	$55	$880	$880	$880
	Reslope banks/remove safety berms				Cat 235 Excavator	hrs	10	$240	$2,400	$2,400	$2,400
	Scarify road surface			2.0	Cat 14H grader	hrs	4	$270	$1,080	$1,080	$1,080
	Erosion barrier (50% of length)				Erosion Barrier	m2	1,979	$3	$6,234	$6,234	$6,234
	Engineering Design				% of Direct Costs	%	8%		$1,371	$1,371	$1,371
								Sub-Total	**$19,644**	**$19,644**	**$19,644**
12.8	**Other Roads and Trails**	**7.7**	**B-0301 & Fig 7-46**								
	Scarify road surface			3.0	Cat 14H grader	hrs	20	$270	$5,400	$5,400	$5,400
	Engineering Design				% of Direct Costs	%	8%		$405	$405	$405
								Sub-Total	**$5,805**	**$5,805**	**$5,805**
Total Estimated Cost for Roads & Trails									**$181,696**	**$181,696**	**$160,303**

Table 9-13

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
13.1	**Mill Runoff Collection & Process Pond**	**7.4.3**									
	Pump down collected water				General Labourer	hrs	36	$55	$1,980	$1,980	$1,980
					Pump	daily	3	$100	$300	$300	$300
	Misc. Supplies and Tools				Misc.	l.s.	1	$1,000	$1,000	$1,000	$1,000
	Characterize pond sediments/sludge				Analytical Costs	Unit Cost	2	$300	$600	$600	$600
					General Labourer	hrs	2	$55	$110	$110	$110
	Remove pond sediments/sludge				Vacuum Truck	hrs	16	$150	$2,400	$2,400	$2,400
					General Labourer	hrs	16	$55	$880	$880	$880
	Breach dyke				D7 Dozer	hrs	4	$275	$1,100	$1,100	$1,100
	Remove & bury HDPE liner				General Labourer	hrs	40	$55	$2,200	$2,200	$2,200
					Cat 235 Excavator	hrs	12	$240	$2,880	$2,880	$2,880
					A30 Haul Truck	hrs	4	$300	$1,200	$1,200	$1,200
	Recontour area				D7 Dozer	hrs	30	$275	$8,250	$8,250	$8,250
	Stabilize slopes with erosion barriers				Cat 235 Excavator	hrs	30	$240	$7,200	$7,200	$7,200
	Remove discharge pipeline				General Labourer	hrs	30	$55	$1,650	$1,650	$1,650
	Engineering Design				% of Direct Costs	%	8%		$2,381	$2,381	$2,381
								Sub-Total	**$34,131**	**$34,131**	**$34,131**
13.2	**Diversion Ditches**										
	Recontour Diversion Ditch to Mill Pond			525	D7 Dozer	hrs	20	$275	$5,500	$5,500	$5,500
					Cat 235 Excavator	hrs	10	$240	$2,400	$2,400	$2,400
	Recontour Diversion Ditch above Mill Area			285	D7 Dozer	hrs	10	$275	$2,750	$2,750	$2,750
					Cat 235 Excavator	cu.m.	5	$240	$1,200	$1,200	$1,200
	Enhance Diversion Ditch above DSTF, to closure criteria			300	D7 Dozer	hrs	10	$275	$2,750	$2,750	$2,750
					Cat 235 Excavator	cu.m.	5	$240	$1,200	$1,200	$1,200
	Revegetate			1	Erosion barriers	m	500	$3	$1,500	$1,500	$1,500
	Engineering Design				% of Direct Costs	%	8%		$1,298	$1,298	$1,298
								Sub-Total	**$18,598**	**$18,598**	**$18,598**
13.3	**Bellekeno 625 WTP - Mine Pool Treatment Transition**	**7.4.2**									
	625 Adit Coffer Dam (S.7.1.3)		S-0302								
	Underground Rehab for Coffer Dam				Misc.	lump sum	1	$10,000	$10,000	$10,000	$10,000
	Construct coffer dam				General Labourer	hrs	24	$55	$1,320	$1,320	$1,320
					Trades Labourer	hrs	24	$100	$2,400	$2,400	$2,400
	Concrete Batch				Misc.	cu.m	2	$1,750	$3,500	$3,500	$3,500
					966 loader	hrs	8	$250	$2,000	$2,000	$2,000
	Misc for concrete coffer dam (anchors, drainage pipe, etc)				Misc.	lump sum	1	$5,000	$5,000	$5,000	$5,000
	Remove salvageable equipment				Cat 235 Excavator	hrs	16	$240	$3,840	$3,840	$3,840
					Trades Labourer	hrs	16	$100	$1,600	$1,600	$1,600
	Load & return extra reagents/chemicals				General Labourer	hrs	8	$55	$440	$440	$440
					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 underground)				Vacuum Truck	hrs		$150	$0	$0	$0
					General Labourer	hrs		$55	$0	$0	$0
	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
					966 loader	hrs	60	$250	$15,000	$15,000	$15,000
					General Labourer	hrs	60	$55	$3,300	$3,300	$3,300
					Environmental Monitor	hrs	8	$75	$600	$600	$600
	Operate Bellekeno 625 bioreactor (included in Post Closure)				Misc.	years	10				
	Site levelling				D7 Dozer	hrs	25	$275	$6,875	$6,875	$6,875
	Scrap hauled to solid waste facility				A30 Haul Truck	hrs	8	$300	$2,400	$2,400	$2,400
					Cat 235 Excavator	hrs	12	$240	$2,880	$2,880	$2,880
	Haul BK 625 sludge from Valley Tailings to BK East UG				Cat 235 Excavator	hrs	30	$240	$7,200	$7,200	$7,200
					A30 Haul Truck	hrs	40	$300	$12,000	$12,000	$12,000
	Misc. Supplies & Tools				Misc.	l.s.	1	$7,500	$7,500	$7,500	$7,500
	Engineering Design				% of Direct Costs	%	8%		$12,334	$12,334	$12,334
								Sub-Total	**$176,789**	**$176,789**	**$176,789**
13.4	**Mill Pond - Bioreactor Transition**										

10 REFERENCES

Access Mining Consultants Ltd. (AMC). 1996. Site Characterization Report. Prepared for United Keno Hill Mines Ltd.

Access Consulting Group (ACG). 2011b. Keno District Soil and Vegetation Baseline Study and Analysis. Prepared for Elsa Reclamation and Development Company Ltd.

Access Consulting Group (ACG). 2012b. Keno District Soil and Vegetation Metal Study Phase II. Prepared for Elsa Reclamation and Development Company Ltd.

Access Consulting Group (ACG). 2013a. Keno Hill Silver District Ecosystem Mapping Project. Prepared for Elsa Reclamation and Development Company Ltd.

Access Consulting Group (ACG). 2013b. Keno District Soil and Vegetation Metal Study Phase II. Prepared for Elsa Reclamation and Development Company Ltd.

Alexco Environmental Group (AEG). 2019b. Wildlife Surveys for the United Keno Hill Mines Reclamation Project. Memorandum prepared for Elsa Reclamation and Development Company, October 21. 2019.

Alexco Environmental Group (AEG). 2020. *Vegetation and Cover Trials Data Memo*. Memorandum prepared for Elsa Reclamation and Development Company, March 2020.

Alexco Keno Hill Mining Corp. (AKHM). 2018. Wildlife Protection Plan Keno Hill Silver District Mining Operations, July 2018.

Alexco Resource Corp. (Alexco). 2021. NI 43-101 *Technical Report on Updated Mineral Resource and Reserve Estimate of the Keno Hill Silver District*. File: MP-8959 Alexco Technical Report Apr 2021. Prepared by Mining Plus Canada.

Alexco Keno Hill Mining (AKHM). 2021a. *Keno Hill Silver District Bermingham Deposit Ground Control Management Plan*.

Alexco Keno Hill Mining (AKHM). 2021b. *Keno Hill Silver District Flame & Moth Operation Ground Control Management Plan*.

Alexco Environmental Group 2018. *Adaptive Management Plan Keno Hil Silver District Mining Operations*. Report prepared for Alexco Keno Hill Mining Corp., July 2018.

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

BGC Engineering, 2002(b). Blue Sediment Waste Rock Storage Area Soil Cover Design Report. Viceroy Minerals Corporation, Brewery Creek Mine. November 2002

Bleiler, L., Burn, C., and O'Donoghue, M. 2006. Heart of the Yukon – a natural and cultural history of the Mayo area. 138p.

British Columbia Resources Inventory Committee (BC RIC). 1999. BC Wildlife Habitat Rating Standards.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2002. COSEWIC assessment and status report on the Woodland Caribou Rangifer Tarandus Caribou.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2007. COSEWIC assessment and status report on the Common Nighthawk *Chordeiles minor* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 64 pp. (http://www.registrelep-sararegistry.gc.ca/status_e.cfm).

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2009. COSEWIC assessment and status report on the Horned Grebe Podiceps auratus in Canada.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2011. COSEWIC Wildlife Species Assessment. Available at: http://cosewic.ca/index.php/en-ca.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2012. COSEWIC assessment and status report on the Little Brown Myotis, Northern Myotis Tri-colored Bat in Canada.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2014. COSEWIC assessment and status report on the Wolverine *Gulo gulo* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 76 pp. (www.registrelepsararegistry.gc.ca/default_e.cfm)

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2019 COSEWIC wildlife species assessment. Available at: http://cosewic.ca/index.php/en-ca/ [accessed October 21, 2019].

Derome & Associates. 2013. Influence of Changing Travel Patterns and Modes of Transportation on Visitor Numbers in Dawson City, Mayo and Keno, Yukon. Derome & Associates Development and Management Inc., October 2013.

EBA Engineering Consultants Ltd. (EBA), 2010. Revision 2010-1. Operation, Maintenance and Surveillance Manual, Dry Stack Tailings Facility, Keno Hill Mill Facility, YT. EBA File: W13101178.008. Prepared for Alexco Keno Hill Mining Corp. September 2010.

EDI Environmental Dynamic Inc. 2008. Elsa Tailings Terrestrial Effects Assessment – Phase 1. Prepared for Access Consulting Group, Whitehorse, YT.

EDI Environmental Dynamic Inc. 2009. Elsa Tailings Terrestrial Effects Assessment – Phase 2. Prepared for Access Consulting Group, Whitehorse, YT.

Energy, Mines and Resources, Yukon, 2008. Yukon Mine Site and Reclamation Closure Policy Financial and Technical Guidelines.

Ensero Solutions and Alexco Keno Hill Mining. (Ensero & AKHM) 2020a. Keno Hill Silver District Mining Operations, Adaptive Management Plan. Report prepared for Alexco Keno Hill Mining Corp., October 2020.

Ensero Solutions and Alexco Keno Hill Mining (Ensero & AKHM). 2020b. *Keno Hill Silver District Mining Operations Hydrogeology Monitoring Plan*. Report prepared for Alexco Keno Hill Mining Corp. October 2020.

Ensero Solutions and Alexco Keno Hill Mining (Ensero and AKHM). 2020c. *Keno Hill Silver District Mining Operations Water Management Plan*. Report prepared for Alexco Keno Hill Mining Corp., October 2020.

Ensero Solutions and Alexco Keno Hill Mining (Ensero & AKHM). 2021a. *Keno Hill Silver District Operations Monitoring, Surveillance and Reporting Plan*. Report prepared for Alexco Keno Hill Mining Corp. October 2021.

Ensero Solutions and Alexco Keno Hill Mining (Ensero & AKHM). 2021b. *Keno Hill Silver District Operations Groundwater Monitoring Plan*. Report under review by YG. Report prepared for Alexco Keno Hill Mining Corp. October 2021.

Ensero Solutions and Alexco Keno Hill Mining (Ensero & AKHM). 2021c. *Keno Hill Silver District Mining Operations Waste Rock Management Plan – Revision 6.4*. Report prepared for Alexco Keno Hill Mining Corp., October 2021.

Ensero Solutions and Alexco Keno Hill Mining (Ensero and AKHM). 2021d. *Keno Hill Silver District Mining Operations Adaptive Management Plan*. Report prepared for Alexco Keno Hill Mining Corp., October 2021. Currently under review by YG.

Environment Canada. 2016. Climate Trends and Variations Bulletin (CTVB).

First Nation of Nacho Nyäk Dun (FNNND et al), Mayo District Renewable Resources Council, and YG Environment. 2003. Community-based Fish and Wildlife Management Plan – Nacho Nyak Dun Traditional Territory, 2002 – 2007

First Nation of Nacho Nyäk Dun (FNNND). 2008. *Na-Cho Nyäk Dun Tan Sothan—A Good Path Integrated Community Sustainability Plan.* Available at: http://nndfn.com/images/uploads/pdfs/NND_SUSTAINABILITY_PLAN.pdf

Government of Yukon. 2019. *Yukon Wildlife Act*.

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

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

Leach, A.J. and Hogan J. 2005. Preliminary Evaluation of Waterbird use in the Christal Creek Area, Keno Hill Mine. Ducks Unlimited Canada, Western Boreal program, March 2005.

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

Minefill Services (Minefill). 2021. Lab Test Report Number 20004-TWR-8002 Issued January 27, 2021, internal document prepared for AKHM, prepared by Minefill Services, Dr. D. Stone.

Minnow Environmental Inc. (Minnow). 2008 *Water Quality Assessment Report for United Keno Hill Mines.* Prepared for Elsa Reclamation and Development Company Ltd., July 2008.

Minnow Environmental Inc. (Minnow). 2013. *Evaluation of Contaminants of Concern for the United Keno Hill Mines Long Term Monitoring Program (revised).* Memorandum prepared for Alexco Environmental Group, November 2013.

Minnow Environmental Inc. (Minnow). 2015. *DRAFT – Proposed Water Quality Goals for United Keno Hill Complex Watersheds.* Technical memorandum prepared for Elsa Reclamation and Development Company Ltd, February 2015.

Minnow Environmental Inc. (Minnow). 2018. *Updated Water Quality Goals for United Keno Hill Complex Watersheds, March 2018.* Technical memorandum prepared for Elsa Reclamation and Development Company Ltd., March 2018.

Minnow Environmental Inc. (Minnow). 2020. *Updated Water Quality Goals for United Keno Hill Mine Complex Watersheds.* Technical memorandum prepared for Elsa Reclamation and Development Company Ltd, December 2020.

O'Donoghue, pers. comm. as cited in Lortie, 2009 "Current State of Wildlife in the Keno Hill Silver District".

O'Donoghue, M., Bellmore, J., Czetwertynski, S., Westover, S. 2016. Moose survey: Mayo Moose Management Unit, late-winter 2014. Yukon Fish and Wildlife Branch Report SR-16-05. Whitehorse, Yukon, Canada.

Oudin, L., Hervieu, F., Michel, C, Perrin, C, Andreassian, V, Anctil, F., Loumagne, C. (Oudin et al). 2005. Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2-Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling. J. Hydrol. (Amsterdam), 303(1-4), 290–306

Smith, C.A.S., Meikle, J.C., and Roots, C.F. (Eds) (Smith et al). 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313p.

SRK Consulting (Canada) Inc. (SRK). 2020. Hydrology Analysis – Valley Tailings Facility, Keno Hill – DRAFT. Prepared for Elsa Reclamation and Development Company Ltd., Vancouver, BC.

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.

Yukon Government (YG). 2020. Water Licence QZ18-044.

APPENDIX 1
RECLAMATION RESEARCH SUMMARY REPORTS

APPENDIX 1.1

2012 DSTF INTERIM RECLAMATION AND COVER SUMMARY REPORT

ACCESS
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

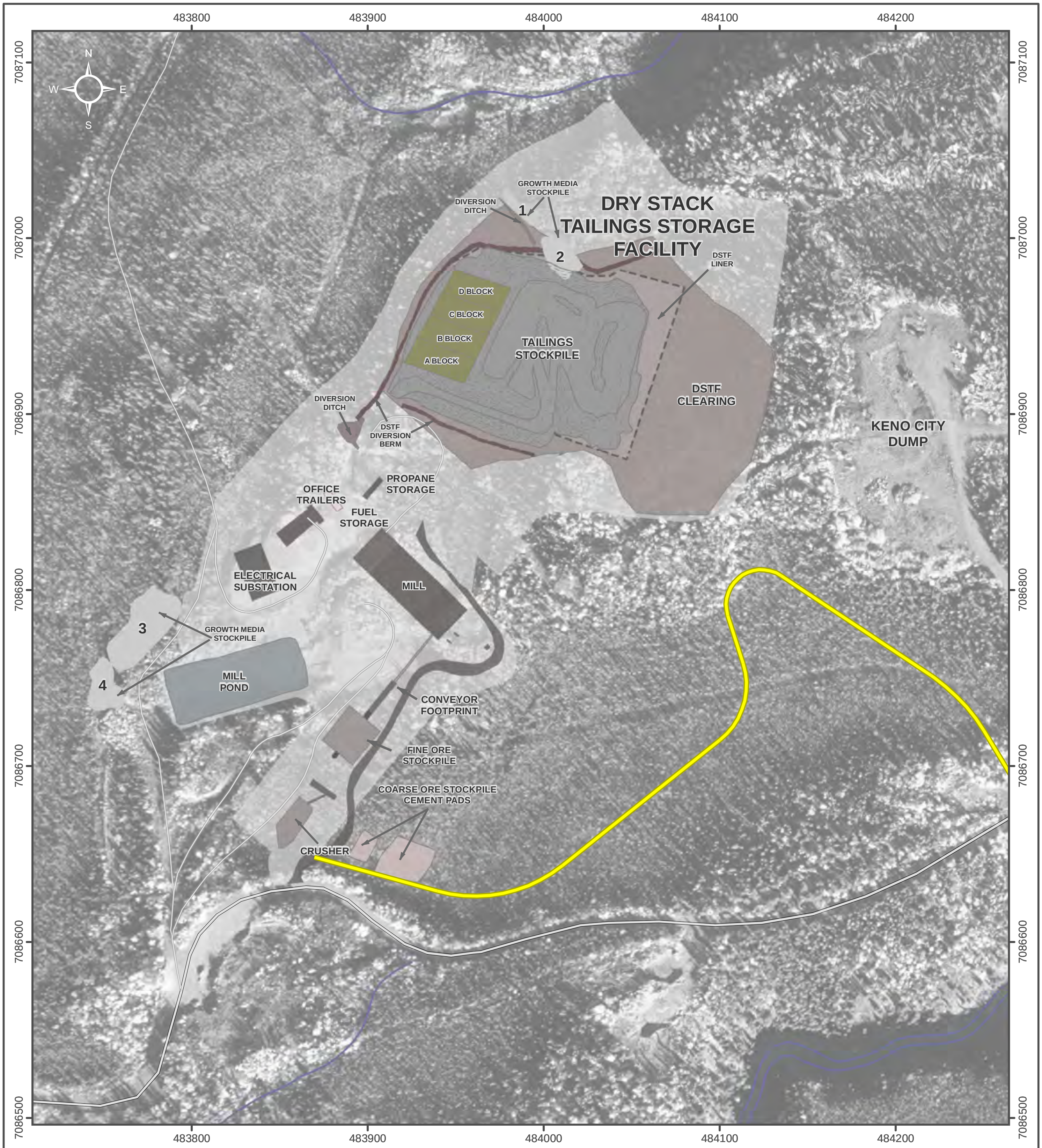
Re: 2012 Dry Stack Tailings Facility Cover Trial

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

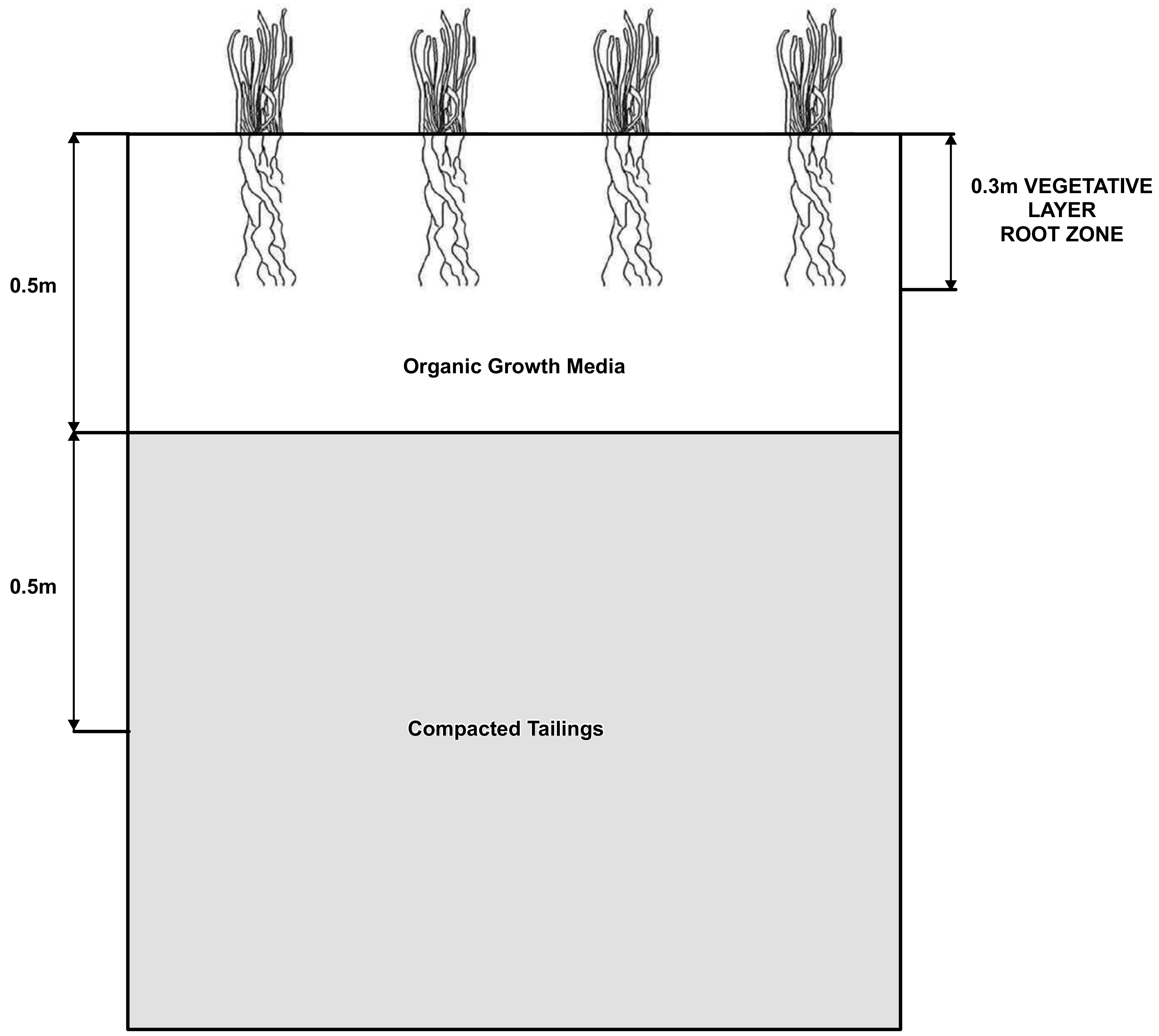
MARCH 2013

I:\ALEX-05-01\Bellekeno\GIS\mxd\Annual_Reports\2012\Groundwater_MillSite_Memo20130314.mxd
(Last edited by: jpan; 3/20/2013/09:16 AM)

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

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

Success Through Science®

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

==
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 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

.

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
www.maxxamanalytics.com

Phone: (604) 444-4808
Fax.: (604) 444-4511
Toll-Free: 1-800-440-4808

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):	PROJECT MANAGER:	LABORATORY CONTACT:
Lisa Knight	Scott Davidson	Lanoy Luangkhamdeng

	FIELD SAMPLE ID	MAXXAM LAB # (LAB USE ONLY)	MATRIX: GROUNDWATER	SURFACE WATER	DRINKING WATER	SOIL	OTHER	SAMPLING: 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 SAMPLER:	DATE: DD/MM/YY	TIME:	RECEIVED BY:
RELINQUISHED BY:	DATE: DD/MM/YY 18/05/12	TIME: 08:30	RECEIVED BY: Nicole Lockyer
RELINQUISHED BY: Lisa Knight	DATE: DD/MM/YY	TIME:	RECEIVED BY LABORATORY:

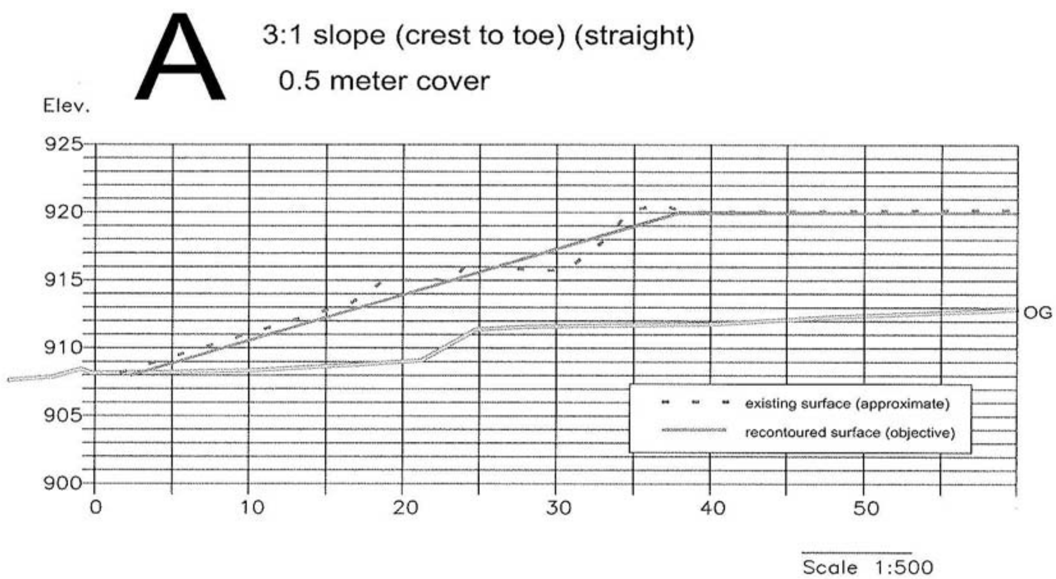
CUSTODY RECORD

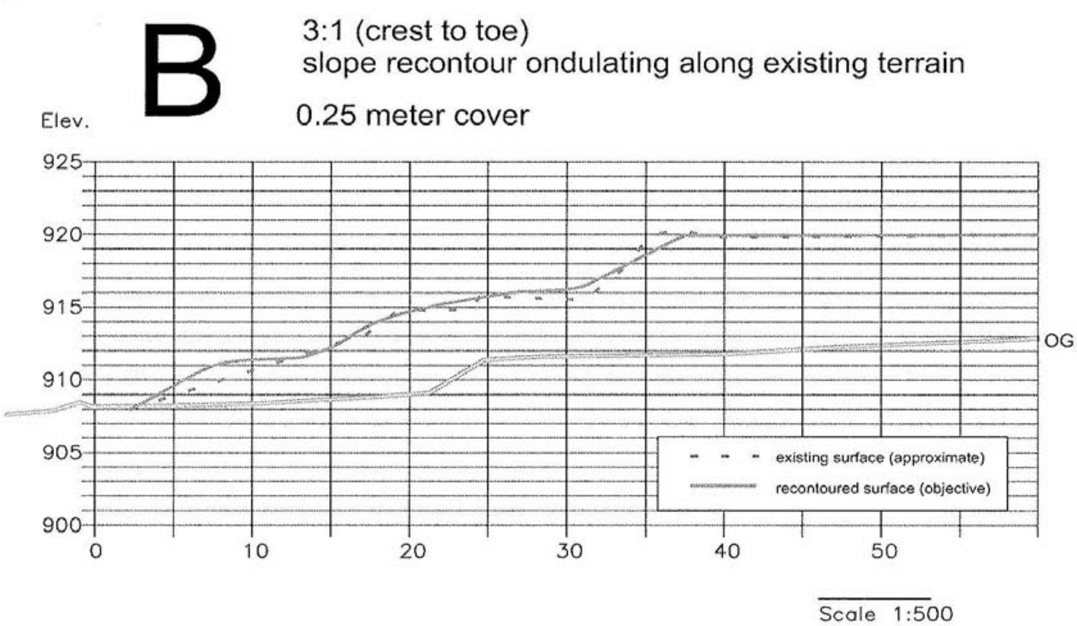
COCFORM - BC - 20070822

APPENDIX B

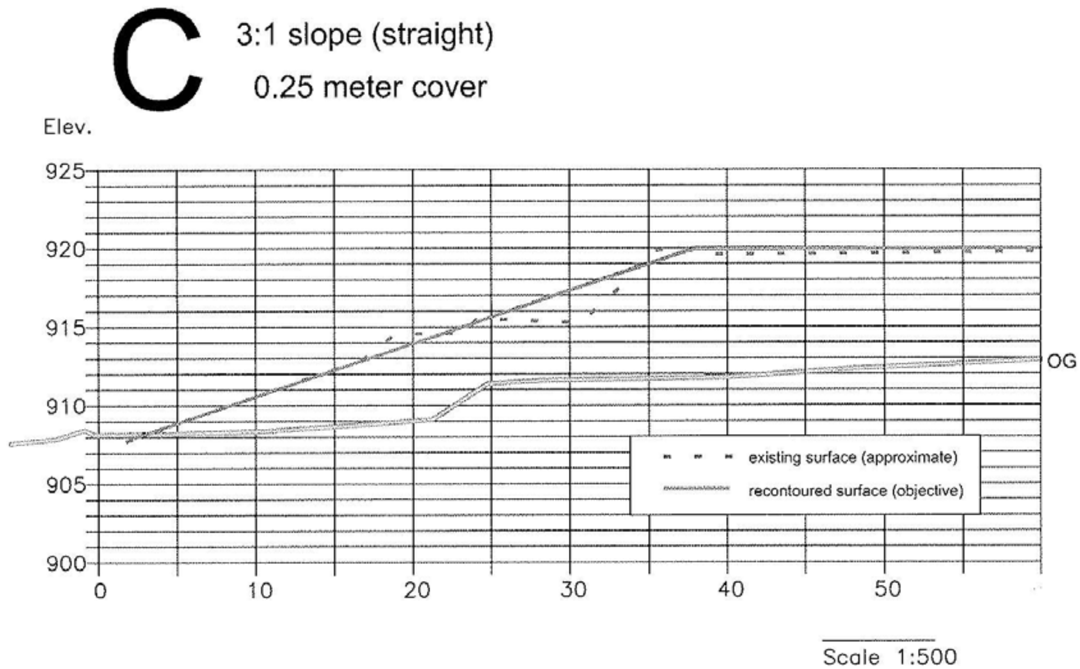
BLOCK PROFILES

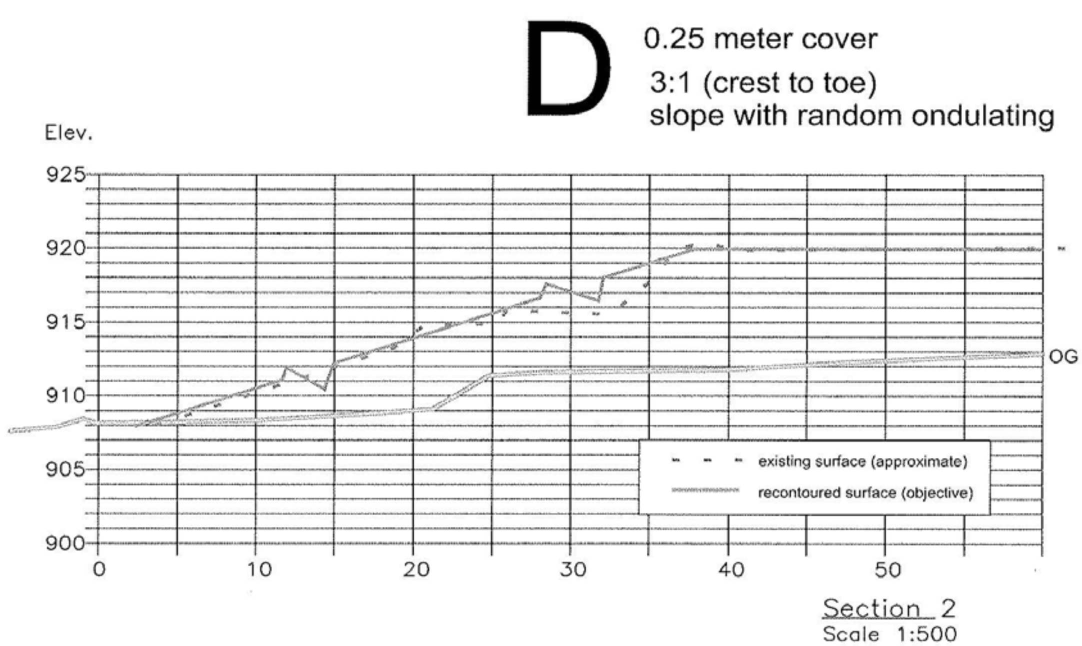
DSTF Phase I Reclamation - Slope Profiles





I


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

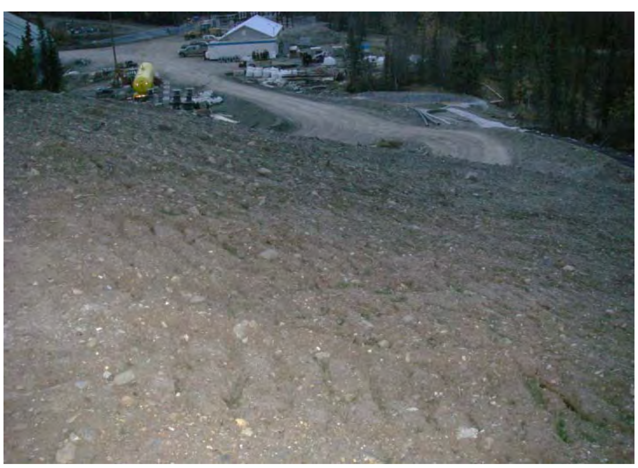


Photo 11: Grass sprouts DSTF looking south from crest

Photo 12: Grass sprouts DSTF looking west from crest

APPENDIX 1.2

SILVER KING IN SITU DEMONSTRATION TEST INTERIM REPORT

3 Calcite Business Centre, 151 Industrial Road
Whitehorse, Yukon Y1A 2V3
Phone (867) 668-6463 Fax (867) 633-4882
www.accessconsulting.ca

Memorandum

To: Elsa Reclamation and Development Company Ltd.

From: Andrew Gault, Jim Harrington (Alexco Environmental Group)

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

Date: October 24, 2016

Re: Silver King In Situ Treatment Test Update: March – August 2016

Deliverable 2016-17-033-2_07

---

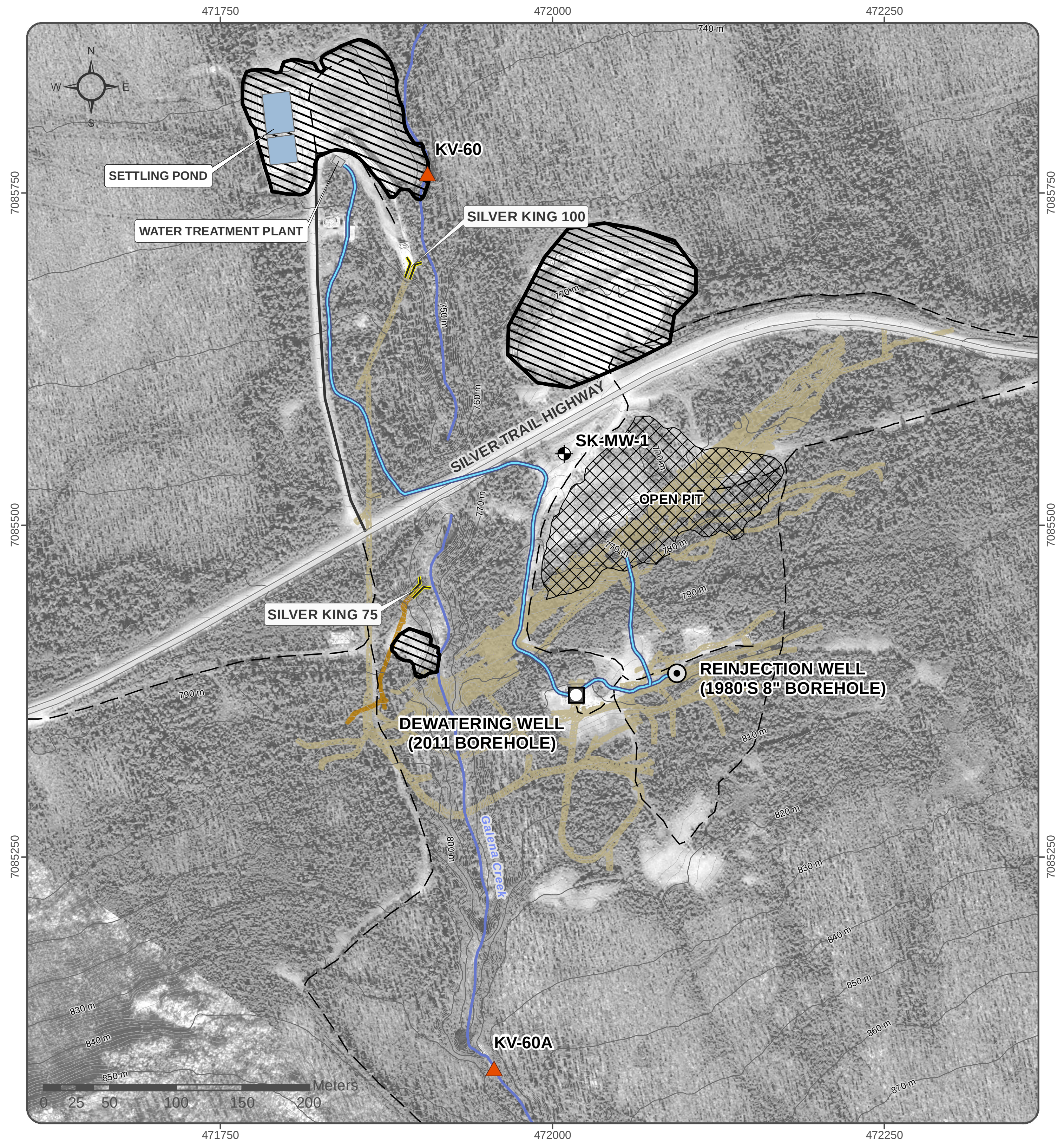
1 INTRODUCTION

This memorandum provides an overview of the work performed and results collected for the Silver King (SK) in situ treatment test between March 2016 and August 2016. It serves to provide an update to INAC on the latest results from the in situ treatment pilot test that was initiated in September 2014.

2 ACTIVITY AND RECENT DATA

2.1 SILVER KING DEWATERING AND GROUNDWATER LEVEL

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 alongside flow rates of mine pool water pumped from the dewatering well to the SK water treatment plant (WTP) and water that is reinjected to create a recirculation loop within the flooded mine workings. The mine pool elevation varied between 728 and 738 masl for the majority of the March to August 2016 period. Overall, the dewatering rate ranged between 5 and 15 L/s, with approximately 3 L/s returned to the Silver King pit between March and the end of April, 2016. The reinjected water was amended with methanol to stimulate subsurface sulphate- and metal-reducing bacteria between January 22 and April 2, 2016.



Surface Water Station
Reinjection Well; Injection Well, n/a
Dewatering Well
Monitoring Well
Adit

Pipeline
Underground Workings (100 level)
Underground Workings (75 level)
Watercourse
Contours (1 m interval)

Silver Trail Highway
Local Road
Limited-Use Road
Buildings
Settling Pond
Open Pit
Waste Rock Dump

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on October 2016

ERDC

AEG

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

SILVER KING IN SITU TEST

FIGURE 2-1
SILVER KING LAYOUT

OCTOBER 2016

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Studies\WaterTreatment\In-SituWaterTreatment\SilverKing_InSitu_Pipeline_Profile\SilverKing_Pipeline_Simple_20161004.mxd
(*Last edited by: amatlashevska; 10/4/2016/14:34 PM*)

Between March and late April 2016, the groundwater level in the SK workings was maintained at 727 – 730 masl by dewatering at 5 – 6 L/s and reinjecting back into the SK pit at ~3 L/s (Figure 2-2). The effects of freshet and the associated increased recharge rate were first observed on April 25, 2016, when the groundwater level started to increase sharply. In response to this, on May 2, 2016 the recirculation of water to the Silver King pit was suspended and the dewatering well pumping rate was increased to run at between 9 and 15 L/s to accommodate the high volumes. Since no water was being injected into the mine, methanol amendment was also suspended at this time. All dewatering flows were directed to the Silver King water treatment plant (WTP). The increased dewatering rate slowed the water level rise in the mine workings and managed to maintain the groundwater level at 731 – 735 masl between May and mid-July 2016. As such, the pilot test remained under hydraulic control, largely due to the increased pumping rate that could be achieved with the replacement pump installed in November 2015. This represents an improvement in the test conditions when compared with the freshet event of 2015 when the previous dewatering pump could not adequately maintain hydraulic control during this period of high recharge rate, leading to full flooding of the mine workings and overflow of water from the adit in the spring of 2015.

Extended precipitation in late summer and fall of 2016 also caused a spike in the recharge to the mine working, leading to a second rise in the groundwater level (735 – 739 masl) between mid-July and the end of August despite dewatering at 11 – 15 L/s. By maintaining a high rate of pumping, overflow of the adit was prevented during this period. However, on August 28, 2016 the motor in the dewatering pump failed, leading to full flooding of the workings by the end of August. During this period that water discharged from the SK100 adit it has been directed to the SK water treatment plant for secondary treatment as necessary.

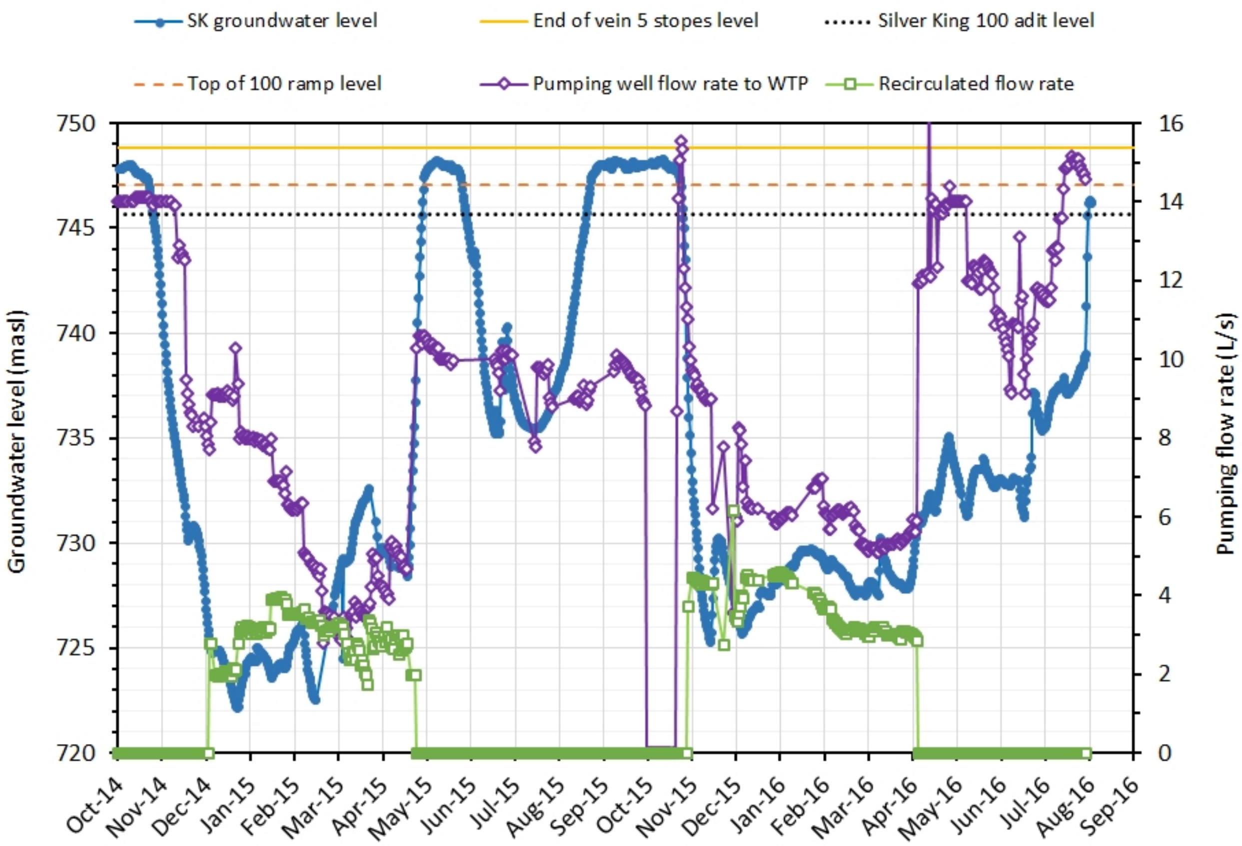


Figure 2-2: Response of groundwater level in SK mine pool during dewatering only and dewatering-recirculation phases of testing at different pumping flow rates. The level of the end of the Vein 5 stopes, top of the 100 ramp and SK100 adit are shown for reference.

2.2 Silver King Mine Pool Geochemistry

Although the March to August 2016 dataset is the primary concern for this update memorandum, the full dataset collected since the start of the SK in situ treatment pilot test is displayed for selected constituents of interest in Figure 2-3 and Figure 2-4 in order to place the data in context.

A sustained rise in dissolved organic carbon (DOC) concentrations in the SK dewatering well water (SKDW; which extracts water from the base of the Vein 5 workings) was observed approximately one month after the start of methanol injection into the SK pit (which infiltrates into the Vein 1 workings). Dewatering well DOC levels peaked (16 mg/L) 3-4 weeks after methanol injection was halted and declined to pre-injection levels approximately 2 months after the end of methanol injection;

The peak in dewatering well DOC concentrations in April-May 2016 coincided with the following trends in the dewatering well water which are consistent with the onset of sulphate-reducing conditions:

- A rise in alkalinity (200 – 240 mg/L over April – June 2016 versus 146 – 160 mg/L prior to April 2016) since metal and sulphate reduction coupled to the oxidation of organic matter produces alkalinity;

- A rise in sulphide concentrations (0.02 – 0.06 mg/L versus non-detect (<0.02 mg/L) in the previous two months) and concomitant decline in sulphate levels (300 – 320 mg/L versus >390 mg/L for duration of test prior to April 2016) consistent with the transformation of dissolved sulphate to sulphide by sulphate-reducing microorganisms; and

- A fall in the total and dissolved concentrations of zinc, cadmium and thallium to their lowest concentrations observed to date as these chalcophile metals reach with the biogenic sulphide to form insoluble metal sulphide phases which precipitate out of the water column.

Following the decline in DOC concentrations to pre-injection levels, the zinc, cadmium, and thallium concentrations have slowly increased between May and August 2016. However, five months after the suspension of soluble carbon injection, the concentrations of these chalcophile metals still remain well below those present prior to the start of in situ treatment, and discharge water from the pumping well has remained below the water licence thresholds for these metals (there is no threshold criteria for thallium).

The ORP increased markedly in July-August 2016, from ~+10 mV in May 2016, likely due to the ingress of oxidizing surface waters from elevated precipitation in late summer/fall as indicated by the rising groundwater level. A similar spike in ORP was observed during the 2015 freshet event with temporarily re-flooded the mine workings. Although this likely prompted the oxidation of some reduced metal sulphide phases, the slow rise in the dissolved zinc and cadmium concentrations suggests that this process did not result in a rapid rebound in chalcophile metal concentrations. It is inferred that the longer treatment of the Vein 1 workings (Jan – April 2016 carbon injection via SK pit) increased both the treated water volume and the treated surface area within the mine pool, allowing it to effectively treat the increased metal loading from the higher rate of recharge that the mine received during freshet and the summer rainy season.

Iron and arsenic concentrations were closely correlated and exhibited spikes in March and May 2016, typically following the decline in sulphide levels following organic carbon injection. The March peak is interpreted as the onset of stronger reducing conditions in March 2016 during the methanol injection period. Influx of particulate iron and arsenic into the mine during freshet and rinsing of unsaturated surfaces as the groundwater level rose may partly explain the spike in iron and arsenic concentrations observed in May 2016. Alternatively, the dissolved sulphide produced from microbial sulphate reduction may have caused "abiotic" reductive dissolution of more recalcitrant iron (oxyhydr)oxides, releasing iron and associated arsenic to solution. However, at all times during the 2016 organic carbon injection period and the passive treatment phases since organic carbon addition ceased, arsenic concentrations have remained well below (i.e., 10% or less) the water licence discharge thresholds (there is no threshold criteria for iron).

Manganese concentration showed little change between March and August 2016, ranging between 2.1 and 2.8 mg/L with no clearly discernable trend. Temperature increased between March and August 2016, but only over a relatively narrow range (2.8 to 5.4°C).

ALEXCO ENVIRONMENTAL GROUP

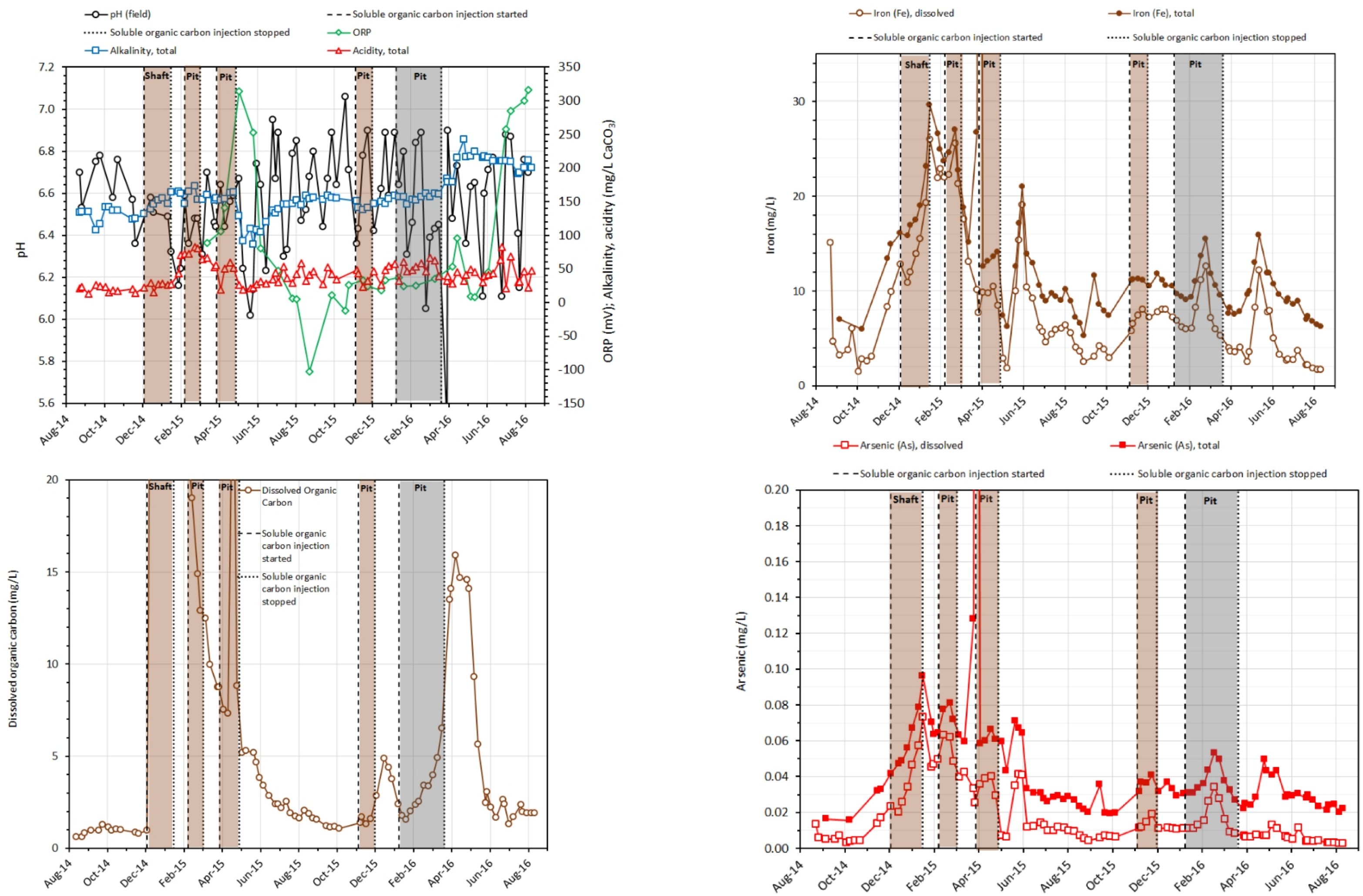


Figure 2-3: Change in selected constituents in SK mine pool water (collected via the dewatering borehole) during the dewatering and molasses amendment phases of the in situ mine pool treatment testing. The shaded areas indicate when continuous injection of molasses (brown) or methanol (grey) was ongoing with recirculation to either the shaft or pit; data collected prior to this were sampled when the mine pool was undergoing dewatering only.

ALEXCO ENVIRONMENTAL GROUP

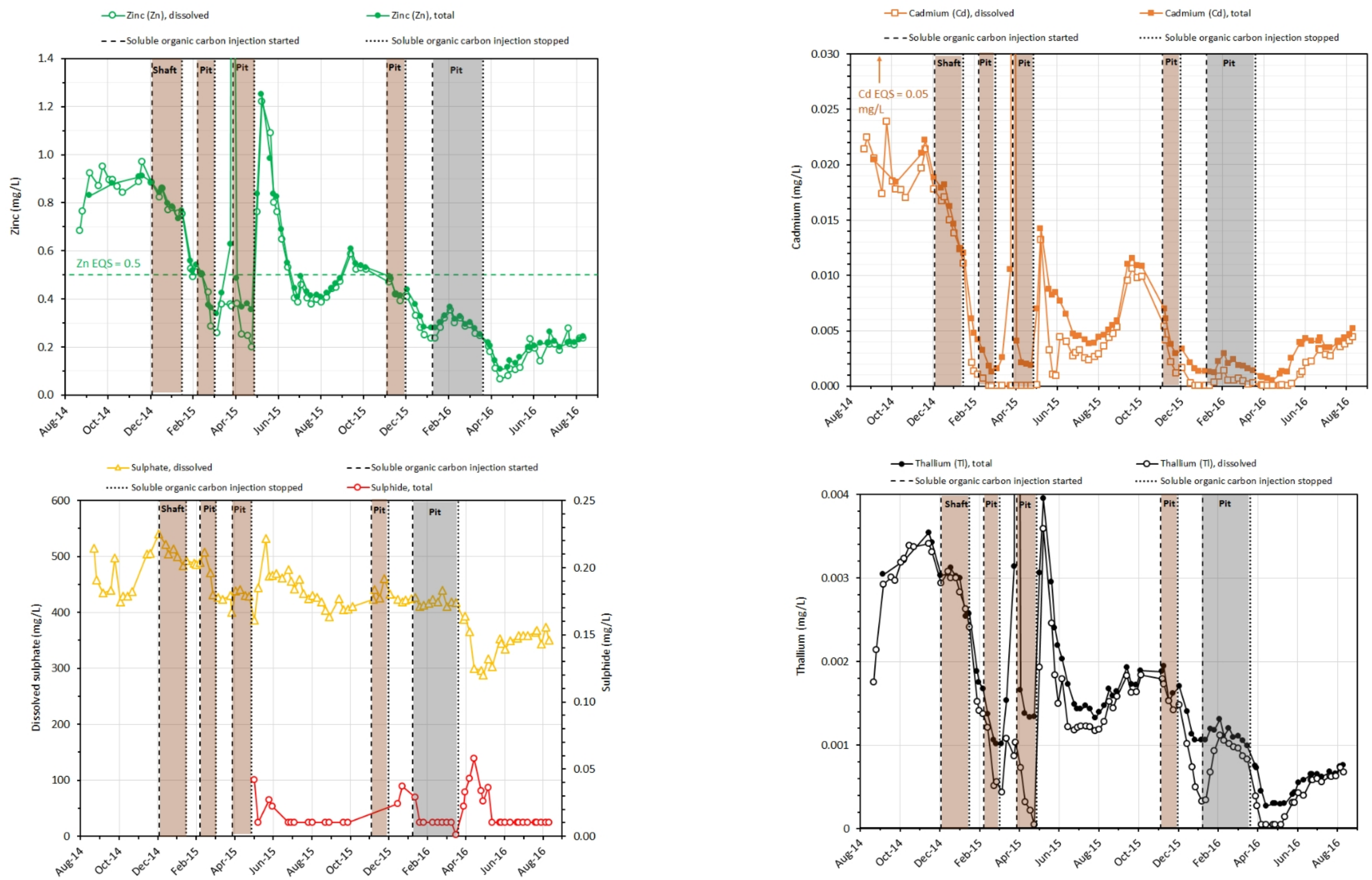


Figure 2-4: Change in zinc, cadmium, sulphur species, and thallium concentrations in SK mine pool water (collected via the 2011 dewatering borehole) during the dewatering and molasses amendment phases of the in situ mine pool treatment testing. The shaded areas indicate when continuous injection of molasses (brown) or methanol (grey) was ongoing with recirculation to either the shaft or pit; data collected prior to this were sampled when the mine pool was undergoing dewatering only. EQS = effluent quality standard.

2.3 SILVER KING MINE POOL MICROBIOLOGY

Dewatering well samples were collected for microbial community profiling in April 2016. These were submitted to Contango Strategies (Saskatoon, SK) for genomic analysis. Further details regarding this analysis are reported in AEG (2016). 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 November 2015 and January 2016 data are also presented in order to provide some context for the April 2016 data (Figure 2-5 to Figure 2-7).

Microbes capable of sulphide production were present in the SK mine pool for all three sampling events. Although the proportion of microorganisms capable of sulphide-production appeared to have declined in the April 2016 sampling event relative to January 2016 (Figure 2-5), the inferred abundance of SPBs, which is based on most probable number measurements of heterotrophic bacteria present in each sample, increased markedly from January to April 2016 (Figure 2-7). The lower proportion of sulphide-producing bacteria in the April 2016 sample is likely exacerbated by the proliferation in methylotrophic bacteria (24% of OTUs) in the April 2016 sample, compared to the November 2016 (3% of OTUs) and January 2016 (1% of OTUs) samples. The sharp rise in methylotroph abundance is due to the methanol injection into the SK mine workings (via the SK pit) that took place from late January to early April, 2016. Of those OTUs that were most closely matched with SPBs, the majority were associated with the *Desulfosporosinus* genus in the January and April 2016 samples (Figure 2-6).

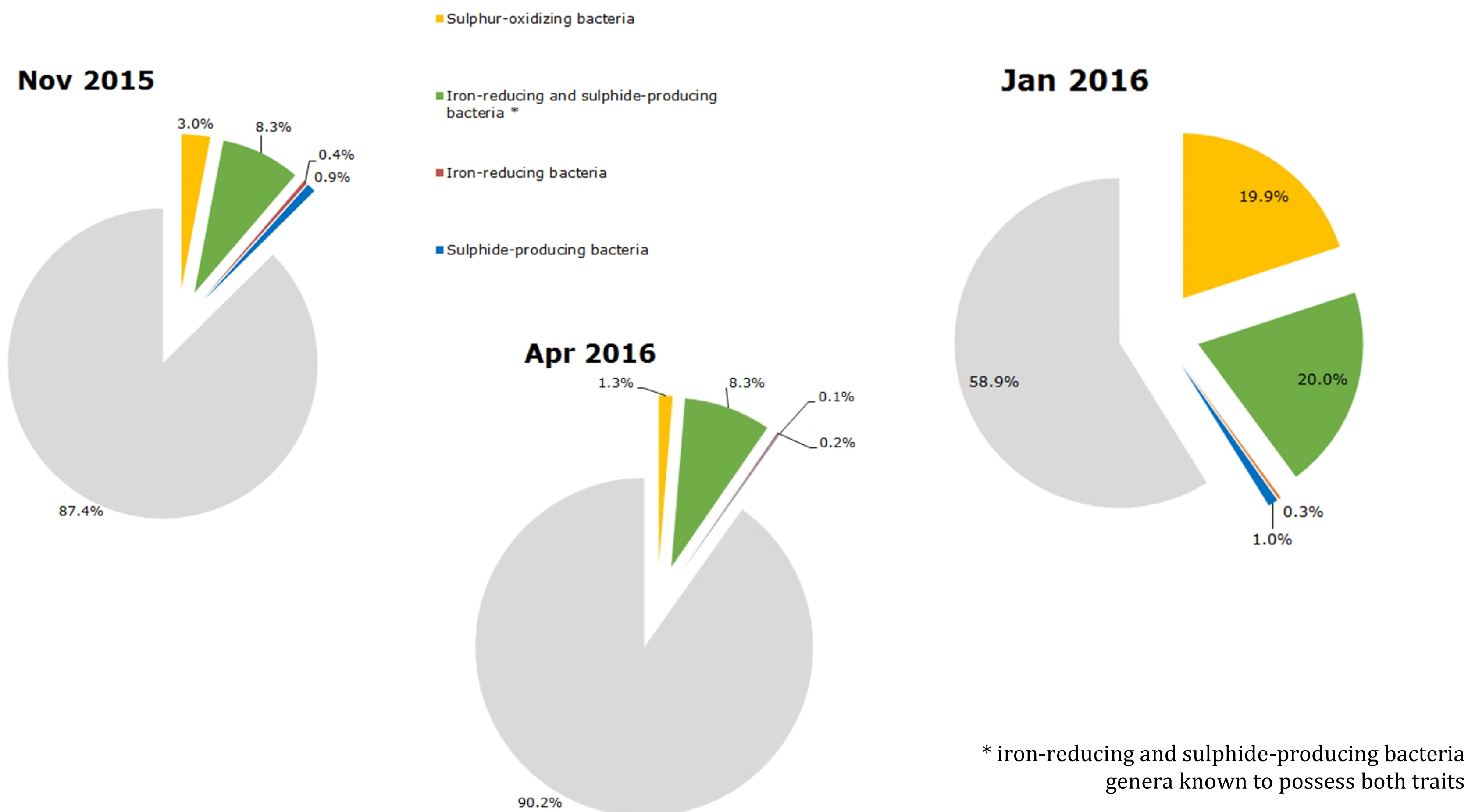


Figure 2-5: Percentage of OTUs assigned as FeRB, SPB and SOB in SK mine pool water samples.

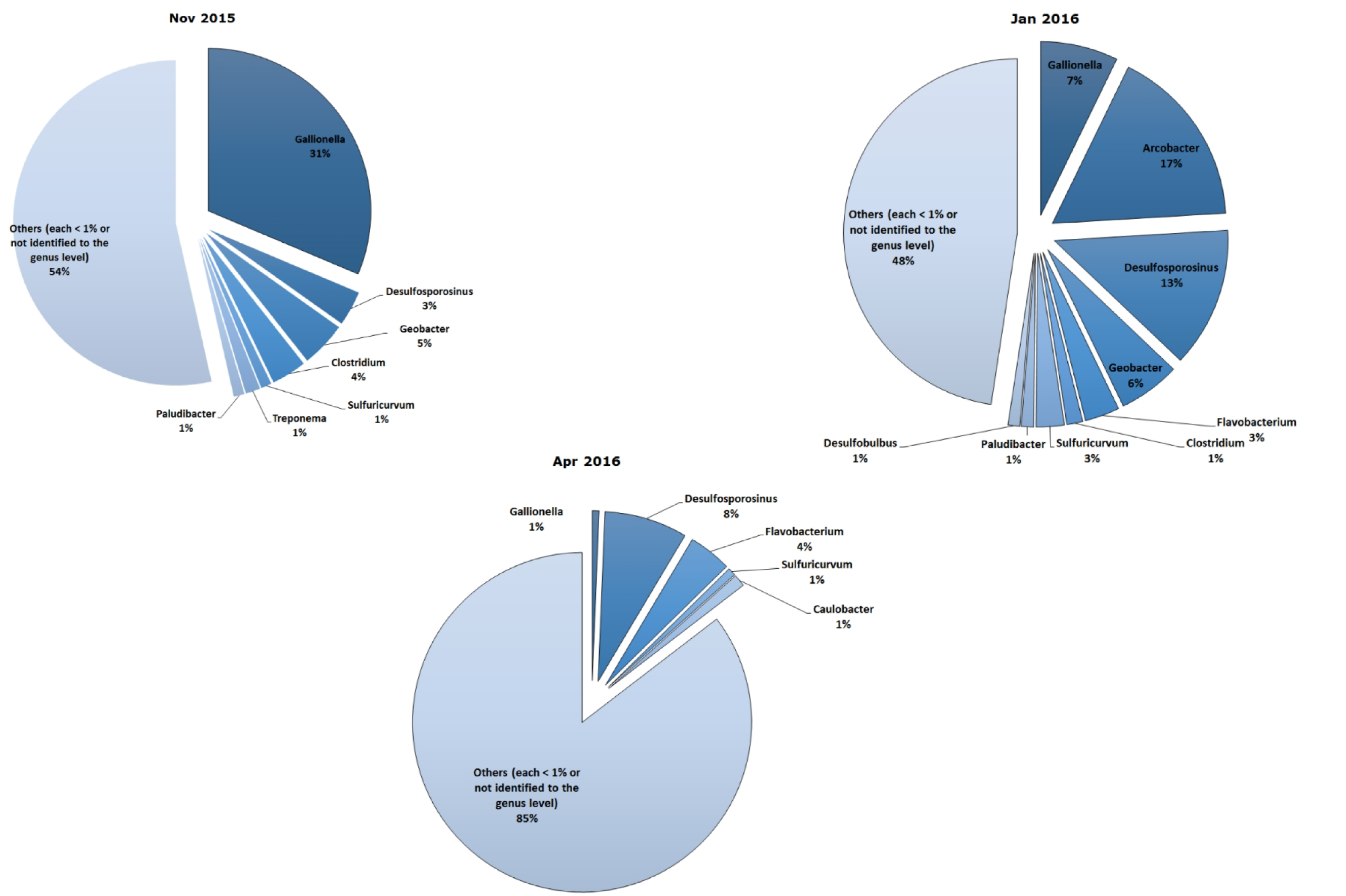


Figure 2-6: Highest percentage of organisms identified to genus level for November 2015, January 2016, and April 2016 sampling events

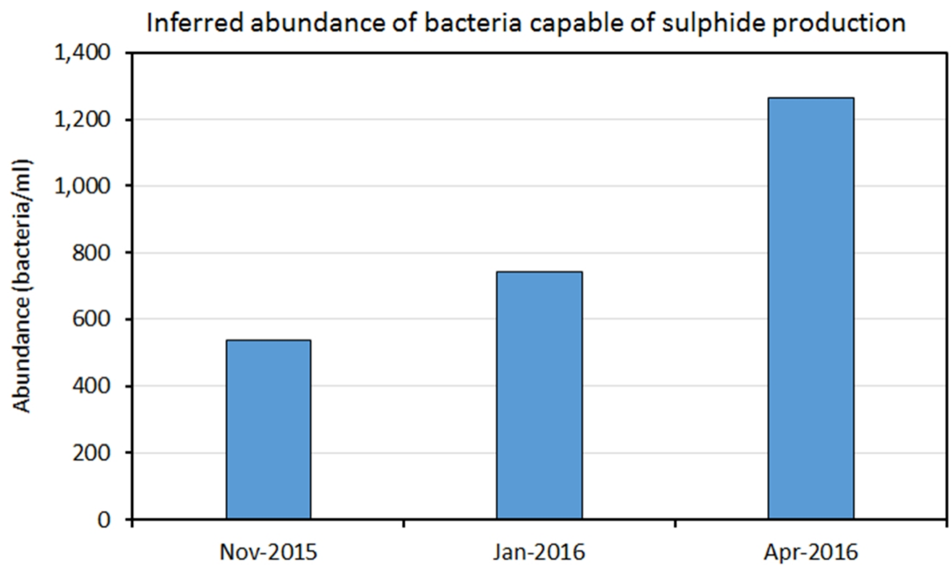


Figure 2-7: Inferred abundance of microorganisms with ability to produce sulphide determined for November 2015, January 2016, and April 2016 sampling events

2.3.1 ^{34}S-SO_4 Isotopic Analysis

The relative differences in stable isotope ratios are reported relative to a standard reference material and in delta notation:

$$\delta = [\ (R_{sample} - R_{std})/R_{std}\ ] \times 1000$$

where R_{sample} and R_{std} are the ratios of the abundance of the heavy to light isotope (^{34}S and ^{32}S, respectively) for the sample and the standard reference material (Canyon Diablo Troilite for $\delta^{34}S$), respectively. Laboratory delays have limited the amount of stable isotope data for evaluation with only samples collected between November 2015 and March 2016 available. This small sample set limits the conclusions that may be drawn from the data; however, the data collected to data are discussed below.

During microbial sulphate reduction, the ^{32}S-O bond is more easily broken than the ^{34}S-O bond. As such, the sulphate that remains during microbial sulphate reduction is expected to become progressively enriched in the ^{34}S isotope, leading to an increase in the $\delta^{34}S$-SO_4 value (i.e. become more positive). This may provide a secondary tool to indicate the development of microbially-induced sulphate reducing conditions in the SK mine pool.

The SK mine pool $\delta^{34}S$-SO_4 data (-1.6 to -3.2‰) lie within the range observed along Galena Creek (-1.2 to -1.9‰ at KV-60A and -3.4 to -3.8‰ at KV-60), and are higher than the $\delta^{34}S$-SO_4 measured in groundwater samples from SK-MW-1 (-5.6 to -6‰) (Figure 2-8). This is consistent with the δD and $\delta^{18}O$ stable isotope data that suggest the majority of the SK mine pool is supplied by Galena Creek (Section 2.4.2).

Measurable sulphide was detected in the SK mine pool between late December 2015 and January 2016 (Figure 2-4), which coincided with a rise in the $\delta^{34}S$-SO_4 ratio between January and mid February, 2016, however, the $\delta^{34}S$-SO_4 data for this period were largely within the range of values observed prior to the detection of sulphide. Furthermore, the dissolved sulphate concentration showed little change over this time, suggesting that any change in the $\delta^{34}S$-SO_4 signature was likely masked by the large sulphate pool. Further data, especially in April and May, 2016, when a marked drop in the SK mine pool dissolved sulphate concentration and concomitant rise in sulphide levels were observed, are required to evaluate the utility of $\delta^{34}S$-SO_4 measurements in identifying microbially mediated sulphate reduction in this system.

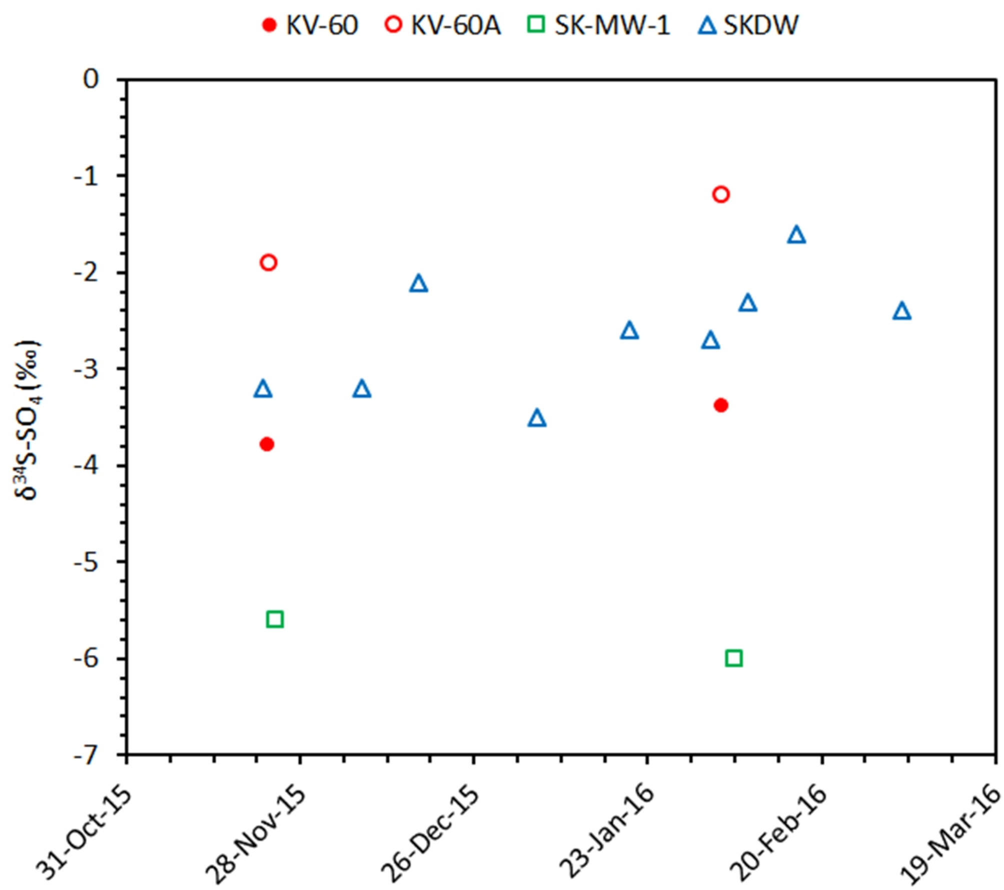


Figure 2-8: $\delta^{34}S$-SO_4 measurements from water samples collected from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

2.4 TRACER ANALYSIS

2.4.1 Dye

Fluorescent tracer (18 L of 20% Rhodamine solution) was injected into the SK workings via the SK pit on February 24, 2016. An inline fluorimeter was placed at the mine water discharge at the treatment plant to provide high resolution data regarding the arrival of the injected dye at the dewatering well. No dye breakthrough has been detected, suggesting that either too little dye was added to the workings, or that the dye was significantly attenuated within the workings.

2.4.2 Stable Isotope (^{2}H and ^{18}O)

Samples for deuterium (^{2}H or D) and oxygen-18 (^{18}O) analyses were collected periodically from the SK dewatering well in addition to Galena Creek (KV-60A and KV-60) and the nearby groundwater monitoring well (SK-MW-1). This work is not intended to provide a quantitative measure of the precise contributions of surface and groundwater sources to the SK workings since the time and budget required for such a study are outwith the scope of the SK in situ treatment pilot test. Nevertheless, stable isotope analyses of water samples from the SK workings, and from likely recharge sources to the SK mine such as Galena Creek and local groundwater, may provide information regarding the dominant source of recharge to the flooded SK workings.

The relative differences in stable isotope ratios are reported relative to a standard reference material and in delta notation:

$$\delta = [\ (R_{sample} - R_{std})/R_{std}\ ] \times 1000$$

where R_{sample} and R_{std} are the ratios of the abundance of the heavy to light isotope for the sample and the standard reference material (standard mean ocean water for both δD and $\delta^{18}O$), respectively. Long analytical delays at the specialist laboratory responsible for the isotopic analysis have resulted in the analysis of only the March, 2016 sample in the March-August, 2016 period; further data are awaited.

Plotting of the δD and $\delta^{18}O$ data collected to date indicates that the Galena Creek samples largely share a similar isotopic signature with the global meteoric water line (GMWL; Figure 2-9), suggesting that local precipitation that ultimately feeds Galena Creek has not undergone substantive subsequent isotopic fraction (e.g. via evaporation and/or mineral-fluid interactions). The SK-MW-1 groundwater samples are generally located further right of the GMWL than the Galena Creek samples, suggesting they have experienced some evaporation and/or mineral-fluid reactions (Figure 2-9). The mine pool samples collected via the dewatering well (SKDW) plot between the Galena Creek and local groundwater data, and are closest to the Galena Creek stable isotope dataset (Figure 2-9).

Examination of temporal trends in the stable isotope data (Figure 2-10) indicates that the Galena Creek and SK flooded mine workings samples have exhibited minimal variation over the sampling period (November 2015 to March 2016); however, an increase in the δD and $\delta^{18}O$ values for the local groundwater (SK-MW-1) was observed in the February and March, 2016 samples. Given the limited dataset available, it is unclear if this increase represents a seasonal trend.

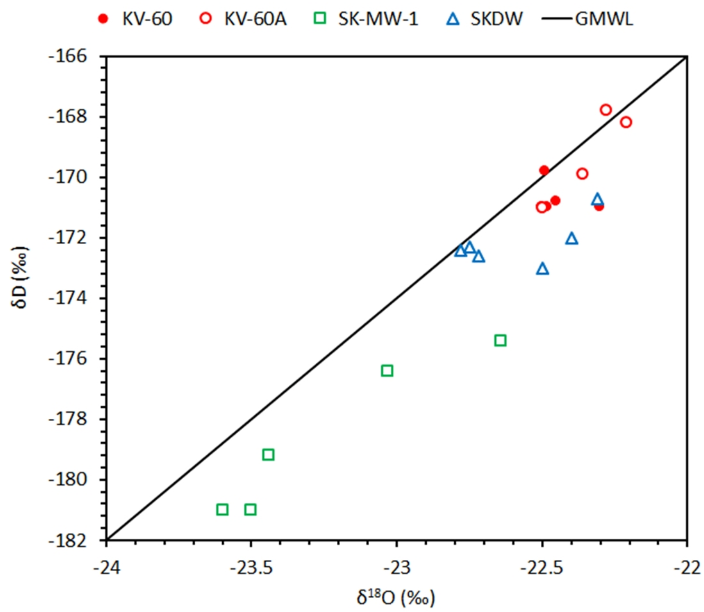


Figure 2-9: δD versus $\delta^{18}O$ plot of water samples from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

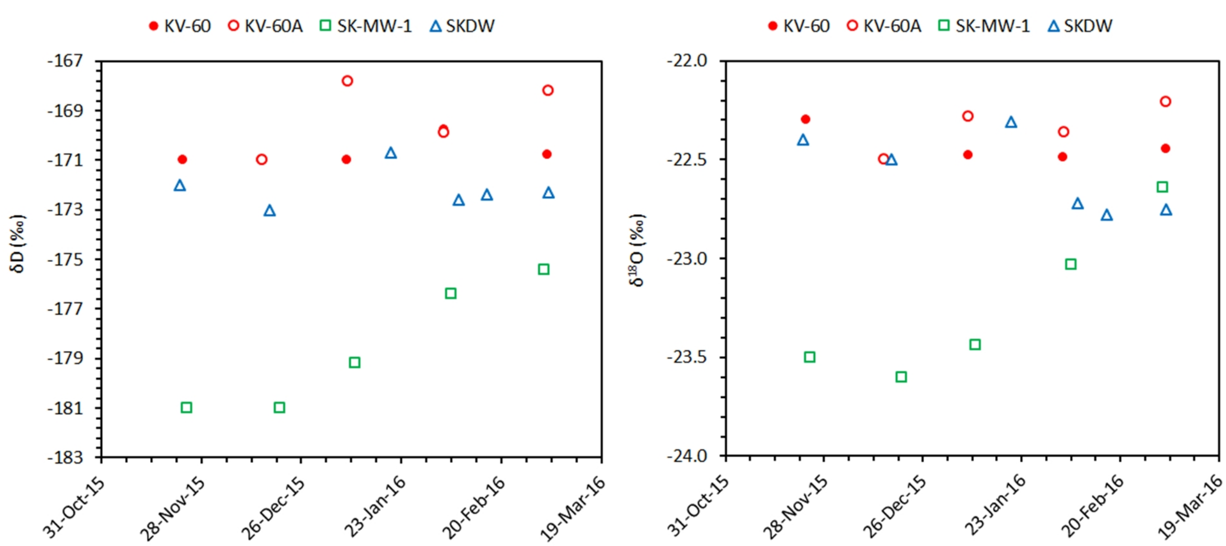


Figure 2-10: Temporal changes in hydrogen (left) and oxygen (right) isotope ratios measured in water samples collected from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

Since the start of collection of samples for isotopic analysis (November 2015), four paired sampling events are available (collected within 5 days of each other) for evaluation (Table 2-1). In order to estimate the relative contribution of Galena Creek and local groundwater to the SK workings, a two component mixing model was assumed where KV-60A data were used for the Galena Creek endmember and SK-MW-1 for the local groundwater endmember.

Table 2-1: Stable isotope and tritium date-paired data collected to date from sampling locations at the SK site

Sample location	Date	δD	δ18O	Tritium
		‰	‰	TU
KV-60	23-Nov-15	-171	-22.3	-
SKDW	22-Nov-15	-172	-22.4	5.4
SK-MW-1	24-Nov-15	-181	-23.5	-
KV-60A	15-Dec-15	-171	-22.5	-
KV-60	15-Dec-15	-171	-22.5	-
SKDW	17-Dec-15	-173	-22.5	-
SK-MW-1	20-Dec-15	-181	-23.6	-
KV-60A	04-Feb-16	-169.9	-22.36	-
KV-60	04-Feb-16	-169.8	-22.49	-
SKDW	08-Feb-16	-172.6	-22.72	-
SK-MW-1	06-Feb-16	-176.4	-23.03	-
KV-60A	04-Mar-16	-168.2	-22.21	-
KV-60	04-Mar-16	-170.8	-22.45	-
SKDW	04-Mar-16	-172.3	-22.75	-
SK-MW-1	03-Mar-16	-175.4	-22.64	-

The proportions of each endmember were varied such that:

$$x*\delta D_{KV\text{-}60A} + (1\text{-}x)*\delta D_{SK\text{-}MW\text{-}1} = \delta D_{SKDW}$$

Where x and (1-x) denote the fractional proportion that Galena Creek (KV-60A) and local groundwater (SK-MW-1) contribute to the SK mine pool. This assumes a two component endmember system.

No KV-60A data were available for the November 2015 sampling event, so KV-60 was used instead; the use of either KV-60 or KV-60A in the mixing model returned largely similar results. The same mixing model exercise using $\delta^{18}O$ also returned similar results.

This two-component mixing model indicated that Galena Creek provided the majority of recharge in November (90%) and December (80%) 2015. This is consistent with the November 2015 SK dewatering well tritium data (Table 2-1), which indicated that 5.4 TU of tritium was present, suggesting that the mine workings had been recharged with relatively young water.

Although Galena Creek was still the predominant source of recharge in the February and March 2016 sampling events, its relative contribution had declined to 58% and 67%, respectively. While this might reflect the lower recharge that may be expected during the winter months when flow in Galena Creek is at its lowest, the increase observed in the δD and $\delta^{18}O$ SK-MW-1 data complicates this assessment since this is responsible for the higher apparent groundwater proportion of the inferred recharge from the mixing model calculation. Further data may help clarify any seasonality in waters from each sampling station and provide additional information regarding source apportionment to the flooded SK mine workings.

3 SUMMARY

- Methanol injection via the SK pit resulted in development of sulphate-reducing conditions in the SK mine pool as indicated by the fall in chalcophile metal and sulphate concentrations alongside a rise in sulphide and alkalinity levels;
- Ongoing monitoring over the 5 months following the suspension of carbon injection indicates that zinc and cadmium concentrations in the SK mine pool remain substantially lower than those present prior to in situ treatment and have exhibited only a slow rate of increase over this time;
- 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; and
- Limited data precludes an in depth assessment of the stable isotope data, however, δD and $\delta^{18}O$ data suggest that Galena Creek is the principal source of recharge to the SK mine workings.

4 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 1.3

SILVER KING IN SITU TREATMENT PILOT – 2019 UPDATE

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Memorandum

To: Elsa Reclamation and Development Company Ltd.

From: Andrew Gault, Alexco Environmental Group

CC: Kai Woloshyn, Alexco Environmental Group

Date: February 28, 2020

Re: Silver King *In Situ* Treatment Pilot – 2019 Update

1 Introduction

The pilot scale implementation of *in situ* treatment at the Silver King (SK) mine was initiated in September 2014. Since then, the performance of the pilot treatment system has been documented in numerous memoranda and reports, the most recent of which described the results obtained in 2018 (AEG, 2019). This memorandum provides an overview of the work performed and results collected for the SK *in situ* treatment test between January and December of 2019.

2 2019

2.1 Operations

The primary focus of work in 2019 was delivery of organic carbon to the SK mine workings to maintain treated conditions within the mine and ongoing monitoring of the SK 100 adit discharge. In late February, shortly after the start of carbon injection and associated water recycling, a partial failure of some adit timbers was observed approximately 6 m from the portal entrance, resulting in a rockfall. This was thought to partially block water flow for a few days, although the reduced flow observed from the adit at this time was likely due to the dewatering from the base of the decline rather than a substantive flow blockage at the portal (described in further detail in Section 3). The interpretation of water accumulation behind the rockfall was complicated by the lack of data from monitoring well SK-MW-04 (located at the top of the decline, at the end of the 100 level adit), which was not functional. Re-establishment of this monitoring well to provide future information on water accumulation in the event of further rockfalls is recommended.

There were no changes to the buildings, equipment or infrastructure during this period.

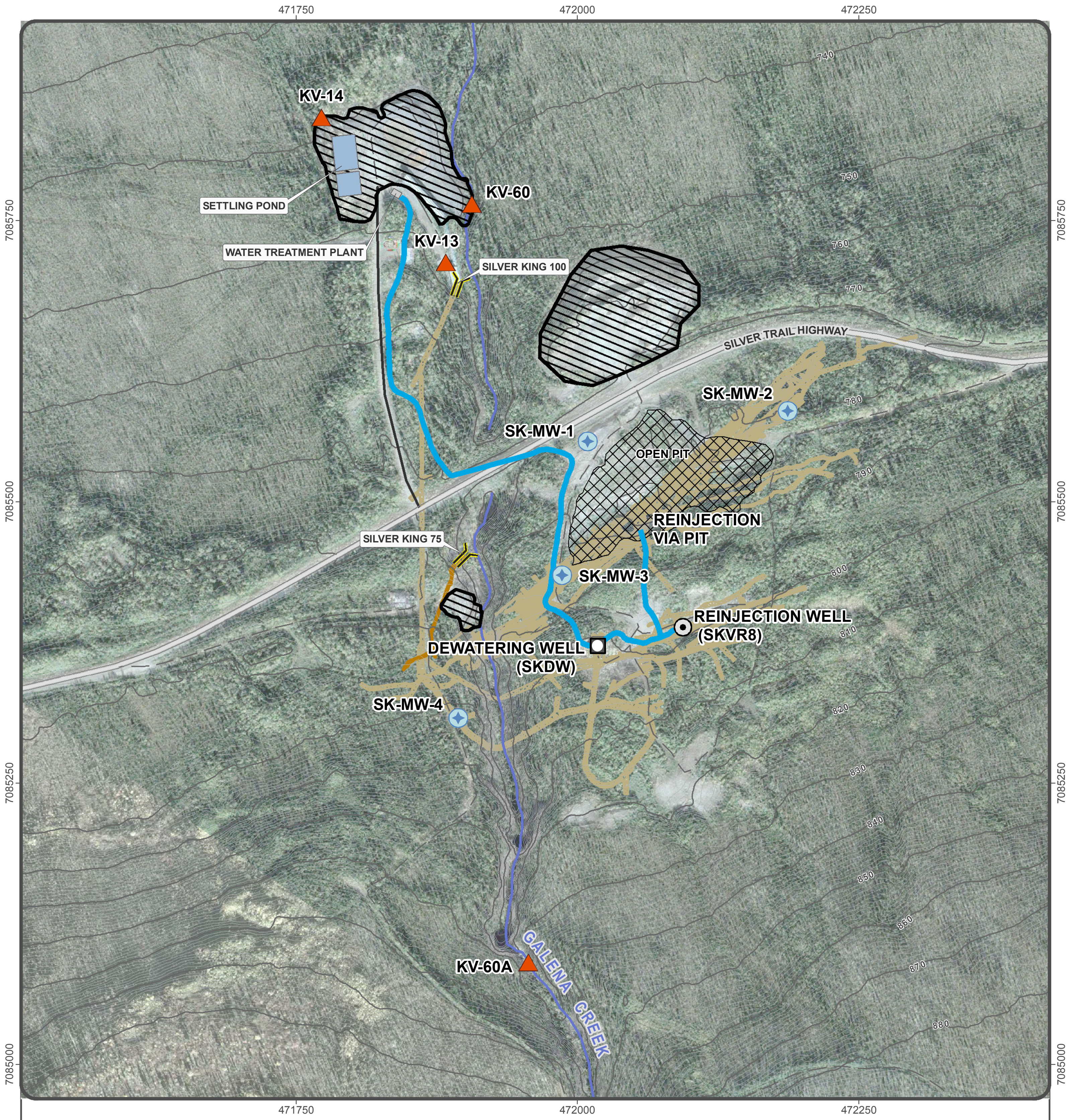
2.2 CARBON INJECTION

In situ treatment involves the injection of organic carbon to flooded subsurface mine workings to stimulate the activity of naturally occurring sulphate-reducing bacteria. Such microorganisms convert sulphate to sulphide, which in turn reacts with chalcophile ("sulphur-loving") elements (e.g., cadmium, zinc, copper, lead, thallium) to form insoluble sulphide minerals that precipitate within the flooded mine workings. The carbon injection events typically last three to six weeks and are achieved by mixing a portion of the pumped mine water with molasses or methanol and re-injecting via a historical borehole (SKVR8) that intersects the Vein 5 workings, or the SK open pit that infiltrates into the Vein 1 mine workings below (Figure 2-1). Such reinjection forms a recirculation loop, helping to mix the organic carbon throughout the mine workings.

Prior to 2019, the last carbon injection event occurred over November/December of 2016. The data were tracked in the intervening years, to evaluate the period of time between reagent additions to safely maintain the treatment system. This information informs both reagent addition and operating controls for long-term (full scale) *in situ* water treatment.

A review of zinc concentrations in the SK 100 adit discharge during the *in situ* treatment pilot shows that concentrations tend to rise during spring freshet (AEG, 2019). This is likely due to surface water recharge of the mine workings via Galena Creek resulting in a shorter hydraulic residence time (HRT) with less time afforded for treatment of the recharge water as it flows through the workings. Since zinc is the only element that requires treatment to meet the site effluent quality standards (EQS), and total zinc levels in the SK 100 adit discharge had approached the EQS (0.5 mg/L) during the 2018 spring freshet, a carbon injection event was scheduled in winter 2019 in anticipation of freshet.

Water was pumped from the SK dewatering well (SKDW; Figure 2-1) at 4 L/s and injected into the SK open pit from which it infiltrated back into the mine workings. The water pumped from SKDW was amended with methanol at an average flow rate of 0.24 L/min. This injection event occurred between February 22 and April 4, 2019.



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.

FIGURE 2-1
PLAN VIEW OF SILVER KING LAYOUT

FEBRUARY 2017

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2.3 WATER QUALITY MONITORING

Water quality monitoring of the SK system via the 100 level adit discharge and wells screened within the mine workings has demonstrated that the treatment has become established as stable and repeatable. That is to say that the target constituents, cadmium and zinc, exhibited markedly decreased concentrations following *in situ* treatment throughout the mine workings, and that such treated concentrations were maintained for prolonged periods (i.e., one year or greater) between maintenance carbon injections. Therefore, water quality monitoring of the wells drilled in the SK mine workings (SK-MW-2, SK-MW-3, and SK-MW-4) was discontinued in 2019. Water quality monitoring continues only for the SK 100 adit discharge (station KV-13).

Water quality was sampled monthly. *In situ* measurement of pH, dissolved oxygen, temperature, and conductivity were made at the time of sampling using a YSI sonde calibrated daily according to the manufacturer's instructions. The samples collected were shipped on ice to ALS (Burnaby, BC) for analysis of:

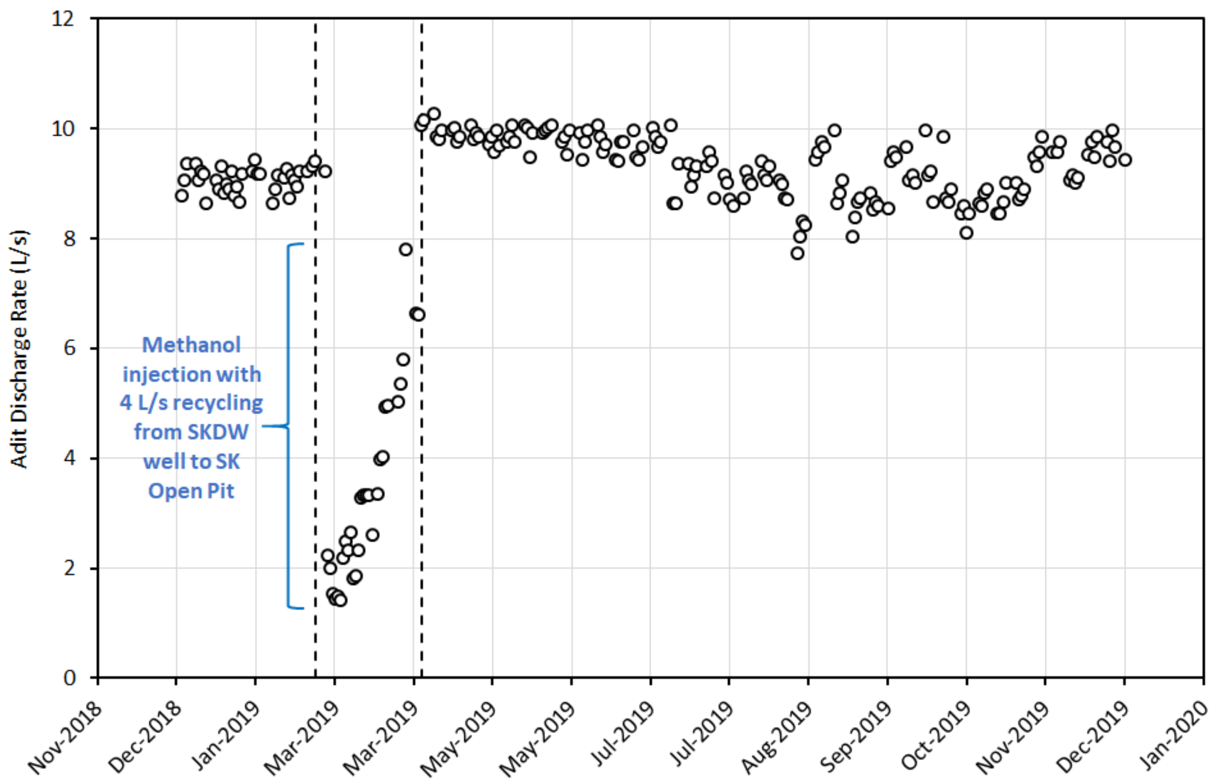
- pH, conductivity;
- Alkalinity, acidity;
- Dissolved organic carbon;
- Sulphide;
- Major anions and ammonia; and
- Total and dissolved metals.

Flow from the SK 100 adit was measured daily by site personnel as part of ongoing care and Maintenance activities.

3 SK100 ADIT FLOW

A marked decrease in flow from the SK 100 adit was observed shortly after the start of dewatering from SKDW at 4 L/s and re-injection to the SK open pit during the carbon injection period (Figure 3-1). The SKDW well is located at the base of the decline in the Vein 5 workings whereas the SK open pit overlies the Vein 1 workings. The limited connectivity and associated slow recharge of water between the two workings likely resulted in the pronounced drop observed in the SK 100 adit flow. Although the SKDW dewatering rate remained constant at 4 L/s, the SK 100 adit discharge increased through the carbon injection period, likely due to a combination of delayed recharge from the Vein 1 workings and overall increased recharge to the SK mine workings during early freshet. The full flow rate from the SK 100 adit was restored upon cessation of water recycling from SKDW to the SK open pit (Figure 3-1).

A rockfall observed close to the portal entrance of the SK 100 adit was initially suspected for the marked decrease in adit flow when carbon injection was initiated with water recirculation. The resumption of flow at a rate consistent with the historical record following the end of water recycling suggests that this rockfall does not impede water discharge from the adit; however, it will continue to be monitored.



Dashed vertical lines bracket the methanol injection period

Figure 3-1: Variation in Silver King 100 Adit Discharge Flow Rate During 2019

4 CHEMISTRY OF SILVER KING ADIT DISCHARGE

Cadmium and zinc are the constituents of concern in receiving waters in the Flat Creek catchment in which the Silver King mine is situated and in the former United Keno Hill Mine site in general (Minnow, 2018). Zinc is also the only element in the SK 100 adit discharge that requires treatment to meet the EQS. The concentrations of total cadmium and zinc in the SK 100 adit discharge during the pilot test are presented in Figure 2-1.

The Silver King mine was dewatered 10 to 15 m below the 100 level adit in the first phase of the *in situ* treatment pilot (September 2014 until December 2016) to provide some control on the HRT within the mine workings. Spikes in the total cadmium and zinc concentrations observed in 2015 and 2016 were due to failures of the dewatering pump, which led to rapid flooding of the mine workings with associated diminished HRT (and so less time for treatment). In addition, such flooding may have dissolved soluble metal salts formed on the unsaturated mine workings surfaces under the previously dewatered conditions. Regardless, water discharged from the Silver King mine, either via the dewatering well (i.e., pre-2017) or via flow from the SK 100 adit has met the zinc EQS consistently since December 2015 (Figure 2-1).

A methanol injection occurred between 18 November and 22 December 2016, after which dewatering of the mine was ended and allowed to flood to its static water level and discharge from the SK 100 adit. Over the subsequent 24 months, treatment of total cadmium and zinc was maintained, including through two spring freshet events (Figure 2-1). The median total cadmium (0.0021 mg/L) and zinc (0.24 mg/L) concentrations observed over this period were 78% and 69% lower than those observed prior to the start of the *in situ* treatment pilot (0.0095 mg/L cadmium and 0.77 mg/L zinc for October 2012 to September 2014 dataset), respectively.

A subsequent methanol injection was performed between late February and early April 2019 to maintain treated conditions within the flooded mine workings. This resulted in a decline in cadmium and zinc levels, which have stabilized since July 2019 at median concentrations equivalent to an 89% and 83% reduction compared to pre-pilot test concentrations.

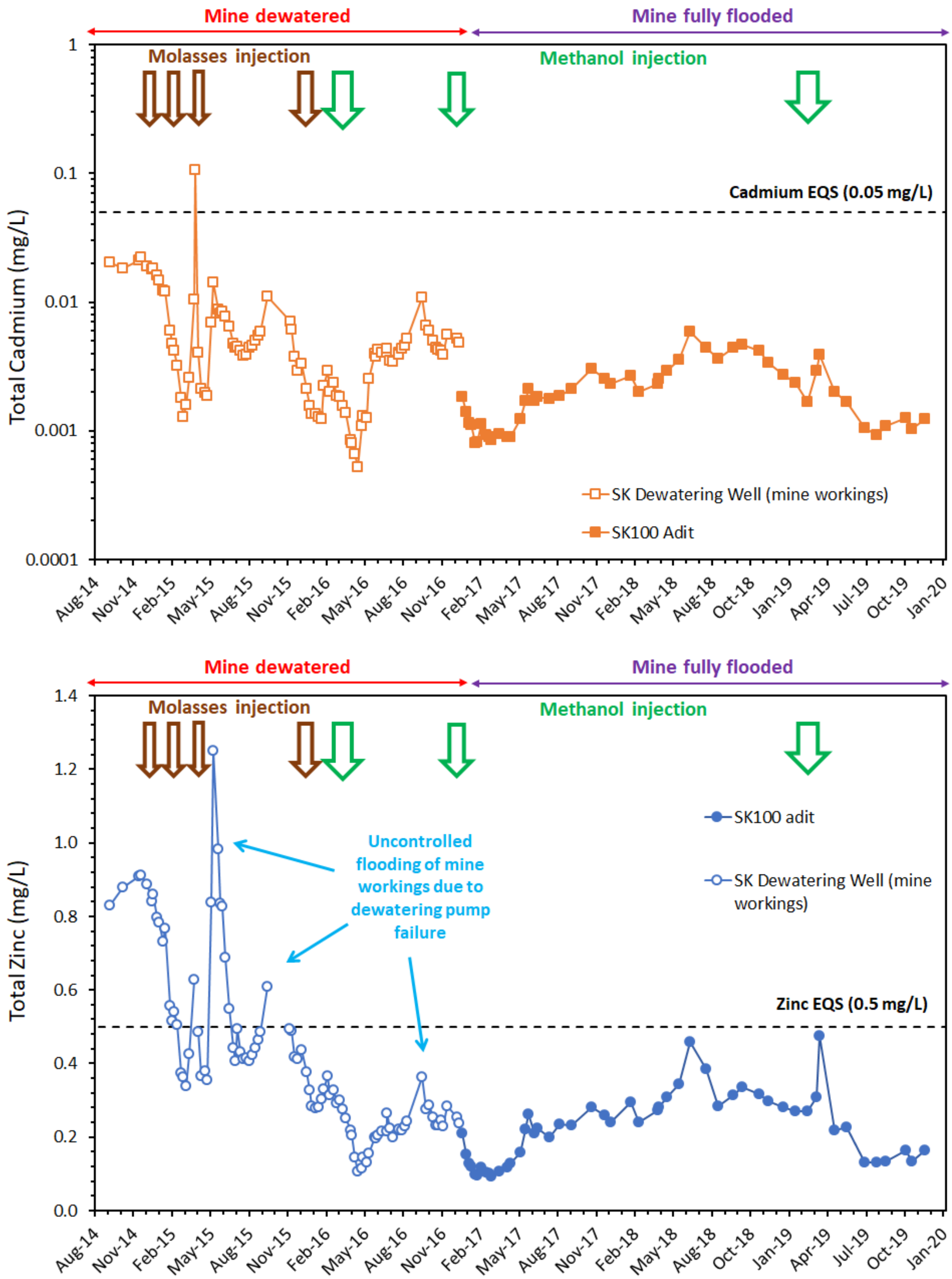


Figure 4-1: Total Cadmium and Zinc Concentrations in Water Discharged from the Silver King Mine During *In Situ* Treatment Pilot Test

5 SUMMARY

- Changes in SK 100 flow observed during the carbon injection were related to water extraction from the Vein 5 workings with limited recharge from the Vein 1 workings into which the water was re-injected. The rockfall observed close to the portal entrance of the SK 100 adit does not seem to materially affect flow, but this will continue to be monitored. Rehabilitation of monitoring well SK-MW-04 is recommended so that water levels can be monitored in the event of further rockfalls in the SK 100 adit.
- The SK *in situ* treatment pilot has demonstrated a stable and repeatable response to carbon injections, that have now transitioned to a tentative biennial schedule for maintenance of treated conditions within the flooded mine workings;
- Ongoing monitoring of the SK pilot has stepped down to monthly sampling of the SK 100 adit discharge, supplemented by regular total zinc measurements of the adit discharge as part of Care and Maintenance treatment activities;
- Treated conditions have been maintained such that the EQS was met for the metals in the SK 100 adit discharge through 2019. Treated metal concentrations are expected to persist into 2020 and the response of the system to freshet conditions will be closely monitored since the snowpack developed at site is such that freshet is anticipated to be significant in 2020;
- The system continues to be considered as pilot scale until total suspended solids and pH excursions over the EQS can be managed via the existing settling ponds at site (AEG, 2017).

6 REFERENCES

Alexco Environmental Group (AEG). 2019. *Silver King In Situ Treatment Pilot, 2018 Operations Update Report*. Report prepared for Elsa Reclamation and Development Company Ltd., March 2019.

Alexco Environmental Group (AEG). 2017. *Silver King In Situ Treatment Test Update – November 2017*. Memorandum prepared for Elsa Reclamation and Development Company Ltd., December 2017.

Minnow Environmental Inc. (2018) *Updated Water Quality Goals for United Keno Hill Complex Watersheds*, Technical memorandum prepared for Elsa Reclamation and Development Company Ltd., November 28, 2018.

APPENDIX 1.4

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.

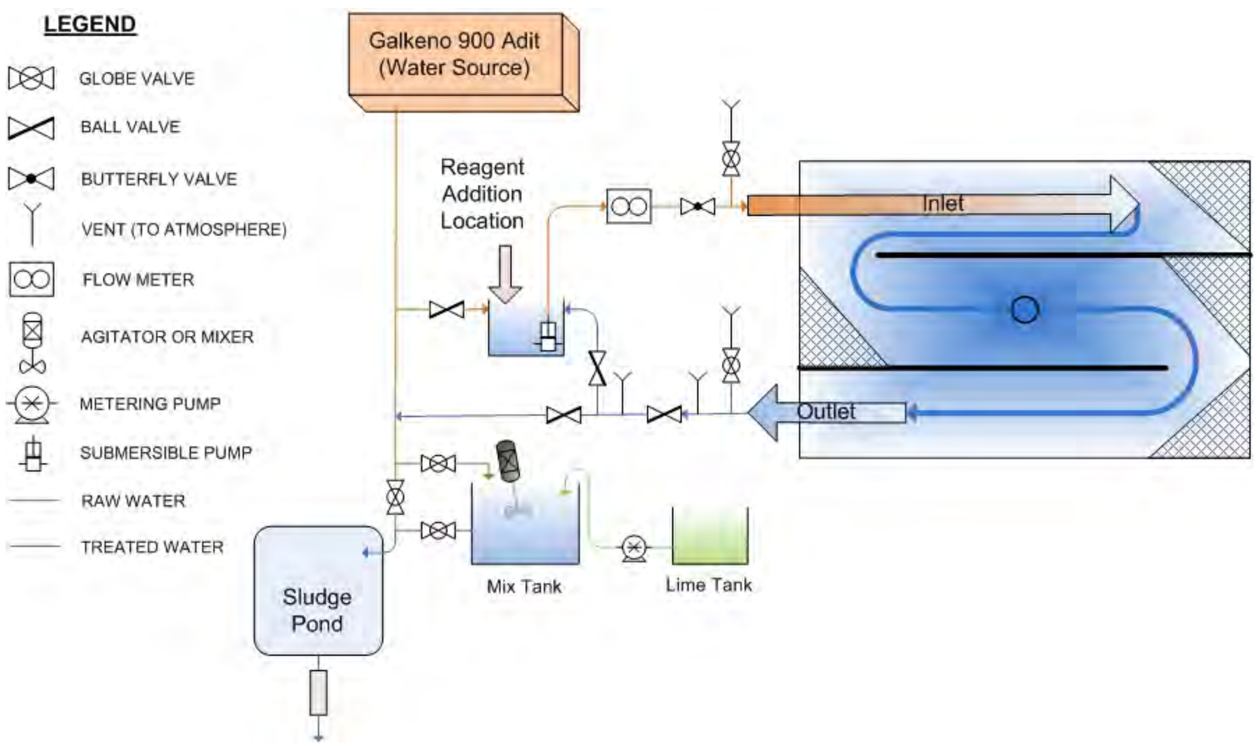

Figure 1 - Galkeno 900 Layout

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.

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.

Figure 4 - Bioreactor Inlet

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

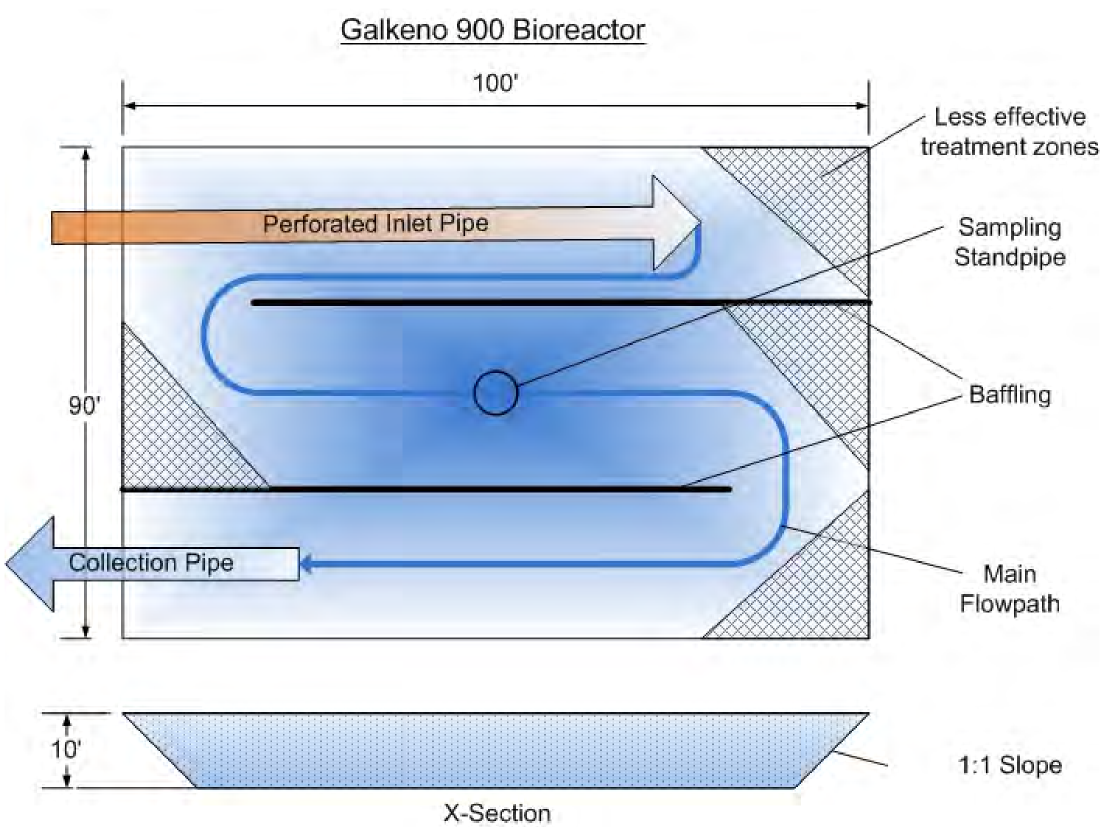

Figure 7 - Bioreactor Layout

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^{0}C to 2^{0}C) as it is in natural environments where the long-term temperature is around 20 ^{0}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.

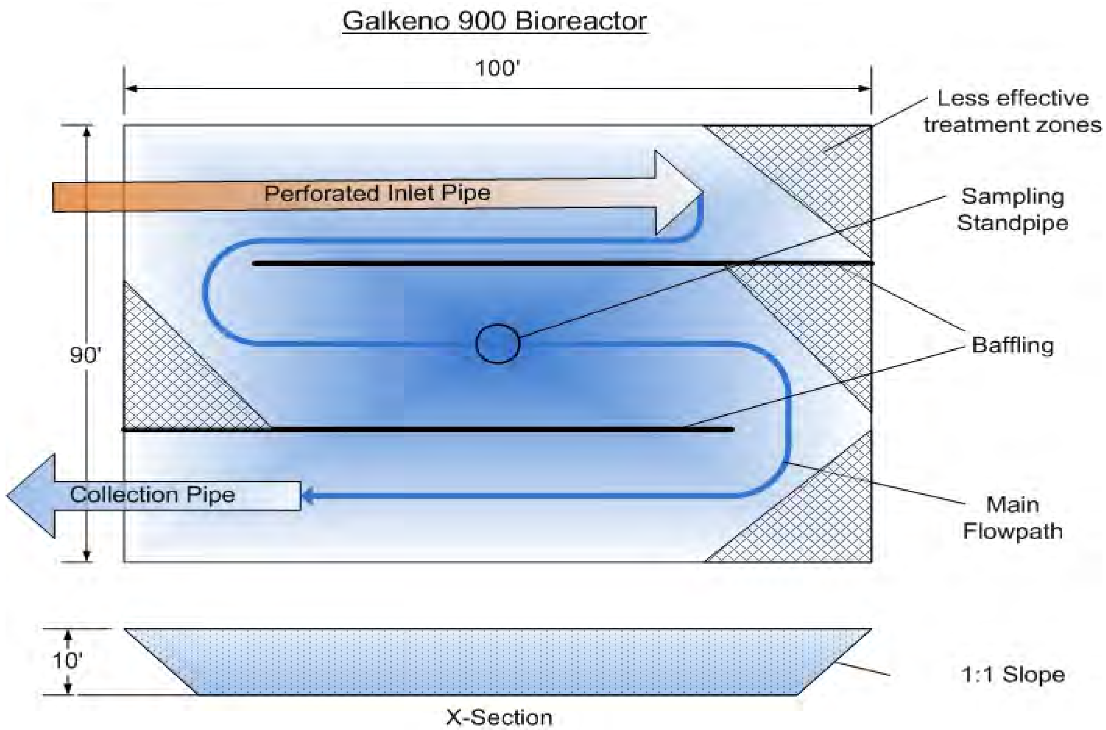

Figure 9 - Conceptualization of Flow Path in the Bioreactor

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.

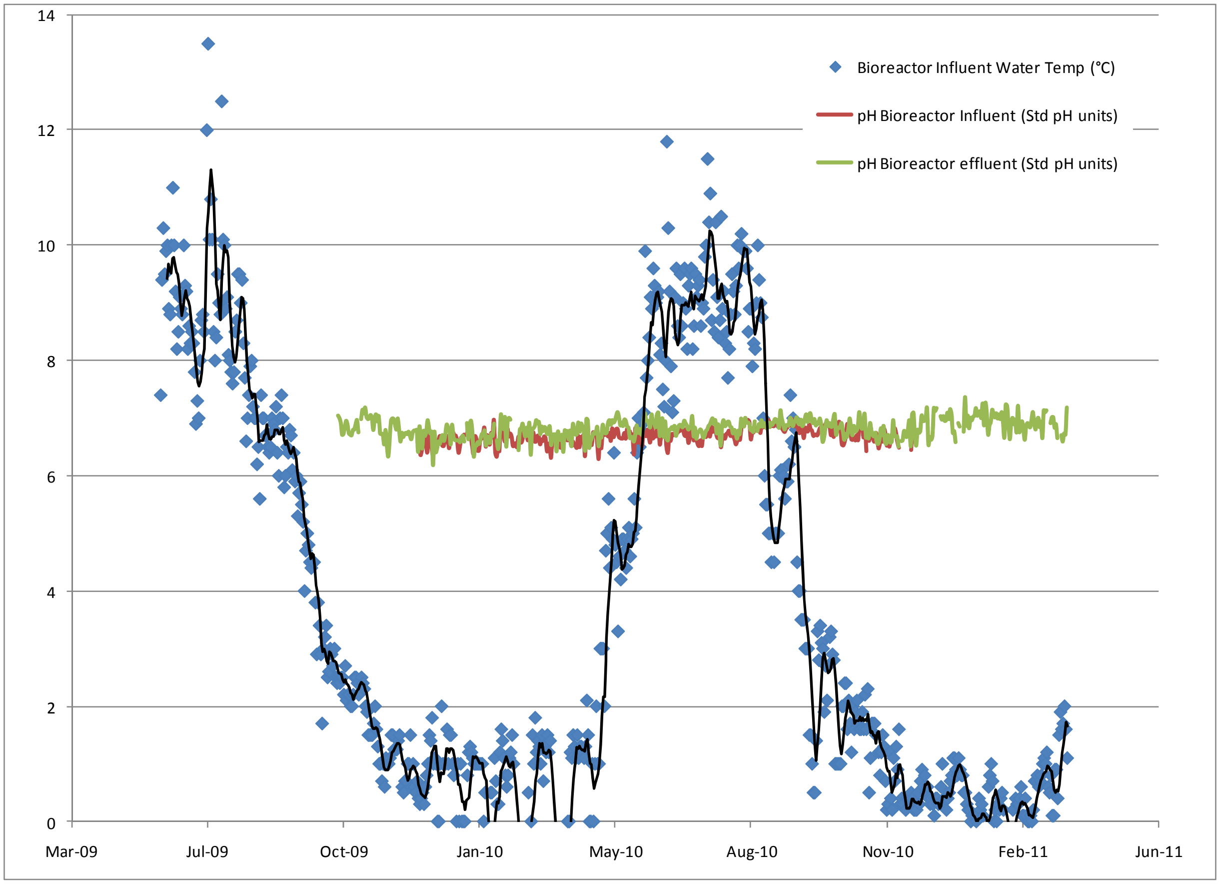

Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp

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%

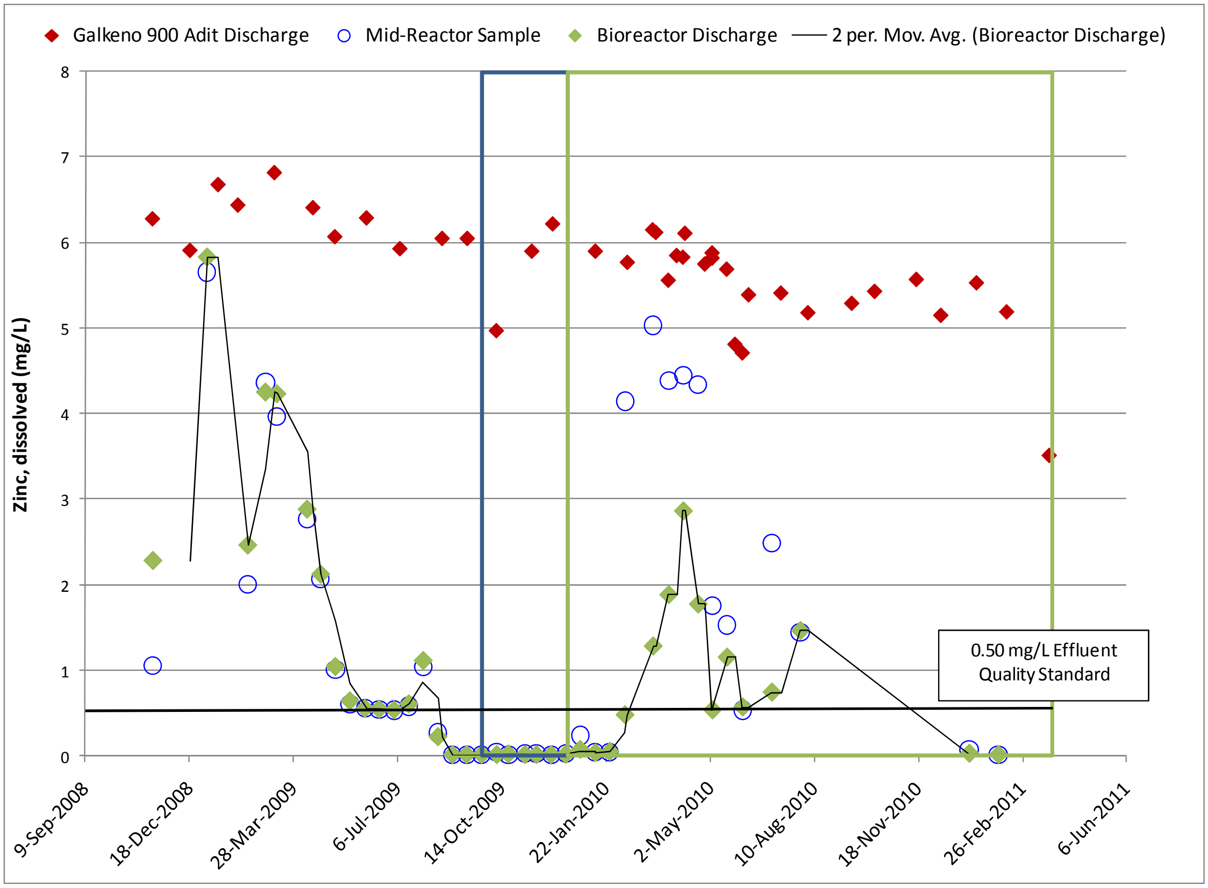

Figure 11 - Zinc removal by the Galkeno 900 Bioreactor

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.

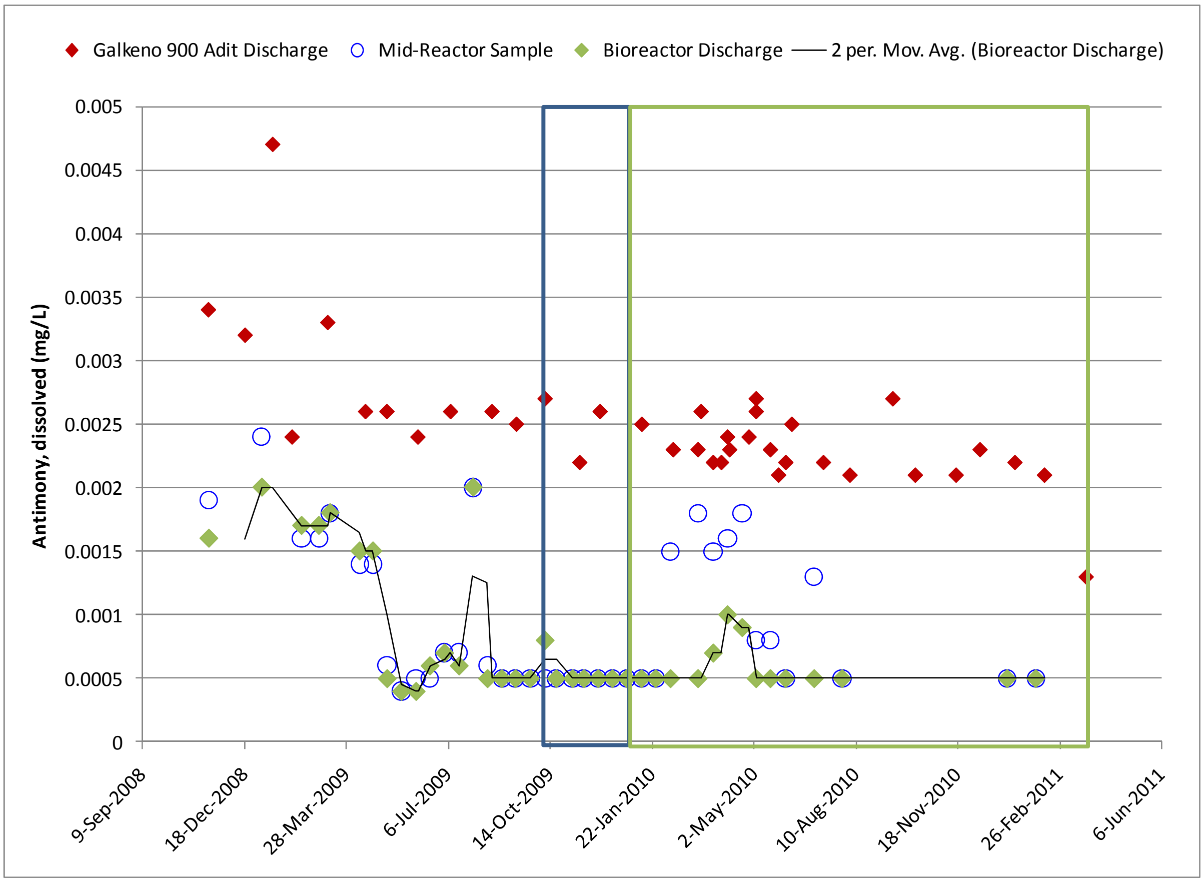

Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor

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.

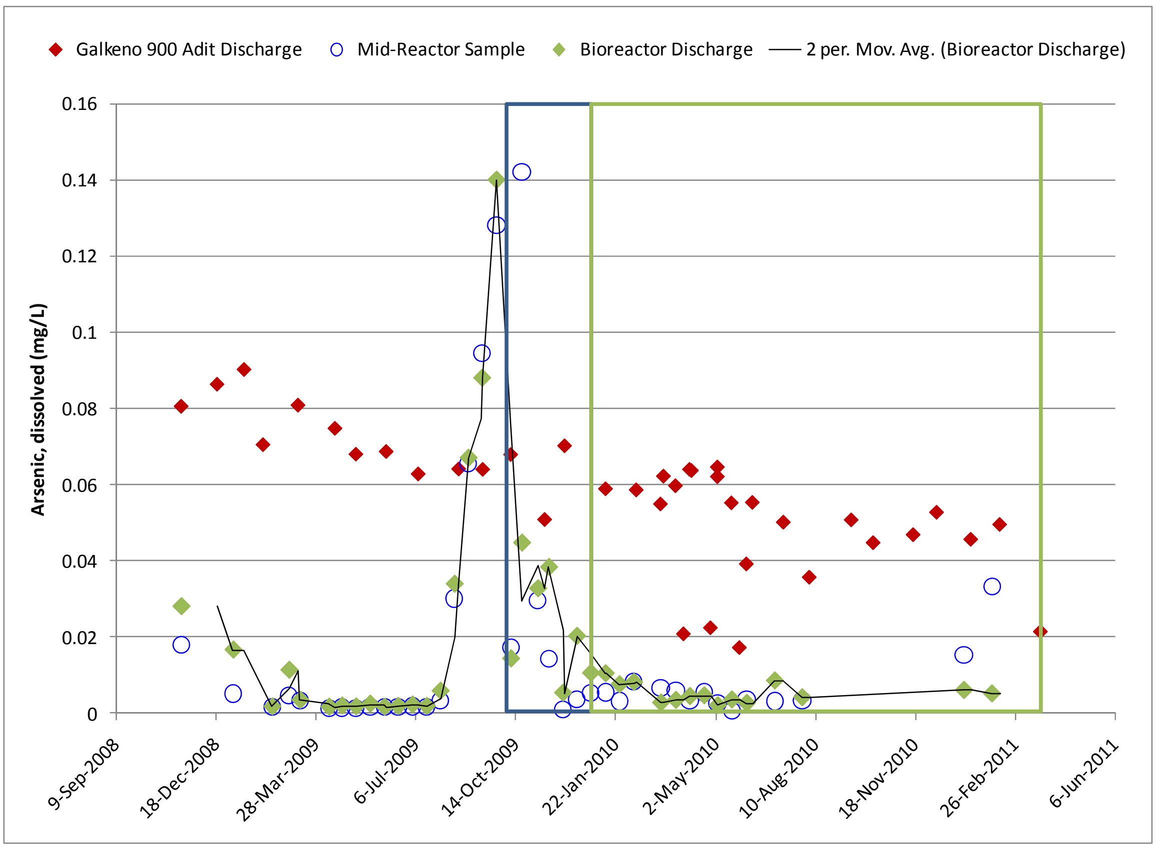

Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor

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.

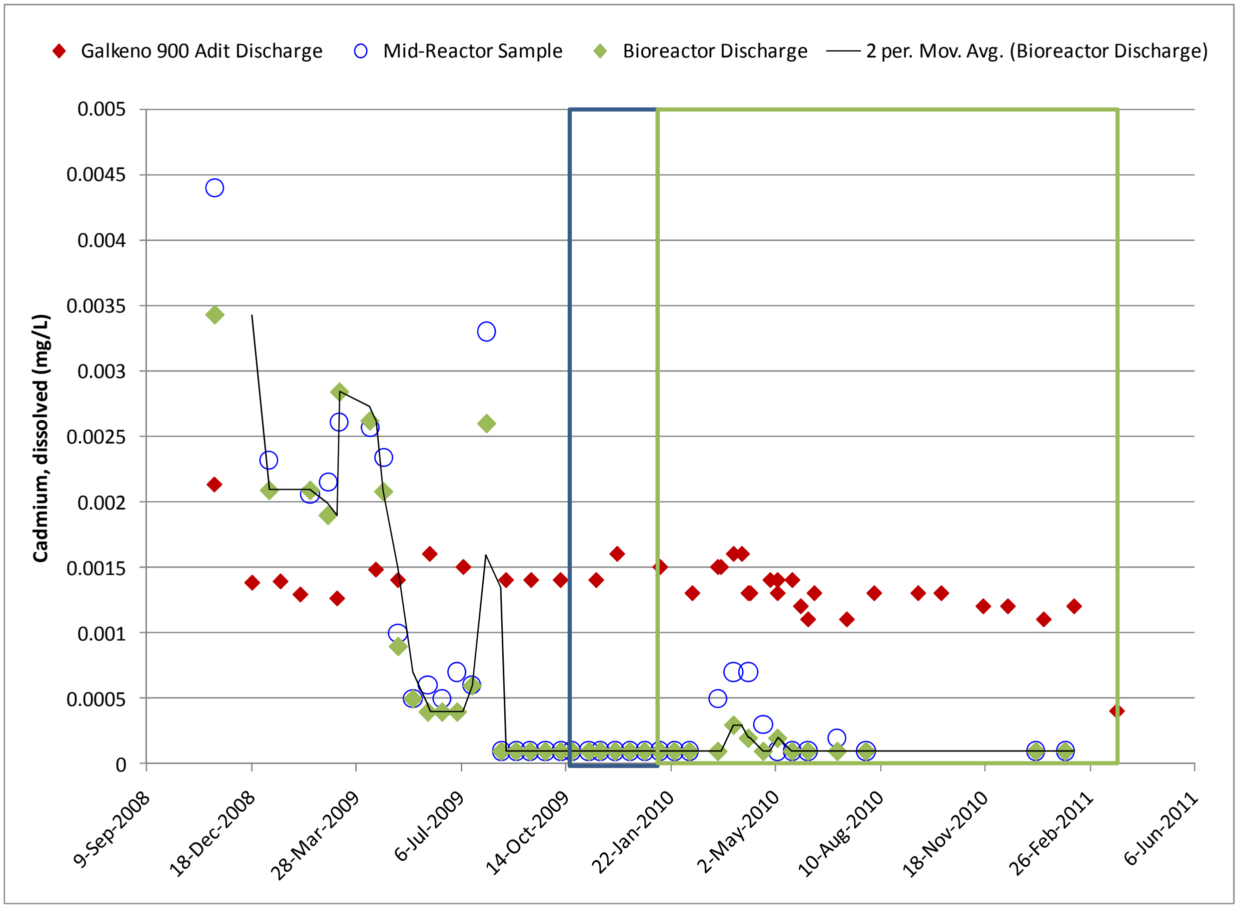

Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor

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.

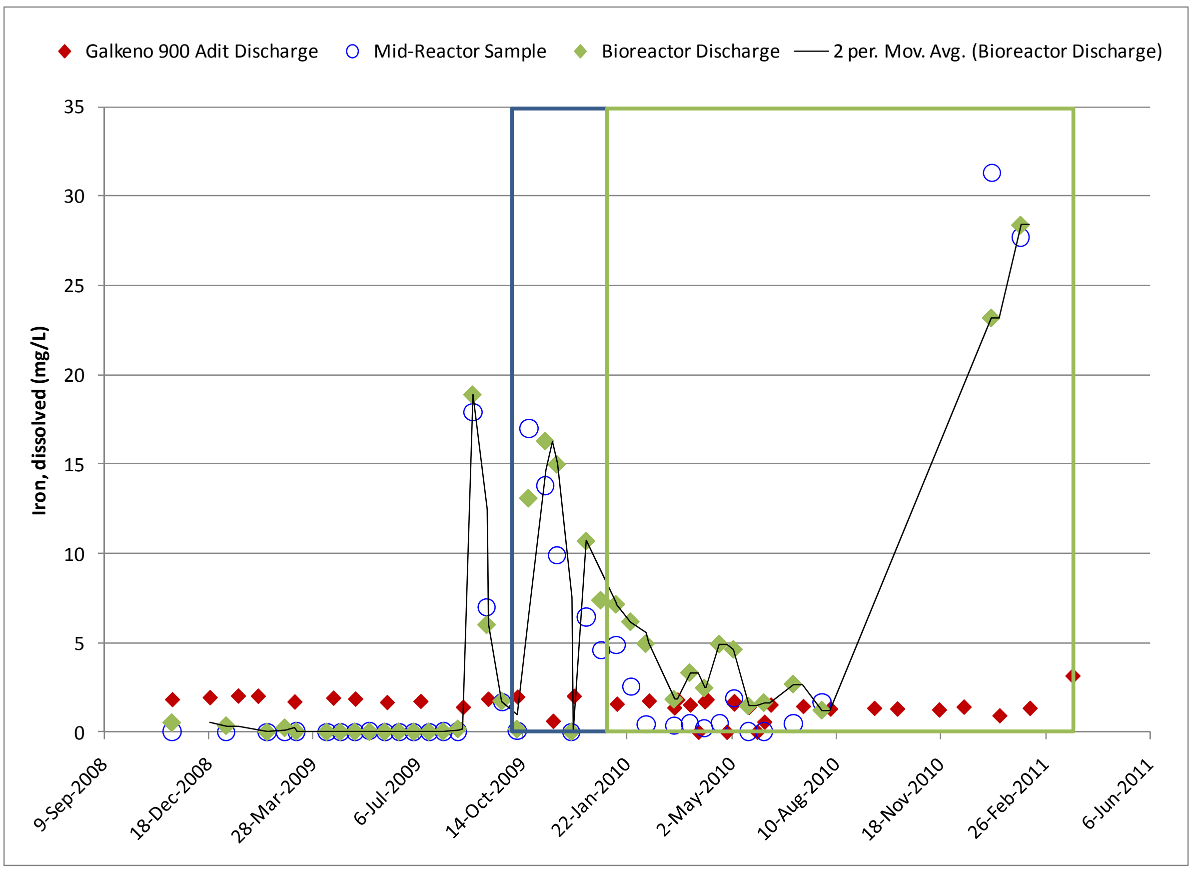

Figure 15 - Iron Removal by the Galkeno 900 Bioreactor

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.

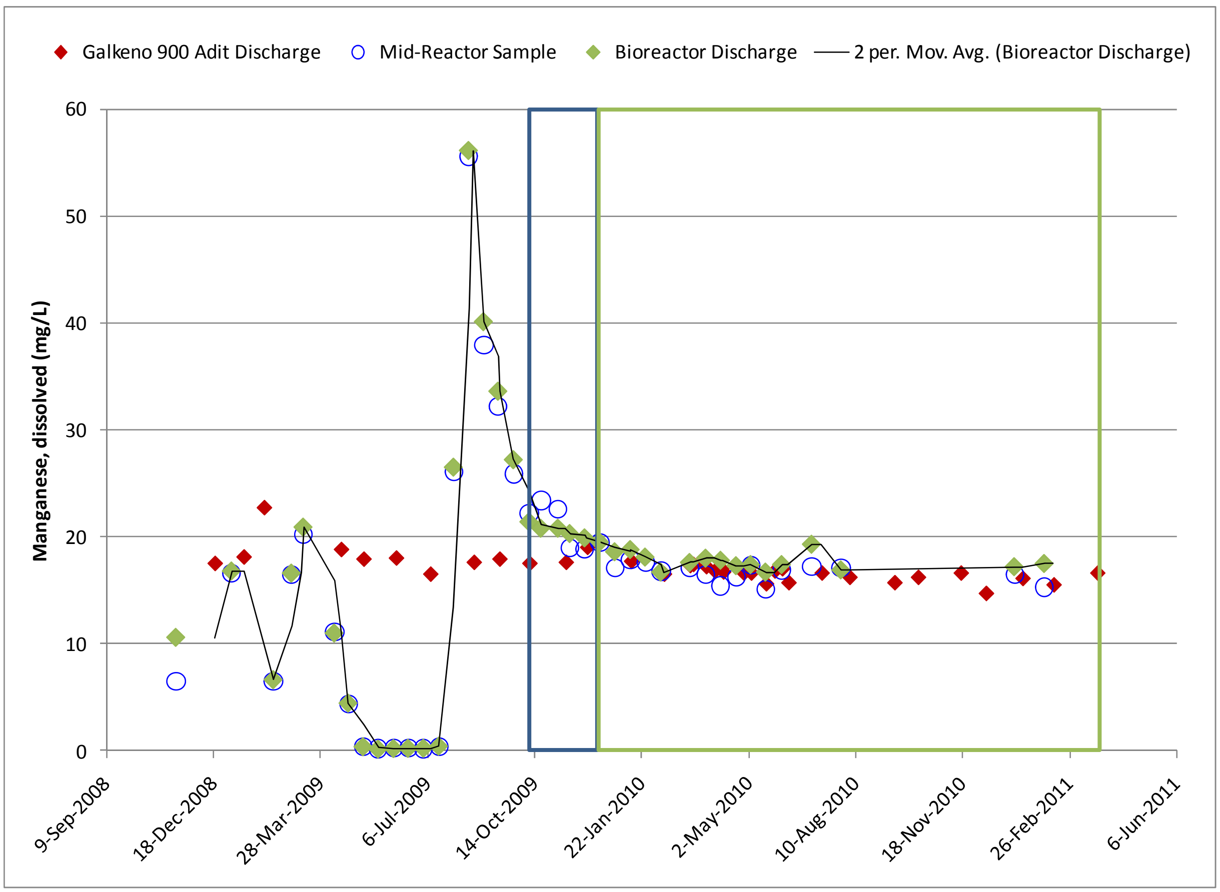

Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor

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.

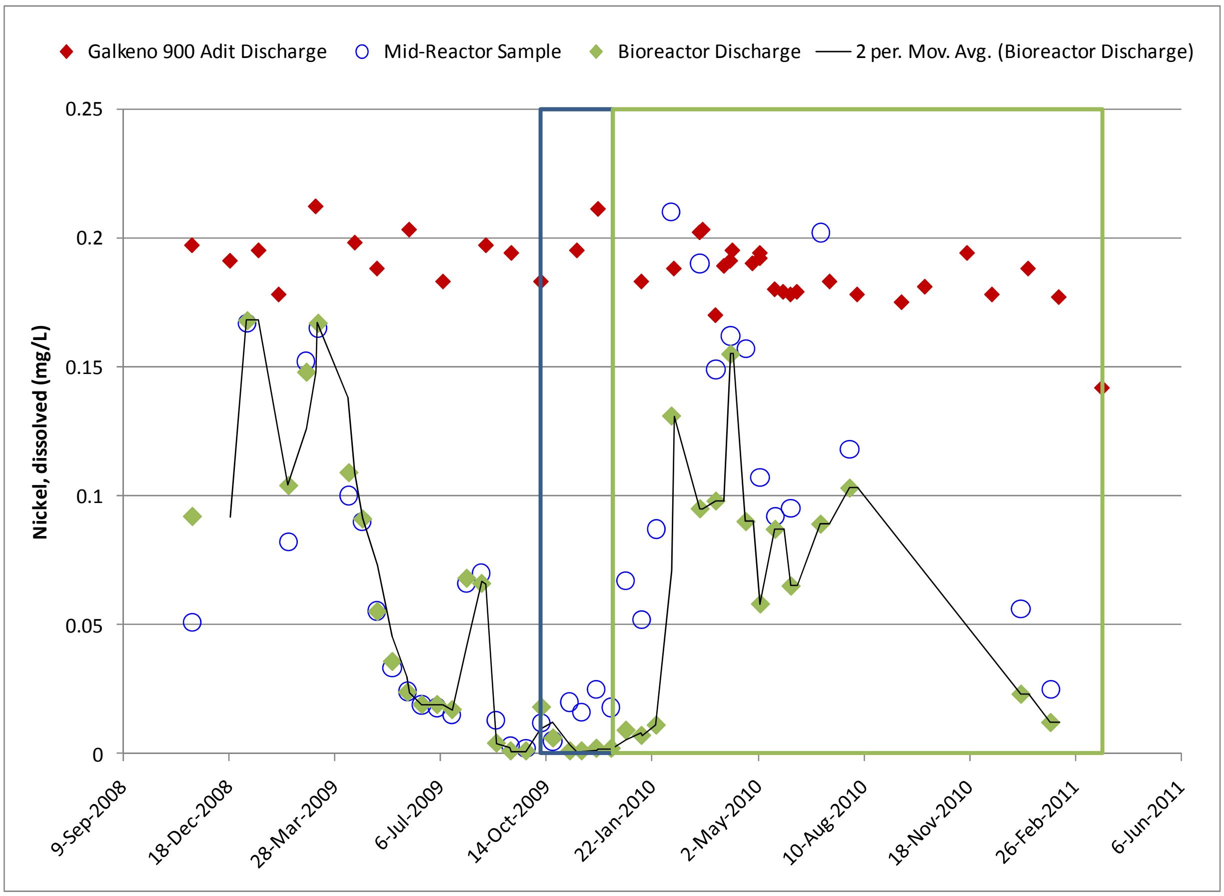

Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor

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.

9 REFERENCES

Alexco Resource US Corp. (2009). *Galkeno 900 Sulphate-Reducing Bioreactor Interim Report 2009 Closure Studies.*

Buccambuso, E., Figueroa, L., Ranville, J., Wildeman, T., & Reisman, D. (2007). *Microbioal Activity in the Peerless Jenny King Sulfate Reducing Bioreactor System.* Lexington: ASMR.

Church, C. D., Wilkin, R. T., Alpers, C. N., Rye, R. O., & McClenskey, R. B. (2007). Microbial sulfate reduction and metal attenuation in pH 4 acid mine water. *Geochemical Transactions* , 8:10-25.

Dar, S. A., Stams, A. J., Kuenen, J. G., & Muyzer, G. (2007). Co-existence of physiologically similar sulfate-reducing bacteria in a full-scale sulfidogenic bioreactor fed with a single organic electron donor. *Appl Microbiol Biotechnol* , 75:1463-1472.

Doshi, S. M. (2006). *Bioremediation of Acid Mine Drainage Using Sulfate-Reducing Bacteria.* Bloomington: University of Indiana.

Gammons, H. C., & Frandsen, A. K. (2001). Fate and transport of metals in H2S-rich waters at a treatment wetland. *Geochem. Trans.* , 1:1-15.

Gusek, J. J. (2002). *Sulfate-Reducing Bioreactor Design and Operating Issues: Is this the Passive Treatment Technology for Your Mine Drainage?* https://fs.ogm.utah.gov/PUB/MINES/AMR_Related/NAAMLP/AMD3/Gusek.pdf.

Gusek, J., Rutkowski, T., Blumenstein, E., & Shipley, B. (2008). *Two-Year Sulfate Reducing Bioreactor Pilot Test Results at the Golinsky Mine, California.* Lexington: ASMR.

Ionic Water Technologies, Inc. (n.d.). *Bioreactor Systems: Semi-Passive Bioreactor Design.* Retrieved from Ionic Water Technologies: http://www.iwtechnologies.com/pdfs/Bioreactor_Design.pdf

Jong, T., & Parry, D. L. (2004). Heavy metal speciation in solid-phase materials from a bacterial sulfate reducing bioreactor using sequential extraction procedure combined with acid volatile sulfide analysis. *J. Environ. Monit.* , 6:278-285.

Miller, G. C. (2005). *Reduction of Sulfate Concentrations in Neutral Mine Effluent.* Reno: Department of Natural Resources and Environmental Science, Univeristy of Nevada.

United States Environmental Protection Agency (EPA). (2006). *SITE Technology Capsule: Compost-Free Bioreactor Treatment of Acid Rock Drainage.* http://www.epa.gov/nrmrl/lrpcd/site/reports/540r06009/540r06009a.pdf.

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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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)

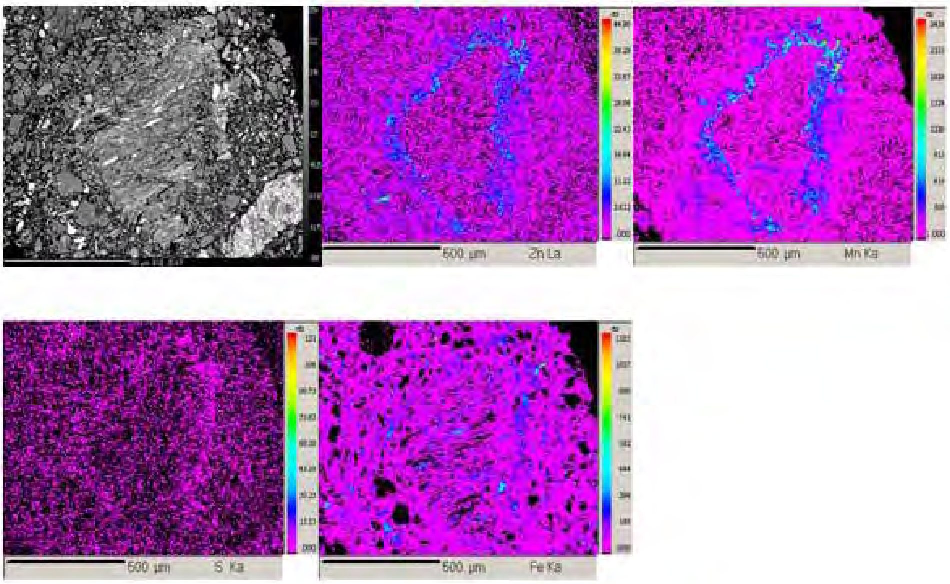

Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain

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).

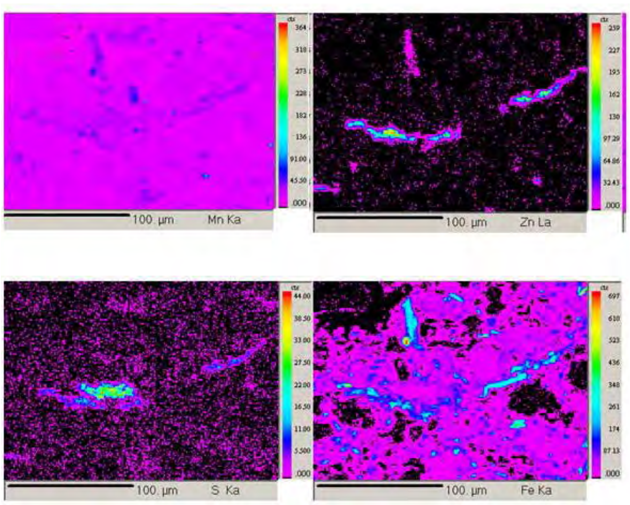

Figure 2: 1B G900 BIO BSE images and element maps

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).

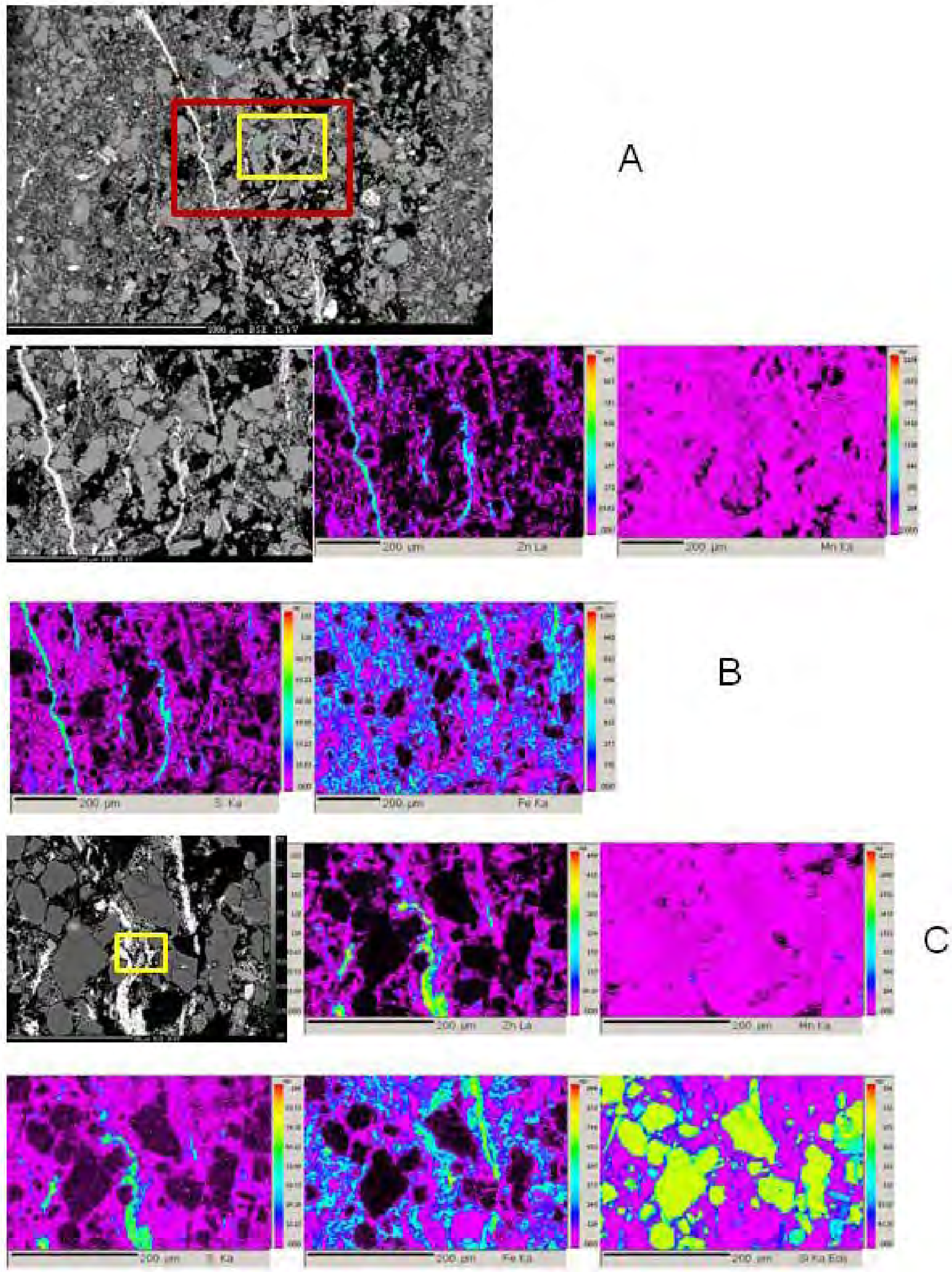

Figure 3 GK900 Bioreactor sample. (A) BSE image showing extensive bright bands of ZnS and Fe(B) BSE image and element scans of area in red box in (A) (C) BSE image and element scans of area yellow box in (A)

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.

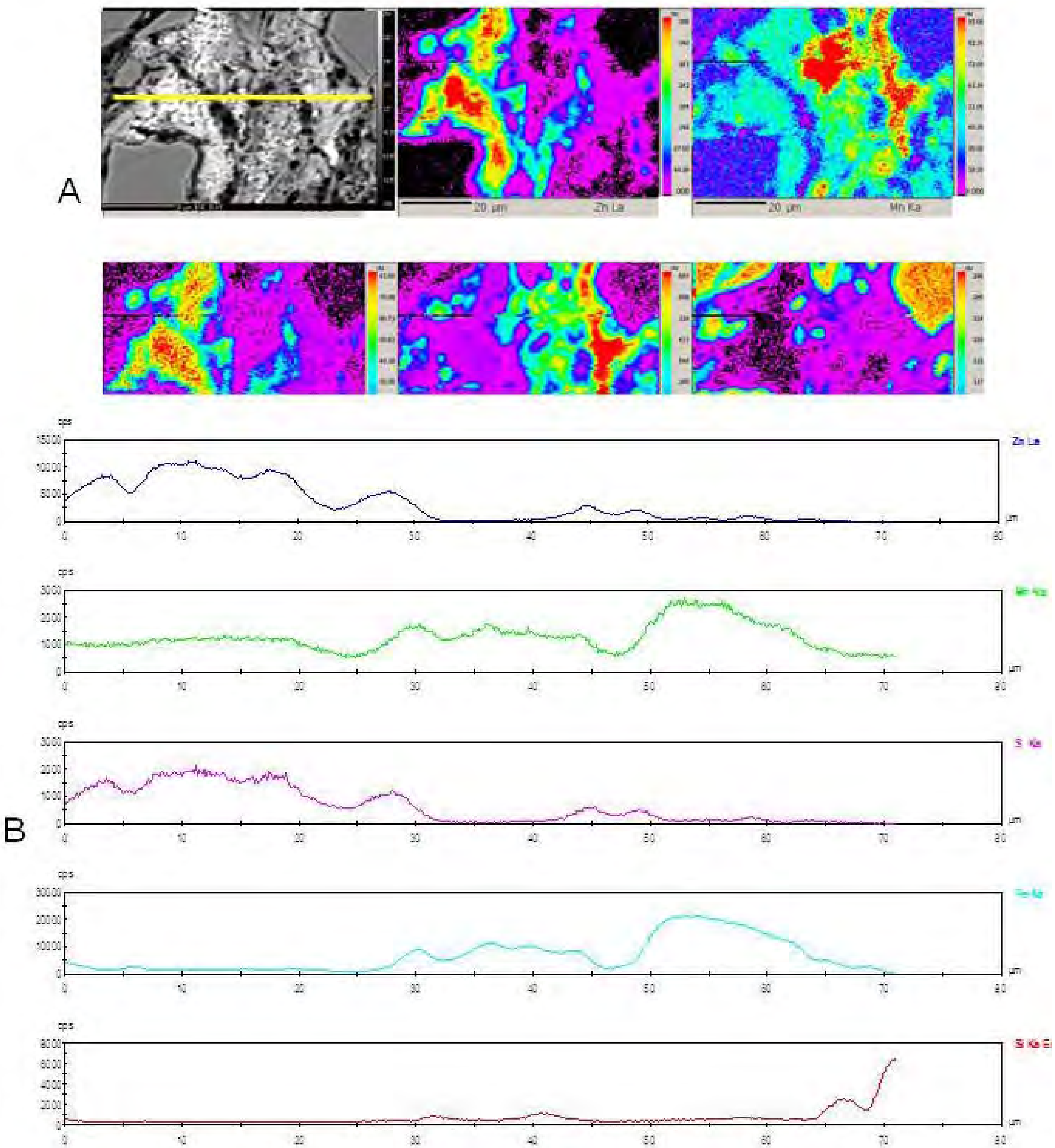

Figure 4: GK900. BSE image and element scans of area in yellow box in Figure 3 Element scans along the yellow line in BSE image (A)

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).

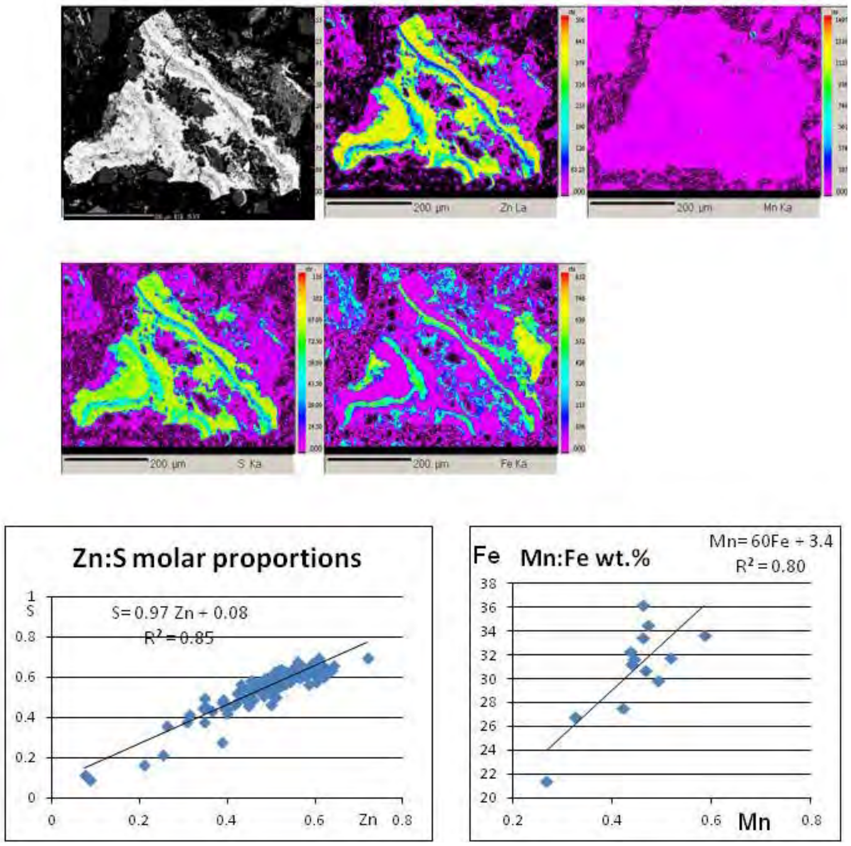

Figure 5: BioR sediment: BSE image and element maps showing the relation ship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.

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

Alexco Resource US Corp (2011) Galkeno 900 Sulphate reducing Bioreactor 2008-2011 Operations Final Report.

Sherriff, B.L. (2011a) Interim Report on optical and electron microprobe analysis of Keno Hills samples set 3

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

APPENDIX 1.5

PRELIMINARY ASSESSMENT OF PERFORMANCE FOR WRSA CLOSURE COVER SYSTEMS

March 30, 2015

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Alexco Environmental Group
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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.

Project Context, Objectives, and Work Scope:

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.

<u>Conceptual Model of Cover System Performance:</u>

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.

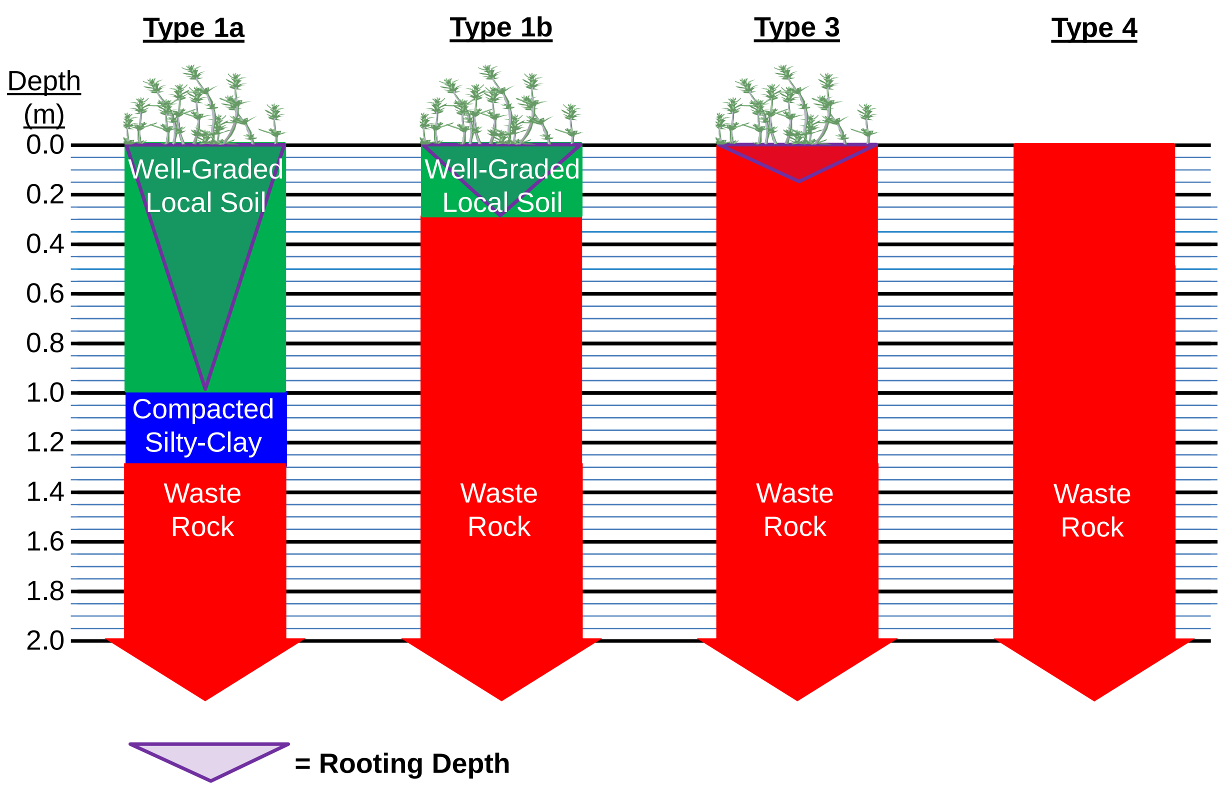


Figure 1 Schematic of four reclamation scenarios modelled for possible closure of WRSAs.

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.

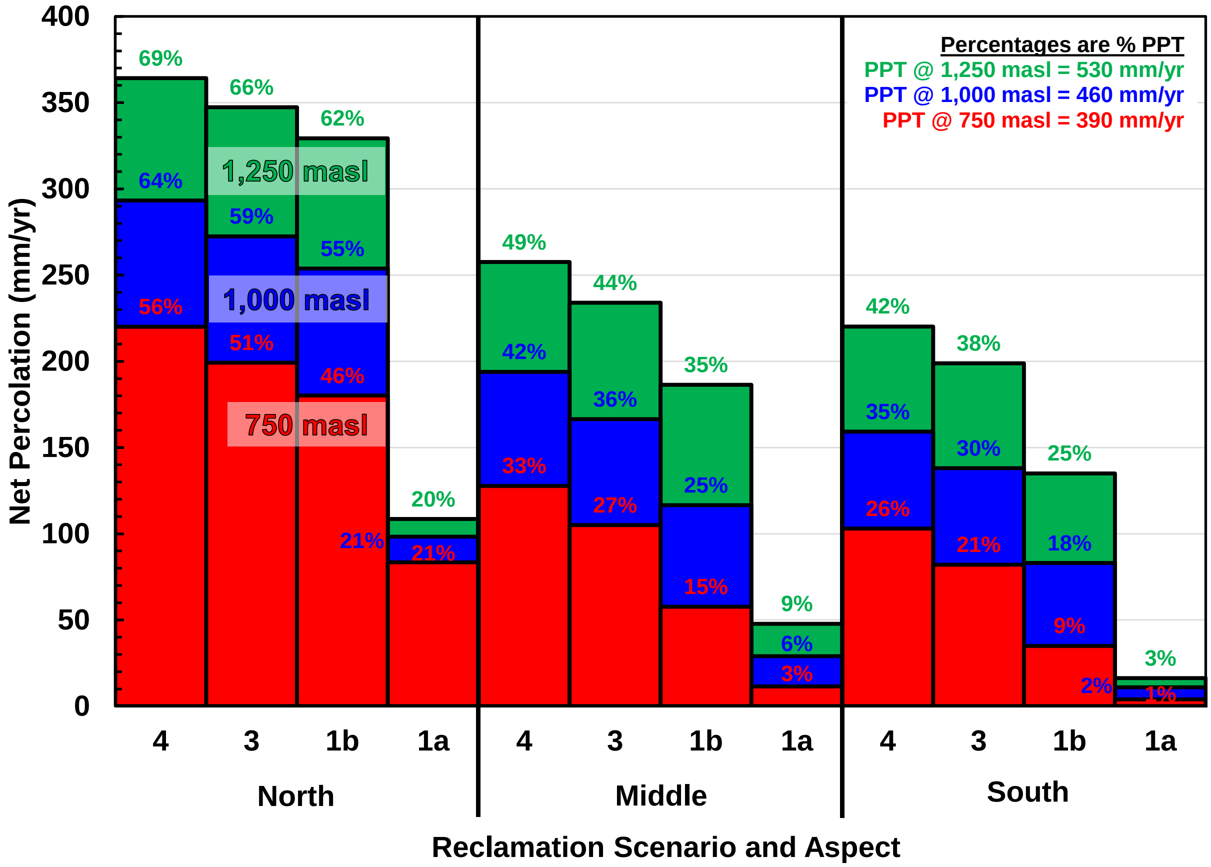


Figure 2 Annual average net percolation rates estimated for range of reclamation scenarios, elevations, and slope aspects.

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.

<u>Closure:</u>

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.

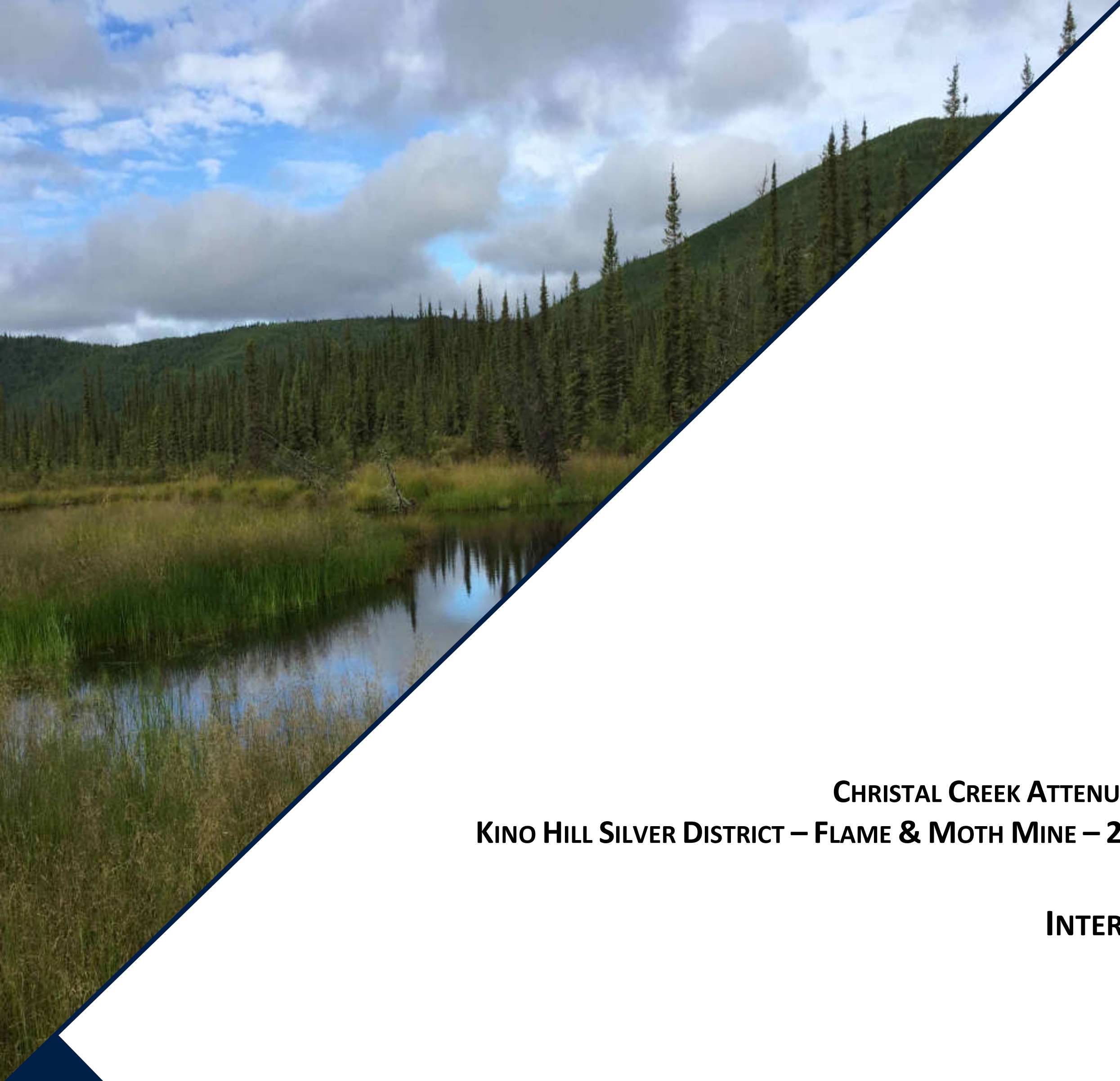
Sincerely yours,

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 1.6

LIGHTNING CREEK ATTENUATION STUDY INTERIM REPORT



Christal Creek Attenuation Study
Kino Hill Silver District – Flame & Moth Mine – 2020 Update

Interim Report

Prepared for:

Alexco Keno Hill Mining Corp.

Date:

March, 2021

ENSERO SOLUTIONS CANADA LTD. SIGNATURES

Report prepared by:	Cheibany Elemine Ould, Ph.D., P.Geo Senior Geochemist	3/31/2021
Report reviewed by:	Andrew Gault, Ph.D Practice Lead Geochemistry	3/31/2021
Report reviewed by:	Kai Woloshyn, B.Sc. P.Chem Vice President Strategic Projects	3/31/2021

EXECUTIVE SUMMARY

Under Water Licence QZ18-044, the water treatment plant (WTP) at the Flame & Moth mine is permitted to discharge to Lighting Creek and Christal Creek. A requirement of the Water Licence was the development of an attenuation plan study in order to demonstrate the potential sequestration of constituents of potential interest (e.g., arsenic, cadmium, nickel, and zinc) between the WTP discharge and Christal Creek, which was assumed as part of the water quality modelling for the Project. Although the WTP has yet to discharge to Christal Creek, this report presents the initial site characterization results along the expected flow path between the WTP discharge and Christal Creek.

Fifteen surficial soil and six moss samples were collected from three transects along the proposed discharge corridor between the Flame & Moth discharge diffuser and Christal Creek edge to assess the potential for natural attenuation mechanisms related to soil conditions along the flow path and current metal content of vegetation. The soil testing program included the determination of physical, chemical and microbiological characteristics of the soil samples and the moss testing consisted of elemental metal analysis.

The soil samples consisted mostly of silt loam (11 samples), silt (two samples), sandy loam (one sample) and loam (one sample) with clay comprising the remainder (average 11% to 15% for the three transects). The high silt and clay content are predicted to result in large surface areas favourable for the retention of metals through adsorption or cation exchange processes with the discharged water.

The soil pHs were neutral (pH 6.0-6.7) reflecting an environment where the solubility of several metal(loid)s, especially iron and aluminum, is at their lowest resulting in the precipitation of metal oxyhydroxides which may co-precipitate or adsorb trace metal(loid)s from the discharge water. Also, under these buffered soil pH values, soil particles (e.g., clay fractions) with a pH-dependent surface charge will likely have a net negatively charged surface favourable for the adsorption of metal cations.

The study site soils had a median moisture content of 52% indicative of a moderate water holding capacity favourable for the development of vegetation cover, peaty and organic-rich surficial material along the discharge channel. The median total organic carbon of the soil samples ranged from 8.6% to13%, which translates to a median soil organic matter content ranging from 14.7% to 22.4%. The soil contained a substantial amount of organic matter that will likely create conditions favourable for metal sorption, immobilization and attenuation.

Sequential extraction analyses indicated that several constituents of potential interest (COPI) were predominantly associated with the residual and reducible phases along transect-1, and with the organic matter and/or sulphide, reducible, and residual phases along transect-2. Along transect-3, the COPI were associated with organic matter and/or sulphide phases and the remaining to either the residual or reducible phases. There was a preferential fractionation of COPI into organic matter and/or sulphide phase in the sample from transect-3 likely due to the elevated organic matter content (25%). The exchangeable and carbonate fractions of the sequential extraction contained the lowest proportions of COPI, except cadmium which was predominantly found in the exchangeable fraction. The carbonate fraction also accounted for up to 11% of cadmium and lead, 14% of manganese and up to 17% of zinc mostly along transect-3.

Large concentrations of COPI are expected to be strongly tied to the mineral lattice and predicted to be stable in the soil matrix significantly decreasing their solubility and potential bioavailability. Significant fractions of COPI could be remobilized should the environment become iron-reducing (fraction bound to reducible phase). However, the predicted reducing environmental conditions caused by the marshy and high organic matter content will favor the uptake, fixation or precipitation of metal(loid)s by sulphides favored under progressively reducing conditions.

These soil data indicate that soil and landcover conditions along the proposed discharge corridor are favorable for natural attenuation of metal(loid)s in the treatment discharge.

The moss samples had different metal contents depending on their location along the expected discharge channel. Vegetation material with highest arsenic, antimony, cadmium, iron, manganese, copper, nickel, lead and zinc concentrations were those collected from transect-1 and the samples from transect-3 had the lowest concentrations. Surface water quality monitoring data show constantly or occasionally elevated concentrations of sulphate, arsenic, cadmium, copper, iron, lead, manganese, and zinc above their respective guidelines at stations along Christal Creek. The water quality data from the groundwater seep KV-121 suggests possible contribution of constituents from the seep to Christal Creek.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	Absolute Value
ACG	Access Consulting Group
AEG	Alexco Environmental Group Inc.
AKHM	Alexco Keno Hill Mining Corp.
B.C	British Columbia
BC ENV	British Columbia Ministry of Environment and Climate Change Strategy
CCME	Canadian Council of Ministers of the Environment
COPI	Constituents of Potential Interest
CRM	Certified Reference Material
DL	Detection Limit
EC	Environment Canada
IRM	Internal Reference Material
KHSD	Keno Hill Silver District
LCS	Laboratory Control Sample
MV	Measured Value
QAQC	Quality Assessment and Quality Control
qPCR	quantitative Polymerase Chain Reaction
RP	Recovery Percentage
RPD	Relative Percent Difference
TC	Total Carbon
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TSE	Tessier Sequential Extraction
OTU	Operational Taxonomic Units
WQ	Water Quality
WTP	Water Treatment Plant
WRB	Water Research Branch
YG	Yukon Government

1 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES OF THE STUDY

Under the Water Licence QZ18-044 the water treatment plant (WTP) at the Flame & Moth mine is permitted to discharge to Lighting Creek and Christal Creek with a few conditions to be satisfied. These conditions include the completion and submission of the findings of a Christal Creek Attenuation Study to confirm the assumption made in the modeling study of the impact of the WTP discharge water quality on the Christal Creek environment (AEG, 2016), and satisfy the requirements of the Water Licence.

Past investigations on natural attenuation mechanisms in the Keno Hill Silver District (KHSD) have documented significant metal(loid) attenuation along mine discharge flow paths (e.g., ITL, 2013). The water quality modeling performed to support the Flame & Moth Project assumed a natural attenuation rate of 50% for selected constituents (arsenic, cadmium, nickel, and zinc) between the WTP discharge diffuser location and the Christal Creek receiving environment (AEG, 2016).

Like elsewhere in the district, it is predicted that the concentration of some metal(loid)s and constituents in the WTP discharge are likely to decrease due to biogeochemical processes and interaction with soil and vegetation cover or mixing with groundwater and surface water along the flow path from the WTP discharge diffuser location to Christal Creek. The geochemically driven changes may include the removal of metals and constituents through direct precipitation, co-precipitation with other major metals (e.g., iron, aluminum), and adsorption on mineral and organic surfaces.

Although the Flame & Moth WTP has not discharged to Christal Creek to date, this third interim report describes the physio-chemical and microbiological characteristics of the expected flow path between the WTP diffuser location and Christal Creek, over which metal(loid) attenuation is assumed to occur, in accordance with the Christal Creek Attenuation Study Plan (AEG, 2018a). This report is an update to the 2020 attenuation report and includes vegetation (i.e., moss) metal data and additional water quality data from surface and groundwater monitoring stations.

1.2 SCOPE

The scope of the study includes:

- Characterization of the site prior to operation by collecting baseline data for parameters that influence or impact the flow of the discharge water and changes its chemistry from the WTP diffuser location to the Christal Creek receiving environment. These baseline data include:
    - Identification of physical and landcover (i.e., vegetation) characteristics of the site;
    - Determination of the type, composition, geochemical and microbiological characteristics of soil along proposed flow path;
    - Determination of baseline metal content of moss along the expected flow path;
    - 12-year baseline surface water records at the following monitoring stations: KV-6, KV-49, KV-50 and KV-51 and two years of water quality at station KV-117; and
    - Collection of baseline water quality data at groundwater seep KV-121.
- Analysis and interpretation of data, and the assessment of attenuation mechanism(s) to confirm the assumptions made in earlier studies.

Once discharge from the WTP to Christal Creek is initiated, the study will also document any physical and geochemical changes that occur along the discharge flow path between the discharge point and Christal Creek. This will include weekly collection of water quality data at sites KV-104, KV-6, and KV-50, and monthly collection at KV-117 (Figure 2-1).

1.3 BACKGROUND ON NATURAL ATTENUATION

Natural attenuation is a combination of physical, chemical, and/or biological processes that naturally reduce the mass, toxicity, mobility, or concentration of contaminants in soil or groundwater. These processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation or reduction of contaminants (EPA, 1999) and metal precipitation. Soil conditions, solution pH, redox potential, soil composition particularity the oxide and clay contents, moisture, organic matter content play significant roles in natural attenuation mechanisms.

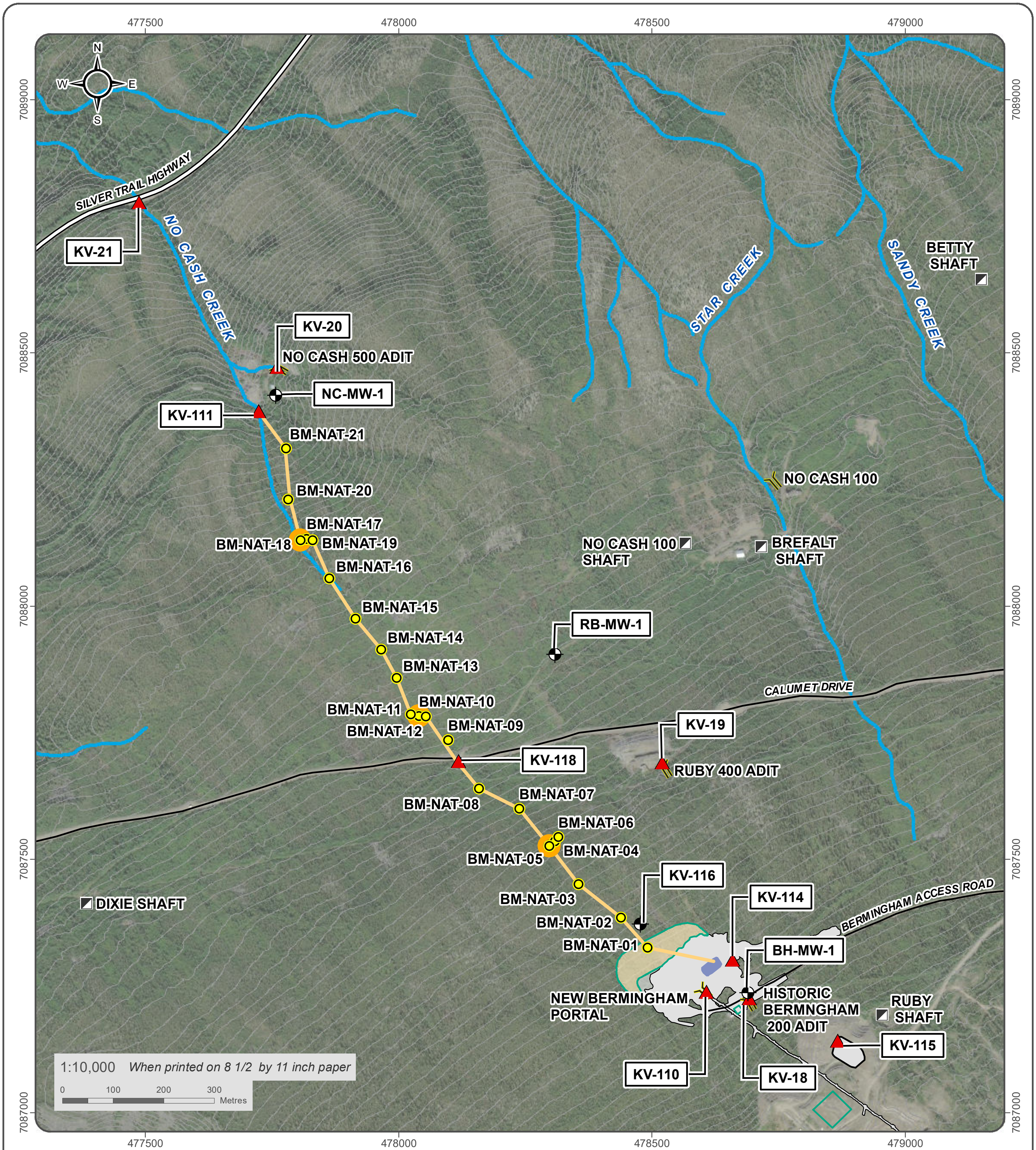
When the solution pH is circum-neutral or slightly acidic, cationic metal species precipitate as aluminum and iron hydroxide, oxyhydroxide, or hydroxy-sulphate minerals (Nordstrom 1982). Under these pH conditions, dissolved metals may adsorb onto surfaces of these amorphous and minerals and/or other surfaces present in the environment, such as organic matter due to decreasing competition with protons, and increased hydrolysis of metal ions at circum-neutral pH (Richard, 2007).

Microorganism such as sulphate-reducing bacteria can attenuate the migration of metals in the natural environment through the precipitation of chalcophile metals as sulphide minerals following the reduction of sulphate in the presence of organic matter. Characterization of microbiological impacts on natural attenuation processes involves tools that can be used during site characterization. Genetic analyses such as molecular biological methods relying on 16S rDNA sequences have been used to identify microbial communities in environmental samples (Richard, 2007).

2 SITE LOCATION

Figure 2-1 shows the location of the District Mill, Flame & Moth WTP and pond, proposed discharge diffuser location, current surface water quality, groundwater, soil and moss sampling locations, and various other mine components and water management structures. The proposed location of the discharge diffuser was selected based on engineering examination and assessment of the topography of the site to limit potential erosion of the channel during discharge and maximize constituent removal and attenuation by promoting longer interaction time between the discharge water and the underlying soils matrix and vegetation cover. By siting the discharge over low grade slopes, the precipitates formed *in situ* will likely remain chemically and physically stable within the discharge area.

The vegetative cover within the discharge location of the diffuser is characterized by stunted white and black spruce, scrub birch, willow and Labrador tea. The area has a thick moss cover, which persists throughout the area. All three sampling transects were similar in terms of vegetative cover. In terms of vegetation density, transect-1 and transect-2 were similar, whereas transect-3 becomes less dense, and a transition occurs from spruce dominated to willow and birch dominated farther down the hillside. The presence of moss/bog materials is found throughout the transects.



Location of Soil Sample Collected Sept 4th 2018

Surface Water Quality Station

Moss Samples Collected on October 06, 2016

Adit

Shaft

Attenuation Study Line

Contours (5m interval)

Waterbody

Permitted To Be Constructed Mine Features

Permitted To Be Constructed Mine Features

Proposed Mine Feature

ALEXCO KENO HILL MINING CORP.

FIGURE 2-1
BERMINGHAM NATURAL ATTENUATION STUDY AREA

MARCH 2021

Satelite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on March 26 2021.
Datum: NAD 83; Projection: UTM Zone 8N

AKHM

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3 DATA COLLECTION AND TESTING

3.1 SOIL BIOGEOCHEMISTRY

Local soil characterization is a crucial part of investing natural attenuation processes at any given site. The geochemical processes controlling the mobility or immobilization of metal(loid)s and other chemical constituents in the natural environment are in large extent controlled by the type of local soil, its composition, structure, metals and organic matter contents, pore water chemistry, soil pH and redox potential. Soil along the discharge corridor was investigated, sampled and tested in order assess its potential for natural attenuation.

3.1.1 SOIL SAMPLING AND TESTING

On July 5, 2018, fifteen surficial (top 30 cm) soil samples were collected from the anticipated discharge corridor between the WTP diffuser and Christal Creek. A transect sampling procedure was followed and five samples were collected from each of three transects evenly spaced along the proposed corridor. The samples were evenly spaced within each transect such they covered the entire transect. The locations of the soil sampling sites are displayed on Figure 2-1 and a brief description of the samples is provided in Table 3-1.

The samples were documented in the field, placed in sealed sampling bags and submitted to ALS Canada (Burnaby, B.C.) for testing. All the 15 samples were analyzed for:

- Moisture content;
- Particle size;
- Paste pH;
- Total organic carbon; and
- *Aqua regia* digestion followed by multi-element analysis of digestate.

Three selected samples (T1-D, T2-F and T3-B) were submitted for sequential extraction using the method of Tessier et al. (1979). The selection was made such to capture the range of (i.e., minimum, median and maximum) cadmium and zinc concentrations (the primary constituents of interest for Flame & Moth discharge), total organic and clay contents.

Additionally, three samples (T1-C, T2-C and T3-C), one from the centre of each transect, were collected, stored in sterile plastic containers and sent to Contango Strategies (Saskatoon, S.K.), for microbial profiling.

Each of the above analytical methods is briefly discussed below or in the results sections where appropriate.

Table 3-1 Description of Soil Samples

Sample ID	Sample Type	Sampling Location	Sampling Date
T1-A	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T1-B	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T1-D	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T1-E	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T1-F	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T2-A	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T2-B	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T2-D	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T2-E	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T2-F	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T3-A	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T3-B	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T3-D	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T3-E	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18
T3-F	Soil	Discharge Corridor, Flame & Moth Mine	5-Jul-18

3.1.2 SEQUENTIAL EXTRACTION

Information regarding the distribution of metal(loid)s between various phases within soils and sediments provides an understanding of the relative mobility of these elements. Several extraction methods (e.g., Tessier et al., 1979; Rauret et al.; 1999, Silveira et al., 2006) have been developed and used to understand the partitioning of major and trace elements in soils and sediments with the Tessier et al. (1979) sequential extraction (TSE) method being the most commonly used. The TSE procedures uses reagents designed to extract metals from a target fraction in a stepwise fashion:

- Fraction 1 – Exchangeable: this fraction represents the weakly bound fraction which is readily remobilized via desorption by competing ions in solution.
- Fraction 2 – Bound to carbonates: this fraction represents the fraction bound to carbonate minerals.
- Fraction 3 – Bound to iron and manganese oxyhydroxides (reducible): this fraction consists of metals associated with iron and manganese oxides that may be remobilized under reducing conditions.
- Fraction 4 – Bound to organic matter (oxidizable): this fraction represents the fraction bound to organic matter such as humic and fulvic acids or sulphide minerals and could be remobilized following oxidation processes.
- Fraction 5 – Residual: this fraction represents the fraction strongly tied to mineral lattice and is relatively immobile.

Understanding the distribution of metal species in soils samples is expected to help gain an insight into natural attenuation processes occurring on site.

3.1.3 SOIL MICROBIOLOGY

Determining the presence, type and the activity of microorganisms in soil is an important factor in understanding of natural attenuation and metal sequestration. Various studies have shown that soil microorganisms promote the attenuation of metals and the transformation of attenuated metals into stable forms such as metal sulphides under anaerobic and organic-rich soils conditions.

The three selected samples were tested for the following:

- Microbial community profiling via 16S rRNA to identify microorganisms to the genus level, including sulphide-producing bacteria; and
- Enumeration of sulphate-reducing bacteria using quantitative polymerase chain reaction (qPCR).

The objective of these tests is to understand the structure of the microbial community, including members that may play an active role in attenuation processes that can immobilize metal(loid)s into stable mineral forms under site conditions, and provide further evidence for the biogeochemical processes in natural attenuation.

In brief, DNA is extracted from the soil 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 species level.

The quantification of sulphate-reducing bacteria was performed by qPCR targeting the β-subunit of the dissimilatory sulfite reductase *dsrB* gene. The dissimilatory sulphite reductase is the primary enzyme in the dissimilatory sulphate reduction gene in sulphate-reducing prokaryotes, hence, this approach targets sulphate-reducing bacteria.

3.2 VEGETATION (MOSS)

Six moss samples (T1-A, T1-B, T2-A, T2-B, T3-A and T3-B) were collected from two locations along each of the three soil sampling transects (T1, T2 and T3) in October 2019 and sent to the laboratory for moisture and metal content analysis of the tissue. The samples were rinsed with deionized water to remove any attached soil/dust particles (or before being homogenized and digested for metal content analysis. The moisture content was determined on a pre-rinsed sample portion. A brief description of the samples is provided in Table 3-2.

Table 3-2 Description of Moss Samples

Sample ID	Sample Type	Sampling Location	Sampling Date
T1-A	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19
T1-B	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19
T2-A	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19
T2-B	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19
T3-A	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19
T3-B	Moss	Discharge Corridor, Flame & Moth Mine	6-Oct-19

3.3 WATER QUALITY

Twelve years (2008 to 2020) of surface water quality (WQ) records from monitoring stations set up along Christal Creek, upstream and downstream of Christal Lake, are used as background data in this study. Additionally, in February 2019, a new background station (KV-117) was established upstream of the proposed channel discharge point along Christal Creek to serve as a background station and capture surface water that will not be affected by the WTP discharge.

Field parameters and total and dissolved metal(loid) concentrations were reviewed from the following monitoring stations:

- KV-49 (Hinton Creek upstream of Christal Creek);
- KV-50 (Christal Creek upstream of Hinton Creek);
- KV-51 (Christal Creek downstream of Hinton Creek and upstream of Christal Lake);
- KV-6 (Christal Creek downstream of Christal Lake); and
- KV-117 (Christal Creek upstream of proposed channel discharge point).

These sites were used to assess surface water conditions before the discharge of treated water begins providing a benchmark for the assessment of water quality variation during and after the water treatment discharge. Upper Christal Creek monitoring stations includes KV-49, KV-50 and KV-51 prior to the entrance to Christal Lake and KV-117 upstream of proposed WTP discharge point. The outflow of Christal Lake is monitored at KV-6. Additionally, WQ data collection from Christal groundwater seep KV-121, a seep located upstream of KV-50 which provides a source of sulphate and metal loads to Christal Creek was initiated in February 2019. Two years of WQ monitoring data from station KV-121 is also provided.

The location of monitoring stations is shown in Figure 2-1 and detailed description are provided in AEG (2018b) and Access (2013).

3.4 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

A standard practice QA/QC program was followed to assess the accuracy and reproducibility of laboratory analytical results. Duplicate samples, methods blanks, Internal Reference Material (IRM), Certified Reference Material (CRM) and Laboratory Control Sample (LCS) were included in the analysis were adequate. The reproducibility of the duplicate analyses was assessed by calculating the relative percent difference (RPD) between the lead sample and the duplicate. An RPD ≤20% was considered acceptable where the parameter measured value (mv) reported was >10 times the reporting detection limit (RDL). The RPD is calculated as follows:

$$RPD\ (\%) = 100\ \mathrm{X}\ \frac{\mathrm{ABS\ (Sample\ mv - Duplicate\ mv)}}{\mathrm{Average\ (Sample\ mv, Duplicate\ mv)}}$$

Where:

ABS is the absolute value

mv: measured value

The accuracy of the IRM and LCS analysis was determined by percent recovery (RP) relative to the set target value as follows:

$$RP\ (\%) = 100\ \mathrm{X}\ \frac{\text{Sample mv}}{\text{IRM or LCS}}$$

Where:

RP: recovery percentage

mv: measured value

An IRM percentage recovery of 80-120% was considered acceptable for total carbon (TC) and total inorganic carbon (TIC) and IRM within the ranges set for particle size distribution (39.1-49.1 for sand; 32.5-42.5 for silt and 13.4-23.4 for clay) and paste pH (5.88-6.48) analyses were also considered acceptable. LCS percentage recoveries of 80-120% and 90-110% were considered acceptable for TIC and TC, respectively, and LCS within the range set for the moisture content (90-110%) and paste pH (5.7-6.3) were also considered acceptable.

One duplicate analysis was done for the moisture content for sample T3-F and the calculated RPD was 0.4% indicating a good analytical reproducibility. All method blanks included in the analysis of moisture content, TIC and TC returned values below the detection limit indicating a laboratory analyses free from contamination. All calculated RP for IRM and LCS retuned values within the set acceptable percentages and value ranges.

One duplicate analysis was done for the metal content of moss sample T3-B and the RPD calculated for the metals ranged between 0.2% to 30% within the targeted RPD of 40% indicating a good analytical reproducibility. All method blanks included in the analysis of moisture and metal content of moss tissue also returned values below the detection limit indicating a laboratory analyses free from contamination. All CRM and LCS retuned values within the set acceptable percentages and value ranges.

All the QA/QC results above show that the results of soil and vegetation tissue geochemical test are acceptable for use in analysis and interpretation.

4 RESULTS

4.1 SOIL GEOCHEMISTRY

The soil test results are discussed below, summarized in Table 4-1 to Table 4-3, and all laboratory reports are compiled in Appendix A.

4.1.1 PASTE PH

Soil pH is a crucial parameter in natural attenuation because it determines the surface charge of clays and the precipitation/dissolution behaviour of metal sinks such as metal oxyhydroxides, carbonates and phosphates. Studies on adsorption mechanisms have shown that generally the adsorption of metal cations increases with increasing pH, while the adsorption of element anions or oxyanions increase with the decrease of pH (Stumm and Morgan, 1996).

The soil pH was determined by saturating a sub-sample with distilled water then an extract from the saturated paste was taken and its pH measured using a pH meter.

The majority of samples had neutral soil pH (6.0 to 6.7) except two samples that had mildly acidic soil pH of 5.4 and 5.5. The median soil pH was 6.3, 6.2 and 6.5 for transect-1, transect-2 and transect-3, respectively, and the site wide average pH was 6.4. These buffered soil pHs reflect an environmental where the solubility of several metal(loid)s, especially iron and aluminum, is at the lowest level leading to their precipitation as oxide or hydroxides, which may co-precipitating other metal(loid)s from the discharge water. These soil pH values are also higher that the point zero charge pH of most clay minerals, therefore clay fractions characterized by a variable surface charge are likely to have a net negatively charged surface favourable for the retention of metals cations under the site soil pH conditions.

4.1.2 MOISTURE CONTENT

Soil moisture content analysis was determined by gravimetric method. The procedure consists of weighting a sub-sample, drying it at 105°C for a minimum of six hours then re-weighing it. Moisture content is then calculated as a percentage weight difference between the initial sample and the dried sample.

The results show that the moisture content ranged from 29.1% to 79.1% along transect-1, 25.8% to 76.4% along transect-2 and 18.6% to 71.9% along transect-3 with a study site median of 52.2%. The median moisture contents along the transects were 55.1% along transect-1, 59.4% along transect-2, and 48.5% along transect-3. These data are indicative of a moderate water holding capacity favourable for the development of the vegetation cover and peaty and organic-rich surficial material along the discharge channel.

4.1.3 TEXTURE

Soil texture was determined based on the particle size distribution. This was performed following the method developed by the United States Department of Agriculture – Natural Resources Conservation Service (Burt, 2009). During the test, dry sieving was used for coarse particles, wet sieving for sand particles, and the pipette sedimentation method for clay particles.

The results indicate that the soil samples consisted predominantly of silt and sand. The silt proportion ranged from 46.6% to 82.7 % along transect-1 with a median of 47.6%; from 35.9% to 75.7% along transect-2 with a median of 64.2%; and from 35.7% to 88.1% along transect-3 with a median of 66.9%. The sand content ranged from 0.05% to 37.5% in the samples from transect-1 with a median of 33.0%; from 1.9% to 41.3% in the samples from transect-2 with a median of 23.9%; and from

1.1% to 41.6 % in the samples from transect-3 with a median of 11.8 %. The median clay contents were 9.7%, 7.2% and 10.0 % along transect-1, transect-2 and transect-3, respectively.

The soil texture of the majority of the samples (11 of the 15 samples) was determined to be silt loam. Two samples from transects-1 and 3 were categorized as silt, one sample from transect-3 as loam and one sample from transect-2 as sandy loam. It was noted that the samples collected from transect-3 had on average a higher clay fraction than transects 1 and 2. The high proportion of silt and clay is predicted to result in a large surface area favourable for the retention of metals through adsorption or cation exchange processes with the discharged water.

4.1.4 ORGANIC MATTER CONTENT

Like soil pH and clay content, soil organic matter content significantly influences the attenuation and immobilization of metals. Organic matter occurs as a mixture of various types of organisms, biochemicals, and humic substances. These provide functional groups where metals can be adsorbed or favor the formation of stable complexes with free ions. Soil organic matter also provides food for the development of microorganisms and serves as electron donor in microbiologically mediated sulphate-reduction reactions. It also improves the water holding capacity of soil thus increasing the water-soil exchange reactions.

The organic matter content of soil was determined by its total organic carbon (TOC). The latter was calculated as the difference between total carbon (TC) and total inorganic carbon (TIC). The TC was determined by ignition in a combustion analyzer where carbon in the reduced CO_2 gas is determined using a thermal conductivity detector. The TIC is determined by reacting the sample with known quality of acetic acid then the pH of the resulting solution is measured and compared against a standard curve relating the pH to weight of carbonate.

The TOC of the soil samples ranged from 2.3% to 37.8% (13.0% median) along transect-1, from 4.8% to 33.2% (8.6% median) along transect-2, and from 1.2% to 25.0% (12.8% median) along transect-3. These soil TOC can be translated into soil organic matter contents using a conversion factor of 1.72 assuming that 58% of organic matter is present as carbon (Pribyl, 2010). This results in an estimated soil organic matter content ranging from 4.0% to 65.0% (22.4% median) along transect-1, from 8.2% to 57.1% (14.7% median) along transect-2, and from 2.0% to 43.0% (22.0% median) along transect-3. In general, the soils sampled contained a significant amount of organic matter that will likely create conditions favourable for sorption, immobilization and attenuation of metals.

4.1.5 METAL CONTENT

The metal content of the soils provides an understanding of current site conditions and offers a benchmark against which future data can be compared following the start of WTP discharge to Christal Creek. The baseline metal content data also provides indications of the presence of minerals that may play a key role in attenuation mechanisms. For example, the presence of elevated calcium, iron and manganese in a sample could be an indication of the presence of carbonate phases and iron and manganese oxides known for their metal attenuation capacities. The baseline data can also reveal unusually elevated metal concentration due to site-specific conditions (i.e., presence of weathering products from mineralization) that could otherwise be interpreted as sign of contamination.

The soil metal content was determined by *aqua region* (3:1 mixture of hydrochloric and nitric acids) digestion followed by inductively coupled plasma – mass spectrometry (ICP-MS). Soil split samples (0.5 g) were digested with the *aqua regia* acid mix in a graphite heating block. After cooling, the digestate was diluted with deionized water and analyzed by ICP-MS. Although the aqua *regia* digestion method does not usually result in a full digestion of a soil sample, it provides a good measure of concentration of major and trace elements of potential environmental concern.

For a site-specific assessment of the metal enrichment or depletion, the average metal content of soil samples from the attenuation study site were compared to the average baseline soil metal composition of the Keno Hill Silver District (KHSD) compiled in July 2018 (CanNorth, 2018; Table 4-4). In the present case, the averages were considered significantly different only if their difference was ten times greater than the detection limit. The results of the comparative analysis are summarized as follows:

- The concentration of lithium, tin and uranium was higher in the KHSD baseline dataset than the study site soil samples;
- The concentration of the following constituents was elevated in the study site soil samples compared to the KHSD baseline: aluminum, arsenic, calcium, cadmium, cobalt, copper, iron, lead, magnesium, manganese, nickel, phosphorus, potassium, molybdenum, strontium, sodium, vanadium and zinc; and
- All other constituents were considered comparable in both datasets.

The elevated content of the several metal(loids)/constituents in the soil samples compared to the baseline may be due to the contribution of localized mineralization.

Table 4-1 Results of Soil Geochemical Tests of Soil Samples along Transect-1

Parameter	Lowest Detection Limit	Sample ID	Transect-1				
			T1-A	T1-B	T1-D	T1-E	T1-F
		Units	Soil	Soil	Soil	Soil	Soil
Physical Tests (Soil)							
Moisture	0.3	%	70.3	55.1	29.1	35.5	79.1
Particle Size (Soil)							
% Gravel (>2 mm)	1	%	4.4	8.5	5.7	12.8	0.5
% Sand (2.0 mm - 0.063 mm)	1	%	34.7	31.4	37.5	33.0	0.5
% Silt (0.063 mm – 4 µm)	1	%	47.6	52.4	47.1	46.6	82.7
% Clay (<4 µm)	1	%	13.4	7.6	9.7	7.7	16.4
Texture		-	Silt loam	Silt loam	Silt loam	Silt loam	Silt
Organic / Inorganic Carbon (Soil)							
Total Organic Carbon	0.1	%	20.6	13.0	2.3	4.9	37.8
Saturated Paste Extractables (Soil)							
Paste pH	0.1	pH	6.04	6.30	5.40	6.54	6.72
Total Metals (Soil)							
Aluminum (Al)	0.01	%	0.87	1.18	1.18	1.24	0.16
Antimony (Sb)	0.05	ppm	1.07	0.79	1.20	0.81	1.65
Arsenic (As)	0.10	ppm	94.2	17.6	47.1	10.0	14.0
Barium (Ba)	10.00	ppm	370	310	230	260	270
Beryllium (Be)	0.05	ppm	0.260	0.320	0.390	0.310	0.070
Bismuth (Bi)	0.01	ppm	0.150	0.490	0.220	0.190	0.050
Boron (B)	10.00	ppm	<10	<10	<10	<10	<10
Cadmium (Cd)	0.01	ppm	1.72	0.79	1.06	0.69	1.48
Calcium (Ca)	0.01	%	1.98	0.8	0.5	0.7	4.1
Chromium (Cr)	1.00	ppm	18	24.0	23.0	26.0	9.0
Cobalt (Co)	0.10	ppm	15.9	8.5	9.5	6.4	4.1
Copper (Cu)	0.20	ppm	55.5	123.5	35.0	34.4	25.3
Iron (Fe)	0.01	%	3.78	2.4	2.6	2.0	2.7

Parameter	Lowest Detection Limit		Transect-1				
		Sample ID	T1-A	T1-B	T1-D	T1-E	T1-F
		Units	Soil	Soil	Soil	Soil	Soil
Lead (Pb)	0.2	ppm	87.9	96.4	230.0	23.8	86.6
Lithium (Li)	0.1	ppm	6.9	12.3	13.9	14.1	0.7
Magnesium (Mg)	0.01	%	0.4	0.5	0.5	0.5	0.2
Manganese (Mn)	5	ppm	1350	627.0	163.0	354.0	1040.0
Mercury (Hg)	0.01	ppm	0.06	0.1	0.1	0.0	0.1
Molybdenum (Mo)	0.05	ppm	2.42	0.7	1.3	0.7	1.3
Nickel (Ni)	0.2	ppm	20	19.4	25.5	19.9	9.9
Phosphorus (P)	10.00	ppm	1260	740.0	820.0	850.0	720.0
Potassium (K)	0.01	%	0.1	0.2	0.1	0.2	0.0
Selenium (Se)	0.2	ppm	1.20	0.90	1.00	0.60	0.40
Silver (Ag)	0.01	ppm	0.430	0.400	0.410	0.310	0.980
Sodium (Na)	0.01	%	0.030	0.030	0.020	0.030	<0.01
Strontium (Sr)	0.2	ppm	60.2	33.4	23.5	29.1	90.5
Sulfur (S)	0.01	%	0.180	0.070	0.050	0.050	0.200
Thallium (Tl)	0.02	ppm	0.09	0.12	0.14	0.13	0.03
Tin (Sn)	0.20	ppm	0.3	0.3	0.3	0.3	0.9
Titanium (Ti)	0.005	%	0.020	0.042	0.045	0.052	<0.005
Uranium (U)	0.05	ppm	0.73	1.01	1.00	0.65	0.18
Vanadium (V)	1.00	ppm	31.00	38.00	39.00	40.00	4.00
Zinc (Zn)	2.00	ppm	148	161	152	114	184

Table 4-2 Results of Soil Geochemical Tests of Soil Samples along Transect-2

Parameter	Lowest Detection Limit		Transect-2				
		Sample ID	T2-A	T2-B	T2-D	T2-E	T2-F
		Units	Soil	Soil	Soil	Soil	Soil
Physical Tests (Soil)							
Moisture	0.3	%	25.8	76.4	59.4	76.2	52.2
Particle Size (Soil)							
% Gravel (>2 mm)	1	%	16.9	0.5	5.7	0.5	5.2
% Sand (2.0 mm - 0.063 mm)	1	%	41.3	1.9	36.3	4.8	23.9
% Silt (0.063 mm – 4 µm)	1	%	35.9	75.7	50.8	74.0	64.2
% Clay (<4 µm)	1	%	5.8	22.4	7.2	21.2	6.7
Texture		-	Sandy loam	Silt loam	Silt loam	Silt loam	Silt loam
Organic / Inorganic Carbon (Soil)							
Total Organic Carbon	0.1	%	4.8	33.2	6.68	22.7	8.6
Saturated Paste Extractables (Soil)							
Paste pH	0.1	pH	6.17	6.61	5.51	6.01	6.59
Total Metals (Soil)							
Aluminum (Al)	0.01	%	1.36	0.71	1.07	0.98	1.35
Antimony (Sb)	0.05	ppm	0.56	1.03	0.78	0.98	0.95
Arsenic (As)	0.10	ppm	22.3	12.1	18.3	18.4	28.6
Barium (Ba)	10.00	ppm	170	250	240	290	250
Beryllium (Be)	0.05	ppm	0.240	0.230	0.310	0.310	0.370
Bismuth (Bi)	0.01	ppm	0.090	0.120	0.170	0.180	0.180
Boron (B)	10.00	ppm	<10	<10	<10	<10	<10
Cadmium (Cd)	0.01	ppm	0.57	1.05	1.95	0.89	0.46
Calcium (Ca)	0.01	%	0.6	3.15	0.85	2.5	0.8
Chromium (Cr)	1.00	ppm	34.0	14	23	18.0	29.0
Cobalt (Co)	0.10	ppm	9.4	3.9	6.2	6.1	9.4
Copper (Cu)	0.20	ppm	22.9	44.2	15.7	34.8	26.6
Iron (Fe)	0.01	%	2.5	1.56	2.41	2.1	3.1
Lead (Pb)	0.2	ppm	46.1	38.7	80.8	28.1	25.7

Parameter	Lowest Detection Limit	Sample ID	Transect-2				
			T2-A	T2-B	T2-D	T2-E	T2-F
		Units	Soil	Soil	Soil	Soil	Soil
Lithium (Li)	0.1	ppm	17.3	6.6	11.8	9.8	15.6
Magnesium (Mg)	0.01	%	0.9	0.46	0.41	0.5	0.5
Manganese (Mn)	5	ppm	542.0	398	315	321.0	377.0
Mercury (Hg)	0.01	ppm	0.1	0.08	0.06	0.1	0.1
Molybdenum (Mo)	0.05	ppm	1.1	0.85	1.23	1.2	1.8
Nickel (Ni)	0.2	ppm	26.8	17.4	16.4	20.0	24.8
Phosphorus (P)	10.00	ppm	560.0	840	710	880.0	770.0
Potassium (K)	0.01	%	0.2	0.11	0.21	0.2	0.2
Selenium (Se)	0.2	ppm	<0.2	0.70	0.50	0.50	0.40
Silver (Ag)	0.01	ppm	0.170	0.530	0.280	0.420	0.280
Sodium (Na)	0.01	%	0.020	0.020	0.030	0.020	0.030
Strontium (Sr)	0.2	ppm	18.3	75.5	33.1	64.6	30.6
Sulfur (S)	0.01	%	0.020	0.160	0.080	0.140	0.040
Thallium (Tl)	0.02	ppm	0.09	0.08	0.11	0.12	0.15
Tin (Sn)	0.20	ppm	0.4	0.2	0.3	0.3	0.5
Titanium (Ti)	0.005	%	0.098	0.012	0.027	0.013	0.036
Uranium (U)	0.05	ppm	0.46	0.46	0.53	0.52	0.46
Vanadium (V)	1.00	ppm	57.00	19.00	35.00	27.00	43.00
Zinc (Zn)	2.00	ppm	177	204	175	178	121

Table 4-3 Results of Soil Geochemical Tests of Soil Samples along Transect-3

Parameter	Lowest Detection Limit		Transect-3				
		Sample ID	T3-A	T3-B	T3-D	T3-E	T3-F
		Units	Soil	Soil	Soil	Soil	Soil
Physical Tests (Soil)							
Moisture	0.3	%	48.5	71.9	48.2	49.1	18.6
Particle Size (Soil)							
% Gravel (>2 mm)	1	%	9.3	0.5	0.5	0.5	24.9
% Sand (2.0 mm - 0.063 mm)	1	%	41.6	1.1	11.8	5.7	31.2
% Silt (0.063 mm – 4 µm)	1	%	39.1	69.3	66.9	88.1	35.7
% Clay (<4 µm)	1	%	10.0	29.5	21.2	6.2	8.3
Texture		-	Loam	Silt loam	Silt loam	Silt	Silt loam / Loam
Organic / Inorganic Carbon (Soil)							
Total Organic Carbon	0.1	%	1.4	25.0	19.8	12.8	1.15
Saturated Paste Extractables (Soil)							
Paste pH	0.1	pH	6.70	6.49	6.72	6.41	6.35
Total Metals (Soil)							
Aluminum (Al)	0.01	%	1.39	1.06	1.11	1.37	1.21
Antimony (Sb)	0.05	ppm	1.28	1.13	1.37	1.02	1.18
Arsenic (As)	0.10	ppm	37.0	25.6	80.7	59.1	35
Barium (Ba)	10.00	ppm	310	340	410	360	240
Beryllium (Be)	0.05	ppm	0.410	0.380	0.390	0.380	0.360
Bismuth (Bi)	0.01	ppm	0.280	0.200	0.220	0.240	0.230
Boron (B)	10.00	ppm	<10	10	10	10	<10
Cadmium (Cd)	0.01	ppm	2.14	38.50	14.65	1.15	1.08
Calcium (Ca)	0.01	%	0.8	2.5	1.9	1.3	0.44
Chromium (Cr)	1.00	ppm	28.0	19.0	21.0	27	26
Cobalt (Co)	0.10	ppm	11.1	7.8	19.2	10.5	12
Copper (Cu)	0.20	ppm	50.2	50.3	37.6	27.7	44.9
Iron (Fe)	0.01	%	3.0	2.2	4.5	3.63	2.98
Lead (Pb)	0.2	ppm	40.9	22.4	21.7	58	22.9

Parameter	Lowest Detection Limit		Transect-3				
		Sample ID	T3-A	T3-B	T3-D	T3-E	T3-F
		Units	Soil	Soil	Soil	Soil	Soil
Lithium (Li)	0.1	ppm	15.1	9.6	10.4	12.7	14.1
Magnesium (Mg)	0.01	%	0.5	0.5	0.5	0.48	0.47
Manganese (Mn)	5	ppm	414.0	692.0	1880.0	810	513
Mercury (Hg)	0.01	ppm	0.1	0.1	0.1	0.07	0.05
Molybdenum (Mo)	0.05	ppm	1.7	1.3	2.4	1.62	1.75
Nickel (Ni)	0.2	ppm	32.9	25.3	25.8	24	33.7
Phosphorus (P)	10.00	ppm	850.0	940.0	1120.0	900	880
Potassium (K)	0.01	%	0.2	0.2	0.2	0.22	0.18
Selenium (Se)	0.2	ppm	0.50	0.80	1.10	0.70	0.70
Silver (Ag)	0.01	ppm	0.380	0.290	0.310	0.290	0.390
Sodium (Na)	0.01	%	0.030	0.020	0.030	0.030	0.020
Strontium (Sr)	0.2	ppm	32.4	64.4	54.6	43	22.3
Sulfur (S)	0.01	%	0.050	0.180	0.250	0.110	0.020
Thallium (Tl)	0.02	ppm	0.18	0.12	0.13	0.16	0.15
Tin (Sn)	0.20	ppm	0.5	0.3	0.3	0.4	0.4
Titanium (Ti)	0.005	%	0.034	0.013	0.015	0.024	0.047
Uranium (U)	0.05	ppm	0.63	0.71	0.94	1.17	0.55
Vanadium (V)	1.00	ppm	44.00	28.00	35.00	44.00	40.00
Zinc (Zn)	2.00	ppm	435	4870	2660	307	142

Table 4-4 Keno Hill Silver District Background Average Concentration of Soil (CanNorth, 2018)

Total Metal Concentration	Unit	Galena Hill, South McQuesten (latest data)
Aluminum (Al)	%	0.734
Antimony (Sb)	ppm	1.06
Arsenic (As)	ppm	27
Barium (Ba)	ppm	220
Beryllium (Be)	ppm	0.45
Bismuth (Bi)	ppm	0.19
Boron (B)	ppm	2.85
Cadmium (Cd)	ppm	0.71
Calcium (Ca)	%	0.882
Chromium (Cr)	ppm	14.3
Cobalt (Co)	ppm	6.34
Copper (Cu)	ppm	22.9
Iron (Fe)	%	1.85
Lead (Pb)	ppm	22.4
Lithium (Li)	ppm	14.3
Magnesium (Mg)	%	0.295
Manganese (Mn)	ppm	451
Mercury (Hg)	ppm	0.05
Molybdenum (Mo)	ppm	1.03
Nickel (Ni)	ppm	17.5
Phosphorus (P)	ppm	712
Potassium (K)	%	0.03
Selenium (Se)	ppm	0.65
Silver (Ag)	ppm	0.47
Sodium (Na)	%	0.00234
Strontium (Sr)	ppm	32.3
Thallium (Tl)	ppm	0.06
Tin (Sn)	ppm	2.19
Titanium (Ti)	%	0.0113
Uranium (U)	ppm	0.84
Vanadium (V)	ppm	23
Zinc (Zn)	ppm	77.2
Zirconium (Zr)	ppm	1.42

4.2 SEQUENTIAL EXTRACTION

The results of TSE testing are summarized in Table 4-5 to Table 4-7 and the laboratory report is provided in Appendix A. The discussion herein is focused on constituents of potential interest (COPI) such as arsenic, cadmium, copper, lead, nickel, manganese, iron, silver, and zinc.

The results indicate the following:

- COPI were predominantly associated with the residual and reducible phases in the transect-1 sample and with the organic matter and/or sulphide, residual and reducible phases in the transect-2 and 3 samples.
- Except for cadmium and manganese (and zinc in transect-3), COPI were below the detection limit or at low concentrations in the exchangeable and adsorbed fraction.
- The carbonate phase associated concentrations of COPI were low to below the detection limit (DL) for arsenic, copper, iron, nickel and silver. Cadmium, lead, manganese, and zinc had concentration up to 16.5% of the total elemental concentration associated with carbonates, consistent with the ability of these elements to form or co-precipitate with carbonate minerals.
- Arsenic was predominantly associated with the residual phase in transect-1 and 2 (73 to 85%) and in the organic matter and/or sulphide phase in transect-3 (67%).
- Cadmium was primarily found with the exchangeable phase (53-66%) and partly tied to the reducible phase (15 to 26%). Some cadmium (up to 11%) was also associated with the carbonate fraction.
- The majority of copper was sequestered in the organic matter and/or sulphide phase (55 to 87%) and the remaining in the residual fraction.
- Iron was largely associated with the residual phase in transect-1 and 2 (64 to 74%) with the remainder bound to the reducible (transect-1) or organic matter and sulphide phase (transect-2). Only 28% of iron was bound to the residual phase in transect-3, while of the majority (61%) was associated with the organic matter and sulphide phase.
- The lead partitioning pattern was somewhat similar to iron – associated with the residual and reducible or residual and organic matter and/or sulphide phases in transect-1 and 2. A minor proportion of lead was bound to the residual phase (20%) in transect-3 while of the majority (69%) was associated with the organic matter and/or sulphide phase.
- Manganese and zinc were mostly associated with the residual and easily reducible phases in transect-1 and 2. In transect-3, 52% and 34% of manganese and zinc were associated with the reducible phase and 23% and 26% were bound to the organic matter and/or sulphide phase, respectively.
- Nickel was concentrated in the residual and reducible phases in transect-1, and in the organic matter and/or sulphide and residual phases in transect-2 and 3.
- Silver concentrations were very low to below DL in most fractions. The highest concentrations measured were 0.19 to 0.22 mg/kg and associated with the residual phases.

These data indicate that most COPI were predominantly associated with the residual and reducible phases in transect-1, with the organic matter and/or sulphide and residual phases or the organic matter and reducible phases in transect-2. In transect-3, the COPI were largely bound to the organic matter and/or sulphide phase and the remainder to either the residual or reducible phase. The preferential fractionation of COPI into organic matter and/or sulphide phase in the sample from transect-3 and in lesser extent in transect-2 are likely due to the elevated organic matter content (25% and 8.7%, respectively) and presence of sulphide minerals. The easily mobilized exchangeable fraction and carbonate phases contained the lowest proportion of COPI, except cadmium which was predominantly associated with the exchangeable fraction. Also, the carbonate fraction accounted for up to 11% of cadmium and lead, 14% of manganese, and up to 17% of zinc mostly along transect-3.

Large concentrations of COPI are expected to be strongly tied to the mineral lattice (i.e., residual phase) and predicted to be stable in the soil matrix significantly decreasing their solubility and potential bioavailability. However, significant fractions of COPI could be remobilized once the environment become reducing (fraction bound to reducible phase) or strongly oxidizing. However, the predicted reducing environmental conditions caused by the boggy/marshy and elevated organic matter content environment, and the precipitation of sulphides favored under reducing conditions will likely prevent the release of COPI by scavenging and precipitating these metal(loid)s.

Table 4-5 Results of Tessier Sequential Extraction of Soil Sample along Transect-1

Parameter	Lowest Detection Limit	Units	T1-D				
			Exchangeable & Adsorbed Metals	Carbonate Metals	Easily Reducible Metals and Iron Oxides	Organic / Sulphide Bound Metals	Residual Metals
Aluminum (Al)	50	mg/kg	<50	57	1050	1160	9990
Antimony (Sb)	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	1.24
Arsenic (As)	0.050	mg/kg	0.086	0.326	7.85	0.317	47.6
Barium (Ba)	0.50	mg/kg	41.0	25.2	47.1	15.7	67.9
Beryllium (Be)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Bismuth (Bi)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Cadmium (Cd)	0.050	mg/kg	0.659	0.107	0.298	0.066	<0.050
Calcium (Ca)	50	mg/kg	1490	140	301	346	2090
Chromium (Cr)	0.50	mg/kg	<0.50	<5.0	1.89	4.63	17.3
Cobalt (Co)	0.10	mg/kg	1.18	0.31	2.86	0.92	4.46
Copper (Cu)	0.50	mg/kg	<0.50	1.51	4.94	23.7	12.7
Iron (Fe)	50	mg/kg	<50	145	6570	660	20700
Lead (Pb)	0.50	mg/kg	1.92	3.66	16.6	3.87	8.47
Lithium (Li)	5.0	mg/kg	<5.0	<5.0	<5.0	<5.0	12.4
Manganese (Mn)	1.0	mg/kg	18.9	<5.0	21.3	8.4	105
Molybdenum (Mo)	0.50	mg/kg	<0.50	<0.50	<0.50	<0.50	1.26
Nickel (Ni)	0.50	mg/kg	2.85	<2.0	7.44	3.41	13.3
Phosphorus (P)	50	mg/kg	<50	<50	<50	–	–
Potassium (K)	100	mg/kg	<100	–	–	–	–
Selenium (Se)	0.20	mg/kg	<0.20	<0.20	0.26	1.06	<0.20
Silver (Ag)	0.10	mg/kg	<0.10	<0.10	0.12	<0.10	0.22
Sodium (Na)	100	mg/kg	<100	–	–	–	–
Strontium (Sr)	0.50	mg/kg	3.76	<5.0	1.66	1.72	13.8
Thallium (Tl)	0.050	mg/kg	<0.050	<0.050	<0.050	<0.050	0.113
Tin (Sn)	2.0	mg/kg	<2.0	<2.0	<2.0	<2.0	<2.0
Titanium (Ti)	1.0	mg/kg	<1.0	<5.0	<2.0	45.0	315
Uranium (U)	0.050	mg/kg	<0.050	0.355	0.279	0.164	0.346
Vanadium (V)	0.20	mg/kg	<0.20	<0.20	5.67	5.00	29.8
Zinc (Zn)	1.0	mg/kg	11.7	5.7	54.4	20.6	58.9

Table 4-6 Results of Tessier Sequential Extraction of Soil Sample along Transect-2

Parameter	Lowest Detection Limit	Units	T2-F				
			Exchangeable & Adsorbed Metals	Carbonate Metals	Easily Reducible Metals and Iron Oxides	Organic / Sulphide Bound Metals	Residual Metals
Aluminum (Al)	50	mg/kg	<50	<50	485	2450	6120
Antimony (Sb)	0.10	mg/kg	<0.10	<0.10	<0.10	0.18	0.83
Arsenic (As)	0.050	mg/kg	<0.050	0.254	2.65	3.83	18.4
Barium (Ba)	0.50	mg/kg	52.8	16.1	46.7	36.1	43.6
Beryllium (Be)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Bismuth (Bi)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Cadmium (Cd)	0.050	mg/kg	0.452	0.094	0.226	0.088	<0.050
Calcium (Ca)	50	mg/kg	8980	1420	1660	851	771
Chromium (Cr)	0.50	mg/kg	<0.50	<5.0	0.51	6.32	10.6
Cobalt (Co)	0.10	mg/kg	<0.10	0.15	1.67	2.51	2.96
Copper (Cu)	0.50	mg/kg	<0.50	<0.50	0.95	17.7	8.42
Iron (Fe)	50	mg/kg	<50	<50	2720	4900	13600
Lead (Pb)	0.50	mg/kg	<0.50	1.04	6.84	9.17	10.6
Lithium (Li)	5.0	mg/kg	<5.0	<5.0	<5.0	<5.0	8.8
Manganese (Mn)	1.0	mg/kg	12.0	33.8	125	29.7	77.8
Molybdenum (Mo)	0.50	mg/kg	<0.50	<0.50	<0.50	0.50	0.76
Nickel (Ni)	0.50	mg/kg	<0.50	<2.0	2.95	9.02	9.0
Phosphorus (P)	50	mg/kg	<50	<50	<50	–	–
Potassium (K)	100	mg/kg	<100	–	–	–	–
Selenium (Se)	0.20	mg/kg	<0.20	<0.20	<0.20	0.39	<0.20
Silver (Ag)	0.10	mg/kg	<0.10	<0.10	<0.10	0.15	0.19
Sodium (Na)	100	mg/kg	<100	–	–	–	–
Strontium (Sr)	0.50	mg/kg	21.4	<5.0	4.14	3.41	5.6
Thallium (Tl)	0.050	mg/kg	<0.050	<0.050	<0.050	<0.050	0.068
Tin (Sn)	2.0	mg/kg	<2.0	<2.0	<2.0	<2.0	<2.0
Titanium (Ti)	1.0	mg/kg	<1.0	<5.0	1.4	87.5	167
Uranium (U)	0.050	mg/kg	<0.050	<0.050	0.082	0.131	0.180
Vanadium (V)	0.20	mg/kg	<0.20	<0.20	1.39	7.71	19.6
Zinc (Zn)	1.0	mg/kg	5.1	7.2	59.6	34.6	37.5

Table 4-7 Results of Tessier Sequential Extraction of Soil Sample along Transect-3

Parameter	Lowest Detection Limit	Units	T3-B				
			Exchangeable & Adsorbed Metals	Carbonate Metals	Easily Reducible Metals and Iron Oxides	Organic / Sulphide Bound Metals	Residual Metals
Aluminum (Al)	50	mg/kg	<50	<50	316	3030	3930
Antimony (Sb)	0.10	mg/kg	<0.10	<0.10	<0.10	0.63	0.44
Arsenic (As)	0.050	mg/kg	<0.050	0.127	4.22	13.0	2.21
Barium (Ba)	0.50	mg/kg	66.5	20.0	52.2	98.2	39.3
Beryllium (Be)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Bismuth (Bi)	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20
Cadmium (Cd)	0.050	mg/kg	18.3	3.12	4.02	2.16	0.067
Calcium (Ca)	50	mg/kg	15200	3420	4200	2820	397
Chromium (Cr)	0.50	mg/kg	<0.50	<5.0	<0.50	6.25	6.7
Cobalt (Co)	0.10	mg/kg	<0.10	0.13	1.20	3.14	1.02
Copper (Cu)	0.50	mg/kg	<0.50	<0.50	1.30	28.8	3.18
Iron (Fe)	50	mg/kg	<50	<50	1750	9490	4340
Lead (Pb)	0.50	mg/kg	<0.50	<0.50	1.65	9.82	2.81
Lithium (Li)	5.0	mg/kg	<5.0	<5.0	<5.0	<5.0	<5.0
Manganese (Mn)	1.0	mg/kg	22.1	64.4	243	109	30.8
Molybdenum (Mo)	0.50	mg/kg	<0.50	<0.50	<0.50	0.65	<0.50
Nickel (Ni)	0.50	mg/kg	0.65	<2.0	2.15	13.4	4.1
Phosphorus (P)	50	mg/kg	<50	<50	87	–	–
Potassium (K)	100	mg/kg	<100	–	–	–	–
Selenium (Se)	0.20	mg/kg	<0.20	<0.20	<0.20	0.70	<0.20
Silver (Ag)	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	0.20
Sodium (Na)	100	mg/kg	<100	–	–	–	–
Strontium (Sr)	0.50	mg/kg	35.2	6.7	8.93	8.14	<5.0
Thallium (Tl)	0.050	mg/kg	<0.050	<0.050	<0.050	<0.050	0.068
Tin (Sn)	2.0	mg/kg	<2.0	<2.0	<2.0	<2.0	<2.0
Titanium (Ti)	1.0	mg/kg	<1.0	<5.0	1.3	29.3	121
Uranium (U)	0.050	mg/kg	<0.050	<0.050	0.189	0.411	0.131
Vanadium (V)	0.20	mg/kg	<0.20	<0.20	0.74	8.54	10.8
Zinc (Zn)	1.0	mg/kg	1140	827	1710	1290	45.0

4.3 SOIL MICROBIOLOGY

Three soil samples were selected for microbial community profiling – one from the centre of each transect (T1-C, T2-C, and T3-C). Bacteria identified to the genus level that comprised >1% of the OTUs in at least one sample are presented in Table 4-8. Species belonging to the *Arthrobacter* and *Flavobacterium* genera, which comprised 0.2% to 1.5% of gene sequences extracted from soil samples, are commonly found in soil and fresh water samples but are not thought capable of modifying the mobility of major and trace elements via redox transformations. Conversely, members of the *Gallionella* (1.3% of OTUs extracted from the transect-1 sample) and *Albidiferax* (0.2% to 1.5% of OTUs in soil samples) genera are capable of iron oxidation and iron reduction, respectively. Similarly, *Clostridium* (0.2% to 1.1% of OTUs in all three samples) and *Sulfuricurvum* (2.1% of OTUs extracted from transect-1 sample) genera contain species known to cycle reduced and oxidized forms of sulphur. The presence of organisms in the soil samples with close genetic similarity to genera known to mediate iron and sulphur redox transformations suggests there is the capacity for microbial controls on trace element mobility, for example via sequestration as metal sulphides under sulphide-producing conditions or sorption/co-precipitation with iron oxyhydroxides mediated by iron-oxidizing microorganisms. Members of the major genera identified are either aerobic or facultatively anaerobic (i.e., can grow with or without oxygen), except for C*lostridum*, which were identified in all three samples and are obligate anaerobes, suggesting that reducing niches are present in the shallow subsurface sampled at all three sites. It is important to note that 93% to 98% of the OTUs sequenced from each sample were either matched to genera of low abundance in the sample (<1%) or could not be matched to the genus level. The latter reflects the limited number of bacteria isolated in pure culture and available for database matching.

Table 4-8 Abundance of Bacteria Identified to the Genus Level in Transect Soil Samples

Genus	Percentage of bacterial community		
	T1-C	T2-C	T3-C
Albidiferax	1.5%	0.2%	0.2%
Arthrobacter	0.5%	1.7%	0.2%
Clostridium_sensu_stricto	1.1%	0.5%	0.2%
Flavobacterium	0.2%	-	1.4%
Gallionella	1.3%	-	-
Sulfuricurvum	2.1%	-	-
Others (each < 1% or not identified to the genus level)	93.2%	97.5%	98.1%

Table 4-9 presents the identification and relative abundance of sulphide-producing bacteria in the transect soil samples, while Figure 4-1 compares the quantity of sulphate-reducing bacteria based on qPCR enumeration. A distinction is made between sulphate-reducing and sulphide-producing since not all bacteria produce sulphide from sulphate-reduction; however, the microbial community profiling and enumeration of sulphate-reducers appear complementary. Sequences associated with the *Clostridium* genus comprised the majority of the sulphide-producing bacteria in all three samples. OTUs associated with the *Desulfosporosinus* were also identified in all three samples, albeit at lower abundance than the *Clostridium* sequences. Sample T1-C had the highest proportion of sulphide-producing bacteria (1.3% of sequenced OTUs) and also had the highest number of sulphate-reducing bacteria (4.8 million gene copies per cm^3 soil). Sample T3-C returned the lowest proportion of sulphide-producing bacteria (0.23% of sequenced OTUs) and also had the lowest number of sulphate-reducing bacteria (0.1 million gene copies per cm^3 soil). Although a minor proportion of the microbial community, the presence of sulphide-producing bacteria in all three soils suggests the capacity exists in these soils for trace element sequestration as sulphide phases.

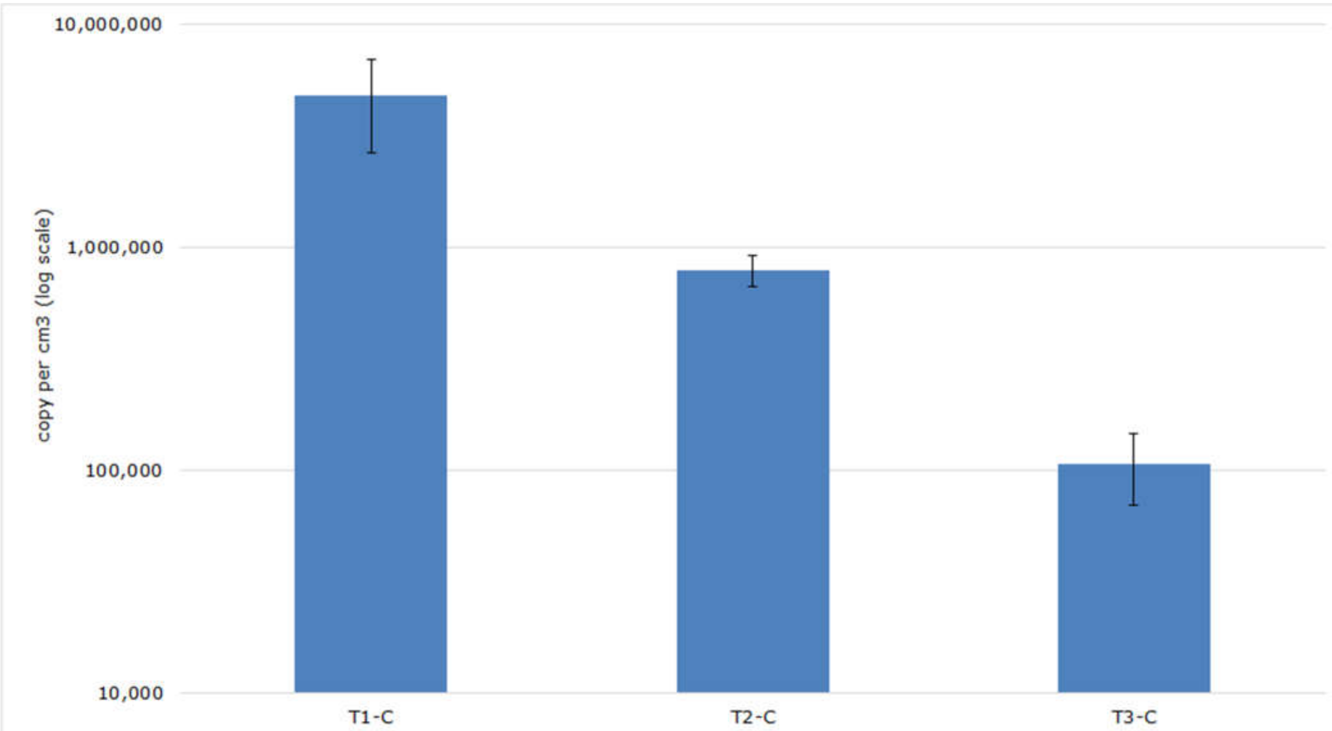

Figure 4-1 Quantity of Sulphate-Reducing Bacteria in Transect Soil Samples

Table 4-9 Identification and Abundance of Known Sulphide-Producing Bacteria in Transect Soil Samples

Genus	Can reduce:				Environment			Trait Assignment Category [1]	Percentage of bacterial community		
	Sulphate	Thiosulphate	Sulphite	Sulphur	Aerobe/Anaerobe Characteristics	Temperature	pH		T1-C	T2-C	T3-C
Desulfosporosinus	Yes	Yes	Yes	Yes	anaerobic	mesophilic, some psychrotolerant	neutrophilic	A	0.15%	0.02%	0.07%
Sulfurospirillum	No	Yes	Yes	Yes	microaerophilic	mesophilic, some psychrotolerant	neutrophilic	A	0.01%	-	-
Clostridium_sensu_ stricto	No	Yes	Yes, some	Yes, some	obligately anaerobic	mesophilic	mildly acidophilic to neutrophilic (4.0-8.5)	B	1.10%	0.54%	0.16%
Geobacter	No	No	No	Yes	anaerobic	mesophilic	neutrophilic	B	0.04%	-	-
Total SPB Percentage									**1.30%**	**0.55%**	**0.23%**

[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

4.4 VEGETATION

The baseline total metal composition of moss collected from the proposed discharge corridor is provided in Table 4-10 and laboratory reports are compiled in Appendix A. The results of the analysis are summarized as follows:

- Transect T-1 generally had the highest metal concentrations. This was especially true for arsenic, antimony, cadmium, iron, manganese, copper, nickel, lead and zinc. The concentration of these constituents was commonly at least two to three times higher than the transect with second highest concentration (T-2);
- Transect-2 had the second highest metal concentration and transect T-3 had the lowest suggesting a decreasing metal content in vegetation downstream of the proposed diffuser location; and
- Transect-3 had the lowest moisture content and T-2 the highest.

Table 4-10 Results of Elemental Analysis Tests of Moss Samples

Parameter	Lowest Detection Limit		Transect-1		Transect-2		Transect-3	
		Sample ID	T1-A	T1-B	T2-A	T2-B	T3-A	T3-B
		Units	Soil	Soil	Soil	Soil	Soil	Soil
Physical Tests (Tissue)								
Moisture	0.50	%	66.0	62.9	77.8	80.9	77.1	73.4
Total Metals (Tissue)								
Aluminum (Al)-Total	2.0	mg/kg	522	480	340	235	243	294
Antimony (Sb)-Total	0.010	mg/kg	32.4	27.3	14.0	6.54	3.59	6.90
Arsenic (As)-Total	0.020	mg/kg	40.6	29.7	11.3	5.47	5.89	8.86
Barium (Ba)-Total	0.050	mg/kg	94.7	67.6	21.3	38.0	84.9	53.0
Beryllium (Be)-Total	0.010	mg/kg	0.021	0.017	0.013	<0.010	0.025	0.011
Bismuth (Bi)-Total	0.010	mg/kg	0.835	0.607	0.285	0.157	0.094	0.151
Boron (B)-Total	1.0	mg/kg	15.9	5.9	3.5	4.5	4.0	4.0
Cadmium (Cd)-Total	0.0050	mg/kg	35.1	26.8	13.5	6.91	4.09	6.66
Calcium (Ca)-Total	20	mg/kg	12900	7360	5160	6030	10700	9960
Cesium (Cs)-Total	0.0050	mg/kg	0.115	0.114	0.0967	0.0635	0.0616	0.0901
Chromium (Cr)-Total	0.050	mg/kg	1.21	0.998	0.769	0.579	0.428	0.621
Cobalt (Co)-Total	0.020	mg/kg	0.739	0.655	0.395	0.282	0.282	0.283
Copper (Cu)-Total	0.10	mg/kg	60.3	44.4	20.8	13.6	7.55	12.7
Iron (Fe)-Total	3.0	mg/kg	4860	3790	1760	1190	796	1260
Lead (Pb)-Total	0.020	mg/kg	4130	2890	1300	794	427	711
Lithium (Li)-Total	0.50	mg/kg	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Magnesium (Mg)-Total	2.0	mg/kg	1170	1170	1100	1390	1030	1250
Manganese (Mn)-Total	0.050	mg/kg	1240	1130	498	420	226	213
Molybdenum (Mo)-Total	0.020	mg/kg	0.217	0.224	0.220	0.310	0.074	0.123
Nickel (Ni)-Total	0.20	mg/kg	3.07	2.17	1.63	1.11	0.99	1.03
Phosphorus (P)-Total	10	mg/kg	626	749	669	840	583	733
Potassium (K)-Total	20	mg/kg	1510	1740	1120	2180	1520	1830
Rubidium (Rb)-Total	0.050	mg/kg	2.25	2.87	2.79	4.13	2.72	4.61

Parameter	Lowest Detection Limit	Sample ID	Transect-1		Transect-2		Transect-3	
			T1-A	T1-B	T2-A	T2-B	T3-A	T3-B
		Units	Soil	Soil	Soil	Soil	Soil	Soil
Selenium (Se)-Total	0.050	mg/kg	0.151	0.108	0.076	0.059	0.082	0.112
Silver (Ag)-Total	0.0050	mg/kg	17.4	9.59	6.97	3.39	3.21	2.81
Sodium (Na)-Total	20	mg/kg	20	21	29	31	<20	23
Strontium (Sr)-Total	0.050	mg/kg	31.3	15.6	9.71	11.2	22.2	21.7
Tellurium (Te)-Total	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Thallium (Tl)-Total	0.0020	mg/kg	0.0261	0.0222	0.0159	0.0108	0.0065	0.0091
Tin (Sn)-Total	0.10	mg/kg	4.02	2.97	1.44	0.80	0.46	0.75
Uranium (U)-Total	0.0020	mg/kg	0.0874	0.0709	0.0491	0.0439	0.0212	0.0361
Vanadium (V)-Total	0.10	mg/kg	1.39	1.27	1.02	0.80	0.60	0.86
Zinc (Zn)-Total	0.50	mg/kg	2900	2130	1020	536	348	591
Zirconium (Zr)-Total	0.20	mg/kg	0.54	0.49	0.36	<0.22	<0.22	0.23

4.5 WATER QUALITY

The concentrations of COPI in surface waters sampled between 2008 and 2020 were compared with the most recently updated guideline from Canadian Council of Ministers of the Environment (CCME) or the British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) Water Quality Guidelines for the Protection of Fresh Water Aquatic Life (WQ FWAL). Total concentrations are presented except where the water quality guideline specifies that the dissolved fraction be used (manganese and zinc). The comparison of water quality results with the generic guidelines was to identify relatively elevated constituents, determine their background concentration, and serve as a benchmark for comparison with surface water quality data after the start of water treatment discharge. This comparative assessment should not be considered as a measure of compliance or lack thereof to these guidelines. The guidelines for hardness-, dissolved organic carbon (DOC)-, and pH-dependent elements were calculated for each sample using its hardness, DOC and pH and the number of exceedances is reported in Table 4-11 to Table 4-17. For plotting purposes (lines on graphs), the average of the 25th percentile hardness and DOC, and 75th percentile pH observed for KV-6, KV-49, KV-50, KV-51 and KV-117 was used to create the guideline displayed on the figures.

Time series plots depicting the results for COPI are shown in Figure 4-2 through Figure 4-10, associated summary statistics are reported in Table 4-11 through Table 4-17 and all laboratory results are compiled in Appendix B. The COPI which constantly or occasionally exceeded the guidelines included sulphate, arsenic, cadmium, copper, iron, lead, manganese, and zinc, while exceedances of the lower guideline for pH were occasionally observed for field pH.

4.5.1 FIELD PH

Beside a few (five) excursions of field pH below pH 6.5 along Hinton Creek (KV-49) and at KV-51, the field pH has remained in the circumneutral CCME FWAL range (pH 6.5 -9.0) during the monitoring period. There were periods of high and low pH measurements, but no clear seasonality was depicted in the field pH data. It was noted that monitoring station KV-6, located downstream of Christal Lake, generally had the highest field pH (median field pH 7.6) followed by KV-117 (median field pH 7.3) (Figure 4-2).

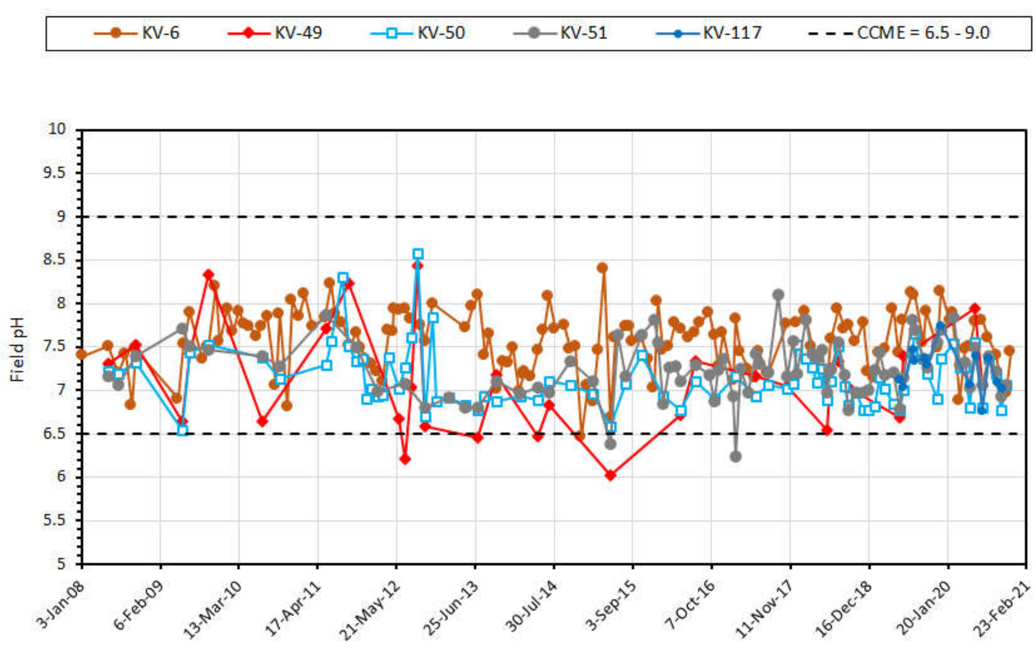

Figure 4-2 Field pH at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

4.5.2 FIELD REDOX POTENTIAL

As expected, the oxidation – reduction potential (ORP) at the monitoring stations was oxidizing but large fluctuations were recurrent in the data (Figure 4-3). The redox potential was largely positive with a median field ORP ranging from +37 mV to +127 mV. However, periodic negative ORP measurements were also observed during several sampling events coinciding with low flows and turbid waters in July-December.

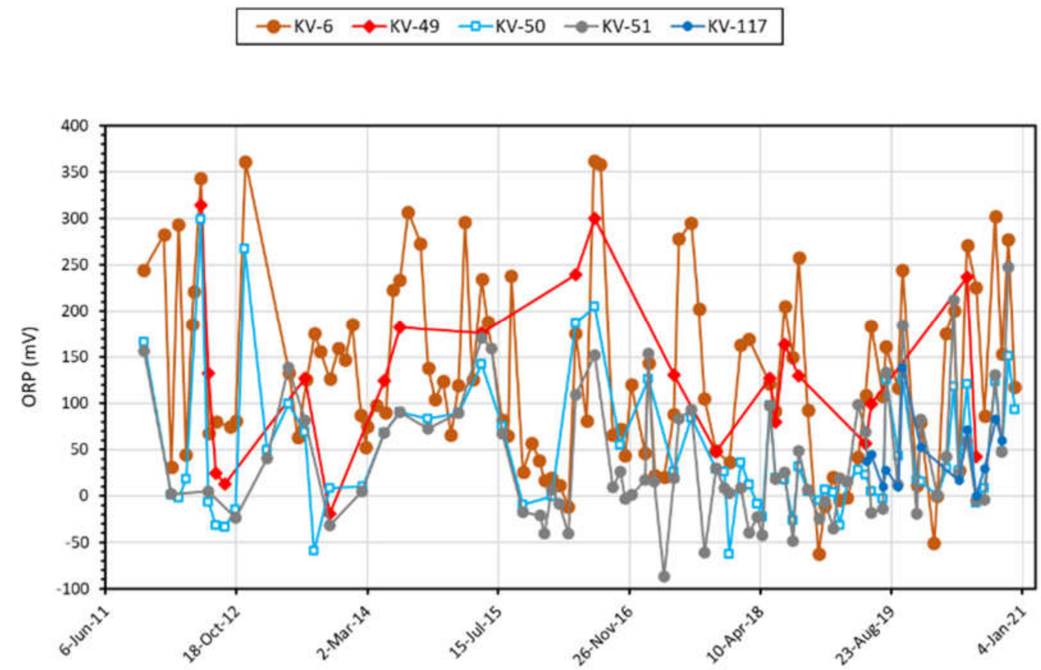

Figure 4-3 Field ORP at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2011-2020 Data

4.5.3 ARSENIC

The total arsenic time series plot and statistical summary of the monitoring data are shown in Figure 4-4 and Table 4-11, respectively. KV-50, KV-51, and KV-117 generally had comparable and the highest total arsenic concentrations, which exceeded the CCME and BC ENV guidelines (0.005 mg/L) for the majority of samples collected. The lowest arsenic concentrations were measured at KV-49 with no exceedance of the guideline during the monitoring period. KV-6 had total arsenic concentrations that were typically comparable to or higher than the guideline (69% sample exceedance; Table 4-11). Most exceedances occurred in May during freshet and a weak seasonality was noticeable in the data since 2013. The total arsenic plot at KV-117 also exhibited a seasonal pattern characterized by the lowest concentration in May-June and highest during July-October.

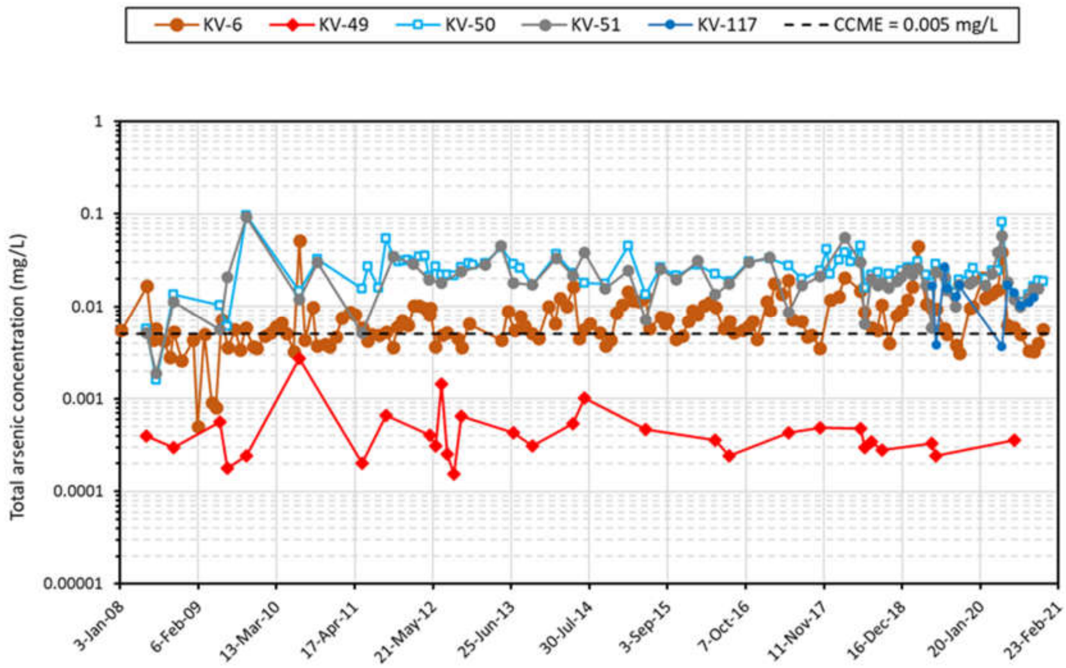

Figure 4-4 Total Arsenic at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-11 Total Arsenic Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Total Arsenic (mg/L); CCME = 0.005 mg/L					
Average	0.00050	0.026	0.022	0.0081	0.013
Count	30	85	65	144	12
Minimum	0.00015	0.0016	0.0019	0.00050	0.0037
Maximum	0.0028	0.096	0.093	0.051	0.027
Count <DL	0	0	0	0	0
Standard Deviation	0.00050	0.013	0.014	0.0067	0.0063
1st Quartile	0.00029	0.019	0.015	0.0047	0.011
Median	0.00036	0.024	0.019	0.0060	0.014
3rd Quartile	0.00049	0.030	0.025	0.0097	0.017
Count over Guideline	0	84	64	99	10
% Over Guideline	0%	99%	99%	69%	83%

4.5.4 ANTIMONY

The total antimony time series plot and statistical summary of the monitoring data are shown in Figure 4-5 and Table 4-12, respectively. Unlike arsenic, total antimony concentrations were low, and no single exceedance of the BC ENV guideline (0.009 mg/L) was recorded. The concentrations were generally comparable at the five monitoring stations (median = 0.0002 to 0.0003 mg/L) although antimony concentrations at KV-6 were slightly higher than the other sites since 2013. The total antimony concentration at KV-49 was relatively stable during the monitoring period. Total antimony concentrations that were below the detection limit were observed at KV-50 and KV-51 in 2020.

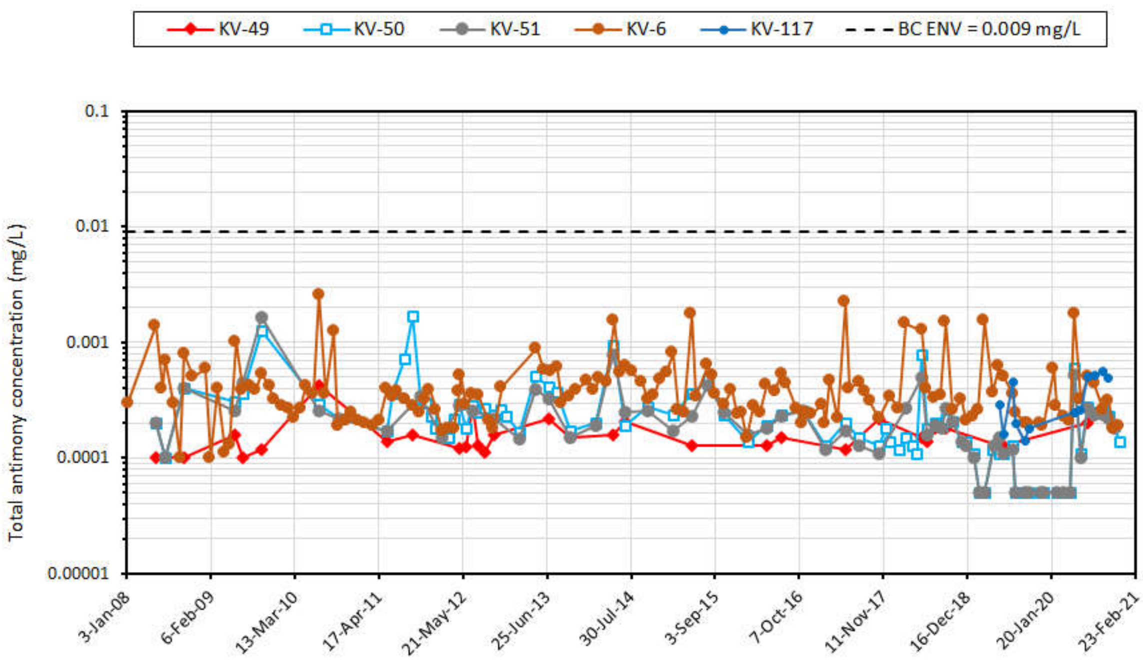

Figure 4-5 Total Antimony at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-12 Total Antimony Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Total Antimony (mg/L); BC ENV = 0.009 mg/L					
Average	0.00016	0.00026	0.00023	0.00046	0.00034
Count	30	85	65	144	12
Minimum	0.00010	0.000050	0.000050	0.00010	0.00014
Maximum	0.00043	0.0017	0.0017	0.0026	0.00056
Count <DL	2	11	11	2	0
Standard Deviation	0.000066	0.00025	0.00023	0.00040	0.00016
1st Quartile	0.00013	0.00013	0.00012	0.00025	0.00020
Median	0.00015	0.00020	0.00018	0.00034	0.00027
3rd Quartile	0.00018	0.00028	0.00026	0.00047	0.00050
Count over Guideline	0	0	0	0	0
% Over Guideline	0%	0%	0%	0%	0%

4.5.5 CADMIUM

The total cadmium plot and statistical summary of the monitoring data are shown in Figure 4-6 and Table 4-13, respectively. Total cadmium concentrations regularly exceeded the CCME guideline at monitoring stations KV-6 (99% of samples), KV-49 (50%), and KV-117 (58%) while only sporadic exceedances were noted at KV-50 and KV-51 (20% to 24%). The median cadmium concentrations at KV-49, KV-50, KV-51, and KV-117 were comparable (median = 0.0002 to 0.0003 mg/L) and lower than that of KV-6 (0.0011 mg/L). The total cadmium concentration at KV-117 increased sharply in 2020 resulting in five of the six measurements being higher than the guideline.

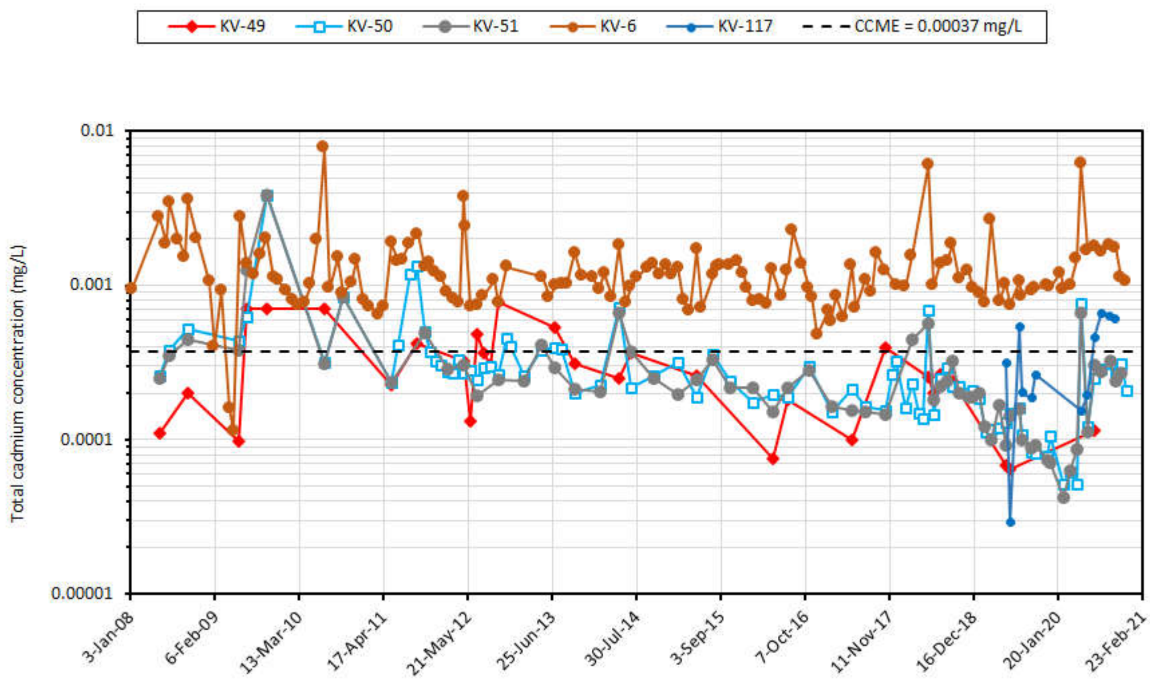

Figure 4-6 Total Cadmium at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-13 Total Cadmium Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Total Cadmium (mg/L); CCME = 0.00037 mg/L					
Average	0.00031	0.00034	0.00032	0.0013	0.00035
Count	30	85	65	144	12
Minimum	0.000064	0.000052	0.000042	0.00011	0.000029
Maximum	0.00077	0.0038	0.0039	0.0078	0.00066
Count <DL	0	0	0	0	0
Standard Deviation	0.00021	0.00044	0.00049	0.0010	0.00022
1st Quartile	0.00014	0.00016	0.00016	0.00086	0.00019
Median	0.00026	0.00026	0.00022	0.0011	0.00029
3rd Quartile	0.00039	0.00032	0.00031	0.0015	0.00056
Count over Guideline	15	20	13	143	7
% Over Guideline	50%	24%	20%	99%	58%

4.5.6 MANGANESE

The dissolved manganese time series plot and statistical summary of the monitoring data are shown in Figure 4-7 and Table 4-14, respectively. Manganese concentrations were higher than the CCME guideline in the majority or all samples at monitoring stations KV-50, KV-51, KV-6, and KV-117 (89%, 80%, 71% and 58% of samples, respectively). KV-50 and KV-51 shared similar trends and had the highest concentrations (median = 1.6 and 1.5 mg/L, respectively). The lowest concentrations were measured at KV-49 (median = 0.01 mg/L) with no exceedance of the CCME guideline. Dissolved manganese concentrations at KV-6 were slightly lower than KV-50 and KV-51 and showed a cyclic pattern characterized by lows in summer (e.g., June-August) after which the concentration gradually increased and peaked in winter (e.g., November-December) then declined afterward. KV-117 had dissolved manganese concentrations generally comparable to KV-50 and KV-51 and above the CCME guideline in all the 2019 samples. The dissolved manganese at KV-117 declined in 2020 with only one elevated concentration among the seven monitoring measurements.

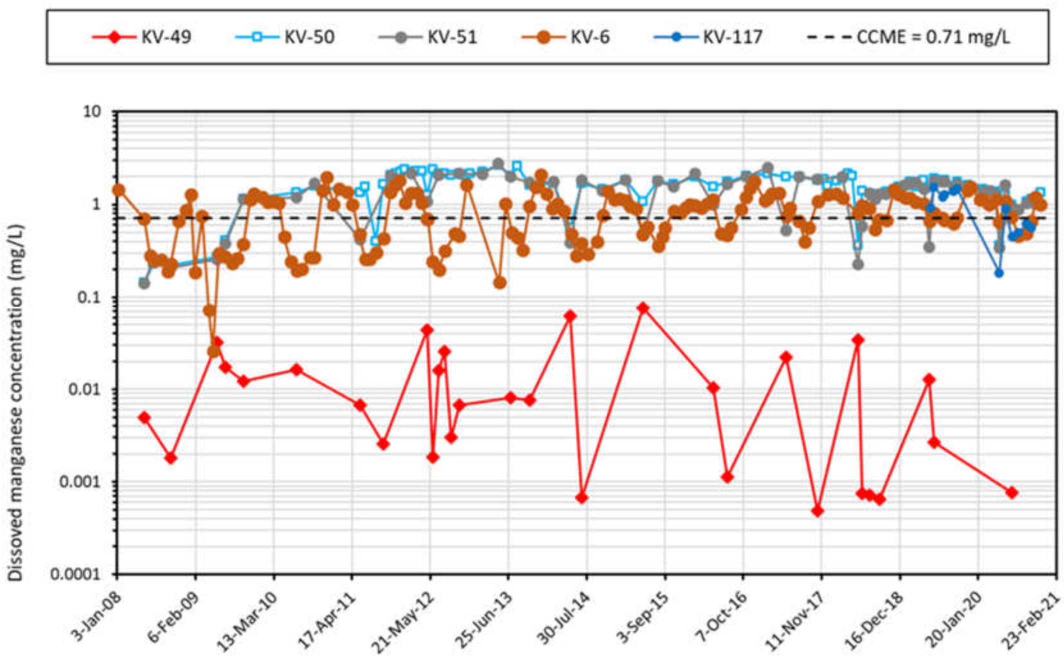

Figure 4-7 Dissolved Manganese at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-14 Dissolved Manganese Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Dissolved Manganese (mg/L); CCME = 0.71 mg/L					
Average	0.014	1.6	1.4	0.83	0.92
Count	30	85	65	146	12
Minimum	0.00049	0.14	0.14	0.026	0.18
Maximum	0.075	2.65	2.8	2.1	1.6
Count <DL	1	0	0	0	0
Standard Deviation	0.019	0.57	0.63	0.44	0.46
1st Quartile	0.0018	1.3	1.0	0.46	0.55
Median	0.0072	1.6	1.5	0.84	0.91
3rd Quartile	0.017	2.0	1.8	1.1	1.3
Count over Guideline*	0	76	52	105	7
% Over Guideline**	0%	89%	80%	71%	58%

*: number of exceedances out of total number of samples for which pH and hardness were available to calculate the guideline;
**percentage exceedance based on samples for which pH and hardness were available to calculate the guideline (i.e., not the total count of samples)

4.5.7 IRON

The total iron concentration time series plot and statistical summary of the monitoring data are shown in Figure 4-8 and Table 4-15, respectively. KV-50, KV-51, and KV-117 returned similar total iron concentrations (median 3.9, 3.1 and 2.3 mg/L, respectively), which were the highest observed of the sites and were higher than the CCME guideline (0.3 mg/L) for all their samples. Lower total iron concentrations were observed at KV-6 (median 0.4 mg/L) and KV-49 (median 0.09 mg/L), The iron concentration measured at KV-49 and KV-6 exceeded the guideline on four occasions (14% of the samples) and in 69% of samples, respectively. The total iron concentration at KV-117 declined in 2020.

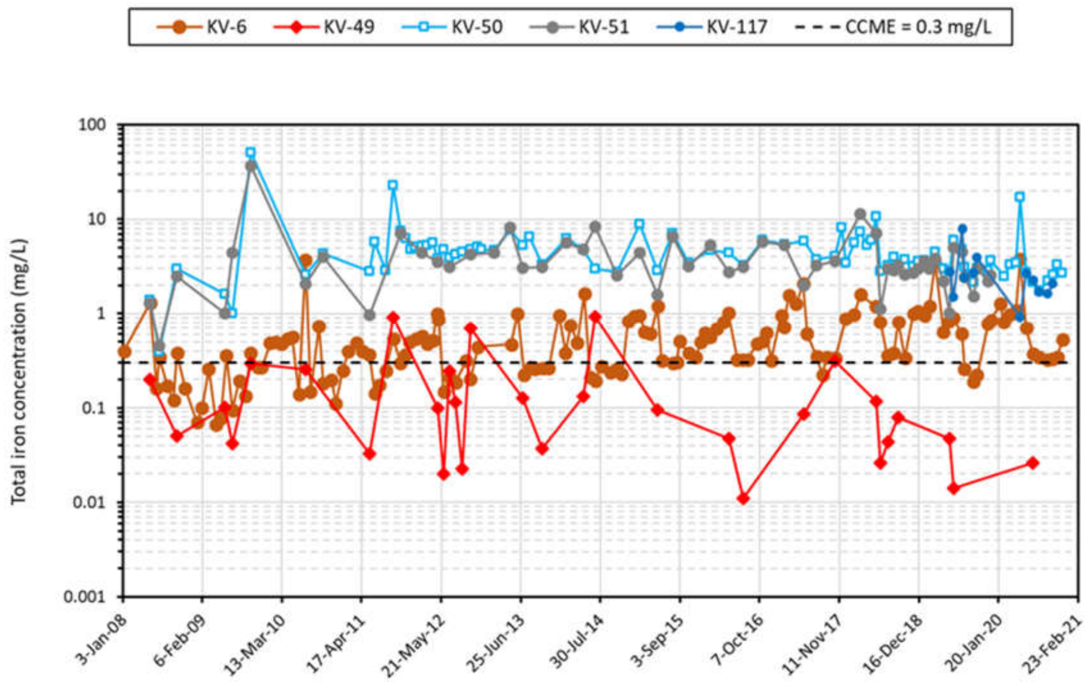

Figure 4-8 Total Iron at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-15 Total Iron Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2019 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Total Iron (mg/L); CCME = 0.3 mg/L					
Average	0.17	5.1	4.2	0.59	2.7
Count	30	85	65	144	12
Minimum	0.011	0.39	0.45	0.066	0.93
Maximum	0.93	51	36	3.8	8.0
Count <DL	0	0	0	0	0
Standard Deviation	0.25	5.9	4.6	0.58	1.8
1st Quartile	0.038	3.0	2.3	0.26	1.7
Median	0.09	3.9	3.1	0.40	2.3
3rd Quartile	0.18	5.3	4.4	0.78	3
Count over Guideline	4	85	65	100	12
% Over Guideline	13%	100%	100%	69%	100%

4.5.8 ZINC

The dissolved zinc concentration time series plot and statistical summary of the monitoring data are shown in Figure 4-9 and Table 4-16, respectively. The patterns of dissolved zinc concentrations were similar at KV-50 and KV-51 (median = 0.19 and 0.18 mg/L, respectively), with 77% and 69% of their samples returning zinc concentrations in excess of the CCME guideline. KV-6 and KV-117 returned 80% and 75% of samples with dissolved zinc concentrations higher than the CCME guideline, respectively. The lowest dissolved zinc concentrations were measured at KV-49 with no recorded exceedance of the CCME guideline. The dissolved zinc concentration at KV-117 increased sharply from May-June to October each year.

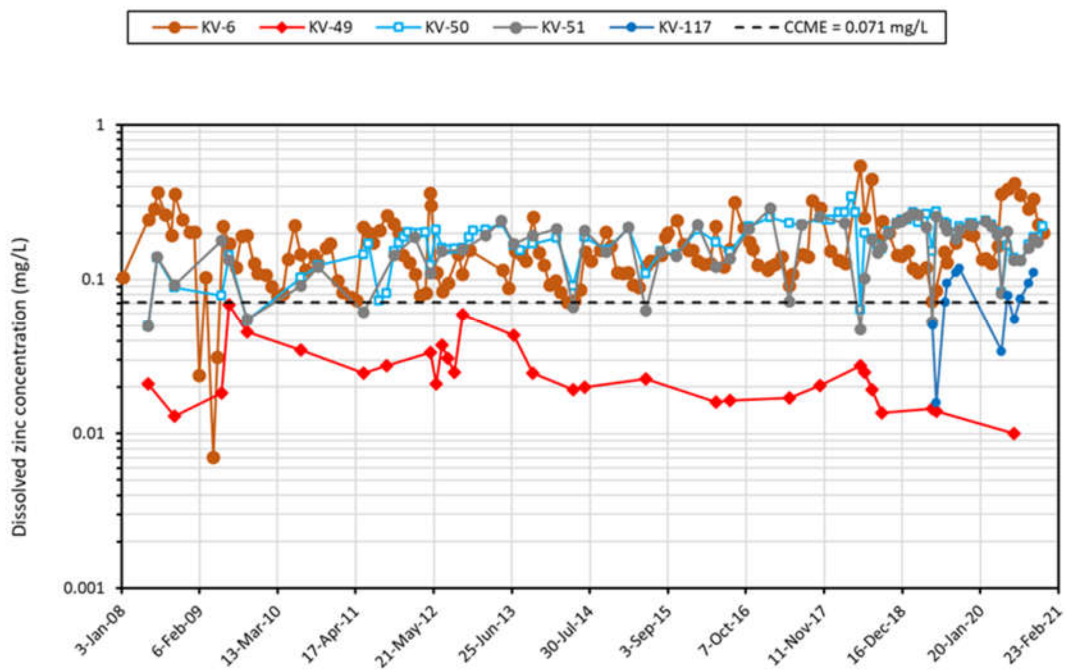

Figure 4-9 Dissolved Zinc at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-16 Dissolved Zinc Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Dissolved Zinc (mg/L); CCME = 0.071 mg/L					
Average	0.026	0.18	0.17	0.17	0.076
Count	30	85	65	146	12
Minimum	0.010	0.050	0.047	0.0071	0.016
Maximum	0.068	0.34	0.29	0.55	0.12
Count <DL	0	0	0	0	0
Standard Deviation	0.014	0.058	0.063	0.086	0.032
1st Quartile	0.017	0.15	0.13	0.11	0.054
Median	0.022	0.19	0.18	0.15	0.077
3rd Quartile	0.030	0.23	0.22	0.20	0.10
Count over Guideline*	0	60	40	99	9
% Over Guideline**	0%	77%	69%	80%	75%

*: number of exceedances out of total number of samples for which pH, DOC and hardness were available to calculate the guideline;
**percentage exceedance based on samples for which pH, DOC and hardness were available to calculate the guideline (i.e., not the total count of samples)

4.5.9 SULPHATE

The dissolved sulphate time series plot and statistical summary of the monitoring data are shown in Figure 4-10 and Table 4-17, respectively. KV-50 and KV-51 had comparable and the highest dissolved sulphate concentrations until mid-2018, and 49% and 33% of their samples were elevated above the BC ENV guideline (429 mg/L), respectively. However, the sulphate concentration measured at both these stations has declined in recent years (2017 onwards). Since mid-2018, dissolved sulphate measured at KV-6 was generally comparable to KV-50 and KV-51 due to a decrease of their dissolved sulphate, and the sulphate concentration at all stations was typically below the BC ENV guideline since mid-2018. The lowest sulphate concentrations were measured at KV-49 and KV-117 (median = 208 mg/L and 134 mg/L, respectively) with only one exceedance at KV-49 during the monitoring period. All stations showed muted or clear seasonality with the lowest sulphate concentrations observed in May-June and peak concentrations in June-October since 2014

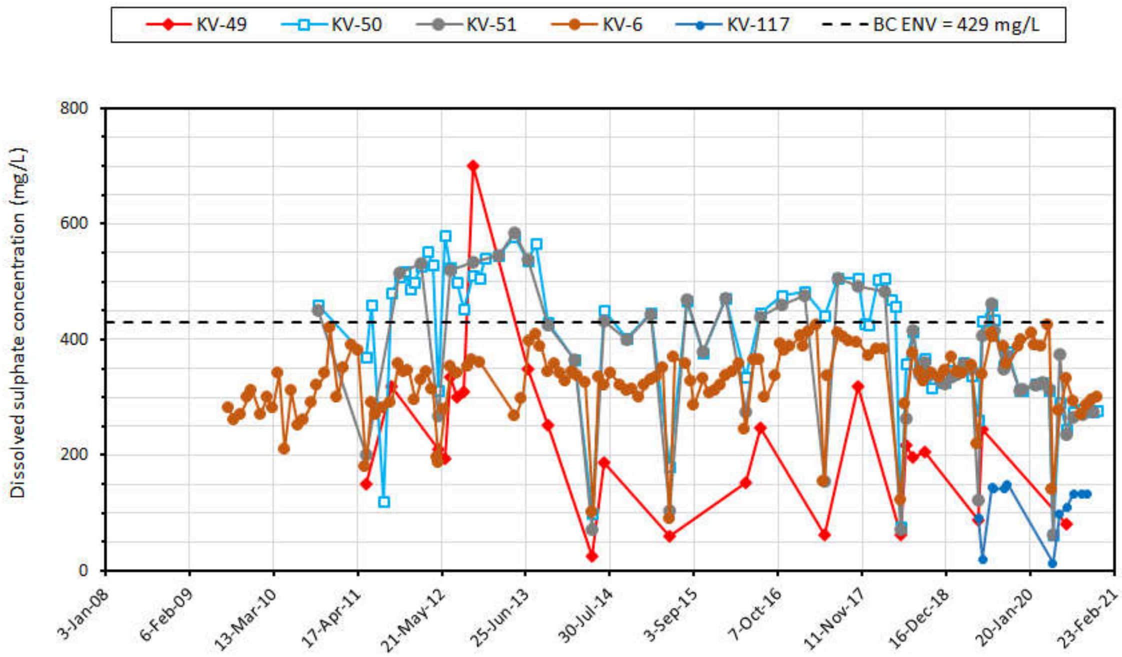

Figure 4-10 Dissolved Sulphate at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

Table 4-17 Dissolved Sulphate Statistics at Monitoring Stations KV-49, KV-50, KV-51, KV-117 and KV-6, 2008-2020 Data

	KV-49	KV-50	KV-51	KV-6	KV-117
Dissolved Sulphate (mg/L); BC ENV = 429 mg/L					
Average	220	399	359	325	110
Count	24	78	58	130	12
Minimum	25	62	62	89	13
Maximum	701	581	584	425	150
Count <DL	0	0	0	0	0
Standard Deviation	141	117	126	65	47
1st Quartile	135	325	290	296	97
Median	208	428	360	336	134
3rd Quartile	302	495	458	365	142
Count over Guideline	1	38	19	0	0
% Over Guideline	4%	49%	33%	0%	0%

4.5.10 SEEP KV-121

The monitoring of this natural seep began in February 2019 to comply with recommendations #1 and #5 of the Water Resources Branch (WRB) as reported in the Water Licence Audit conducted in June 2018 (WRB, 2018). These recommendations stipulate that the seep should be added to the water quality monitoring program, monitored regularly and included in this study. The seep was sampled monthly for dissolved and total metals since February 10, 2019 and a statistical summary of WQ data for parameters of interest is shown in Table 4-18.

The dissolved concentration generally accounted for the majority of total concentration, indicating most elements were transported as dissolved species. The exceptions were February and June 2019 when the dissolved concentrations of several constituents (cadmium, iron, manganese, arsenic, antimony, and zinc) represented less than 50% of the total concentration. Fluctuations of sulphate and metal(loid)s concentrations occurred at the seep and the peak total concentration of parameters of interest occurred at different periods of the year generally in May through October. Antimony (and silver, lead, chromium, and copper) concentrations were mostly below the detection limit.

The two-year dataset was plotted with KV-117 and KV-50 to determine how its WQ compared to the baseline (KV-117) and the downstream station (KV-50) and assess its potential metal loadings contribution to Christal Creek. The visual comparison shows that:

- Concentrations of cadmium, antimony, manganese, sulphate, zinc, arsenic, iron at KV-121 were comparable with the data collected at KV-50 until June 2020 after which they diverged such that concentrations at KV-121 tended to be higher (except cadmium and antimony which were lower). All comparative plots are compiled in Appendix C.
- The total concentration of cadmium and antimony at the seep KV-121 were slightly lower than the baseline station KV-117, field pH and ORP were comparable, but sulphate, arsenic, manganese, and zinc were higher than KV-117 (Appendix C).

The data above suggest that the groundwater seep may be impacting the concentrations of some metals and metalloids in Christal Creek. This may be particularly true for sulphate and cadmium. However, other unidentified sources of metals could be present along the water course between KV-117 and KV-50. The discharge from this seep will continue to be monitored.

Table 4-18 Summary of Main Constituents of Interest at KV-121, 2019-2020 Data

	Seep KV-121							
Parameter	**Field pH**	**Dissolved Sulphate**	**Arsenic**	**Antimony**	**Cadmium**	**Manganese**	**Iron**	**Zinc**
Unit	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Average	7.1	362	0.031	0.000086	0.00029	1.4	3.2	0.30
Count	22	21	21	21	21	21	21	21
Minimum	6.6	115	0.0068	0.000050	0.000065	0.24	0.55	0.088
Maximum	8.0	536	0.047	0.00068	0.0035	2.4	5.1	0.63
Count <DL	0	0	0	18	0	0	0	0
Standard Deviation	0.33	107	0.013	0.00014	0.00073	0.61	1.3	0.12
1st Quartile	6.9	306	0.023	0.000050	0.000085	1.18	2.6	0.23
Median	7.1	361	0.031	0.000050	0.00013	1.7	3.6	0.31
3rd Quartile	7.3	447	0.043	0.000050	0.00016	1.8	3.9	0.37

*: All concentrations are totals except sulphate

5 CONCLUSIONS

The results of physical, chemical and microbiological testing conducted on surficial soil and moss samples collected from three transects along the proposed discharge corridor between the Flame & Moth discharge diffuser and Christal Creek indicate the following:

- The soil samples consist mostly of silt loam with a significant clay content (up to 15% on average). The high silt and clay contents are predicted to create large surface areas favourable for the retention of metals through adsorption or cation exchange with the discharged water;

- The soil pHs were neutral (pH 6.0 to 6.7) reflecting an environment where low mobility of several metal(loid)s is anticipated due to the precipitation of oxide or hydroxides (iron and aluminum) that may also co-precipitate other metal(loid)s from the discharge water. Under the buffered soil pH conditions, soil particles such as clay with a pH-dependent surface charge will be net negatively charged creating conditions favourable for the adsorption of metal cations;

- The study site had a median soil moisture content of 52% indicative of a moderate water holding capacity favourable for the development of vegetation cover, peaty and organic-rich surficial materials along the discharge channel which may promote natural attenuation. The median soil organic matter content ranged from 14.7% to 22.4%. The soil along the proposed discharge channel contains a significant amount of organic matter that will likely create favourable conditions for metal sorption, immobilization and attenuation;

- The majority of COPI were predominantly associated at varying proportions with the residual, reducible and organic matter/sulphide soil compartments. Although the exchangeable fraction and carbonate phases contained the lowest fractions of COPI, cadmium was predominantly tied to the exchangeable phase. Carbonate minerals also hosted up to 17% of the cadmium, lead, manganese and zinc in the soils, suggesting metal removal via precipitation as (or co-precipitation with) carbonate phases may also assist natural attenuation;

- The largest concentrations of COPI in the soils were often associated with the residual phase, indicating this portion of the metal inventory is strongly tied to the mineral lattice and predicted to be stable in the soil matrix significantly decreasing their solubility and potential bioavailability. Although the proportion of COPI associated with the reducible soil fraction could be remobilized following the development of iron-reducing conditions, the marshy and organic matter rich environment lends itself to the subsequent development of sulphate-reducing conditions under which previously mobilized chalcophile metals may be re-sequestered as sulphide mineral assemblages;

- Microbial community profiling identified the presence of bacteria closely related to microorganisms capable of mediating iron and sulphur redox transformations, indicating the microbial potential exists for long term metal sequestration via sulphide mineral precipitation;

- These data indicate that soil and landcover conditions along the proposed discharge corridor are favourable for natural attenuation of metal(loid)s in the treatment discharge;

- Transect T-1 generally had the highest metal concentrations especially arsenic, antimony, cadmium, iron, manganese, copper, nickel, lead and zinc. The concentration of these constituents was commonly at least two- to three- fold higher than the transect-2. Transect-3 had the lowest suggesting a decreasing metal content in vegetation downstream along the proposed discharge channel; and

- The 2008 to 2020 surface water quality data show that the concentrations of sulphate, arsenic, cadmium, copper, iron, lead, manganese, and zinc were constantly or occasionally above their respective guidelines along Christal Creek, while pH below pH 6.0 were occasionally observed at KV-49 and KV-51.

6 NEXT STEPS

The next steps in this study will involve:

- Continue to collect water quality data from existing locations;
- Install drive-point piezometers along flow path;
- Additional characterization of the topography and landcover along the discharge corridor if discharge to Christal Creek starts including monitoring for any glaciation of discharge between the diffuser and Christal Creek; and
- Monitoring and assessment of natural attenuation after the discharge has begun.

7 REFERENCES

Access Consulting Group (ACG). 2013. *2013 Water Quality Review for the Keno Hill Silver District*, Prepared for Elsa Reclamation and Development Company Limited.

Alexco Environmental Group (AEG). 2016. *Flame & Moth Mine – Mass Load Modeling Results for Christal Creek and Lightning 2016*, prepared for Alexco Keno Hill Mining Corporation.

Alexco Environmental Group (AEG). 2018a. *Christal Creek Attenuation Study Plan, Keno Hill Silver District Mining Operations, 2018*, prepared for Yukon Government.

Alexco Environmental Group (AEG). 2018b. *Keno Hill Silver District Stream Discharge Monitoring and Automated Stream Discharge Monitoring 2017 Report. 2018*, Prepared for Elsa Reclamation and Development Company Limited.

Burt, R. 2009. *Soil Survey Field and Laboratory Methods Manual*. Soil Survey Investigations Report No. 5. Method 3.2.1.2.2. United States Department of Agriculture Natural Resources Conservation Service.

Canada North Environmental Services. (CanNorth). 2018. *Updated Post-Reclamation Human Health and Ecological Risk Assessment for the United Keno hill Mines*, Yukon. 2018. Prepared for Elsa Reclamation and Development Company Limited.

Interralogic, Inc. (ITL). 2013. *Natural Attenuation Evaluation Summary Report, United Keno Hill Mines, Elsa, YT.* Report submitted to Elsa Reclamation and Development Company Ltd., November 2013.

Nordstrom, D.K. 1982. *Aqueous pyrite oxidation and the consequent formation of secondary iron minerals*. In J.A. Kittrick, D.S. Fanning, and L.R. Hossner, Eds. Acid sulfate weathering, Volume 10, p. 37-56. Soil Science Society of America, Madison.

Pribyl, D.W., 2010. A critical review of the conventional SOC to SOM conversion factor. Geoderma 156, 75–83.

Rauret G., Lopez-Sanchez J., Sahuquillo A., Rubio R., Davidson C., Ure A. 1999. *Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials*. Journal of Environment Monitoring, 1: p. 57–61.

Richard, T.W. 2007. *Metal Attenuation processes at Mining Sites. Ground Water Issues* - United States Environmental Protection Agency.

Silveira, M.L. Alleoni, L.R.F., O'Connor, G.A., Chang, A.C. 2006. *Heavy metal sequential extraction methods– A modification for tropical soils*. Chemosphere, 64. p. 1929–1938.

Stumm, W., Morgan, J.J. 1996. *Aquatic Chemistry*, New York: Wiley and Sons.

Tessier, A., Campbell, P.G.C. and Bisson, M. 1979. *Sequential extraction procedure for the speciation of particulate trace metals.* Analytical Chemistry, vol.51, pp 844-851.

United States Environmental Protection Agency (EPA). 1999. *Monitored Natural Attenuation of Chlorinated Solvent*. Yukon Government. 2018. *Water Licence Audit for QZ09-092-2 and QZ17-084*. December 31, 2018. Water Resources Branch

APPENDIX A.
Laboratory Analytical Reports

Soil and Moss Geochemical and Microbiological -Surface water and Groundwater Quality Data

APPENDIX 1.7

CHRISTAL CREEK ATTENUATION STUDY INTERIM REPORT

No Cash Creek Attenuation Study Interim Report

Keno Hill Silver District – Bermingham Mine

March 31, 2021

Prepared for:

Alexco Keno Hill Mining Corp.

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EXECUTIVE SUMMARY

Attenuation studies previously conducted in the No Cash Creek catchment area have shown significant reduction of metals such as cadmium, manganese and zinc along flow path from the No Cash 500 adit discharge. The decreases were attributed to various attenuation mechanism including precipitation of iron and manganese oxides/hydroxides, coprecipitation of metals, update by plants and adsorption (Interralogic, 2012). Also, water quality modelling work performed to support the Flame & Moth and Bermingham Projects assumed natural attenuation rates of 50% for selected constituents such as arsenic, cadmium, nickel and zinc between the water treatment plant (WTP) discharge locations and the designated terminus (AEG, 2016, AEG 2018a) based on those previous studies.

This No Cash Creek Attenuation Study Plan (AEG, 2018b) was undertaken to satisfy a recommendation issued by the Yukon Government under term 5 of the Bermingham Mine Yukon Environmental and Socio-economic Assessment Decision Document. YESAB had recommended the implementation of a study to monitor the mechanism of natural attenuation of constituents of the discharge and surface water in the No Cash Creek catchment following the initiation of the Bermingham water treatment plant. Additionally, this interim report has been prepared to satisfy Clauses 40 and 119 e) of Water Licence QZ18-044 that requires interim results to be provided as part of the annual report.

The ultimate aim of the study is to better understand the mechanism of natural attenuation along the 1,500 m proposed discharge pathway from the Bermingham mine discharge and headwaters of No Cash Creek to verify the assumptions made during the water quality modelling studies conducted for the No Cash Creek. This report presents the initial site characterization results along the expected flow path between the Bermingham discharge and No Cash Creek upper catchment area.

Twenty-one surficial soil samples were collected along the discharge channel between the Bermingham discharge location and the upper catchment area of No Cash Creek to assess the potential for natural attenuation mechanisms related to soil conditions along the flow path. The soil testing program included the determination of physical, chemical and microbiological characteristics of the soil samples. The program also included the collection of moss samples from six sites along the discharge channel for metals analysis and the sampling of baseline surface water and groundwater water quality.

The soil samples consisted mostly of silt (twelve samples), silty loam (five) and gravel (one sample) with various proportions of clay and sand comprising the remainder of soil. The combined silt and clay contents are predicted to result in large surface areas favourable for metal adsorption or cation exchange processes with the discharged water.

The study site had a low organic matter content (median of 13.3%) that do not reflect the most favorable conditions for sorption, immobilization and attenuation of metals but will offer some level of attenuation;

The soil pHs were acidic to mildly acidic (median pH 5.4) with only one neutral soil pH reflecting an environment impacted by the weathering products of local mineralization. The soil pH conditions of the first two thirds of the channel do not constitute an optimum environment for the precipitation of oxide or hydroxides, however the soil pH values were higher than the point zero charge pH of most clay minerals which are conducive for the retention of metals cations by variable surface charge clays.

The study site had a median soil moisture content of 48.3% indicative of a moderate water holding capacity favourable for the development of vegetation cover, peaty and organic-rich surficial materials along the discharge channel which will promote natural attenuation.

Microbial profiling identified the presence of microorganisms capable of mediating sulphur redox transformations, indicating the potential exists for long-term metal sequestration via sulphide mineral precipitation. The marshy and organic matter rich environment will favor the development of sulphate-reducing conditions under which chalcophile metals may be sequestered as sulphide mineral assemblages. These soil data indicate conditions favorable for natural attenuation of metal(loid)s in the treatment discharge along the proposed discharge corridor.

The moss samples had different metal contents depending on their location along the discharge channel. Vegetation material in the most downstream moss sampling site (BM-NAT-18) had the highest concentration of arsenic, cadmium, iron, manganese, copper, nickel, lead, and zinc and the vegetation located in the area closest to the Bermingham discharge location had the lowest. The elevated metals concentrations in the BM-NAT-18 moss was likely caused by soil residue left in the sample after washing during sample preparation.

The concentration of arsenic, cadmium, copper, nickel, ammonia, selenium and zinc in the Bermingham discharge increased during early monitoring (July 2007 to August 2018) and in the second half of 2020 (June to December 2020: arsenic, ammonia-N and selenium only) due to development activities.

Surface water monitoring data indicate circumneutral pH and oxic conditions at the monitoring stations. The water quality at the Bermingham discharge was often better or comparable to the water quality at KV-118 (upper No Cash Creek at Calumet Drive) except for arsenic, selenium and ammonia for the same period. This means that the WTP discharge from the Bermingham mine will contribute to improving water quality downstream except during the isolated peak concentrations. It was also noted that the water quality at KV-111 (No Cash Creek above the No Cash 500 adit) was better than KV-118 suggesting that attenuation and/or dilution mechanism are occurring in the discharge channel.

Local groundwater monitoring data indicate sub-oxic to oxic, circumneutral pH and low salinity groundwater. The data also show recurrent or occasional exceedance of Yukon Contaminated Site Regulation value by arsenic, and cadmium in one of monitoring wells or both.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	Absolute Value
ACG	Access Consulting Group
AEG	Alexco Environmental Group Inc.
AKHM	Alexco Keno Hill Mining Corp.
BC	British Columbia
BCMOE	British Columbia Ministry of Environment
CCME	Canadian Council of Ministers of the Environment
COPI	Constituents of Potential Interest
DL	Detection Limit
IRM	Internal Reference Material
KHSD	Keno Hill Silver District
MV	Measured Value
QAQC	Quality Assessment and Quality Control
qPCR	quantitative Polymerase Chain Reaction
RP	Recovery Percentage
RPD	Relative Percent Difference
TC	Total Carbon
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
OTU	Operational Taxonomic Units
WQ	Water Quality
WTP	Water Treatment Plant
YESAB	Yukon Environmental and Socio-economic Assessment

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES OF THE STUDY

Under term 5 of the Bermingham mine Yukon Environmental and Socio-economic Assessment (YESAB) Decision Document, YESAB recommended the implementation of a study to monitor the mechanism of natural attenuation of discharge and surface water constituents in the No Cash Creek catchment following the initiation of the Bermingham water treatment plant (WTP) and verify the assumptions of attenuation rates used in modelling studies.

Past investigations on natural attenuation mechanisms in the Keno Hill Silver District (KHSD) have documented significant metal(loid) attenuation along groundwater and surface water flow paths, (Interralogic, 2010, Interralogic, 2012, SRK, 2009, Kwong et al., 1994, 1997, AEG, 2011). Attenuation studies conducted in the No Cash Creek catchment area have shown a modest reduction of sulphate and significant decrease of metals such as cadmium, manganese and zinc along flow path from the No Cash adit discharge. The authors attributed these metal reductions to various attenuation mechanism including precipitation of iron and manganese oxides/hydroxides, coprecipitation of metals and uptake by plants and adsorption (Interralogic, 2012). Water quality modelling works performed to support the Flame & Moth and Bermingham Projects assumed a natural attenuation rate of 50% for selected constituents (arsenic, cadmium, nickel, and zinc) between the WTP discharge locations and the designated terminus (AEG, 2016, 2018a).

The aim of the No Cash Creek Attenuation Study is to better understand the mechanism of natural attenuation along the 1500 m proposed discharge pathway from the Bermingham discharge (KV-114) and headwaters of No Cash Creek (KV-111) as discussed in the study plan (AEG, 2018b) and verify the assumptions of attenuation rate made during or determined by the water quality modelling studies conducted for the No Cash Creek environment (Hatch, 2016; AEG, 2018a).

Like elsewhere in the district, it is predicted that the concentration of several metal(loid)s and constituents in the Bermingham WTP discharge are likely to decrease due to biogeochemical processes, exchanges with soil and vegetation or mixing with groundwater and surface water along the discharge corridor. These biogeochemically driven changes may include the removal of metal(loids) and other constituents through direct precipitation, coprecipitation by various oxides/hydroxides (e.g., iron, aluminum, manganese), adsorption on mineral and organic matter and update by vegetation.

This interim report describes the baseline physio-chemical and microbiological characteristics of the environment of the flow path between the Water Treatment Plant (WTP) discharge location and headwaters of No Cash Creek, over which metal(loids) attenuation is assumed to occur.

1.2 SCOPE

The scope of the study includes:

- Characterization of the site prior to WTP operation by collecting baseline data for parameters that influence or impact the flow of the discharge water and changes of its chemistry from the discharge location to No Cash Creek headwater. These baseline data include:
  - Identification of physical and landcover (i.e., vegetation) characteristics of the site;
  - Determination of the type, composition, geochemical and microbiological characteristics of soil along proposed flow path;

- Up to 12-years of available surface water records at the following monitoring stations: KV-18, KV-19, KV-20, KV-21, KV-110, KV-111, KV-114, and KV-118;
- Determination of existing metal content of moss along the flow path; and
- Document existing groundwater quality from wells BH-MW-1, RB-MW-1, NC-MW-1 and KV-116.

- Analysis and interpretation of data, and the assessment of attenuation mechanism to confirm the assumptions made in earlier studies.

1.3 BACKGROUND ON NATURAL ATTENUATION

Natural attenuation is a combination of physical, geochemical, and/or biological processes that naturally reduce the mass, toxicity, mobility, or concentration of contaminants in soil or groundwater. These processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation or reduction of contaminants (EPA, 1999) and metal precipitation. Soil conditions, solution pH, redox potential, soil composition particularity the oxide and clay contents, moisture, organic matter content play significant roles in natural attenuation mechanisms.

When the solution pH is circumneutral or slightly acidic, cationic metal species precipitate as aluminum and iron hydroxide, oxyhydroxide, or hydroxy-sulphate minerals (Nordstrom 1982). Under these pH conditions, dissolved metals may adsorb onto surfaces of these amorphous and minerals and/or other surfaces present in the environment, such as clays and organic matter due to decreasing competition with protons, and increased hydrolysis of metal ions at circumneutral pH (Richard, 2007).

Microorganism such as sulphate-reducing bacteria (SRB) can attenuate the migration of metals in the natural environment through the precipitation of chalcophile metals as sulphide minerals following the reduction of sulphate in the presence of organic matter. Characterization of microbiological impacts on natural attenuation processes involves tools that can be used during site characterization. Genetic analyses such as molecular biological methods relying on 16S rRNA sequences have been used to identify microbial communities in environmental samples (Richard, 2007).

1.4 IMPACT OF BENTONITE ON NATURAL ATTENUATION

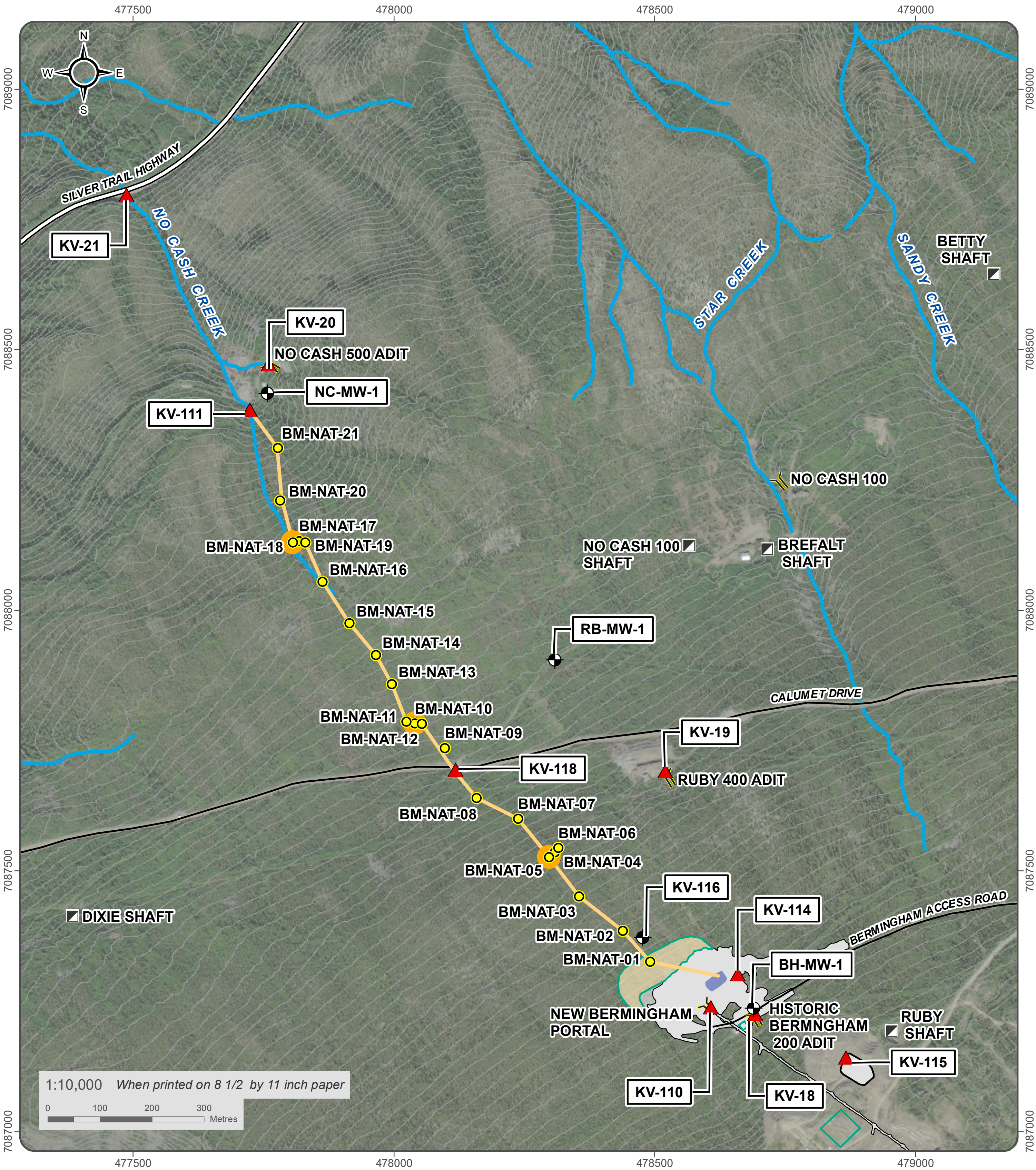
Bentonite clays are mainly composed of montmorillonite; a 2:1 structured phyllosilicate composed of one octahedral sheet located between two tetrahedral sheets. Substitutions inside the structure of lower valence ions for those with higher valance such substitution of aluminium for silicon in the tetrahedral layer and magnesium for trivalent aluminium in the octahedral layer usually create negative electric charge on the bentonite surface. The overall negative charges on the surface attract cations and confers to clay minerals their important metal sequestration properties.

Bentonite clay is used as drilling fluid during exploration activities and bentonite particles can be found mixed with dewatering effluents from the Bermingham adit as noted by Water Resources Branch during their site inspection in June 10 to14, 2018. Although bentonite particles could create a physical water infiltration barrier, bentonite clay is known for its high metal adsorption capacity and effectiveness for the removal of metals (and organic contaminants) due to its structure, high specific surface area, small particle size and high cation exchange capacity (Doulia et al., 2009; Khan et al., 2018). Several studies have tested and proved the high adsorption capacity of bentonite (natural and modified) for metals such as lead, cadmium, copper, chromium, nickel and zinc (Doulia et al., 2009; Khan et al., 2018; Vega et al., 2005) and demonstrated its property as chemical barrier. It is thus expected that bentonite particles mixed with drilling fluids seeping from the adit will contribute to metal attenuation on site instead of hindering it.

2. SITE LOCATION

Figure 2-1 shows the location soil and moss sampling along the discharge channel, mine adits and current and proposed surface water and groundwater quality monition locations. The proposed location of the discharge was selected based on engineering examination and assessment of the topography of the site to limit potential erosion of the channel during discharge and maximize constituent removal and attenuation by promoting longer interaction time between the discharge water and the underlying soils matrix and vegetation cover. By siting the discharge over low grade slopes, the precipitates formed *in situ* will likely remain chemically and physically stable within the discharge area.

The vegetative cover within the discharge corridor is characterized by stunted white and black spruce, scrub birch, willow and Labrador tea. The area has a thick moss cover, which persists throughout the area. The site is homogenous in terms of vegetative cover. In terms of vegetation density, vegetation becomes less dense, and a transition occurs from spruce dominated to willow and birch dominated farther down the hillside. The presence of moss/bog materials is found throughout the discharge corridor .



Location of Soil Sample Collected Sept 4th 2018

Surface Water Quality Station

Moss Samples Collected on October 06, 2016

Adit

Shaft

Attenuation Study Line

Contours (5m interval)

Waterbody

Permitted To Be Constructed Mine Features

Permitted To Be Constructed Mine Features

Proposed Mine Feature

Satelite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on March 26 2021.
Datum: NAD 83; Projection: UTM Zone 8N

AKHM

ALEXCO KENO HILL MINING CORP.

FIGURE 2-1

BERMINGHAM NATURAL ATTENUATION STUDY AREA

MARCH 2021

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(*Last edited by: amatlashevska; 2021-03-26/20:13 PM*)

3. DATA COLLECTION AND TESTING

3.1 SOIL BIOGEOCHEMISTRY

Soil characterization is a fundamental part of investing natural attenuation mechanisms at any given site. The biogeochemical processes controlling the mobility, immobilization and bioavailability of metal(loid)s and other chemical constituents in the natural environment are in large extent controlled by the type of local soil, its composition, structure, metals and organic matter contents, microbiology, pore water chemistry, soil pH and redox potential. Soil along the discharge corridor was investigated, sampled and tested in order assess its potential for natural attenuation.

3.1.1 SOIL SAMPLING AND TESTING

On September 4, 2018, eighteen (18) surficial (top 30 cm) soil samples were collected for geochemical testing from the likely discharge corridor between the Bermingham decant pond (KV-114) and headwater of No Cash Creek (KV-111). The samples were collected such that they were evenly spaced covering the entire proposed study area. Three additional samples destined for microbial profiling were also collected from the same location as three samples collected for geochemical soil testing. The locations of all the twenty-one (21) soil sampling sites are displayed on Figure 2-1 and a description is provided in Table 3-1.

The samples were documented in the field, placed in sealed sampling bags and submitted to ALS Canada (Burnaby, BC) for testing. Eighteen samples were analyzed for:

- Moisture content;
- Particle size;
- Paste pH;
- Total organic carbon; and
- *Aqua regia* digestion followed by multi-element analysis of digestate.

Three samples (BM-NAT-04, BM-NAT-10 and BM-NAT-17) were stored in sterile plastic containers and sent to Contango Strategies (Saskatoon, S.K.) for microbial profiling.

Each of the above analytical methods is briefly discussed below or in the results sections where appropriate.

A sequential extraction test could not be done this time but will be conducted on select samples in future analytical programs and before the discharge begins. The selection of the samples will be done such to capture the range of concentration (i.e., minimum, median and maximum) of constituents of interest such as cadmium and zinc, and soil total organic and clay contents.

Table 3-1: Description of Soil Samples

Sample ID	Sample Type	Distance for Decant Pond (m)	Sampling Date	Type of Test
BM-NAT-01	Soil	170	4-Sep-18	Soil physical and chemical
BM-NAT-02	Soil	248.95	4-Sep-18	Soil physical and chemical
BM-NAT-03	Soil	355.95	4-Sep-18	Soil physical and chemical
BM-NAT-05	Soil	450.65	4-Sep-18	Microbial profiling
BM-NAT-04	Soil	464.95	4-Sep-18	Soil physical and chemical
BM-NAT-06	Soil	475.95	4-Sep-18	Soil physical and chemical
BM-NAT-07	Soil	545.45	4-Sep-18	Soil physical and chemical
BM-NAT-08	Soil	634.65	4-Sep-18	Soil physical and chemical
BM-NAT-09	Soil	747.5	4-Sep-18	Soil physical and chemical
BM-NAT-10	Soil	824.35	4-Sep-18	Microbial profiling
BM-NAT-11	Soil	840.75	4-Sep-18	Soil physical and chemical
BM-NAT-12	Soil	811.35	4-Sep-18	Soil physical and chemical
BM-NAT-13	Soil	918.25	4-Sep-18	Soil physical and chemical
BM-NAT-14	Soil	981.95	4-Sep-18	Soil physical and chemical
BM-NAT-15	Soil	1060.75	4-Sep-18	Soil physical and chemical
BM-NAT-16	Soil	1156.35	4-Sep-18	Soil physical and chemical
BM-NAT-17	Soil	1249.75	4-Sep-18	Microbial profiling
BM-NAT-18	Soil	1261.75	4-Sep-18	Soil physical and chemical
BM-NAT-19	Soil	1237.85	4-Sep-18	Soil physical and chemical
BM-NAT-20	Soil	1345.95	4-Sep-18	Soil physical and chemical
BM-NAT-21	Soil	1446.95	4-Sep-18	Soil physical and chemical

3.1.2 SOIL MICROBIOLOGY

Determining the presence, type and the activity of microorganisms in soil is an important aspect in understanding of natural attenuation and metal sequestration. Various studies have shown that soil microorganisms promote the attenuation of metals and the transformation of attenuated metals into stable forms such as metal sulphides under anaerobic and organic-rich soils conditions.

Three select samples (BM-NAT-04, BM-NAT-10 and BM-NAT-17) were tested for the following:

- Microbial community profiling via 16S rRNA to identify microorganisms to the genus level, including sulphide-producing bacteria; and
- Enumeration of sulphate-reducing bacteria using quantitative polymerase chain reaction (qPCR).

The objective of these tests is to understand the structure of the microbial community, including members that may play an active role in attenuation processes that can immobilize metal(loid)s into stable mineral forms under site conditions.

In brief, DNA is extracted from the soil 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 species level.

The quantification of sulphate-reducing bacteria was performed by qPCR targeting the β-subunit of the dissimilatory sulfite reductase *dsrB* gene. The dissimilatory sulphite reductase is the primary enzyme in the dissimilatory sulphate reduction gene in sulphate-reducing prokaryotes, hence, this approach targets sulphate-reducing bacteria.

3.2 VEGETATION (MOSS)

Six (6) moss samples (BM-NAT-05-A, BM-NAT-05-B, BM-NAT-10-A, BM-NAT-10-B, BM-NAT-18-A and BM-NAT-18-B) were collected from three locations along the likely discharge corridor between the Bermingham decant pond (KV-114) and headwater of No Cash Creek (KV-111) (Figure 2-1). Two samples were collected at each location between October 03 and 05, 2019 and sent to the laboratory for moisture and metal content analysis of the tissue. The samples were rinsed with deionized water to remove soil/dust particles before being homogenized and digested for metal content analysis. The moisture content was determined on a pre-rinsed sample portion. A brief description of the samples is provided in Table 3-2.

Table 3-2: Description of Moss Samples

Sample ID	Sample Type	Distance from Decant Pond (m)	Sampling Date
BM-NAT-05-A	Moss	476	6-Oct-19
BM-NAT-05-B	Moss	476	6-Oct-19
BM-NAT-10-A	Moss	824	6-Oct-19
BM-NAT-10-B	Moss	824	6-Oct-19
BM-NAT-18-A	Moss	1262	6-Oct-19
BM-NAT-18-B	Moss	1262	6-Oct-19

3.3 WATER QUALITY

Twelve years (2008 to 2020) of surface water quality (WQ) and seven years (2013 to 2020) of groundwater records from monitoring stations set up along study area were used as background data in this study. Field parameters and total and dissolved metal(loid) concentrations were reviewed from the following operating surface monitoring stations and groundwater monitoring wells:

- KV-18 (Bermingham 200 adit; monthly sampling);
- KV-19 (Ruby 400 adit; monthly sampling);
- KV-20 (No Cash 500 adit; monthly sampling);
- KV-21 (No Cash Creek u/s Silver Trail Highway; monthly sampling);

- KV-110 (Bermingham Adit discharge; weekly sampling since July 2017);
- KV-111 (No Cash Creek above No Cash 500 adit; monthly sampling since September 2017);
- KV-114 (Bermingham Decant Pond; weekly sampling since September 2020);
- KV-116 (Bermingham N-AML waste rock disposal area Monitoring Well; monthly sampling since November 2020);
- KV-118 (Upper No Cash Creek at Calumet Road; monthly sampling since July 2018);
- BH-MW-1 (Bermingham adit Monitoring Well; monthly sampling since September 2013);
- RB-MW-1 (Ruby 400 adit Monitoring Well; monthly sampling since September 2013); and
- NC-MW-1 (No Cash 500 adit Monitoring Well; monthly sampling since November 2020).

WQ data for these monitoring sites are used to assess surface water and groundwater baseline conditions before the discharge of treated water begins providing a benchmark for the assessment of water quality variation during and after the water treatment discharge. Note that limited WQ data were available for KV-111, KV-114, and KV-118 because they were recently initiated. Several groundwater wells including KV-116 and NC-MW-1 were drilled in the Bermingham area in Q4 of 2020 and were only sampled twice. Due to limited information, these data are omitted from this report but will be added to future revisions when sufficient data are available. The location of operating surface stations and groundwater monitoring wells is shown in Figure 2-1

3.4 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

A standard practice QA/QC program was followed to assess the accuracy and reproducibility of laboratory analytical results. Duplicate samples, methods blanks, Internal Reference Material (IRM), Certified Reference Material (CRM) and Laboratory Control Sample (LCS) were included in the analysis were adequate. The reproducibility of the duplicate analyses was assessed by calculating the relative percent difference (RPD) between the lead sample and the duplicate. An RPD ≤20% was considered acceptable where the parameter measured value (mv) reported was >10 times the reporting detection limit (RDL). The RPD is calculated as follows:

$$RPD\ (\%) = 100\ \mathrm{X}\ \frac{\mathrm{ABS\ (Sample\ mv - Duplicate\ mv)}}{\mathrm{Average\ (Sample\ mv, Duplicate\ mv)}}$$

Where:

ABS is the absolute value

mv: measured value

The accuracy of the IRM and LCS analysis was determined by percent recovery (RP) relative to the set target value as follows:

$$RP\ (\%) = 100\ \mathrm{X}\ \frac{\mathrm{Sample\ mv}}{\mathrm{IRM\ or\ LCS}}$$

Where:

RP: recovery percentage

mv: measured value

An IRM percentage recovery of 80-120% was considered acceptable for total carbon (TC) and IRM within the ranges set for particle size distribution (39.1 - 49.1 for sand; 32.5 - 42.5 for silt and 13.4 - 23.4 for clay) and paste pH (5.9 - 6.5) analyses were also considered acceptable. LCS percentage recoveries of 80 - 120% and 90 - 110% were considered acceptable for TIC and TC, respectively, and LCS within the range set for the moisture content (90 - 110%) and paste pH (5.7 - 6.3) were also considered acceptable.

Two duplicates analysis was done for the moisture content for samples BM-NAT-09 and BM-NAT-11 and the calculated RPDs were 13% and 2.3%, respectively indicating a good analytical reproducibility. Also, one duplicates analysis was done for the particle size distribution for samples BM-NAT-16 and all the calculated RPDs were bellow the maximum RPD limit of 25% indicating a good analytical reproducibility. All method blanks included in the analysis of moisture content, TIC and TC returned values below the detection limit indicating a laboratory analyses free from contamination. Calculated RP for IRM and LCS retuned values within the set acceptable percentages and value ranges.

All method blanks included in the analysis of the moisture and metal content of moss tissue returned values below the detection limit indicating a laboratory analyses free from contamination. All CRM and LCS analyses returned values within the set acceptable percentages and value ranges. Thus, the QA/QC results show that the results of soil geochemical tests are acceptable for use in analysis and interpretation.

4. RESULTS

4.1 SOIL GEOCHEMISTRY

The soil test results are discussed below, summarized in Table 4-1 to Table 4-2, and all laboratory reports are compiled in Appendix A.

4.1.1 PASTE pH

Soil pH is a crucial parameter in natural attenuation because it determines the surface charge of clays and the precipitation/dissolution behaviour of metal sinks such as metal oxyhydroxides, carbonates and phosphates. Studies on adsorption mechanisms have shown that generally the adsorption of metal cations increases with increasing pH, while the adsorption of element anions or oxyanions increase with the decrease of pH (Stumm and Morgan, 1996).

The soil pH was determined by saturating a sub-sample with distilled water then an extract from the saturated paste was taken and its pH measured using a pH meter.

The soil pH ranged from 3.8 to 7.1 (median pH of 5.4) with only one sample having a neutral soil pH (pH = 7.1). The majority of samples (10 of the 18 sample; 56%) had an acidic or mildly acidic soil pH less than pH <5.5 with the majority of those located in the first two thirds of the flow path; from the discharge location to mid-distance between Calumet Road and surface water station KV-111. A plot of soil pH versus distance shows a slightly increasing soil pH along the discharge channel with the samples with a soil pH ≈ or > 6 located in lower end of the channel (Figure 4-1).

These acidic to mildly acidic soil pHs reflect an environmental influenced by the weathering products of mineralization or the presence of organic acids from the local organic matter. The results of X-ray diffraction and acid-base accounting tests conducted on soils and sediment samples in previous studies had revealed the presence of sulphide minerals in sediment and soil along attenuation routes (Interralogic, 2012). The current environmental conditions of the channel, especially the first two thirds, are ones where the precipitation of oxide or hydroxides, which may co-precipitate other metal(loid)s from the discharge water, is less than optimum for low metal(loids) solubility. However, the soil pH values, especially in the lower end of the channel, were higher that the point zero charge pH of most clay minerals, therefore the clay fractions characterized by a variable surface charge are likely to have a net negatively charged surface favourable for the retention of metals cations under the site soil pH conditions.

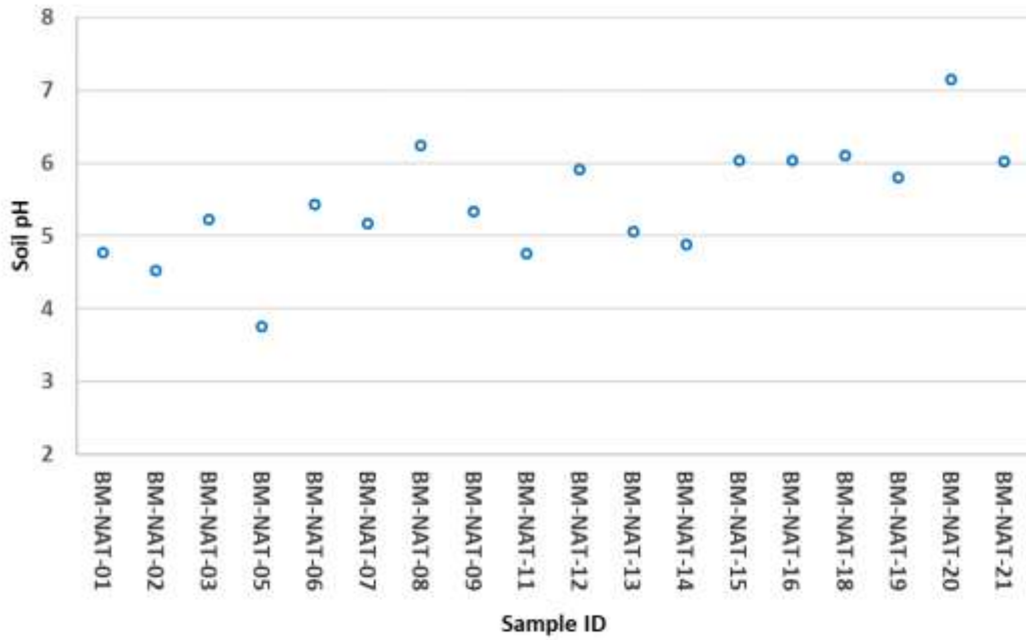


Figure 4-1: Soil paste pH Profile along the Discharge Channel

4.1.2 MOISTURE CONTENT

Soil moisture content analysis was determined by gravimetric method. The procedure consists of weighting a sub-sample, drying it at 105°C for a minimum of six hours then re-weighing it. Moisture content is then calculated as a percentage weight difference between the initial sample and the dried sample.

The results show that the moisture content ranged from 22.3% to 60.1% with a median of 48.3%. The majority of samples except one (BM-NAT-02) had a moisture content greater than 30%. The moisture content varied between the sampling sites; however, an increasing trend was observed in the samples collected after Calumet Road (BM-NAT-12 to BM-NAT-21; Figure 4-2). These moisture content data are indicative of moderate water holding capacity favourable for the development of the vegetation cover and peaty and organic-rich surficial material.

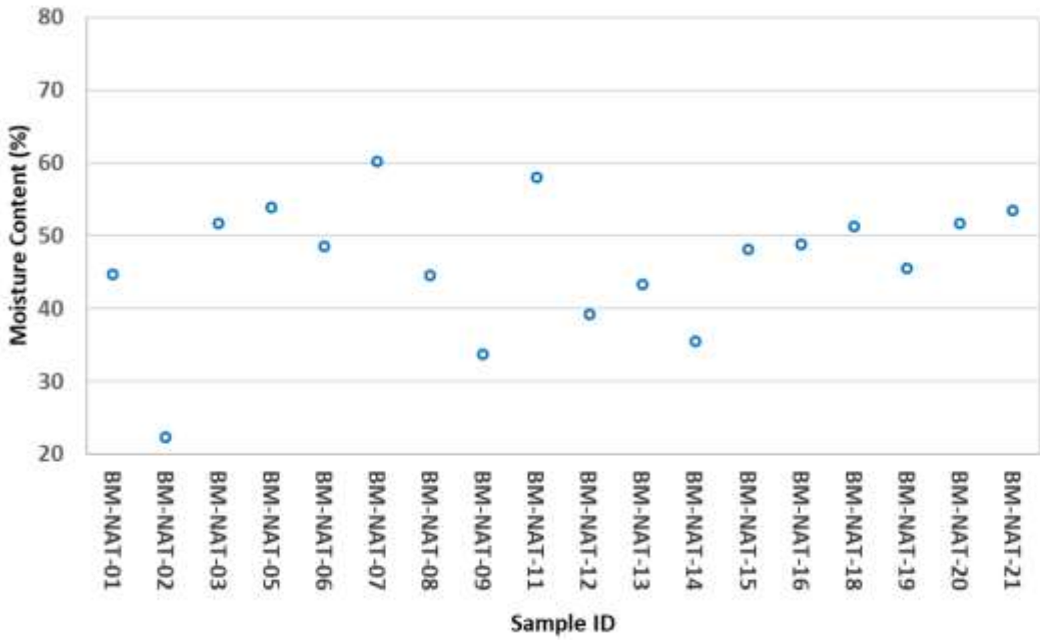


Figure 4-2: Moisture Content of soil along the Discharge Channel

4.1.3 TEXTURE

Soil texture was determined based on the particle size distribution. This was performed following the method developed by the United States Department of Agriculture – Natural Resources Conservation Service (Burt, 2009). During the test, dry sieving was used for coarse particles, wet sieving for sand particles, and the pipette sedimentation method for clay particles.

The results indicate that the soil samples consisted predominantly of silt with gravel dominating in BM-NAT-02 (57.1%) explaining its very low moisture content. The silt proportion ranged from 19.1% to 88.8% with a median of 80.7% and the sand content ranged from 2.3% to 27.7% with a median of 8.8%. The clay content ranged from 2.0% to 9.8% with a median of 8.3% and showed a modestly decreasing trend further away from the discharge location.

The soil texture of the majority of the samples (12 of the 18 samples) was determined to be silt, five (5) were categorized as silty loam and one (1) was sandy loam. The high proportion of silt plus clay is predicted to result in a large surface area favourable for the retention of metals through adsorption or cation exchange processes with the discharged water.

4.1.4 ORGANIC MATTER CONTENT

Like soil pH and clay contents, soil organic matter content plays a significant role in the attenuation and immobilization of metals. Organic matter occurs as a mixture of various types of organisms, biochemicals, and humic substances. These provide functional groups where metals can be adsorbed or favorable for the formation of stable complexes with free ions. Soil organic matter also provides food for the development of microorganisms and serves as electron donor in microbiologically mediated sulphate reduction reactions. It also improves the water holding capacity of soil thus increasing the water-soil exchange reactions.

The organic matter content of soil was determined by its total organic carbon (TOC). The latter was calculated as the difference between total carbon (TC) and total inorganic carbon (TIC). The TC was determined by ignition in a combustion analyzer where carbon in the reduced CO_2 gas is determined using a thermal conductivity detector. The TIC is determined by reacting the sample with known quality of acetic acid then the pH of the resulting solution is measured and compared against a standard curve relating the pH to weight of carbonate.

The TOC of the soil samples was low ranging from 2.4% to 15.5% with a 7.8% median and no particular trend was reflected in the data. The sample with the highest gravel content (BM-NAT-02) had the lowest TOC content (2.4%). These soil TOC can be translated into soil organic matter contents using a conversion factor of 1.72 assuming that 58% of organic matter is present as carbon (Pribyl, 2010). This results in an estimated soil organic matter content ranging from 4.1% to 26.7% (13.3% median). The soils samples contained a relatively low amount of organic matter which will likely impact the extent of sorption, immobilization and attenuation of metals but will offer some level of attenuation.

4.1.5 METAL CONTENT

The metal content of the soil provides an understanding of current site conditions and offers a benchmark against which future data can be compared following the start of WTP discharge. Baseline metal content data also provides indications of the presence of minerals that may play a key role in attenuation mechanisms. For example, the presence of elevated calcium, iron and manganese in a sample could be an indication of the presence of carbonate phases and iron and manganese oxides known for their metal attenuation capacities. The baseline data can also reveal unusually elevated metal concentrations due to site-specific conditions (i.e., presence of weathering products from mineralization) that could otherwise be interpreted as sign of contamination.

The soil metal content was determined by *aqua region* (3:1 mixture of hydrochloric and nitric acids) digestion followed by inductively coupled plasma – mass spectrometry (ICP-MS). Soil split samples (0.5 g) were digested with the *aqua regia* acid mix in a graphite heating block. After cooling, the digestate was diluted with deionized water and analyzed by ICP-MS. Although the aqua *regia* digestion method does not usually result in a full digestion of a soil sample, it provides a good measure of concentration of trace and major elements of potential environmental concern.

For a site-specific assessment of the metal enrichment or depletion, the average metal content of soil samples was compared to the average baseline soil metal composition of the KHSD compiled in July 2018 (CanNorth, 2018;Table 4-3). In the present case, the averages were considered significantly different only if their difference was ten times greater than the detection limit. The results of the comparative analysis are summarized as follows:

- The concentration of arsenic, calcium, copper, strontium, tin and zirconium was higher in the KHSD baseline dataset than the study site soil samples;
- The concentration of the following constituents was elevated in the study area soil samples compared to the KHSD baseline: aluminum, barium, cadmium, cobalt, manganese, vanadium and zinc. The concentration of constituents such as cadmium, manganese and zinc investigated in previous attenuation studies were two, three and four times higher in the study site samples than the baseline soil composition, respectively; and
- All other constituents were considered comparable in both datasets including several constituents related to the mineralization such as iron, silver, nickel, and selenium.

The elevated content of cadmium, manganese and zinc in the study soil samples compared to the baseline are indicative of the greater presence of weathering products of the mineralization. The lower calcium and comparable magnesium and iron concentration with the baseline coupled with low organic matter content and mildly acidic pH indicate less than ideal environment for attenuation, but the elevated silt and manganese contents will likely play a positive role in metals attenuation on site.

Table 4-1: Results of Physical and Geochemical Tests of Soil Samples

Parameter	Lowest Detection Limit	Sample ID	BM-NAT-01	BM-NAT-02	BM-NAT-03	BM-NAT-05	BM-NAT-06	BM-NAT-07	BM-NAT-08	BM-NAT-09	BM-NAT-11
		Units	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Physical Tests (Soil)											
Moisture	0.25	%	44.7	22.3	51.6	53.8	48.5	60.1	44.5	33.6	58.0
Particle Size (Soil)											
% Gravel (>2mm)	1.0	%	9.0	57.1	3.0	<1.0	2.8	2.4	<1.0	15.6	<1.0
% Sand (2.0mm - 0.063mm)	1.0	%	10.5	21.9	16.7	7.3	3.8	8.1	4.8	23.2	2.9
% Silt (0.063mm - 4um)	1.0	%	71.7	19.1	71.3	84.4	84.9	79.7	86.8	55.5	87.8
% Clay (<4um)	1.0	%	8.9	2.0	9.0	8.0	8.6	9.8	8.4	5.7	9.3
Texture		-	Silt	Sandy loam	Silt loam	Silt	Silt	Silt	Silt	Silt loam	Silt
Organic / Inorganic Carbon (Soil)											
Total Organic Carbon	0.05	%	8.13	2.37	7.62	10.3	7.82	10.2	6.41	5.98	11
Saturated Paste Extractables (Soil)											
Paste pH	0.1	pH	4.76	4.52	5.22	3.75	5.42	5.17	6.23	5.33	4.75
Total Metals (Soil)											
Aluminum (Al)	0.01	%	1.33	0.9	1.15	1.19	1.35	1.31	1.4	1.13	1.32
Antimony (Sb)	0.05	ppm	1.62	2.41	1.02	0.95	1.13	1.66	1.1	1.37	1.41
Arsenic (As)	0.1	ppm	16.3	24.8	10.2	10.6	15.1	18.2	12.8	13.6	12.1
Barium (Ba)	10	ppm	320	140	270	210	370	440	440	360	380
Beryllium (Be)	0.05	ppm	0.28	0.23	0.2	0.18	0.29	0.33	0.32	0.22	0.31
Bismuth (Bi)	0.01	ppm	0.22	0.13	0.12	0.15	0.19	0.16	0.17	0.14	0.16
Boron (B)	10	ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium (Cd)	0.01	ppm	0.79	0.38	0.53	0.4	0.57	1.12	0.66	0.62	0.7
Calcium (Ca)	0.01	%	0.22	0.13	0.4	0.16	0.29	0.27	0.42	0.28	0.31
Chromium (Cr)	1.0	ppm	25	21	21	20	23	24	24	20	23
Cobalt (Co)	0.1	ppm	4.7	5.2	5.8	4.7	6.1	29.4	10.5	13.9	8.3

Parameter	Lowest Detection Limit	Sample ID	BM-NAT-01	BM-NAT-02	BM-NAT-03	BM-NAT-05	BM-NAT-06	BM-NAT-07	BM-NAT-08	BM-NAT-09	BM-NAT-11
		Units	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Copper (Cu)	0.2	ppm	15	13.9	10.5	8.9	12.1	14.4	13.9	11	13.8
Iron (Fe)	0.01	%	1.77	1.82	1.57	1.46	1.77	1.94	1.9	1.56	1.97
Lead (Pb)	0.2	ppm	28.9	18.6	14.1	15	17.5	49.3	14.1	30.9	16.5
Lithium (Li)	0.1	ppm	11.9	8.9	13.5	10.8	13.2	14.1	15.9	12.5	12.4
Magnesium (Mg)	0.01	%	0.28	0.21	0.32	0.24	0.28	0.31	0.35	0.29	0.29
Manganese (Mn)	5.0	ppm	161	223	167	131	304	1580	645	1270	546
Mercury (Hg)	0.01	ppm	0.09	0.1	0.17	0.1	0.09	0.1	0.07	0.06	0.11
Molybdenum (Mo)	0.05	ppm	0.98	1.21	0.71	0.8	0.73	0.79	0.66	0.66	0.75
Nickel (Ni)	0.2	ppm	16.6	14.9	14.5	12.3	14.9	18.5	17.9	13.6	17.2
Phosphorus (P)	10	ppm	980	590	880	880	950	880	770	600	890
Potassium (K)	0.01	%	0.04	0.03	0.04	0.04	0.04	0.05	0.04	0.04	0.04
Selenium (Se)	0.2	ppm	0.9	0.5	1	1.1	1.1	1.4	1.9	0.9	1.7
Silver (Ag)	0.01	ppm	1.55	0.46	0.52	0.48	0.78	1.11	0.34	0.72	0.42
Sodium (Na)	0.01	%	0.01	0.01	0.01	0.01	0.02	0.01	<0.01	<0.01	<0.01
Strontium (Sr)	0.2	ppm	19.4	16.3	20.5	13.2	19.5	18.1	20.7	16.9	22.1
Sulfur (S)	0.01	%	0.06	0.02	0.05	0.05	0.06	0.06	0.05	0.05	0.08
Thallium (Tl)	0.02	ppm	0.15	0.08	0.1	0.16	0.27	0.26	0.22	0.18	0.22
Tin (Sn)	0.2	ppm	0.4	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3
Titanium (Ti)	0.01	%	0.021	0.026	0.024	0.019	0.021	0.023	0.025	0.025	0.021
Uranium (U)	0.05	ppm	1.08	0.74	0.63	0.63	0.84	0.97	0.85	0.57	0.87
Vanadium (V)	1.0	ppm	36	34	30	31	39	37	39	36	36
Zinc (Zn)	2.0	ppm	129	74	72	62	78	99	104	119	89

Table 4-2: Results of Physical and Geochemical Tests of Soil Samples

Parameter	Lowest Detection Limit	Sample ID	BM-NAT-12	BM-NAT-13	BM-NAT-14	BM-NAT-15	BM-NAT-16	BM-NAT-18	BM-NAT-19	BM-NAT-20	BM-NAT-21
		Units	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Physical Tests (Soil)											
Moisture	0.25	%	39.1	43.2	35.4	48.1	48.8	51.2	45.4	51.6	53.4
Particle Size (Soil)											
% Gravel (>2mm)	1.0	%	10.2	<1.0	<1.0	<1.0	<1.0	16.7	<1.0	5.8	3.4
% Sand (2.0mm - 0.063mm)	1.0	%	27.7	5.9	7.5	2.3	7.2	10.1	9.4	27.2	24.3
% Silt (0.063mm - 4um)	1.0	%	57.1	85.2	83.5	88.8	85.0	67.0	81.6	61.8	66.5
% Clay (<4um)	1.0	%	5.1	8.9	9.1	9.0	7.9	6.2	8.1	5.2	5.7
Texture		-	Silt loam	Silt	Silt	Silt	Silt	Silt	Silt	Silt loam	Silt loam
Organic / Inorganic Carbon (Soil)											
Total Organic Carbon	0.05	%	4.45	8.15	5.58	10.4	5.57	15.5	7.68	11.2	6.69
Saturated Paste Extractables (Soil)											
Paste pH	0.1	pH	5.91	5.05	4.87	6.03	6.03	6.09	5.80	7.14	6.02
Total Metals (Soil)											
Aluminum (Al)	0.01	%	1.17	1.15	1.16	1.29	1.25	1.3	1.06	1.07	1.1
Antimony (Sb)	0.05	ppm	2.36	1.17	0.78	2.14	1.41	1.11	1.18	1.24	0.91
Arsenic (As)	0.1	ppm	15.4	18.9	7.3	23.5	17.8	24.9	17.1	36.9	19.7
Barium (Ba)	10	ppm	340	300	240	400	500	480	220	320	400
Beryllium (Be)	0.05	ppm	0.36	0.3	0.2	0.32	0.32	0.5	0.27	0.51	0.3
Bismuth (Bi)	0.01	ppm	0.15	0.17	0.14	0.17	0.17	0.18	0.15	0.19	0.16
Boron (B)	10	ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium (Cd)	0.01	ppm	1.17	0.34	0.24	5	2.53	1.31	4.17	6.09	0.77
Calcium (Ca)	0.01	%	0.64	0.36	0.22	0.57	0.43	0.73	0.36	1.14	0.51
Chromium (Cr)	1.0	ppm	22	21	21	23	22	20	20	22	20
Cobalt (Co)	0.1	ppm	6.2	5.9	4.7	20	91.5	14.7	9.1	11.3	15.6
Copper (Cu)	0.2	ppm	21.3	10.6	8.8	14.3	10.2	60.7	11.6	39.1	18.7

Parameter	Lowest Detection Limit	Sample ID	BM-NAT-12	BM-NAT-13	BM-NAT-14	BM-NAT-15	BM-NAT-16	BM-NAT-18	BM-NAT-19	BM-NAT-20	BM-NAT-21
		Units	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Iron (Fe)	0.01	%	1.71	1.83	1.37	2.21	2.91	2.88	2.01	2.22	2.11
Lead (Pb)	0.2	ppm	67.3	13.7	14	72.5	17.4	17.2	19.6	14.9	17
Lithium (Li)	0.1	ppm	12.2	11.5	11.8	13.6	12.6	12.6	11	11.8	12
Magnesium (Mg)	0.01	%	0.34	0.28	0.28	0.35	0.31	0.48	0.29	0.39	0.32
Manganese (Mn)	5.0	ppm	205	318	180	4890	6210	2040	683	3030	2510
Mercury (Hg)	0.01	ppm	0.09	0.08	0.09	0.11	0.07	0.06	0.05	0.06	0.17
Molybdenum (Mo)	0.05	ppm	0.66	0.75	0.4	0.95	1.41	1.21	0.85	1.24	1.06
Nickel (Ni)	0.2	ppm	16.1	13.2	11.9	20.8	18.9	26.3	17.8	43.3	19.5
Phosphorus (P)	10	ppm	800	680	560	890	720	860	680	650	740
Potassium (K)	0.01	%	0.04	0.04	0.03	0.05	0.04	0.04	0.04	0.05	0.04
Selenium (Se)	0.2	ppm	1.9	1	0.9	1	1	1.3	0.6	1.4	0.6
Silver (Ag)	0.01	ppm	1.53	0.3	0.24	1.24	0.29	0.26	0.31	0.27	0.29
Sodium (Na)	0.01	%	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium (Sr)	0.2	ppm	24.7	19.4	15	21.6	21.7	31.7	16.6	32.3	23.3
Sulfur (S)	0.01	%	0.1	0.06	0.05	0.05	0.05	0.06	0.03	0.07	0.04
Thallium (Tl)	0.02	ppm	0.18	0.18	0.19	0.22	0.2	0.12	0.14	0.1	0.14
Tin (Sn)	0.2	ppm	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.2	0.3
Titanium (Ti)	0.01	%	0.026	0.022	0.023	0.024	0.024	0.037	0.025	0.017	0.024
Uranium (U)	0.05	ppm	0.94	0.63	0.62	0.85	0.71	0.82	0.72	1.2	0.81
Vanadium (V)	1.0	ppm	34	43	29	38	44	63	37	34	37
Zinc (Zn)	2.0	ppm	158	69	56	486	616	112	658	2340	102

Table 4-3: Keno Hill Silver District Background Average Concentration of Soil (CanNorth, 2018)

Total Metal Concentration	Unit	Galena Hill, South McQuesten (latest data)
Aluminum (Al)	%	0.734
Antimony (Sb)	ppm	1.06
Arsenic (As)	ppm	27
Barium (Ba)	ppm	220
Beryllium (Be)	ppm	0.45
Bismuth (Bi)	ppm	0.19
Boron (B)	ppm	2.85
Cadmium (Cd)	ppm	0.71
Calcium (Ca)	%	0.882
Chromium (Cr)	ppm	14.3
Cobalt (Co)	ppm	6.34
Copper (Cu)	ppm	22.9
Iron (Fe)	%	1.85
Lead (Pb)	ppm	22.4
Lithium (Li)	ppm	14.3
Magnesium (Mg)	%	0.295
Manganese (Mn)	ppm	451
Mercury (Hg)	ppm	0.05
Molybdenum (Mo)	ppm	1.03
Nickel (Ni)	ppm	17.5
Phosphorus (P)	ppm	712
Potassium (K)	%	0.03
Selenium (Se)	ppm	0.65
Silver (Ag)	ppm	0.47
Sodium (Na)	%	0.00234
Strontium (Sr)	ppm	32.3
Thallium (Tl)	ppm	0.06
Tin (Sn)	ppm	2.19
Titanium (Ti)	%	0.0113
Uranium (U)	ppm	0.84
Vanadium (V)	ppm	23
Zinc (Zn)	ppm	77.2
Zirconium (Zr)	ppm	1.42

4.2 SOIL MICROBIOLOGY

BM-NAT-04, BM-NAT-10 and BM-NAT-17 were selected for microbial community profiling. Bacteria identified to the genus level that comprised >1% of the OTUs in at least one sample are presented in Table 4-4. Only a single genus, *Nitrospira*, accounted for >1% of the OTUs in at least one soil sample.

Nitrospira are widely distributed in nature and are key nitrite oxidizing bacteria but are not capable of modifying the mobility of major and trace elements via redox transformations. Conversely, *Clostridium* (0.1% to 0.5% of OTUs in all three samples; Table 4-5) genera contain species known to cycle reduced and oxidized forms of sulphur. The presence of organisms in the soil samples with close genetic similarity to genera known to mediate sulphur redox transformations suggests there is the capacity for microbial controls on trace element mobility, for example via sequestration as metal sulphides under sulphide-producing conditions. Members of the genera identified are either anaerobic or obligately anaerobic (i.e., can grow without oxygen) were identified in all three samples suggesting that sulphate-reducing niches are present in the shallow subsurface soil. It is important to note that 99.4% to 99.9% of the OTUs sequenced from each sample were either matched to genera of low abundance in the sample (<1%) or could not be matched to the genus level. The latter reflects the limited number of bacteria isolated in pure culture and available for database matching.

Table 4-4: Abundance of Bacteria Identified to the Genus Level in Transect Soil Samples

Genus	Percentage of bacterial community		
	BM-NAT-10	BM-NAT-17	BM-NAT-4
Nitrospira	0.39%	1.02%	0.14%
Others (each < 1% or not identified to the genus level)	99.61%	98.98%	99.86%

Table 4-5 presents the identification and relative abundance of sulphide-producing bacteria in the three soil samples, and Figure 4-3 compares the quantity of sulphate-reducing bacteria based on qPCR enumeration. A distinction is made between sulphate-reducing and sulphide-producing since not all bacteria produce sulphide from sulphate-reduction; however, the microbial community profiling and enumeration of sulphate-reducers appear complementary. Sequences associated with the *Clostridium* genus comprised the majority of the sulphide-producing bacteria in all three samples with BM-NAT-10 having the highest abundance. OTUs associated with the *Desulfobulbus and Desulfobulbaceae* were only identified in BM-NAT-10 and in much lower abundance than the *Clostridium* sequences. BM-NAT-10 sample had the highest proportion of sulphide-producing and sulphate-reducing bacteria (0.57% of sequenced OTUs and 343,770 gene copies per cm^3 soil, respectively). BM-NAT-04 and BM-NAT-17 returned a similar proportion of sulphide-producing bacteria (0.11% of sequenced OTUs) but BM-NAT-17 had the lowest number of sulphate-reducing bacteria (66,770 gene copies per cm^3 soil). Although a minor proportion of the microbial community, the presence of sulphide-producing bacteria in all three soils suggests the capacity exists for trace element sequestration as sulphide phases.

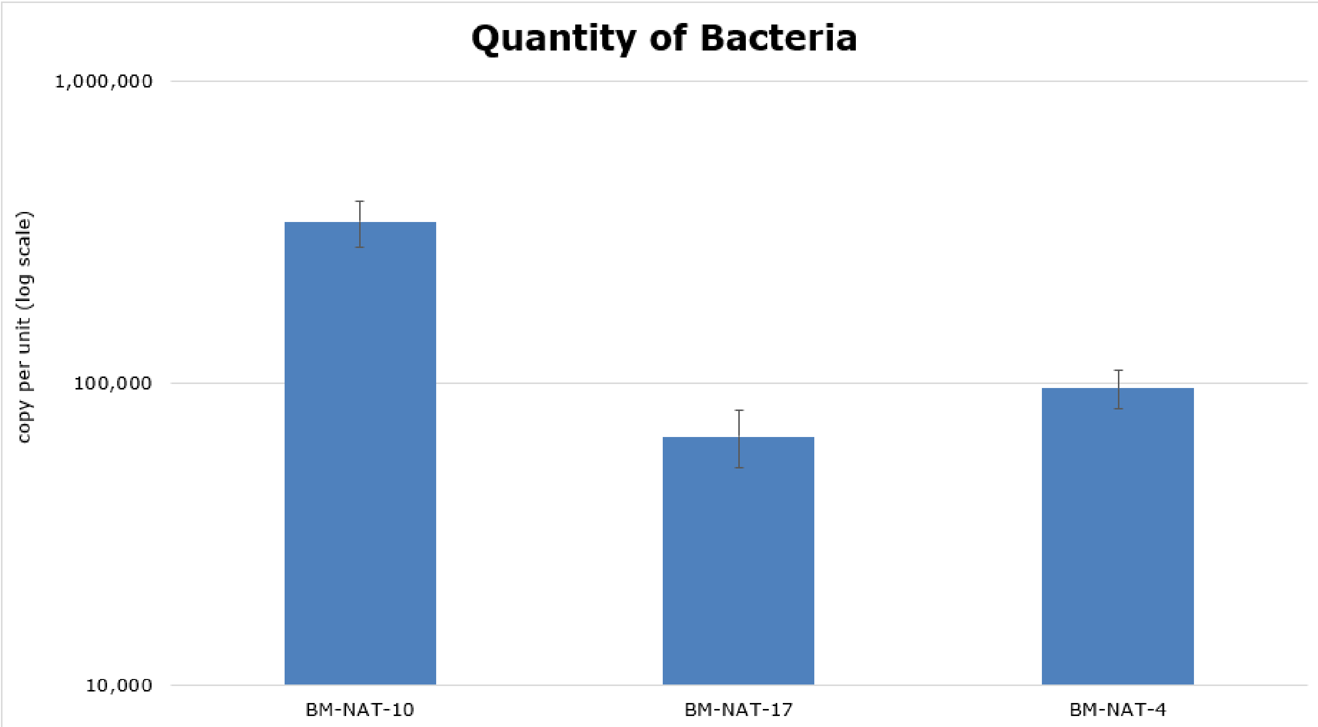


Figure 4-3: Quantity of Sulphate-Reducing Bacteria in Soil Samples

Table 4-5: Identification and Abundance of Known Sulphide-Producing Bacteria in Soil Samples

Genus	Can reduce				Environment			Trait Assignment Category [1]	Percentage of bacterial community		
	Sulphate	Thiosulphate	Sulphite	Sulphur	Aerobic/Anaerobic Characteristics	Temperature	pH	-	BM-NAT-10	BM-NAT-17	BM-NAT-04
Desulfobulbus	Yes	Yes	Yes	No	anaerobic	mesophilic	neutrophilic	A	0.05%	-	-
Desulfobulbaceae family	Yes	Yes, some	Yes, some	Yes, some	anaerobic	mesophilic, some psychrotolerant	typically neutrophilic	A	0.01%	-	-
Clostridium_sensu_stricto	No	Yes	Yes, some	Yes, some	obligately anaerobic	mesophilic	mildly acidophilic to neutrophilic	B	0.51%	0.11%	0.11%
Total SPB Percentage									**0.57%**	**0.11%**	**0.11%**
[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											

4.3 VEGETATION (MOSS)

The baseline total metal composition of moss collected from the likely discharge corridor is provided in Table 4-6 and laboratory reports are compiled in Appendix A. The results of the analysis are summarized as follows:

- The two samples collected from area BM-NAT-18, the most downstream of the sampling sites had the highest metal concentrations. This was especially true for arsenic, cadmium, copper, iron, manganese, copper, nickel, lead, and zinc. The average concentration of these constituents was 2 to 47 times higher than the sampling area with second highest concentration (BM-NAT-110). Cadmium, nickel, and zinc at BM-NAT-18 were particularly elevated compared to BM-NAT-05 and/or BM-NAT-10. The average cadmium concentration at BM-NAT-18 was 14 and 47 times higher than BM-NAT-10 and BM-NAT-05, respectively and the average zinc concentration was 12 and 63 times higher than BM-NAT-10 and BM-NAT-05, respectively. Also, the average aluminum and iron concentration at BM-NAT-18 were nearly 3 and 5 times higher than BM-NAT-10 and 12 and 8 times higher than BM-NAT-05, respectively. These elevated metal data in BM-NAT-18 samples suggest residual soil contamination despite the washing in preparation of testing.
- BM-NAT-10 samples had the highest antimony and second highest metal concentration of arsenic, cadmium, copper, manganese, copper, lead and zinc and BM-NAT-05 had the lowest suggesting an increasing metal content in vegetation downstream of the proposed charge location. The disparity of concentration was not as high as between BM-NAT-18 and BM-NAT-10. The average cadmium and zinc concentration at BM-NAT-10 were only 3 and 5 times higher than BM-NAT-05.
- BM-NAT-10 samples reported the second highest iron and nickel content after BM-NAT-18.

Table 4-6: Results of Elemental Analysis of Moss Samples

Parameter	Lowest Detection Limit		BM-NAT-05		BM-NAT-10		BM-NAT-18	
		Sample ID	BM-NAT-05-A	BM-NAT-05-B	BM-NAT-10-A	BM-NAT-10-B	BM-NAT-18-A	BM-NAT-18-B
		Units						
Physical Tests (Tissue)								
Moisture	0.50	%	81.2	93.6	92.1	86.5	78.3	78.9
Total Metals (Tissue)								
Aluminum (Al)-Total	2.0	mg/kg	395	601	127	97	1080	1550
Antimony (Sb)-Total	0.010	mg/kg	0.2	0.2	0.4	0.36	1.21	1.71
Arsenic (As)-Total	0.020	mg/kg	0.7	0.9	1.4	1.34	4.76	8.82
Barium (Ba)-Total	0.050	mg/kg	18.6	120	24.6	34.6	91.8	92.3
Beryllium (Be)-Total	0.010	mg/kg	0.019	0.036	<0.010	<0.010	0.101	0.140
Bismuth (Bi)-Total	0.010	mg/kg	<0.010	<0.010	<0.010	<0.010	0.026	0.021
Boron (B)-Total	1.0	mg/kg	<1.0	<1.0	1.6	5.0	6.3	6.0
Cadmium (Cd)-Total	0.0050	mg/kg	0.6	0.8	2.2	2.55	32.9	34.1
Calcium (Ca)-Total	20	mg/kg	1530	4160	5310	5500	13900	13900
Cesium (Cs)-Total	0.0050	mg/kg	0.507	0.076	0.0645	0.0499	0.736	0.494
Chromium (Cr)-Total	0.050	mg/kg	0.38	0.333	0.288	0.250	1.73	2.28
Cobalt (Co)-Total	0.020	mg/kg	0.377	1.60	0.252	0.387	1.73	2.84
Copper (Cu)-Total	0.10	mg/kg	2.1	2.1	2.7	4.6	17.2	24.4
Iron (Fe)-Total	3.0	mg/kg	314	625	365	295	1980	3030

Parameter	Lowest Detection Limit	Sample ID	BM-NAT-05		BM-NAT-10		BM-NAT-18	
			BM-NAT-05-A	BM-NAT-05-B	BM-NAT-10-A	BM-NAT-10-B	BM-NAT-18-A	BM-NAT-18-B
		Units						
Lead (Pb)-Total	0.020	mg/kg	10	19	24	19	28	46
Lithium (Li)-Total	0.50	mg/kg	<0.50	<0.50	<0.50	<0.50	0.71	1.01
Magnesium (Mg)-Total	2.0	mg/kg	627	1160	1250	1270	1740	1960
Manganese (Mn)-Total	0.050	mg/kg	415	350	311	918	1540	2440
Molybdenum (Mo)-Total	0.020	mg/kg	0.073	0.102	0.043	0.067	0.247	0.356
Nickel (Ni)-Total	0.20	mg/kg	0.70	2.12	1.03	0.79	37.2	39.2
Phosphorus (P)-Total	10	mg/kg	629	524	949	893	1380	1590
Potassium (K)-Total	20	mg/kg	3090	3010	3520	2270	2190	2670
Rubidium (Rb)-Total	0.050	mg/kg	16.0	10.7	8.05	5.26	19.5	23.2
Selenium (Se)-Total	0.050	mg/kg	<0.050	0.055	<0.050	<0.050	0.306	0.468
Silver (Ag)-Total	0.0050	mg/kg	0.4	0.26	0.53	0.51	1.30	1.50
Sodium (Na)-Total	20	mg/kg	<40	182	41	<20	48	123
Strontium (Sr)-Total	0.050	mg/kg	4.8	18.1	11.00	9.1	35.8	35.1
Tellurium (Te)-Total	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Thallium (Tl)-Total	0.0020	mg/kg	0.0052	0.0247	0.0128	0.0029	0.0620	0.0821
Tin (Sn)-Total	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	0.11	0.14
Uranium (U)-Total	0.0020	mg/kg	0.0123	0.0477	0.0124	0.0087	0.306	0.534
Vanadium (V)-Total	0.10	mg/kg	0.48	0.51	0.35	0.25	2.98	4.19
Zinc (Zn)-Total	0.50	mg/kg	42	46	276	175	2740	2780
Zirconium (Zr)-Total	0.20	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.25	0.91

4.4 WATER QUALITY

4.4.1 SURFACE WATER QUALITY

The dissolved concentrations of constituents of potential interest (COPI) in surface waters sampled from KV-118 to KV-21 between 2008 and 2020 were compared with the effluent quality standards (EQS) for the Bermingham WTP and the No Cash Creek water quality objectives (WQO), respectively. The EQS are defined in the Water Licence (QZ18-044) that came into effect on July 23, 2020 (YG, 2020), while the WQO are listed in the adaptive management plan (Ensero, 2020). Although they do not apply to the untreated discharge, the EQS were also compared with data collected from KV-110 to provide a benchmark for comparison. For hardness-, pH-, dissolved organic carbon- (DOC), and temperature-dependent constituents namely copper, nickel and lead, the WQO was determined on a sample-by-sample basis. The comparison of water quality results with the EQS and WQO was to provide a benchmark for comparison with surface WQ data after the Bermingham water treatment discharge has begun, identify relatively elevated constituents in WQ data prior to the July 2017 decline discharge during advanced exploration, and determine WQ changes during the July 2017-December 2020 discharge period.

Time series plots depicting the results for COPI are shown in Figure 4-4 through Figure 4-15 and associated summary statistics are reported in Table 4-7 through Table 4-16. Only dissolved arsenic was elevated above the EQS in more than

10% of the samples. These elevated concentrations mostly occurred pre-2019 and since the end of September 2020. Also, cadmium and zinc rose above the WQO in 2020 at KV-21 and the copper and zinc concentration in 10% of the samples was greater than the WQO. Three of the thirteen samples collected at KV-114 returned a pH greater than 9.5.

4.4.1.1 Field pH

Field pH data indicate a generally stable neutral field pH despite a few isolated exceedances. Also, there was no seasonality depicted in the field pH data. The field pH has remained in the neutral range (pH 6.5 -9.0) during the monitoring period with the exception of a few excursions of field pH below pH 6.5 at the Bermingham 200 adit and Ruby 400 adit mostly pre-2016 and recurrent alkaline pH at KV-114. One excursion below pH 6.5 was observed at station at KV-111 coinciding with a decline of the field pH at KV-20 (No Cash 500 adit) in September 2018, one excursion below 6.5 was observed at KV-118 in May 2019, and five exceedances of the alkaline pH upper CCME pH boundary (pH = 9) were observed at the Bermingham discharge between July 2017 and December 2018 (Figure 4-4). Also, three of the thirteen samples collected at KV-114 returned a pH greater than EQS 9.5 and all of these were taken from November and December 2020.

4.4.1.2 Field Redox Potential (ORP)

As expected, the oxidation – reduction potential (ORP) at the monitoring stations was oxidizing but large fluctuations were recurrent in the dataset (Figure 4-5). The redox potential was largely positive with a median field ORP ranging from +43.2 mV (at the Bermingham discharge location) to +154 mV (at Bermingham 200 Adit KV-18).

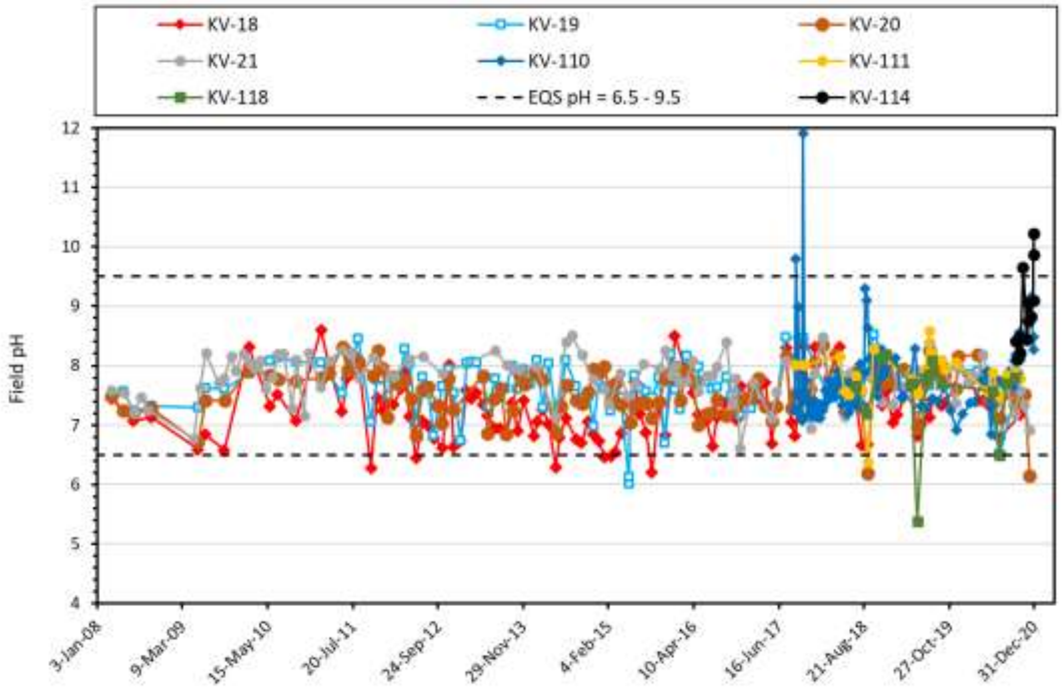


Figure 4-4: Field pH at Monitoring Stations, 2008-2020 Data

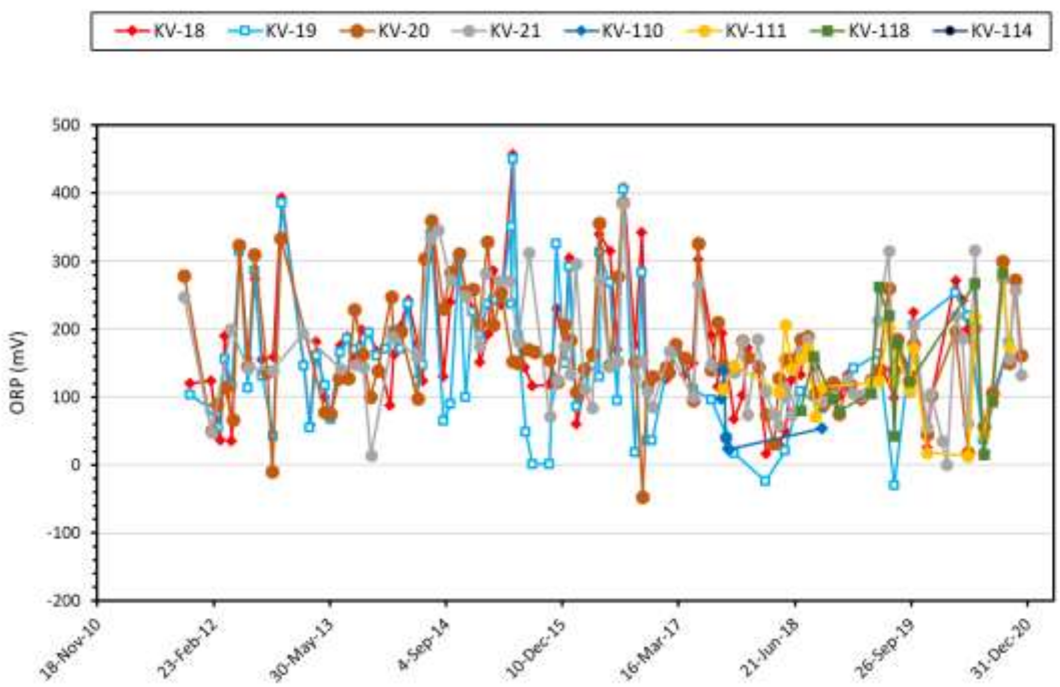


Figure 4-5: Field ORP at Monitoring Stations, 2011-2020 Data

4.4.1.3 Silver

The dissolved silver time series plot and statistical summary of the monitoring data are shown in Figure 4-6 and Table 4-7, respectively. Dissolved silver concentrations in the Bermingham adit discharge (KV-110) were never elevated above the EQS (0.00062 mg/L) and were below the detection limit in the decant pond (KV-114). The dissolved silver concentration at KV-21 was recurrently below the detection limit and was above the WQO in 2% of samples. Dissolved silver was regularly below the detection limit at KV-20. It was noted that elevated silver concentrations at the adit monitoring stations (KV-18 and KV-20) and KV-110 and KV-111 were generally associated with summer months (April-October) and the lowest concentration during winter months reflecting release during freshet. However, a clear seasonality was only seen at KV-18 and KV-21 since 2012. KV-111 also shows a seasonality marked by peak silver concentrations during freshet (April-May) followed by a decline and lowest concentration in the summer/fall (August through October). The higher silver concentrations were observed at KV-118 compared to KV-110 and KV-111 in 2019 and 2020 may suggest an influence of the Ruby 400 adit.

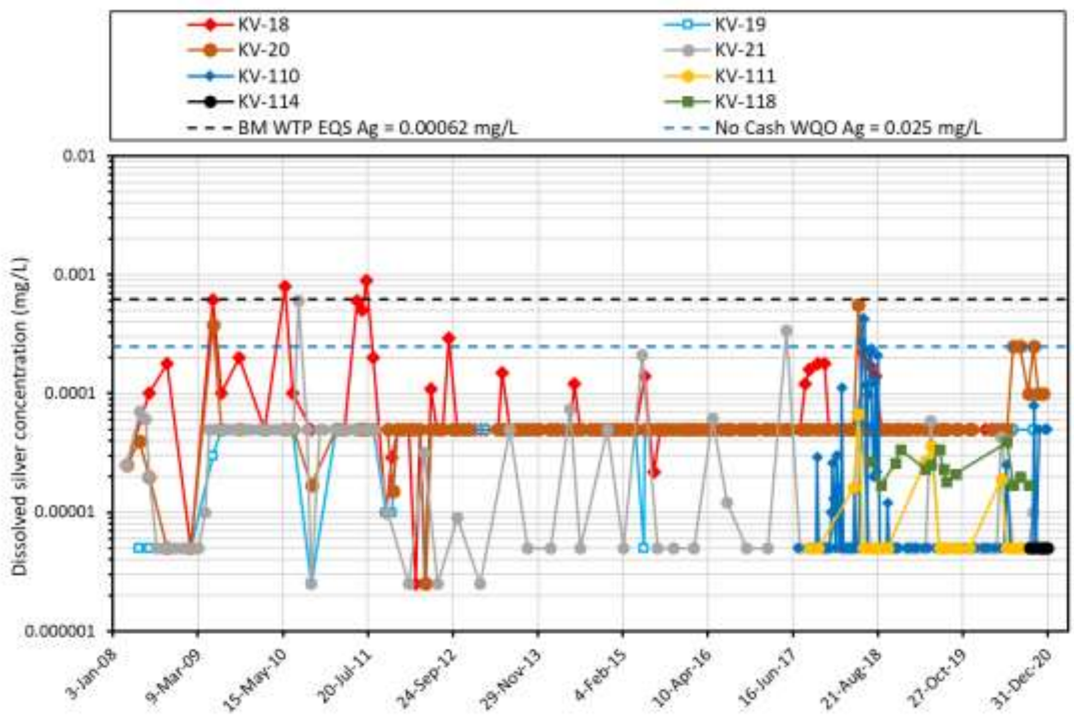


Figure 4-6: Dissolved Silver at Monitoring Stations, 2008-2020 Data

Table 4-7: Dissolved Silver Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Silver (EQS = 0.00062 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.000090	0.000046	0.000061	0.000033	0.000031	0.000011	0.0000050	0.000024
Count	121	97	121	102	105	23	11	14
Minimum	0.0000025	0.0000025	0.0000025	0.0000025	0.0000050	0.0000050	0.0000050	0.000017
Maximum	0.00090	0.000050	0.00056	0.00060	0.00043	0.000067	0.0000050	0.000039
Count <DL	96	96	116	84	82	18	11	0
Standard Deviation	0.00013	0.000013	0.000064	0.000071	0.000074	0.000015	0.0	0.0000070
1st Quartile	0.000050	0.000050	0.000050	0.0000050	0.0000050	0.0000050	0.0000050	0.000019
Median	0.000050	0.000050	0.000050	0.0000050	0.0000050	0.0000050	0.0000050	0.000023
3rd Quartile	0.000050	0.000050	0.000050	0.000050	0.000012	0.0000050	0.0000050	0.000027
Count over Guideline	-	-	-	2	0	-	0	-
% Over Guideline	-	-	-	2%	0%	-	0%	-

[a] KV-21 compared to WQO (0.00025 mg/L) and KV-110 and KV-114 compared to Bermingham EQS (0.00062 mg/L).

4.4.1.4 Arsenic

The dissolved arsenic time series plot and statistical summary of the monitoring data are shown in Figure 4-7 and Table 4-8, respectively. The dissolved arsenic concentrations at KV-110 were lower than the EQS during early monitoring in 2017 then increased and remained above, at or slightly below the EQS (0.061 mg/L) until end of 2019. Most of the samples collected in the first part of 2020 were below the EQS then the concentration increased surpassing the EQS since October 2020. This increase above the EQS was also observed at KV-114 (at which the EQS applies) and coincided with the increase of field pH to alkaline levels. Twenty-eight percent and 64% of the samples from KV-110 and KV-114 had dissolved arsenic higher than the EQS, respectively. However, these elevated arsenic concentrations from the adit discharge and decant pond did not affect the downstream stations KV-111 and KV-118 which remained well below the arsenic EQS. Low dissolved arsenic concentrations were also measured at KV-21 without ever surpassing the WQO in the 12-year dataset. Elevated arsenic concentrations were noted at KV-18 and comparable moderate concentration KV-19 and KV-20. There was a marked seasonality at Bermingham 200 adit (KV-18) where discharge dissolved arsenic concentrations were generally lowest in May-June then gradually increased peaking in January-March the following year. However, this seasonal pattern was less evident in recent year (2018 to 2020). A similar seasonal pattern was also observed at the No Cash adit (KV-20). KV-111 also shows arsenic seasonal variation marked by peak concentrations during freshet (April-May) and lowest concentration in the fall (September-October). Interestingly, dissolved arsenic concentrations at Upper No Cash Creek at Calumet Drive (KV-118) have remained nearly unchanged for the last two years.

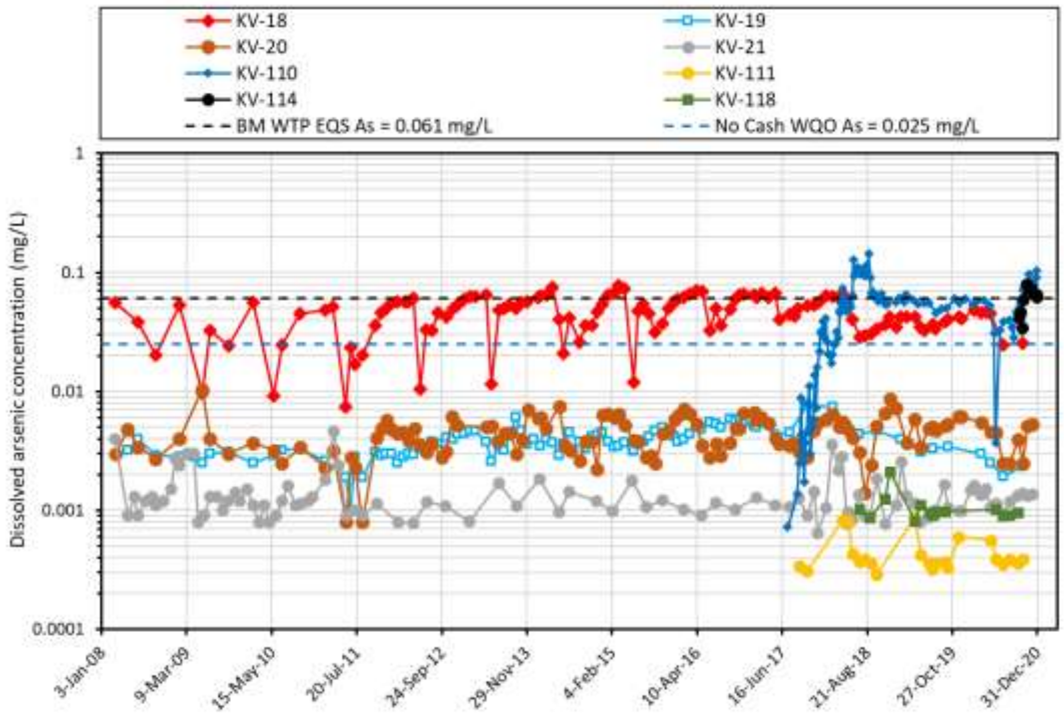


Figure 4-7: Dissolved Arsenic at Monitoring Stations, 2008-2020 Data

Table 4-8: Dissolved Arsenic Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Arsenic (EQS = 0.061 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.046	0.0039	0.0044	0.0013	0.050	0.00044	0.060	0.0011
Count	121	97	121	102	105	23	11	14
Minimum	0.0074	0.0010	0.00080	0.00064	0.00072	0.00029	0.034	0.00082
Maximum	0.078	0.0077	0.010	0.0046	0.14	0.00087	0.080	0.0021
Count <DL	0	0	3	0	0	0	0	0
Standard Deviation	0.016	0.0011	0.0016	0.00068	0.031	0.00017	0.014	0.00032
1st Quartile	0.036	0.0031	0.0032	0.0010	0.028	0.00036	0.053	0.00091
Median	0.048	0.0038	0.0044	0.0012	0.053	0.00037	0.064	0.0010
3rd Quartile	0.057	0.0045	0.0054	0.0014	0.063	0.00042	0.069	0.0010
Count over Guideline	-	-	-	0	29	-	7	-
% Over Guideline	-	-	-	0%	28%	-	64%	-

[a] KV-21 compared to WQO (0.025 mg/L) and KV-110 and KV-114 compared to Bermingham EQS (0.061 mg/L).

4.4.1.5 Cadmium

The dissolved cadmium time series plot and statistical summary of the monitoring data are shown in Figure 4-8 and Table 4-9, respectively. The dissolved cadmium concentrations at KV-110 were frequently lower than the EQS (0.01 mg/L) with only four samples returning cadmium concentration higher than the EQS, two of which in late May and June 2020. Cadmium concentrations were not higher than the EQS at KV-114 and cadmium concentrations were typically one to three orders of magnitude lower than the EQS. The dissolved cadmium concentrations at KV-110 were orders of magnitude higher than KV-111 during early monitoring, became comparable in 2018, then decreased below KV-111 due to a significant decrease of cadmium at KV-110. Both KV-111 and KV-118 returned cadmium concentration generally higher than KV-110 except in May-September. The higher cadmium at KV-118 compared to KV-110 and KV-111 may suggest an influence from the Ruby 400 adit. Water discharged from the Bermingham 200, Ruby 400, and No Cash 500 adits constantly had elevated cadmium. Elevated dissolved cadmium concentrations were also measured at KV-21 with 8% of the samples being higher than the WQO, most of which occurred in 2020. A seasonal pattern characterized by peak concentrations in May-July followed by a gradual decline during the rest of the year (lowest concentrations in winter months) was observed at the Bermingham 200 adit, Ruby 400 adit and No Cash 500 adit monitoring stations. The seasonality observed at No Cash 500 adit was also reflected in water collected from No Cash Creek station KV-21. KV-111 also showed a seasonality marked by peak cadmium concentrations during freshet (April-May) followed by a decline and lowest concentration in the summer/fall (August through October). The Ruby 400 adit also showed an increase in dissolved cadmium after relatively unchanged concentrations in 2019.

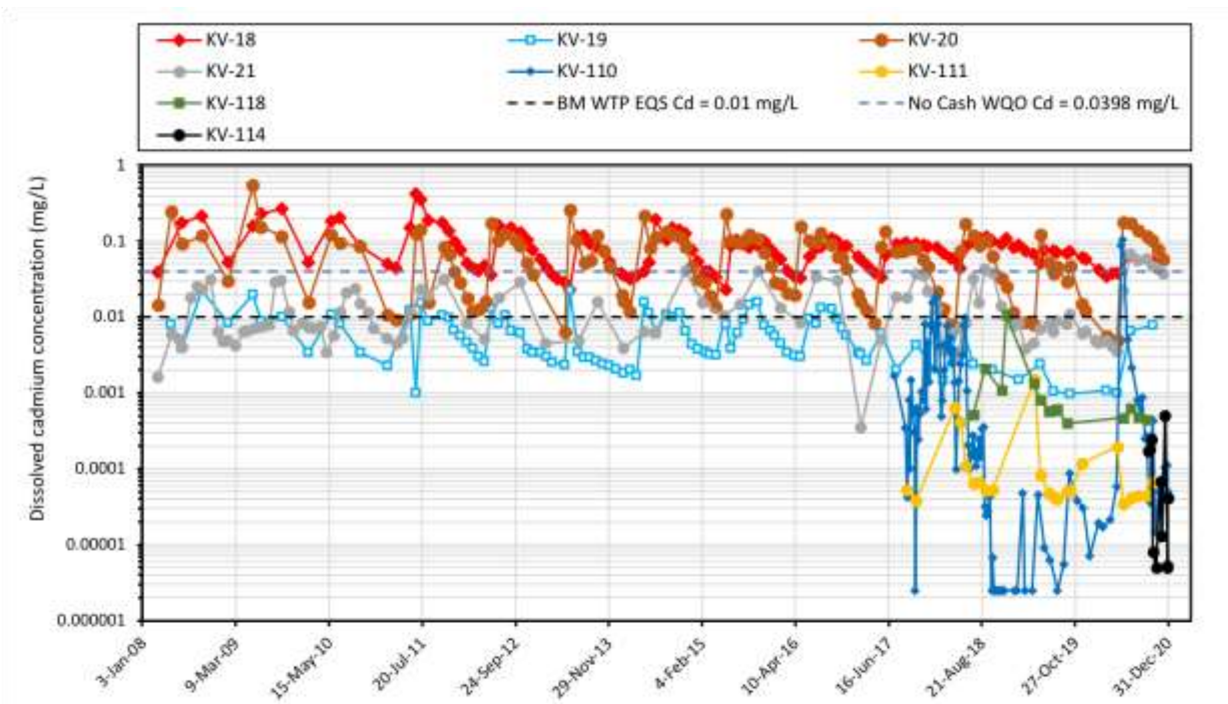


Figure 4-8: Dissolved Cadmium at Monitoring Stations, 2008-2020 Data

Table 4-9: Dissolved Cadmium Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Cadmium (EQS = 0.01 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.088	0.0064	0.075	0.015	0.0034	0.00017	0.00011	0.0015
Count	122	97	121	102	105	23	11	14
Minimum	0.023	0.0010	0.0049	0.00035	0.0000025	0.000034	0.0000050	0.00040
Maximum	0.42	0.022	0.55	0.067	0.11	0.0015	0.00050	0.011
Count <DL	0	0	0	0	17	0	2	0
Standard Deviation	0.061	0.0047	0.070	0.014	0.014	0.00032	0.00015	0.0027
1st Quartile	0.049	0.0029	0.020	0.0054	0.000030	0.000044	0.0000066	0.00049
Median	0.076	0.0046	0.063	0.0082	0.00025	0.000052	0.000041	0.00060
3rd Quartile	0.10	0.0091	0.11	0.022	0.0015	0.000095	0.00018	0.0010
Count over Guideline	-	-	-	8	4	-	0	-
% Over Guideline	-	-	-	8%	4%	-	0%	-

[a] KV-21 compared to WQO (0.0398 mg/L) and KV-110 and KV-114 compared to Bermingham EQS (0.01 mg/L).

4.4.1.6 Copper

The dissolved copper time series plot and statistical summary of the monitoring data are shown in Figure 4-9 and Table 4-10, respectively. The dissolved copper concentrations at KV-110 were generally lower than the EQS (0.024 mg/L) in 2017 and early 2018, then increased above the EQS on three occasions (4% of sample dataset) between March and August 2018 and finally decreased below the EQS during the remainder of monitoring period. The dissolved copper concentrations at KV-114 were also low and below the detection limit during the last three sampling events in 2020. KV-111 and KV-118 had overall comparable concentrations that were lower than those observed at KV-110 during 2017 to September 2018 but higher since late 2018 due to the decline of copper below the detection limit at KV-110. KV-18, KV-20, and KV-21 showed copper seasonality although more muted compared to dissolved cadmium, while KV-19 copper concentrations were commonly below the detection limit since 2014. KV-111 also showed a weak copper seasonality marked by peak concentrations during freshet and lowest concentration in the summer/fall (August through October).

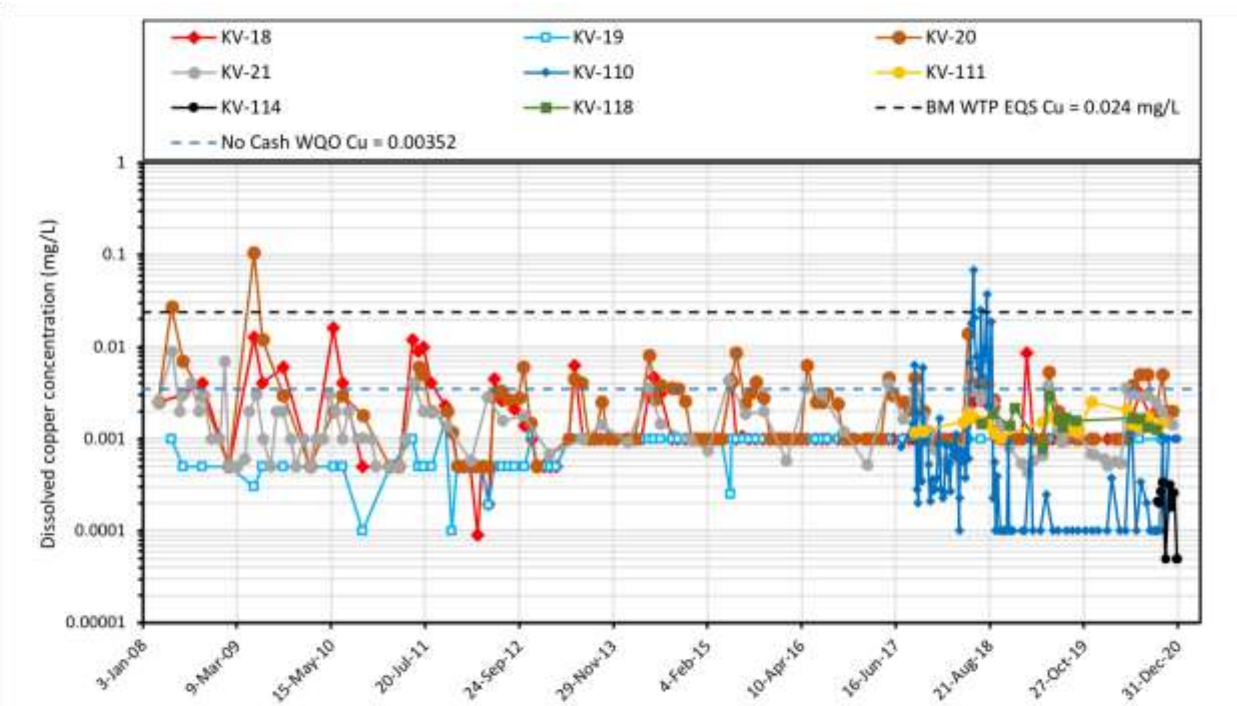


Figure 4-9: Dissolved Copper at Monitoring Stations, 2008-2020 Data

Table 4-10: Dissolved Copper Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Copper (EQS = 0.024 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.0019	0.0008	0.0034	0.0017	0.0028	0.0015	0.0002	0.0016
Count	121	97	121	102	105	23	11	14
Minimum	0.000090	0.00010	0.00050	0.00043	0.00010	0.0010	0.00010	0.00078
Maximum	0.016	0.0016	0.11	0.0090	0.068	0.0025	0.00040	0.0030
Count <DL	88	89	65	11	38	0	7	0
Standard Deviation	0.0025	0.00028	0.010	0.0014	0.0084	0.00033	0.00012	0.00050
1st Quartile	0.0010	0.00050	0.0010	0.00074	0.00010	0.0013	0.00010	0.0014
Median	0.0010	0.0010	0.0015	0.0013	0.00038	0.0015	0.00010	0.0016
3rd Quartile	0.0011	0.0010	0.0031	0.0025	0.0010	0.0016	0.00028	0.0017
Count over Guideline	-	-	-	10	3	-	0	-
% Over Guideline	-	-	-	10%	3%	-	0%	-

[a] KV-21 compared to WQO (0.00352 mg/L) and KV-110 and KV-114 compared to Bermingham EQS (0.024 mg/L).

4.4.1.7 Lead

The dissolved lead time series plot and statistical summary of the monitoring data are shown in Figure 4-10 and Table 4-11, respectively. The dissolved lead concentrations at KV-110 were commonly much lower than the EQS (0.048 mg/L) in 2017 and early 2018 and increased above the EQS twice (2% of samples) between March and August 2018. Then the concentration decreased significantly below the EQS during the remainder of monitoring. The dissolved lead concentration at KV-114 was also one or more orders of magnitude below the EQS. The elevated dissolved lead concentrations from the decline discharge in 2018 did not affect the downstream stations KV-111 and KV-118 that remained well below the EQS. Dissolved lead concentrations at KV-111 and KV-118 were higher than that in the discharge from the Bermingham adit in 2019 and the first half of 2020. Elevated dissolved lead concentrations above the WQO were occasionally measured at KV-21 due to seasonal patterns (8%). A seasonal lead pattern characterized by peak concentrations in May-September followed by gradual decline during the rest of the year were observed at the Bermingham 200 adit and No Cash creek KV-21 monitoring stations while dissolved lead at the Ruby 400 adit and No Cash 500 adit were below the detection limit since mid-2013.

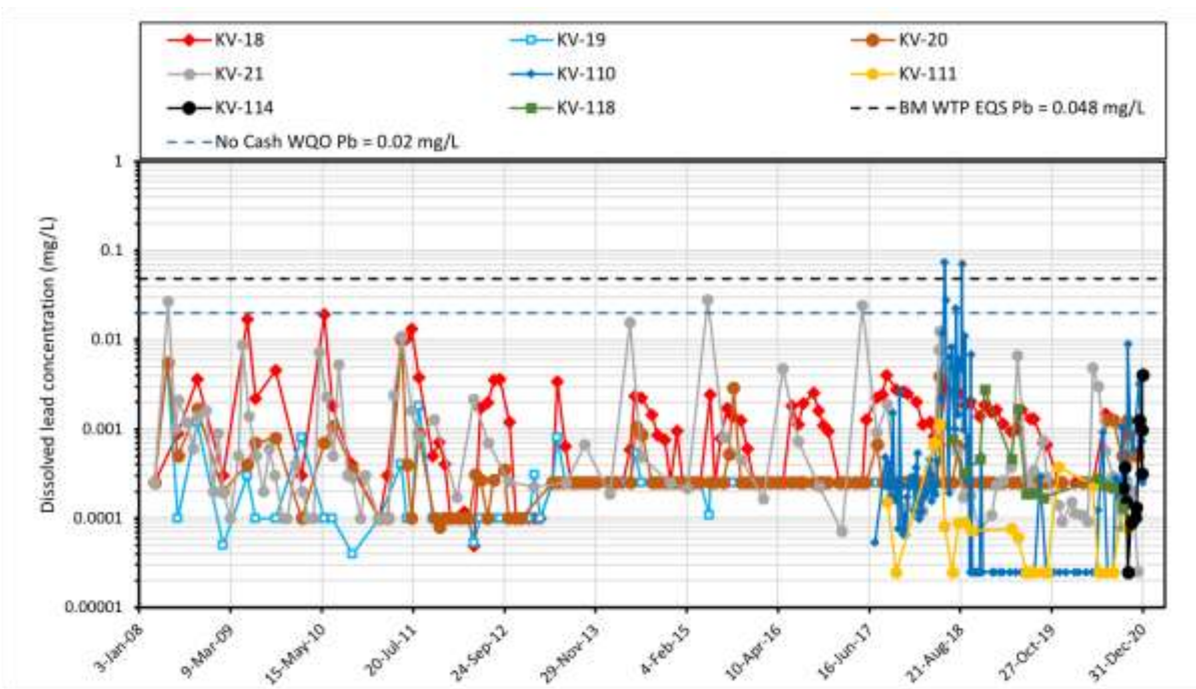


Figure 4-10: Dissolved Lead at Monitoring Stations, 2008-2020 Data

Table 4-11: Dissolved Lead Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Lead (EQS = 0.048 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.0016	0.00030	0.00050	0.0021	0.0028	0.00015	0.00070	0.00073
Count	121	97	121	102	105	23	11	10
Minimum	0.000049	0.000040	0.000080	0.000025	0.000025	0.000025	0.000025	0.00017
Maximum	0.019	0.0054	0.010	0.028	0.073	0.0011	0.0040	0.0028
Count <DL	43	84	96	11	30	10	1	0
Standard Deviation	0.0029	0.00057	0.0011	0.0050	0.011	0.00026	0.0012	0.00087
1st Quartile	0.00025	0.00010	0.00025	0.00017	0.000025	0.000025	0.00012	0.00019
Median	0.00083	0.00025	0.00025	0.00030	0.00023	0.000073	0.00022	0.00039
3rd Quartile	0.0018	0.00025	0.00025	0.0013	0.00060	0.00012	0.00068	0.00070
Count over Guideline	-	-	-	8	2	-	0	-
% Over Guideline	-	-	-	8%	2%	-	0%	-

[a] KV-21 compared to WQO (hardness-dependent based on BCMOE guideline) and KV-110 and KV-114 compared to Bermingham EQS (0.048 mg/L).

4.4.1.8 Nickel

The dissolved nickel time series plot and statistical summary of the monitoring data are shown in Figure 4-11 and Table 4-12, respectively. Total nickel concentrations are reported for KV-110 and KV-114 since the EQS applies to the total fraction. Total nickel concentrations in the Bermingham adit discharge exceeded the EQS (0.37 mg/L) twice; no exceedances were observed for the dissolved nickel concentration. No elevated nickel concentrations were observed at the WTP decant pond (KV-114). KV-110 had higher dissolved concentrations compared to KV-111 and KV-118 during the same sampling period. The dissolved nickel concentrations measured at Bermingham 200 adit (KV-18) were below the detection limit since April 2013. The dissolved nickel concentration at the No Cash 500 adit (KV-20) was the highest of the three historical adits and Ruby 400 adit (KV-19) was second, slightly lower than KV-20. The latter showed a cyclic pattern characterized by lows in summer/fall (June-September) after which the concentration gradually increased and peaked in winter (November-December). This cyclic pattern was not observed in 2019. KV-111 also showed a seasonal trend marked by peak nickel concentrations during freshet (April-July) followed by a sharp decline and lowest concentration in the fall to early winter (October). Dissolved nickel was constantly below the WQO at KV-21.

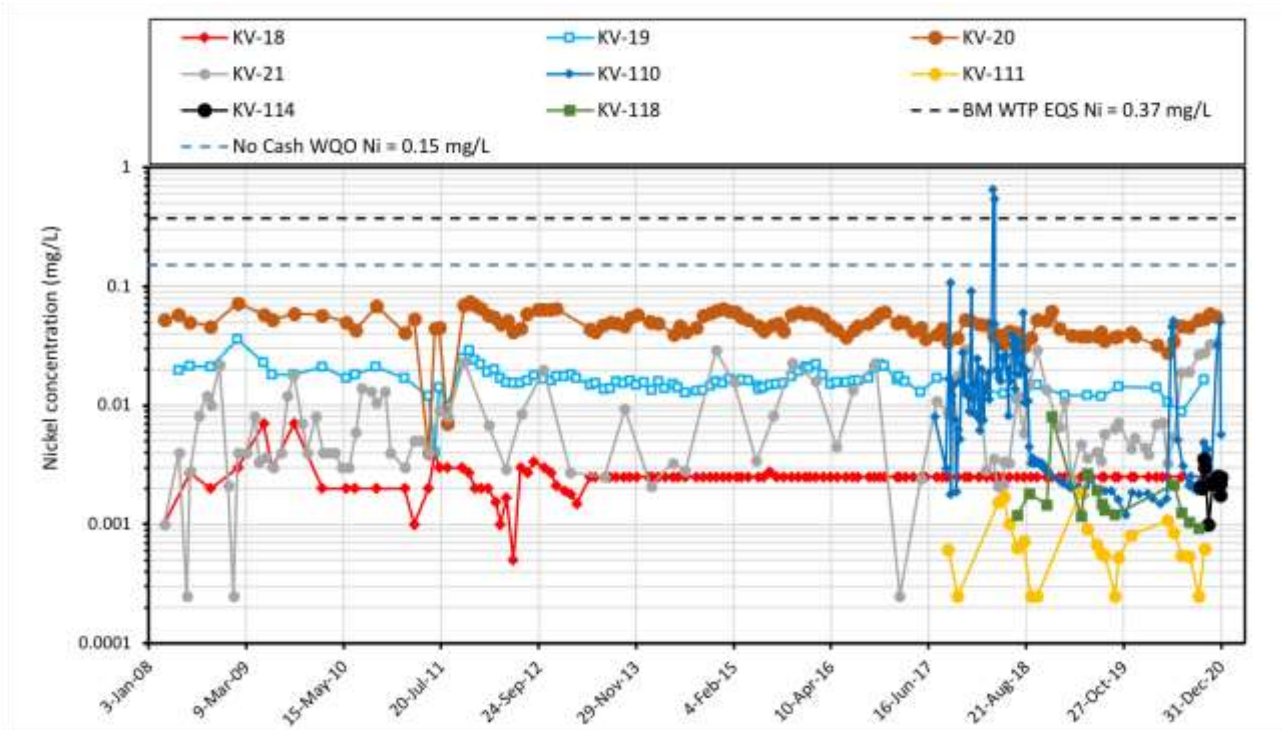


Figure 4-11: Dissolved Nickel at KV-18, KV-19, KV-20, KV-21, KV-111, and KV-118 and Total Nickel at KV-110 and KV-114 Monitoring Stations, 2008-2020 Data

Table 4-12: Dissolved Nickel at KV-18, KV-19, KV-20, KV-21, KV-111, and KV-118 and Total Nickel at KV-110 and KV-114 Monitoring Stations, 2008-2020 Data

Total Nickel (EQS = 0.37 mg/L)*	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.0025	0.017	0.049	0.0091	0.025	0.00074	0.00228	0.0020
Count	121	97	121	102	107	23	11	14
Minimum	0.00050	0.0040	0.0040	0.00025	0.0012	0.00025	0.00099	0.00094
Maximum	0.0070	0.036	0.074	0.033	0.65	0.0019	0.00355	0.0080
Count <DL	87	0	0	5	1	5	0	0
Standard Deviation	0.00072	0.0041	0.011	0.0080	0.082	0.00045	0.00066	0.0018
1st Quartile	0.0025	0.014	0.042	0.0034	0.0024	0.00054	0.00202	0.0012
Median	0.0025	0.016	0.049	0.0058	0.0075	0.00062	0.00251	0.0014
3rd Quartile	0.0025	0.018	0.057	0.013	0.019	0.00089	0.0035	0.0019
Count over Guideline	-	-	-	0	2	-	0	-
% Over Guideline	-	-	-	0%	2%	-	0%	-

[a] KV-21 compared to WQO (hardness-dependent based on CCME guideline) and KV-110 and KV-114 compared to Bermingham EQS (0.37 mg/L).

*All nickel concentrations are dissolved except for KV-110 and KV-114 which are total concentrations.

4.4.1.9 Selenium

The dissolved selenium concentration time series plot and statistical summary of the monitoring data are shown in Figure 4-12 and Table 4-13, respectively. The dissolved selenium concentration at KV-110 ranged between 0.0003 and 0.007 mg/L with the highest concentrations observed between October 2017 and April 2018. After that the concentrations declined significantly and remained relatively stable between 0.0003 and 0.0004 mg/L between November 2018 and May 2020. The selenium concentration rose again peaking at 0.0025 mg/L in October 2020 then declined. The dissolved selenium concentration at KV-114 also exhibited a similar pattern to KV-110 for the same period. KV-110 had selenium concentrations higher than KV-118 and KV-111 and the latter typically returned the lowest selenium concentrations observed (typically <0.00024 mg/L). Dissolved selenium concentrations at KV-21 were constantly below the WQO (0.002 mg/L) except on one occasion, and were commonly below the detection limit (30% of samples; Table 4-13). Selenium concentrations in the Bermingham 200, No Cash 500, and Ruby 400 adit discharges were also commonly below the detection limit (63%, 85%, and 55%, respectively). Dissolved selenium also showed a seasonal pattern at KV-111 similar to other COPI.

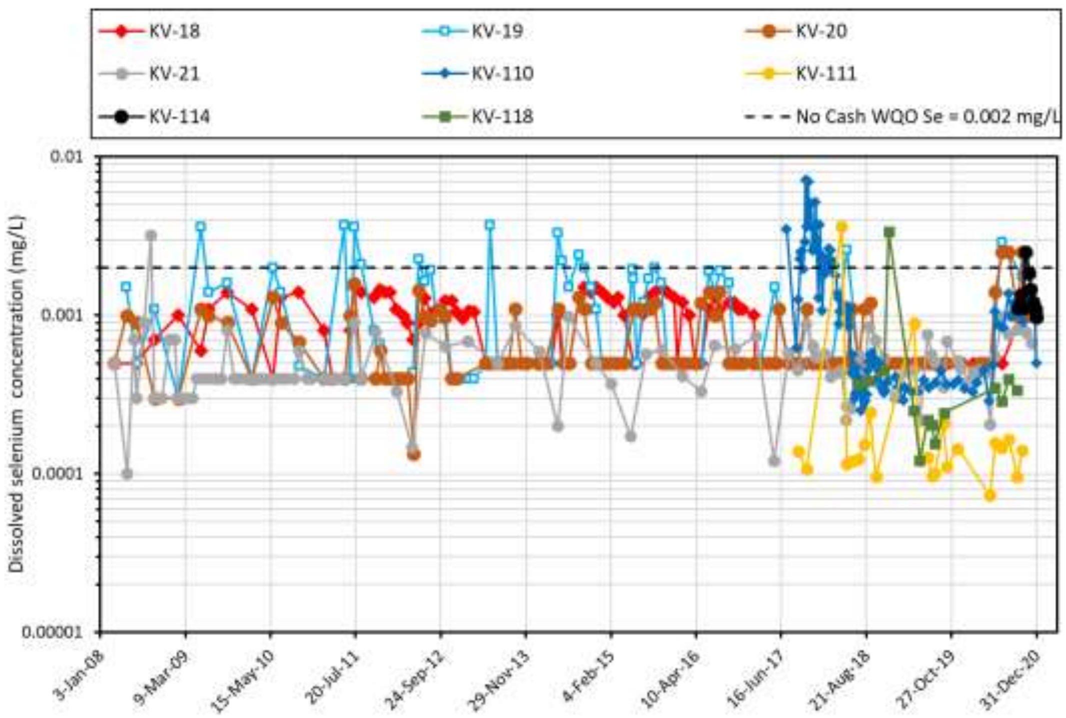


Figure 4-12: Total Selenium at Monitoring Stations, 2008-2020 Data

Table 4-13: Dissolved Selenium Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Selenium WQO = 0.002 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.00081	0.0011	0.00072	0.00052	0.0013	0.00032	0.0014	0.00051
Count	121	97	121	102	105	23	11	14
Minimum	0.00040	0.00030	0.00013	0.00010	0.00025	0.00007	0.00097	0.00012
Maximum	0.0015	0.0037	0.0025	0.0032	0.0072	0.0036	0.0025	0.0034
Count <DL	63	55	85	31	1	0	0	0
Standard Deviation	0.00037	0.00087	0.00042	0.00033	0.00134	0.00074	0.00045	0.00083
1st Quartile	0.00050	0.00050	0.00050	0.00040	0.00039	0.00011	0.0011	0.00023
Median	0.00050	0.00050	0.00050	0.00044	0.00089	0.00013	0.0012	0.00031
3rd Quartile	0.0011	0.0016	0.0010	0.00063	0.0020	0.00016	0.0014	0.00038
Count over Guideline	-	-	-	1	-	-	-	-
% Over Guideline	-	-	-	1%	-	-	-	-

[a] KV-21 compared to WQO (0.002 mg/L).

4.4.1.10 Zinc

The dissolved zinc concentration time series plot and statistical summary of the monitoring data are shown in Figure 4-13 and Table 4-14, respectively. The dissolved zinc concentrations at KV-110 and KV-114 were regularly lower than the EQS (0.5 mg/L) with only five samples (5%) above the EQS at Bermingham adit discharge (KV-110) and all pre-October 2020. Dissolved zinc concentrations at KV-110 dropped more than two orders of magnitude from 0.6 mg/L in January 2018 to between 0.005 and 0.02 mg/L between late 2018 and April 2020. Dissolved zinc then increased sharply to 4.4 mg/L in June 2020 at KV-110, then sharply decreased to concentrations almost two orders of magnitude lower than the EQS over the remainder of 2020. The dissolved zinc concentrations at KV-118 were typically higher than at KV-110 for the same period (July 2018 onward) indicating an additional source of zinc, likely from Ruby 400 adit. Dissolved zinc concentrations at KV-111 were generally lower or comparable to KV-110 for the same period. The patterns of dissolved zinc concentrations were similar at Bermingham adit (KV-18), No Cash 500 adit (KV-20), and No Cash Creek (KV-21), although the concentrations were slightly higher at KV-20. Dissolved zinc concentrations at KV-21 were in excess of the WQO in 10% of samples. A seasonal cyclic zinc pattern characterized by peak of the concentration in May-July after which the concentration gradually decreased reaching the lowest level in March-April of the following year was observed for the Bermingham 200 adit (KV-18) and No Cash 500 adit (KV-20) since 2012. A seasonal zinc pattern characterized by peak concentrations in April followed by a sharp decline reaching the lowest level in September-October was also observed at KV-111.

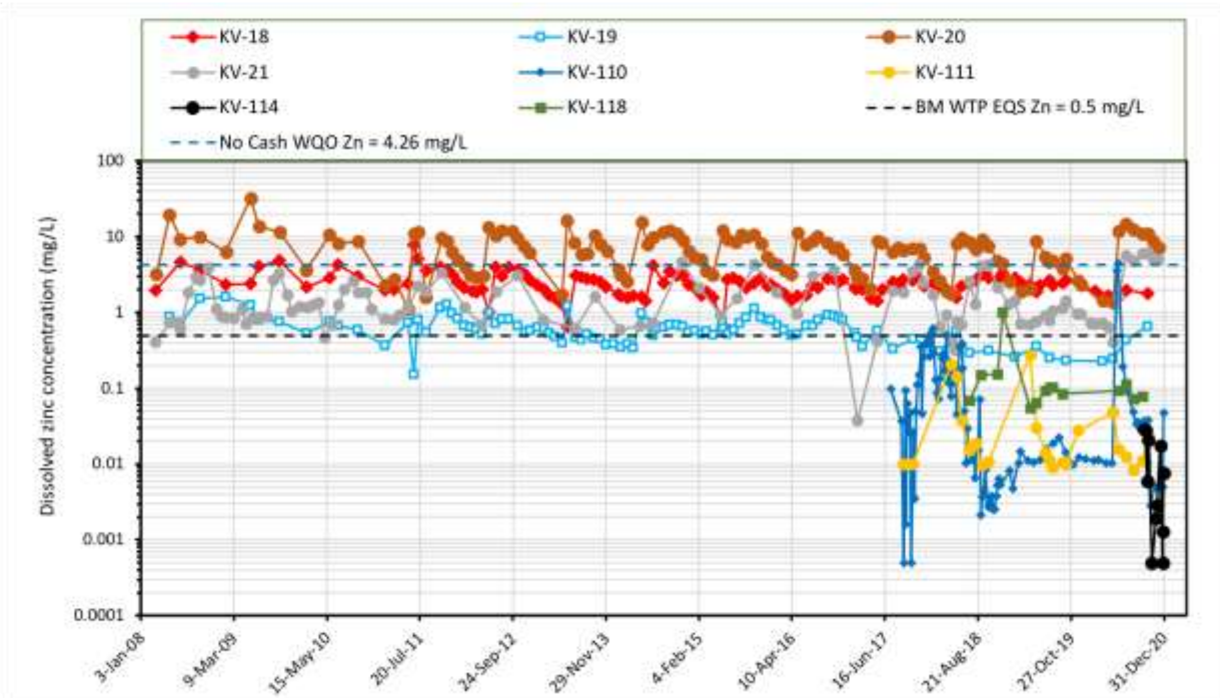


Figure 4-13: Dissolved Zinc at Monitoring Stations, 2008-2020 Data

Table 4-14: Dissolved Zinc Statistics at Monitoring Stations, 2008-2020 Data

Dissolved Zinc (EQS = 0.5 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	2.5	0.64	7.2	1.7	0.16	0.042	0.011	0.16
Count	122	98	121	102	105	23	11	14
Minimum	0.66	0.15	1.1	0.037	0.00050	0.0084	0.00050	0.055
Maximum	7.7	1.60	32	6.1	4.4	0.27	0.029	1.00
Count <DL	0	0	0	0	6	0	2	0
Standard Deviation	0.93	0.27	4.4	1.4	0.55	0.070	0.011	0.24
1st Quartile	1.9	0.47	3.6	0.76	0.010	0.010	0.0016	0.074
Median	2.3	0.60	6.9	1.1	0.029	0.014	0.0060	0.094
3rd Quartile	2.8	0.78	9.7	2.1	0.13	0.029	0.019	0.11
Count over Guideline	-	-	-	8	5	-	0	-
% Over Guideline	-	-	-	8%	5%	-	0%	-

[a] KV-21 compared to WQO (4.26 mg/L) and KV-110 and KV-110 and KV-114 compared to Bermingham EQS (0.5 mg/L).

4.4.1.11 Sulphate

The dissolved sulphate time series plot and statistical summary of the monitoring data are shown in Figure 4-14 and Table 4-15, respectively. The highest dissolved sulphate concentrations were observed in the No Cash 500 adit discharge (KV-20; median 457 mg/L) and downstream No Cash Creek (KV-21; median 336 mg/L). Strong seasonality was observed at both sites with concentrations highest over winter and lowest in summer. The cyclicity was most pronounced at KV-21, where concentrations declined close to an order of magnitude between the winter maxima and spring minima due to dilution from freshet. Dissolved sulphate concentrations above the WQO (524 mg/L) were observed during nine sampling events (11%) at KV-21. Much lower sulphate concentrations were observed at the other sites. The sulphate concentration at KV-118 (median 41.5 mg/L) and KV-111 (median 53.1 mg/L) were comparable (KV-118) or slightly higher (KV-111) than KV-110 for the same period (July -December 2020; median 38.2 mg/L) suggesting an additional source of sulphate along the flow path likely from Ruby 400 adit (KV-19). The sulphate concentration in the Bermingham adit discharge rose briefly in May-June 2020 then sharply declined similar to zinc. The sulphate concentration at Bermingham decant pond (KV-114) was low and stable (median 44.4 mg/L). A sulphate seasonality characterized by peak concentration in April followed by a sharp decline was also observed at KV-111.

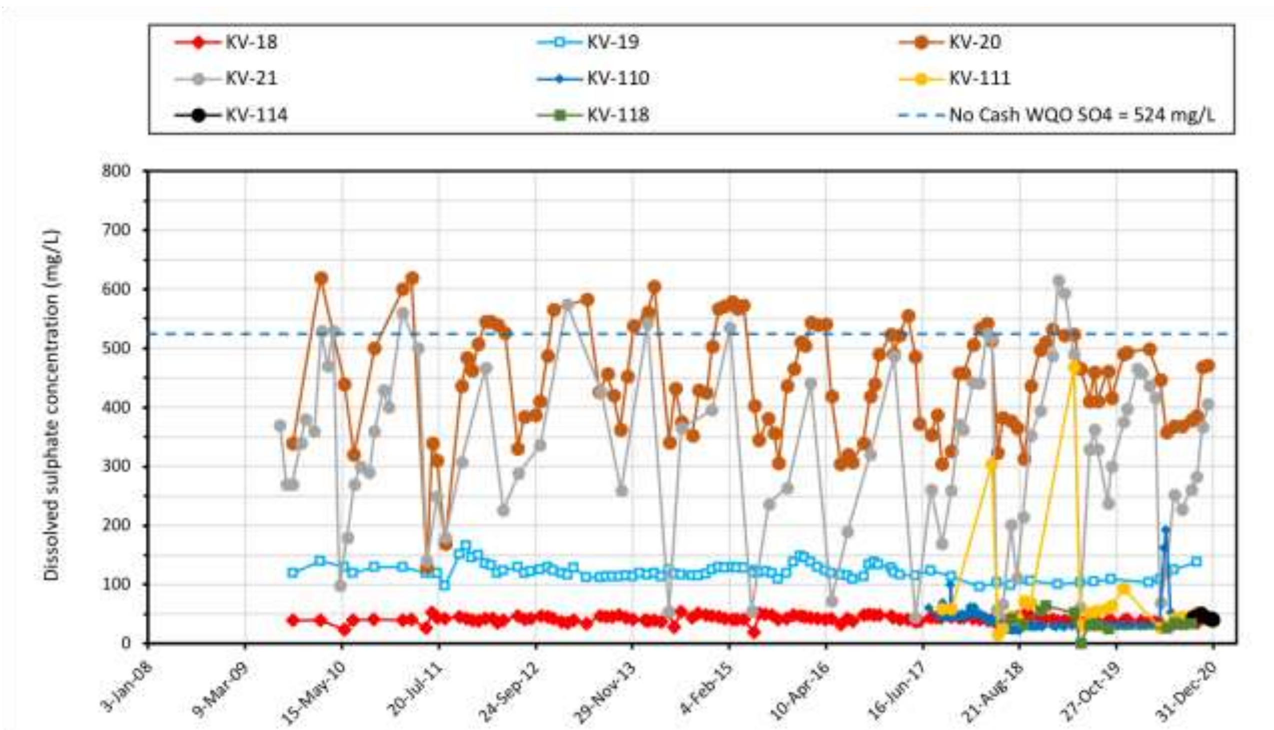


Figure 4-14: Dissolved Sulphate at Monitoring Stations, 2009-2020 Data

Table 4-15: Dissolved Sulphate Statistics at Monitoring Stations, 2009-2020 Data

Dissolved Sulphate (WQO = 524 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	42	122	446	324	41	80	45	36
Count	113	89	112	85	106	23	11	14
Minimum	19	97	130	45	22	15	40	1.4
Maximum	54	166	620	615	193	468	51	65
Count <DL	0	0	0	0	0	0	0	0
Standard Deviation	5.6	13	93	148	23	101	3.4	15
1st Quartile	39	115	376	237	30	44	43	32
Median	42	120	457	336	38	53	44	34
3rd Quartile	45	129	523	436	47	62	47	41
Count over Guideline	-	-	-	9	-	-	-	-
% Over Guideline	-	-	-	11%	-	-	-	-

[a] KV-21 compared to proposed WQO (524 mg/L)

4.4.1.12 Ammonia

The ammonia-N time series plot and statistical summary of the 2014-2020 monitoring data are shown in Figure 4-15

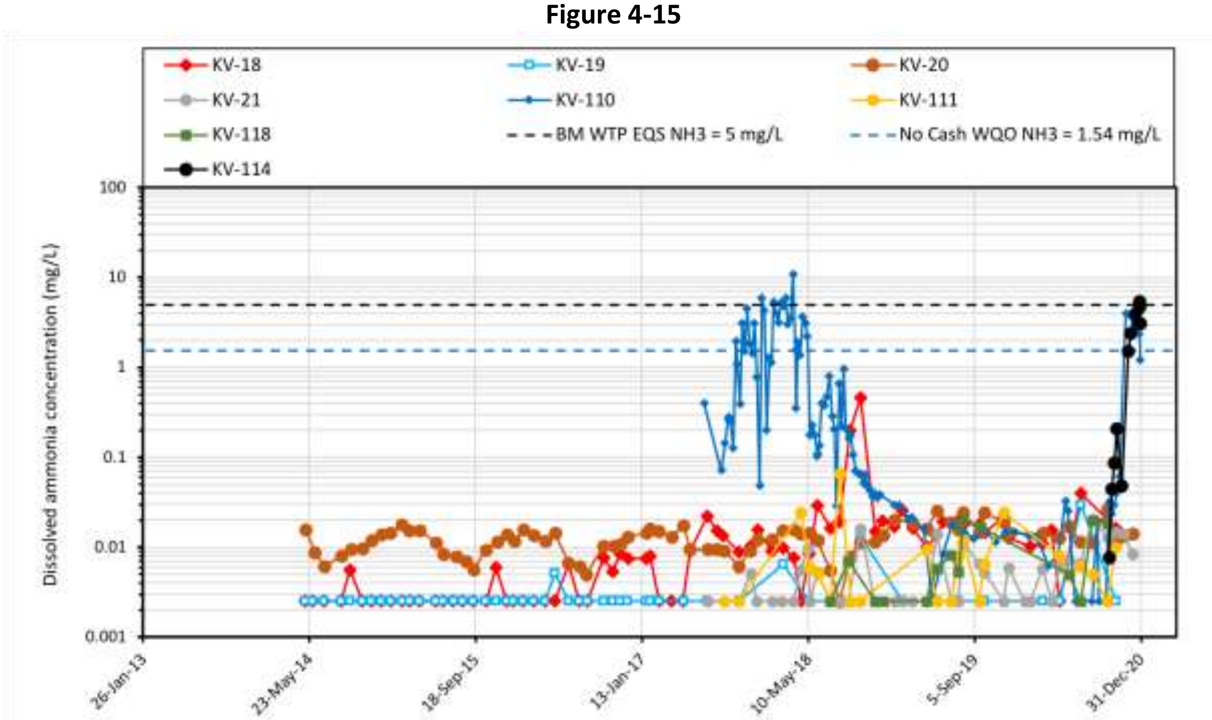


Figure 4-15 and Table 4-16, respectively. Ammonia-N was commonly very low (median <0.02 mg/L) at all monitoring stations except at KV-110 and KV-114. The ammonia-N concentration at the Bermingham adit discharge station (KV-110) was typically orders of magnitude higher than the other stations except between November 2018 and August 2020. Like most COPI, ammonia-N concentrations at KV-110 were lower than the EQS (5 mg/L) in early 2017, then increased above the EQS on five occasions (5% of samples) between December 2017 and March 2018 and then it sharply decreased to orders of magnitude below the EQS until mid 2020. The ammonia-N concentration rose sharply in the second half of 2020 to levels close to the EQS. The ammonia-N concentration at KV-114 also increased similarly to

KV-110 but marginally surpassed the EQS in one occasion (5.4 mg/L). KV-111 and KV-118 returned dissolved ammonia-N concentrations comparable to KV-110 in 2019 and the first half of 2020, but were much lower earlier in the monitoring period. Dissolved ammonia-N at KV-21 was below the detection limit in 54% of the samples and never increased above the WQO (1.54 mg-N/L).

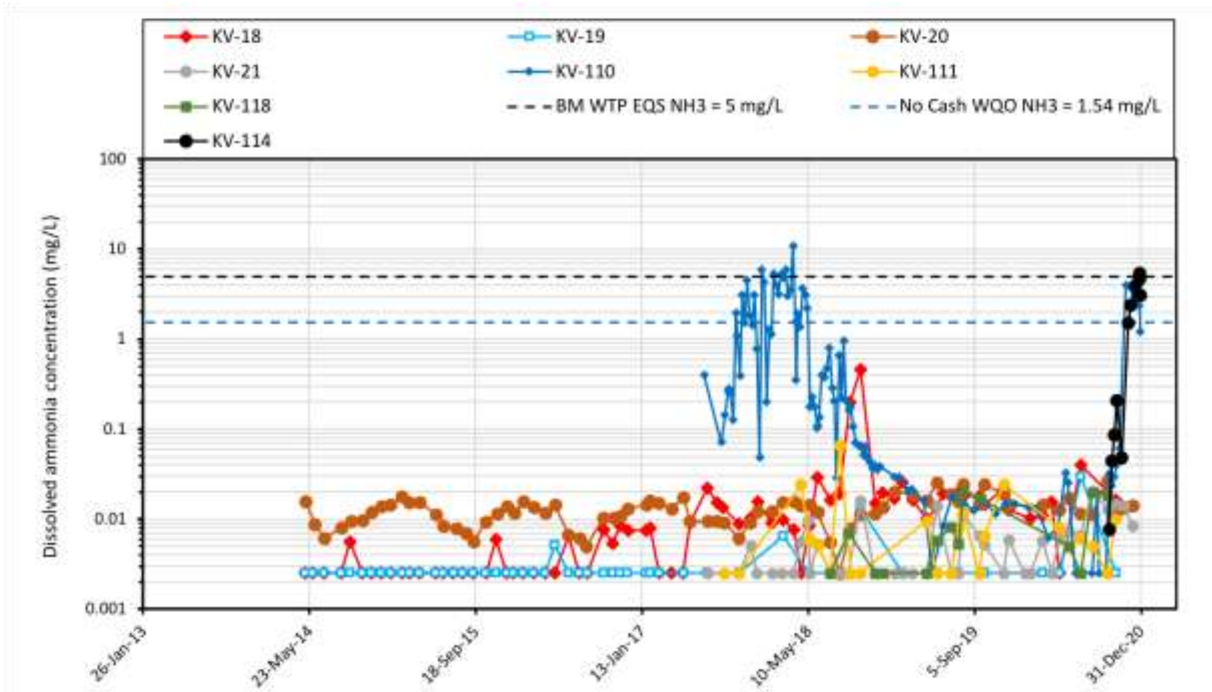


Figure 4-15: Dissolved Ammonia-N at Monitoring Stations, 2014-2020 Data

Table 4-16: Dissolved Ammonia-N Statistics at Monitoring Stations, 2014-2020 Data

Dissolved Ammonia-N (EQS = 5 mg/L)	KV-18	KV-19	KV-20	KV-21	KV-110	KV-111	KV-114	KV-118
Average	0.018	0.0034	0.013	0.0058	1.1	0.0095	2.0	0.0085
Count	74	50	77	41	106	23	11	14
Minimum	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0078	0.0025
Maximum	0.46	0.030	0.027	0.020	11	0.067	5.4	0.020
Count <DL	30	46	1	22	7	9	0	5
Standard Deviation	0.057	0.0041	0.0047	0.0047	1.8	0.014	2.1	0.0070
1st Quartile	0.0025	0.0025	0.0095	0.0025	0.029	0.0025	0.067	0.0025
Median	0.0076	0.0025	0.013	0.0025	0.17	0.0051	1.52	0.0056
3rd Quartile	0.015	0.0025	0.015	0.0067	1.4	0.0088	3.6	0.015
Count over Guideline	-	-	-	0	5	-	1	-
% Over Guideline	-	-	-	0%	5%	-	9%	-

[a] KV-21 compared to WQO (1.54 mg/L) KV-110 and KV-110 and KV-114 compared to Bermingham EQS (5 mg/L).

4.4.1.13 Summary of Water Quality along Attenuation Corridor

The analysis of background surface water quality data and trend from monitoring stations during the monitoring period indicate the following:

- Generally, circumneutral pH and oxic conditions at the surface water monitoring stations. The lowest field pH level recorded was pH 5.4 (KV-118) and pH 6.4 (KV-111). Recent data from KV-114 show recurrent alkaline pH at the decant pond.
- A gradual increase in COPI concentrations at KV-110 was observed from the onset of monitoring to a peak in April– July 2018. The concentrations of COPI declined thereafter to levels that were below the EQS and often below the detection limit (silver, copper, lead, nickel, zinc). The only exception was dissolved arsenic that was higher than the EQS in 29% of the samples and remained comparable or slightly below the EQS between late 2018 and mid-2020 before rising to above the EQS in the second half of 2020.
- The Bermingham decant pond (KV-114) 2020 water quality showed elevated arsenic, and, ammonia, and the most alkaline pH observed on site. However, these elevated concentrations were not recorded at monitoring stations downstream of the pond.
- In general, concentrations of most of metal parameters, and sulphate at Bermingham adit discharge (KV-110) were below or comparable to concentrations of those parameters at downstream stations located at Upper No Cash Creek (KV-118) and at No Cash Creek (KV-111) with exception arsenic and ammonia-N. Arsenic and ammonia-N remained one to three orders of magnitude higher at KV-110. Nickel remained higher in KV-110 and KV-114 than KV-111, but comparable to that at KV-118.
- The concentration of arsenic, lead, nickel, ammonia- N and selenium at KV-110 increased sharply in the second half of 2020 becoming higher than KV-111 and KV-118 before declining to comparable to lower levels except for arsenic, ammonia-N and selenium.
- The concentration of dissolved arsenic, cadmium, copper, lead, nickel, selenium, zinc, and sulphate measured at KV-21 were higher than those at KV-111 reflecting the input of COPI from the No Cash 500 adit discharge. The concentration of COPI at KV-21 often mimicked that at KV-20 although at slightly lower concentrations.
- The water quality of the Bermingham adit discharge was generally better than at KV-118 for the same period between July 2018 to June 2020 and would have resulted in an improvement of WQ at KV-118 and probably at monitoring stations downstream of it. Since mine start-up the water quality at KV-110 has changed reflecting mining operations without noticeable impact on KV-118.

4.4.2 GROUNDWATER WATER QUALITY

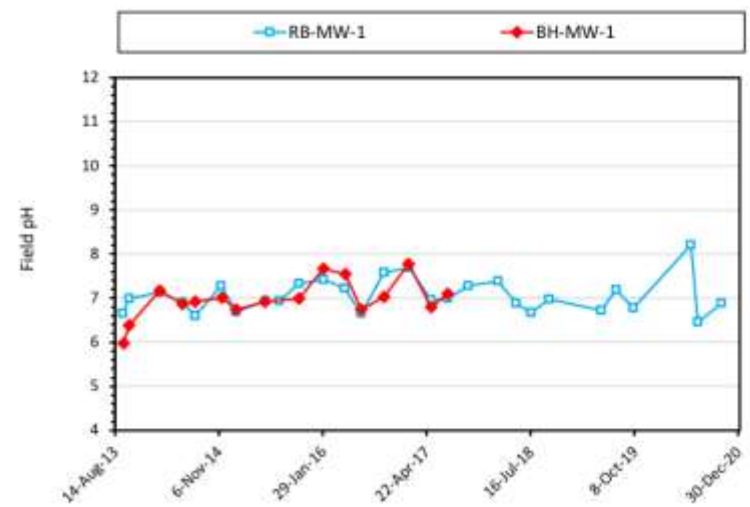
The dissolved concentrations of COPI in groundwater samples collected from monitoring wells BH-MW-1 and RB-MW-1 between 2013 and 2020 were compared with the Yukon Contaminated Site Regulation Schedule 3 Aquatic Life (YCSR, 2002). The comparison of water quality results with the generic guidelines was aimed at identifying relatively elevated constituents, determining their background concentration to serve as a benchmark for comparison with water quality data after the water treatment discharge has begun. This comparative assessment should not be considered as a measure of compliance or lack thereof to the YCSR. The guidelines for hardness -pH, DOC and temperature dependent elements were calculated for each sample using its hardness, pH, DOC and temperature data. For plotting purposes (lines on graphs), the 25th percentile hardness and DOC and 75th percentile pH and temperature observed for KV-111, the first surface water station likely to capture the groundwater discharge from the two monitoring wells, were used to create the guidelines displayed on Figure 4-17 to Figure 4-19.

Time series plots depicting the results for COPI are shown in Figure 4-16 through Figure 4-19 and associated summary statistics of those showing excess of the guidelines are reported in Table 4-17 through Table 4-21.

The COPI which were constantly higher or comparable to the guidelines in one of the wells or both were arsenic, selenium, and sulphate, while rare exceedances of the pH (lower limit), cadmium, copper, lead and zinc guidelines were also observed.

4.4.2.1 Field pH and Redox Potential

Besides the two first pH measurements, the groundwater field pH remained neutral between pH 6.5 and 7.8 (median pH = 7 for both wells) during the monitoring period (Figure 4-16). The ORP at the Bermingham monitoring well BH-MW-1 was oxidizing and constantly above +55 mV despite the fluctuation noted between summer and winter months. The redox potential at the Ruby groundwater monitoring well RB-MW-1 was lower and fluctuated between -200 mV to +157.3 mV indicating more reducing conditions than observed in the Bermingham monitoring well (Figure 4-16). The ORP at RB-MW-1 was below 0 mV since February 2017 except during the freshet of 2018. The median electrical conductivity for BH-MW-1 and RB-MW-1 was 256 and 415 µS/cm, respectively, indicating low salinity (fresh) groundwater.



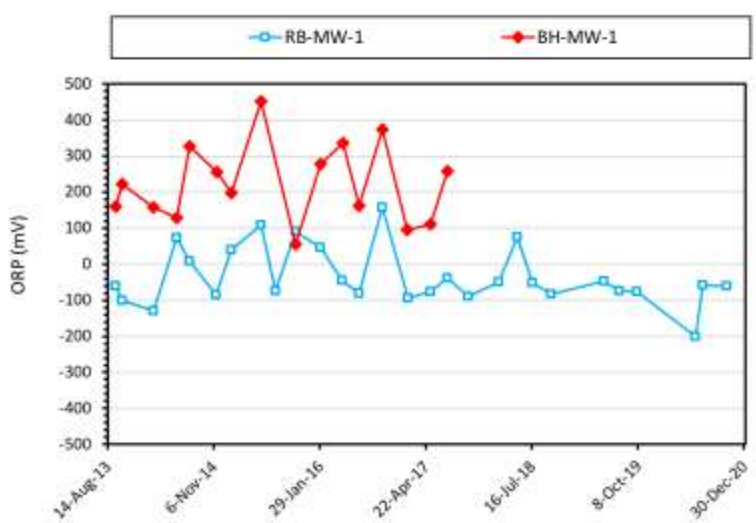


Figure 4-16: Field pH and ORP of Groundwater Monitoring Wells, 2013-2020 Data

4.4.2.2 Constituents of Potential Interest

Analysis of COPI trends revealed that arsenic and cadmium regularly or occasionally exceeded their respective guidelines in at one of monitoring wells. Dissolved arsenic, and cadmium concentrations exceeded at RB-MW-1 (79%, 7% respectively) and dissolved cadmium exceeded at BH-MW-1 (6%) as shown in the statistical summary tables and figures below.

Table 4-17: Dissolved Arsenic in Groundwater Monitoring Wells, 2013-2020 Data

	RB-MW-1	BH-MW-1
Dissolved Arsenic YCSR = 0.05 mg/L		
Average	0.065	0.00017
Count	28	16
Minimum	0.00035	0.000050
Maximum	0.098	0.00051
Count <DL	0	2
Standard Deviation	0.027	0.00011
1st Quartile	0.053	0.00012
Median	0.078	0.00015
3rd Quartile	0.085	0.00021
Count over Guideline	22	0
% Over Guideline	79%	0%

Table 4-18: Dissolved Cadmium in Groundwater Monitoring Wells, 2013-2020 Data

	RB-MW-1	BH-MW-1
Dissolved Cadmium YCSR = Hardness Dependent		
Average	0.00012	0.00016
Count	28	16
Minimum	0.0000058	0.000038
Maximum	0.00083	0.00052
Count <DL	0	0
Standard Deviation	0.00020	0.00012
1st Quartile	0.000019	0.000089
Median	0.000031	0.00012
3rd Quartile	0.000095	0.00019
Count over Guideline	2	1
% Over Guideline	7%	6%

Table 4-19: Dissolved Copper in Groundwater Monitoring Wells, 2013-2020 Data

	RB-MW-1	BH-MW-1
Dissolved Copper YCSR = Hardness Dependent		
Average	0.00045	0.00022
Count	28	16
Minimum	0.00010	0.00010
Maximum	0.0037	0.00054
Count <DL	16	8
Standard Deviation	0.00080	0.00015
1st Quartile	0.00010	0.00010
Median	0.00010	0.00015
3rd Quartile	0.00037	0.00030
Count over Guideline	0	0
% Over Guideline	0%	0%

Table 4-20: Dissolved Selenium in Groundwater Monitoring Wells, 2013-2020 Data

	RB-MW-1	BH-MW-1
Dissolved Selenium YCSR = 0.01 mg/L		
Average	0.000050	0.0010
Count	28	16
Minimum	0.000025	0.00079
Maximum	0.00010	0.0013
Count <DL	15	0
Standard Deviation	0.000020	0.00017
1st Quartile	0.000025	0.00091
Median	0.000050	0.0010
3rd Quartile	0.000061	0.0012
Count over Guideline	0	0
% Over Guideline	0%	0%

Table 4-21: Dissolved Sulphate in Groundwater Monitoring Wells, 2013-2020 Data

	RB-MW-1	BH-MW-1
Dissolved Sulphate YCSR = 1000 mg/L		
Average	114	45
Count	28	16
Minimum	74	41
Maximum	143	50
Count <DL	0	0
Standard Deviation	20	2.9
1st Quartile	99	43
Median	118	45
3rd Quartile	131	47
Count over Guideline	0	0
% Over Guideline	0%	0%

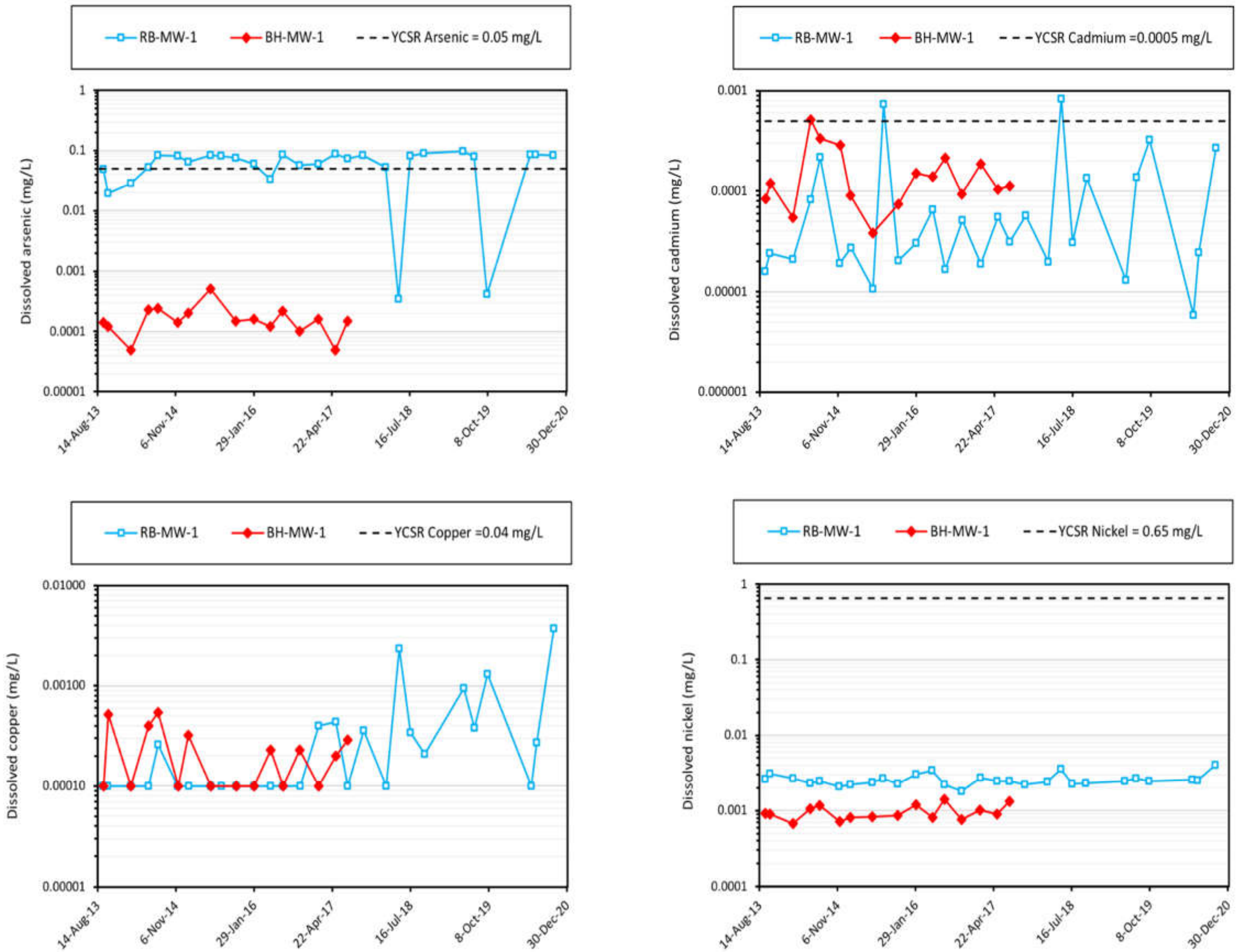


Figure 4-17: Dissolved Arsenic, Cadmium, Copper and Nickel of Groundwater Monitoring Wells, 2013-2020 Data

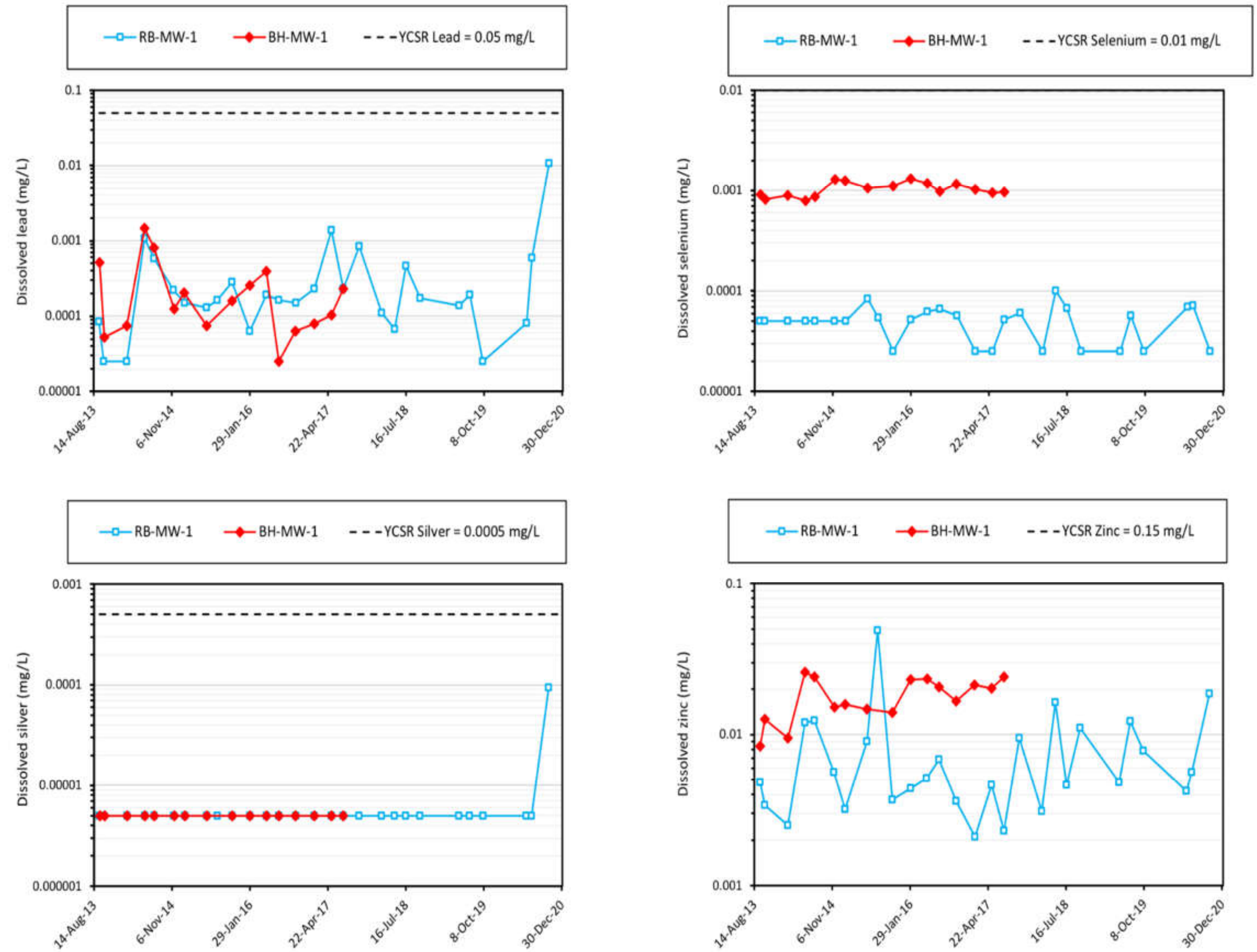
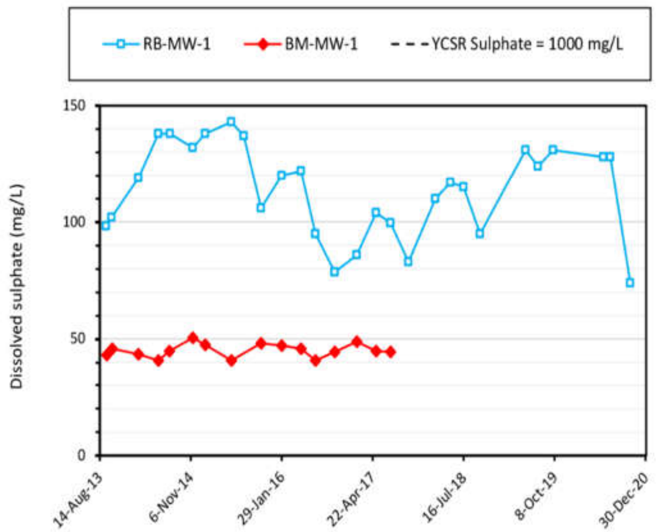


Figure 4-18: Dissolved Lead, Selenium, Silver and Zinc of Groundwater Monitoring Wells, 2013-2020 Data



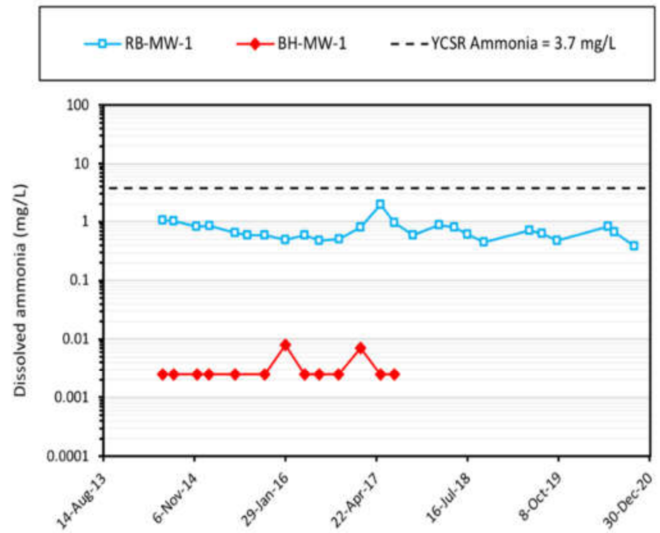


Figure 4-19: Dissolved Sulphate and Ammonia of Groundwater Monitoring Wells, 2013-2020 Data

5. CONCLUSIONS

The results of physical, geochemical and microbiological testing conducted on surficial soil and moss samples collected from the proposed discharge channel and surface water and groundwater monitoring data indicate the following:

- The soil samples consist mostly of silt and silt loam with a relatively low clay content (median 8.3%). The mixture of silt and clay are predicted to result in large surface areas favourable for the retention of metals through adsorption or cation exchange with the WTP discharge;

- The study site had a median soil organic matter content of 13.3% median. This low organic content along the proposed discharge channel do not create the most favorable conditions for sorption, immobilization and attenuation of metals but will offer some level of attenuation;

- The soil pHs were acidic to mildly acidic (median pH 5.4) with only one neutral soil pH reflecting an environment impacted by the weathering products of mineralization. The soil pH conditions of the first two thirds of the channel are not optimum for the precipitation of oxide or hydroxides because of the low pH. However, the soil pH values were higher that the point zero charge pH of most clay minerals which create conditions favourable for the retention of metals cations by variable surface charge clays;

- The study site had a median soil moisture content of 48.3% indicative of a moderate water holding capacity favourable for the development of vegetation cover, peaty and organic-rich surficial materials along the discharge channel which may promote natural attenuation.

- Microbial community profiling identified the presence of bacteria closely related to microorganisms capable of mediating sulphur redox transformations, indicating the potential exists for long-term metal sequestration via sulphide mineral precipitation. The marshy and organic matter rich environment will favor the development of sulphate-reducing conditions under which chalcophile metals may be sequestered as sulphide mineral assemblages; and

- These data indicate that soil and landcover conditions along the proposed discharge corridor are favourable for natural attenuation of metal(loid)s in the treatment discharge.

- The moss samples had different metal contents depending on their location along the discharge channel. BM-NAT-18 moss samples generally had high metal concentrations especially arsenic, cadmium, iron, manganese, copper, nickel, lead and zinc compared to other two sites likely due to contamination by residual soil left after washing. The concentration of these constituents was commonly 2 to 47- fold higher than BM-NAT-10 which had the second elevated metals concentrations. Cadmium and zinc were particularly elevated in the moss present in area BM-NAT-18 compared to others. The moss collected from BM-NAT-05 had the lowest average metal content.

- Available surface water monitoring data indicate circumneutral pH and oxic conditions at the monitoring stations. Although the increase of COPI concentrations at the Bermingham adit discharge occurred in 2020, it did not result concentrations exceedances compared to EQS at Bermingham pond decant (KV-114) except for arsenic which surpassed its EQS in 64% of the samples.

- The COPI concentrations at Bermingham adit discharge (KV-110) was often better or comparable to the COPI concentrations at the Upper No Cash Creek (KV-118) except during peak concentration of arsenic, selenium, and ammonia observed in 2020. This means that discharge from the Bermingham decline will generally contribute to improving COPI concentrations at downstream stations. It was also noted that COPI concentrations at downstream No Cash Creek (KV-111) was better than COPI concentrations at Upper No Cash Creek (KV-118) suggesting that attenuation and/or dilution mechanism are already occurring in the discharge channel.

- Bermingham and Ruby adit groundwater monitoring data since 2013 indicate sub-oxic to oxic, circumneutral pH and low salinity groundwater. The data also show recurrent or occasional exceedance of YCSR guideline by arsenic and cadmium in one of monitoring wells or both. Dissolved arsenic was recurrently elevated at RB-MW-1 and dissolved cadmium intermittently exceeded at RB-MW-1 and BH-MW-1.

6. NEXT STEPS

The next steps in this study will involve:

- Survey Bermingham WTP discharge pathway to confirm if overland flow or the discharge is going to ground and monitor for any glaciation of between the WTP discharge and upper No Cash Creek;
- Continued collection of water quality data from surface stations KV-110, KV-114, KV-111, KV-118, KV-21, and groundwater monitoring wells RB-MW-1, NC-MW-1 and KV-116; and
- Complete assessment of natural attenuation in upper No Cash Creek in 2021 now that WTP discharge began in Q4 of 2020.

7. REFERENCES

Access Consulting Group (ACG). 2013. *2013 Water Quality Review for the Keno Hill Silver District*, Prepared for Elsa Reclamation and Development Company Ltd.

Alexco Environmental Group (AEG). 2011. *Attenuation Column Test Program Summary Memo. 2011*, prepared for Elsa Reclamation and Development Company Ltd.

Alexco Environmental Group (AEG). 2016. *Flame and Moth Mine – Mass Load Modeling Results for Christal Creek and Lightning 2016*, prepared for Alexco Keno Hill Mining Corp.

Alexco Environmental Group (AEG). 2018a. *Mass Load Model for Bermingham Production and Development Program, 2018*, prepared for Alexco Keno Hill Mining Corp.

Alexco Environmental Group (AEG). 2018b. *No Cash Creek Attenuation Study Plan, Keno Hill Silver District Mining Operations, 2018*, prepared for Alexco Keno Hill Mining Corp.

Burt, R. 2009. *Soil Survey Field and Laboratory Methods Manual*. Soil Survey Investigations Report No. 5. Method 3.2.1.2.2. United States Department of Agriculture Natural Resources Conservation Service.

Canadian Council of Ministers of the Environment (CCME). 2003. Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedure for Deriving Numerical Water Quality Objectives.

Canada North Environmental Services. (CanNorth). 2018. *Updated Post-Reclamation Human Health and Ecological Risk Assessment for the United Keno hill Mines*, Yukon. 2018. Prepared for Elsa Reclamation and Development Company Limited.

Doulia, D., Leodolpoulos, C., Gimouhopoulos, K., Rigas, F. 2009. A*dsorption of humic acid on acid-activated Greek bentonite*. Journal of Colloid and Interface Science Vol 340 – issue 2, pp. 131-141

Ensero Solutions Ltd. (Ensero) and Alexco Keno Hill Mining Ltd. (AKHM) 2020. *Keno Hill Silver District Mining Operations, Adaptive Management Plan*. Prepared for Alexco Keno Hill Mining Ltd., October 2020.

Hatch Ltd. 2016. *Mass Load Model for No Cash Creek: Description and Results*. Draft Report. 2016. Prepared for Alexco Environmental Group.

Interralogic, Inc.. 2010. *Metal Attenuation Processes in the No Cash Creek Drainage- Final Draft Report.* Report submitted to Elsa Reclamation and Development Company Ltd., March 2010.

Interralogic, Inc.. 2012. *Natural Attenuation Evaluation Summary Report, United Keno Hill Mines, Elsa, YT.* Report submitted to Elsa Reclamation and Development Company Ltd., March 2012.

Khan, M.R, Hedge, R.A Venkatachalam, G. 2018. *Removal of Cadmium from Aqueous Solution using Bentonite Clay*. International Journal of Applied Environmental Sciences, Vol 13, pp.353-364

Kwong, Y.T.J., C. Roots, and W. Kettley.1994. *Lithochemistry and Aqueous Metal Transport in the Keno Hill Mining District, Central Yukon Territory*. Current Research 1994-E, Geological Survey of Canada, pp 7-15.

Kwong, Y.T.J., C. Roots, and W. Kettley. 1997. *Post-mine Metal Transport and Attenuation in the Keno Hill mining district, central Yukon*, Canada. Environ. Geol., 30, 98-107.

Nordstrom, D.K. 1982. *Aqueous pyrite oxidation and the consequent formation of secondary iron minerals*. In J.A. Kittrick, D.S. Fanning, and L.R. Hossner, Eds. Acid sulfate weathering, Volume 10, p. 37-56. Soil Science Society of America, Madison.

Pribyl, D.W., 2010. A critical review of the conventional SOC to SOM conversion factor. Geoderma 156, 75–83.

Rauret G., Lopez-Sanchez J., Sahuquillo A., Rubyo R., Davidson C., Ure A. 1999. *Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials*. Journal of Environment Monitoring, 1: p. 57–61.

Richard, T.W. 2007. *Metal Attenuation processes at Mining Sites. Ground Water Issues* - United States Environmental Protection Agency.

Silveira, M.L. Alleoni, L.R.F., O'Connor, G.A., Chang, A.C. 2006. *Heavy metal sequential extraction methods– A modification for tropical soils*. Chemosphere, 64. p. 1929–1938,

SRK Consulting Ltd. 2009. *2007/08 Geochemical Studies*, Keno Hill Silver District, YT., 2009, prepared for Elsa Reclamation and Development Company Limited

Stumm, W., Morgan, J.J. 1996. *Aquatic Chemistry*, New York: Wiley and Sons.

United States Environmental Protection Agency (EPA). 1999. *Monitored Natural Attenuation of Chlorinated Solvent*.

Vega, J.L. Ayala, J. Loredo, J. Iglesias, J.G.2005. *Bentonites as adsorbents of heavy metals ions from mine waste leachates: Experimental data*. 9th International Mine Water Congress.

Yukon Government. 2018. *Water Licence Audit for QZ09-092-2 and QZ17-084*. December 31, 2018. Water Resources Branch

Yukon Government. 2020. *Water Licence QZ18-044*. July 22, 2020. Water Resources Branch

APPENDIX A.

Laboratory Analytical Reports

Soil and Moss Geochemical and Microbiological -Surface water and Groundwater Quality Data

APPENDIX 2
SUPPORTING ENVIRONMENTAL DATA

Keno Hill Silver District

QML-0009 Site Characterization Report

March 31, 2020

Prepared for:

ALEXCO KENO HILL MINING CORP.

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1. INTRODUCTION

The Site Characterization Plan (SCP) summarizes environmental conditions for the mining operations in the Keno Hill Silver District (KHSD) conducted by Alexco Keno Hill Mining Corp. (AKHM), a wholly owned subsidiary of Alexco Resource Corp. (Alexco). The Project areas within the KHSD include Bermingham, Bellekeno, Flame and Moth, Onek 990, Lucky Queen, and the Mill District, and these areas are discussed in this report. All Project areas are in the Traditional Territory of the First Nation of Na-cho Nyak Dun (FNNND).

1.1 PROJECT LOCATION

The KHSD is 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.

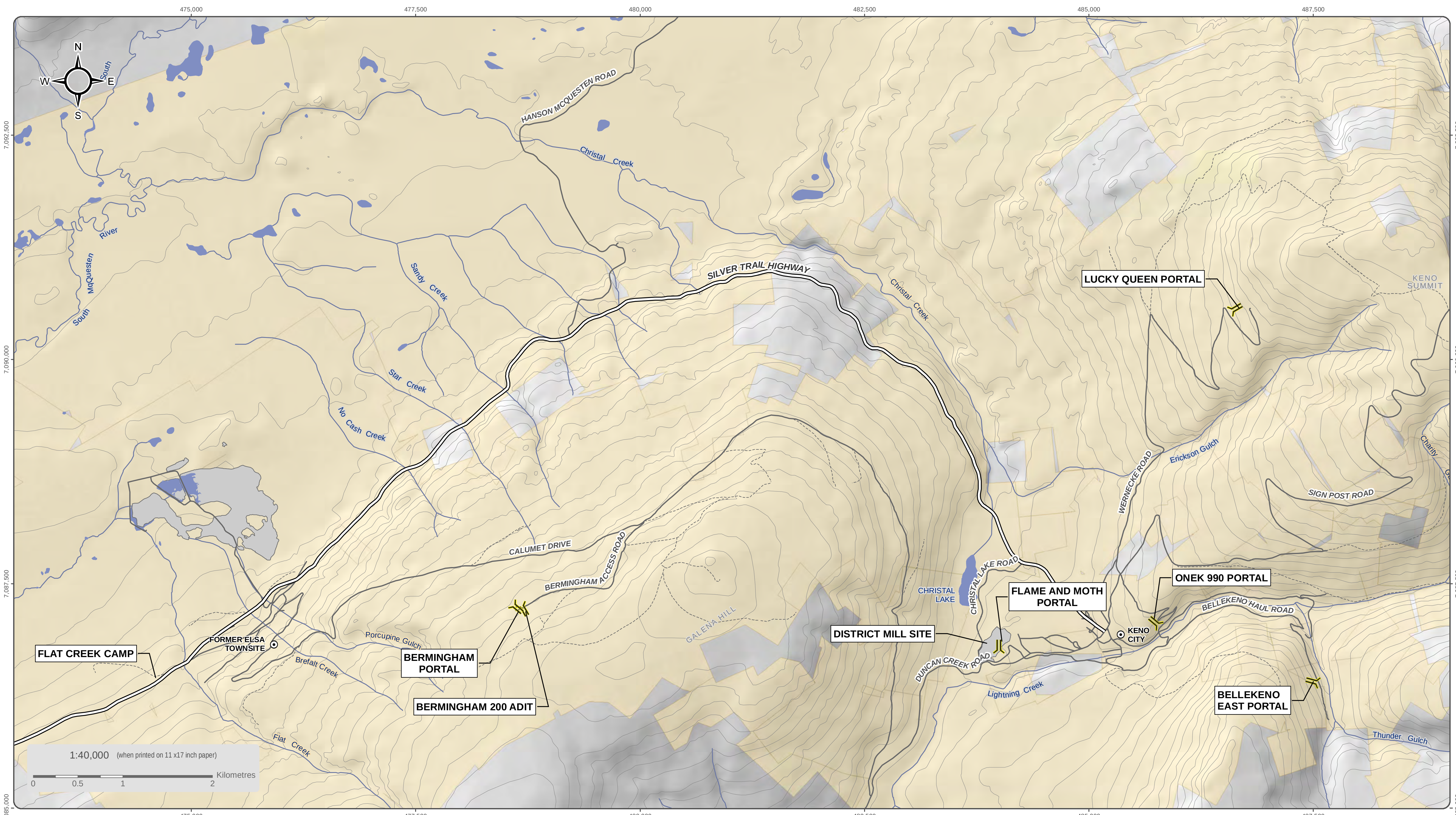
The KHSD is located on and around Galena Hill, Keno Hill and Sourdough Hill, collectively known as the KHSD (Figure 1-1). The properties lie along the broad McQuesten River valley with three prominent hills to the south of the valley. The Bermingham deposit is located on Galena Hill. The Lucky Queen and Onek 990 Mines are located on Keno Hill, while the Bellekeno Mine is located on Sourdough hill. The Flame and Moth Mine and the Keno District Mill are located at the headwaters of Christal Creek.

1.2 PERMITTING CONDITIONS

Currently licenced mines under the Quart Mining License (QML-0009) include the Bellekeno deposit, Dry Stack Tailings Facility (DSTF) phase 1, and District Mill operation (Type A Water Licence QZ09-092), the Onek 990 and Lucky Queen Mines (Water Licence amendment QZ12-053), the Flame and Moth mine and the DSTF expansion (phase 2) (Water Licence amendment QZ09-092-2) and the Bermingham Mine (renewal application QZ18-044) (Table 1-1).

Table 1-1: KHSD Permitting Timeline

Mine	Date
Bellekeno	2009
District Mill and DSTF	2009
Onek	2013
Lucky Queen	2013
Flame and Moth	2016
New Bermingham	2019



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

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

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Legend		
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.
BERMINGHAM

FIGURE 1-1

KENO HILL SILVER DISTRICT MINING OPERATIONS AREA OVERVIEW

OCTOBER 2017

2. GEOLOGY AND SOILS

The KHSD has been subject to numerous faulting and folding events that have shaped the district's geology and mineralogy, and therefore the surface and groundwater flow regime.

A complete description of the regional, district and surficial geology has been provided to add insight into structural controls (faults, permeable flowpaths, etc.) on groundwater flow in the alluvial material, bedrock zone, and the surface/groundwater interfaces. Hydrogeology studies and mine histories suggest that groundwater within the KHSD originates from infiltrated meteoric water, which migrates within unconsolidated glacial deposits and through fractures in metamorphic rocks (SRK, 2014).

2.1 REGIONAL DESCRIPTION

The KHSD is located within the northwestern part of the Selwyn Basin, in an area characterized by the Robert Service and Tombstone Thrust Sheets that are overlapping and trend northwest. This area is underlain by Upper Proterozoic to Mississippian sedimentary rocks 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 lying to the south of the KHSD is composed of Late Proterozoic to Cambrian coarse-grained, quartz-rich turbidite succession with interbedded shales and locally limestone, of the Hyland Group, Yusezyu Formation. The Tombstone Thrust Sheet that lies to the north and underlies the KHSD consists of Devonian phyllite, felsic meta-tuffs and metaclastic rocks from the Earn Group, which is conformably overlain by Mississippian Keno Hill Quartzite. The Keno Hill Quartzite unit is locally thickened due to folds and thrusts and is the main host for silver mineralization. There are four suites that intrude the sedimentary sequence: Late Triassic gabbro to diorite sills; Early Cretaceous Tombstone granite to granodiorite; Cretaceous lamprophyre dykes and sills; and Upper Cretaceous McQuesten suite peraluminous porphyritic granite.

2.2 PROPERTY GEOLOGY

The Keno Hill District is underlain primarily by Yukon Group metasedimentary rocks, locally divided into three formations; Upper Schist, Central Quartzite and Lower Schist. The Upper Schist (Hyland Group, pre- Cambrian to Cambrian age) overlies the quartzite in what is inferred to be a thrust contact (Robert Service Thrust) and consists of quartz-mica schist, quartzite, graphitic schist and minor limestone. The Central Quartzite (Keno Hill Quartzite, Mississippian age) contains thick-and thin-bedded quartzite, massive quartzite, graphitic phyllite, graphitic schist, calcareous schist and minor Triassic greenstone. This unit is approximately 700 m thick and is host to most of the past producing ore bodies. Structurally juxtaposed below the quartzite is the Lower Schist which has been correlated with the Devonian-Mississippian Earn Group. The Lower Schist includes graphitic schist, argillite, thin-bedded quartzite, calcareous schist, phyllite, slate, sericite schist, minor thick-bedded quartzite and locally significant intervals of Triassic greenstone. The greenstone forms sills and / or boudins and consists of metadiorite and metagabbro. The sills and boudins form bodies up to one kilometre long and thirty metres thick. Regional, greenschist facies metamorphism of all units is believed to have occurred in the Middle Cretaceous, about 105 million years ago.

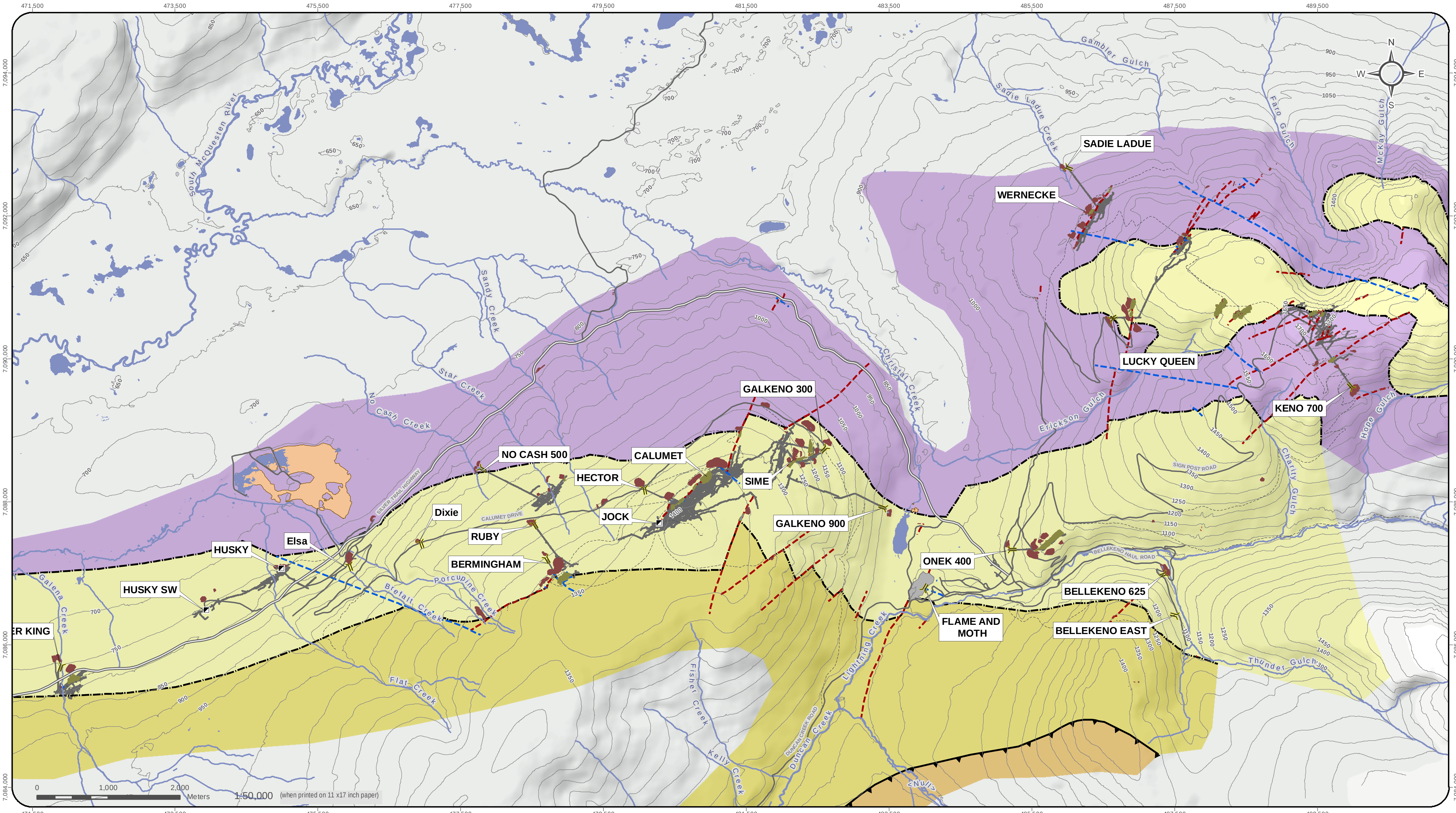
A number of quartz-feldspar porphyritic sills have intruded the stratigraphy parallel to schistosity. The sills are most common in the Lower and Upper Schists and can reach thicknesses of up to fifty metres; reports of occurrences in the Central Quartzite are inconclusive and vague. The quartz-porphyry sills are believed to be of Cretaceous age.

A series of faults, striking northeast and dipping steeply southeast, host the silver-lead-zinc lode deposits. These vein faults exhibit left lateral movement, commonly offsetting the surrounding metasedimentary sequences by over 150 m (Watson, 1986). The vein faults are offset in places by two types of unmineralized faults; cross faults which strike northwest and dips southwest and the bedding plane thrust faults which exhibit movements ranging from 1 m to 30 m.

Within the KHSD, up to four main periods of faulting are recognized. The oldest fault set consists of south-dipping foliation-parallel structures that developed contemporaneously with the first phase folding. The silver mineralization in the KHSD is hosted by a series of north-east–trending pre-mineral and syn-mineral vein-faults that display apparent left lateral normal displacement locally referred to as longitudinal veins that, depending on the competency of the host rock, can be up to 30 m wide with an anastomosing system of subveins.

A related set of faults, known as transverse faults, that strike north-northeast and dip moderately to the southeast, can reach up to 5 m in thickness. High angle cross faults, low angle faults, and bedding faults offset veins and comprise post-mineralization faults. Most commonly, these comprise northwest-striking cross faults recognized by offset veins that show apparent right-lateral displacement. Mine histories indicate that enhanced groundwater flow into mine workings can occur when cross faults are intersected (SRK, 2014).

A map indicating the locations of the Keno Hill Basal Quartzite, Earn Group, Sourdough Hill Member and Hyland Group along with the contacts between these are provided as Figure 2-1. The locations of main pre- and post-mineralization faults are also shown on this figure. Galena Hill is characterized by the Keno Hill Basal Quartzite Member, Earn Group, and the Sourdough Hill Quartzite Member, which are cut by two major faults: the Brefalt Fault and the MacLeod Fault. Keno Hill is characterised by the Keno Hill Basal Quartzite Member and Earn Group with numerous pre- mineral and post-mineral faults.



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

- Underground Workings
- Post-Mineral Fault
- Pre-Mineral Fault
- Main Stratigraphic Break
- Robert Service Thrust Fault
- Keno Hill Basal Quartzite Member
- Earn Group
- Keno Hill Sourdough Hill Member
- Hyland Group
- Adit
- Shaft
- Silver Trail Highway
- Other Road
- Limited-Use Road
- Contours (50m intervals)
- Watercourse
- Waterbody
- District Mill
- Open Pit
- Waste Rock Dump
- Tailings

* Only showing mine sites referenced in document

ERDC

ACCESS

KENO HILL SILVER DISTRICT
CHARACTERIZATION REPORT

FIGURE 2-1

KHSD GEOLOGICAL FORMATIONS AND FAULTS

OCTOBER 2015

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\WQ01-GROUNDWATER\Specific_Focus\Groundwater_Investigation\Rev_1\Revised20151027\Fig_3_1_Geologic_Faults2015
(Last edited by: mheynen; 10/27/2015/10:24 AM)

2.3 PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The KHSD lies within the northeastern part of the Yukon Plateau, and is characterised by mountainous terrain, with elevations that range from 610 masl (metres above sea level) (McQuesten River valley) to 1,848 masl (Summit of Keno Hill). The KHSD has been shaped by several glacial advances, notably the McConnell glaciation (approximately twenty thousand years ago (Ka)) and the Reid glaciation (approximately 200 Ka-300 Ka) (Lipovsky et al., 2001). The Reid glaciation almost completely covered the KHSD, with the exception of the peaks of Keno Hill, while the McConnell glaciation was not as extensive, with the peak extent of glaciation reaching an approximate elevation of 1,100 masl. There is less evidence of the Reid glaciation around the KHSD compared to the more recent McConnell glaciation. The McConnell glaciation advanced from east to west, flowing onto the McQuesten River valley, while a tongue of this glacier extended between Galena and Keno Hills terminating near Keno City.

This extensive glaciation has defined the KHSD's surficial geology and surficial groundwater flow. The valleys are broad, glacially scoured and typically boggy with thick peat deposits. The lower slopes of Galena and Keno Hills have a variety of sand, gravel, and silt deposits, including kames and terraces, that were deposited off the sides of retreating glaciers and meltwater streams. These till deposits range from 10 m to 50 m thick, and are typically present up to 1,100 masl, the extent of the last glaciation. Till deposits through the KHSD are striated with lenses dominated by gravel or sand within a silt matrix. These were used during construction and mining as foundation and road material and are considered good borrow sources for covers and other reclamation activities. Keno City is underlain by 85 m of sand and gravel. At higher elevations, above the last glaciated extents, are thin layers of colluviated sediments and soils with exposed bedrock along ridge-tops, gulches, and cirques (LeBarge et al., 2002). Freeze-thaw cycles for over 300,000 years have created frost-shattered bedrock boulder fields running down the higher elevation hillsides of Keno and Galena Hills. A map of the surficial geology of the KHSD is provided on Figure 2-2.

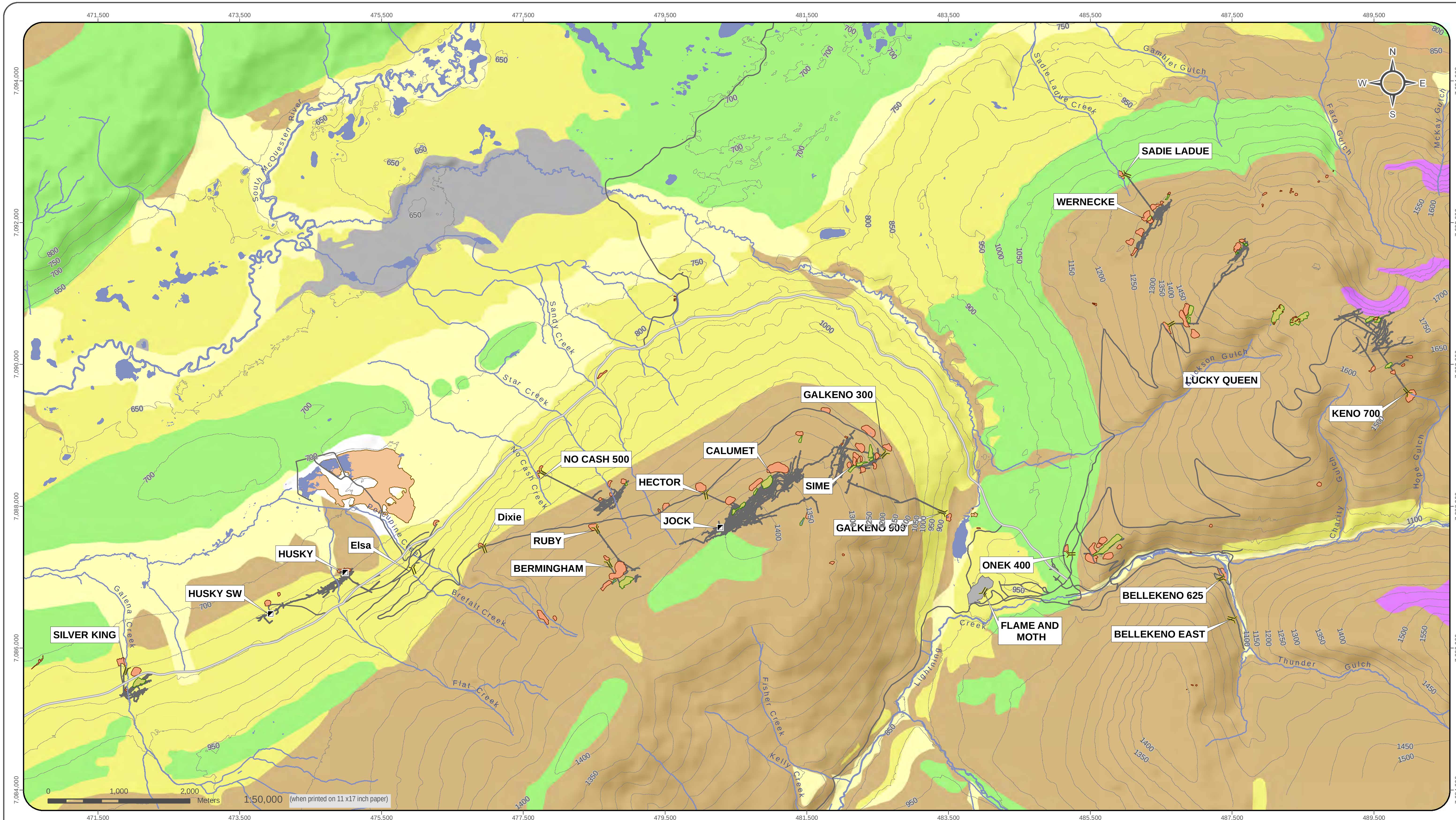
Galena Hill trends northeast between Duncan Creek and the McQuesten River valley. It has an elevation of 1444 masl, a moderately steep southwestern slope, and steeper north, northwestern, and southeastern slopes. The terrain above 1310 masl is relatively flat and rolling, and marked by several level grassy meadows. The north, northwestern, and southeastern slopes of the hill are crossed by several streams that have cut steep gulches into the rock strata. The principal streams responsible for these gulches are Galena, Flat, Brefalt, and Sandy Creeks and Porcupine Gulch on the northwestern slope and Hinton and Fisher Creeks on the eastern and southeastern slopes.

Keno Hill and Sourdough Hill are adjacent hills separated by Lightning Creek. Keno Hill trends northeast and lies between the Keno Ladue-McQuesten River valley and Allen, Faith, Lightning, and Christal Creeks. The hill has relatively gentle southern and southeastern slopes and a precipitous northern slope, marked by two cirques, Faro Gulch and Silver Basin Gulch. The terrain above 1372 masl is relatively flat and rolling with five prominent rocky knolls known as Keno, Minto, Monument (the highest point on Keno Hill, elevation 1848masl), Caribou, and Beauvette. On the slopes of the hill several streams follow steep gulches in the rock strata, the principal ones being Gambler, Faro, McKay, and Silver Basin on the northern slope, Faith, Hope, and Charity on the northeastern and southern slopes, and Erickson on the western slope.

Sourdough Hill lies southwest of Keno Hill and trends north between Thunder, Lightning, and Duncan Creeks. The part of the hill described in this report is on the northern and northwestern slopes, which are gentle up to 1280m and from there rise abruptly to a steep rocky hogsback that trends southwest for some 1828 masl.

Extensive rock outcrops are uncommon on Galena, Keno, and Sourdough Hills, and with the exception of the gulches and cirques where relatively good geological sections are present, detailed mapping can only be done by observing float. Below an elevation of 1341 masl rock outcrops are sparse, and the slopes are covered with till, soil, rock debris, much, and muskeg, in which conifers, birch, aspen, Arctic black-birch, and other vegetation grow abundantly. Above this elevation the soil is thin, outcrops are more numerous, the ground is covered with local rock float, the terrain is treeless, and the vegetation is limited to alpine species and grassy meadows.

The lower slopes of the hills were severely glaciated during Pleistocene time by ice sheets that spread, from the east, over the entire area. Glacial till, gravel, and other debris lie in a series of benches on the slopes of the hills and floor the valleys. The deposits are generally 1.5 to 6m thick, but in some areas as on the southern slope of Keno Hill facing Lightning Creek and north of Christal Lake, they are 9 to 15 m thick or more.



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

Legend		
Anthropogenic	Adit	Watercourse
Colluvium	Shaft	Waterbody
Fluvial (Active)	Underground Workings	District Mill
Fluvial (Glacial)	Silver Trail Highway	Open Pit
Morainal	Secondary Road	Waste Rock Dump
Organic	Contours (50 meter)	Tailings
Bedrock		

* Only showing mine sites referenced in document

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KENO HILL SILVER DISTRICT
CHARACTERIZATION REPORT

FIGURE 2-2
KHSD SURFICIAL GEOLOGY

APRIL 2016

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2.4 PERMAFROST

The Keno Hill-Galena Hill area is in the region of permanently frozen ground. The permafrost is irregularly distributed, and its occurrence is dependent upon the elevation, hillside exposure, depth of overburden, 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.

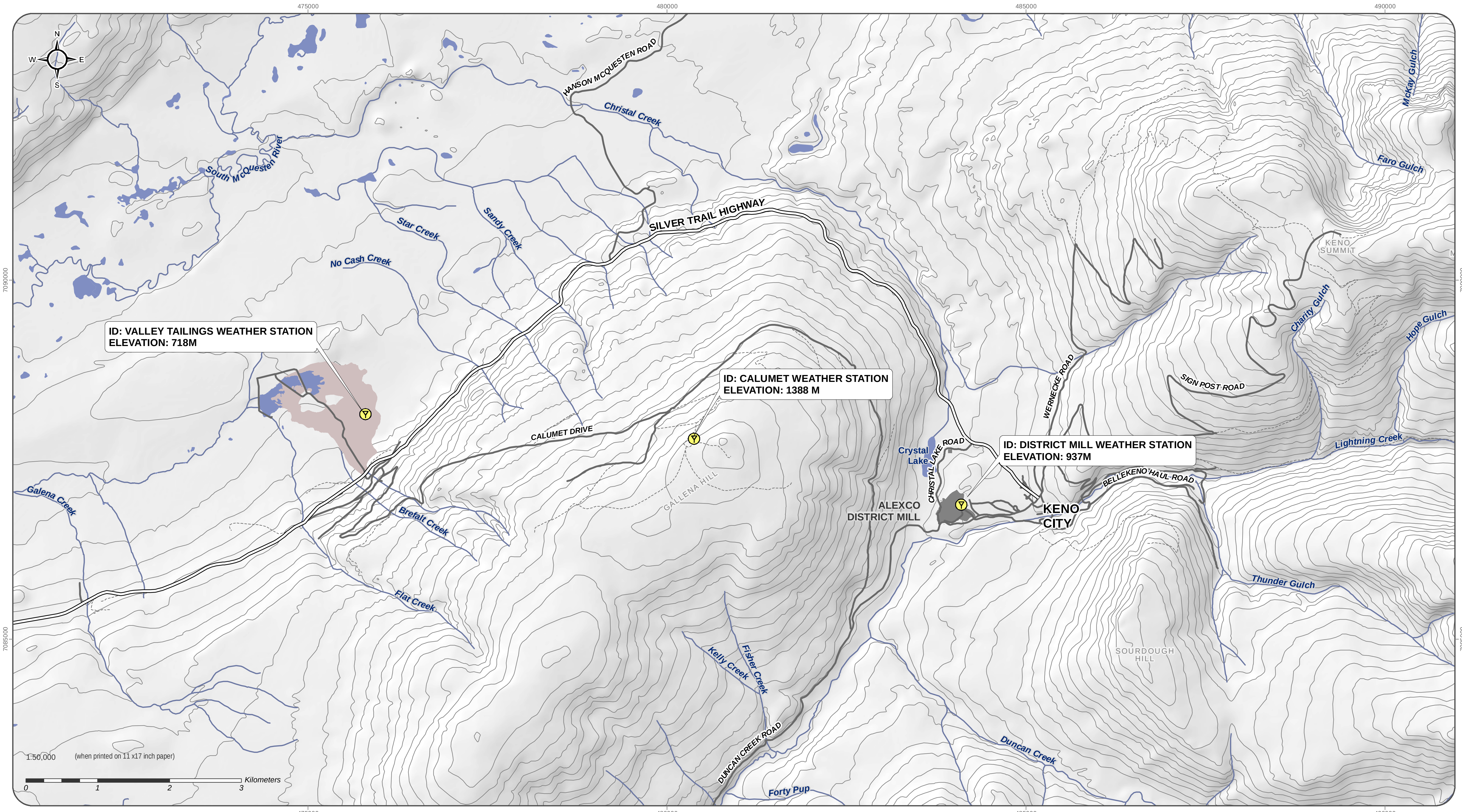
On Keno Hill, the mine workings on the top of the hill and on the northern slope encountered permafrost some 120 m below the surface. On the northern slopes of Sourdough Hill and Galena Hill a similar situation prevails, and frost and ice lenses have been encountered at depths of 76 m or more in the mine workings. On the lower southern slope of Keno Hill, however, the workings of the Onek and Mount Keno mines show little evidence of permafrost. In places where surface and underground water are flowing the permafrost has been thawed out and frost-free windows and strips are present. These provide access and egress for waters that are oxidizing the lodes.

The effects of frost action, soil creep, and slope wash are marked on the hills, particularly at the higher elevations. Frost action is responsible for features such as stone rings and stripes, and produces a general ‘boiling action’ that brings rock float, mineralized float, and soil from deeper layers to the surface, thus facilitating the mapping of both the underlying bedrock and the tracing of vein faults. On steep slopes, however, frost action and land creep have transported float downhill places, 30m or more, making the accurate mapping of contacts and vein faults difficult.

3. CLIMATE

3.1 METEOROLOGICAL STATIONS

This section describes the meteorological data collected for the Keno Hill mines property since 2007 at the Calumet weather station, since 2011 at the Keno District Mill meteorological station (installed as part of Bellekeno mining operations) and since 2012 at the Valley Tailings meteorological station. The locations of the three weather stations are shown on Figure 3-1. A summary of the climate information available is presented in the following sections.



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.

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

Weather Station
District Mill
Tailings Area
Waterbody
Silver Trail Highway
Road
Limited-Use Road
Contours (100 ft)
Watercourse

ERDC

AEG

ALEXCO KENO HILL MINING CORP.

FIGURE 3-1

KENO METEOROLOGICAL STATIONS

JANUARY 2020

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3.1.1 CALUMET WEATHER STATION

This station is an automated Onset HOBO meteorological station installed on Galena Hill above the Hector Adit at 1380 masl in June 2007 (UTM coordinates: 08 V 480377 7087790). Table 3-1provides a list of the station's complete component list.

Table 3-1: Calumet 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 Installed April 19, 2019: S-WCF-M003	1254995 20584743
BP Sensor	S-BPA-XXXX	1037089
Solar Panel	SOLAR-6W Installed August 3, 2019: SOLAR-15W	

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 3-2 and Table 3-3 respectively below.

Table 3-2: Monthly values for average temperature collected at the Calumet Station (2007-2019)

	Average Temperature (°C)												
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
January	-	-17.18	-18.84	-14.08	-16.78[3]	-18.71[4]	-16.90	[6]	-13.22	*-8.34*[12]	*-13.06*[14]	-13.80	[18]
February	-	-16.99	-16.95	-9.09	-15.88[3]	-9.94[4]	-10.81	-15.69	-13.42	-9.32	[14]	-16.86	[18]
March	-	-11.04	-16.39	-9.21	-12.92[3]	-12.92[4]	-14.45	-11.95	-10.69	-5.84	*-16.43*[14]	-11.99	[18]
April	-	-4.93	-4.75	-2.01	-3.77[3]	-1.88[4]	-12.32	-4.39	-3.33	-0.43	*-3.62*[15]	-6.33	*-4.21*[18]
May	-	3.31	3.66	5.35	4.41[3]	1.61[4]	n/a	4.17	7.85	5.55	[15]	2.84	*-2.50*[19]
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	[15]	8.68	[19]
July	11.80	8.17	12.45	10.5	3.80[3]	7.84[4]	11.11	[11]	9.67	10.60	*11.81*[15]	11.93	[19]
August	9.63	5.54	7.47	9.61	[2]	8.34[5]	10.58	7.95	6.71	9.25	10.03	7.14	*6.02*[19]
September	1.12	2.27	3.58	2.40	[2]	3.39	3.33	1.86	*2.17*[12]	2.95	4.74	1.55	7.22
October	-6.53	-7.20	-4.73	-4.86	[2]	-8.16	-2.52	-5.02	[12]	-6.23	-4.94	-2.64	[20]
November	-9.41	-10.17	-11.94	-11.19	-17.39[4]	-18.44	-15.50	-9.87	[12]	-8.87	-17.31	-9.29	[20]
December	-16.19	-18.34	-11.16	-17.72	-11.78[4]	-18.83	*-14.56*[6]	-10.43	[12]	-15.27	*-5.31*[16]	*-10.67*[18]	[20]

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

[14] Temperature data missing between January 14, 2017 and March 4, 2017.

[15] Data missing between April 7, 2017 and July 17, 2017.

[16] Last data download on December 15, 2017.

[17] Rain data missing between January 26, 2017 and March 4, 2017.

[18] Data missing between December 26, 2018 and April 19, 2019. Battery depletion and windspeed sensor failure.

[19] Data missing between May 8, 2019 and August 3, 2019. Solar panel issues.

[20] Data missing as battery depleted due to solar panels being covered by snow.

Table 3-3: Monthly values for total rainfall collected at the Calumet Station (2007-2019)

	Total Rainfall (mm)												
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
January	-	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-	-	-	-	-	-
April	-	1.0	-	1.3[2]	2.8[2]	[9]	0.2	6.2	8.6	7.8	*4.3*[9]	0.8	*1.0*[10]
May	-	25.4	21.8	32.3[2]	15.5[2]	[9]	-	17.2	4	23.0	[9]	82.8	*0.5*[11]
June	*55.2*[1]	44.6	*11.9*[3]	56.7[2]	121.8[2]	[9]	45.2	*69.8* [6]	45.2	43.0	[9]	116.3	[11]
July	108.8	108.4	*22.9*[4]	137.7[2]	135.9[2]	*27.8*[5]	39.2	[6]	135.5	[8]	*71.3*[9]	31.6	[11]
August	54.8	110.2	89.4	140.0[2]	[9]	45.0	35.6	112.0	97.0	[8]	44.5	164.3	*21.2*[11]
September	57.6	61.4	50.4	78.0[2]	[9]	17.4	64.6	43.8	*46.4*[7]	[8]	115.2	15.9	41.5
October	-	12.6	-	16.0[2]	[9]	1.6	14.6	15.2	[7]	*0.01*[8]	16	9.4	
November	-	-	-	-	-	-	-	-	-	-	-	-	-
December	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes:
Values in grey italics indicate a partial month
No values are presented from November to March as the gauge only measures rainfall, and values are likely snowmelt (i.e. snowfall not measured).
[1] Station commissioned June 15, 2007
[2] Calculated from MAYO A data
[3] Rainfall gauge malfunction on June 11; total rainfall provided for June 1-11
[4] Rainfall gauge back online; total rainfall provided for July 7-31.
[5] Tipping bucket repaired July 4th; total rainfall provided for July 4-31.
[6] Station was down between June 26 and July 31, 2014
[7] Data missing from September 17, 2015 to January 5, 2016
[8] Rainfall data missing from June 23, 2016 to October 23, 2016
[9] Data missing between April 7, 2017 and July 17, 2017
[10] Data missing between December 26, 2018 and April 19, 2019. Battery depletion and windspeed sensor failure
[11] Data missing between May 8, 2019 and August 3, 2019. Solar panel issues

3.1.2 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). All the District Mill Meteorological station components are present in Table 3-4.

Table 3-4: 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
Barometric Pressure	PTB110 1B0CA	P3220823

Monthly averages since 2011 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, barometric pressure, and solar radiation. Annual temperature, humidity, windspeed, solar radiation wind speed and direction, and total rainfall are shown on Table 3-5 below.

Note that the barometric pressure has not been corrected for elevation and therefore represents the absolute pressure.

Wind data from time of commissioning to the end of December 2019 are also depicted in the wind rose presented in Figure 3-2, which was produced using WRPLOT View software. This period has a 92% data availability, i.e. refers to the available wind data in the total dataset, with the remaining 8% missing data attributed to periods of frozen sensors and maintenance.

Table 3-5: Monthly values for meteorological parameters collected at District Mill Weather Station

Year	Total Rain (mm)	Average Max Temp. (ºC	Average Temp. (ºC)	Average Min Temp. (ºC)	Average Relative Humidity (%)	Extreme Max Wind Speed (m/s)	Average Wind Speed (m/s)	Average Wind Direction (º)	Max Solar Radiation (W/m^2)	Average Solar Radiation (W/m^2)
2011		23.7	0.7	-34.7	43.0	14.5	1.1	211.4		
2012	217.5	27.6	-4.1	-37.3	59.9	15.6	1.2	217.3	0.018	0.001
2013	327.9	30.5	-3.6	-41.5	72.1	16.1	1.4	202.2	0.900	0.103
2014	240.4	24.9	-2.2	-33.6	71.8	19.2	1.2	188.4	0.938	0.101
2015	256.7	26.5	-2.0	-39.4	74.9	15.6	1.2	182.7	0.921	0.099
2016	247.6	26.0	-0.9	-32.2	73.6	15.4	1.2	202.8	0.888	0.100
2017	227.5	28.3	-2.3	-33.9	71.3	13.7	1.3	203.1	0.879	0.102
2018	323.5	27.7	-2.8	-33.8	71.9	17.1	1.3	196.9	0.859	0.098
2019	127.1	26.1	-1.8	-33.4	70.0	13.7	1.3	210.5	0.878	0.102

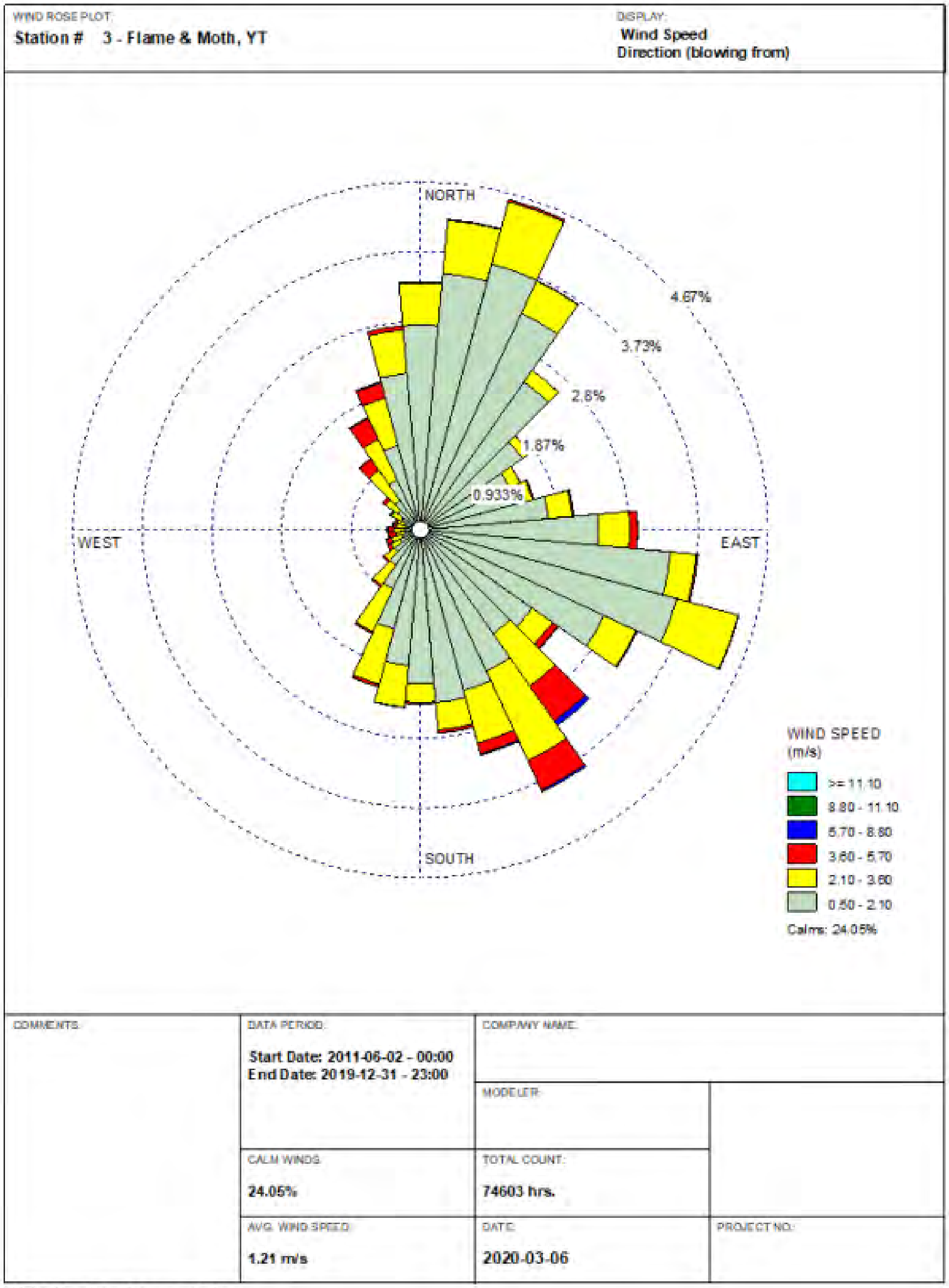


Figure 3-2: District Mill Wind Rose, June 2011-December 2019

Evapotranspiration rates were not calculated for 2011 and 2012 as the pyranometer was only installed in December 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 3-6 presents the comparison between the 2013 through to 2019 datasets and the 1996 WREVAP evapotranspiration dataset. During fall 2019 winterization, a change in the code affected the evapotranspiration rate calculations, and thus the evapotranspiration rates from September 2019 to the end of the year are erroneous. The code is currently under review with the instrumentation manufacture.

Table 3-6: Evapotranspiration data values compared to 1996 WREVAP dataset (mm)

Month	2013	2014	2015	2016	2017	2018	2019	1996 WREVAP
January								
February								
March								
April	14.5	15.8	16.0	15.9	15.4	15.9	17.6	10
May	21.7	29.8	34.7	26.0	28.0	22.0	32.5	42
June	29.8	28.6	26.5	29.8	28.6	21.8	35.6	43
July	27.1	23.8	20.0	17.4	25.5	29.0	27.9	44
August	21.4	15.7	13.9	17.7	21.7	12.3	23.3	20
September	10.9	11.6	10.1	14.0	10.4	*6.6*	[1]	20
October	4.3	3.4	*2.9*	4.2	*3.4*	*4.6*	[1]	0
November								
December								
Annual Total	**129.6**	**128.7**	**124.1**	**124.9**	**132.4**	**112.1**	[1]	**179**

Notes:
Values in grey italics indicate a partial month
[1] ET code issues, code is under review

3.1.3 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. All components of the station are presented in Table 3-7.

Table 3-7: Valley Tailings HOBO Meteorological Station

Component	Model	Serial Number
Datalogger	U30 NRC	10231016
Input Expander kit		
Solar Panel	SOLAR-6W Installed August 3, 2019: SOLAR-15W	
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	
Barometric Pressure	BPB-CM50	10212093
Soil Moisture Sensor	SMC-M005	10225679
Tripod	TPA-KIT 3m	

Monthly averages since 2011 from installation to the end of October 2019 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. Annual temperature, relative humidity, maximum gust speed and total rainfall are shown in Table 3-8 below. Note that the barometric pressure has not been corrected for elevation and therefore represents the absolute pressure.

Table 3-8: Annual values for meteorological parameters collected at the Valley Tailing Station, October 2012 to October 2019

Year	Sum of Rain (mm)	Max Temp (°C)	Avg Temp (°C)	Min of Temp (°C)	Average of RH, %	Max Solar Radiation (W/m²)	Avg. Solar Radiation (W/m²)	Max Wind Speed (m/s)	Avg of Wind Speed (m/s)	Avg Wind Direction (ø)	Avg Water Content, (m³/m³)
2012*		-4.0	-23.5	-44.2	82.4	260.6	9.5	4.53	0.33	160.4	-0.09
2013	233.6	32.8	-5.0	-45.6	74.0	979.4	94.3	12.84	0.93	148.3	0.01
2014	112.4	28.2	-5.9	-39.4	73.9	1059.4	93.2	8.31	0.69	144.8	0.03
2015	272.2	27.6	-1.9	-41.5	77.6	999.4	96.6	10.32	0.78	147.9	0.07
2016	226.6	27.5	-1.1	-39.7	76.4	1073.1	98.1	8.81	0.87	234.6	0.09
2017	269.2	30.1	-2.8	-39.8	74.5	1014.4	99.7	9.32	0.83	284.9	0.07
2018		21.1	-11.4	-40.3	85.6	883.1	34.0	8.31	0.43	135.4	0.00
2019*		26.0	-6.4	-40.5	79.2	826.9	64.5	8.81	0.64	145.2	0.04

* Data presented is for a partial year.

3.1.4 SNOW SURVEYS

There are three regional snow survey sites that are monitored by the Yukon Government: Mayo Airport A, Mayo Airport B, and Calumet. Mayo Airport A and B are located in the Village of Mayo at an elevation of 540 masl and Calumet is on Galena Hill, near Keno City at an elevation of 1310 masl. The March and April monthly snow water equivalent (SWE) statistics for the three regional sites are shown in Table 3-9: Regional snow survey station .

Table 3-9: Regional snow survey station Snow-Water Equivalent (SWE)

Station	Elevation (masl)	Period	Month	Minimum (mm)	Maximum (mm)	Average (mm)
Mayo A	540	1968-2019 n = 50	March	30	160	92
			April	10	176	96
Mayo B	540	1987-2019 n = 63	March	42	166	93
			April	48	192	103
Calumet	1310	1975-2019 n = 42	March	94	298	171
			April	101	300	195

AEG has been conducting manual snow surveys since 2011 at ten monitoring stations in order to represent the varying snow conditions as a function of aspect and elevation. Two additional stations (BKS-11 Lucky Queen and BKS-12 Bermingham) were established in 2016 and a third one (BKS-13 Onek) was established in 2017. In 2019, surveys were conducted on January 12-15, February 5-8, March 8 and April 19. Due to difficult access, no surveys were conducted at BKS-11 and 13 in March and April of 2019. As snow survey stations BKS-11, BKS-12, and BKS-13 are newer stations and have only three years of data, results were presented for comparison with the regional data for the same period of record, and the averages for each regional station for the entire period of record are also shown to provide context (Figure 3-3).

SWE measured at BKS-11 (1338 masl) is comparable in magnitude to the regional Calumet station (1310 masl), which are at similar elevations. The SWE measured at BKS-12 is variable from year to year, as the SWE measured in April 2016 is higher than both the highest elevation stations (regional Calumet station and BKS-11) and the SWE measured in April 2018 is lower than all other locations. BKS-12 is relatively sheltered by conifers and acts as a trap for snow being deposited from adjacent areas, especially from historical adjacent waste rock piles which have no ability to retain snow from wind erosion. The lower SWE at BKS-12 is likely partly attributed to the survey being conducted later in April, and to melt occurring earlier in the month due to warming temperatures earlier in the month. BKS-13 is the newest station and has only two SWE measurements on record, which are similar in magnitude to the lower elevation regional Mayo A and Mayo B stations, despite having a higher elevation.

The locations of the snow survey stations are shown on Figure 3-4. The annual snow water equivalent (SWE) results for each of the 13 Alexco snow survey stations are presented in Table 3-10

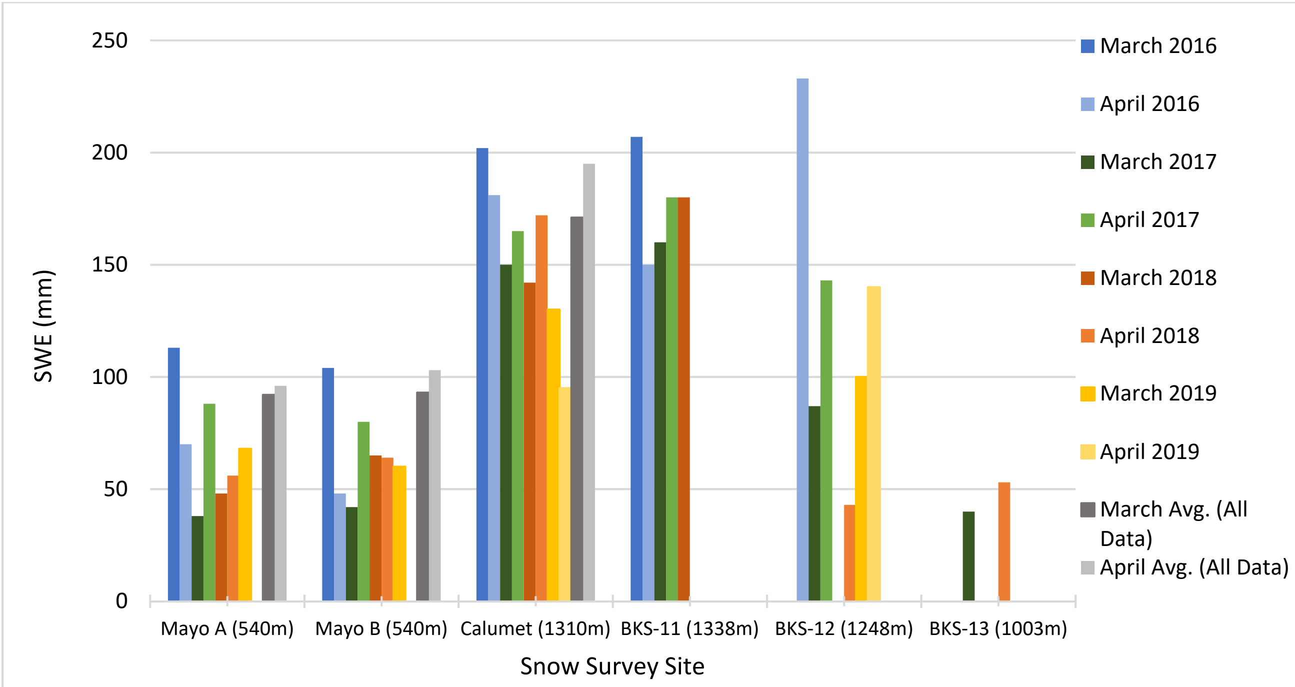
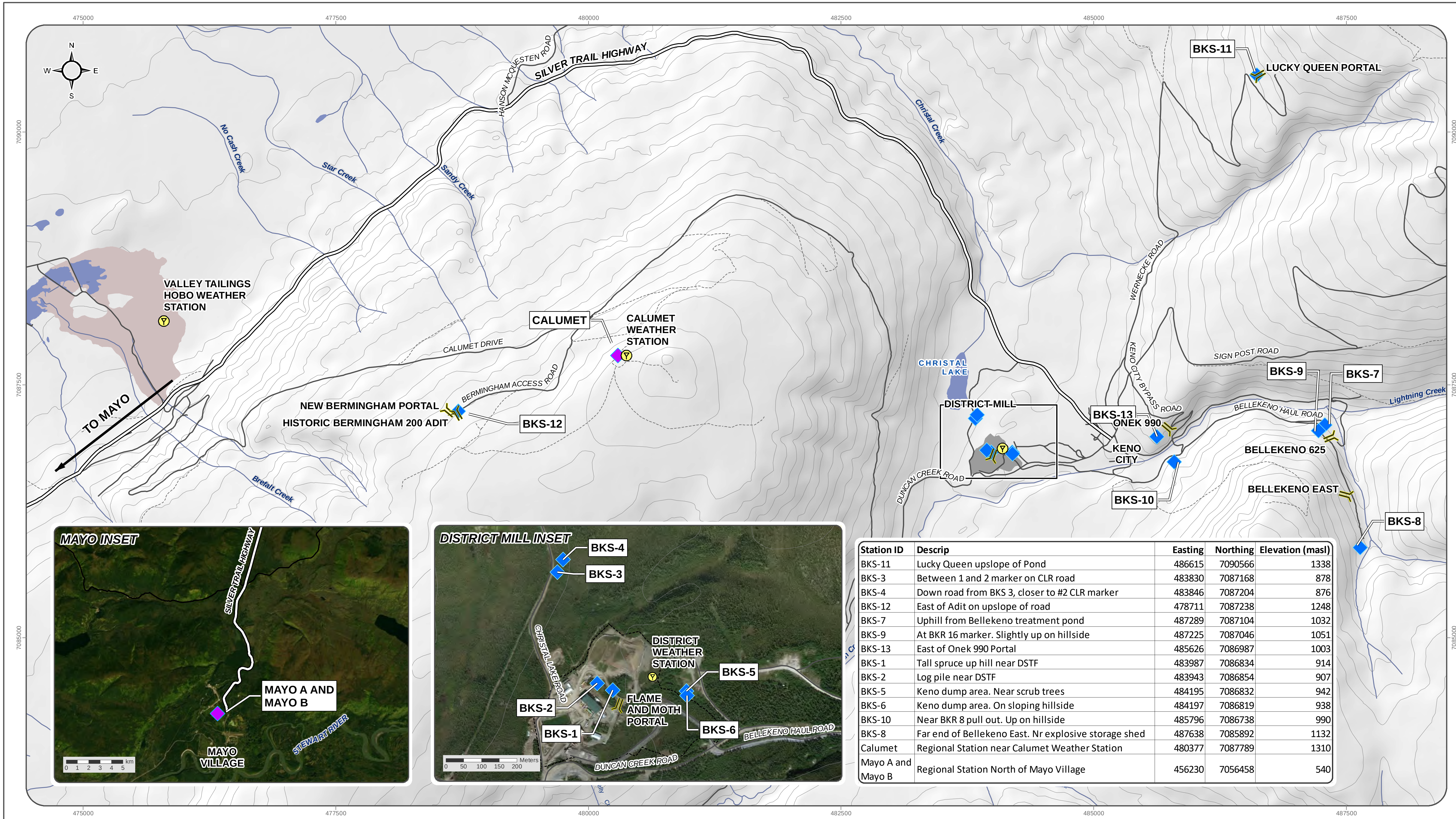


Figure 3-3:Regional SWE compared to BKS-11/12/13 for 2016 -2019



Station ID	Descrip	Easting	Northing	Elevation (masl)
BKS-11	Lucky Queen upslope of Pond	486615	7090566	1338
BKS-3	Between 1 and 2 marker on CLR road	483830	7087168	878
BKS-4	Down road from BKS 3, closer to #2 CLR marker	483846	7087204	876
BKS-12	East of Adit on upslope of road	478711	7087238	1248
BKS-7	Uphill from Bellekeno treatment pond	487289	7087104	1032
BKS-9	At BKR 16 marker. Slightly up on hillside	487225	7087046	1051
BKS-13	East of Onek 990 Portal	485626	7086987	1003
BKS-1	Tall spruce up hill near DSTF	483987	7086834	914
BKS-2	Log pile near DSTF	483943	7086854	907
BKS-5	Keno dump area. Near scrub trees	484195	7086832	942
BKS-6	Keno dump area. On sloping hillside	484197	7086819	938
BKS-10	Near BKR 8 pull out. Up on hillside	485796	7086738	990
BKS-8	Far end of Bellekeno East. Nr explosive storage shed	487638	7085892	1132
Calumet	Regional Station near Calumet Weather Station	480377	7087789	1310
Mayo A and Mayo B	Regional Station North of Mayo Village	456230	7056458	540

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Satelite imagery obtained from ESRI ArcGIS map service https://services.arcgisonline.com/ArcGIS/rest/service on January 02 2020
Datum: NAD 83; Map Projection: UTM Zone 8N

1:35,000 (when printed on 11 x17 inch paper)

0 500 1,000 1,500 2,000 Meters

ERDC Snow Monitoring Station
Regional Snow Monitoring Stations
AKHM District Mill
Tailings Area
Waterbody
Watercourse
Silver Trail Highway
Other Road
Limited-Use Road
Contours (100 ft)

ERDC
AEG

ALEXCO KENO HILL MINING CORP.

FIGURE 3-4
SNOW SURVEY STATIONS

JANUARY 2020

Table 3-10: Snow survey (SWE) results (mm)

Station	BKS-1	BKS-2	BKS-3	BKS-4	BKS-5.0	BKS-5.1	BKS-6	BKS-7	BKS-8	BKS-9	BKS-10	BKS-11	BKS-12	BKS-13	Mayo A	Mayo B	Calumet
Elevation (m)	914	907	878	876	942	942	938	1032	1132	1051	990	1338	1248	1003	540	540	1310
Description	Tall spruce up hill near dry stack	Log pile near dry stack	Between 1 and 2 markers on CLR road	Down road from BKS 3, closer to #2 CLR marker	Keno dump area. Near scrub trees	Keno dump area. Near scrub trees	Keno dump area. On sloping hillside	Uphill from Bellekeno treatment pond	Far end of Bellekeno East. Nr explosive storage shed	At BKR 16 marker. Slightly up on hillside	Near BKR 8 pull out. Up on hillside	Lucky Queen, upslope of the pond	East of Bermingham 200 adit, Upslope of road	Onek, upslope of portal near powerline	Mayo Airport	Mayo Airport	
Jan-11	7.6	7.6	7.6	7.6	5.1	-	2.5	7.6	7.6	7.6	10.1	-	-	-	-	-	-
Feb-11	7.6	7.6	10.2	7.6	7.6	-	2.5	10.2	7.6	10.2	7.6	-	-	-	-	-	-
Mar-11	5.1	7.6	7.6	7.6	5.1	-	0	7.6	5.1	10.2	5.1	-	-	-	90	84	139
Jan-12	6	12.2	9.6	8.5	13.7	-	11.2	12.5	9.9	12.4	13.3	-	-	-	-	-	-
Feb-12	16.1	13.6	12.5	17.6	-	11.3	12.6	13.6	13.8	13.3	16.5	-	-	-	-	-	-
Mar-12	18.7	9.3	4.4	12.3	-	12.2	14.8	4.8	17.6	17.1	27.7	-	-	-	78	100	151
Apr-12	8.7	20.8	7.7	8.8	-	9.6	19.8	8.5	19.5	0	10.7	-	-	-	144	156	180
Jan-13	7.3	9.3	7.3	9.3	-	6.7	6.7	6.7	8.0	7.3	9.3	-	-	-	-	-	-
Feb-13	11.3	10.7	10.0	11.7	-	9.7	9.2	11.0	10.0	10.0	10.0	-	-	-	-	-	-
Mar-13	13.0	11.7	14.3	18.3	-	13.3	12.0	10.3	18.5	15.0	12.3	-	-	-	129	80	158
Apr-13	15.0	13.8	14.7	14.3	-	13.0	11.3	13.7	19.7	14.0	14.3	-	-	-	120	-	186
Jan-14	12.3	10.3	13.0	12.7	-	11.0	10.7	13.3	9.3	12.3	14.0	-	-	-	-	-	-
Feb-14	14.0	10.7	12.3	12.0	-	12.0	10.3	13.0	12.7	11.7	15.7	-	-	-	-	-	-
Mar-14	12.3	10.0	11.0	11.7	-	10.7	8.7	13.0	12.7	11.3	14.3	-	-	-	103	120	189
Apr-14	9.7	7.7	9.7	7.3	-	8.7	8.3	10.0	10.7	9.0	7.0	-	-	-	123	126	207
Feb-15	8.0	9.0	9.3	3.7	-	8.3	7.3	9.0	6.7	7.7	10.0	-	-	-	-	-	-
Mar-15	9.3	10.3	7.0	8.7	-	10.7	8.7	12.7	17.0	10.7	10.0	-	-	-	76	90	184
Apr-15	8.7	9.0	10.7	7.3	-	12.0	9.0	14.0	12.3	8.3	12.0	-	-	-	103	118	232

Station	BKS-1	BKS-2	BKS-3	BKS-4	BKS-5.0	BKS-5.1	BKS-6	BKS-7	BKS-8	BKS-9	BKS-10	BKS-11	BKS-12	BKS-13	Mayo A	Mayo B	Calumet
Feb-16	4.0	8.0	8.0	10.0	-	10	8.0	7.3	7.3	7.3	10.7	20.3	-	-	-	-	-
Mar-16	8.7	11.0	9.3	8.7	-	8.7	8.0	7.0	9.3	7.0	6.0	20.7	-	-	113	104	202
Apr-16	7.7	10.3	10.7	12.3	-	10.7	8.3	11.3	-	0	11.7	15.0	23.3	-	70	48	181
Feb-17	5.7	6.7	4.0	5.7	-	5.7	7.3	7.0	7.7	7.0	6.0	11.0	7.0	3.0	-	-	-
Mar-17	8.7	9.3	9.3	10.3	-	8.3	8.0	8.3	10.7	7.3	9.3	16.0	8.7	4.0	38	42	150
Apr-17	9.3	11.7	13.0	11.3	-	10.7	9.3	11.0	13.0	6.7	6.7	18.0	14.3	0	88	80	165
Jan-18	4.3	6.0	6.3	6.3	-	6.0	5.7	5.7	9.0	8.0	8.7	8.7	6.3	6.3	-	-	-
Feb-18	6.7	7.3	10.0	8.7	-	9.3	8.0	8.7	10.7	10.0	10.0	11.7	11.0	6.0	-	-	-
Mar-18	8.7	10.0	10.0	10.7	-	13.3	11.3	11.3	11.3	13.3	12.0	18.0	-	-	48	65	142
Apr-18	4.0	4.3	4.0	5.0	-	5.0	5.0	5.0	5.7	4.3	4.7	-	4.3	5.3	56	64	172
Jan-19	4.67	4.67	6.0	6.67	-	4.0	4.0	7.64	5.33	6.0	5.3	6.7	10.7	4.7	-	-	-
Feb-19	6.0	6.0	6.0	6.0	-	8.0	8.0	6.0	8.0	8.0	7.3	8.0	-	6.0	-	-	-
Mar-19	5.3	4.7	5.3	5.3	-	5.3	5.3	5.3	6.7	6.7	6.7	-	10.0	-	68	60	130
Apr-19	-	-	-	-	-	-	-	-	9.3	7.3	8.0	-	14.0	-	0	0	95[E]

[E] Estimated by the Water Resources Branch, Department of Environment, Government of Yukon

3.1.5 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 (Access, 1996). Assuming a linear relationship, a line was fitted to the data of these stations. Figure 3-5 was reproduced from Access (1996) and updated to include the three stations in this memo and including more recent data where available. 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 values in other regions of the Yukon interior.

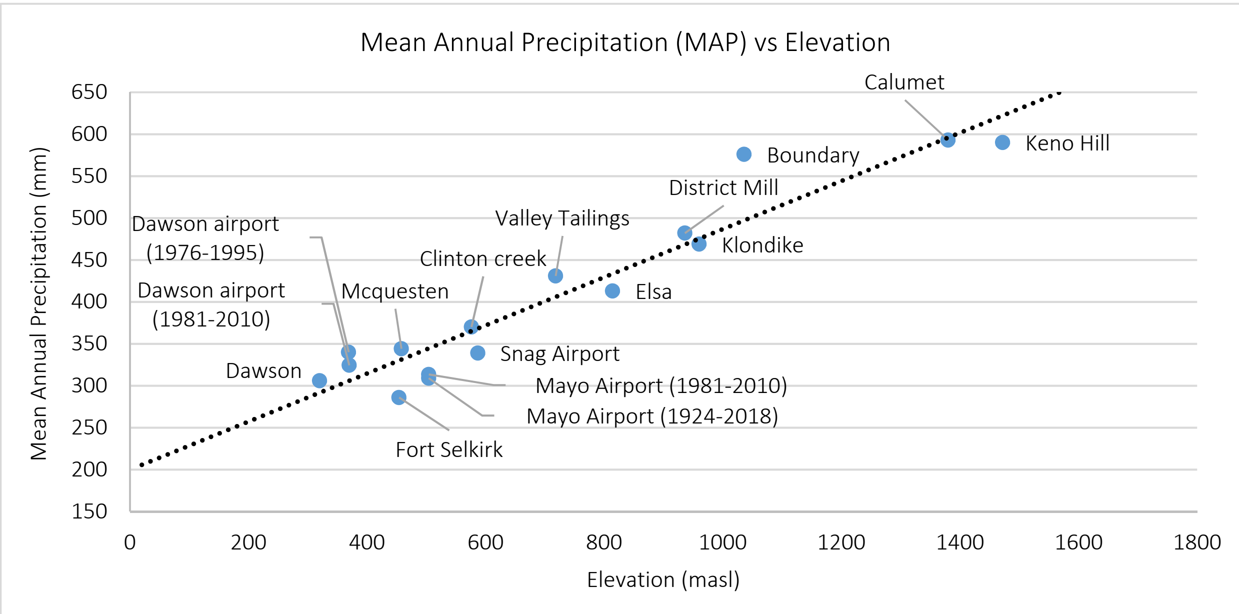


Figure 3-5: Mean annual precipitation (MAP) as a function of elevation

Monthly Precipitation

As with MAP, the seasonal or monthly distribution is influenced by elevation. To demonstrate this influence, the monthly distributions for Elsa, Keno Hill and Mayo Airport have been plotted in Figure 3-6, which was part of the same assessment conducted by Clearwater Consultants in 1996 (Access, 1996), but with Mayo Airport updated to include recent data. The proportion of total precipitation which falls as rain decreases as elevation increases (53% of total precipitation at Elsa, 1% at Keno Hill and 60% at Mayo Airport). 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.

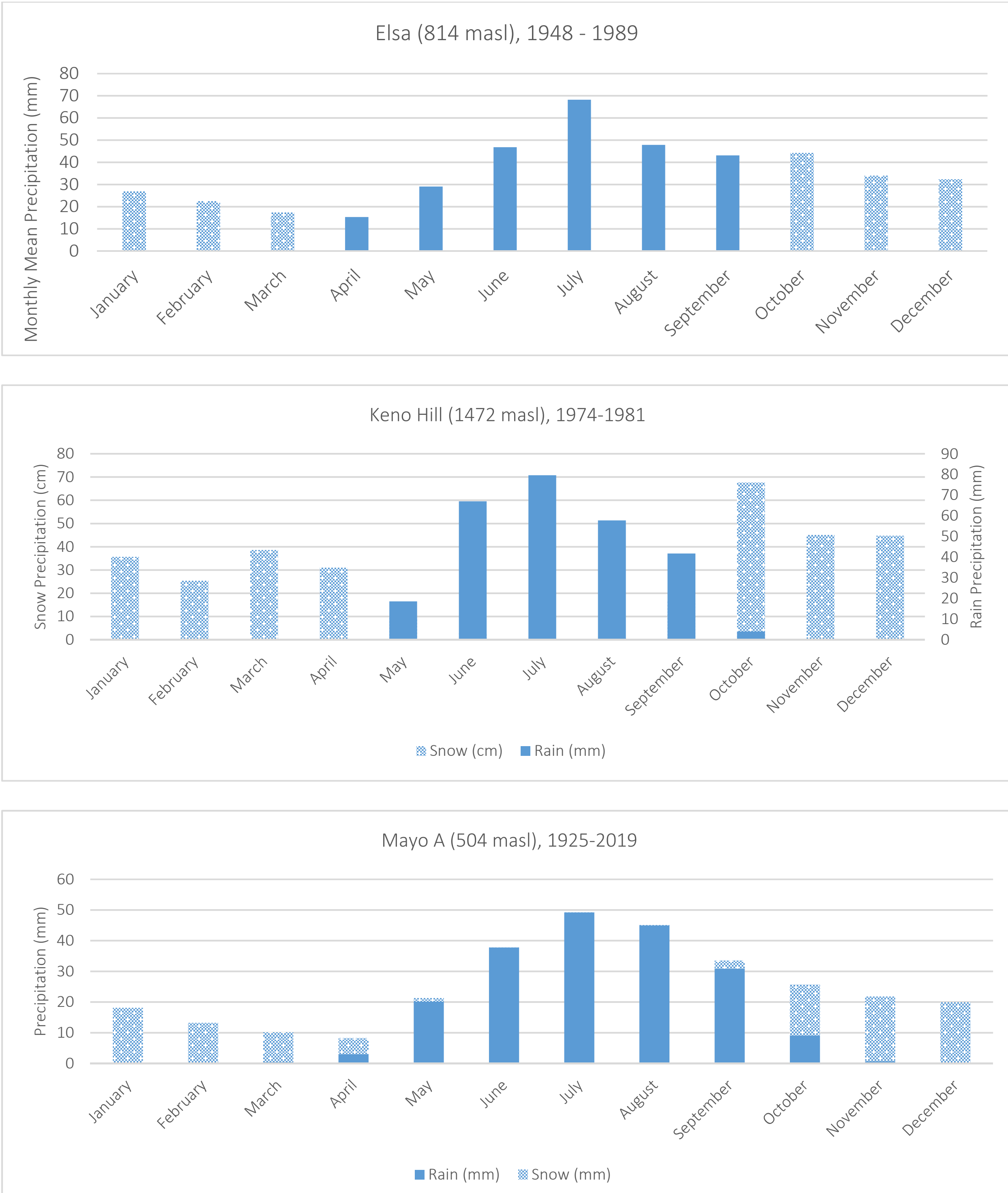


Figure 3-6: Mean monthly precipitation

Note: Reproduced from Access (1996) with Mayo Airport updated to include more recent data

Mayo A Recent Precipitation and Temperature Comparison to Site Stations

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 2019, except for the year 2013, which is missing. Therefore, the common periods with the Calumet station (2007-2019), the District Mill station (2012-2019) and the Valley Tailings (2014-2019) were used for this comparison. Mayo A reports both rain and total precipitation, while Calumet 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 3-11 presents the proportion of total precipitation that fell as rain for the 2007-2019 period at Mayo A.

Table 3-11: Annual precipitation at Mayo A, 2007-2019

	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	226.3	144.1	359.2	63.0
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
2017	246.8	94.1	312.7	78.9
2018	292.5	74	338	86.5
2019	137.8	168.7	233.9	58.9
AVG	**227.3**	**136.8**	**340.9**	**66.7**

For this 12-year period, the average proportion of total precipitation that fell as rain was 66.7%, 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 trends observed in the Yukon. Figure 3-7 shows the temperature trend at Mayo A since 1925. Maximum, minimum and mean temperatures recorded over the 1925-2019 time period all show an increasing trend.

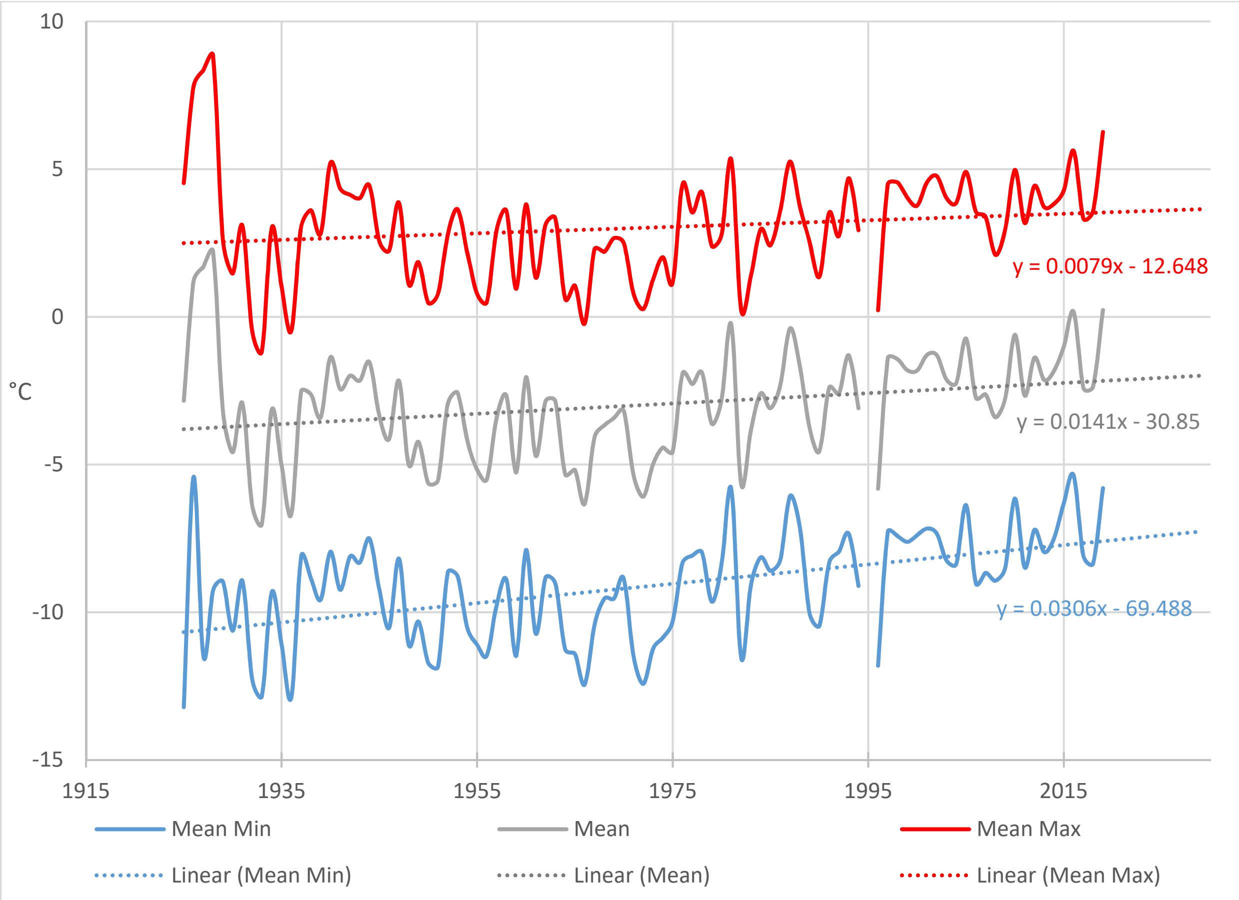


Figure 3-7: Mayo A annual temperatures, 1925-2019

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 Calumet, 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 (Access, 1996). Based on Mayo A annual total precipitation from 2007 to 2018 (Table 3-11), predicted total rainfall is compared to total rainfall measured at Calumet, District Mill and Valley Tailings (Table 3-12). Note that Calumet observed rainfall data for 2016 and 2017 are largely incomplete (see Table 3-3 for details) and those years were therefore not included in the comparison below.

Table 3-12: Predicted versus measured total rain (mm)

Year	Predicted Annual Total Precipitation (mm)	Predicted Total Rain (mm)	Measured Total Rain/Precip (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	595.7	269.1	200.6	-68.5	-34.2
2014	612.8	276.9	264.4	-12.5	-4.7
2015	629.9	284.6	*339.7*	55.1	16.2
2018	574.5	259.6	430.9	171.3	39.8
2019	470.4	212.5	*64.2*	-148.4	-231.2
AVG	**577.4**	**260.9**	**259.8**	**-2.1**	**-38.7**
District Mill (936 masl)					
2012	419.5	226.8	217.5	-9.3	-4.3
2013	502.6	271.7	400.0**	128.3	32.1
2014	519.7	280.9	292.6**	11.7	4.0
2015	536.8	290.2	296.9**	6.7	2.3
2016	459.4	248.3	277.7**	29.4	10.6
2017	456.1	246.6	265.9**	20.7	7.8
2018	481.4	260.2	344.9**	84.7	24.5
2019	377.3	204.0	127.0	-77.0	-60.6
AVG	**469.1**	**253.6**	**278.0**	**24.4**	**2.0**
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
2017	397.2	232.1	269.2	37.1	13.8
2018	422.5	246.8	*75.6*	-171.2	-226.5
2019	318.4	186.0	*69.40*	-116.6	-168.0
AVG	**412.9**	**241.2**	**170.9**	**-70.3**	**-87.7**

**Values in grey italics indicate a partial total*
*** Measured total precipitation, corrected for winter undercatch and wind deflection*

Discussion Between Predicted and Observed Precipitation

Some years have incomplete rain data at Calumet (refer to Table 3-3 for specific details) and Valley Tailings (refer to Table 3-8), and this could explain the negative difference between actual and predicted rainfall in 2009, 2011-2012, and 2019 at the Calumet station and 2014 and 2018-2019 at the Valley Tailings station (Table 3-8). In other cases, however, the difference is positive even though the Calumet dataset is incomplete (e.g. 2015). For three of the years where the Calumet dataset is complete, the difference between actual and predicted total rainfall is positive in 2008, 2010 and 2018, and for two other years it is negative in 2013 and 2014. The average difference between actual and predicted for those five years is positive (13.3%), implying that the linear relationship between MAP and elevation developed by Clearwater Consultants (Access, 1996) 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, 2016 and 2017 dataset are complete and actual versus predicted rainfall are relatively similar (-2.6%, -3.3% and 13.8% difference, respectively).

In the case of the District Mill, there is good agreement between predicted and measured total rain for the year 2012. From 2014 to 2019, 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 (2014-2019) 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 under catch 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 Consultants (Access, 1996) will be possible as more years of data become available at Calumet and at the District Mill, and as total precipitation data become available at the District Mill weather station.

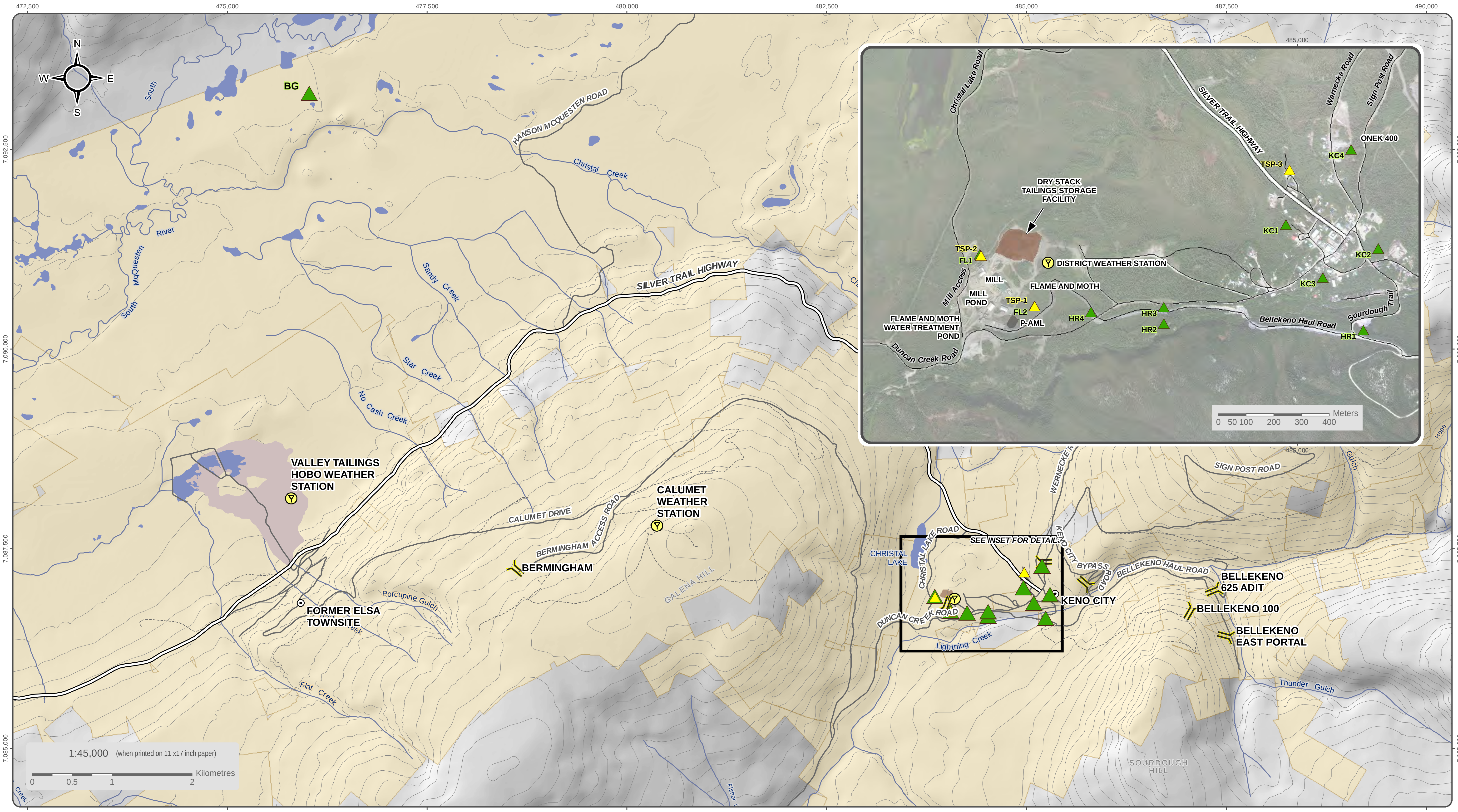
3.2 AIR QUALITY

Alexco Keno Hill Mining Corp. (Alexco) established an air quality monitoring program in 2009. Air quality was monitored using dustfall monitoring stations installed at four locations near the Keno District Mill site (2011). The monitoring program was amended in 2012 to measure total particulates per volume of air for select size fractions (total suspended particulates (TSP)). Additional sampling for coarse and fine fractions of particulate matter (PM_{10} and $PM_{2.5}$, respectively) was instigated in August 2015. Currently there are three air quality sampling stations in use for the project.

The goal of the current sampling program is to collect samples from three locations (TSP-1, TSP-2, TSP-3: see Figure 3-8) each month, to capture variability in air quality from various weather conditions. Potential dust sources include the dry stack tailings facility (DSTF), the crusher, and unpaved access roads.

Results of the gravimetric analyses are converted into 24-hour average ambient concentrations based on the flow rate of the instruments. These are compared with the Yukon Ambient Air Quality Standard (YAAQS) (24-hour average):

- 120 $\mu g/m^3$ for TSP;
- 50 $\mu g/m^3$ for PM_{10}; and
- 28 $\mu g/m^3$ for $PM_{2.5}$.



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Satellite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on March 2020

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

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Alexco TSP Monitoring Stations
YG PM10 Monitoring Sites 2013
Weather Station
Adit
Mine Feature Footprint
Current DSTF
Alexco/ERDC Quartz Claims
Waterbody
Watercourse
Silver Trail Highway
Other Road
Limited-Use Road

AKHM

ENSERO solutions

ALEXCO KENO HILL MINING CORP.

FIGURE 3-8
AIR QUALITY MONITORING STATIONS

MARCH 2020

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(*Last edited by: amatlashevska;2020-03-04/10:06 AM*)

3.2.1 AIR PARTICULATE

Summary statistics for 2012-2019 are presented in Table 3-13 for the three sampling locations (TSP-1, TSP-2 and TSP-3). When results were below the detection limit half the detection limit was used to calculate the summary statistics.

All results met standards for YAAQS, apart from one $PM_{2.5}$ exceedance at TSP-3 on July 14, 2017 and one at TSP-1 on July 9, 2019. These samples are considered outliers as they were an order of magnitude higher than historic TSP-3 and TSP-1 results; and results for TSP-2 from samples collected on the same day. Note that over half of the results for each of the three parameters are below the detection limit at all three stations.

The air quality monitors located on site are 160 m (TSP-1) and 46 m (TSP-2) away from the DSTF and 163 m (TSP-1) and 240 m (TSP-2) away from the crusher, two of the main potential dust sources. The nearest residence is 710 m from the DSTF and 860 m from the crusher. TSP levels experienced at the nearest residence are better approximated by levels observed at air quality monitor TSP-3, located in Keno City (950 m from the DSTF and 1240 m from the crusher). Note that the mine announced a temporary closure as of September 4th, 2013 and operation is suspended at this time. Therefore, the crusher and DSTF would not have contributed to fugitive dust emissions during that period.

Table 3-13: Total Suspended Particulates, Coarse and Fine Particulate Matter Summary Statistics 2012 –2019 (µg/m³)

	TSP (µg/m³)			PM_{10} (µg/m³)			$PM_{2.5}$ (µg/m³)		
Yukon Ambient Air Quality Standards	120			50			28		
Sampling Location	**TSP-1***	**TSP-2**	**TSP-3**	**TSP-1**	**TSP-2**	**TSP-3**	**TSP-1**	**TSP-2**	**TSP-3**
Average	5.3	6.3	5.3	5	4.9	4.5	4.1	4.4	4.5
Count	272	257	170	149	133	141	145	138	140
Minimum	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Maximum	53.2	62.2	68.1	46	38.1	22.5	**28.2**	23.1	21.2
Geometric Mean	4.1	4.6	4	3.8	3.7	3.8	3.5	3.6	3.8
Count <DL	189	159	118	115	103	102	115	109	100
Standard Deviation	5.6	7.3	6.7	6	5.5	3.4	3.3	3.7	3.1
1st Quartile	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Median	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
3rd Quartile	6.6	7.2	6.1	2.8	2.8	6	2.8	2.8	6
Count Over Standard	0	0	0	0	0	0	1	0	1
% Over Standard	0	0	0	0	0	0	0.7	0	1.1

Note: Bold = exceedance of YAAQS
** Two outliers removed (TSP-1 976.4 µg/m³ on July 1, 2015; TSP-3 65 µg/m³ on July 15, 2017)*

The greatest average TSP concentration was measured at TSP-2 (6.3 µg/m³), TSP-1 and TSP-3 had the same measured average (both 5.3 µg/m³), however the difference is not statistically significant, and concentrations are less than the YAAQS. For coarse particulate matter (PM_{10}), the greatest average concentration was recorded at TSP-1 (5.0 µg/m^3), the lowest average at TSP-3 (4.5 µg/m^3). For fine particulate matter ($PM_{2.5}$), the greatest average concentration was recorded at TSP-1 (4.1 µg/m^3), the lowest average at TSP-2 (4.4 µg/m^3). These results do not greatly deviate from the 2019 results. Exceedances were recorded for TSP concentration at monitoring location TSP-1 (July 1, 2015) and $PM_{2.5}$ concentration at location TSP-3 (July 15, 2017); however, these were determined to be outliers; all other results were less than the YAAQS.

3.2.2 METAL SPECIATION

There are no ambient air quality standards for metals in Yukon; however, the Ontario Ministry of Environment has developed a comprehensive list of Ambient Air Quality Criteria (AAQC) that includes 24-hour average concentrations for metals.

presents the summary statistics for 2012 to 2019 for metal concentrations from samples TSP-1, TSP-2 and TSP-3, while the complete result tables are presented in Appendix B. When results were below the detection limit a value of half the detection limit was used to calculate the statistics.

All parameters met AAQC criteria except for cadmium (TSP-2 – 0.8 % of samples; TSP-3 – 0.6% of samples), lead (TSP-1 – 0.7% of samples; TSP-2 – 0.4% of samples), and manganese (TSP-2 – 1.6% of samples). Note that criteria for chromium and manganese did not come into effect until July 1, 2016 but were still used as reference for the entire sampling period.

Table 3-14: Metal Concentrations Summary Statistics (24-hour) 2012 – 2019

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	K	Se	Si	Ag	Na	Sr	S	Sn	Ti	V	Zn	Zr
Ontario Ambient Air Quality Criteria (µg/m³)	-	25	0.3	10	0.01	120	0.025	-	0.5	0.1	50	4	0.5	-	0.4	120	2	-	-	10	-	1	-	120	-	10	120	2	120	-
TSP-1*																														
Average	0.178	0.119	0.048	0.003	0.005	0.023	0.012	0.328	0.078	0.030	0.03	0.192	0.056	0.034	0.01	0.030	0.030	0.186	0.598	0.03	0.359	0.018	0.245	0.003	9.7	0.048	0.014	0.02	0.035	0.03
Count	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	208	272	272	272	269	272	272	272	272	272
Minimum	<0.20	<0.005	<0.005	<0.005	<0.005	<0.30	<0.001	<1.0	<0.30	<0.005	<0.005	<0.30	<0.005	<0.30	<0.005	<0.003	0.0061	<0.80	<0.50	<0.005	<2.0	<0.002	<1.0	<0.005	<2.0	<0.005	<0.20	<0.20	<0.050	<0.050
Maximum	5.292	0.139	0.056	0.022	0.006	0.264	0.014	8.722	0.146	0.035	0.035	2.528	**1.083**	0.429	0.301	0.035	0.035	0.208	0.694	0.079	3.875	0.021	2.444	0.041	69.4	0.193	0.042	0.021	0.817	0.035
Geometric Mean	0.121	0.058	0.028	0.002	0.004	0.022	0.007	0.205	0.073	0.018	0.023	0.11	0.036	0.027	0.006	0.017	0.022	0.171	0.455	0.018	0.245	0.01	0.213	0.002	0.3	0.027	0.014	0.02	0.020	0.024
Count <DL	229	272	264	210	272	268	247	184	15	272	235	45	230	216	203	268	233	272	267	270	175	271	225	205	246	270	271	272	180	272
Standard Deviation	0.45	0.049	0.019	0.003	0.002	0.021	0.005	0.774	0.025	0.012	0.012	0.252	0.080	0.043	0.025	0.012	0.012	0.054	0.231	0.013	0.556	0.007	0.201	0.004	23.9	0.023	0.002	0.002	0.072	0.011
1st Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.064	0.035	0.035	0.051	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
Median	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.076	0.035	0.035	0.108	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
3rd Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.361	0.095	0.035	0.035	0.308	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.031	0.035
Count Over Standard	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Over Standard	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TSP-2																														
Average	0.143	0.119	0.048	0.003	0.005	0.022	0.012	0.271	0.079	0.030	0.03	0.254	0.061	0.039	0.025	0.030	0.030	0.186	0.602	0.030	0.389	0.018	0.222	0.003	9.4	0.048	0.014	0.02	0.045	0.03
Count	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	256	196	256	256	256	253	256	256	256	256	256
Minimum	<0.20	<0.005	<0.005	<0.005	<0.005	<0.30	<0.001	<1.0	<0.30	<0.005	<0.005	<0.30	<0.005	<0.30	<0.005	<0.003	0.0061	<0.80	<0.50	<0.005	<2.0	<0.002	<1.0	<0.005	<2.0	<0.005	<0.20	<0.20	<0.050	<0.050
Maximum	1.625	0.139	0.056	0.048	0.006	0.099	**0.040**	3.472	0.189	0.035	0.035	2.778	**0.736**	0.468	**0.651**	0.035	0.064	0.208	0.694	0.035	5.028	0.021	1.125	0.032	69.4	0.056	0.032	0.021	0.482	0.035
Geometric Mean	0.118	0.060	0.030	0.002	0.004	0.021	0.008	0.207	0.074	0.018	0.023	0.141	0.042	0.03	0.009	0.017	0.022	0.172	0.466	0.018	0.261	0.010	0.205	0.002	0.3	0.027	0.014	0.02	0.026	0.025
Count <DL	227	251	240	207	256	253	228	163	16	255	221	36	208	184	165	252	219	256	250	256	158	250	220	194	227	256	255	256	153	256
Standard Deviation	0.142	0.049	0.019	0.004	0.002	0.007	0.005	0.31	0.027	0.012	0.012	0.297	0.066	0.043	0.071	0.012	0.012	0.054	0.226	0.012	0.584	0.007	0.114	0.003	23.7	0.019	0.001	0.002	0.063	0.011
1st Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.063	0.035	0.035	0.06	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
Median	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.079	0.035	0.035	0.162	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
3rd Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.375	0.097	0.035	0.035	0.359	0.056	0.044	0.012	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.047	0.035
Count Over Standard	0	0	0	0	0	0	2	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Over Standard	0	0	0	0	0	0	0.8	0	0	0	0	0	0.4	0	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TSP-3*																														
Average	0.166	0.107	0.043	0.002	0.004	0.025	0.011	0.368	0.076	0.027	0.027	0.098	0.043	0.039	0.006	0.027	0.027	0.173	0.546	0.027	0.245	0.016	0.22	0.005	14.8	0.043	0.014	0.019	0.037	0.028
Count	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	161	173	173	173	170	173	173	173	173	173
Minimum	<0.20	<0.005	<0.005	<0.005	<0.005	<0.30	<0.001	<1.0	<0.30	<0.005	<0.005	<0.30	<0.005	<0.30	<0.005	<0.003	0.0061	<0.80	<0.50	<0.005	<2.0	<0.002	<1.0	<0.005	<2.0	<0.005	<0.20	<0.20	<0.050	<0.050
Maximum	2.778	0.139	0.056	0.024	0.006	0.218	**0.032**	6.417	0.158	0.035	0.035	0.514	0.056	0.553	0.07	0.035	0.035	0.208	0.694	0.035	1.569	0.021	1.472	0.175	69.4	0.056	0.014	0.021	0.647	0.035
Geometric Mean	0.106	0.035	0.018	0.002	0.003	0.022	0.005	0.224	0.072	0.012	0.018	0.066	0.023	0.028	0.005	0.011	0.017	0.154	0.366	0.012	0.213	0.007	0.199	0.002	0.4	0.017	0.014	0.019	0.020	0.02
Count <DL	141	173	169	129	173	168	147	96	4	173	135	44	141	132	128	165	133	173	167	173	145	173	140	122	161	171	173	173	113	173
Standard Deviation	0.34	0.059	0.023	0.003	0.002	0.024	0.006	0.816	0.024	0.015	0.014	0.096	0.023	0.068	0.006	0.015	0.014	0.064	0.272	0.015	0.202	0.009	0.129	0.021	28.4	0.023	0	0.003	0.072	0.014
1st Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.061	0.035	0.035	0.021	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
Median	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.139	0.076	0.035	0.035	0.064	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.1	0.056	0.014	0.021	0.014	0.035
3rd Quartile	0.139	0.139	0.056	0.002	0.006	0.021	0.014	0.389	0.089	0.035	0.035	0.119	0.056	0.021	0.006	0.035	0.035	0.208	0.694	0.035	0.208	0.021	0.208	0.002	0.3	0.056	0.014	0.021	0.031	0.035
Count Over Standard	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Over Standard	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

** Two outliers removed (TSP-1 976.4 µg/m³ on July 1, 2015; TSP-3 65 µg/m³ on July 14, 2017)*

Note: **Bold** = exceeded standard

Half the RDL was used to calculate averages for samples that were below the RDL. As the samples were not normally distributed and variances were not equal, non-parametric tests (Kruskal-Wallis; Wilcoxon) were used for statistical comparisons of the sample medians at a significance level (p) of 0.05. The concentrations of total metals measured at sample stations differed significantly ($p<<0.05$) for iron and zinc and found no detectable difference for boron, calcium, chromium, sodium, strontium, sulphur, and titanium. All other analytes differed slightly ($0.01<p<0.05$).

Dust originating from the DSTF may contain arsenic, aluminum, calcium, iron, magnesium, manganese, lead, and zinc, based on metal characterization analyses of the tailings conducted from 2012 to 2013. From the wind direction distribution, TSP-2 is more frequently located downwind of the DSTF than TSP-1 and may be expected to record concentrations of the above metals. This was observed for historical maximum lead (August 2012) and manganese (March 2013) concentrations; however, the current average concentrations of these parameters remain below recommended standards (Ontario AAQC). Samples taken from TSP-2 were found to have significantly higher concentrations of lead and manganese compared to TSP-1.

Historically, days where TSP levels were higher than average and where exceedances of the Ontario AAQCs were observed (lead at TSP-1), winds were generally blowing from the northeast and from the east (October 23. 2012 and June 18, 2013 respectively). Site activities occurring in October 2012 and June 2013 included active mining at Bellekeno, development at Lucky Queen and Onek, milling at the Keno District Mill, and explorations activities at Flame & Moth. Unpaved road may have been a contributing source of ambient dust on these occasions. Roads within the vicinity of the TSP stations include mine access roads, as well as public roads including Duncan Creek Road.

Historically, when metals concentrations exceeded the Ontario AAQCs (cadmium, lead, and manganese) at TSP-2, winds were generally blowing from the north-northeast (August 23, 2012). A source of ambient dust in this event could have been the unpaved roads. On days where TSP levels were higher than average and/or where exceedances of the Ontario AAQCs were observed for manganese at TSP-2, winds were generally blowing from the northeast (March 23-24, 2013; August 9, 2017) and from the east (April 7, 2013). On these occasions, the DSTF could have been a source of TSP at TSP-2. Similarly, on days where exceedances of the Ontario AAQCs were observed for cadmium at TSP-2 (on September 28, 2013 and October 21, 2015 respectively), winds were generally from the northeast or north-northeast suggesting a possible influence of the DSTF but also eventually of the unpaved roads. Site activities occurring in August 2012, March 2013 and April 2013 included mining at Bellekeno, development at LQ and Onek, and milling at the Keno District Mill. Between September 2013 and December 2018, only care and maintenance activities were taking place as the mine and mill were under a temporary suspension of operations with exception of collaring Flame and Moth Portal in 2016 and the preparation of the Flame and moth Pond.

3.2.3 WIND ANALYSIS

The wind rose plot, Figure 3-2, depicts this information based on 16 wind direction categories. The average wind speed is 1.26 m/s and winds are calm 20% of the time. Note that the wind sensor experienced occasional icing during the winter months and extended periods of zero wind speed were excluded from this analysis. Also, 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. Wind speed and direction frequency distribution are compiled in Table 3-15 below, and are based on eight wind direction categories, and six wind speed categories.

Table 3-15: Wind Frequency Distribution Keno District Mill, December 2012 – December 2019

Directions / Wind Classes (m/s)	0.5 – 1.0	1.0 – 2.0	2.0 – 3.0	3.0 – 4.0	4.0 – 5.0	>= 5.0	Total (%)
N	4.49	7.75	3.42	0.65	0.11	0.04	16.45
NE	5.28	4.86	1.35	0.16	0.01	0.00	11.66
E	3.57	7.88	2.32	0.45	0.08	0.01	14.29
SE	3.80	5.88	3.03	1.46	0.57	0.35	15.09
S	3.31	5.63	2.49	0.46	0.08	0.04	12.01
SW	0.71	1.60	1.49	0.40	0.07	0.01	4.28
W	0.34	0.56	0.49	0.34	0.16	0.09	1.98
NW	0.81	1.34	1.36	0.85	0.38	0.12	4.86
Sub-Total	22.30	35.50	15.95	4.77	1.45	0.66	80.62
					Calm		19.38
					Total		100

The dominant wind direction is from the north (16% of the time), followed by the southeast (15%). As can be seen on the wind rose plot (Figure 3-2), the strongest winds tend to originate from the southeast. When the predominant wind direction is from the northeast, air quality stations TSP-1 and TSP-2 (Figure 3-8), are located downwind of the DSTF and the crusher. When the wind blows from the SE those same stations are upwind from the DSTF and crusher. Given these generalities TSP-1 and TSP-2 may capture influences from facilities when the wind is from the northeast but are otherwise not downwind. Air quality station TSP-3, located on the outskirts of Keno City, is east of these potential dust sources. Based on Table 3-15, westerly winds only occur about 2% of the time (or roughly 10% of the time when combining NW, W and SW), so the DSTF and crusher are expected to have very limited influence on air quality in Keno City (TSP-3).

3.2.4 PM_{10} SAMPLING BY YUKON GOVERNMENT

Independent PM_{10} sampling was conducted by Yukon Government in 2013 at the locations shown in Figure 3-8. The station labelled BG represents background (8 km outside of Keno), stations labelled KC are in Keno City, stations labelled HR are along the Bellekeno Haul Road and stations labelled FL are fence line stations and correspond to TSP-1 and TSP-2 locations. 5-minute data averaged over the different sampling periods are presented in Table 3-16 below. The sampling period varies between sites (ranges from about 14 to 53 hours) but for comparison purposes, the average results are all below the 24-hour YAAQS of 50 µg/m^3. Note that in some cases the measured background PM_{10} concentration is higher than that measured at some of the receptors, for example during the July 15-17 sampling event site HR1 measured coarse particulate matter at 5.2 µg/m^3 and the background at 10.2 µg/m^3. This suggests there is some variability in the data and that the difference between background and receptors sites may not be significant. Results are generally comparable to the PM_{10} concentrations measured by Alexco at stations TSP-1, TSP-2 and TSP-3 (August 2015 to December 2017).

Table 3-16: Average Coarse Particulate Matter (PM_{10}) concentrations

	PM_{10} (µg/m^3)		
Site Locations	June 11-13, 2013	July 15-17, 2013	August 21-22, 2013
BG	2.8	10.2	3.8
KC1	6.2	NS	NS
KC2	3.8	NS	NS
KC3	8.3	NS	NS
KC4	2.1	NS	NS
HR1	NS	5.2	NS
HR2	NS	2.1	NS
HR3	NS	13.8	NS
HR4	NS	16.4	NS
FL1	NS	NS	0.8
FL2	NS	NS	39.3

Source: Yukon Government, 2014
NS: Not Sampled

4. SURFACE WATER

4.1 HYDROLOGY

The KHSD falls within the subarctic clime of the Koppen climate classification. The closest current long term climate record is that at the Mayo Airport at 504 masl. The 1981-2010 Canadian Climate Normals for Mayo give an average daily temperature of -2.4 °C and average annual precipitation of 313.5 mm with 203.8 mm falling as rain. The wet season occurs in summer/fall with dryer winters. The Keno District Mill sits at 913 masl and typically get more precipitation than Mayo.

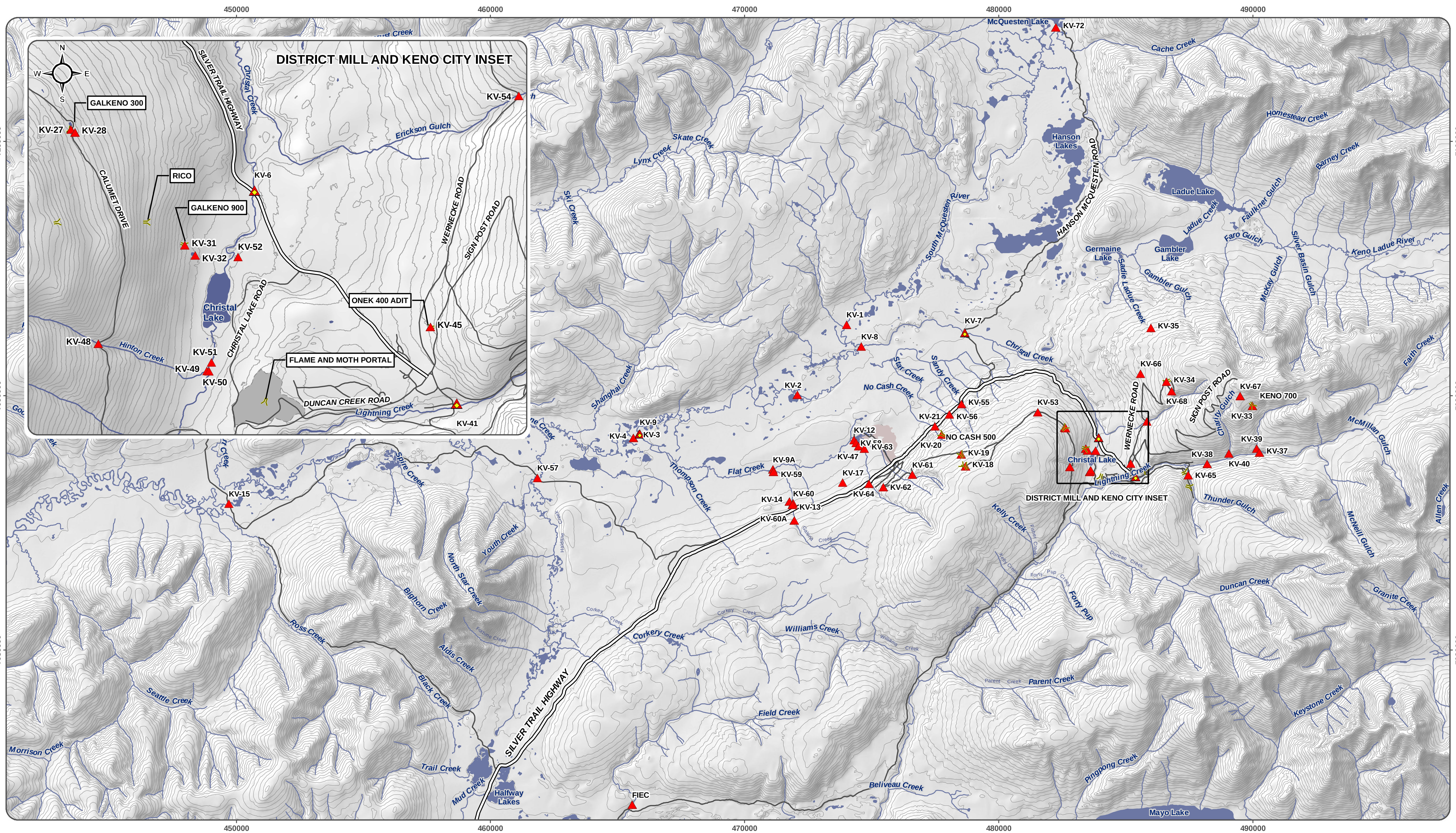
Maximum daily flows typically occur in spring in response to snowmelt and rain on snow events. However, summer and fall rainstorms can produce large events which can in some cases be the maximum annual flood. Large increases in flow in response to rain events is common in the small streams of the area. There are many historic adits in the region, some of which are free draining.

Open water season is typically late May until mid-October. Ice cover can be several feet in some locations and most stream continue to flow year-round though flows may become very low. Low flows typically occur in March-April as the water table drops over the winter.

The new Bermingham Portal and associated infrastructure is in the No Cash Creek Catchment. The No Cash Creek is situated on the northwest slope of Galena Hill and flows down the hillside towards the wetlands northeast of Flat Creek. There is no direct connection between No Cash Creek and either Flat Creek or the South McQuesten River as No Cash Creek ends in a bog. From the headwaters on Galena Hill to dispersion in the bog, the distance is roughly 2.3 km. There is one routine sampling station on No Cash Creek, located just above the Silver Trail Highway (KV-21). Located within the No Cash Creek catchment are the historic Bermingham 200 adit (KV-18), Ruby 400 (KV-19) and No Cash 500 (KV-20) adit discharges. The monitoring stations currently monitored for the KHSD and Project area are shown on Figure 4-1.

As part of Water Licence QZ09-092-2 continuous water levels are recorded during the open water season at fifteen minute intervals using Solinst water level recorders at stations KV-6, KV-7 and KV-41 (Figure 4-1). Discharge measurements and staff gauge observations are taken at regular intervals during the open water season, approximately once per month. Occasionally, salt slugs are used to determine flow when conditions do not permit regular velocity-area discharge measurements. These data have been used together to develop rating curves which facilitate the translation of continuous water level data into continuous discharge. Discharge measurements are taken in winter when conditions permit using the salt dilution gauging method.

For the period 2004 to 2009, Clearwater Consultants Ltd. (Clearwater) processed the water level data to produce a flow record on behalf of Access Consulting Group (now Ensero Solutions Inc.). Clearwater have patched the data record over the winter months when gauging data were not collected and have shown through regional analysis that this practice gives realistic values for the purpose of calculating mean and annual and monthly runoff (CCL, 2008) These data are summarized in memorandums CCL-UKHM-1 and CCL-UKHM2. Since 2010 data have been managed by Access Consulting Group.



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

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1:142,000 (when printed on 11 x17 inch paper)

0 1 2 3 4 5 Kilometers

- Automatic Hydrometric Monitoring Stations with Barologger
- Instantaneous Hydrometric Monitoring Stations
- Adit
- Valley Tailings
- Silver Trail Highway
- Other Road
- Watercourse
- Waterbody

ERDC

AEG

ALEXCO KENO HILL MINING CORP.

FIGURE 4-1
KHSD DISCHARGE MONITORING LOCATIONS

JANUARY 2020

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(Last edited by: amatiashevska; 2020-01-15/15:57 PM)

4.1.1 REGIONAL HYDROLOGY

The closest and most relevant hydrometric station in the region is the Water Survey of Canada operated McQuesten River near the Mouth (Stn. # 09DD004) which has been monitored for flow and level from 1979 to present. The drainage area is 4,750 km^2 and includes the towns of Keno and Elsa and Christal Creek. The mean annual discharge for the McQuesten River is 3.4 x 10^6 m^3/d (38.9m^3/s) or 8.2 $L/s/km^2$ and the mean annual runoff (MAR) is 258.5 mm. Table 4-1 presents the mean daily as well as mean low flow and mean daily high flow for the 1979 to 2017 at McQuesten River near the mouth.

Table 4-1: McQuesten River Mean, Mean Minimum and Mean Maximum Daily Flows

Discharge	Mean	Min	Max
m^3/d	3.4 x 10^6	3.6 x 10^5	3.6 x 10^7
m^3/s	39	4.2	420
$L/s/km^2$	8.2	0.9	88.4

Return periods for both high and low flows were also calculated for this record using the Log Pearson Type III distribution chosen for best fit visually. The results of this analysis are shown in Table 3-8 in both discharge and unit runoff.

Table 3-2: High and Low Flow for Various Return Periods (T_p) for McQuesten River Near the Mouth

	Annual Daily Flood			Annual Daily Low Flow		
T_p	**m^3/d**	**m^3/s**	**$L/s/km^2$**	**m^3/d**	**m^3/s**	**$L/s/km^2$**
2	2.1 x 10^7	240.1	50.5	6.0 x 10^5	6.9	1.5
10	3.1 x 10^7	355.4	74.8	4.2 x 10^5	4.8	1.0
50	4.0 x 10^7	457.5	96.3	3.2 x 10^5	3.7	0.8
s100	4.3 x 10^7	501.7	105.6	2.9 x 10^5	3.4	0.7

The mean monthly flow distribution is typical of the region and Yukon in general exhibiting a snowmelt dominated freshet period. Peak mean monthly and daily flows most often occur in May, but also in June, with summer and early fall rain sustaining flows till the onset of winter at which time discharge begins to decrease, reaching their lowest in March (Figure 3-3).

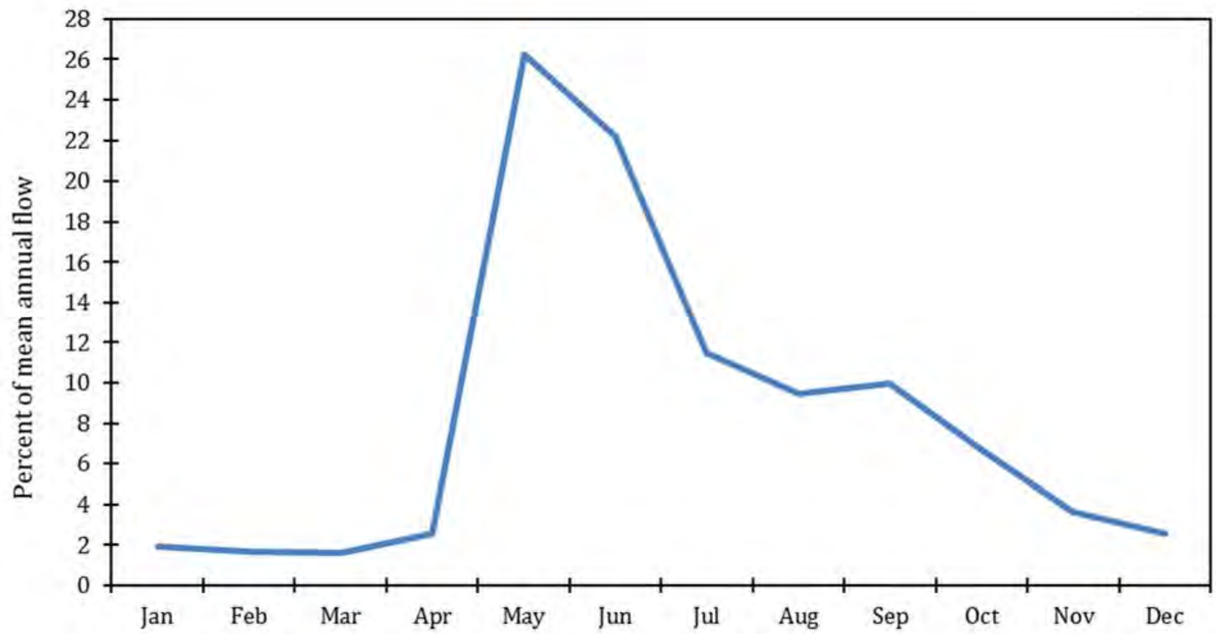


Figure 4-2: Annual Flow Distribution at McQuesten River Near the Mouth (09DD004)

4.1.2 HYDROMETRIC MONITORING STATIONS

Figure 4-1 shows the hydrometric monitoring stations in the KHSD. The following sections discuss the stations on No Cash Creek, Christal Creek and Lightning Creek. A summary of the hydrometric stations is provided as Table 3-9.

Table 3-3: KHSD Hydrometric Stations Summary

Site	Description	Sampling Schedule	Continuous (Y/N)	Drainage Area (km^2)	Median Elevation (masl)	Station Elevation (masl)	Max elevation (masl)	Instrumentation	Measurement Frequency	Accuracy (+/- %FS)	Number of Benchmarks
KV-6	Christal Creek at Silver Trail Highway	Monthly	Y	6.1	1002	855	1350	Solinst M5	15 min	0.05	3
KV-7	Christal Creek at Hanson Road	Monthly	Y	35.8	970	675	1685	Solinst M5	15 min	0.05	3
KV-9	Flat Creek upstream of South McQuesten River	Monthly	Y	56.5	830	625	1411	Solinst M2	15 min	0.05	3
KV-21	No Cash Creek at Silver Trail Highway	Monthly	N discontinued	1.4	1212	821	1389	Solinst M2	15 min	0.05	3
KV-41	Lightning Creek upstream of bridge at Keno City	Monthly	Y	59	1400	935	1988	Solinst M2	15 min	0.05	3
KV-51	Christal Creek downstream of Hinton Creek	Monthly	Y	2.8	1172	861	1443	Solinst M2	15 min	0.05	3
KV-60	Galena Creek upstream of Silver King Adit	Quarterly	N discontinued	9.4	997	739	1400	Solinst M2	15 min	0.05	3
KV-64	Flat Creek at Silver Trail Highway	Quarterly	N discontinued	4.4	1159	818	1412	Solinst M2	15 min	0.05	3

KV-21 No Cash Creek at the Silver Trail Highway

No Cash Creek flows just northeast of the former townsite of Elsa and has a catchment area of ~1.4 km^2 at the Silver Trail Highway (KV-21). The median elevation is ~1,212 masl and includes the No Cash 500 adit (KV-20), which is free draining. In June of 2015, AEG personnel installed a V-notch weir to gather continuous data on No Cash Creek; however, the station was unsuccessful due to significant glaciation and channel braiding in winter and high sedimentation in the summer, as such the station was discontinued.

Average flows for each month for KV-21 were originally established from the monthly discrete discharge measurements using data that was filtered to have less than 15% RPD during field data collection measurements. This limited the data set to 2012 to 2018. The mean monthly values have been updated since using a new synthetic, continuous dataset for KV-21 which covers the period from June 2014 to Dec 2018. The continuous KV-21 synthetic dataset was derived by reviewing and selecting instantaneous discharge measurements with good QAQC values collected at KV-21 between June 2014 to December 2018. A relationship between these KV-21 field discharge measurements and the KV-9 continuous discharge dataset was established. The KV-9 continuous data was used as this station has open water year-round and has a reliable continuous discharge dataset from June 2014 to December 2018. The relationship established between the KV-21 field discharge measurements and the KV-9 continuous discharge data was then applied to the entire KV-9 continuous dataset to create a synthetic KV-21 continuous discharge record. The winter low flow monthly data was also compared to KV-20 low flow data and had good alignment. The No Cash Creek mass load model has been revised to use the synthetic dataset. The revised monthly values are shown in Table 3-4.

Monthly 1 in 10 year wet and 1 in 10 year dry values were calculated for No Cash Creek (KV-21) using EasyFit Professional (v5.6) software to fit continuous probability distributions (e.g., Log Pearson Type III, Generalized Extreme Value) to the monthly observations derived from the KV-21 synthetic dataset. Statistical tests, such as Kolmogorov Smirnov and Anderson Darling, were applied by EasyFit to identify the continuous probability distribution that best fit the observations or return a conservative result. Mean, dry and wet flows by month are shown in Table 3-4.

Table 3-4: KV-21 Monthly Discharge for Mean, Dry and Wet Scenarios

Month	Dry (m^3)	Mean (m^3)	Wet (m^3)
January	8999	13120	15508
February	7814	12625	16886
March	8142	12932	16124
April	7335	32715	54069
May	8812	185683	254100
June	22991	56242	93053
July	34310	46019	57612
August	29543	72338	105850
September	39580	68036	106790
October	14196	45654	80807
November	14982	18024	22550
December	11972	14820	17302

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 meters downstream of Christal Lake. That catchment area is 6.1 km^2 with a median elevation of 1,002 masl.

A Solinst water level recorder was deployed at KV-6 in a stilling well on July 20th, 2011 and retrieved on October 23, 2011. Instantaneous discharge measurements have been collected since June 2008 on a monthly basis as often as possible. There was one discharge measurement taken during the continuous water level record, but no staff gauge was installed at that time.

The 2012 Solinst Level Logger record begins May 1 and extends until mid-October. Ice begins to affect the pressure readings on October 10 making water levels following that unreliable. A staff gauge was installed along with the Level Logger on May 1 with a corresponding BaroLogger (barometric pressure data logger). After mid-July the record becomes unreliable due to a ponding effect.

In 2013 the KV-6 station was moved upstream due to the ponding encountered from the road culvert in 2012; however, due to infrequent measurements a continuous record could not be produced. 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 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 higher winter measurement uncertainty. The peak annual discharge in 2015 at KV-6 was 3.05×10^4 m^3/d (0.353 m^3/s) on May 11th, 2015. The 2016 hydrograph peaks at 2.41×10^4 m^3/d (0.280 m^3/s), on April 27th, 2016. The peak measured on the 2017 hydrograph was much higher at 6.2×10^4 m^3/d (0.72 m^3/s). One discrete measurement in August of 2017 appears to disagree with the derived record, but the measurement showed high uncertainty (23%) so can be disregarded.

Mean Monthly Flow

The mean measured discharge at KV-6 is 89×10^3 m^3/d (0.103 m^3/s) or 16.9 L/s/km^2 and yields a MAR of 533 mm (Table 3-5). The highest flows tend to be in May and September as a result of snowmelt and late summer rain storms, respectively. May is assumed to be the least representative of the true monthly mean since discharge fluctuates the greatest in this month. Based on other sites in the region these numbers are not in line with a catchment of the calculated size and median elevation. It is possible that additional water is being delivered by adits within the catchment or simply that the record is not representative of the true mean. Figure 3-4 shows the mean monthly flow distribution based on the discrete measurement record.

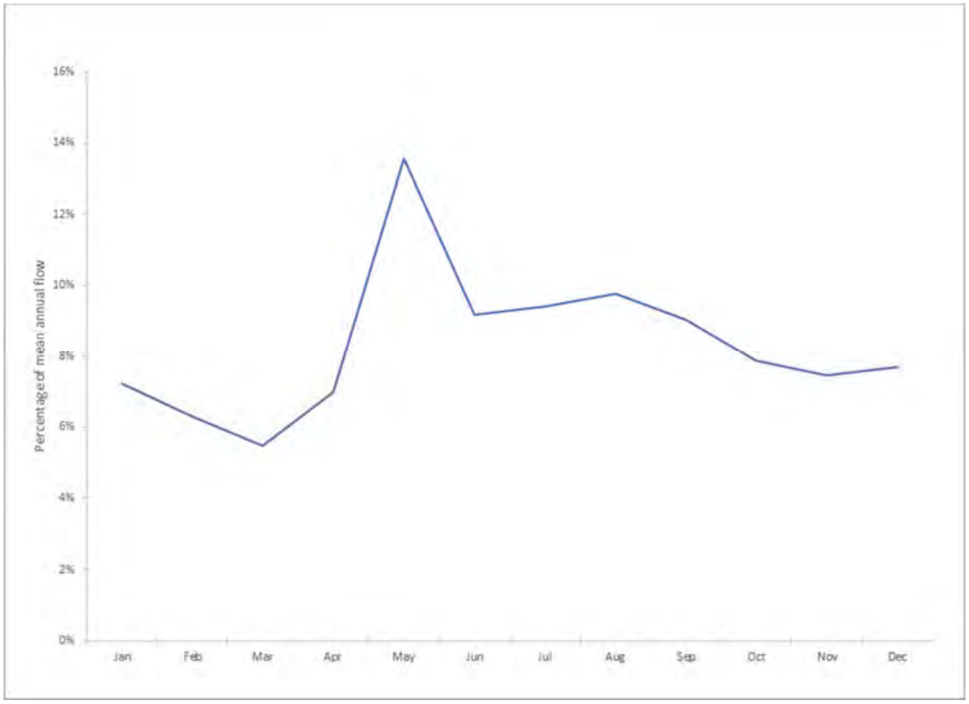


Figure 4-3: Annual Flow Distribution at KV-6 Christal Creek

Although since continuous data were obtained in 2012, attempts have been unsuccessful until the establishment of the station at its current location in 2014. Since that time reliable continuous data have been obtained with winter data filled in by extrapolation between discrete winter measurements. The MAR for the continuous data is 8.8 x 10^3 m^3/d (0.102 m^3/s), which is equivalent to 528 mm.

Table 3-5: Mean Monthly Discharge at KV-6, Christal Creek Below Christal Lake, for Months Where Continuous Data are Available (m^3/d)

	Month											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012					1.1 X 10^4	7.7 X 10^3	8.8 X 10^3					
2013												
2014					5.4 X 10^3	8.3 X 10^3	6.3 X 10^3	1.0 X 10^4	9.9 X 10^3	9.2 X 10^3	7.0 X 10^3	6.7 X 10^3
2015	7.9 X 10^3	6.7 X 10^3	5.7 X 10^3	7.3 X 10^3	1.6 X 10^4	9.5 X 10^3	1.0 X 10^4	1.1 X 10^4	1.1 X 10^4	1.0 X 10^4	9.9 X 10^3	9.2 X 10^3
2016	8.7 X 10^3	7.8 X 10^3	6.2 X 10^3	9.9 X 10^3	1.1 X 10^4	9.5 X 10^3	1.2 X 10^4	1.3 X 10^4	1.1 X 10^4	9.8 X 10^3	8.8 X 10^3	8.0 X 10^3
2017	7.3 X 10^3	6.7 X 10^3	6.1 X 10^3	6.1 X 10^3	1.3 X 10^4	9.0 X 10^3	9.7 X 10^3	5.9 X 10^3	6.7 X 10^3	6.2 X 10^3		
2018	5.7 X 10^3	4.3 X 10^3	3.7 X 10^3	6.3 X 10^3	3.0 X 10^4	1.4 X 10^4	1.0 X 10^4	1.3 X 10^4	1.1 X 10^4	7.9 X 10^3	7.3 X 10^3	6.8 X 10^3
2019	6.3 X 10^3	5.8 X 10^3	5.5 X 10^3	5.1 X 10^3	7.0 X 10^3	6.3 X 10^3	5.7 X 10^3	5.3 X 10^3	4.8 X 10^3	4.0 X 10^3	4.1 X 10^3	
Mean	7.2 X 10^3	6.3 X 10^3	5.4 X 10^3	6.9 X 10^3	1.4 X 10^4	9.0 X 10^3	8.9 X 10^3	9.7 X 10^3	9.0 X 10^3	7.8 X 10^3	7.4 X 10^3	7.7 X 10^3
95% Confidence limit	1.3 X 10^3	1.4 X 10^3	1.2 X 10^3	1.7 X 10^3	6.8 X 10^3	1.7 X 10^3	1.5 X 10^3	2.6 X 10^3	1.6 X 10^3	1.7 X 10^3	1.7 X 10^3	1.5 X 10^3

Winter Low Flows

The lake and bog area may have the effect of creating a more stable annual flow regime so that winter low flows do not drop nearly as low as a catchment of similar size due to the lake storage. Typically, base flows slowly drop over the winter and the lowest flows occur in March or April. Since 2012 April discrete measurements have been relatively consistent ranging from 4.5 x 10^3 m^3/d (0.052 m^3/s) to 6.1 x 10^3 m^3/d (0.071 m^3/s) with a mean of 5.3 x 10^3 m^3/d (0.061 m^3/s) or 10.0 $L/s/km^2$. As such 5.3 x 10^3 m^3/d (0.061 m^3/s) is considered a good estimate of mean winter low flow, and it does appear that the lake allows KV-6 to maintain a much higher unit runoff baseflow than KV-7.

Peak Flow

Given that KV-6 is the outlet of the lake and wetland area with little long term data it is not possible to produce a proxy record with which to conduct a return period analysis. May 2018 has the highest measured peak discharge to date at 3.2 x 10^4 (0.366 m^3/s) for the discrete measurement with a derived continuous record peak of 5.3 x 10^4 m^3/d (0.608 m^3/s). The average peak to date between two seasons where it was reliably captured is 2.98 x 10^4 m^3/d (0.345 m^3/s) which is considered a good working estimate for the mean peak annual flood.

KV-7 Christal Creek at Hanson-McQuesten Lakes Road Bridge

Christal Creek at KV-7 is located at the Hanson and McQuesten Lakes Road Bridge approximately 7 km downstream of KV-6. KV-7 drains an area of 35.8 km^2 with a median elevation of 970 m and includes KV-6 and Christal Lake. Ice-free continuous water level data typically extends from early May 1st to late September/early October. There are a number of old workings within the watershed including Galkeno 300, Galkeno 900, Brewis Red Lake (aka Shepard), 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. The MAR at KV-7 is 238.5 mm or 2.34 x 10^4 m^3/d (0.271 m^3/s) (7.6 $L/s/km^2$) using the available continuous data and discrete measurements as a measure of mean monthly for winter months. MAR calculated in 2008 was 221 mm and 2.63 x 10^{4} m^{3}/d (0.304 m^{3}/s) (Clearwater, 2008), based on a different catchment area. Recalculating for our new catchment area that would be 268 mm. The MAR estimates in the initial hydrology study found in UKM/96/01 was 230 mm. The continuous data show that the original estimates were appropriate, but the new mean is considered the best estimate.

Mean Monthly Flow

Clearwater summarized the data for 2004 to 2009 (Clearwater, 2008 and 2009). Data for 2010 and 2011 were processed by Access Consulting Group following the same methodology as Clearwater. Access Consulting Group has processed data at this site using Aquarius time series software since 2012. Mean monthly discharge calculated from the continuous record (unless otherwise noted) is shown since 2003 at KV-7 in Table 3-16.

Table 3-6: Mean Monthly Discharge at KV-7, Christal Creek at Hanson-McQuesten Road Bridge (m^{3}/d)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2003								3.6 X 10^{4}	4.4 X 10^{4}			
2004			1.3 X 10^{4}	1.4 X 10^{4}	1.0 X 10^{5}	2.7 X 10^{4}	1.0 X 10^{4}	9.7 X 10^{3}	1.4 X 10^{4}	1.2 X 10^{4}	8.9 X 10^{3}	8.7 X 10^{3}
2005		1.1 X 10^{4}	9.7 X 10^{3}	3.4 X 10^{4}	1.3 X 10^{5}	2.3 X 10^{4}	2.5 X 10^{4}	3.4 X 10^{4}	2.9 X 10^{4}	2.2 X 10^{4}	1.6 X 10^{4}	1.3 X 10^{4}
2006	1.4 X 10^{4}	1.2 X 10^{4}	1.0 X 10^{4}	1.1 X 10^{4}	9.4 X 10^{4}	4.5 X 10^{4}	3.4 X 10^{4}	2.4 X 10^{4}	3.6 X 10^{4}	3.2 X 10^{4}	1.8 X 10^{4}	1.2 X 10^{4}
2007	1.3 X 10^{4}	1.0 X 10^{4}			6.5 X 10^{4}	2.8 X 10^{4}	4.7 X 10^{4}	1.9 X 10^{4}	2.9 X 10^{4}	1.3 X 10^{4}		
2008								3.7 X 10^{4}	2.9 X 10^{4}	3.0 X 10^{4}		1.2 X 10^{4}
2009	6.8 X 10^{3}	5.9 X 10^{3}	4.1 X 10^{3}	6.4 X 10^{3}	9.7 X 10^{4}	2.9 X 10^{4}	8.8 X 10^{3}	1.6 X 10^{4}	3.2 X 10^{4}			
2010					2.7 X 10^{4}	2.1 X 10^{4}	3.1 X 10^{4}	2.0 X 10^{4}	2.0 X 10^{4}	1.6 X 10^{4}		
2011					1.1 X 10^{5}	1.2 X 10^{4}	4.3 X 10^{4}	3.6 X 10^{4}	2.3 X 10^{4}	1.5 X 10^{4}	1.1 X 10^{4}	
2012	1.3 X 10^{4}	6.7 X 10^{3}			6.3 X 10^{4}	2.2 X 10^{4}	3.5 X 10^{4}	1.9 X 10^{4}	2.3 X 10^{4}	1.7 X 10^{4}		
2013	6.5 X 10^{3}	5.7 X 10^{3}				2.5 X 10^{4}	1.1 X 10^{4}	6.9 X 10^{3}	2.9 X 10^{4}	2.0 X 10^{4}	1.2 X 10^{4}	9.5 X 10^{3}
2014	8.4 X 10^{3}	8.9 X 10^{3}	7.4 X 10^{3}	6.7 X 10^{3}	6.4 X 10^{4}	3.7 X 10^{4}	1.7 X 10^{4}	5.0 X 10^{4}	3.0 X 10^{4}	1.9 X 10^{4}	1.5 X 10^{4}	1.2 X 10^{4}
2015	7.7 X 10^{3}	6.2 X 10^{3}	5.1 X 10^{3}	1.4 X 10^{4}	9.4 X 10^{4}	1.7 X 10^{4}	3.2 X 10^{4}	4.5 X 10^{4}	5.3 X 10^{4}	2.3 X 10^{4}	1.4 X 10^{4}	1.2 X 10^{4}
2016	1.1 X 10^{4}	1.1 X 10^{4}	7.0 X 10^{3}	2.3 X 10^{4}	5.0 X 10^{4}	2.3 X 10^{4}	4.8 X 10^{4}	6.0 X 10^{4}	4.6 X 10^{4}	2.3 X 10^{4}	1.5 X 10^{4}	1.3 X 10^{4}
2017	1.2 X 10^{4}	1.2 X 10^{4}	7.0 X 10^{3}	5.4 X 10^{3}	6.0 X 10^{4}	2.3 X 10^{4}	1.5 X 10^{4}	1.2 X 10^{4}	3.2 X 10^{4}	1.3 X 10^{4}	9.6 X 10^{3}	8.0 X 10^{3}
2018	6.7 X 10^{3}	5.5 X 10^{3}	4.6 X 10^{3}	5.4 X 10^{3}	1.0 X 10^{5}	6.0 X 10^{4}	2.6 X 10^{4}	4.1 X 10^{4}	2.8 X 10^{4}			
2019	9.4 X 10^{3}	7.5 X 10^{3}	6.4 X 10^{3}	7.3 X 10^{3}	2.0 X 10^{4}	1.4 X 10^{4}	1.1 X 10^{4}	7.9 X 10^{3}	9.9 X 10^{3}	7.9 X 10^{3}	8.8 X 10^{3}	
Mean	9.7 X 10^{3}	8.6 X 10^{3}	7.4 X 10^{3}	1.1 X 10^{4}	6.2 X 10^{4}	2.6 X 10^{4}	2.5 X 10^{4}	3.1 X 10^{4}	2.9 X 10^{4}	1.6 X 10^{4}	1.2 X 10^{4}	1.1 X 10^{4}
95% Confidence limit	1.9 X 10^{3}	1.5 X 10^{3}	1.9 X 10^{3}	6.3 X 10^{3}	1.6 X 10^{4}	6.4 X 10^{3}	7.1 X 10^{3}	7.6 X 10^{3}	4.8 X 10^{3}	3.5 X 10^{3}	2.0 X 10^{3}	1.2 X 10^{3}

Note: Grey numbers are discrete discharge measurements.

Figure 4-4 shows the distribution of flow annually by month. The distribution is dominated by the snow melt driven high flows occurring in May, with flow throughout the rest of the open water season driven by precipitation events and a slow decline through the winter with lows typically reached in February or March.

However, the lowest winter flows could also result in early April. It is likely then that the April mean flows are overestimated by discrete measurements late in the month.

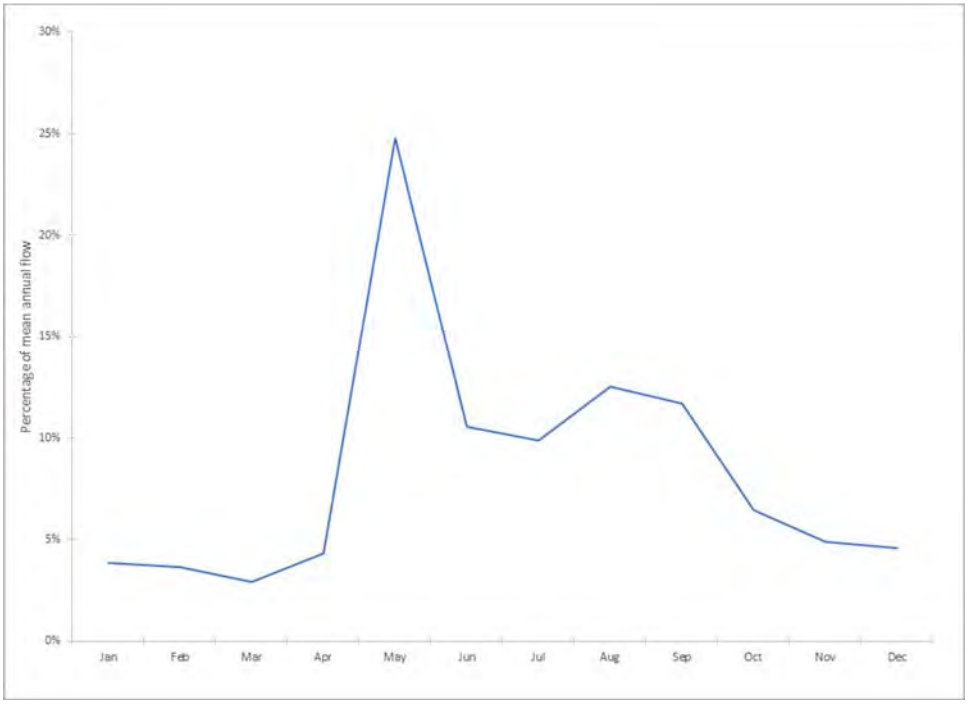


Figure 4-4: Annual Flow Distribution at KV-7 Christal Creek

Winter Low Flows

Typically, runoff decreases steadily over the winter months assuming there is no major thaw or rain on snow event. Thus, discharge typically reaches the lowest volume in March or early April and begins to rise as temperatures warm near the end of the month. More recent data gather since 2015 suggests an average winter low flow (March) of 5.9 x 10^3 m^3/d (0.069 m^3/s) while the long term mean is 7.6 x 10^3 m^3/d (0.087 m^3/s). Due to advances in salt dilution gauging technology and methodology 5.9 x 10^3 (0.069 m^3/s) is recommended as the best estimate of the mean annual low flow at KV-7.

Peak Flow

There are eight years of flow data at KV-7 from which peak flows can be taken; however, it is important to note that since peak flows can occur when ice is still impacting the water level it is possible that the true peak may not have been captured in the continuous record for some years. Nonetheless, a frequency analysis was carried out on peak instantaneous and daily flows using the Log Pearson Type III distribution to predict L-moments and yielded the results in Table 3-7.

Table 3-7: Peak Instantaneous and Daily Flows for Various Return Periods at KV-7, Christal Creek

	Instantaneous			Max Daily		
T_p	m^3/d	m^3/s	$L/s/km^2$	m^3/d	m^3/s	$L/s/km^2$
2	2.0×10^5	2.3	64.4	1.7×10^5	2.0	55.3
10	3.4×10^5	3.9	109.5	2.8×10^5	3.2	89.9
25	3.9×10^5	4.5	124.5	3.1×10^5	3.6	100.3
50	4.1×10^5	4.8	133.2	3.3×10^5	3.8	105.9

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. 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 1.5×10^4 m^3/d (0.17 m^3/s) was taken May 12th during the freshet period. As at KV-7 freshet did not produce the peak annual flow at KV-51; peak discharge occurred on July 25th, 2016 at 1.2×10^4 m^3/d (0.14 m^3/s). One discrete measurement in August of 2017 appears to disagree with the derived record, but the measurement showed high uncertainty (28%) so can be disregarded. The peak discharge on the 2017 hydrograph was recorded at 2.1×10^4 m^3/d (0.24 m^3/s) on 13 May 2017. Table 3-18 summarizes the continuous data collected to date as mean monthly discharge). This station data indicates backwater effects through the spring, which would affect the spring data.

Table 3-8: Mean Monthly Discharge at KV-51, Christal Creek Downstream of Hinton Creek (m^3/d)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015						2.1×10^3	2.5×10^3	2.9×10^3	3.9×10^3	3.3×10^3	3.0×10^3	2.9×10^3
2016	2.9×10^3	2.7×10^3	2.7×10^3	3.1×10^3	4.6×10^3	3.7×10^3	4.5×10^3	5.8×10^3	4.5×10^3			
2017	1.4×10^3	1.3×10^3	1.1×10^3	1.0×10^3	7.0×10^3	2.0×10^3	1.9×10^3	1.3×10^3				
2018				7.8×10^2	2.1×10^4	7.9×10^3	3.2×10^3	5.2×10^3	5.0×10^3			
Mean	2.1×10^3	2.0×10^3	1.9×10^3	1.6×10^3	1.1×10^4	3.9×10^3	3.0×10^3	3.8×10^3	4.5×10^3	3.3×10^3	3.0×10^3	2.9×10^3
95% Confidence limit	1.4×10^3	1.4×10^3	1.5×10^3	1.4×10^3	1.0×10^4	2.7×10^3	1.1×10^3	2.0×10^3	6.4×10^2			

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 1,400 masl. Lightning Creek originates to the east of Keno City and drains the southern flank of Keno Hill and the northern flank of Mount Hinton. Lightning Creek flows to the south of Galena hill into Duncan Creek. Within the Lightning Creek watershed are multiple adits including Keno 200 and 700, multiple old surface workings, active mining at Bellekeno East and placer mining on Thunder Gulch.

Hydrometric station KV-41 is located on Lightning Creek above the Keno City Bridge and downstream of the Bellekeno mine and local placer mining activity. Ice-free continuous water level data typically extends from late

May to late September/early October after which ice begins to affect water level readings and the stage-discharge relationship.

MAR at KV-41 is 331 mm, 5.35 x 10^4 m^3/d (0.620 m^3/s) or 10.5 $L/s/km^2$. This is similar to earlier estimates by Clearwater of 344 mm or 5.57 x 10^4 m^3/d (0.645 m^3/s). Unit runoff is much higher on Lightning Creek as compared to Christal Creek. This is likely due to less vegetative cover compared to Christal Creek owing to the higher elevations and steeper rocky terrain characterising Lightning Creek.

Mean Monthly Flow

Table 3-9 shows the mean monthly discharge record with some winter months estimated with discrete measurements. Data from 2013 was lost due to a failure with the logger and while discrete measurements are shown they are not used to calculate the means in summer months. Monthly means are used to calculate a percentage of total annual flow by month (Figure 4-5). Peak flows occur slightly later at this site than in Christal Creek, presumably due to the higher median elevation delivering a more temporally spread out spring snowmelt and holding high elevation snowpack longer. Flows then decrease throughout the summer and into winter with low flows occurring March or early April.

Table 3-9: Mean Monthly Discharge at KV-41, Lightning Creek Above Keno City Bridge (m^3/d)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004								3.7 X 10^4	2.7 X 10^4	2.1 X 10^4	1.3 X 10^4	1.1 X 10^4
2005	8.5 X 10^3	5.8 X 10^3	4.8 X 10^3	1.1 X 10^4	1.6 X 10^5	1.2 X 10^5	8.5 X 10^4	9.6 X 10^4	8.3 X 10^4	5.5 X 10^4	3.9 X 10^4	2.6 X 10^4
2006	1.9 X 10^4	1.7 X 10^4	1.7 X 10^4	2.4 X 10^4	6.9 X 10^4	1.7 X 10^5	1.1 X 10^5	8.0 X 10^4	9.4 X 10^4	7.7 X 10^4	4.8 X 10^4	3.9 X 10^4
2007					1.1 X 10^5	1.7 X 10^5	1.0 X 10^5					
2008								9.8 X 10^4	6.7 X 10^4	8.9 X 10^4		
2009		9.5 X 10^3	1.1 X 10^4	6.0 X 10^3	1.4 X 10^5	1.4 X 10^5						
2010					1.0 X 10^5	1.2 X 10^5	8.7 X 10^4	6.6 X 10^4	4.9 X 10^4	3.9 X 10^4		
2011						1.0 X 10^5	1.6 X 10^5	1.3 X 10^5	8.0 X 10^4			2.3 X 10^4
2012	2.2 X 10^4	1.4 X 10^4	1.6 X 10^4			1.8 X 10^5	1.2 X 10^5	6.1 X 10^4	7.5 X 10^4	4.9 X 10^4		
2013						1.6 X 10^5	6.1 X 10^4	3.8 X 10^4	6.7 X 10^4	6.6 X 10^4	3.6 X 10^4	1.5 X 10^4
2014	1.3 X 10^4	1.1 X 10^4	8.3 X 10^3		1.1 X 10^5	1.5 X 10^5	6.1 X 10^4	1.1 X 10^5	7.4 X 10^4	5.3 X 10^4	2.9 X 10^4	1.8 X 10^4
2015	1.7 X 10^4	1.7 X 10^4	1.7 X 10^4	1.7 X 10^4	2.1 X 10^5	1.0 X 10^5	8.9 X 10^4	1.2 X 10^5	1.3 X 10^5	6.4 X 10^4	3.4 X 10^4	1.9 X 10^4
2016	1.7 X 10^4	1.8 X 10^4	1.8 X 10^4	1.7 X 10^4	8.4 X 10^4	1.1 X 10^5	7.2 X 10^4	8.6 X 10^4	6.6 X 10^4	2.6 X 10^4	7.5 X 10^3	6.1 X 10^3
2017	6.7 X 10^3	1.0 X 10^4	1.3 X 10^4	1.0 X 10^4	6.2 X 10^4	8.0 X 10^4	4.9 X 10^4	4.5 X 10^4	5.7 X 10^4	3.4 X 10^4	1.7 X 10^4	1.9 X 10^4
2018	1.9 X 10^4	1.5 X 10^4	1.4 X 10^4	1.3 X 10^4	8.2 X 10^4	1.3 X 10^5	6.2 X 10^4	9.0 X 10^4	5.0 X 10^4			
2019	2.1 X 10^4	1.5 X 10^4	1.5 X 10^4	1.6 X 10^4	9.3 X 10^4	5.1 X 10^4	2.6 X 10^4	2.5 X 10^4	2.4 X 10^4	2.5 X 10^4	1.6 X 10^4	
Mean	1.8 X 10^4	1.7 X 10^4	1.7 X 10^4	1.7 X 10^4	1.1 X 10^5	1.1 X 10^5	6.8 X 10^4	7.1 X 10^4	6.2 X 10^4	4.3 X 10^4	2.9 X 10^4	2.3 X 10^4
95% Confidence limit	3.7 X 10^3	2.7 X 10^3	2.9 X 10^3	4.2 X 10^3	2.9 X 10^4	1.7 X 10^4	1.8 X 10^4	1.7 X 10^4	1.4 X 10^4	1.3 X 10^4	9.7 X 10^3	6.1 X 10^3

Note: Grey numbers are discrete discharge measurements.

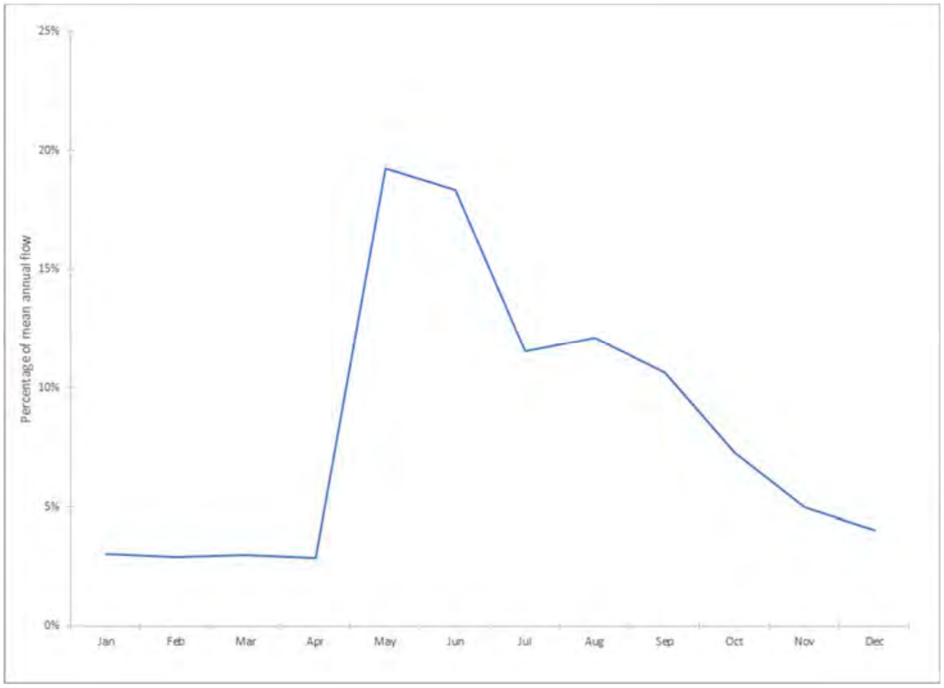


Figure 4-5: Annual Flow Distribution at KV-41 Lightning Creek

Winter Low Flows

The lowest measured flow on record was in February 2005 at 5.4 x 10^3 m^3/d (0.063 m^3/s) or 1.1 $L/s/km^2$ followed by March 2014 at 8.3 m^3/d (0.096 m^3/s) or 1.63 $L/s/km^2$. The lowest mean monthly flow calculated is that from the 2005 record at 4.8 x 10^3 m^3/d (0.056 m^3/s) or 1.0 $L/s/km^2$. It is likely that the continuous record in 2005 was adjusted to this single measurement so it should be considered with caution. The mean flow for February and March is 1.3 x 10^4 m^3/d (0.152 m^3/s) which is likely closer to the mean annual low flow than the extreme lows previously observed. If the lowest measured or derived flow from each year is average the value is 1.1 x 10^4 m^3/d (0.124 m^3/s). There are enough years of supporting data to suggest this is a good estimate of the mean annual low flow.

Peak Flow

There are nine years of flow data from which peak flows can be taken at KV-41; however, it is important to note that since peak flows can occur when ice is still impacting the water level it is possible that the true peak may not have been captured in the continuous record for some years. Nonetheless, a frequency analysis was carried out on peak instantaneous and daily flows using the Log Pearson Type III distribution to predict moments- and yielded the results in Table 3-10.

Table 3-10: Peak Daily and Instantaneous Flood at KV-41, Lightning Creek

	Instantaneous			Daily		
T_p	m^3/d	m^3/s	$L/s/km^2$	m^3/d	m^3/s	$L/s/km^2$
2	3.5×10^5	4.1	69.0	2.6×10^5	3.0	51.0
10	5.8×10^5	6.7	114.4	4.3×10^5	5.0	85.6
25	7.0×10^5	8.1	137.0	5.4×10^5	6.3	107.0
50	7.9×10^3	9.1	153.7	6.4×10^5	7.4	124.9

The unit runoff of peak flows is similar between KV-7, KV-41 and McQuesten River at the mouth for the 2 year mean daily flood which may also be considered the mean annual flood. The value at Lightning Creek is highest followed by Christal Creek and then McQuesten River. This is the expected trend as we move to lower median catchment elevations. The size of the McQuesten River watershed will also dampen peak flows. As return period increases so too does the gap between the estimates at the McQuesten River and the smaller Christal and Lightning Creek. This may be explained by the smaller watersheds having more distinct physiography and shorter lag times to event responses. In other words, less storage means a proportionally larger (flashier) response to melt and precipitation events of combinations of in smaller catchments.

4.2 WATER QUALITY

The KHSD property lies along the broad McQuesten River valley with three prominent hills to the south of the valley, Galena Hill, Sourdough Hill, and Keno Hill. It is surrounded by three major watersheds: the McQuesten River watershed, the Mayo River watershed, and the Keno Ladue Watershed. For this report, surface water quality results will be discussed, focussing on those watercourses potentially impacted by Project operations, that is, the McQuesten Watershed: South McQuesten River, No Cash Bog/Creek, and Christal Creek, and the Mayo River watershed: Lightning Creek catchment. Water quality stations are shown in Figure 4-6.

Water quality for watercourses in the KHSD have been thoroughly assessed over the last ten years (Minnow, 2008, 2011, 2013, 2015, 2017). These reports provided: a data quality review (from 2006-2007), identified contaminants of concern (COCs), potential contaminants of concern (PCOCs), and characterized water quality for stations in the KHSD. Reports were prepared as part of district closure studies and the long term monitoring plan and included assessments for background stations, Lightning Creek, Christal Creek, No Cash Creek, Flat Creek and the South McQuesten River. The following PCOCs were identified as being elevated above recommended water quality guidelines and potentially hazardous to aquatic life: aluminum, arsenic, cyanide, chromium, copper, iron, lead, manganese, mercury, nitrate, nitrite, phosphorus, selenium, silver, sulphate, total Kjeldahl nitrogen, and uranium. For many of the total metal parameters, the maximum values tended to occur when the total suspended solids (TSS) was also elevated (such as during spring freshet), suggesting that concentrations were associated with particulate matter in water samples. Comparison of filtered metal (dissolved) values at the same sites were confirmed to be below guidelines and less bioavailable (and less harmful) to aquatic life. As well many constituents that exceeded guidelines showed concentrations that had either stabilized or decreased over time and were therefore not considered future COCs. Final COCs flagged for the project sites were cadmium and zinc and will be the focus of the following sections. Unless otherwise noted, total cadmium and dissolved zinc will be discussed since these reflect the fractions that have Canadian Council of Ministers of the Environment (CCME) cadmium and zinc long term guidelines for the protection of aquatic life (PAL).

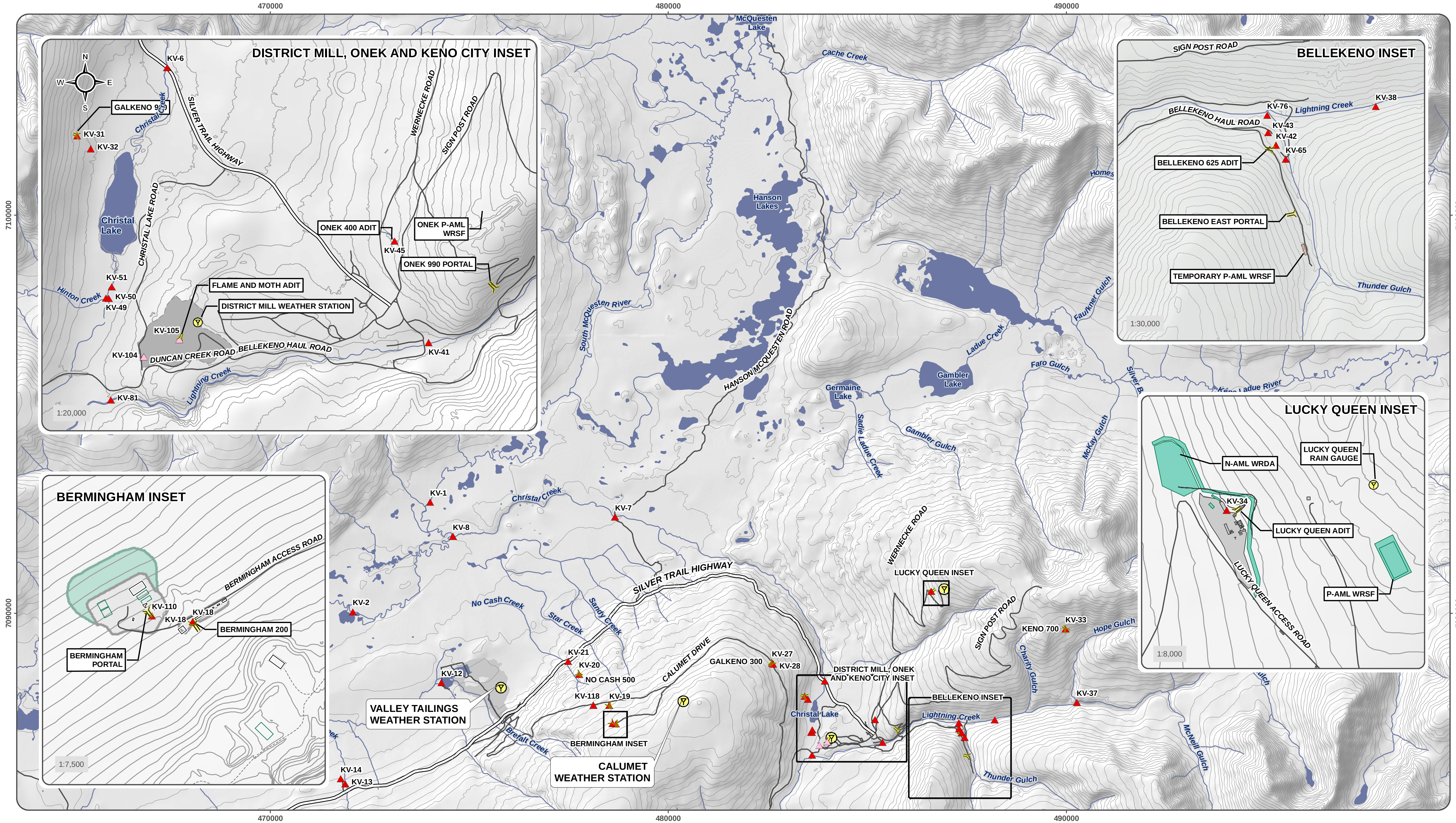
The following sections describe an overview of results of the KHSD water quality sampling program from 2007 to 2019 which includes the surface water quality monitoring stations at Lightning Creek, Christal Creek, No Cash Creek and the South McQuesten River, and the relevant AKHM adits, wastewater treatment plants, and decline within their respective catchments. Monitoring locations for each catchment are presented on Figure 4-6 and in Table 4-11 and Table 4-12.

Table 4-11: KHSD Surface Water Quality Monitoring Stations

Site	Description	Guideline
Mayo River Watershed		
Lightning Creek		
KV-37	Lightning Creek upstream of Hope Gulch	CCME PAL
KV-38	Lightning Creek upstream of Thunder Gulch	
KV-41	Lightning Creek upstream of bridge at Keno City	
KV-65	Thunder Gulch upstream of Bellekeno East Portal	
KV-76	Thunder Gulch downstream of Bellekeno 625 Adit	
KV-81	Lightning Creek southwest of Mill Site	
McQuesten River Watershed		
Christal Creek		
KV-6	Christal Creek at Silver Trail Highway	CCME PAL
KV-7	Christal Creek at Hanson Road	
KV-8	Christal Creek at mouth	
KV-49	Hinton Creek upstream of Christal Creek	
KV-50	Christal Creek upstream of Hinton Creek	
KV-51	Christal Creek downstream of Hinton Creek	
No Cash Creek		
KV-21	No Cash Creek upstream of Silver Trail Highway	CCME PAL
KC-111	Upper No Cash Creek above No Cash 500 adit	
KV-118	Upper No Cash Creek at Calumet Drive	
South McQuesten River		
KV-1	South McQuesten River upstream of Christal Creek	CCME PAL
KV-2	South McQuesten River at pump house downstream of Christal Creek	

Table 4-12: KHSD Adits, Wastewater Treatment Plants, and Decline Locations

Site	Description	Water Licence Effluent Quality Standards (EQS)
Mayo River Watershed		
Lightning Creek		
KV-33	Keno 700 Adit	No EQS
KV-42	Bellekeno 625 Adit	No EQS
KV-43	Bellekeno 625 Treatment Pond Decant	Type A Water Licence QZ09-092-2
KV-104LC	Flame and Moth effluent discharged to Lightning Creek	Type A Water Licence QZ09-092-2
KV-105	Flame and Moth Adit discharge	No EQS
McQuesten River Watershed		
Christal Creek		
KV-27	Galkeno 300 Adit	No EQS
KV-28	Galkeno 300 Treatment Pond Decant	Type B Water Licence QZ17-076
KV-31	Galkeno 900 Adit	No EQS
KV-32	Galkeno 900 Treatment Pond Decant	Type B Water Licence QZ17-076
KV-34	Lucky Queen Adit	No EQS
KV-45	Onek 400 Adit	No EQS
No Cash Creek		
KV-18	Historic Bermingham 200 Adit	No EQS
KV-19	Ruby 400 Adit	No EQS
KV-20	No Cash 500 Adit	No EQS
KV-110	New Bermingham Decline discharge	No EQS



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

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1:90,000 (when printed on 11 x17 inch paper)

0 1 2 3 4 5 Kilometers

Legend

- Active Surface Water Quality Station
- Pending/Proposed Water Quality Station
- Weather Station
- Adit
- Mine Feature Footprint
- To Be Constructed Feature
- Silver Trail Highway
- Other Road
- Watercourse
- Waterbody

AKHM

AEG

Site Characterization Plan

FIGURE 4 - 6
SURFACE WATER QUALITY STATIONS

APRIL 2019

4.2.1 SOUTH MCQUESTEN RIVER DRAINAGE

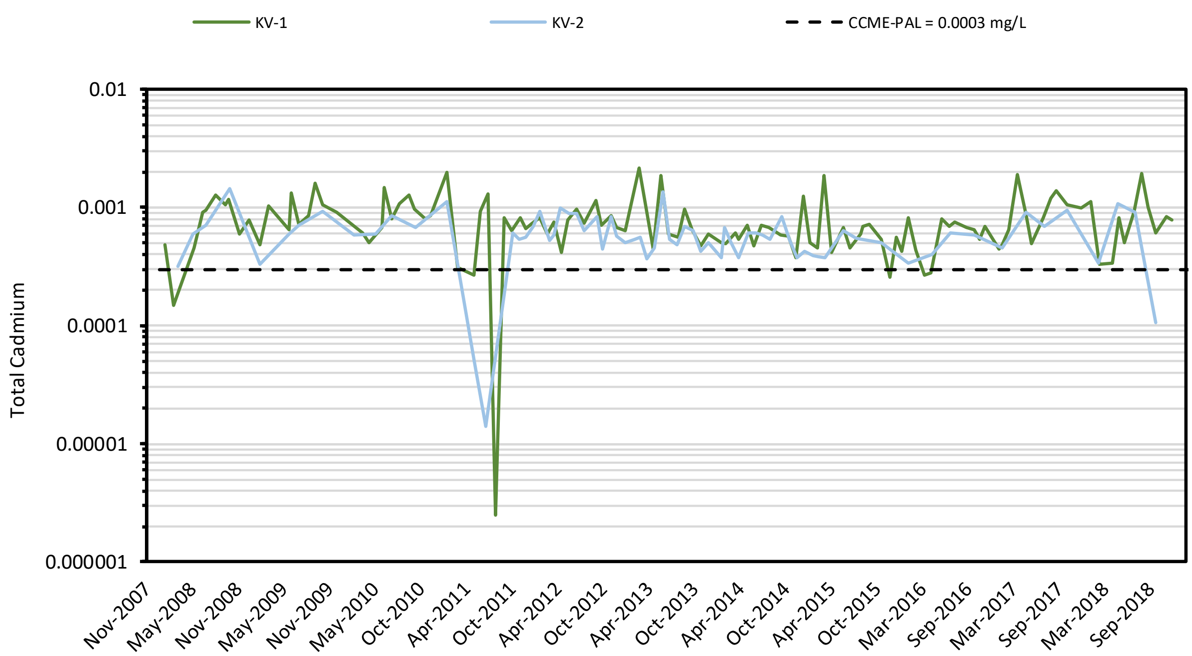
The South McQuesten River is a large watercourse that drains much of the western portion of the KHSD. It receives drainage from Christal and Flat Creeks; the Flat Creek catchment will not be discussed in this section as it falls under the care and maintenance of ERDC. No Cash Creek also drains towards the South McQuesten River, but infiltrates to ground approximately 2 km south of the South McQuesten River.

4.2.1.1 South McQuesten River

Water quality stations installed along the South McQuesten River have been monitored by AKHM (2008-2019) to evaluate any potential impact on water quality related to mining activities at the project site.

Water quality in the South McQuesten River downstream of all mining related activities has improved over the years as management practices and interim Care and Maintenance activities at the Keno site have reduced the overall loading of metals into the receiving environment. However, since 2006 an unrelated source (Cache Creek) upstream of project influence on the South McQuesten River has been impacting downstream water quality and resulting in increasing concentrations of metals, particularly cadmium and zinc. For example, samples collected at KV-1 between 1994 and 2006 yielded a median total zinc concentration of 0.031 mg/L (n = 72), whereas samples collected between 2007 and 2016 returned a median total zinc concentration of 0.12 mg/L (n=108). An investigation into the source of the elevated metals indicated that a scree field in the upper headwater region of Cache Creek was responsible for the increase in metal concentrations in the South McQuesten River (ITL, 2011; EDI, 2005). This area is located upstream of United Keno Hill Mines (UKHM) claims and although the Cache Creek drainage has had some minimal surface exploration, no substantial mining activity has taken place in this area.

Total cadmium and dissolved zinc concentrations decreased moving downstream from station KV-1, located upstream of Christal Creek and associated AKHM activities, to station KV-2, located downstream of Christal Creek (Figure 4-7). At KV-2 and KV-1, 89% and 94% of samples exceeded the CCME PAL, respectively. Similarly, 68% of samples at KV-2 and 89% of samples at KV-1 exceeded the CCME PAL dissolved zinc guideline. Seasonal patterns of dissolved zinc concentrations were similar at the South McQuesten River sites in which minima normally occurred in September and October and peak concentrations observed in the spring. Similar seasonality was observed for total cadmium concentrations.



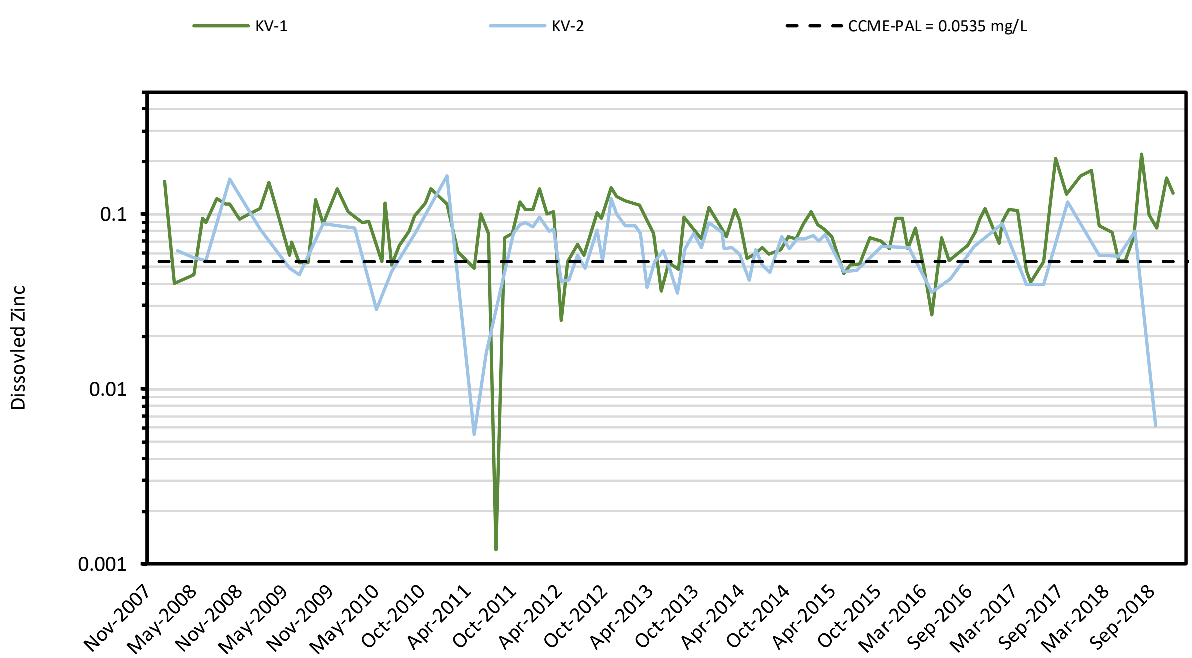


Figure 4-7: Total Cadmium and Dissolved Zinc Concentrations (in mg/L) at Stations KV-1 and KV-2 in the South McQuesten River

4.2.1.2 Christal Creek Catchment

Christal Creek originates on the south side of Galena Hill, flows into Christal Lake, and discharges at the north end of the lake, where it meanders north and west until it discharges into the South McQuesten River approximately 10 km downstream of the lake. The stream is predominately high gradient with erosional habitat through most of the upper reaches, but near the mouth of the creek, it becomes a low gradient meandering watercourse.

Major sources of metal load to Christal Creek include the Galkeno 300 and Galkeno 900 adits, both of which are treated under care and maintenance as part of the Type B Water Licence (QZ17-076). The Onek 400 adit discharge, which infiltrates to ground within a few hundred metres of the portal, and tailings from the historical Mackeno mill, which are deposited at the moth of Christal lake and dispersed downstream within Christal Creek, are additional sources of metal load.

Of the AKHM components, the Flame and Moth water treatment plant (WTP) and District mill pond are the primary sources of water discharge to the Christal Creek catchment.

Flame & Moth WTP

The Flame & Moth water treatment system can discharge to Christal Creek or Lightning Creek. The EQS for each watershed are further defined by the discharge rate, with four ranges identified in Part D, Clause 42 and 43 of Water Licence QZ09-092. No discharge from the Flame & Moth WTP has been directed to Christal Creek to date.

District Mill

Construction and placement of the dry stack tailings facility (DSTF) was initiated in December 2010 during the commissioning of the District mill. The District mill pond and DSTF are located south of Christal Lake, and immediately north of Lightning Creek. Until August 2015, the mill had not produced a discharge to the receiving environment. On August 24, 2015 water was released from the sedimentation pond with decanting discontinued by October 17, 2015 to lower the level within the mill pond. Water was discharged from the pond at about 0.5 L/s over 50 or so days with a total effluent volume of 2,025 m^3 released in 2015.

Water was again released from the sedimentation pond starting June 26, 2016 with periodic discharges occurring through July to August 20, 2016. During September 10 to 20, 2016 additional water was pumped from the sedimentation pond for a total of 1,675 m^3 released in 2016.

No water was released from the district mill pond in 2017.

On June 18, 2018 water started being discharged from the sediment pond with periodic discharges occurring in July, August, October and November 1st. No discharge from the district mill pond to the environment occurred in 2019. Cadmium and Zinc concentrations in the District mill pond discharge have remained below the EQS to date (Figure 4-8).

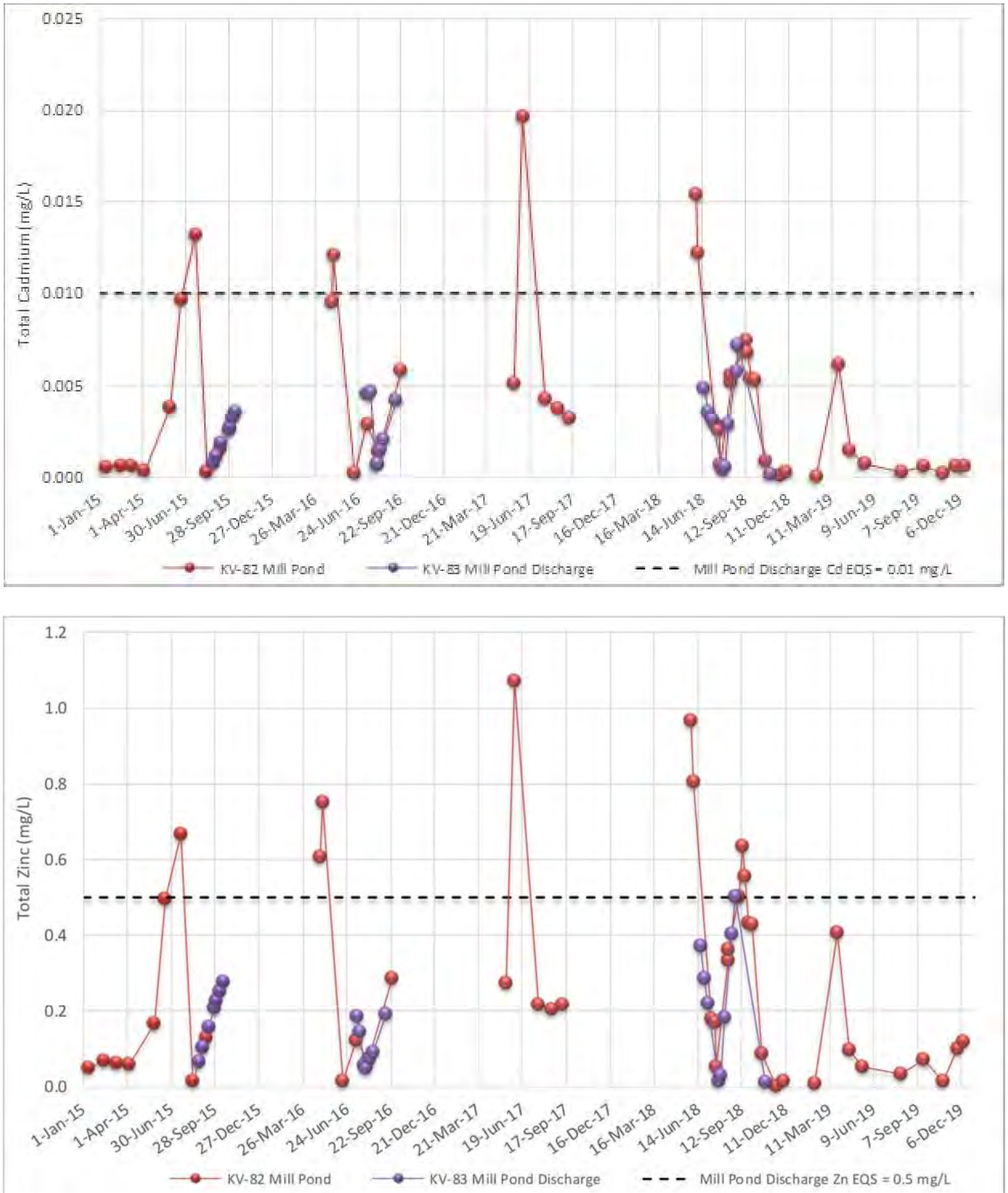


Figure 4-8: Cadmium and Zinc Concentrations in the District Mill Pond

Christal Creek

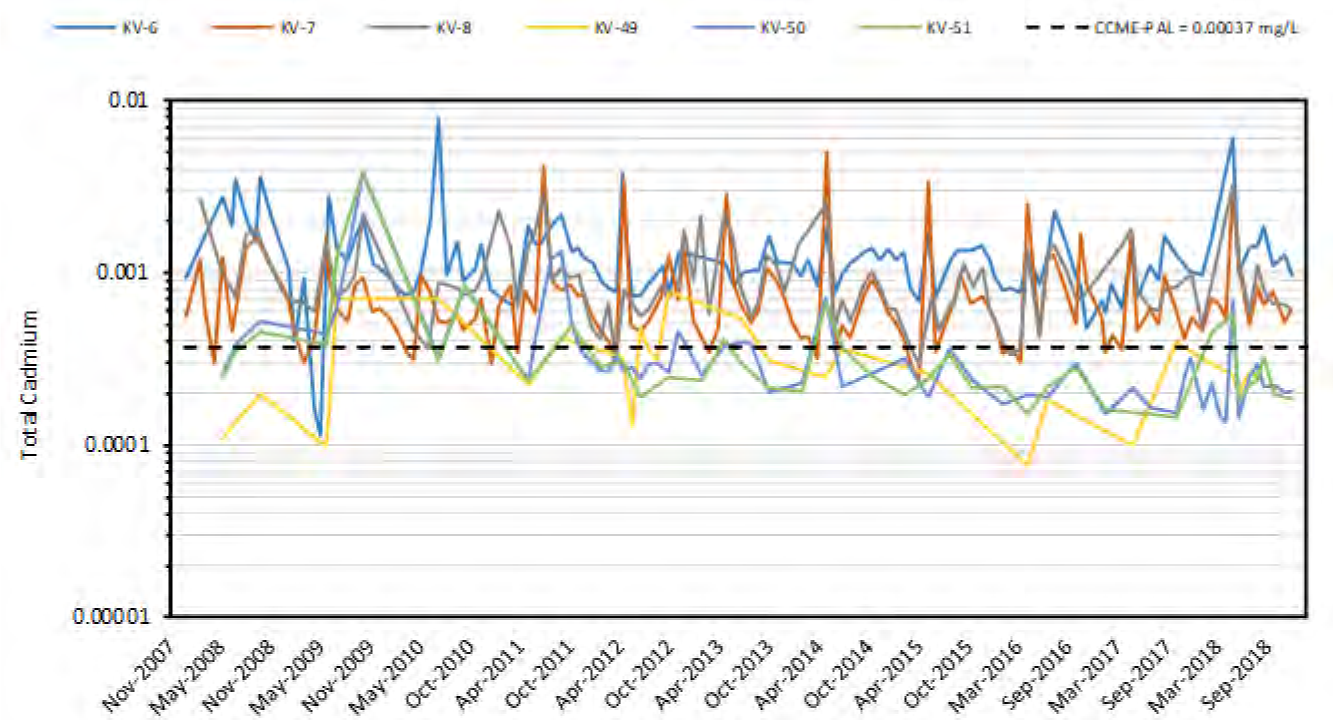
Water quality in Christal Creek is monitored at upstream stations KV-49, KV-50, and KV-51, and downstream along the creek at KV-6, KV-7, KV-8. Stations KV-7 and KV-8 are downstream of all mine sources and integrate effects from the main load sources in the catchment (treated discharge from the Galkeno 300 and Galkeno 900 adits, untreated discharge from the Onek 400 adit, and the Mackeno Tailings that are adjacent to and partially within Christal Lake and upper Christal Creek). These sites also capture effects of contributions from the UN and Lucky Queen adits, dispersed tailings within Christal Creek, and drainage from Erickson Gulch.

Christal Creek waters are circumneutral to mildly alkaline pH (7.0 – 8.5; median pH 7.8) and relatively hard (380 mg/L). Time series of total cadmium and dissolved zinc concentrations at each station in the Christal Creek catchment are shown in Figure 4-9. The CCME cadmium guideline is hardness-dependent; for reference, the CCME guideline displayed in Figure 4-9 is calculated based on the median hardness for all samples (KV-6, KV-7, KV-8, KV-49, KV-50, KV-51) collected in the Christal Creek catchment (420 mg/L). Similarly, the CCME dissolved zinc guideline is hardness, pH and dissolved organic carbon (DOC) dependent; for reference, the CCME guideline displayed in Figure 4-9 is calculated based on the median hardness, pH and DOC for all samples (KV-6, KV-7, KV-8, KV-49, KV-50, KV-51) collected in the Christal Creek catchment (420 mg/L, pH 7.40 and 1.83 mg/L, respectively).

Cadmium and zinc concentrations have remained relatively steady within seasonal bounds, typically peaking during spring freshet and again in the late fall. The concentrations of both metals typically exceeded their CCME guidelines during spring freshet, due to the markedly lower hardness (and therefore, lower CCME guidelines) present at this time owing to dilution by snowmelt. Cadmium concentrations increased moving downstream through upper Christal Creek (KV-50, KV-49, and KV-51) to lower Christal Creek (KV-6, KV-7 and KV-8). A calculated 31%, 28% and 56% of samples exceeded the CCME PAL cadmium guideline at KV-50, KV-51 and KV-49, respectively. At lower Christal Creek, KV-6, KV-7 and KV-8 had higher total cadmium concentrations compared to the upstream locations, with KV-6 having the highest median total cadmium concentration of all sites within the catchment. A calculated 86% of samples at KV-7, 95% at KV-8, and 99% at KV-6 exceeded the total cadmium guideline. These downstream sites generally show total cadmium concentrations peaking from May to July (during freshet).

Dissolved zinc concentrations decreased moving downstream through upper Christal Creek (KV-50 and KV-51, 0.174 mg/L and 0.152 mg/L, respectively) to Hinton Creek (KV-49) and lower Christal Creek (KV-6, KV-7 and KV-8). At upper Christal Creek, 94% and 84% of samples exceeded the CCME PAL dissolved zinc guideline at KV-50 and KV-51. A calculated 26% of samples exceeded the CCME PAL dissolved zinc guideline at KV-49. Lower dissolved zinc concentrations were generally recorded May to July at KV-50 and KV-51. Seasonal fluctuations are likely related to dilution from spring snowmelt. No seasonal variation for dissolved zinc was observed at KV-49.

At lower Christal Creek, sampling sites at KV-6, KV-7 and KV-8 had relatively lower dissolved zinc concentrations, compared to the upstream locations except for KV-49. 91% of samples at KV-6, 87% of samples at KV-7 and 90% of samples at KV-8 exceeded the CCME PAL dissolved zinc guideline. The trends in the lower Christal Creek stations (KV-7 and KV-8) are similar to those observed at the mouth of Christal Creek (KV-6) with higher levels of dissolved zinc concentrations observed during May to September.



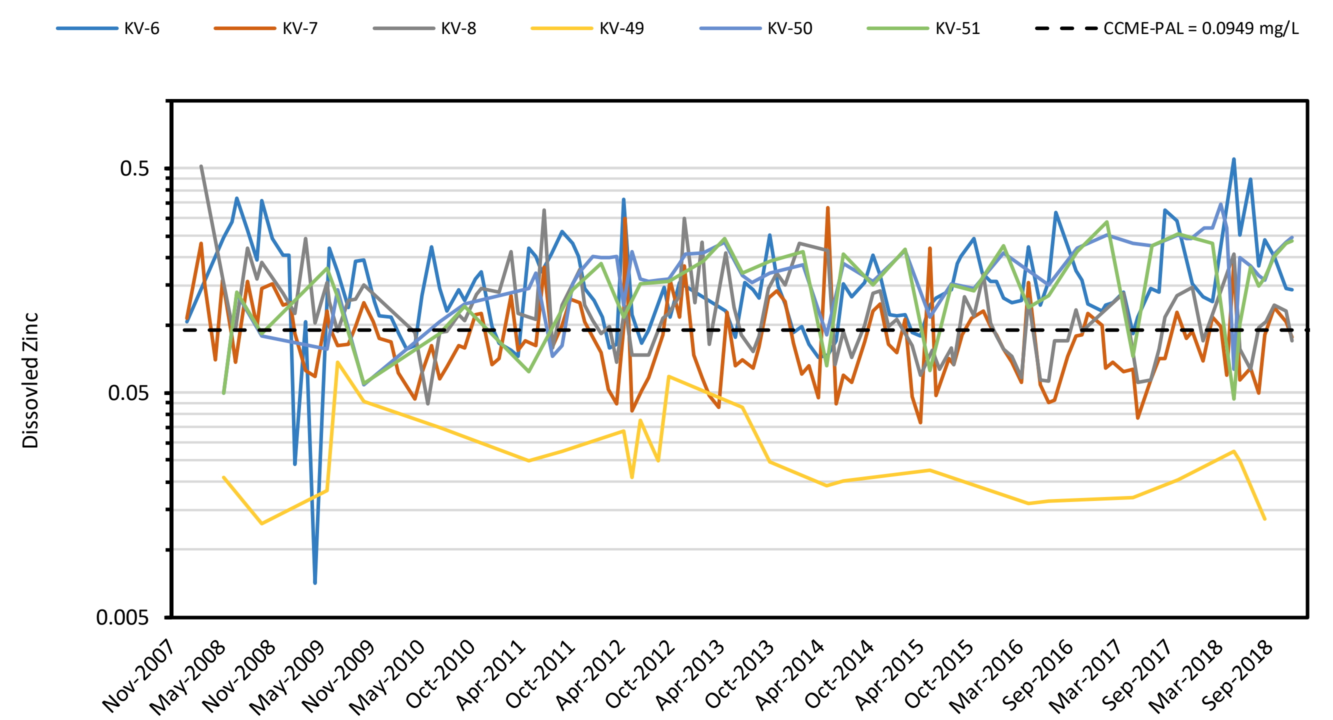


Figure 4-9: Total Cadmium and Dissolved Zinc Concentrations (in mg/L) in Christal Creek

4.2.1.3 No Cash Creek Catchment

No Cash Creek is located on the northwest side of Galena Hill. The No Cash Creek headwaters are located upstream of the No Cash 500 adit, although the majority of flow in No Cash Creek is supplied by discharge from No Cash 500. The Ruby 400 and historical Bermingham 200 adits are located farther up the hillside; discharge from these adits infiltrates to ground such that there is no surface connection to No Cash Creek, but may be one in winter when ground is frozen. Below the Silver Trail Highway, No Cash Creek intersects the No Cash Diversion Ditch and then runs through a poorly drained valley containing extensive areas of heavily vegetated peat bog/marsh. No Cash Creek 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.

Discharge of untreated wastewater from No Cash 500, Ruby 400, and Bermingham 200 adits is authorized under the Type B Water Licence (QZ17-076). No EQS is specified for these adits under the Water Licence. The New Bermingham mine exploration decline is located adjacent to the historical Bermingham 200 adit.

New Bermingham Decline

Discharge from the New Bermingham mine commenced in mid-2017. Since then flow has ranged between 0.4 and 10.3 L/s (median 3.4 L/s). The discharged water infiltrates to ground and there is no overland connection with downstream watercourses such as No Cash Creek. Total cadmium and dissolved zinc concentrations in the decline discharge (station KV-110) were highest between November 2017 and June 2018 (median 0.0062 mg/L total cadmium and 0.17 mg/L dissolved zinc; Figure 4-10) as water was pumped from the historical Bermingham 200 adit for decline excavation purposes. Concentrations decreased markedly in the fall of 2018 as decline development was suspended. Between September 2018 and December 2019, total cadmium (0.000063 median mg/L) and dissolved zinc (0.0073 median mg/L) concentrations were between one and two orders of magnitude lower, reflecting local groundwater baseline concentrations.

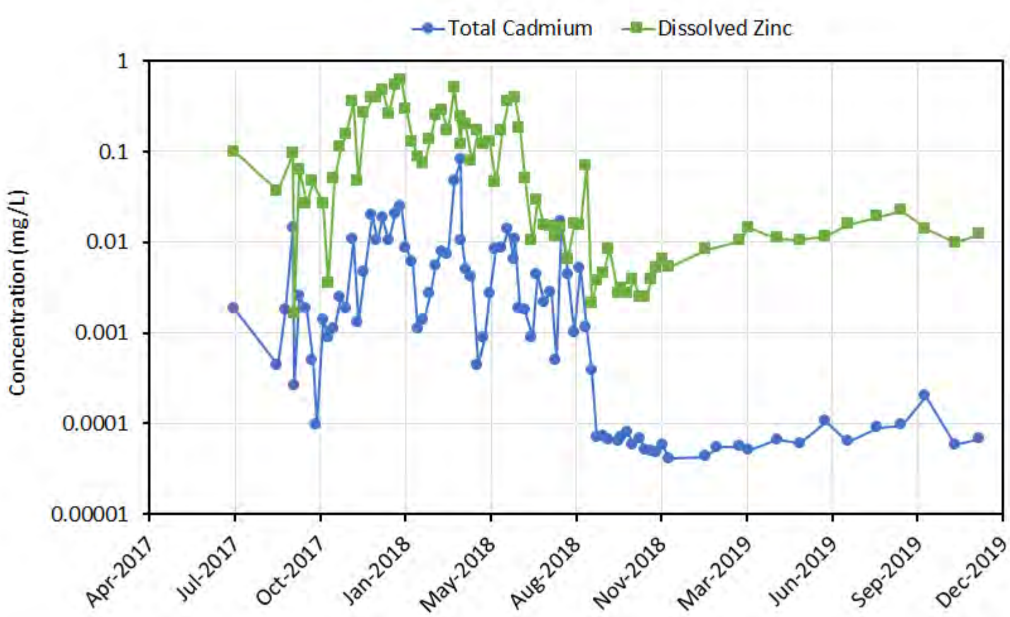


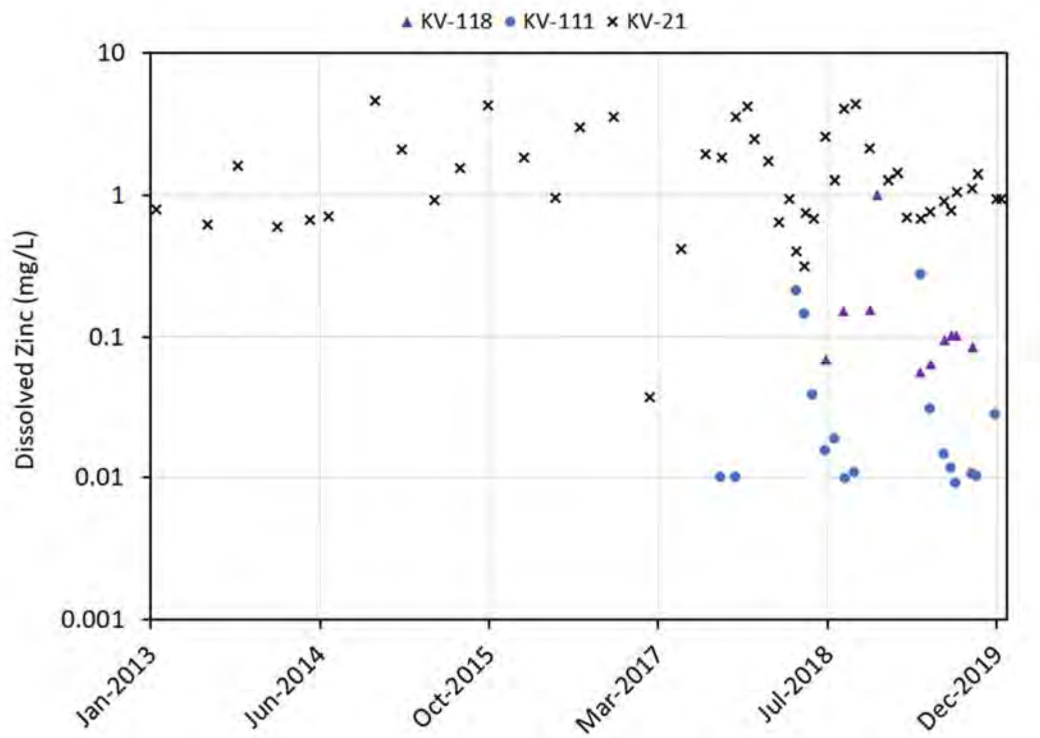
Figure 4-10: Total Cadmium and Dissolved Zinc Concentrations in New Bermingham Decline Discharge

No Cash Creek

Water quality in No Cash Creek is monitored at station KV-21, located at the Silver Trail Highway, and more recently at stations KV-111 (immediately upstream of the No Cash 500 adit) and KV-118 (upper No Cash Creek at Calumet Drive, upstream of KV-111). Water at stations KV-118 and KV-111 only flows seasonally and is typically dry/frozen to ground between October and March.

All samples exceeded the CCME PAL cadmium and zinc guidelines at both KV-21 and KV-118, whereas 33% of samples exceeded the guideline at KV-111. Cadmium and zinc concentrations displayed little seasonality at station KV-118, although the highest concentrations tended to occur in late fall or winter (Figure 4-11), likely due to contributions from the historical Bermingham 200 and/or Ruby 400 adit flow that travels farther over frozen ground. Changes in cadmium and zinc concentrations at KV-118 did not correlate with those at KV-111. At KV-111, cadmium and zinc concentrations were highest in April, then declined through the year. Concentrations observed at KV-111 (median 0.000065 mg/L total cadmium and 0.014 mg/L dissolved zinc) were significantly lower than those observed downstream at KV-21 (median 0.012 mg/L total cadmium and 1.1 mg/L dissolved zinc), reflecting the contribution of the No Cash 500 adit discharge to KV-21. Peak concentrations of total cadmium were normally observed in May and October at KV-21. The highest dissolved zinc concentrations were generally observed in the fall at KV-21.

Natural attenuation of cadmium and zinc via co-precipitation with and sorption on iron and manganese (oxyhydr)oxides along the reach of No Cash Creek serves to lower concentrations of cadmium and zinc such that they approach their respective CCME guidelines towards the terminus of No Cash Creek (ITL, 2013).



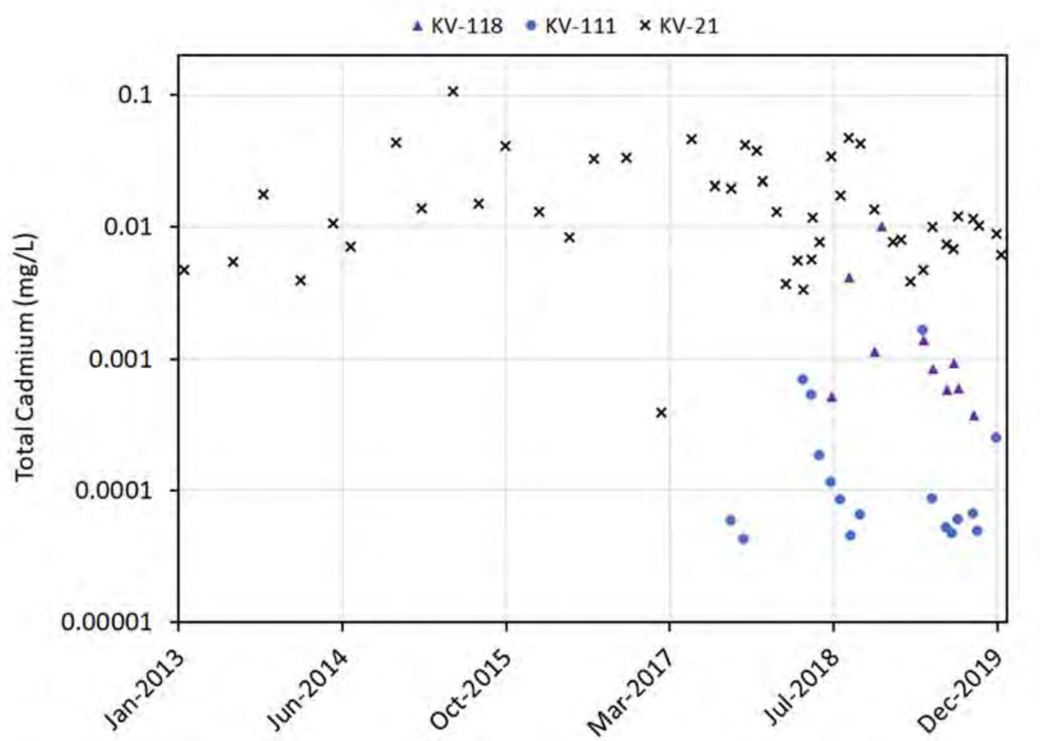


Figure 4-11: **Total Cadmium and Dissolved Zinc Concentrations in No Cash Creek**

4.2.2 MAYO RIVER DRAINAGE

4.2.2.1 Lightning Creek Catchment

Lightning Creek is a mountainous alpine stream flowing within a narrow valley with a steep gradient from the north side of Sourdough Hill into Duncan Creek, which drains into the Mayo River. Historically several mines have been in operation in the Lightning Creek catchment of which the Keno 700 adit is the primary source of metal load. Habitat within Lightning Creek is heavily impacted by historical and ongoing placer mining activities that have been active on the stream and its tributary, Thunder Gulch, since the 1960s. Placer mining operations have had a significant effect on water quality with respect to suspended solids.

Of the AKHM components, the Bellekeno 625 WTP pond decant (KV-43) and Flame & Moth WTP effluent discharged to Lightning Creek (KV-104LC) are currently regulated under the Type A Water Licences (QZ09-092-2).

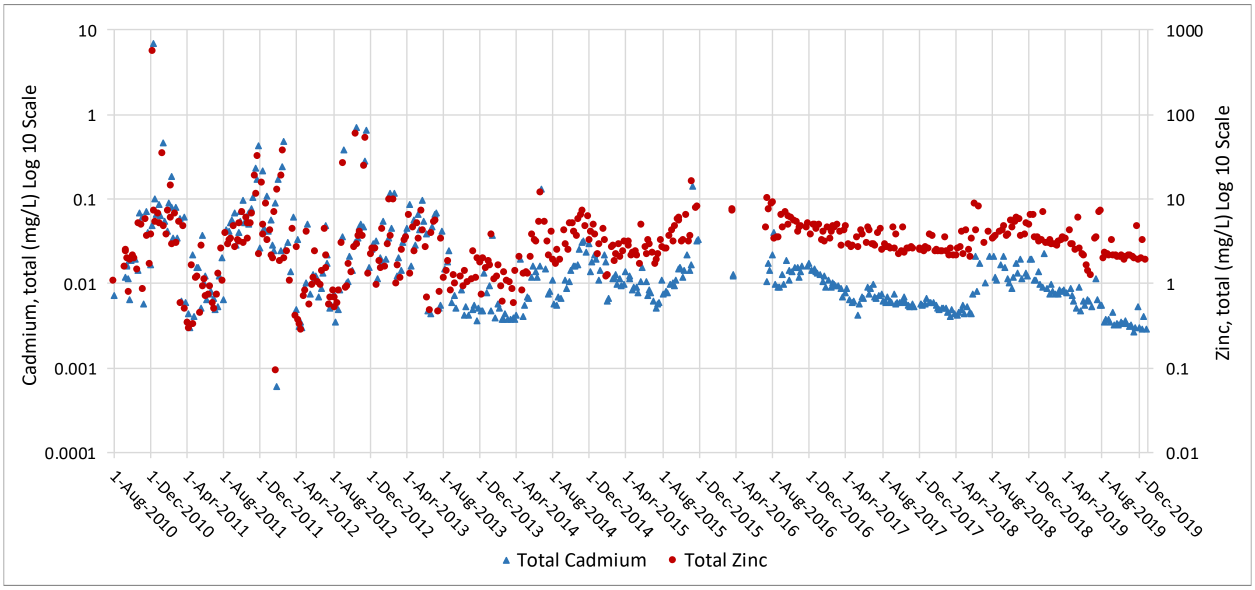
Bellekeno WTP

The Bellekeno mine site is near the confluence of Thunder Gulch with Lightning Creek, on the north side of Sourdough Hill. Thunder Gulch flows into Lightning Creek roughly 300 m down the hill from the Bellekeno Treatment Facility. Bellekeno 625 WTP decant water is discharged east of the treatment facility and reports to ground, eventually flowing via a diffuse surface pathway into Lightning Creek, downstream of Thunder Gulch.

In the fall of 2015 infrastructure was removed from the 900 level of the Bellekeno Mine to allow the 900 level working to flood up to the 800 level. Flooding of the 900 level workings began in November 2015, therefore, no discharge from the mine occurred for several months. In early July 2016, groundwater reached the 800 level and water was once again pumped to surface and treated as required, with treated effluent discharge starting up again July 8, 2016.

Discharge at the Bellekeno portal has been monitored since at least 1984, with consistent records beginning in 2006. Zinc and cadmium concentrations co-vary in the Bellekeno 625 adit discharge (Figure 4-12), reflecting a common source (likely sphalerite). Of the EQS-regulated parameters, zinc has the highest concentrations ranging between 1 and 10 mg/L (EQS of 0.5 mg/L) since the suspension of mining operations in the fall of 2013. Over the same period, total cadmium concentrations have typically remained comparable with or below the EQS (0.01 mg/L; Figure 4-12).

Total zinc concentrations and pH of the treated decant water at Bellekeno are shown in Figure 4-12. Total zinc concentrations in the treated decant have typically remained well below the EQS (0.5 mg/L). Occasional marginal exceedances (e.g., November 24, 2015, January 17, 2017, October 31, 2019) were related to elevated particulates in the sample or power outages resulting in the suspension of lime addition.



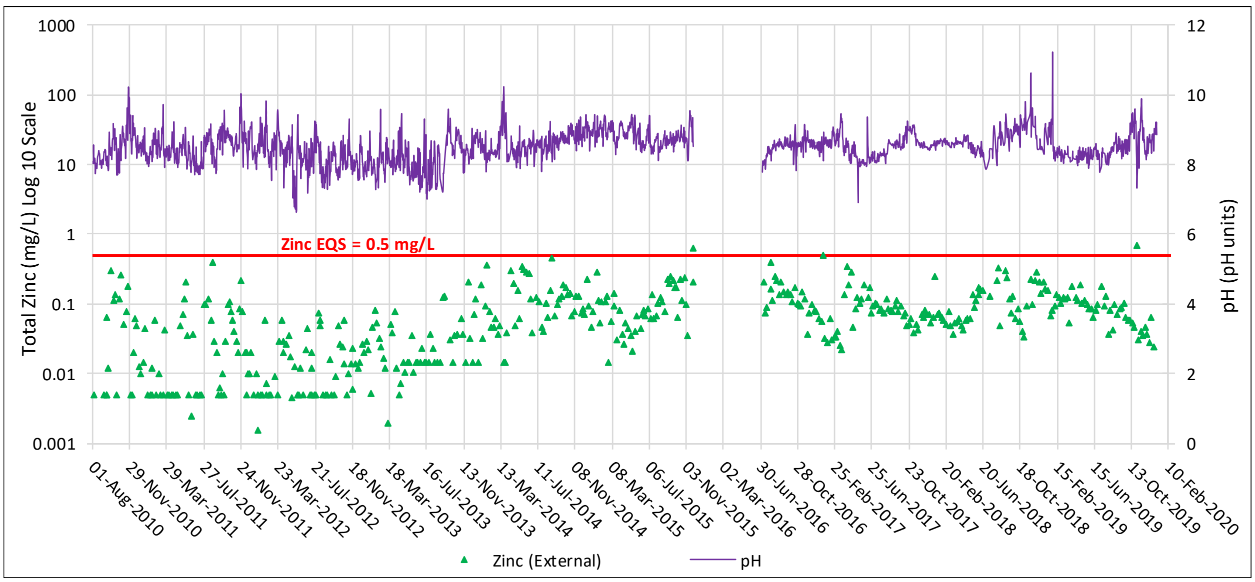


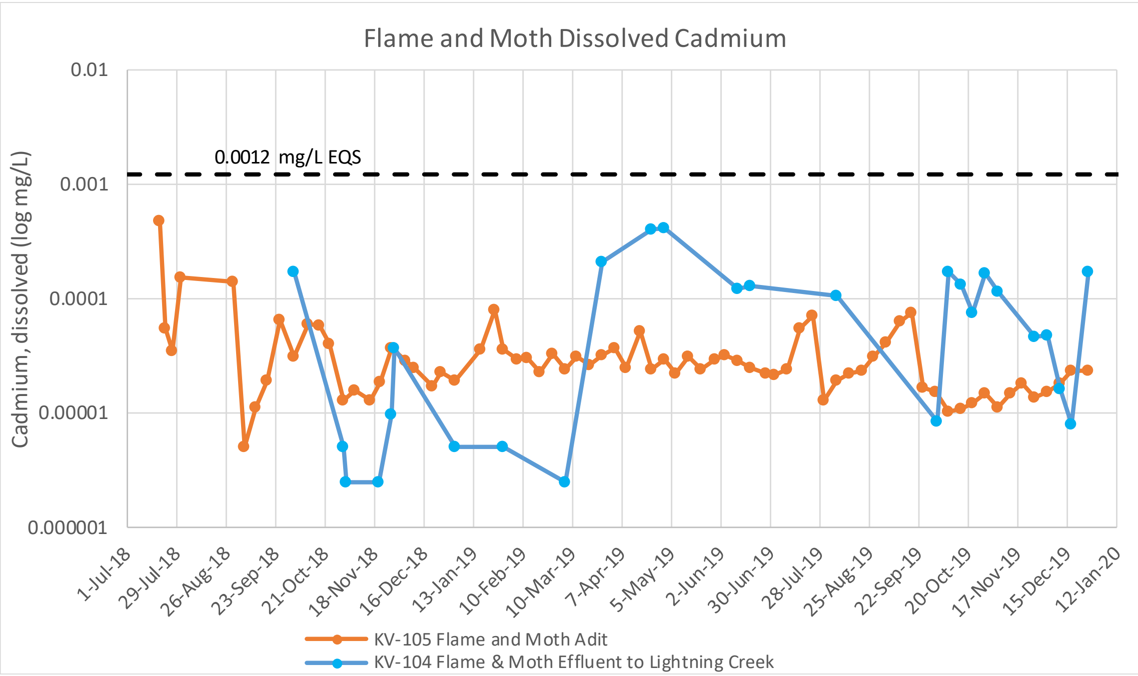
Figure 4-12: Untreated Total Cadmium and Zinc Concentrations in the Untreated Bellekeno 625 Adit Discharge (top) and Treated Bellekeno 625 WTP Decant pH and Zinc Concentrations (bottom)

Flame & Moth WTP

The Flame & Moth water treatment system can discharge to Christal Creek or Lightning Creek. The EQS for each watershed are further defined by the discharge rate, with four ranges identified in Part D, Clause 42 and 43 of Water Licence QZ09-092.

In July and August 2018, the first Flame and Moth adit (KV-105) samples were collected with discharge going to the water management ponds. Effluent discharge occurred periodically to the Lightning Creek watershed

(<10 L/s), with none directed to the Christal Creek watershed in 2018 and 2019. Dissolved cadmium and zinc concentrations in the adit discharge typically ranged between 0.00001 and 0.0001 mg/L cadmium and 0.02 to 0.1 mg/L zinc and were typically below their respective EQS prior to treatment (Figure 4-13).



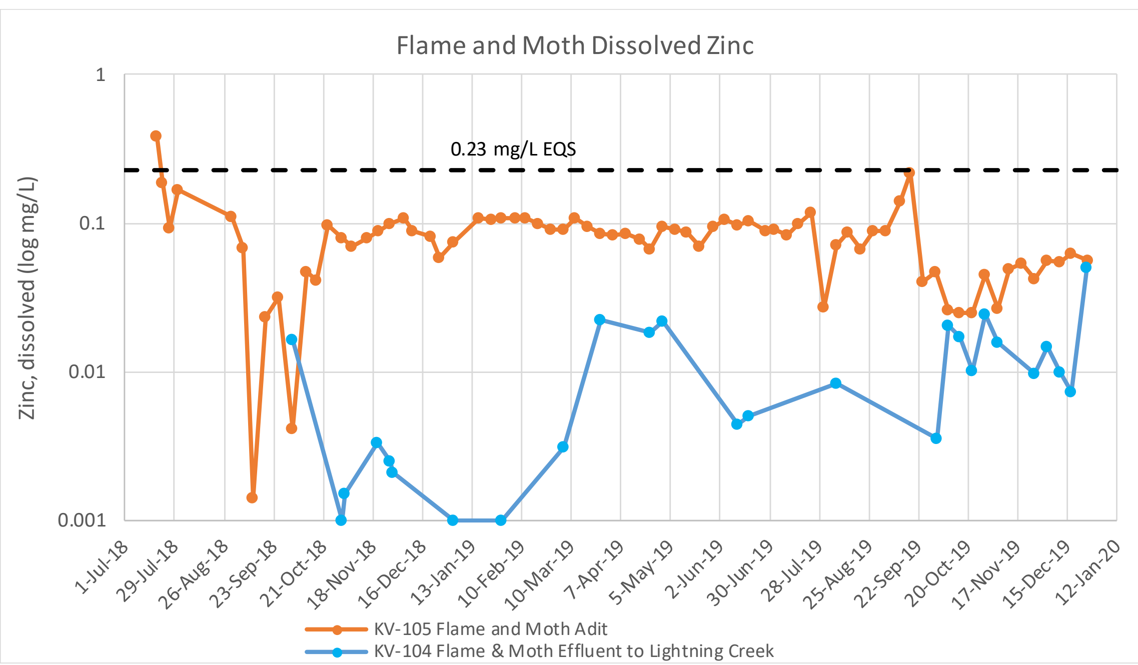


Figure 4-13: Dissolved Cadmium and Zinc Concentrations in Flame & Moth Discharge

Lightning Creek

There are nine regularly monitored sites under QZ09-092 within the Lightning Creek catchment, of which the cadmium and zinc concentrations in samples collected from stations located on Lightning Creek and Thunder Gulch are discussed herein. Of relevance to the AKHM operations are stations:

- KV-37, located upstream of AKHM and historical mine inputs and represent background concentrations (although placer mining has occurred upstream in recent years);
- KV-38 located on Lightning Creek downstream of input from the historical Keno 700 adit and upstream of the AKHM Bellekeno and Flame & Moth WTP discharges;
- KV-41 located on Lightning Creek downstream of the Bellekeno WTP discharge and upstream of the Flame & Moth WTP discharge; and
- KV-81 located on Lightning Creek downstream of both the Bellekeno and Flame & Moth WTP discharges.

Time series of total cadmium and dissolved zinc concentrations at each site in the Lightning Creek catchment are shown in Figure 4-14. The CCME cadmium guideline is hardness-dependent; for reference, the CCME guideline displayed in Figure 4-14 is the calculated based on the median hardness for all samples (KV-37, KV-38, KV-41, KV-65, KV-76, KV-81) collected in the Lightning Creek catchment (106 mg/L). Similarly, the CCME dissolved zinc guideline is hardness, pH and DOC dependent. For reference, the CCME guideline displayed in Figure 4-14 is calculated based on the median hardness, pH and DOC for all samples (KV-37, KV-38, KV-41, KV-65, KV-76, KV-81) collected in the Lightning Creek catchment (106 mg/L, pH 7.75 and 0.965 mg/L, respectively).

The median total cadmium concentration was lowest at the sites upstream of mine inputs (i.e., KV-37, 0.000011 mg/L and KV-65, 0.00006 mg/L). The highest median cadmium concentrations were observed at KV-76 (0.00014 mg/L) and KV-38 (0.00013 mg/L). KV-38 had the second highest median total cadmium concentration within the Lightning Creek catchment due to load contributions from the upstream untreated Keno 700 adit. Of the samples collected at KV-38, 41% exceeded the CCME PAL guideline compared to 11% at KV-37, located upstream of the Keno 700 adit contribution in lower Lightning Creek. Similarly, the median dissolved zinc concentration observed at KV-38 (0.0114 mg/L; 42% samples exceeded CCME PAL) was highest, whereas the median dissolved zinc concentration observed farther upstream at KV-37 (0.0021 mg/L; 9% samples exceeded CCME PAL) was the lowest within the entire catchment. CCME PAL exceedances were normally observed in May during freshet, coincident with the lowest hardness levels and therefore lower hardness dependent calculated CCME PAL guideline. That KV-38 generally returned the highest dissolved zinc concentrations is due to the Keno 700 adit discharge, which contains elevated zinc (median 1.6 mg/L) and flows into Hope Gulch, which in turn discharges to Lightning Creek just upstream of KV-38.

At Thunder Gulch, the median total cadmium concentration at KV-76 (0.00014 mg/L) was approximately double that observed at KV-65 (0.00006 mg/L). CCME PAL exceedances for total cadmium were commensurately higher at KV-76 (49% of samples) than KV-65 (26%). The trends in total cadmium concentrations gradually increased at both sites throughout the years, perhaps due to ongoing placer mining activities at Thunder Gulch. Most of the exceedances the Thunder Gulch sampling locations occurred through May to July, which coincides with spring freshet and periods when placer mining is active on Thunder Gulch.

The median dissolved zinc concentration at KV-65 was 0.0028 mg/L (4% samples exceeded CCME PAL) and increased moving downstream at KV-76 (0.0057 mg/L; 18% samples exceeded CCME PAL)). Most of the exceedances occurred May to August. Seasonal variations also occurred with peak concentrations observed during the same period.

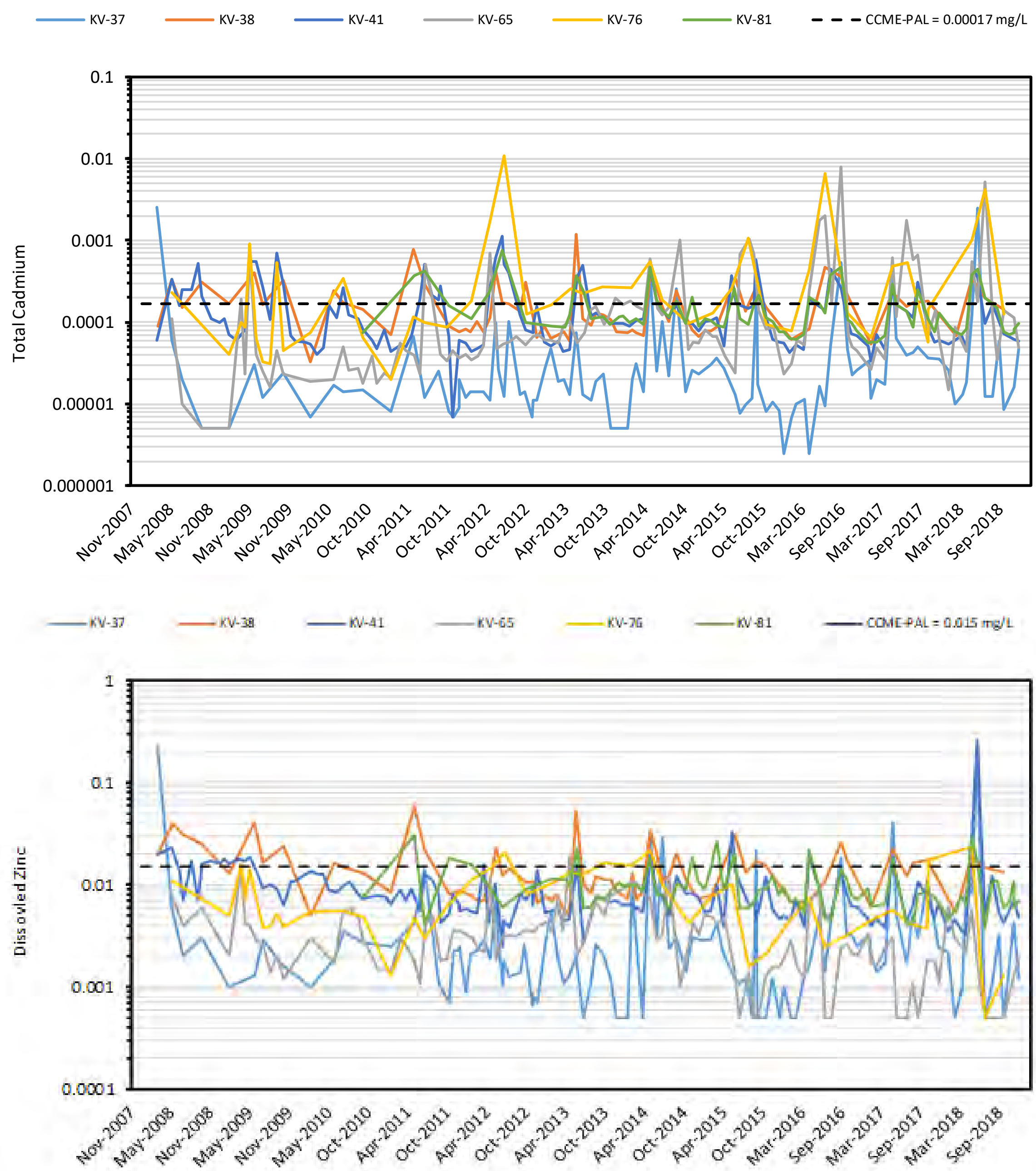


Figure 4-14: Cadmium and Zinc Concentrations (in mg/L) in Lightning Creek and Thunder Gulch (KV-65 and KV-76)

KV-41 and KV-81 had 33% and 30% of samples that exceeded the cadmium CCME PAL guideline, respectively. Total cadmium concentration at KV-41 and KV-81 were generally similar with exceedances and annual peaks occurring May to September. At lower Lightning Creek, KV-81 had the second highest median dissolved zinc concentration (0.0080 mg/L) of the catchment and 14% of samples exceeded the CCME PAL dissolved zinc guideline. The median dissolved zinc concentration was slightly decreased moving farther upstream at KV-41 (0.0073 mg/L). KV-41 had 15% of samples exceeded the CCME PAL dissolved zinc guideline. Dissolved zinc concentration at KV-41 and KV-81 were similar with annual peaks normally occurring in May (during freshet). Overall, discharge from the Flame & Moth WTP to Lightning Creek in 2018 and 2019 does not appear to have materially changed cadmium and zinc concentrations in Lightning Creek.

It should be noted that the median dissolved cadmium concentrations were generally lower than the median total cadmium concentrations within the Lightning Creek catchment, suggesting that the cadmium in this catchment had a significant particulate component. This reflects the influence of placer mining activities and associated raised TSS levels, which in turn result in elevated total cadmium concentrations. The number of dissolved cadmium samples that exceeded the CCME PAL cadmium guideline were greatly reduced at each site (i.e., 1% of samples exceeded the guideline at KV-65, 27% of samples exceeded the guideline at KV-76, 8% of samples exceeded the guideline at KV-37, 37% of samples exceeded the guideline at KV-38, 10% of samples exceeded the guideline at KV-41 and KV-81). These exceedances were mostly observed through May to September like the trend of total cadmium concentrations. The generally higher cadmium concentrations observed in spring and summer likely reflect the influence of both spring freshet and placer activity, both of which can raise the particulate content of downstream waters.

5. GROUNDWATER

5.1 GROUNDWATER CONDITIONS

Extensive groundwater studies have been conducted throughout the KHSD, which include reasonably extensive mapping of the geology and mine development in the KHSD, hydrogeological investigations, ongoing monitoring, as well as a Conceptual Model and Preliminary 3D Groundwater Model (Piteau, 2016) that also includes preliminary particle tracking to map the potential groundwater flow paths from historical mine workings.

Regionally, the District groundwater flow regime is controlled by (1) topography, (2) hydraulic characteristics of the local geologic units, and (3) natural infiltration of meteoric water (recharge), particularly in the hills that comprise the KHSD. The water table is generally a muted image of the overlying topography so that groundwater flow directions are similar to the regional ground slopes. Groundwater flow divides are interpreted to coincide with the major watershed divides. Groundwater migrates from highland areas (where most recharge occurs) towards lowland areas where groundwater discharges to perennial streams. Groundwater flow is concentrated in higher permeability geologic materials, which include overburden (where present) and shallow bedrock (which tends to be more fractured).

Locally, the regional groundwater flow characteristics can be altered by the presence of higher permeability rock discontinuities (faults, fracture zones, mineralized veins) and underground mine workings. It is common for underground mine workings to operate as hydraulic sinks so that groundwater inflows are conveyed through the workings to adit portals where the collected groundwater is discharged to surface water (Piteau, 2016). Adit discharges can be significant for underground workings that intersect permeable faults or are located below open mine pits that collect surface runoff/snowmelt and convey this water into the subsurface. Some underground workings collect groundwater at upgradient locations, convey this water through the workings, and then recharge the groundwater system at downgradient locations without adit discharges.

The regional groundwater flow system results in perennial streams that are gaining (receiving groundwater discharge) along most of their lengths. An exception to this occurs along Lightning Creek south and west of Keno City. Along this reach, Lightning Creek is a losing stream that recharges the groundwater system north of the Creek.

The groundwater monitoring well locations for the proposed and existing KHSD mine operations are described by the catchments in Table 5-1, and the locations of the wells are shown on Figure 5-1 to Figure 5-5.

Groundwater flow is concentrated in higher permeability geologic materials, which include overburden (where present) and shallow bedrock (which tends to be more fractured).

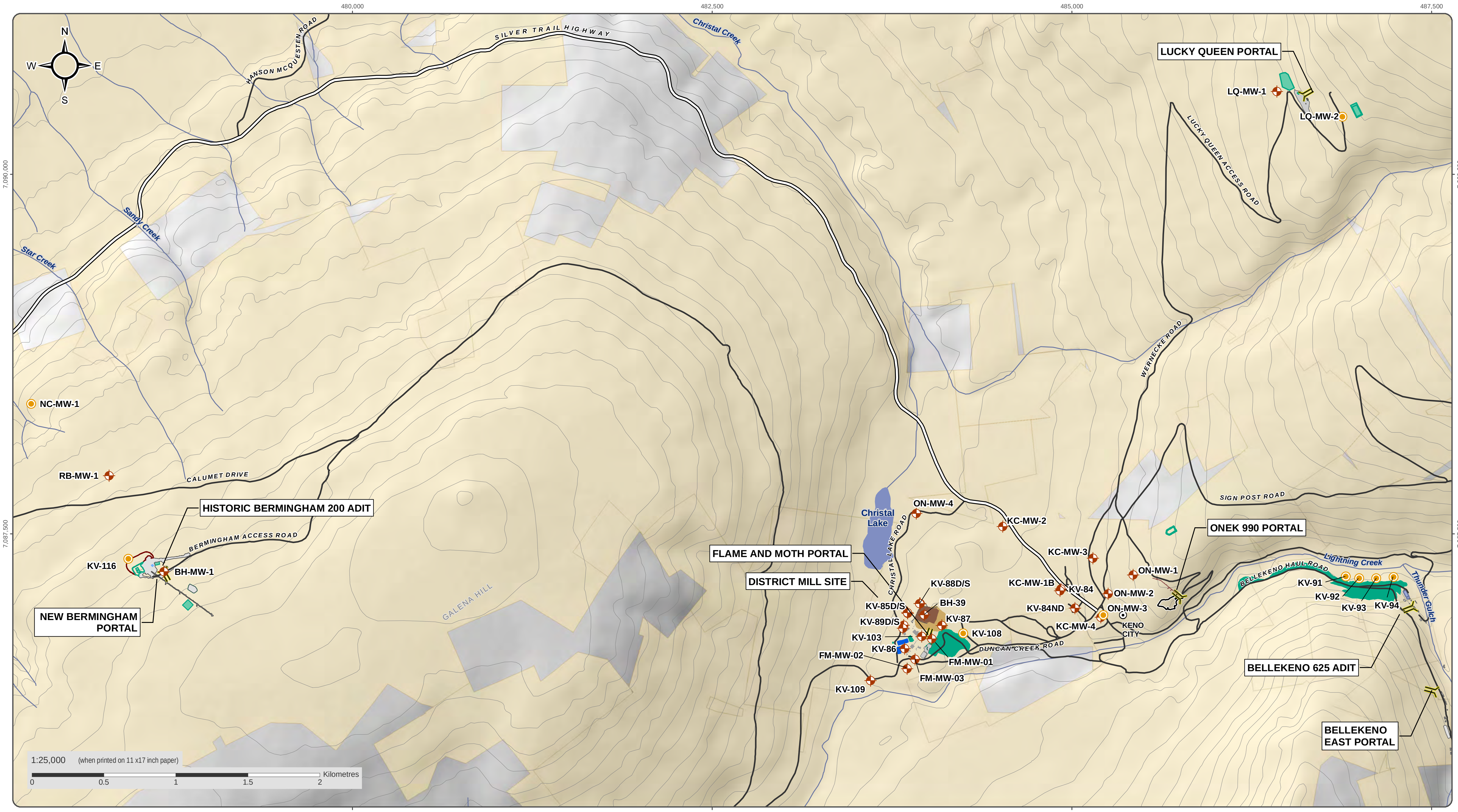
Table 5-1: KHSD Groundwater Monitoring Well Network

Site	Description	Total Depth (m)	Screen Length (m)	Geology/lithology of screened interval	Monitoring Date Range
BH-MW-1	Well d/g of the historic Bermingham 200 Adit	21.34	3.0	Graphitic Schist/Quartzite	September 2013 – Present
RB-MW-1	Well d/g of the Ruby 400 Adit and WRSA	13.41	3.0	Gravel, Sand, Silt and Cobble/Graphitic Schist	September 2013 – Present
NC-MW-1	Proposed Well u/g of the NC 500 Adit	TBD	TBD	TBD	TBD
KV-116	Proposed new Bermingham Waste Rock Disposal Area	TBD	TBD	TBD	TBD
KV-84ND	Bedrock well on Keno Firehall lot to replace KV-84	88.39	12.0	Graphite/Schist/Quartzite/Muscovite/Sericite Schist/Pyrite	2013 to present
KV-85D	DSTF and Mill Site Groundwater Well #1 (PH2) Deep	42.7	3.0	Bedrock	2010
KV-85S	DSTF and Mill Site Groundwater Well #1 (Shallow)	4.03	1.5	Gravel and Silt	October 2011 - Present
KV-86	DSTF and Mill Site Groundwater Well #2 (PH5)	36	3.0	Fine gravel and coarse sand	2010 - Present
KV-87	DSTF and Mill Site Groundwater Well #3 (PH6)	57.9	3.1	Bedrock	2010 - Present
KV-88D	DSTF and Site Groundwater Well #4 (Deep)	50.1	15	Bedrock	October 2011 - Present
KV-88S	DSTF and Mill Site Groundwater Well #4 (Shallow)	4.11	1.5	Sand/Gravel/Silt/Bedrock	October 2011 - Present
KV-89D	Flame and Moth Site Groundwater Well #5 (Deep)	38.3	10	Bedrock	October 2011 - Present
KV-89S	DSTD and Mill Site Groundwater Well #5 (Shallow)	4.8	1.5	overburden	October 2011 - Present
KV-103	Mill Supply Well	82.3	n/a	Sand with Gravel/Glitstone (Shale)	November 2015 - Present
KV-107	Proposed DSTF expansion area	TBD	TBD	TBD	TBD

Site	Description	Total Depth (m)	Screen Length (m)	Geology/lithology of screened interval	Monitoring Date Range
KV-108	Proposed Upgradient of DSTF expansion area	TBD	TBD	TBD	TBD
BH39	Phase I of DSTF	7.5	7.5	Tailings	2012 - present
FM-MW-1[a]	Flame and Moth Well #1 (KAR-01)	182.3	12.2 12.2	Quartzite/Schist/Graphite Schist/Sericite Schist Greenstone/Mineralized Vein	August 2013 - Present
FM-MW-2[a]	Flame and Moth Well #2 (KAR-02)	244.4	12.2 12.2	Quartzite Quartzite/Stringer Zone	August 2013 - Present
FM-MW-3	Flame and Moth Well #3 (KAR-16)	195.7	12.2	Quartzite/Graphics Schist	September 2013 – Present
KC-MW-4	Well south of Onek 400 adit	82.3	2.2	Gravel/Sand/Boulder/Cobble	
ON-MW-2	Onek Monitoring Well #1 d/g Project Facilities	66.3	6.0	Bedrock/quartzite/graphitic schist	August 2012 - Present
ON-MW-3	Proposed Well south of Onek 400 adit	TBD	TBD	TBD	TBD
LQ-MW-1	Lucky Queen Monitoring Well d/g N-AML WRDA	23	6.1	Quartzite/Sericite Schist/Graphitic Schist/Chlorite-sericite schist	August 2012
LQ-MW-2	Proposed Lucky Queen Monitoring Well d/g N-AML WRDA	TBD	TBD	TBD	TBD
KV-109	Flame and Moth Lightning Creek Discharge area near KV-81	27.6	3.1	Schist/Quartzite	July 2018 - Present
KV-91	Proposed Bellekeno Waste Rock Disposal Area well #1	TBD	TBD	TBD	TBD
KV-92	Proposed Bellekeno Waste Rock Disposal Area well #2	TBD	TBD	TBD	TBD
KV-93	Proposed Bellekeno Waste Rock Disposal Area well #3	TBD	TBD	TBD	TBD
KV-94	Proposed Bellekeno Waste Rock Disposal Area well #4	TBD	TBD	TBD	TBD

*TBD – To be determined, these wells are proposed.

[a] These wells have two sections of screen. Screen lengths and lithology values are presented in order of upper screen and lower screen.



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

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- Proposed Monitoring Well
- Monitoring Well
- Adit
- Alexco/ERDC Quartz Claims
- As Built Mine Feature
- Pond
- DSTF 322k Tonnes Design
- Current DSTF
- To Be Constructed Features
- Silver Trail Highway
- Other Road

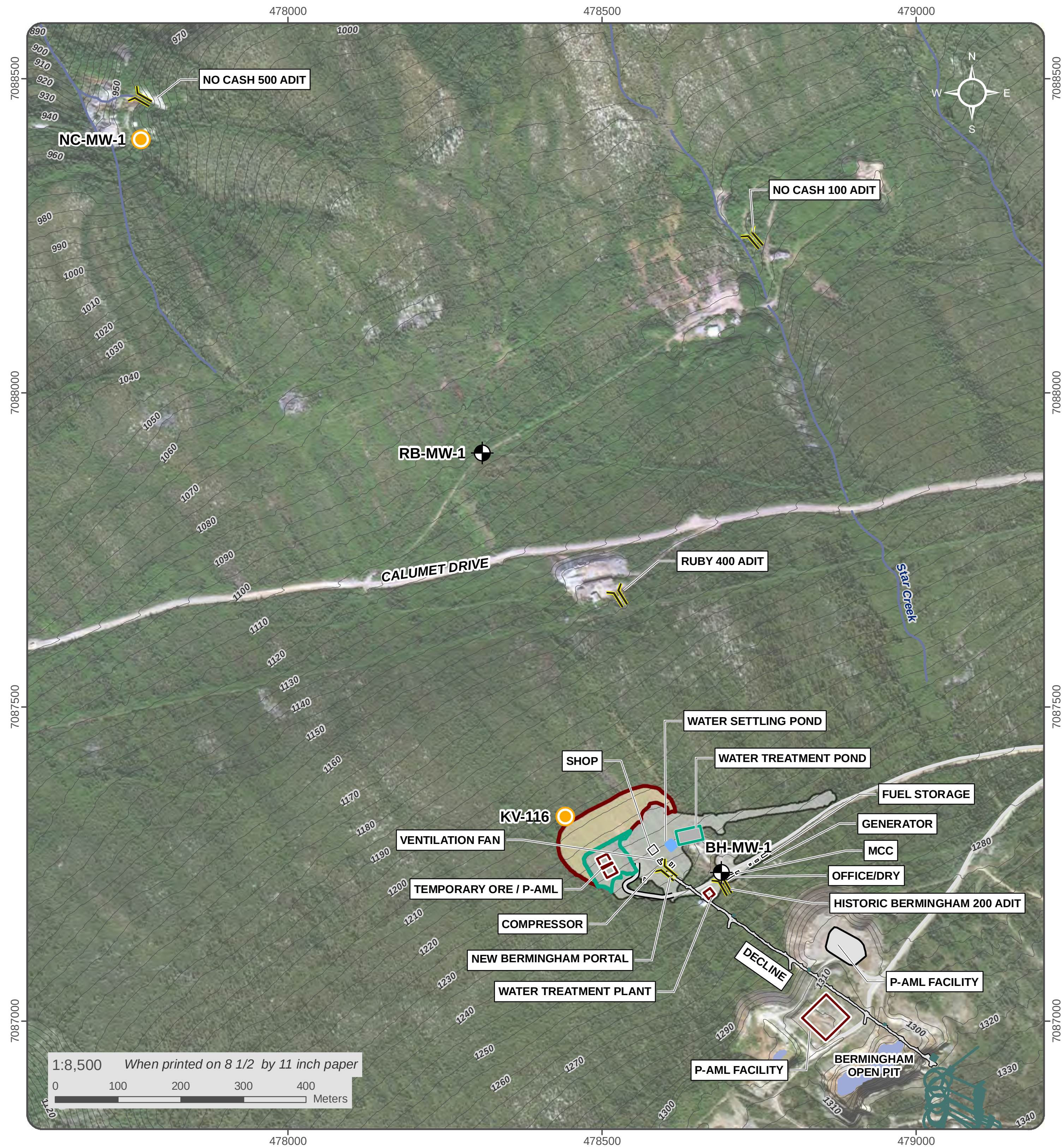
AKHM

AEG

ALEXCO KENO HILL MINING CORP.

FIGURE 5-1
KHSD GROUNDWATER MONITORING LOCATIONS

APRIL 2019



Adit/Portal

Proposed Monitoring Well

Monitoring Well

Permitted To Be Constructed Mine Features

Proposed Mine Feature

As Built Mine Feature

As Built Pond

Proposed Underground Workings

Contours (10m)

ALEXCO KENO HILL MINING CORP.

FIGURE 5-2
GROUNDWATER MONITORING LOCATIONS AT BERMINGHAM

APRIL 2019

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Aeral Imagery was obtained on September 2017 and June 2018
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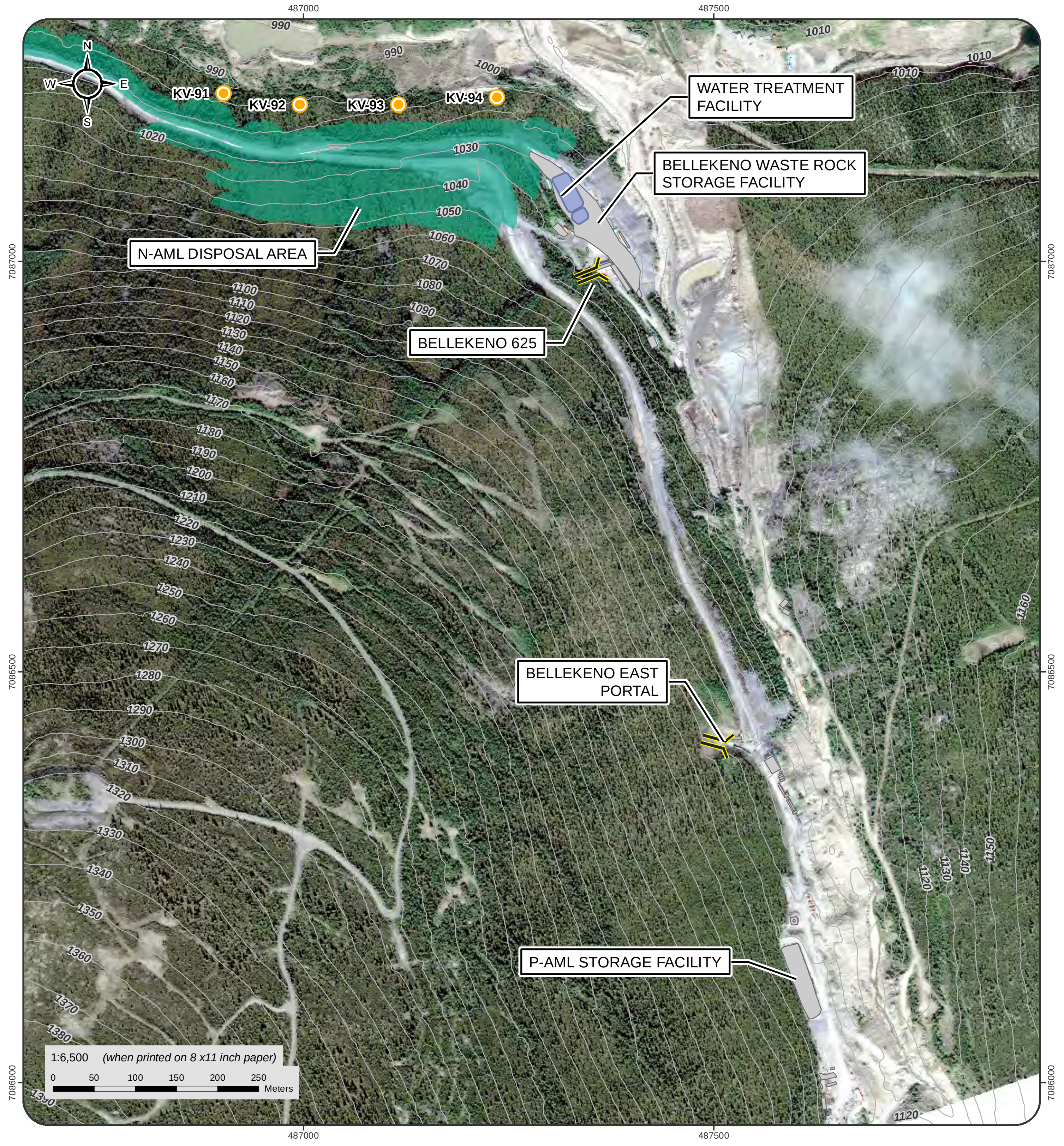

Adit

Proposed Monitoring Well

Permitted To Be Constructed Features

As Built Mine Features

Pond

Contours (10 m)

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on April 2019

Datum: NAD 83; Projection: UTM Zone 8N

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FIGURE 5-3 GROUNDWATER MONITORING LOCATIONS AT BELLEKENO

APRIL 2019

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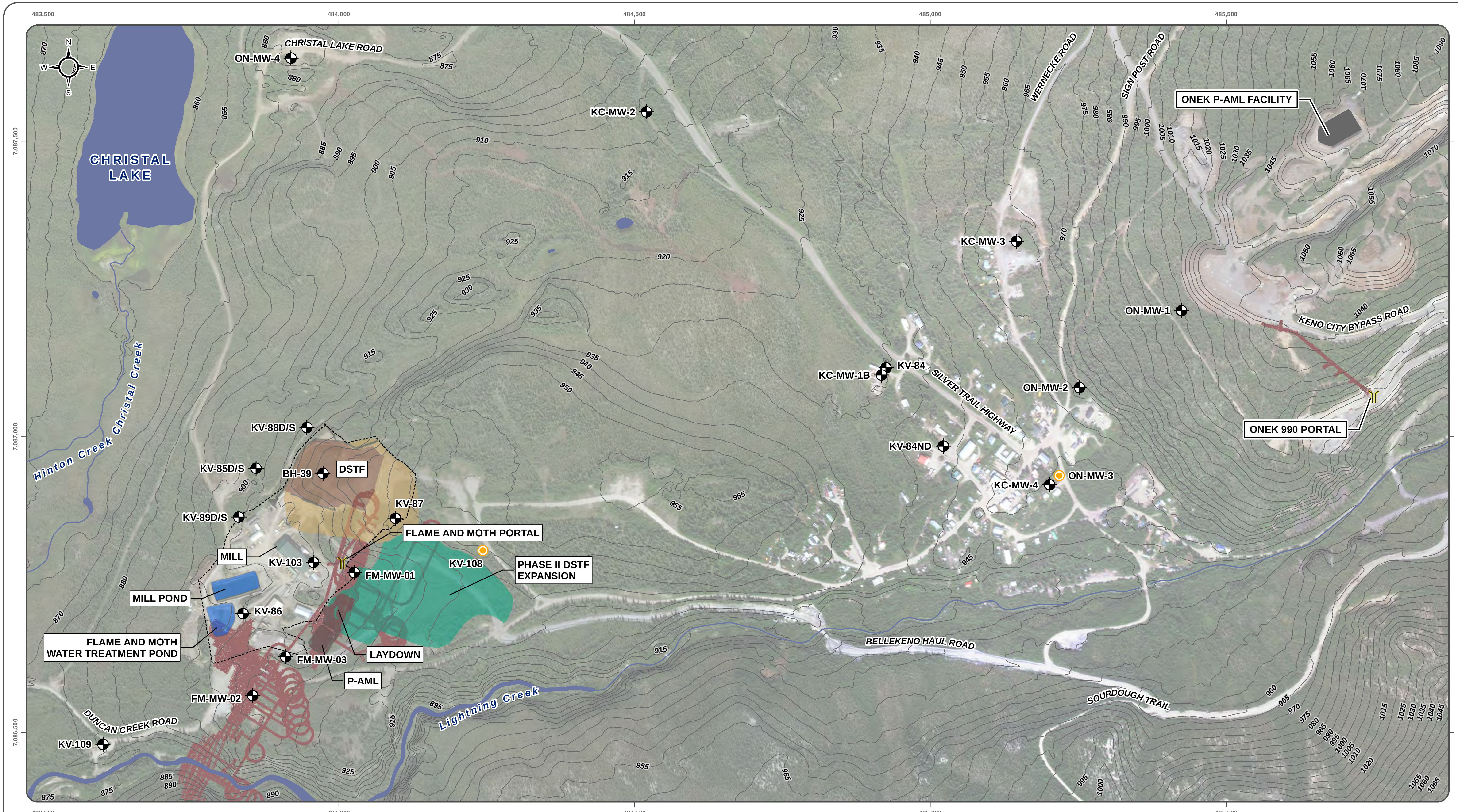

Satelite imagery obtained from ESRI Imagery map service http://goto.arcgisonline.com/maps/World_Imagery on April 2019

Datum: NAD 83; Projection: UTM Zone 8N

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1:6,000 *(when printed on 11 x17 inch paper)*

0 50 100 150 200 250 Meters

- Proposed Monitoring Well
- Monitoring Well
- Adit
- Underground Workings
- Infrastructure Footprint
- Pond
- DSTF 322k Tonnes Design
- Current DSTF
- Permitted To Be Constructed Features
- Waterbody
- Watercourse
- Contour (5m)

AKHM

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FIGURE 5-4

GROUNDWATER MONITORING LOCATIONS AT DISTRICT MILL SITE, FLAME AND MOTH, ONEK 990 AND KENO CITY

APRIL 2019

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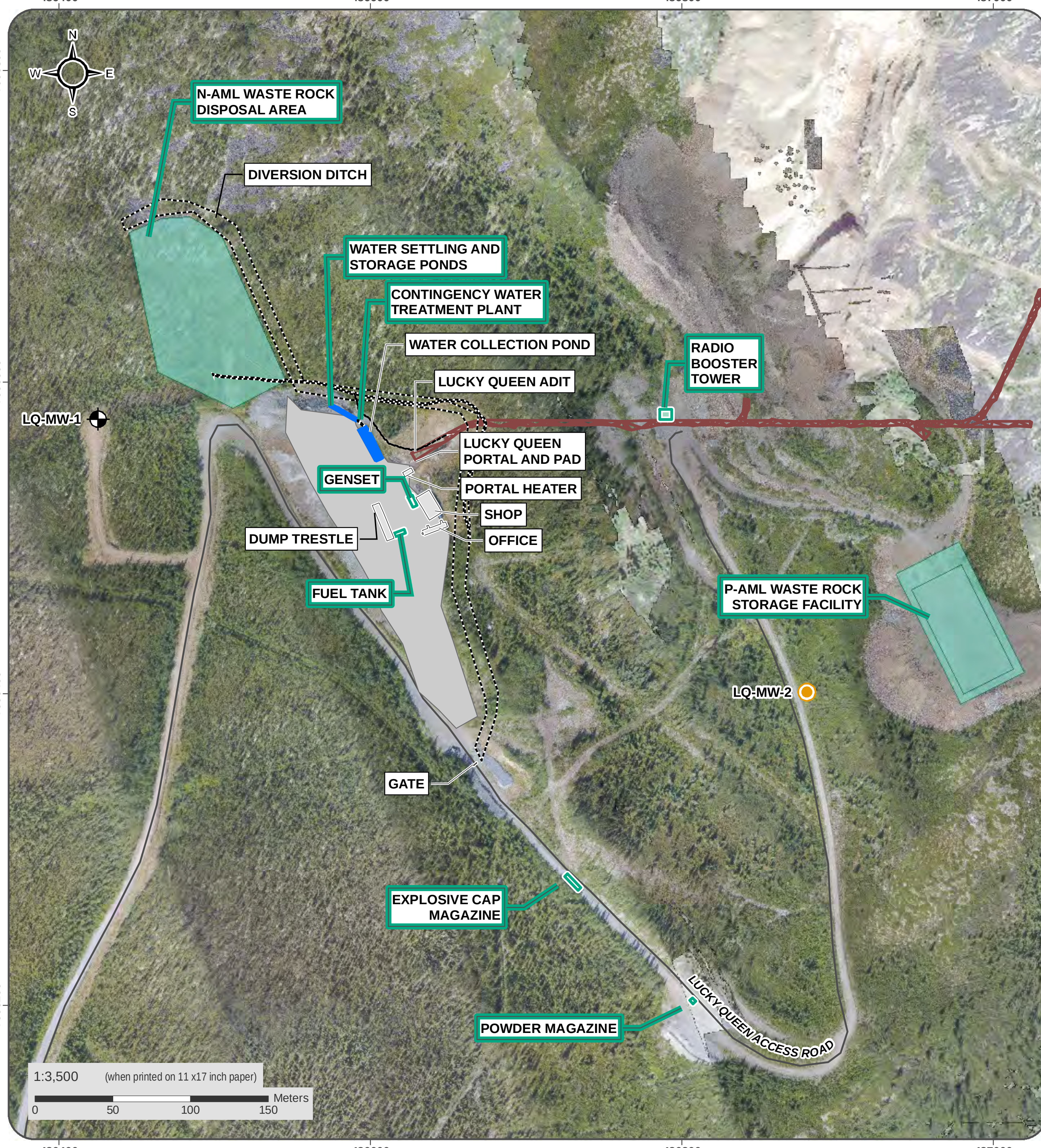

Proposed Monitoring Well
Monitoring Well
Existing Mine Workings
As Built Mine Features
Permitted To Be Constructed Features
Pond
Ditch/Pipeline
Other Road

Drone imagery acquired by AEG , August 2018
Datum: NAD 83; Projection: UTM Zone 8N

AKHM

AEG

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FIGURE 5-5
GROUNDWATER MONITORING LOCATIONS AT LUCKY QUEEN

APRIL 2019

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5.2 GROUNDWATER HYDROLOGY

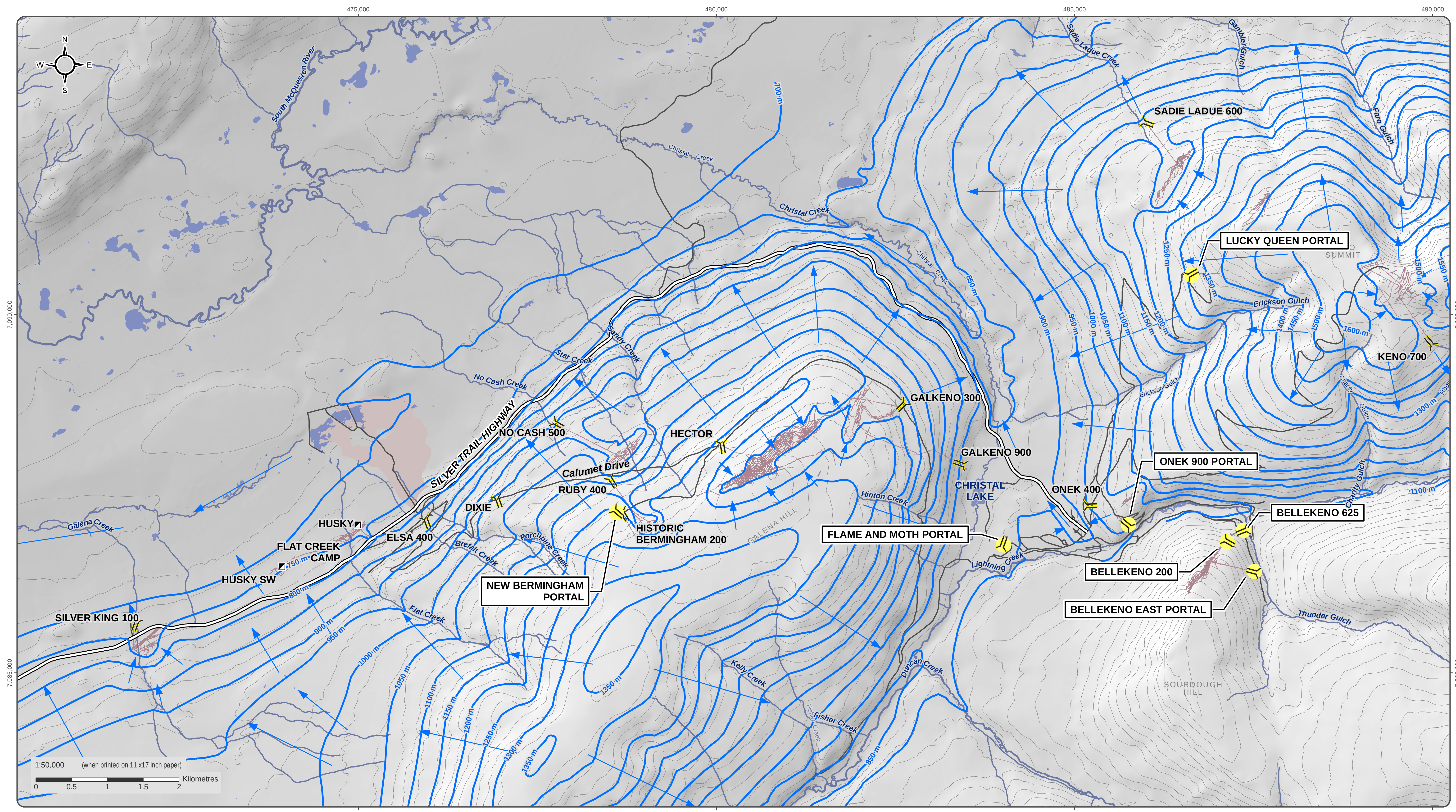
Characterization of the KHSD groundwater hydrology has been done conceptually, as well as through physical testing. Pumping tests and slug tests have been conducted on most of the wells installed throughout the District, and water level elevations are tracked manually and through a network of continuous loggers. This field data combined with the mapped geology is used to describe the expected flow paths and seasonal changes to the water table for each mine.

Additional characterization work was done around some mines where mine dewatering rates needed to be estimated. Air lift testing was conducted at the new Bermingham and Flame and Moth mine sites during drilling of new monitoring wells.

Figure 5-6 presents conceptual groundwater level contours and groundwater flow directions for Galena Hill. The contours were constructed so that: water levels were below ground surface; were at ground surface at streams in gullies; were consistent with measured water levels; and met with mine pool levels. Although the contours are conceptual in nature, they provide an indication of flow directions and the apparent catchment area of the various mines. The primary discharge areas illustrated are Flat Creek Valley, No Cash Creek, Star Creek Sandy Creek, Christal Creek Valley and Lightning Creek Valley.

Based on the contours, the gradients indicated range from 3% to 30%. Much of the groundwater is expected to migrate in the more permeable shallow bedrock and overburden. Typical velocities on the north and northwest side above an elevation of 950 m to 1150 m, are estimated to be 1 to 10 m/day in the sand and gravel overburden and 10 m/day to 100 m/day in the disturbed bedrock.

The groundwater entering the mine workings is sourced from meteoric recharge. This recharge is enhanced in some areas by open-pit workings that overlie underground workings, and waste dumps that reduce evapotranspiration. Some mine workings have caused noticeable deviations from natural groundwater flowpaths toward mine discharge areas, including Galkeno and Hector Calumet, Ruby, No Cash, and Silver King.



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Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on April 2019

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

- Adit
- Shaft
- AKHM Deposits
- Valley Tailings Area
- Underground Mine Workings
- Groundwater Flow Direction
- Groundwater Contour (50m Intervals)
- Waterbodies
- Watercourses
- Silver Trail Highway
- Secondary Road
- Contours (100 ft intervals)

* Only showing mine sites referenced in document

* * Depth to water table displayed in MASL when used for contour interpretation

ALEXCO KENO HILL MINING CORP.

FIGURE 5-6
GALENA HILL INFERRED GROUND WATER TABLE

APRIL 2019

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No Cash Creek

In 2016, Piteau Associates Engineering Ltd. (Piteau) conducted a preliminary groundwater model for the KHSD for Elsa Reclamation and Development Company Ltd. for mine reclamation. The preliminary model included particle tracking to determine probable groundwater flow paths from historic mine workings. The particle tracking indicates that regional groundwater derived from the Ruby, historic Bermingham, and No Cash Mine workings discharges downgradient between the lower reaches of Star Creek and Christal Creek (Piteau, 2016).

In October 2016 drilling and testing of two boreholes at new Bermingham were performed. After each hole was drilled, one or two airlift pumping tests were performed. After a period of sustained pumping, the airlift was discontinued, and time was allowed for water-level recovery in the borehole. The best-estimate hydraulic conductivities were calculated for the two boreholes and were found to be similar, providing evidence that the rock mass is relatively homogeneous with regard to hydraulic properties. The average of the calculated hydraulic conductivities is 4.3×10^{-6} cm/s, which is taken as the best-estimate of the large-scale (bulk) hydraulic conductivity for rock within the mine area. Based on the average hydraulic conductivities a portal discharge rate during closure was estimated to be 220 m^3/d (2.5 L/s).

Water levels are collected from the Ruby and new Bermingham groundwater wells. The well BH-MW-1 adjacent to the historic Bermingham 200 adit has been dry since October 2017, the July 2017 measurement, the lowest recorded since installation, shows the decline of the groundwater elevation due to the development of the Bermingham decline.

Water levels are collected from the Ruby and new Bermingham groundwater wells, the water levels are shown on Figure 5-7. The well BH-MW-1 adjacent to the historic Bermingham 200 adit has been dry since October 2017, the July 2017 measurement, the lowest recorded since installation, shows the decline of the groundwater elevation due to the development of the Bermingham decline.

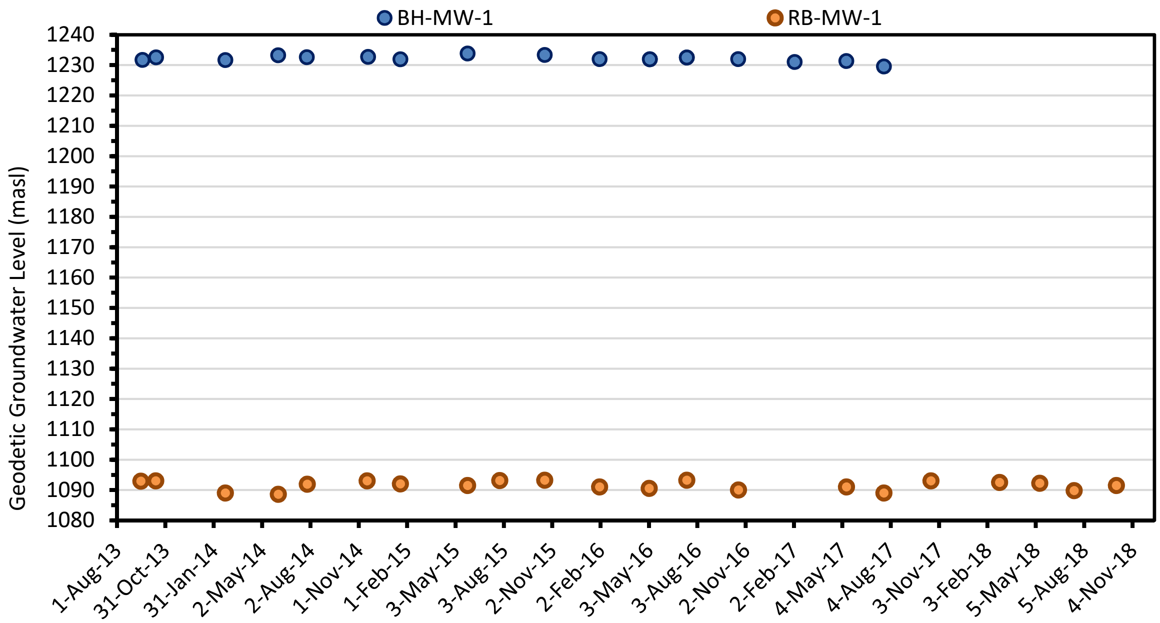


Figure 5-7: Groundwater Level (masl) in No Cash Creek Catchment Wells

Christal Creek

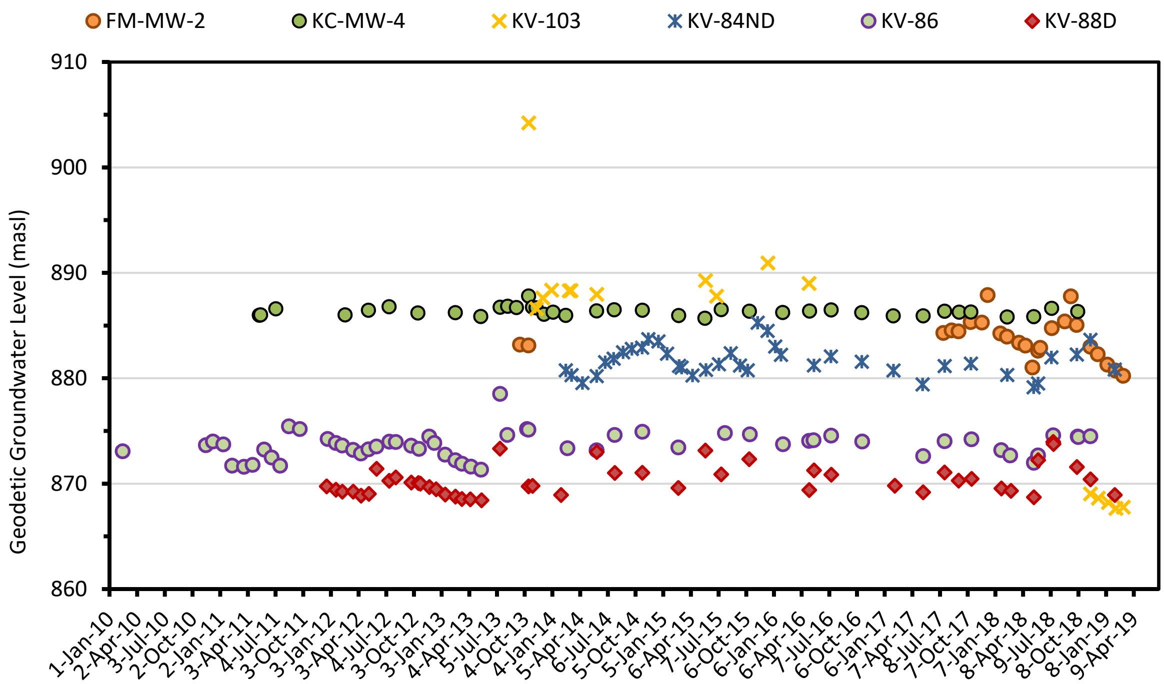
The 2016 preliminary groundwater modeling and particle tracking conducted by Piteau indicated that groundwater from the area of the historical Onek 400 mine workings would flow towards the upper reaches of Christal Creek (Piteau, 2016). The Keno City conceptual groundwater model conducted by Interralogic estimated from synoptic water level events that groundwater from the town flows northwest towards Christal Lake (Interralogic, 2012). Generally, groundwater flow converges in Keno City and flows to the northwest towards Christal Lake and Christal Creek. Groundwater in the vicinity of the historical Lucky Queen 500 Adit is also conceptually understood to flow down towards Christal Creek.

In August and September 2013, three deep monitoring wells (FM-MW-1, FM-MW-2 and FM-MW-3) were drilled and a 72-hr air lift pumping test was completed on FM-MW-1 to calculate the potential mine inflows for the Flame and Moth Mine. The maximum predicted flow rate for the Flame and Moth mine was conservatively calculated to be 3.0 x 10^3 m^3/d or 35 L/s. The conclusion of the dewatering estimations and conceptual model is that Flame and Moth Mine dewatering will not have a significant impact on surface water flows in Lightning Creek and it is highly unlikely that mine dewatering will have an effect on groundwater levels and the availability of water supply in the Keno City area.

A groundwater flow directional map for Keno City and the Keno District Mill area which is presented in Figure 5-9. These groundwater contours were created using water level measurements taken on the October 17, 2013. Generally, groundwater flows from Keno City to the North West towards Christal Lake or west towards Christal Creek. The groundwater flow direction for the Flame and Moth Mine is towards the North West in the direction of Christal Lake.

Figure 5-8 presents water level elevations for the bedrock wells in the District Mill area. Water elevations around the Keno District Mill have been recorded between ~865 to 900 masl. Generally, this equates to being approximately 20 m below ground surface. The groundwater elevation for the proposed Flame & Moth portal location has been estimated to be 888 masl from Figure 5-9, compared to the surface elevation of the portal at 910 masl (a difference of 22 m).

The groundwater levels follow a seasonal pattern, which was broadly observed at all sites. It was typically lowest in early May prior to the onset of freshet. Once snowmelt began, the groundwater levels rose due to increased recharge until around November, when progressive freezing over winter likely limited recharge and lowered groundwater levels.



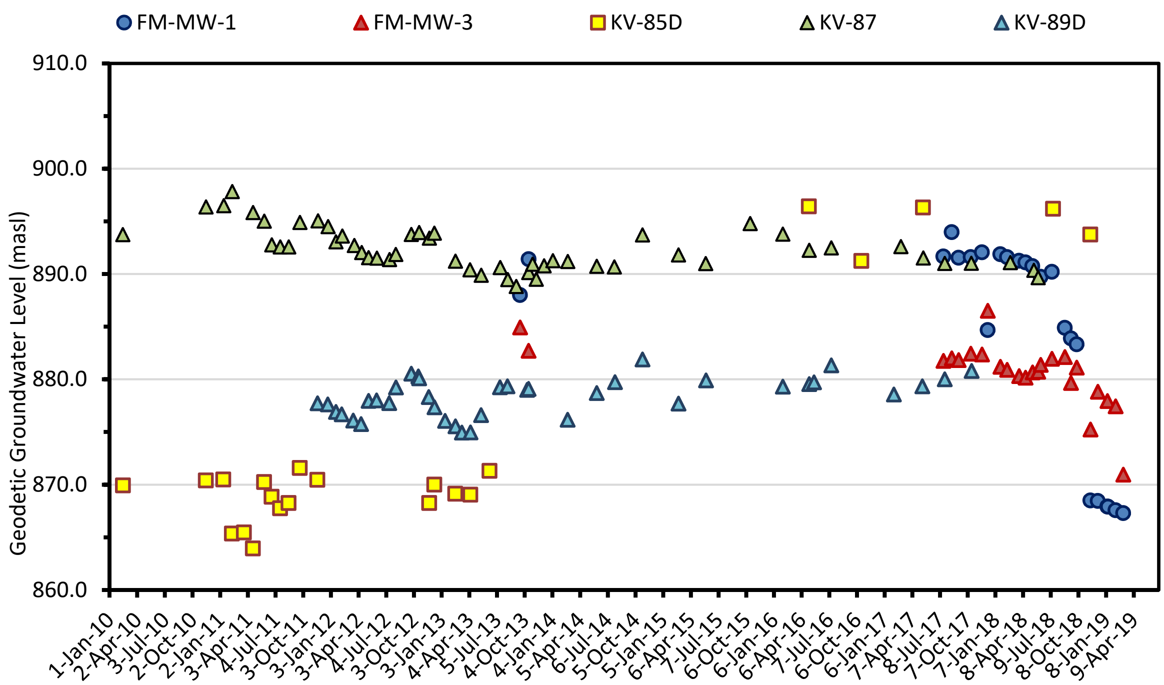
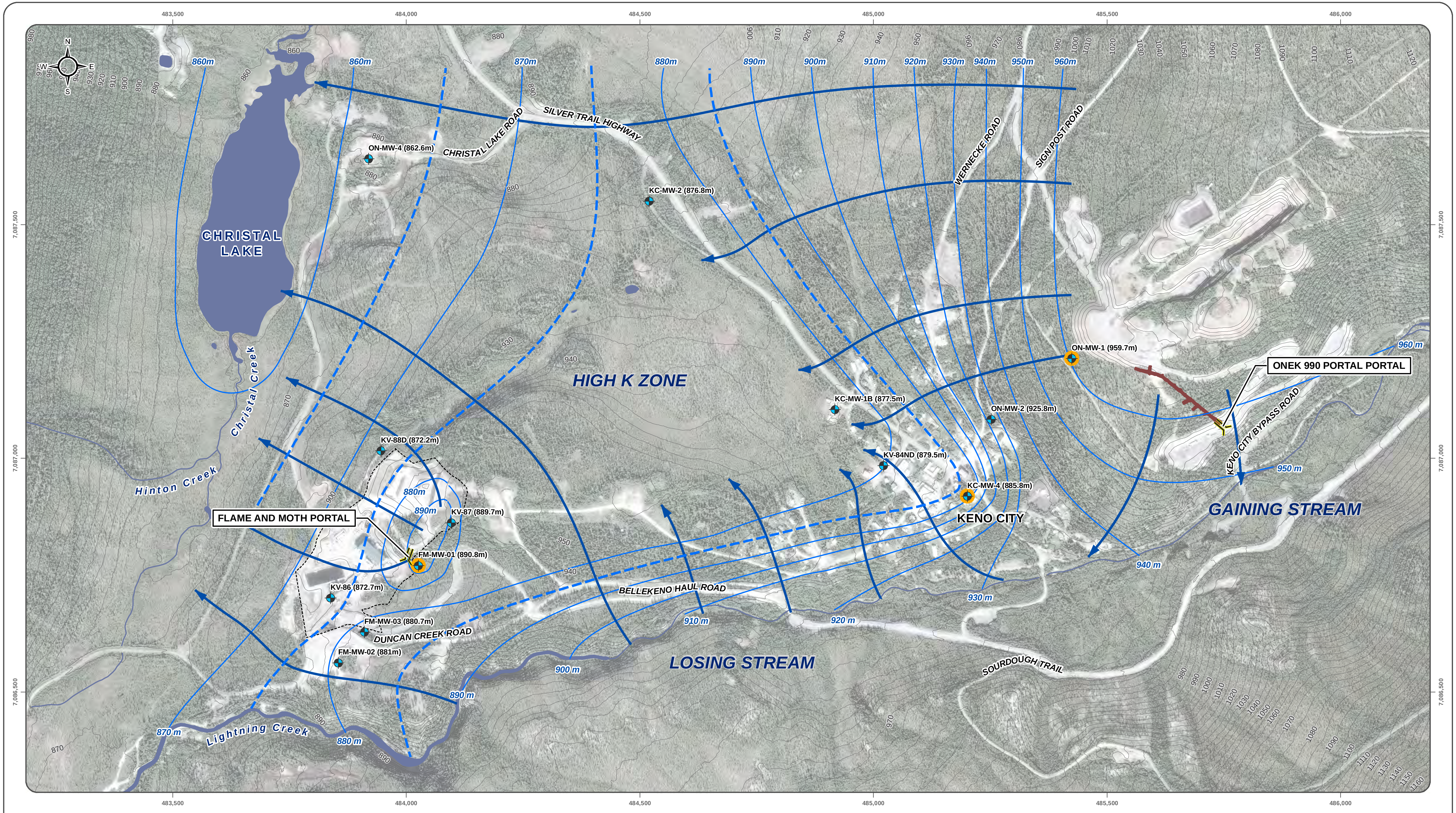


Figure 5-8: District Mill Area Groundwater Water Levels



Satelite imagery obtained from ESRI Imagery map service http://goto.arcgisonline.com/maps/World_Imagery on April 2019

Datum: NAD 83; Projection: UTM Zone 8N

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1:7,500 *(when printed on 11 x17 inch paper)*

0 100 200 300 400 Meters

- Adit
- Well (water levels measured May 28th, 2018)
- Water Level Measured May 9th or May 14th, 2018
- Groundwater Contour (5m)
- Groundwater Contour (10m)
- Groundwater Flow Direction
- Underground Workings
- AKHM District Mill
- Topo Contour (5m)
- Watercourse
- Waterbody

WATER ELEVATIONS ARE BASED ON GROUNDWATER DATA COLLECTED MAY, 2018

AKHM

AEG

ALEXCO KENO HILL MINING CORP.

FIGURE 5-9
KENO DISTRICT MILL SITE AND KENO CITY GROUNDWATER CONTOUR, MAY SAMPLING EVENT

APRIL 2019

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(*Last edited by: amatlashevska;16/04/2019/13:44 PM*)

Lightning Creek

In June 2018, a monitoring well (KV-109) was installed between Lightning Creek and the proposed Flame and Moth mine, to meet Clause 108 (c) of Water License QZ09-92-2. The KV-109 was subsequently pump-tested in July 2018 by a two-hour step-test. A best-estimate hydraulic conductivity of 1.3 x 10^{-4} cm/s was calculated for the well by relating flow rates to drawdown. Figure 5-10 presents water level elevations for KV-109.

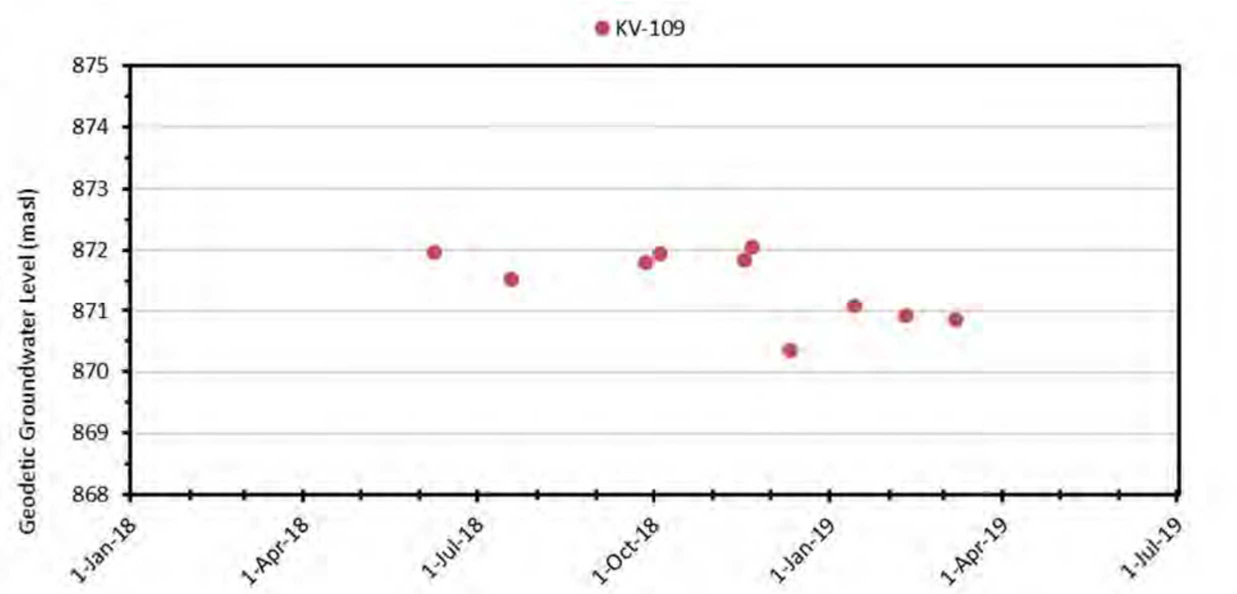


Figure 5-10: Lightning Creek Groundwater Levels

5.3 GROUNDWATER QUALITY

The groundwater monitoring well network (Table 5-1) is monitored for groundwater levels in addition to groundwater chemistry, with data available since 2010. Generally, the presence and behaviour of the parameters monitored within the KHSD wells, are related to:

- The occurrence of natural mineralization in the subsurface; and
- Differences in the prevailing local geochemical regime of the groundwater (e.g. reducing conditions).

Within KHSD observed elevated concentrations of indicator parameters cadmium and zinc are expected to be controlled by the local mineralization. Sphalerite is the primary source of zinc and cadmium in KHSD waters. As such, both elements showed a correspondence with dissolved sulphate such that elevated levels of dissolved zinc and cadmium typically coincided with high dissolved sulphate concentrations.

5.3.1 *NO CASH CREEK*

Adit discharge from both the historic Bermingham and Ruby adits are documented to infiltrate within a few hundred metres of their respective adit portals; however, there is no evidence that groundwater impacts water quality in No Cash Creek, upstream of the No Cash 500 adit. Indeed, No Cash Creek water sampled at station KV-111 located immediately upstream of the No Cash 500 adit typically has relatively low concentrations of cadmium (median 0.000065 mg/L) and zinc (0.012 mg/L), suggesting that any groundwater metal loading contribution to the upstream reach of No Cash Creek was minimal. Furthermore, extensive natural attenuation of cadmium and zinc concentrations has been documented by monitoring studies in No Cash Creek over the past two decades (ITL, 2013; Kwong et al., 1994; 1997), indicating that any nominal groundwater metal load would likely be sequestered along the reach of No Cash Creek by natural attenuation processes.

The dissolved cadmium, and zinc are presented in Figure 5-11 and Figure 5-12, respectively.

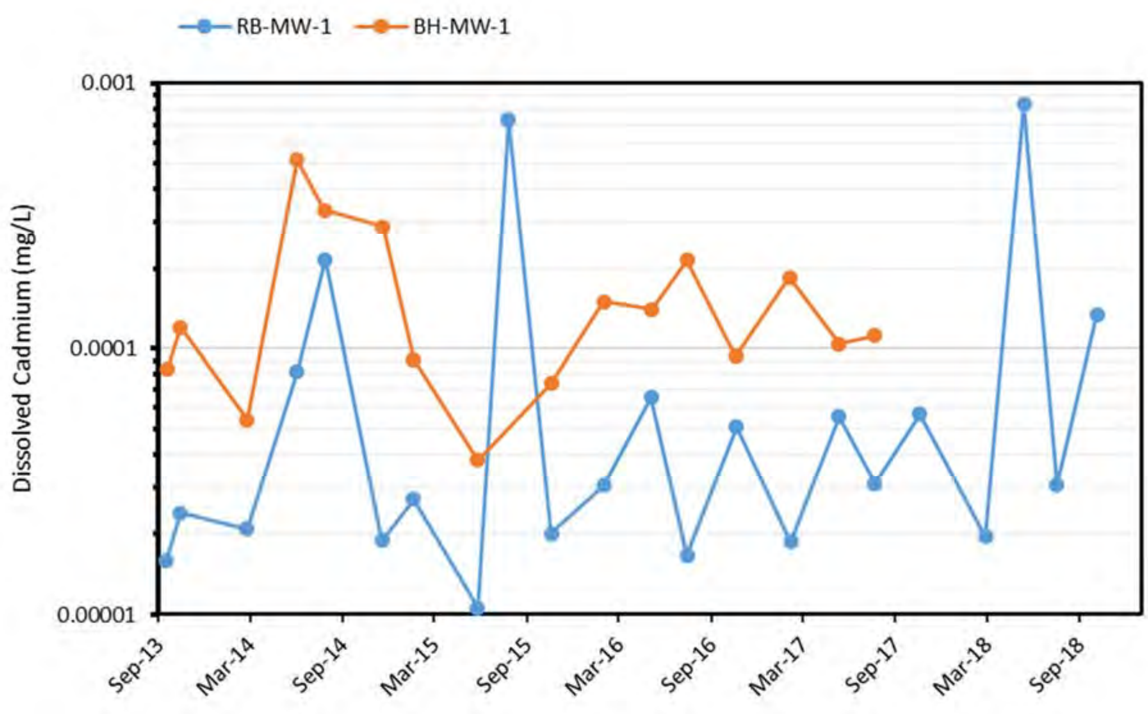


Figure 5-11: Dissolved Cadmium (mg/L) in No Cash Creek Catchment Wells

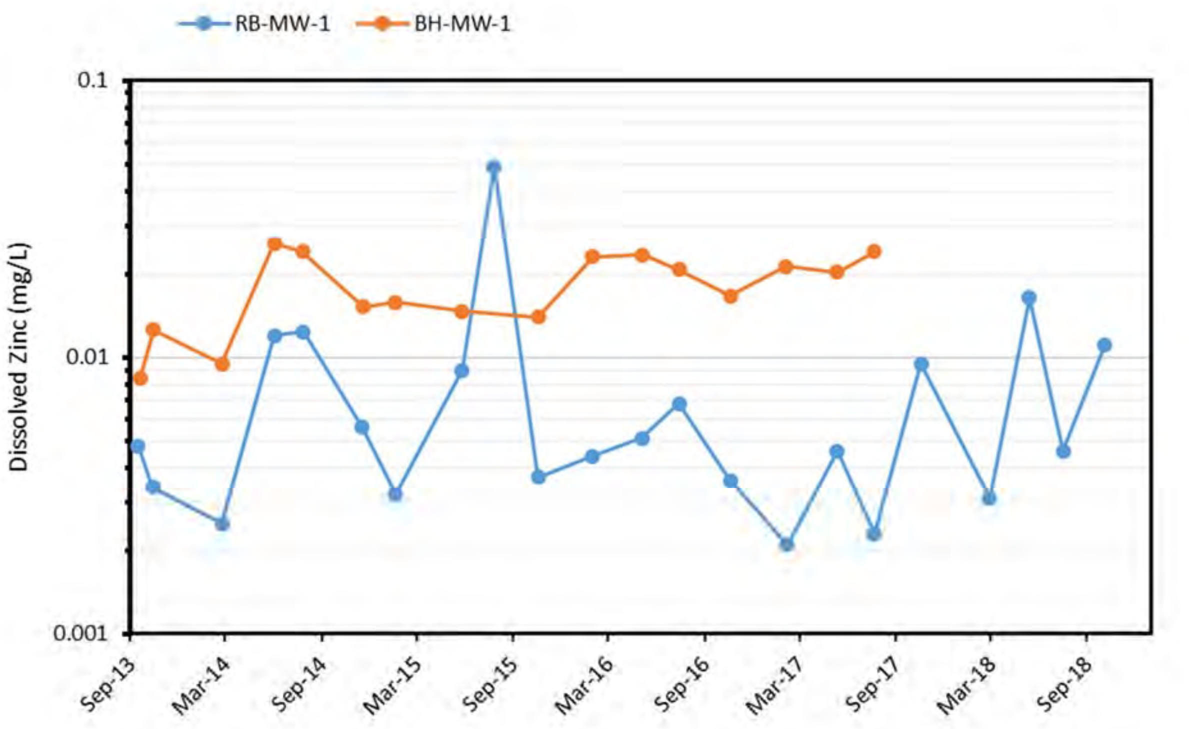


Figure 5-12: Dissolved Zinc (mg/L) in No Cash Creek Catchment Wells

5.3.2 *CHRISTAL CREEK*

Figure 5-13 to Figure 5-16 presents the dissolved cadmium, and zinc concentrations, respectively, for the bedrock wells in the Christal Creek catchment.

The deep groundwater boreholes (FM-MW-1, FM-MW-2, and FM-MW-3) were sampled following airlifting 2013. The dissolved zinc concentrations in the deep groundwater wells ranged from 0.0026 mg/L to 0.014 mg/L, all below the CCME guideline (0.03 mg/L), and the dissolved cadmium concentrations were below the detection limit (<0.000010 mg/L to <0.000020 mg/L). Dissolved metals concentrations in the deep wells were generally lower than those measured in the shallower groundwater wells around the Mill. It is therefore anticipated that groundwater encountered during the development of the Flame and Moth will not contain significant metals concentrations.

Concentrations of dissolved cadmium from wells in Keno City (May 2011 to Dec 2018) ranged from below the detection limit (<0.000010 mg/L) to 0.007 mg/L. The maximum concentrations of dissolved cadmium in the KC-MW-4, and KV-84D wells ranged from 0.005 to 0.0006 mg/L Dissolved zinc concentrations were higher in the Keno City wells compared to the deep Flame and Moth wells. Wells ON-MW 2 (1.56 to 2.57 mg/L), KC-MW 4 (0.04 to 0.06 mg/L), and KV-84ND (0.58 to 0.71 mg/L).

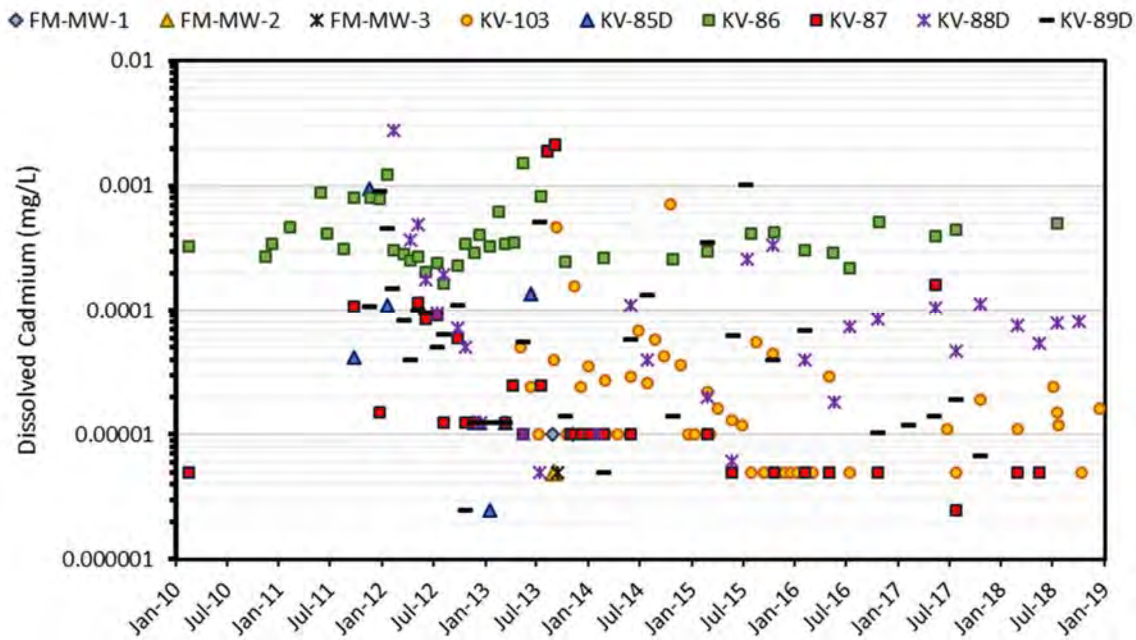


Figure 5-13: Dissolved Cadmium (mg/L) in Christal Creek Wells near the District Mill

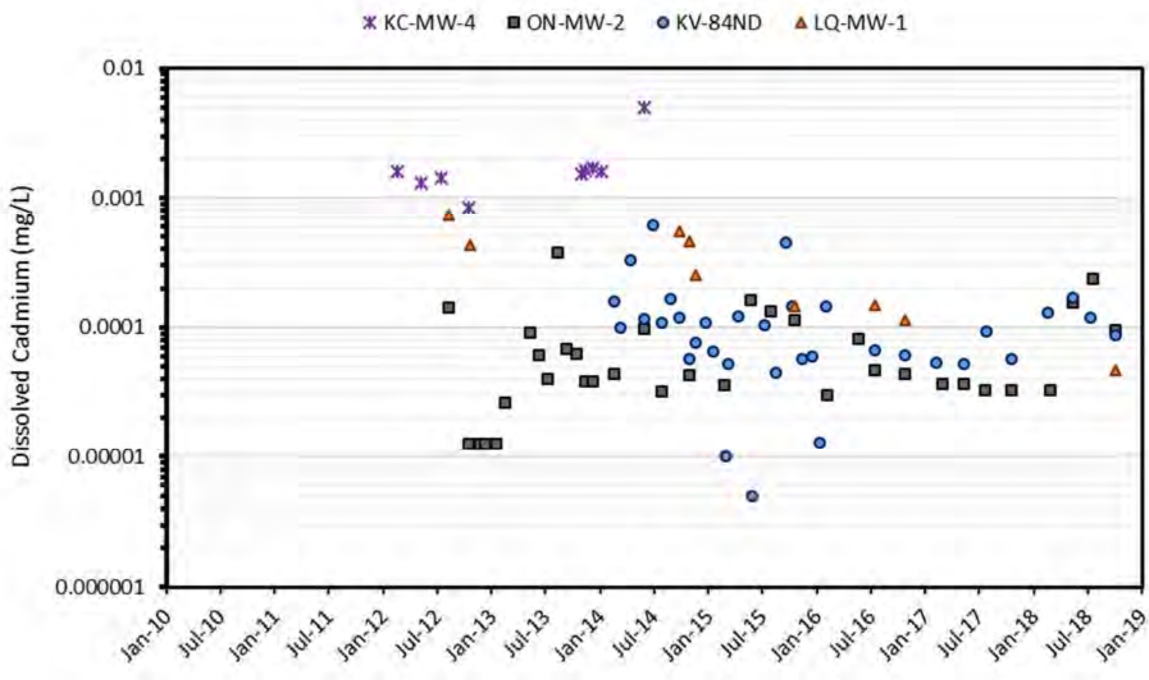


Figure 5-14: Dissolved Cadmium (mg/L) in Christal Creek Wells near Keno City

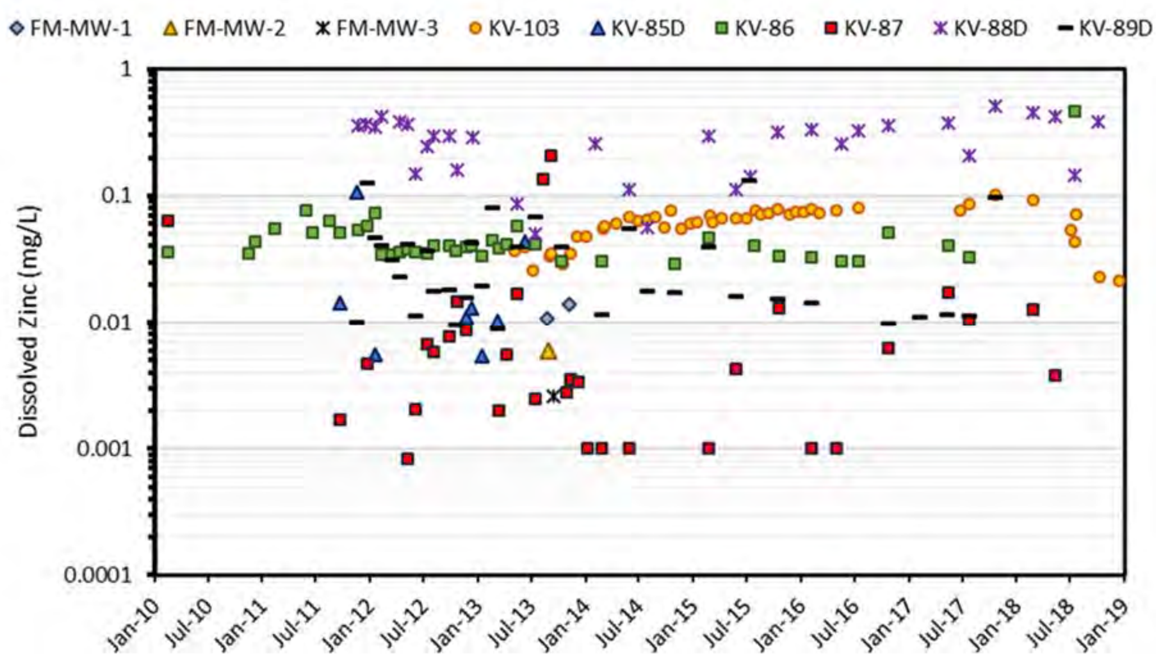


Figure 5-15: Dissolved Zinc (mg/L) in Christal Creek Wells near the District Mill

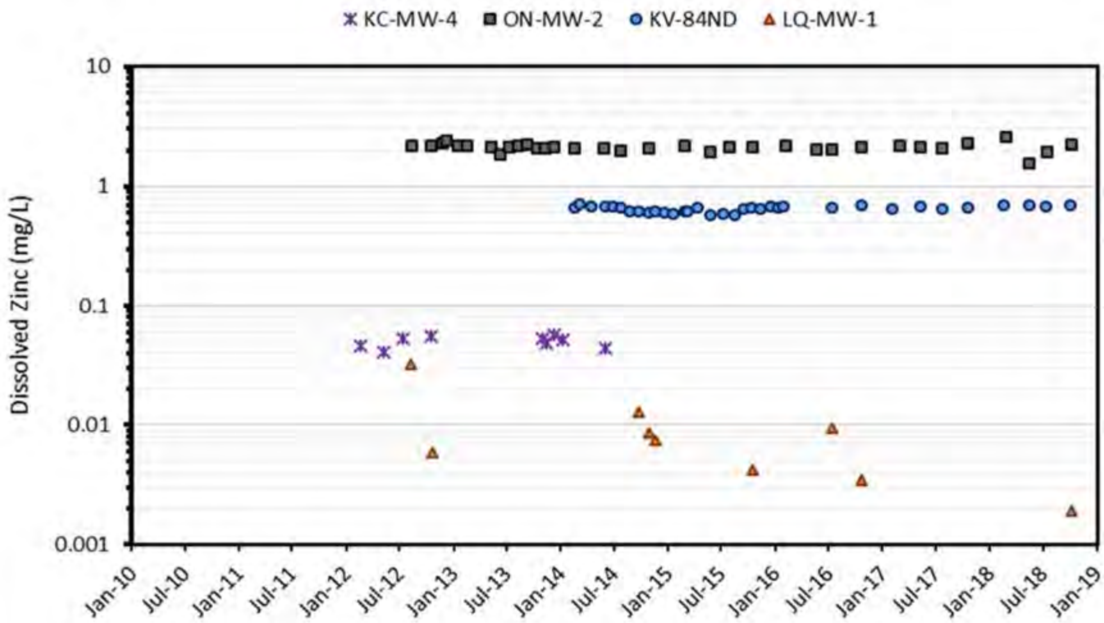


Figure 5-16: Dissolved Zinc (mg/L) in Christal Creek Wells near Keno City

5.3.3 *LIGHTNING CREEK*

Following development of the KV-109 monitoring well on 8 June 2018 a water quality samples were collected to characterise groundwater chemistry. The concentration of dissolved cadmium ranges from 0.000014 to 0.000095 mg/L, and dissolved zinc ranges from 0.021 to 0.027 mg/L, as shown in Figure 5-17 and Figure 5-18, respectively. Sampling will continue monthly for a year before changing to quarterly.

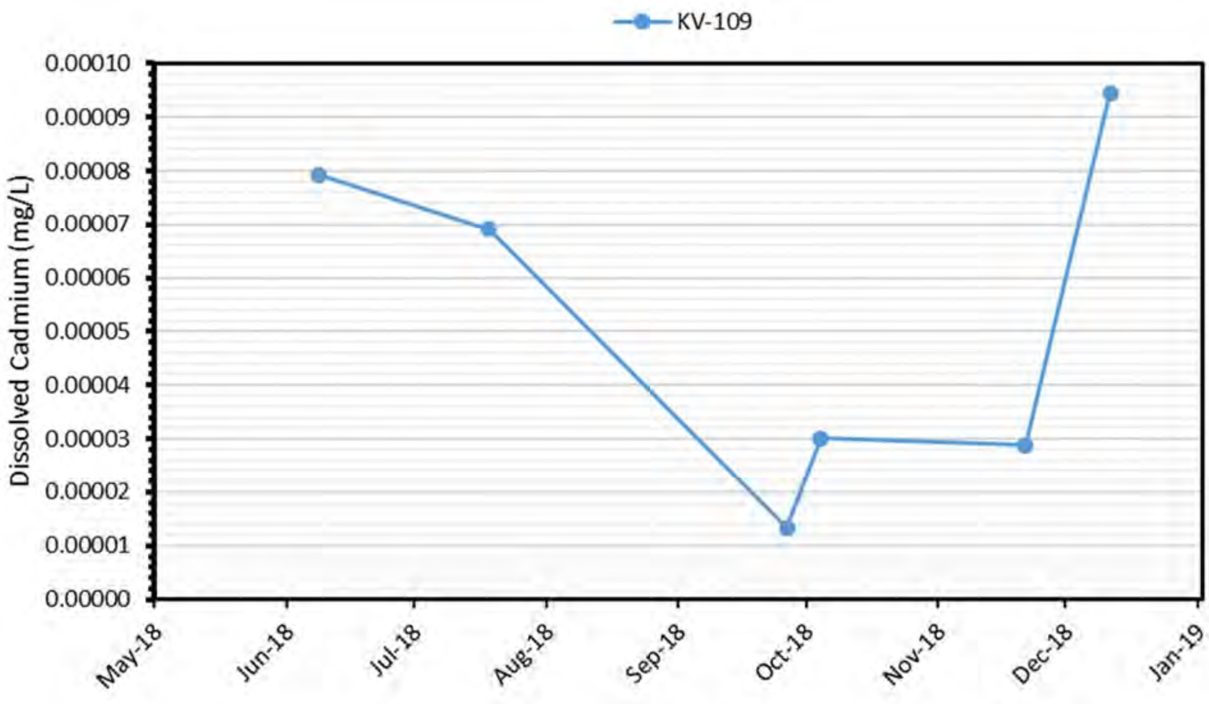


Figure 5-17: Dissolved Cadmium (mg/L) in Lightning Creek Catchment Wells

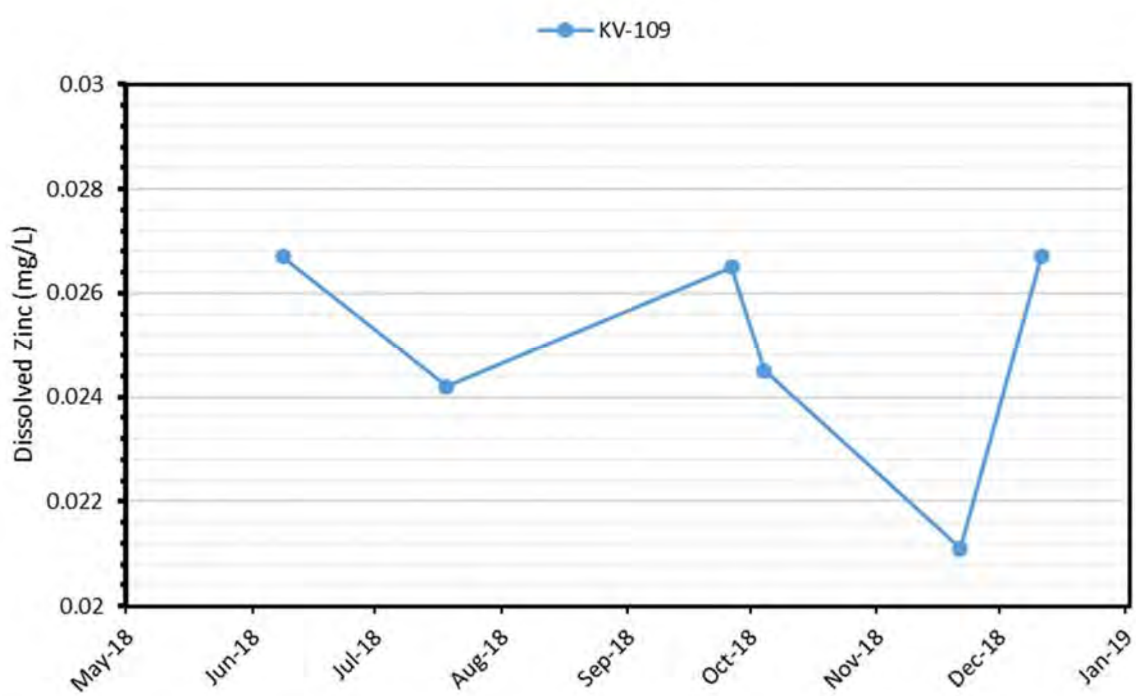


Figure 5-18: Dissolved Zinc (mg/L) in Lightning Creek Catchment Wells

6. BIOLOGY

This section provides a summary of components that make up the regional ecosystem that may be affected by mining operations, including fish and fish habitat, wildlife, and vegetation.

6.1 AQUATIC RESOURCES

Aquatic resources have been documented in the KHSD through numerous environmental studies conducted over the last two decades. Study methods and results were presented in previous assessments for projects within the KHSD. In general, most of the reports were consistent in their findings with respect to the characterization of the aquatic resources in local watersheds or catchment areas within the KHSD.

The main watercourses in the KHSD potentially affected by the Project (Figure 6-1) are Lightning Creek, downgradient of the Bellekeno adit and Mill and flows west and south into Duncan, ultimately draining into the Mayo River and Stewart River watershed. No Cash and Star Creeks drain the No Cash, Ruby, and Bermingham adits into a bog catchment (approximate 2 km radius) with no surface connection to any rivers. Christal Creek is directly west of the Keno District Mill and DSTF and flows into Christal Lake and eventually into the South McQuesten River and Stewart River watershed. Flat Creek drains the Valley Tailings Facility (VTF) and flows into the South McQuesten River. The Keno Ladue watershed is located northeast of the Project site and is not discussed in this report.

6.1.1 FISHERIES

Historical fisheries resource data for Lightning Creek and surrounding drainages is limited to information collected by White Mountain Environmental Consulting (WMEC) in 1995 and 2006, Access Consulting Group (ACG) in September 2008, De Graff and Burns in 2011 and Minnow Environmental in 2012. Investigations of fish and fish habitat were conducted at numerous sites, including two sites on Lightning Creek. More recent investigations have been conducted as part of the Environmental Effects Monitoring (EEM) conducted by AEG for the Bellekeno Mine, and completed in 2018 (AEG 2019d; Figure 6-2).

Other than No Cash Bog, which is not fish bearing and has no surface connection to fish bearing waters, most of the drainages identified in the KHSD support a diverse fish population. Ten different fish species were identified within the KHSD Including: Arctic Grayling *(Thymallus arcticus)* (most abundant), slimy sculpin *(Cottus cognatus)* (most widely dispersed), round whitefish (*Prosopium cylindraceum*), Northern pike *(Esox lucius),* Arctic lamprey (*Lethenteron camtschaticum*), Chinook salmon (*Oncorhynchus tshawytscha*), burbot (Lota lota), longnose sucker (*Catostomus catostomus*), least cisco (*Coregonus sardinella*), and lake chub (*Couesius plumbeus*).

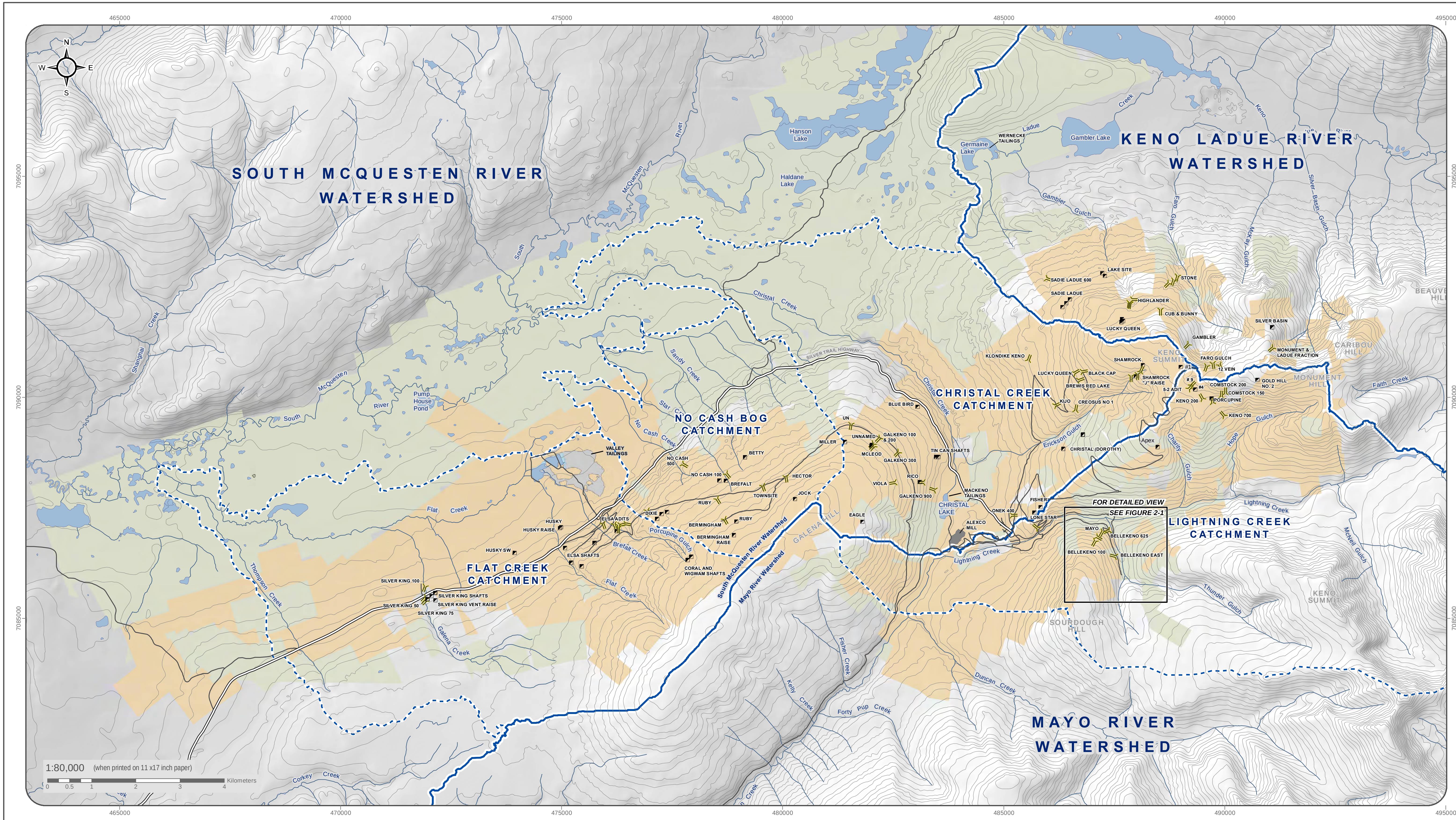
The fish laboratory exposure study conducted as part of the EEM, allowed for distinguishing potential effects from the Bellekeno Mine effluent from those of the Thunder Gulch placer mine discharge, influences that are not possible to isolate *in situ*. The Metal Mining Technical guidance for EEM (Environment Canada 2012) suggested a critical effect size (CES) of ±10% (of the reference mean) for condition factor and 25% for weight-at-age. Exceeding the effects threshold may indicate potential for impacts to environmental variables. At experiments end, these thresholds were not exceeded. Condition factor for the Exposure 2 treatment group measured midway through the experiment showed a greater than 10% positive change compared to the reference tank and may suggest an ecologically significant change. However, fish exposed to mine effluent only (Exposure 1) were not statistically different than fish in the reference treatment. Suggesting any ecological changes detected in fish size are a result of exposure to a combination of mine effluent and upstream placer activity, rather than caused by mine effluent alone.

6.1.2 BENTHIC INVERTEBRATES

Benthic invertebrate sampling has taken place sporadically in the KHSD, dating back to 1975. Environmental Protection Services carried out biological monitoring in the area in 1975, 1985, 1986, and 1990, 1994, 2007, and 2011. More recent investigations have been conducted as part of EEM for the Bellekeno mine, completed in 2018 (AEG 2019d; Figure 6-2).

Benthic communities in each watercourse varied based on habitat conditions and historical impacts, but are generally dominated by Plecoptera, Diptera, and Chironomids. Benthic communities in Lighting Creek drainage were found the be robust and represented by a healthy proportion of population-sensitive species. Benthic community metrics in Christal and Flat Creek suggest communities are potentially stressed compared to reference condition. Benthic samples within No Cash and Star Creek are limited to one sampling event in September 2018.

Potential effects to benthic invertebrates were determined during EEM by comparing reference sites to all downstream exposure sites, as reference sites were upstream of mine effluent discharge and encompassed effects from historical placer and current mine activities. Although some of the metrics assessed for exposure sites showed an effect to benthics, either negatively or positively, this difference was also detected between reference sites located upstream of effluent discharge. This suggests that impairment of the benthic community existed previously and is unrelated to mine effluent. This was supported by water chemistry, as one of the reference sites shared similar water chemistry with the exposure site, for TSS and elevated total metals (aluminum, iron, zinc), chemistry that is often associated with placer activity. As well, sediment chemistry measured metals exceedances in all reference sites, with some parameters far exceeding concentrations measured in downstream exposure sites. This is likely an influence from the placer mining in Thunder Gulch, which may explain some differences in benthic community composition. Considering the various lines of evidence in context with the legacy mining that has occurred upstream of the Mine, the effects measured are likely caused by historical placer mining activities, rather than by mine effluent. It is suggested that standard monitoring continue for subsequent biological monitoring.



Topographic Data (CANVEC) data at a scale of 1:50,000 and crown grant (land parcels and mineral survey claims) data compiled by the Department of Natural Resources Canada. Quartz claim boundaires and ownership are current as of March[th] 2017; obtained from Geomatics Yukon, Government of Yukon. Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on March 2017

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

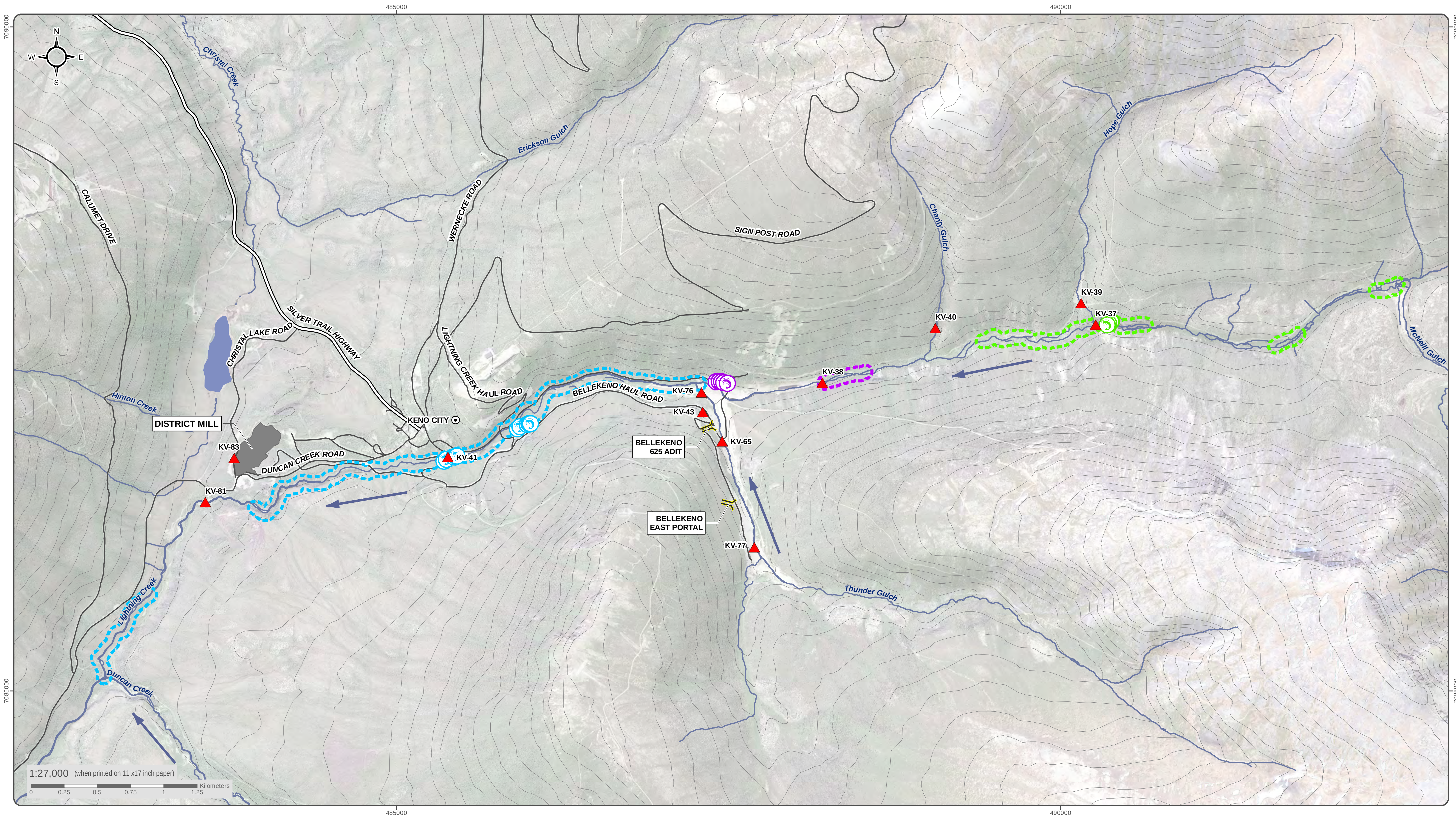
- Adit
- Shaft
- Mill
- Tailings
- ERDC Owned Quartz Claims or Crown Grants
- Waterbody
- Watercourse
- Silver Trail Highway
- Other Road
- Contours (100 ft intervals)

ALEXCO ENVIRONMENTAL GROUP

CHARACTERIZATION REPORT

FIGURE 6-1
KENO HILL WATERSHED OVERVIEW

APRIL 2019



Topographic Data (CANVEC) data at a scale of 1:50,000 and crown grant (land parcels and mineral survey claims) data compiled by the Department of Natural Resources Canada.
Sattelite Imagery obtained from Yukon Geomatics web service http://mapservices.gov.yk.ca/ArcGIS/services on January 2018

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

Adit
Surface Water Quality Station of Interest
Pristine Reference
Placer-Influenced Reference
Effluent-Exposed
Pristine Reference Area (REF 1)
Placer-Influenced Reference Area (REF 2)
Effluent-Exposed Area (EXP)
Mill Site Footprint
Waterbody
Water Flow Direction
Watercourse
Silver Trail Highway
Other Road

AKHM
ALEXCO ENVIRONMENTAL GROUP

CHARACTERIZATION REPORT

FIGURE 6-2

BENTHIC INVERTEBRATE COMMUNITY AND FISH SURVEY SAMPLING LOCATIONS

JANUARY 2018

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(*Last edited by: amatlashevska;24/01/2018/13:50 PM*)

6.1.3 STREAM SEDIMENT

Stream sediment sampling was carried out annually or biannually since 2010 in Christal and Lightning Creek. Sediment quality within each of the affected watercourses has not exhibited obvious increasing or decreasing trends since 1990. Despite several metals that exceeded the Canadian Interim Sediment Quality Guideline (ISQG) and the Sediment Quality Guideline Probable Effects Level (PEL), sediment toxicity tests suggested that elevated metals were not in a form that was biologically available (i.e. dissolved at concentrations that would induce mortalities or sublethal effects), at most sites.

In Lightning Creek, arsenic consistently exceeded the PEL at all sites (KV-37, KV-38, and KV-41) (Table 6-1), while cadmium, lead and zinc frequently exceeded the ISQG and occasionally the PEL. Copper frequently exceeded the ISQG. In Christal Creek, arsenic, cadmium, lead and zinc all consistently exceed the PEL at both KV-6 and KV-7 (Table 6-2). In Flat Creek Arsenic, cadmium, lead, and zinc all exceeded the PEL at KV-9 (Table 6-3). Copper exceeded the PEL once and exceeded the ISQG on three occasions. No Cash drainage measured arsenic exceedance of the PEL at KV-21 and KV-56, cadmium, lead and zinc all exceeded the PEL at KV-21 and the ISQG for cadmium and zinc at KV-56. In the South McQuesten arsenic, cadmium, and zinc all frequently exceed the PEL at KV-1, KV-3, and KV-4 (Table 6-5). Lead exceeds the PEL at KV-3 and KV-4. Copper exceeds the ISQG at KV-3 and KV-4 during all events and twice at KV-1.

Table *6-1: Metal Concentrations in Lightning Creek Sediment at KV-37, KV-38 and KV-41, July 2007 to September 2018*

Total Metal Concentration mg/kg	Lab MDL	Guideline		KV-37					KV-38							KV-41								
		CCME ISQG	CCME PEL	31-Jul-07	23-Sep-11	23-Aug-12	2-Sep-15	13-Sep-18	31-Jul-07	30-Aug-13	26-Aug-14	1-Sep-15	22-Sep-16	18-Aug-17	13-Sep-18	31-Jul-07	23-Sep-11	22-Aug-12	30-Aug-13	26-Aug-14	1-Sep-15	22-Sep-16	18-Aug-17	12-Sep-18
Aluminum	50	-	-	12533	6828	8110	8940	8650	9023	8280	6940	8510	11598	10452	7502	8693	6625	8550	7033	7530	9430	10290	12067	7140
Antimony	0.1	-	-	0.4	2.69	9.38	17.7	4.67	13.9	19.6	16.8	1.61	9.7	7.57	8.62	0.5	2.67	1.67	3.05	2.7	1.98	1.63	2.18	2
Arsenic	0.1	5.9	17	**115.4**	**74.1**	**82.6**	**324**	**95.3**	**433**	**179**	**277**	**27.1**	**185**	**143**	135	**62.5**	**37.8**	**21.5**	**67**	**50**	**28.3**	**30.6**	**40.7**	**31**
Cadmium	0.02	0.6	3.5	**2.7**	**0.9**	**0.87**	**20.4**	**8.23**	**31.2**	**15.4**	**16.8**	**1.11**	**8.61**	**5.22**	7.36	**3.4**	**0.84**	**1**	**2.28**	**1.74**	**1.48**	**1.63**	**2.13**	1.05
Copper	0.5	35.7	197	**41.6**	**39.5**	26.1	**46.6**	**41.9**	**56**	**58.7**	**46.7**	24.1	**62.5**	**51.1**	43.0	33.8	30.6	30.9	**55**	**40**	34.2	35.8	55.3	26
Iron	50	-	-	27633	20072	18400	27000	29533	34833	30250	23600	19200	31467	23683	24333	26000	20072	20600	21600	19233	21700	22333	25083	19633
Lead	2.5	35	91.3	**40**	**51.9**	**53.2**	**541**	**129.5**	**642**	**352**	**275**	30.2	**216**	**173**	162	**82.2**	**40.4**	31.5	**138**	**108**	**70.6**	30.1	**47.1**	**42.7**
Mercury	0.005	0.17	0.486	0.084	<0.05	0.033	0.135	0.02	**0.228**	0.079	0.106	0.0443	n/a*	0.0566	0.035	0.055	<0.05	0.037	0.055	0.029	0.032	n/a*	0.058	0.016
Nickel	0.5	-	-	29.7	21.3	20	33.3	24.9	42.3	32.7	23.9	24.5	40.2	33.9	45	30.4	22.6	26.4	34.3	28.8	27	27.5	35.1	36.5
Selenium	0.2	-	-	1.4	<0.5	0.67	1.37	0.32	2	0.83	0.89	0.59	0.91	0.97	0.59	0.8	<0.5	0.63	0.72	0.47	0.47	0.81	0.91	0.45
Silver	0.1	-	-	0.8	0.31	0.55	16.1	1.11	15	9.95	15.5	0.49	4.52	3.72	3.57	1.9	0.35	0.91	2.38	2.35	1.09	0.51	0.92	0.87
Zinc	10	123	315	**125**	**137**	**118**	**1260**	**621**	**1637**	**1259**	**1357**	**127**	**638**	**430**	**539**	**247**	121	110	**228**	**196**	**177**	**127**	**200**	**134**

Table *6-2: Metal Concentration in Christal Creek Sediment at KV-6 and KV-7, 2007- 2018*

Total Metal Concentration mg/kg	Lab MDL	Guideline		KV-6									KV-7						KV-50
		CCME ISQG	CCME PEL	31-Jul-07	8-Aug-09	13-Jul-10	30-Aug-11	21-Aug-12	26-Aug-14	1-Sep-15	23-Sep-16	8-Sep-18	31-Jul-07	22-Aug-09	13-Jul-10	21-Aug-13	4-Sep-15	8-Sep-18	9-Sep-18
Aluminum	50	-	-	9410	8420	5880	7563	7130	6733	7450	7470	2490	7253	9540	6000	6580	6050	5043	8286
Antimony	0.1	-	-	14.8	2	96.2	37.2	66.7	37.3	0.84	5.45	44.1	0.25	21.8	9.5	9.12	5.89	5.65	3.39
Arsenic	0.1	5.9	17	**284**	**31.8**	**1030**	**448**	**923**	**544**	**16.5**	**85.2**	**598**	**34.7**	**194**	**121**	**122**	**66.2**	**85.2**	**597**
Cadmium	0.02	0.6	3.5	**28.2**	**2.48**	**91.4**	**33.5**	**95.3**	**43.1**	0.99	**6.97**	**50.6**	**3.7**	**32.4**	**18.8**	**16.1**	**3.83**	**9.92**	**4.72**
Copper	0.5	35.7	197	**41.3**	**39**	**67.6**	35.5	**69.6**	**54.2**	21.9	33.3	**49.6**	26.6	**48.5**	32.2	28.1	17.3	26.0	34.3
Iron	50	-	-	27133	18400	43800	28467	46900	36500	15100	21867	38400	20367	32300	24200	22600	16700	21567	124750
Lead	2.5	35	91.3	**954**	**73.4**	**4130**	**1388**	**3400**	**1533**	27.5	**237**	**1980**	**56.4**	**1040**	**453**	**348**	**227**	**223**	34.5

Total Metal Concentration mg/kg	Lab MDL	Guideline		KV-6									KV-7						KV-50
		CCME ISQG	CCME PEL	31-Jul-07	8-Aug-09	13-Jul-10	30-Aug-11	21-Aug-12	26-Aug-14	1-Sep-15	23-Sep-16	8-Sep-18	31-Jul-07	22-Aug-09	13-Jul-10	21-Aug-13	4-Sep-15	8-Sep-18	9-Sep-18
Mercury	0.005	0.17	0.486	0.102	0.06	0.18	0.07	0.164	0.096	0.036	n/a*	0.090	0.068	0.1	0.025	0.051	0.047	0.026	0.04
Nickel	0.5	-	-	27.9	29.5	32.8	25.8	45.8	46	25.2	29.1	99.6	22.6	59.3	38.4	36.1	18.7	55.6	65.27
Selenium	0.2	-	-	2.5	1.6	1.5	0.8	2.1	1.3	1	1.2	1.11	1.2	1.7	1.2	1	0.4	0.62	1.43
Silver	0.1	-	-	12.2	1.04	66.5	22.6	50.6	32.5	0.43	3.19	29.1	0.8	14.1	5.51	3.72	3.23	2.62	0.6
Zinc	10	123	315	**1483**	**237**	**5820**	**2122**	**5270**	**3100**	**132**	**599**	**4154**	**404**	**4330**	**2010**	**1580**	**362**	**1021**	**1207**

Table *6-3: Metal Concentrations in Flat Creek sediment KV-9, July 2007 to September 2018*

Total Metal Concentration mg/kg	Lab MDL	Guideline		KV-9					
		CCME ISQG	CCME PEL	31-Jul-07	22-Aug-09	31-Aug-11	22-Aug-12	3-Sep-15	7-Sep-19
Aluminum	50	-	-	7323	7520	6600	6600	7630	5867
Antimony	0.1	-	-	150	63.6	145	58.2	106	62.9
Arsenic	0.1	5.9	17	**586**	**196**	**413**	**167**	**319**	**217**
Cadmium	0.02	0.6	3.5	**57.1**	**71.4**	**37.4**	**16.1**	**25.4**	**31.1**
Copper	0.5	35.7	197	**194**	**285**	**141**	**62.3**	99.3	97.7
Iron	50	-	-	75533	31500	51000	27600	43800	32983
Lead	2.5	35	91.3	**6290**	**5850**	**4760**	**2300**	**3580**	**3305**
Mercury	0.005	0.17	0.486	**0.589**	0.150	0.340	0.156	0.309	0.140
Nickel	0.5	-	-	31.6	47.9	26.1	19.6	27.3	34.7
Selenium	0.2	-	-	11	0.6	1.5	0.67	1.12	0.66
Silver	0.1	-	-	16	22.3	65.3	24.6	42.1	23.8
Zinc	10	123	315	**3143**	**3360**	**2670**	**1130**	**1680**	**1552**

Table *6-4: Metal Concentrations in No Cash sediment at KV-21 and KV-56, September 2018*

Total Metal Concentration	Lab MDL	Guideline		KV-21	KV-56
mg/kg		CCME ISQG	CCME PEL	9-Sep-18	9-Sep-18
Aluminum	50	-	-	5925	7862
Antimony	0.1	-	-	43	1.46
Arsenic	0.1	5.9	17	**205**	**118.6**
Cadmium	0.02	0.6	3.5	**80**	**1.59**
Copper	0.5	35.7	197	28.5	32.15
Iron	50	-	-	30283	29033
Lead	2.5	35	91.3	**1522**	25.98
Mercury	0.005	0.17	0.486	0.11	0.03
Nickel	0.5	-	-	95.5	57.2
Selenium	0.2	-	-	1.08	0.61
Silver	0.1	-	-	58.6	0.34
Zinc	10	123	315	**10363**	**192.7**

Table *6-5: Metal Concentration in South McQuesten Sediment at KV-1, KV-3 and KV-4, July 2007 to October 2018.*

Total Metal Concentration mg/kg	Lab MDL	Guideline		KV-1					KV-3						KV-4					
		CCME ISQG	CCME PEL	31-Jul-07	23-Aug-09	1-Sep-11	21-Aug-12	8-Sep-18	31-Jul-07	22-Aug-09	1-Sep-11	22-Aug-12	3-Sep-15	6-Oct-18	31-Jul-07	22-Aug-09	31-Aug-11	22-Aug-12	3-Sep-15	7-Sep-18
Aluminum	50	-	-	8050	9570	9810	12000	9440	8140	7640	12900	10600	8750	9098	9557	9790	8690	8470	9360	7062
Antimony	0.1	-	-	<0.5	0.9	0.8	1.17	0.94	15.6	29	15.1	23.2	22.4	14	32.3	21.9	26.5	18.4	12.3	8.88
Arsenic	0.1	5.9	17	18.8	22.6	17.7	32.8	40.6	130	128	94.1	145	108	113	180	109	116	100	68.7	45.3
Cadmium	0.02	0.6	3.5	3.3	4.18	4.08	9.44	6.49	13.5	13.9	15.7	22.8	11.5	14.7	17	16.1	14	11.8	8.57	3.57
Copper	0.5	35.7	197	25.4	36.2	32.7	64.1	42.3	41.5	37.3	67	67.1	42.2	45.2	59	57.1	39.9	40.7	37.6	22.6
Iron	50	-	-	17533	19900	17900	24000	24367	25467	24000	25900	25300	23900	25167	31800	25000	24100	22600	19700	15800
Lead	2.5	35	91.3	13.9	11.9	11.1	16.7	14.9	423	463	336	614	342	388	985	422	376	372	266	248
Mercury	0.005	0.17	0.486	0.054	<0.05	<0.05	0.0716	0.0284	0.088	0.06	0.07	0.0856	0.0634	0.0502	0.173	0.07	<0.05	0.0557	0.0707	0.0311
Nickel	0.5	-	-	74	103	102	195	210	69.4	56.1	186	140	96	161	66.8	128	93.3	101	81.6	52.1
Selenium	0.2	-	-	1.2	1.3	1.5	3.01	1.32	2.5	1.3	2.5	2.07	1.14	1.30	3.5	1.5	1.4	1.14	1.16	0.32
Silver	0.1	-	-	0.2	0.21	0.14	0.3	0.19	7.1	11.6	5.77	8.78	7.32	5.14	16.2	8.87	8.47	6.61	4.85	2.81
Zinc	10	123	315	512	800	799	1300	1190	1054	1380	1960	1960	1280	1534	1333	1690	1390	1270	922	271

6.2 Wildlife

The KHSD supports a variety of wildlife including ungulates, fur-bearers, small mammals, upland game birds and waterfowl. Moose (*Alces alces*) are the most common and important sustenance animal in the area, with woodland caribou and sheep no longer present in the area. Black Bear (*Ursus americanus*) and Grizzly Bear (*Ursus arctos*; listed as 'Special Concern' by COSEWIC) are common in the area. The remaining large mammals being carnivores are generally considered Fur Bearers: wolves (*Canis lupus*), coyotes (*Canis latrans*), foxes (*Vulpes vulpes*), marten (*Martes Americana)*, mink (*Neovison vison)*, lynx (*Lynx canadensis*), wolverine (*Gulo gulo*) and river otter (*Lontra canadensis*) are, to varying degrees, all indigenous to the area. Beaver and muskrat are also economically important and common in aquatic habitats in the region. Other small mammals common to the area include Ground Squirrel *(Marmotini),* Red Squirrel *(Sciurus vulgaris),* varying hare, Weasel *(Mustela),* Vole *(Cricetidae),* and Shrew *(Soricidae).* Less common are Porcupine *(Erethizon dorsatum)* and Chipmunk *(Tamias).* Alpine areas have local populations of Hoary Marmot (*Marmota caligata*) and Pika (*Ochotona*). The KHSD is also host to a diverse community of birds including both waterfowl and songbirds, three species which are COSEWIC listed as threatened (common nighthawk), or of special concern (rusty blackbird and olive-sided flycatcher).

The effects of the Project on flora and fauna were discussed in a Human Health and Ecological Risk Assessment by SENES Consultants Ltd. (2011, 2014). Key findings of the assessment indicate that there are no issues for large mammals directly exposed to conditions on site. Waterfowl that consume benthic invertebrates as their main food source and incidental sediments, and beaver may be exposed to elevated levels of arsenic, lead and selenium from Christal Creek and Christal Lake.

6.3 Vegetation

Three bioclimatic zones exist within the general Keno study area: Boreal High, Boreal Subalpine, and Alpine, described in Table 6-6. The Boreal High bioclimate zone is the most predominant, comprising roughly two thirds of the KHSD, followed by the Boreal Subalpine (approximately one quarter of the study area). The Boreal Subalpine bioclimatic zone is found on both Galena and Keno Hill. The Alpine zone occurs over a relatively confined area on Keno Hill in the eastern extent of the claims.

Table 6-6: Bioclimate Zones in the Keno Hill Silver District

Bioclimatic Zone (elevation range)	Definition
Boreal High (500−1,225 m)	The Boreal High forested areas are predominantly a mix of white and black spruce, with a shrub, lichen, and moss understory. The higher elevation extents of this bioclimatic zone supports a mix of subalpine fir, scrub birch, and willow as it approaches the Boreal Subalpine zone. The Boreal High tends to have more of an open canopy than Boreal Low and a moderate to well-developed shrub layer. Non-forested areas include: wetlands, riparian areas, avalanche tracks, exposed soil/rock, and anthropogenic disturbances.
Boreal Subalpine (1,225−1,450 m)	Open to sparse forest canopy cover, main trees species are subalpine fir and white spruce that become less frequent at the higher elevations. A well-developed shrub layer is composed mainly of scrub birch, willow species, and vaccinium. At the higher extent of this zone small woody shrubs, Dryas, mosses, and lichen replace the forest cover with only a few krummholtz subalpine fir scattered amongst the landscape.
Alpine (1,450 m+)	Alpine communities include dwarf ericaceous shrubs, scrub birch, willow species, grass/sedges, forbs, lichen, and bare bedrock at elevations above the treeline. Trees if present are low growing krummholtz that exist in small microsites where they can receive enough moisture and nutrients to grow. This bioclimatic zone is present only on Keno Hill.

An assessment of disturbance mine site areas completed by AEG (2016c) focused on waste rock pits, dumps, and trenching. Photo records kept of natural revegetation at disturbed waste rock storage and pit sites (No Cash mine) provided examples of the level of succession over a six-year period. As expected, once primary colonizing species were established on site, microsites were created that increased surface organics and promoted growing conditions for greater diversity of species. Several sites showed evidence of more than one factor that would limit successful revegetation such as: insufficient substrate moisture, unfavourable substrate texture and unfavourable slope. Vegetation trials at KHSD have been ongoing to determine feasible surface treatments for optimizing revegetation of disturbed sites including scarifying the disturbance with machinery to add microsite conditions, applying a seed mix and fertilizer amendment, and adding natural growth media in the form of organic material or coarse woody fragments.

The most vegetation disturbance at sites was generally around access roads, adits, waste rock pits, and tailings storage. Most disturbed sites that dated back 45 years were observed to support plant communities consistent with early stage serial succession. There was noticeable change in natural revegetation over a six-year period at No Cash 100 waste rock storage and pit (disturbed from 1948 to 1975). The trial sites show that once initial vegetation was established on site, it created microsites and increased surface organics which promoted growing conditions for additional species. Furthermore, the vegetation within the KHSD provided an abundant seed source that, if the right conditions exist, naturally established primary colonizing species.

Results of terrestrial effects assessments done by Environmental Dynamics Inc. (EDI 2008, 2009, 2010)) concluded there was aerial contamination of metals to lichens but was limited to the eastern portion of the Valley Tailings Facility (2007). Other results showed evidence of elevated heavy metal concentrations in some medicinal plants used by FNNND as compared to control sites, particularly near the tailings (2008). EDI noted that metal concentration in plants appears to be species-specific; willow samples had higher concentrations of metals, while Labrador tea contained lower concentrations. The data further suggests that in this region there is little to no correlation between metal concentration in soils and metal concentration in plants. Therefore, the most likely pathway of metal accumulation in plant samples is aerial deposition of dust from the VTF on the surface of plant tissues and is likely not being incorporated into the tissues of plants (2009). Please refer to Appendix J for more information.

7. SOCIAL ENVIRONMENT

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

Keno City is a small community situated at the end of the Silver Trail Highway with a population of approximately 12 permanent residents. The community was originally established to support mining operations in the area and the community's population has fluctuated over the last hundred years in response to local mineral development activity. Today, Keno City is a small community with residences, a few small and growing businesses, the Keno City Mining Museum, and the Keno City Alpine Interpretive Centre.

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

8. GEOCHEMISTRY

8.1 ORE

Alexco Keno Hill Mining Corp (AKHM) has not conducted geochemical testing to assess the potential for acid rock drainage and metal leaching (ARD/ML) related to the ore. AKHM will collect and test representative ore samples when the production resumes.

8.2 WASTE ROCK

AKHM conducted waste rock geochemical characterization studies throughout the Keno Hill Silver District (KHSD) and specifically within each of the mineralized target zones (Bellekeno, Onek 990, Lucky Queen, Flame and Moth, and Bermingham) in order understanding the weathering behavior and potential for acid rock drainage and metal leaching (ARD/ML) potential related to the rocks. These characterization studies have been ongoing since Alexco Keno Hill Mining Corp. (AKHM) initiated exploration in 2006. The results of these studies were summarized in (AEG, 2019a), reports for each deposit were compiled as appendices to the Bermingham WUL application (AEG, 2019b). and the most relevant are appended to this document.

8.2.1 LABORATORY TEST PROGRAM

The samples were sourced from exploration drill hole of deposits from Bellekeno, Lucky Queen, Onek, Flame and Moth, Silver King and Birmingham and sent to off-site accredited laboratories for testing. The laboratory test program included static and kinetic. The static testing consisted of:

- Acid base accounting (ABA) analyses, including:
    - Paste pH;
    - Modified Sobek and/or Siderite-corrected neutralization potential (NP) as per 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).

Kinetic testing consisted of humidity cells and field leach barrels. Humidity cells tests have all been conducted for the following materials:

- Flame and Moth non-acid generating/metal leaching (N-AML) waste rock composite (98 weeks, completed);
- Bermingham N-AML cover hole waste rock composite HC-01 (57 weeks, completed); and
- Bermingham N-AML advance exploration hole waste rock composite HC-03 (33 weeks, ongoing).

Field kinetic consisted of five field barrels containing N-AML and potentially acid generating/metal leaching (P-AML) waste rock from the Flame and Moth.

Table 8-1 list the number of samples tested per productions zone and Table 8-2 provides a breakdown of number of samples per lithology and per productions zone. Further detail on the material tested, testing program and interpretation results for each site can be found in Altura (2008) for Bellekeno, ACG (2011a) for Onek, ACG (2011b) for Lucky Queen, ACG (2011c) for Silver King, AEG (2016a) for Flame and Moth and AEG (2019) for Bermingham.

Table 8-1: Number of ARD/ML Samples per ARD/ML Test and per Production Zone

Production Zone	ARD/ML Test					
	ABA	Elemental Analysis	SFE	Mineralogy	Humidity Cell	Field Bin
Bellekeno	71	6478	12	*	-	-
Onek and Lucky Queen	74	7507	17	-	-	-
Silver King	24	24	-	-	-	-
Flame & Moth	50	50	50	-	1	5
Bermingham [a]	60	311	29	4	2	-
Total	**279**	**14370**	**108**	**4**	**3**	**5**

Note:* type of and number not identified

Table 8-2: Lithologies Sampled for ARD/ML Characterization per KHSD Production Zones

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**

8.2.2 RESULTS

Static Testing

Acid-Base Accounting

ABA is used to quantify the acid potential (AP) and neutralization (NP) of rock samples and to determine the ratio of their potentially acid producing and potentially acid consuming minerals. This provides an indication of the potential of geologic materials to generate acid in the long-term. The potential for acid potential was assessed using the MEND criteria (Price, 2009). Based on this criteria, three categories of potential for acid generation can be defined based on the NP/AP ratio (or neutralization potential ration; NPR):

- Samples are classified as potentially acid generating (PAG) if NPR<1;
- Samples are capable of acid generation but with some uncertainty if 1≤NPR≤2; and,
- Samples are classified as not potentially acid generating (non-PAG) if NPR>2.

Plots of NP versus AP for all the KHSD waste rock samples is displayed in Figure 8-1, and broken out by lithology in Figure 8-2 to Figure 8-6.

Most of waste rock samples collected from potential production zones from the KHSD had low potential for acid generation (i.e., NPR>2). The majority of the samples from Lucky Queen, Onek, Flame and Moth, Bermingham, and Bellekeno had low potential for acid generation (58%, 73%, 74%, 48%, and 87% of samples, respectively). Overall, the waste rock from the easternmost deposits (e.g., Bellekeno, Onek, and Flame and Moth) tended to have higher NP than waste rock from the deposits located in the western portion of the KHSD (i.e., Silver King and Bermingham). Silver King had the most samples with high potential for ARD (i.e., NPR<1; 68%), largely due to their low NP content of the samples (Figure 8-1). 29% and 23% of the samples collected from Bermingham were also PAG and Uncertain category, respectively, due to combination of low NP and AP. Onek also had a few PAG samples (16%); however, unlike Bermingham, these generally had high AP and NP.

Analyzed based by major lithology, the QTZT, TQTZT, and GSCH samples broadly reflected the general NPR sample distribution (11% to 31% PAG; 44% to 76% non-PAG), consistent with the numerical dominance of these lithologies. The GNST and SSCH samples are predominantly non-PAG (Figure 8-2 to Figure 8-6).

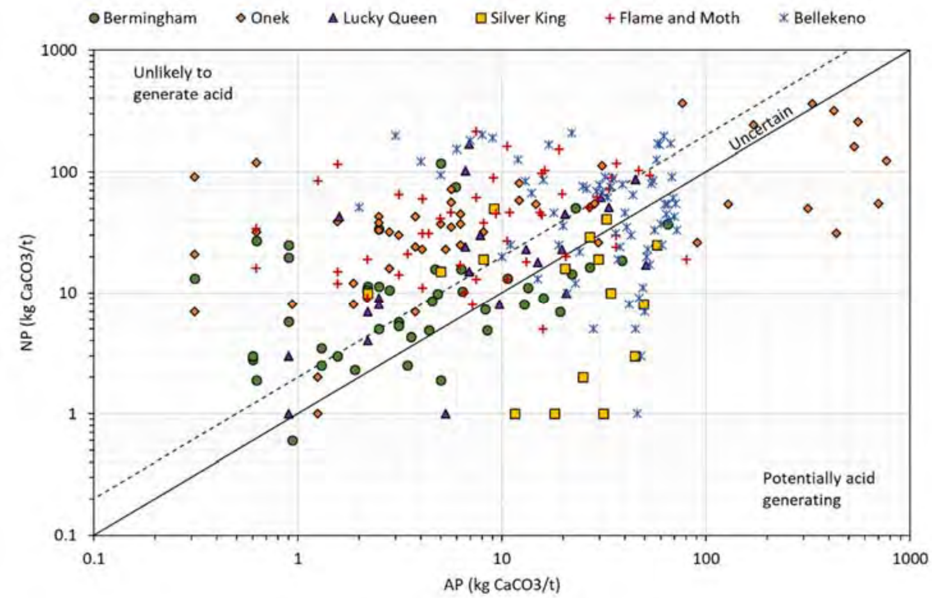
Elemental Chemistry

The bulk concentration of an element is not a direct measure of how mobile an element may be during weathering because several parameters, including but not limited to, site hydrogeology, biogeochemistry, climate, pH and redox conditions ultimately affect the mobility and bioavailability of an element. It however provides a preliminary indication of constituents that are elevated in the rock samples and should be monitored for high solubility in during leach and/or kinetic tests.

The results of the bulk elemental analysis were compared to 10times (10x) the average crustal abundance to assess whether the waste rock from AKHM deposits are enriched or depleted compared to the crustal average (CRC, 2005). Bulk metal content of antimony, arsenic, selenium, silver, cadmium, and zinc often exceed their respective average crustal abundance by an order of magnitude. Also, elevated lead concentration was evident in a few rock samples from all deposits except Lucky Queen and Flame and Moth. The concentrations of these elements in waste rock from the AKHM deposit are shown in Figure 8-7.

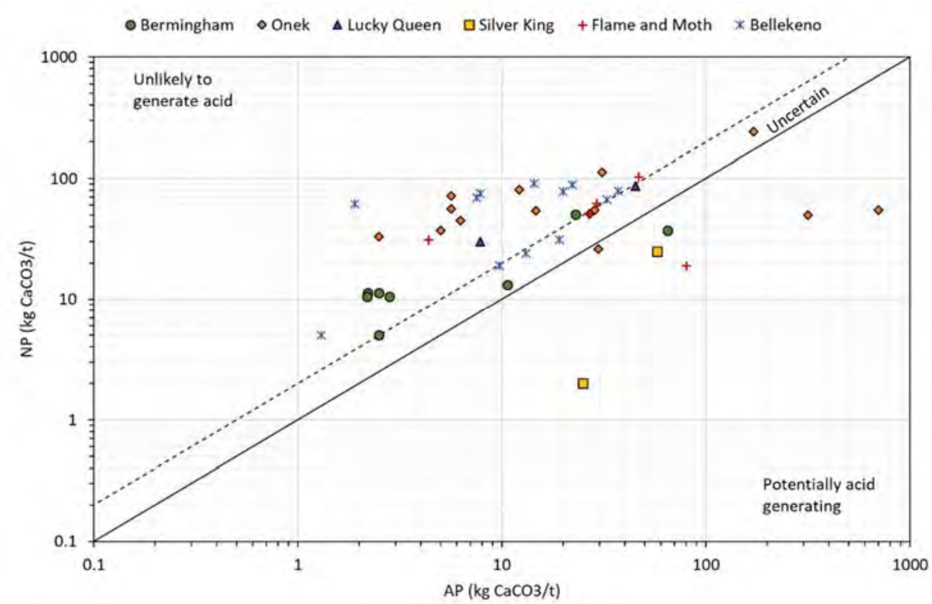
Antimony and silver concentrations were higher than their respective 10x crustal abundance (2 and 0.85 ppm, respectively) in the majority of waste rock samples from Bermingham, Bellekeno, Onek, Lucky Queen, and Silver King. Lower antimony and silver concentrations were observed for Flame and Moth waste rock. Bulk selenium concentrations exhibited similar distributions and were elevated above the 10x crustal abundance (0.5 ppm) in the majority of Bermingham and Flame and Moth samples. Selenium was not analyzed in Bellekeno or Onek waste rock and the poor detection limits (10 ppm) used for Lucky Queen and Silver King dataset prevent from a meaningful interpretation of their selenium data.

The highest arsenic, cadmium, and zinc concentrations were observed in waste rock from Onek, Bermingham and Bellekeno. The lowest concentrations of these metal(loids), and silver, were recorded in Flame and Moth waste rock, which were consistently lower than the crustal abundance for all four elements.



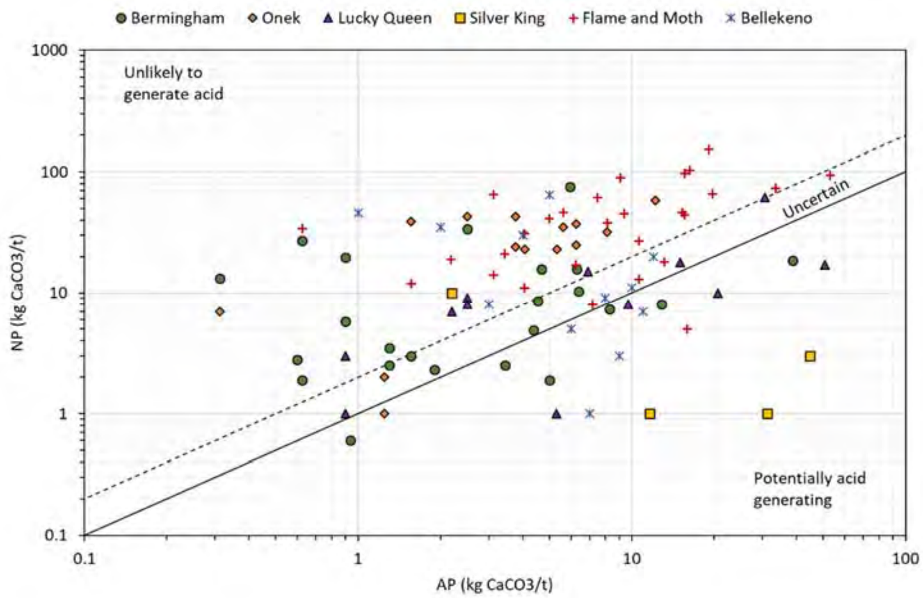
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively

Figure 8-1: Variability in NP and AP of Waste Rock Samples from KHSD Deposits



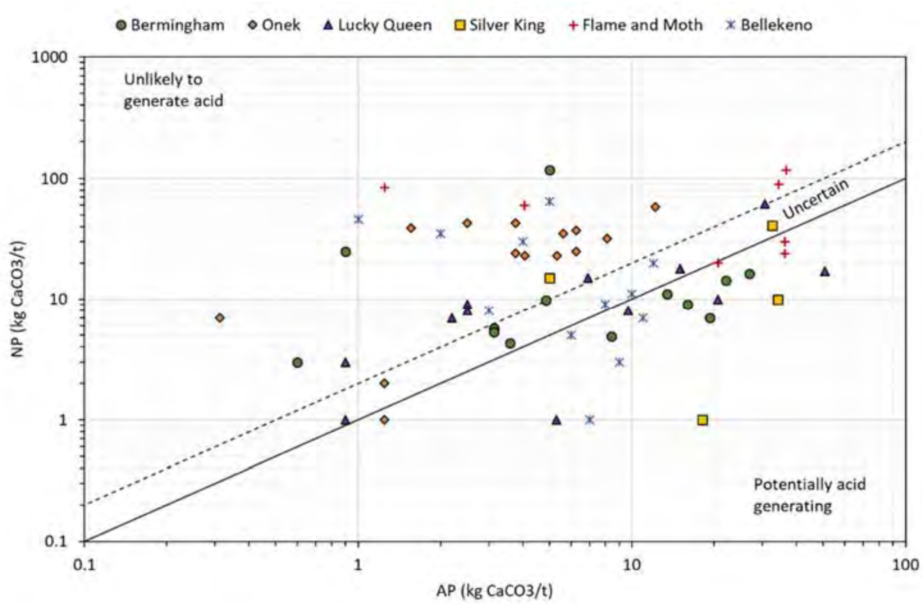
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively

Figure 8-2: Variability in NP and AP of GSCH Lithology Waste Rock Samples from KHSD Deposits



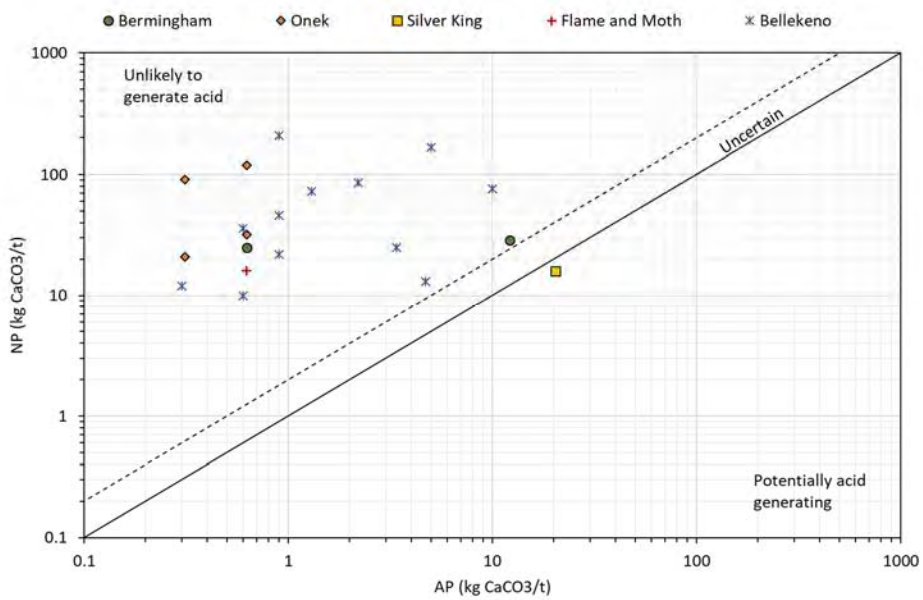
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively

Figure 8-3: Variability in NP and AP of QTZT Lithology Waste Rock Samples from KHSD Deposits



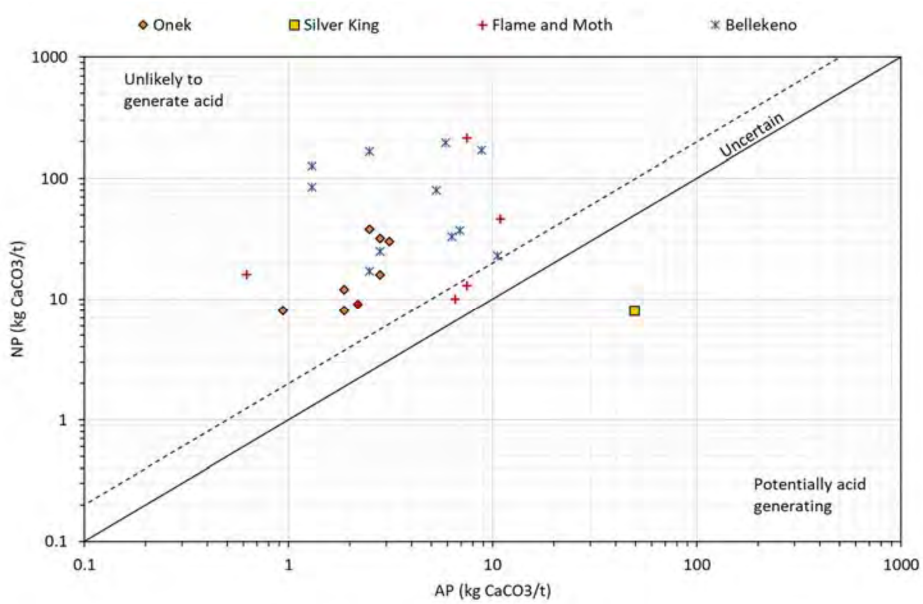
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively

Figure 8-4: Variability in NP and AP of TQTZT Lithology Waste Rock Samples from KHSD Deposits



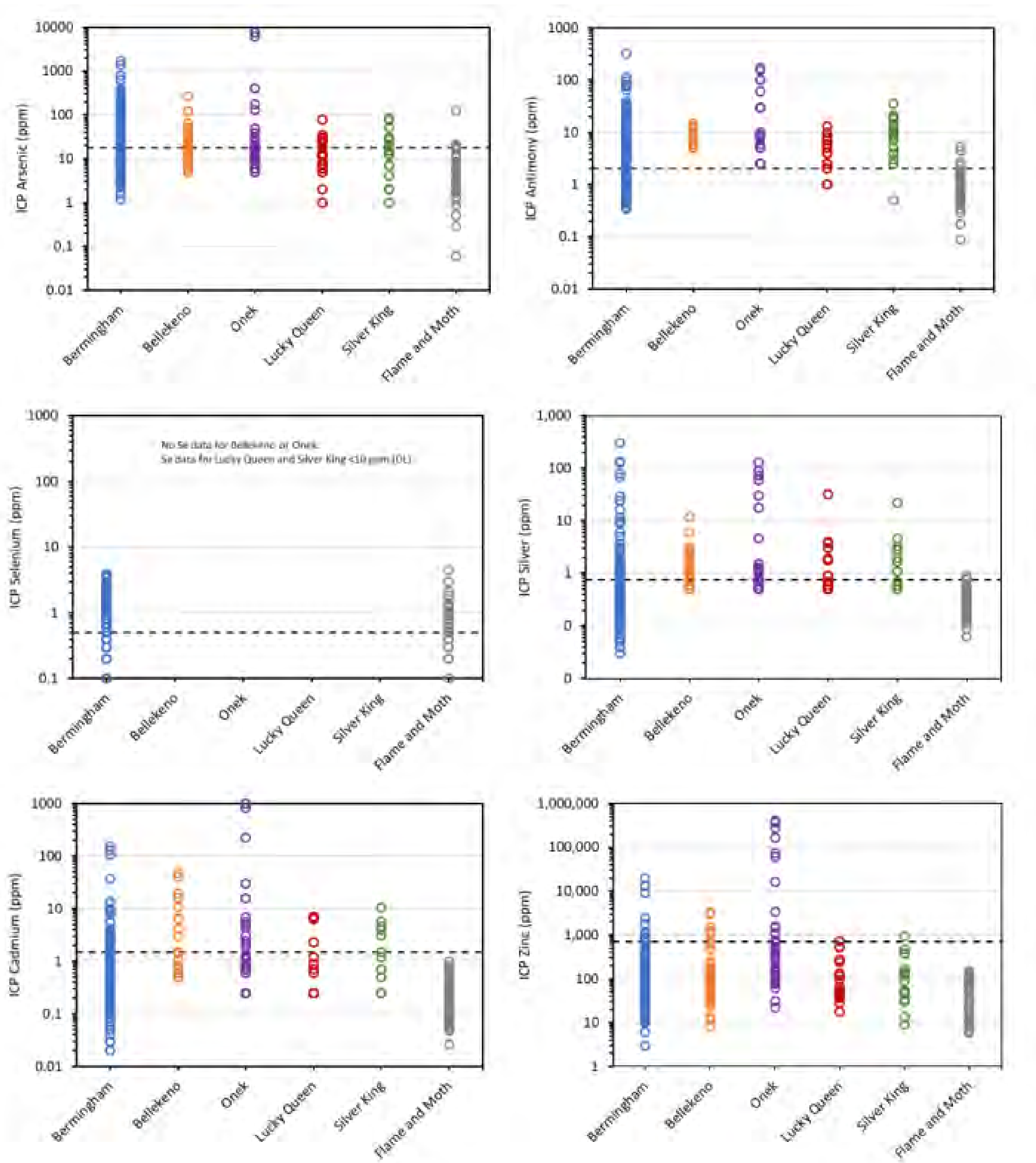
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively

Figure 8-5: 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 8-6: Variability in NP and AP of SSCH Lithology Waste Rock Samples from KHSD Deposits



Dashed line represents 10x crustal abundance

Figure 8-7: Elemental Concentrations of Antimony, Arsenic, Selenium. Silver, Cadmium, and Zinc by Deposit

Shake Flask Extraction

SFE provides an indication of readily soluble element in a sample that may be mobilized/solubilized under the short-term leaching. A summary of results of SFE test carried out on samples from the main lithologies at Flame and Moth and Bermingham reported in Table 8-3 and Table 8-4, respectively. No SFE data with adequate trace element detection limits for a meaningful comparison with generic water quality guidelines are available for the other deposits.

The focus of the discussion herein is on constituents that were enriched in the rock sample relative to 10x average crustal abundance during the elemental analysis and/or had SFE results 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 the protection of freshwater aquatic life (WQGPAL). The most recent of the two genetic guidelines was used in the analysis because it represents the most up to date scientific data with respect environmental risk assessment. This comparison aids in the identification of potentially elevated concentrations of soluble constituents, is strictly for reference purposes and does not indicate compliance or otherwise with respect to CCME or BCMOE guidelines.

The SFE pH of Flame and Moth and Bermingham samples was circumneutral to alkaline, with five samples (three Bermingham and two Flame & Moth) having pH higher than 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). 92% and 76% of samples from Flame and Moth exceeded fluoride and aluminum CCME guidelines (0.12 mg/L and 0.1 mg/L), respectively whereas a lower proportion of exceedances for the same elements were obtained from Bermingham samples (45% and 31% for fluoride and aluminum, respectively).

A high proportion of SFE antimony concentrations exceeded the BCMOE guideline (0.009 mg/L; 78% of samples) in the Flame and Moth dataset, whereas only 21% of Bermingham samples exceeded despite higher bulk antimony concentrations in the Bermingham waste rock samples (Figure 8-7). Conversely, a higher proportion of Bermingham samples had SFE arsenic concentrations exceeding the CCME water quality guideline (0.005 mg/L; 41% of samples) compared with the Flame and Moth SFE results (6% of samples), consistent with the higher elemental arsenic in Bermingham samples compared to Flame and Moth (Figure 8-7). On the other hand, a similar proportion samples from both Flame and Moth and Bermingham had SFE selenium concentrations exceeding the BCMOE guideline for selenium (0.002 mg/L; 46% and 45% of samples, respectively) consistent with their comparable bulk selenium content.

In summary, the same constituents (fluoride and selenium) were observed at elevated levels in the SFE leachate from of samples from both Bermingham and Flame and Moth. The main differences were the elevated arsenic concentrations observed in 41% of the Bermingham samples compared to 6% of the Flame and Moth samples, and the elevated above the guidelines concentrations of antimony and aluminum recorded in the majority of Flame and Moth samples compared to the generally lower than the water quality guidelines concentrations of the same elements in the Bermingham samples.

Table 8-3: Comparison of SFE data from Flame and Moth 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						

Table 8-4: Comparison of SFE data from Bermingham 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 CCME/BCMOE							

Kinetic Testing

The results of completed and ongoing laboratory humidity cell and ongoing field leach barrels tests are presented and discussed herein. The discussion is focused on constituents identified as constituents of potential interest due to their elevated concentration. The effluent quality standards (EQS) set out in the water licence QZ09-092, water quality objectives (WQO) at KV-21 for Bermingham, and CCME or BCMOE WQGPAL are used for comparison with leachate chemistry. The hardness dissolved organic carbon (DOC) and pH of nearest receiving environment was used to calculate the guidelines for hardness-, DOC- and pH-dependent elements. Station KV-51 in Christal Creek and Station KV-21 in No Cash Creek were used for Flame and Moth and Bermingham datasets, respectively.

Humidity Cell

Flame and Moth

The results of 98 weeks of testing of N-AML Flame and Moth waste rock are presented below. Figure 8-8 to Figure 8-10 present the humidity cell leachate data collected for constituents of interest.

pH, Acidity, Alkalinity and Sulphate

The leachate of N-AML humidity cell was slightly alkaline during the entire test period, ranging from pH 7.5 to 8.4. The alkalinity was much higher than the acidity generated during the entire test period. It declined from a peak of 127 mg/L $CaCO_3$ at week 1 and stabilized around 50 - 60 mg/L $CaCO_3$ since week 60. Acidity was not measured during the first 9 weeks of humidity cell operations, was 17 mg/L $CaCO_3$ at the initial sampling ate week 10 then remained below 6 mg/L $CaCO_3$ during the reminder of the test (Figure 8-8).

Dissolved sulphate concentrations were below the BCMOE guideline (429 mg/L) at all times Dissolved sulphate concentrations were highest during the initial rinse cycle (183 mg/L at week 0) as soluble sulphate salts stored in the sample were rinsed out. Sulphate concentrations then declined slightly before reaching a plateau of between 100 and 130 mg/L for weeks 2 to 11 as a results of metal sulphides weathering. Thereafter, sulphate concentration declined and stabilized between 20 and 30 mg/L since week 66.

Constituents of Interest

Dissolved concentrations of cadmium, zinc, silver, lead, nickel, and copper in the N-AML humidity cell leachate were typically below their respective detection limits for most of the test duration, and well below their respective water quality guidelines (Figure 8-8 and Figure 8-9).

The concentrations of antimony were highest during the initial rinse (0.011 mg/L), marginally above the BCMOE WQG (0.009 mg/L), then gradually declined over time stabilizing around 0.001 mg/L since week 41 (Figure 8-10). Arsenic concentration was stable between 0.00071 and 0.001 mg/L between week 0 and week 20, then rose slowly reaching 0.0024 mg/L by week 54. Thereafter, arsenic concentration declined slightly and stabilized between 0.0016 and 0.002 mg/L (Figure 8-10). Arsenic concentration was at least two times lower than the CCME guideline (0.005 mg/L) during the test.

Selenium concentrations in the leachate had a pattern different from all other constituents. Selenium initially declined sharply 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 8-10). The selenium peak coincided with the sulphate peak suggesting that the dissolution of selenium-bearing sulphides is the likely source of selenium. Selenium concentrations then tailed off sharply 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).

Sulphides and NP depletion times were estimated at 16 and 54 years, respectively, indicating that substantial amount of NP will remain after the sulphide minerals have been exhausted. The Flame and Moth N-AML humidity cell was terminated after the concentrations of constituents of interest had stabilized

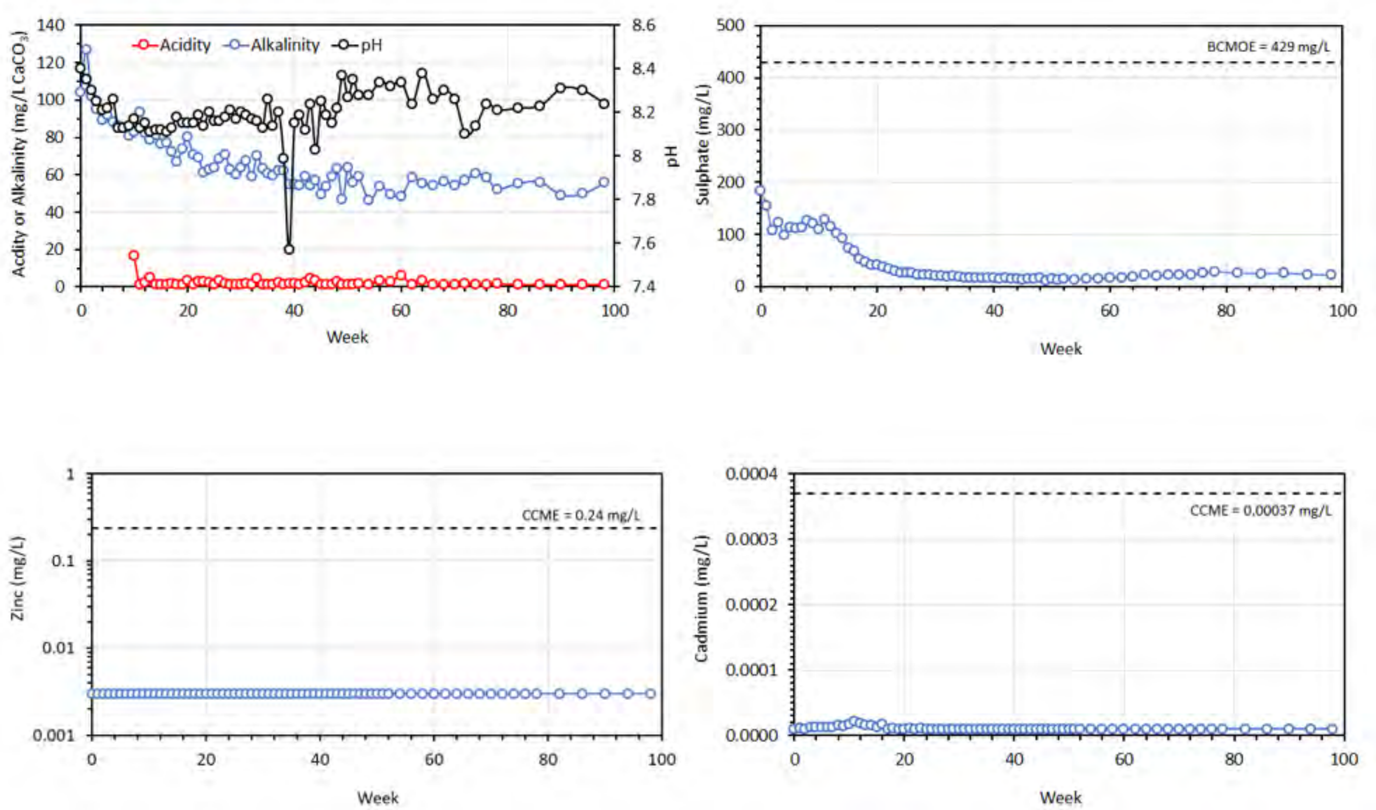


Figure 8-8: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends of Flame and Moth Humidity Cell

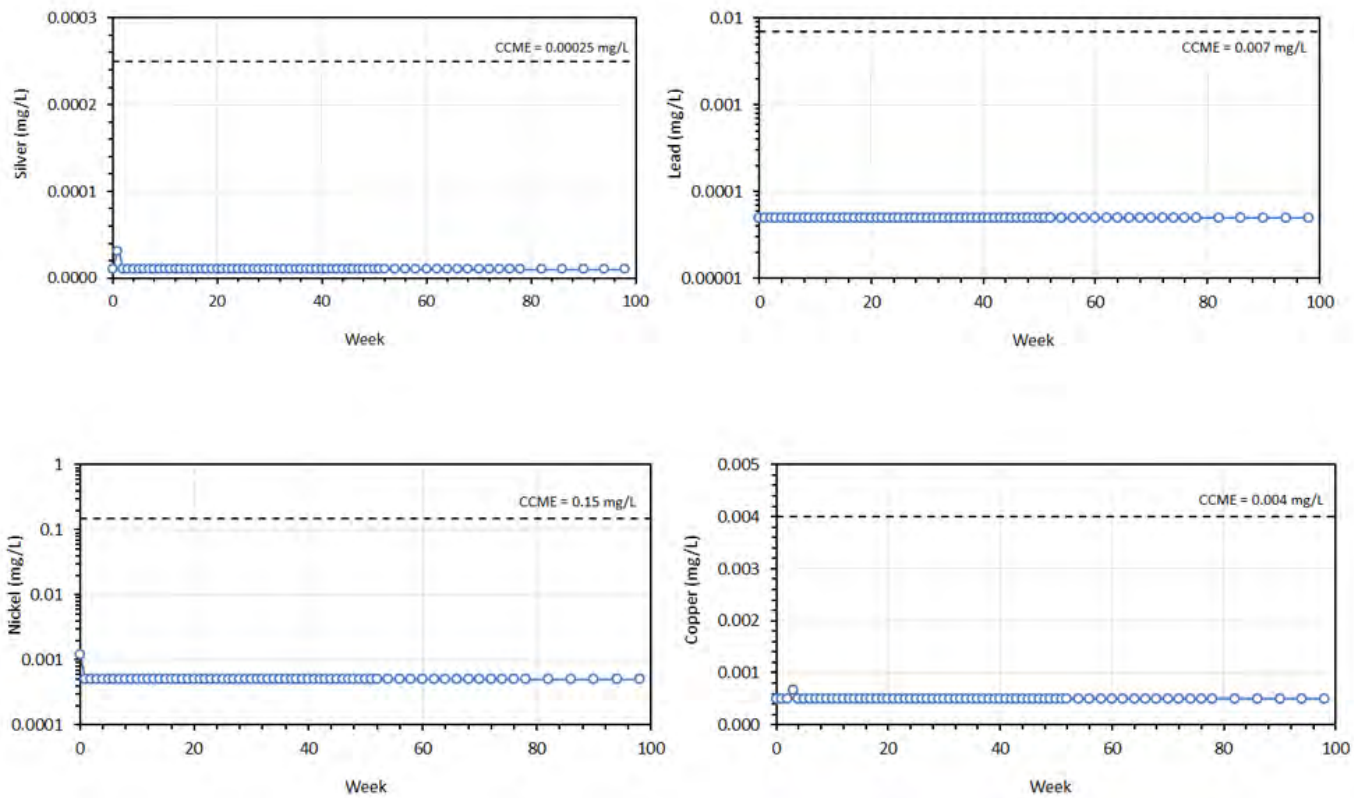


Figure 8-9: Silver, Lead, Nickel, and Copper Trends of Flame and Moth Humidity Cell

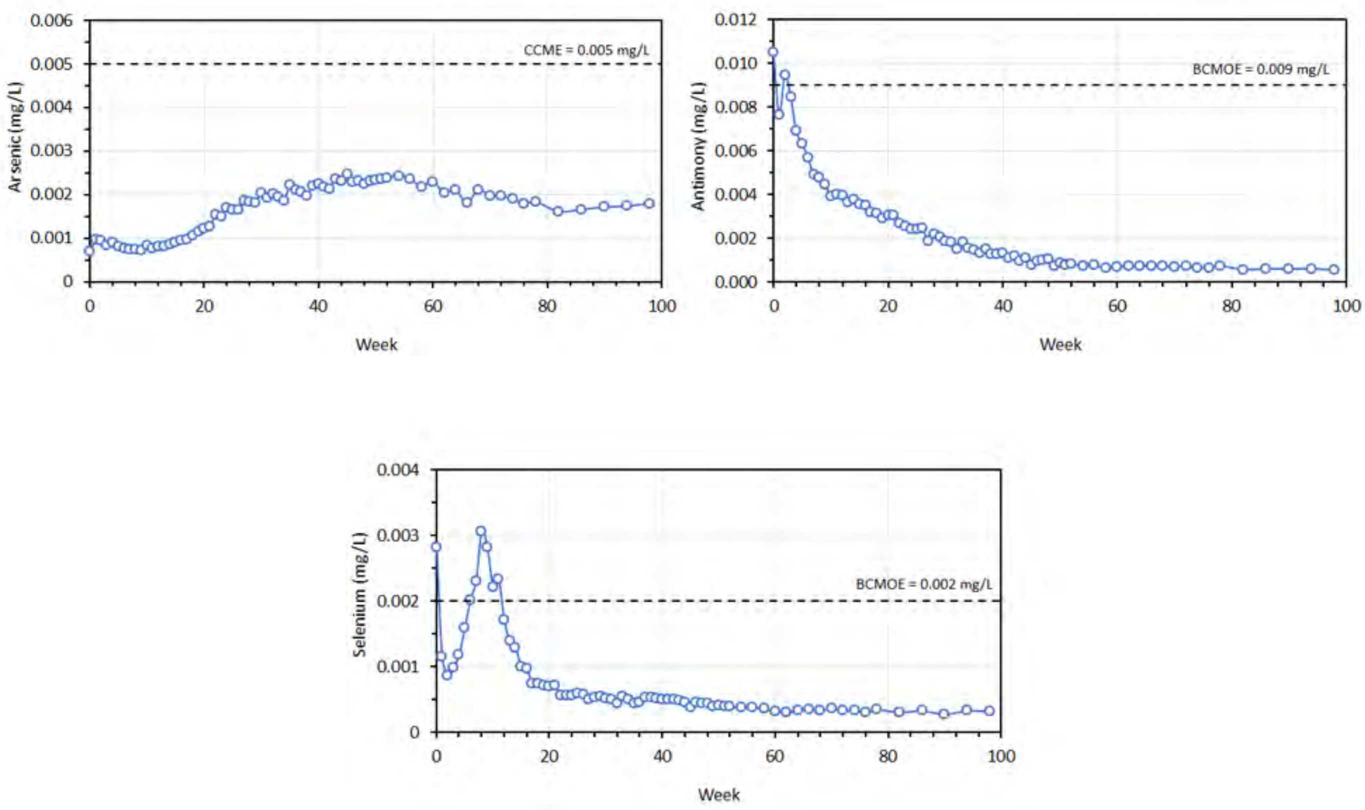


Figure 8-10: Arsenic, Antimony and Selenium Trends of Flame and Moth Humidity Cell

Bermingham

Two waste rock humidity cells were operated for Bermingham in order understand the potential for ARD/ML and rates of release from the Bermingham N-AML waste rock. The first humidity cell (HC-01) was constructed using a composite of N-AML Bermingham waste rock from cover holes with total sulphur and NP closer to the lower percentile (36%), NP close to the median (51%) of ABA data and an NPR of 4.1 (Total sulphur = 0.09 Wt.%; NP= 10.3 kg $CaCO_3$/t; AP= 2.5 kg $CaCO_3$/t). The cell also had trace metal contents close to the 70th percentile and was operated for 57 weeks. The second humidity cell (HC-03) was constructed using a composite of N-AML Bermingham waste rock from advanced exploration drill holes with total sulphur close to the 78th percentile, NP close to the 87%, AP close to the 79% of ABA data and an NPR of 2.6 (Total sulphur = 0.36 Wt.%; NP= 29.0 kg $CaCO_3$/t; AP= 11.3 kg $CaCO_3$/t). The second cell also had trace metal content close to the 90th percentile of the elemental data and is still operating. Figure 8-11 to Figure 8-13 show the cell leachate data collected for constituents of interest.

pH, Acidity, Alkalinity and Sulphate

Humidity cell HC-01 leachate was circumneutral (pH 6.7 to 7.6; Figure 8-11), with relatively low levels of alkalinity (4.5 to 16 mg/L $CaCO_3$) and negligible acidity (below or at the detection limit of 0.5 mg/L $CaCO_3$). Sulphate concentrations were also low (2.5 to 15.3 mg/L) and much lower than the sulphate WQO (352 mg/L; Figure 8-11).

Humidity cell HC-03 leachate was also neutral to slightly alkaline (pH 7.3 to 8.1) with relatively low levels of alkalinity (9.0 to 27.5 mg/L $CaCO_3$) and negligible acidity (0.5 to 1.1 mg/L $CaCO_3$). Sulphate concentrations from HC-03 were higher than HC-01, ranging between 16.6 and 42.8 mg/L, reflecting its higher sulphur content. The sulphate concentration difference between the two cells has gradually widened after cycle 16 but the sulphate concentration of the HC-03 was also much lower than the WQO (Figure 8-11).

Constituents of Interest

Aside from selenium in HC-01 and antimony in HC-03 first ten cycles, the concentrations of all constituents of interest in the Bermingham humidity cells were well below their respective WQO (Figure 8-11 to Figure 8-13). Aside from selenium, HC-03 had higher (pH, sulphate, zinc, nickel, arsenic, antimony and molybdenum) or comparable (cadmium, silver, lead and copper) leachate concentrations with HC-01.

Selenium in HC-01 concentrations peaked at 0.009 mg/L after week 1, then gradually declined such that is was below the WQO (0.002 mg/L) by week 11 (0.0018 mg/L). Selenium concentration in HC-03 had a similar trend as HC-01, but with concentrations constantly below the WQO. Cadmium concentrations of HC-01 and HC-03 were comparable and more two orders of magnitude lower than the WQO (0.017 mg/L). Arsenic concentrations in HC-03 was higher than HC-01, increased to 0.01 mg/L at week 3, remained around 0.01 mg/L for the next 4 weeks, then sharply declined such as comparable to HC-01 at week 23 (Figure 8-13).

The concentrations of cadmium, zinc, lead, nickel, and copper in the Bermingham N-AML humidity cell HC-01 and HC-03 were relatively low and more than an order of magnitude below their respective WQO (Figure 8-11 and Figure 8-12). Silver was below the detection limit in all humidity cells.

Sulphide and NP depletion times estimated for HC-01 were 21 and 39 years, respectively, and 30 and 39 years, respectively, for HC-03. This indicates that a significant amount of NP will remain after the depletion of sulphide minerals. HC-01 was terminated after the concentrations of constituents of interest had stabilized, while HC-03 is still ongoing.

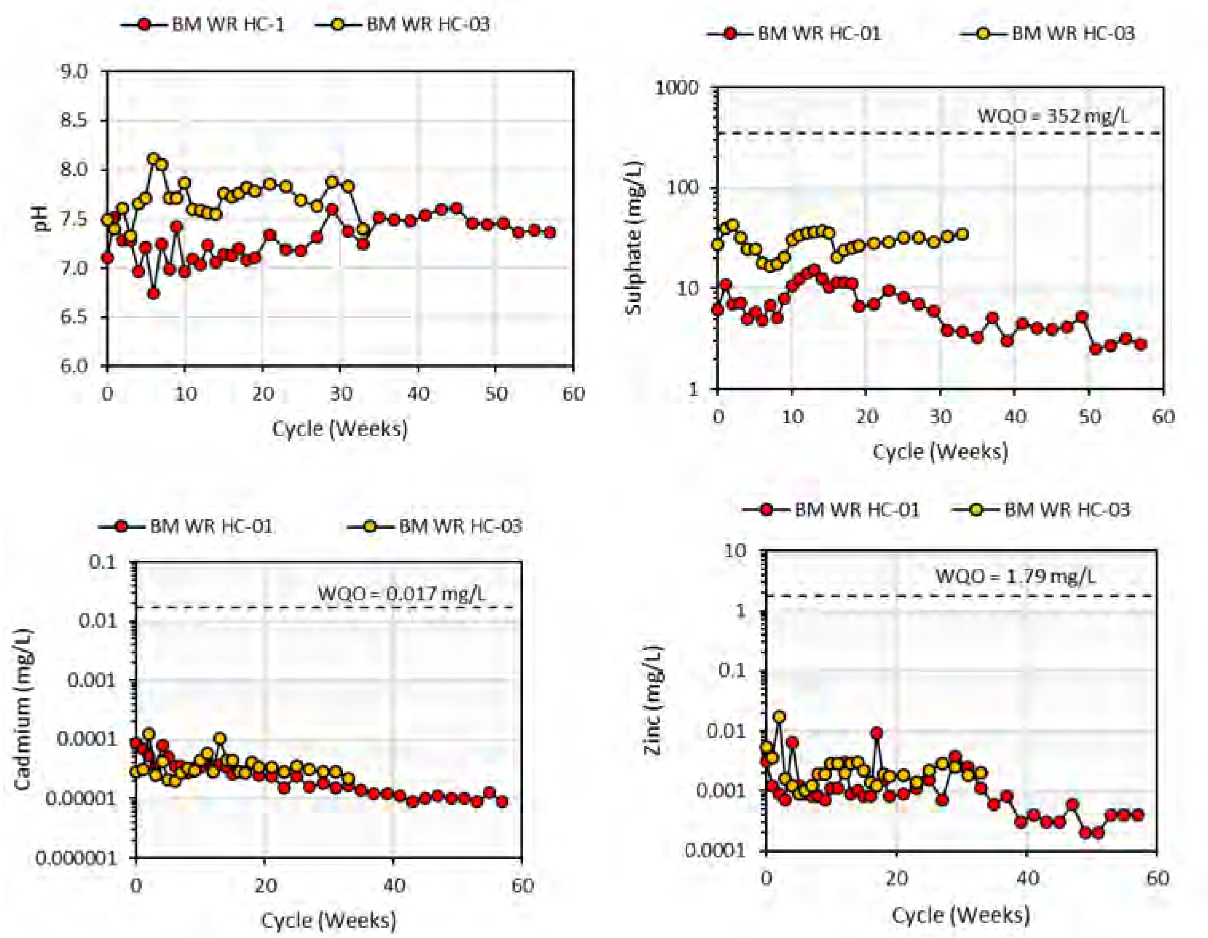


Figure 8-11: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends of Bermingham Humidity Cells

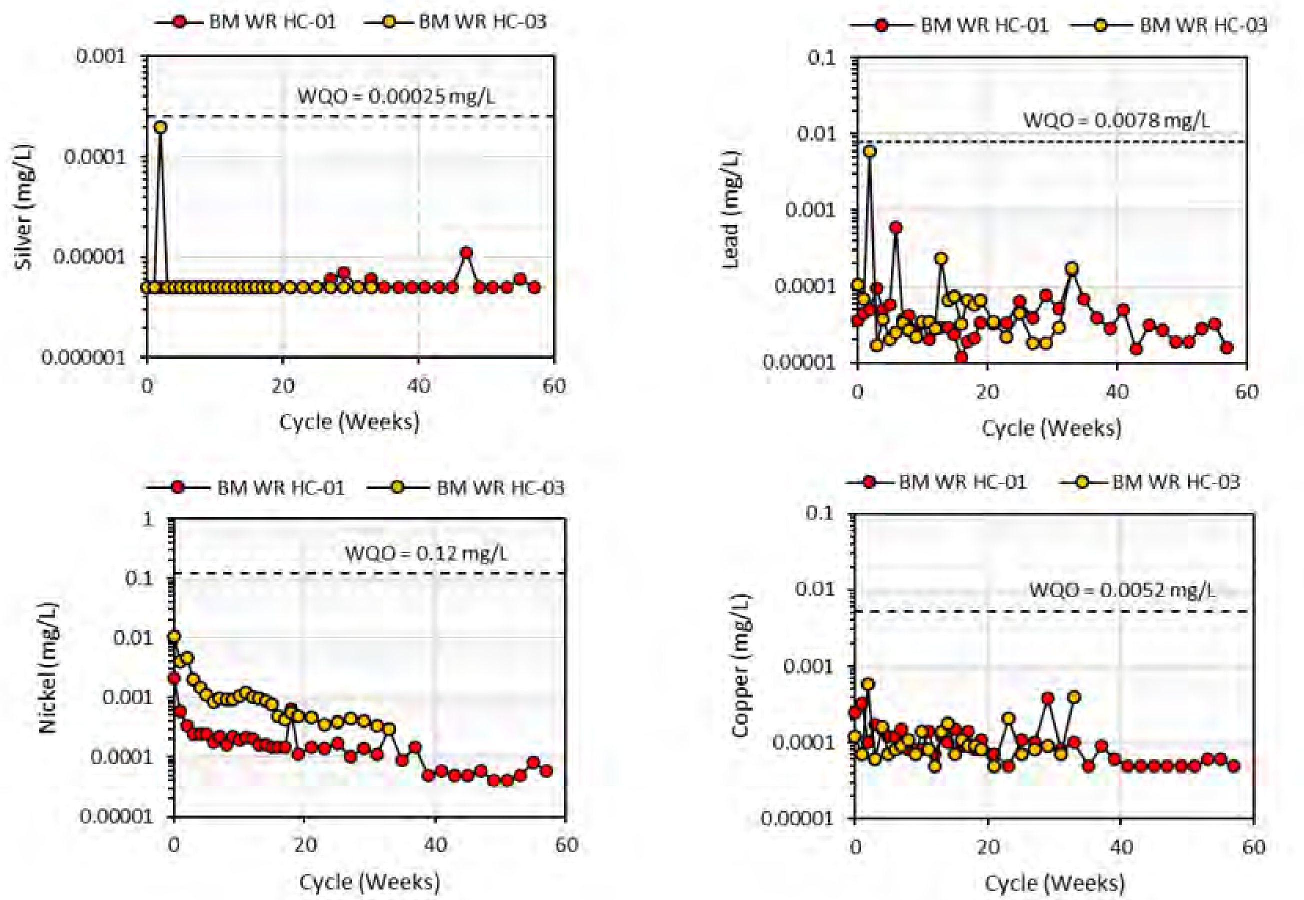


Figure 8-12: Silver, Lead, Nickel, and Copper Trends of Bermingham Humidity Cells

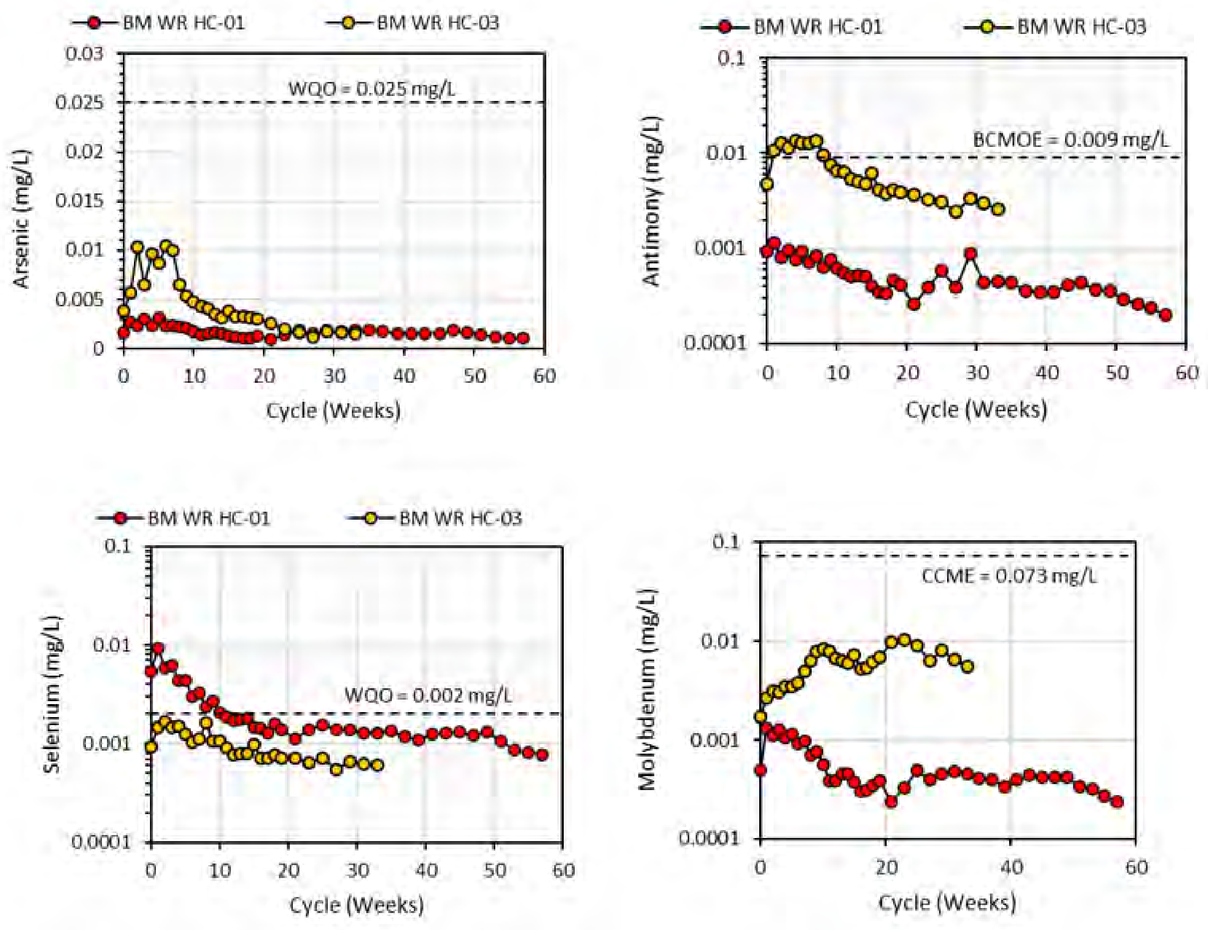


Figure 8-13: Arsenic, Antimony Selenium and Molybdenum Trends of Bermingham Humidity Cells

Field Leach Barrels

Five field barrels containing Flame and 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 geochemical characteristics of the waste rock and examine the impact of P-AML rock on the overall potential for ARD/ML from the dominantly N-AML waste rock materials that would be stored within surface waste rock dumps.

Field barrels 1 through 4 were created to examine P-AML and N-AML from the dominant lithologies to be encountered during the development of the Flame and Moth deposit. Field barrel 1 (FMB1) was filled with P-AML rock with elevated sulphur content (median 2.79%), median NPR <1, and high maximum metal concentrations. Field barrel 2 (FMB2) was filled entirely with N-AML rock and had the highest median NP, relatively low sulphur content and maximum metal content of all the field bins. Field barrels 3 and 4 (FMB3 and FMB4) were filled with N-AML rock based on Flame and Moth screening criteria. 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).

The results are discussed and displayed here and further details regarding the composition of the field barrels can be found in AEG (2016b). The field leach barrels are generally sampled at least four times a year except in 2019 when they were only sampled twice due to dry conditions and lack of leachate in the collection bins.

pH, Acidity, Alkalinity and Sulphate

The field barrel leachate pH has remained circumneutral to slightly alkaline during the monitoring period until 2016. Since 2016, leachate pH below 6.5 was constantly observed in FMB1 and occasionally observed (three times) in FMB2. FMB1 generally displayed pH below 6.0 values since September 2017. This was expected considering it contains P-AML material. The highest pH values were often recorded in the leachate from FMB3 although its pH decreased below 6.5 during September 2018 and 2019 samplings events. All N-AML barrels also had leachate pH <6.5 during the September 2018 and 2019 sampling events except FMB4 that had a pH of 7.6 in 2019 (Figure 8-14).

FMB1 consistently exhibited significantly higher acidity (<1.0 – 226 mg/L $CaCO_3$) than observed for FMB2, FMB3 and FMB4 (<1.0 – 4.8 mg/L $CaCO_3$). The acidity difference between FMB1 and the N-AML barrels increased as the test progressed reaching about 200 mg/L $CaCO_3$ during the 2018 last two sampling events then the gap decreased in May 2019 (Figure 8-14). The September 2019 acidity result for FMB1 was unusually high (1560 mg/L $CaCO_3$) as soluble products may have accumulated in the barrel since the barrel was not sampled between May and July. Alkalinity levels broadly showed a correlation with pH, as FMB1, which was had the lowest leachate pH range also had the lowest alkalinity (<0.5 – 56 mg/L $CaCO_3$). In general, alkalinity levels were the highest at the start of the experiment and declined gradually as the test progressed. FMB1 alkalinity was below the detection limit during the last six sampling events indicating a depletion of buffering capacity and explaining the acidic leachate pH observed.

FMB1 and FMB3 showed the highest and lowest dissolved sulphate concentrations, respectively (Figure 8-14). Dissolved sulphate concentrations were typically highest in the summer months (July-September) and lowest in the spring and fall sampling events, except for the 2017 and 2018 datasets, which showed a general increase in sulphate concentrations through the year. FMB1 recorded its highest sulphate concentration (4,930 mg/L) in September 2019. FMB1 sulphate concentrations always exceeded the BCMOE guideline (429 mg/L), FMB2 and FMB4 had sulphate about the BCMOE guideline and FMB3 generally had sulphate concentrations below the BCMOE. All field barrel samples exceeded the BCMOE sulphate guidelines in September 2019 likely due to the build up of soluble products in the field barrels between May and July and subsequent flushing in September.

Constituents of Interest

The trends of trace element were broadly reflected the P-AML / N-AML classification of the barrels. FMB1 was composed of potentially acid generating material and the leachate from it regularly contained the highest concentrations of zinc, cadmium, nickel, lead, copper, and silver (Figure 8-15 and Figure 8-16) with cadmium and zinc constantly exceeding the EQS and nickel and copper in exceedance since August 2016. FMB2, FMB3, and FMB4 were primarily composed of waste rock with low potential for ARD. These field barrels generally exhibited much lower zinc, cadmium, nickel, lead, copper, and silver leachate concentrations, and did not exceed any EQS except six copper exceedances in FMB4, and one copper, cadmium and zinc exceedance in FMB2 and FMB3 (Figure 8-15 and Figure 8-16).

Zinc

The lowest zinc concentrations were recorded in the Leachate from the N-AML FMB4, and were consistently below the CCME guideline (Figure 8-15). Zinc concentrations from FMB2 were also typically lower than the CCME guideline but higher than FMB4. Zinc concentrations from FMB3 were higher than FMB2 and recurrently higher than the CCME guideline but constantly lower than the EQS for zinc (0.5 mg/L) except during the last sampling and coinciding with the high sulphate and low pH measurements. FMB1 consistently showed the highest increasing zinc concentrations (0.4 – 722 mg/L) between 2013 and 2019. Almost all the FMB1 samples exceeded the EQS for zinc and were one to two orders of magnitude higher than the zinc levels recorded in the other field barrels. Zinc concentrations observed in 2017 and 2018 in FMB1 were generally higher than in previous years and coincided with the high sulphate and acidity levels. This metal leaching pattern reflects the character of P-AML rock in FMB1. The zinc concentration in leachates collected from the N-AML field leach barrels FMB1, FMB2, and FMB3 have remained lower than the EQS to date except for the September 2019 sampling event for FMB3. The high zinc release in 2019 coincided with the high sulphate release indicating a common source, likely the flushing of soluble weathering products stored in the field barrels between May and September.

Cadmium

Cadmium concentrations had very similar trends to those of zinc (Figure 8-15). Cadmium concentration in the leachate from FMB1 and FMB3 exceeded the CCME guideline (0.00037 mg/L) for all samples collected to date. Cadmium concentration in FMB2 leachate also regularly exceeded the CCME guideline except during one sampling in 2015. FMB4 cadmium concentrations were regularly lower or just slightly above CCME except in September 2019 when the concentration was much higher than the CCME guideline. FMB1 displayed the highest cadmium concentrations (0.01 – 1.5 mg/L), all of which exceeded or comparable to the EQS (0.01 mg/L), further confirming that its material is P-AML. Like zinc, cadmium concentrations observed in 2017 and 2018 in FMB1 leachate were higher than in previous years, coinciding with the high sulphate and acidity in 2017 and 2019. The other three N-AML field barrels contained cadmium levels that were below the EQS except the last sampling event of FMB3 where the concentration was above the EQS (0.0315 mg/L). Like zinc and sulphate, unusually high cadmium concentrations were recorded in all field barrels in September 2019.

Nickel

Nickel concentrations were also highest in the leachate from the P-AML FMB1 barrel (Figure 8-15), exceeded the CCME threshold (0.15 mg/L) for all FMB1 samples since June 2015, and higher than the nickel EQS (0.5 mg/L) in three consecutive sampling events in the summer and fall of 2015, and the majority of sampling events since July 2016. Like zinc and cadmium. nickel concentrations observed in 2017 and 2018 in FMB1 leachate were generally higher than in previous years and coincided with high sulphate and acidity levels in 2017 and 2019. Nickel concentrations in the leachate from the three N-AML field barrels (FMB2, FMB3 and FMB4) have gradually declined during the test period until September 2019 when relatively high nickel concentrations were recorded. Nickel concentrations in leachate from FMB2, FMB3 and FMB4 were consistently lower than the CCME guideline and EQS. Like zinc, sulphate, and cadmium, unusually high nickel concentrations were measured in all field barrels in September 2019 likely due to accumulation of soluble nickel-bearing weathering products over the summer.

Lead

FMB1 generally contained the highest lead concentrations (0.0013 – 0.74 mg/L) constantly exceeding the CCME threshold (0.007 mg/L) since August 2016. Lead concentrations in FMB1 also exceeded the EQS (0.2 mg/L) in July 2018 and September 2019 (Figure 8-15). This confirms the P-AML nature of its waste rock content. FMB1 lead concentrations observed in 2017, 2018, and 2019 were generally also higher than in previous years and coincided with the high sulphate and acidity levels measured in 2017, 2018 and 2019. Lead concentrations from the three N-AML field barrels (FMB2, FMB3 and FMB4) were typically below the CCME guideline (0.007 mg/L; Figure 8-15) except in a few instances for FMB2 and one instance for FMB4. Like previous constituents of interest, the highest lead concentrations were recorded in September 2019, likely due to flushing of soluble lead-bearing weathering products accumulated over the summer. The lead concentrations observed in the leachate from the N-AML field barrels in September 2019 were broadly consistent with historical levels.

Copper

Copper concentrations had similar trends as lead except there was a higher rate of exceedances of the CCME copper guideline and EQS in leachates from N-AML barrels. FMB1 generally had the highest copper concentrations over the monitoring period (0.003 – 7.7 mg/L), exceeding the EQS (0.1 mg/L) in the first three sampling events in 2013 and for the majority of the 2017 – 2019 sampling events (Figure 8-16). Copper concentrations in N-AML FMB3 remained below both the EQS and CCME guideline for the majority of sampling events since late 2014 except in August 2018 and September 2019. Conversely, FMB2 exceeded the copper EQS once in 2017 and FMB4 periodically exceeded the EQS since 2016. The copper concentrations from both FMB2 and FMB4 frequently exceeded the CCME threshold since the beginning of each test (Figure 8-16). Like all previous metals, an unusually high copper concentration was measured in FMB1 in September 2019 due to flushing of accumulated weathering products. The copper concentrations observed in the leachate from the N-AML field barrels in September 2019 were broadly consistent with historical levels.

Silver

FMB1 displayed the highest silver concentration of all field leach barrels (<0.00005 – 0.001 mg/L). Silver concentration in P-AML FMB1 was comparable to the N-AML field barrels (<0.00001 - 0.0001 mg/L; Figure 8-16) until September 2017 after which the silver concentration in the leachate from N-AML field barrels fell below the detection limit whereas the P-AML silver concentration remained an order of magnitude higher. Only the initial sampling event and the September 2019 sample (0.00046 and 0.001 mg/L, respectively) of FMB1 had exceeded the silver CCME guideline (0.00025 mg/L; Figure 8-16). The silver levels in leachates from 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 had comparable levels of arsenic (typically 0.0005 – 0.012 mg/L), which were below the CCME threshold (0.005 mg/L) for all but three FMB1 samples (Figure 8-16). Arsenic concentrations in FMB2 and FMB4 were also comparable (0.006 – 0.019 mg/L), higher than FMB1 and FMB3, and exceeded or were comparable to the CCME guideline for the majority of samples (Figure 8-16). Arsenic concentration in FMB2 leachate is gradually decreasing since May 2016 such that the concentrations were recurrently below the CCME since late 2017. The arsenic concentrations in all the field barrel leachates were well below the EQS (0.1 mg/L). Unlike all constituents of interests discussed thus far, no increase of arsenic concentration was observed in any of the N-AML field barrels in September 2019.

Antimony

The antimony leaching behaviour was similar to arsenic in the sense that the lowest antimony concentrations were observed in leachate from FMB1 and FMB3 (0.0013 – 0.026 mg/L), in which the majority of the samples were comparable to or below the BCMOE working guideline (0.009 mg/L) (Figure 8-16). The antimony concentrations in the FMB4 and FMB2 were the highest and above or comparable to the BCMOE guideline, with the latter field barrel showing the highest antimony concentrations (0.012 – 0.071 mg/L). A declining trend of antimony concentration was broadly observed for all barrels, with the sharpest decline observed in FMB2. Like arsenic, no increase of antimony concentration was observed in any of the N-AML field barrels in September 2019.

Selenium

The selenium concentrations in the field barrels exceeded the BCMOE guideline (0.002 mg/L) for all (FMB2 and FMB4) or the majority (FMB1 and FMB3) of samples collected to date (Figure 8-17). The lowest (FMB3: 0.00037 – 0.0087 mg/L) and highest (FMB2: 0.002 – 0.065 mg/L; FMB4: 0.0037 – 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. It is however worth noting that an identical selenium pattern was observed for all field barrels since June 2016 despite the difference in selenium absolute concentrations and FMB1 and FMB3 were almost comparable during the same period. Also, an increase in leachate selenium concentration was observed in all field barrels in September 2019.

The similar patterns of zinc, cadmium, nickel, copper, and lead and their high concentrations in the P-AML leach barrel FMB1, coincident with high sulphate and acidity levels, indicate a common source via sulphide oxidation. Conversely, the low concentrations of arsenic, antimony, and selenium in FMB1 leachates compared with the N-AML field barrels may suggest lower release rate of oxyanions under acidic conditions of the P-AML rock drainage compared with circumneutral N-AML drainage. A decrease of pH below 6.5 was observed in FMB3 in September 2018 and 2019. This tendency toward acidic pH may explain the low concentrations of arsenic, antimony and selenium in this barrel similar to that observed for the P-AML FMB1.

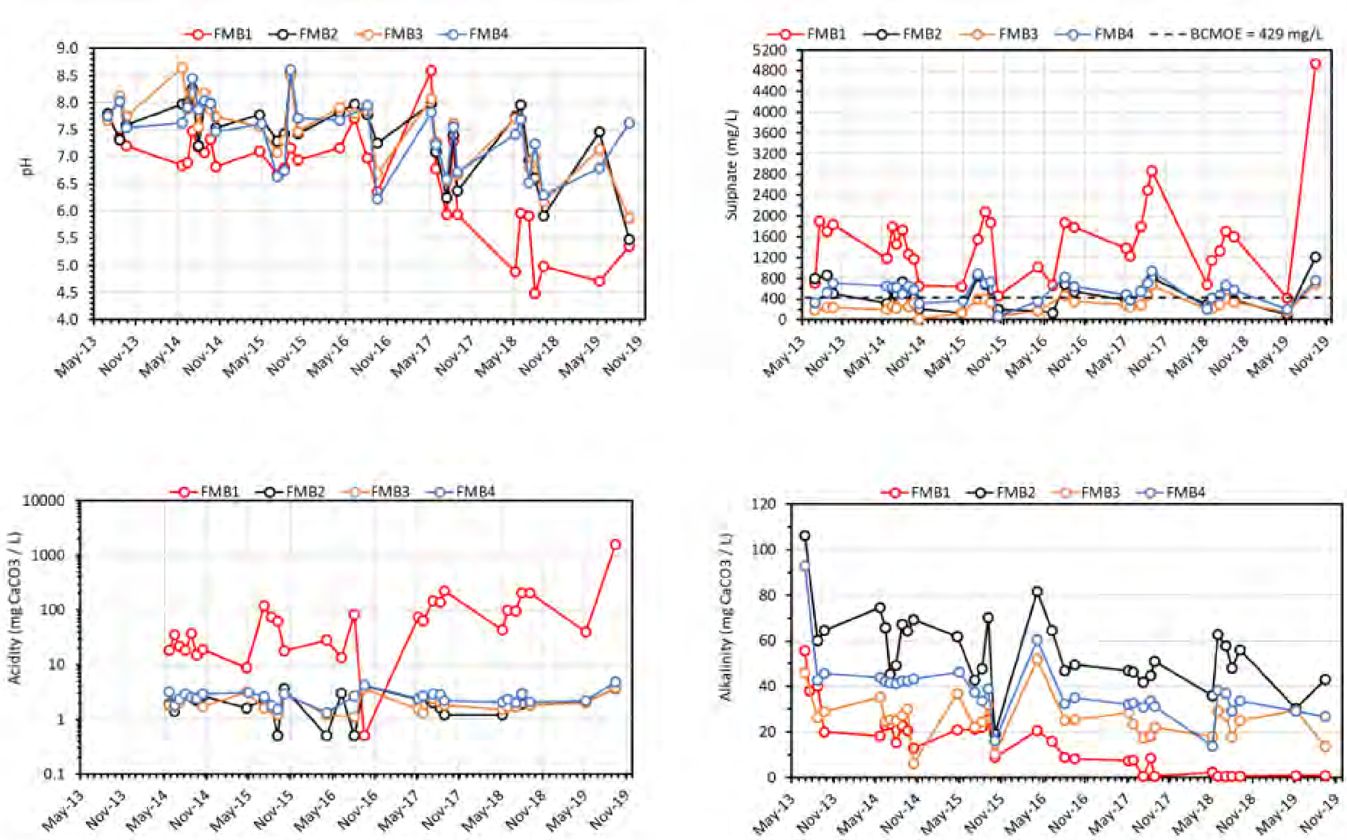


Figure 8-14: Trends of pH, Sulphate, Alkalinity and Acidity in Flame and Moth Field Barrels

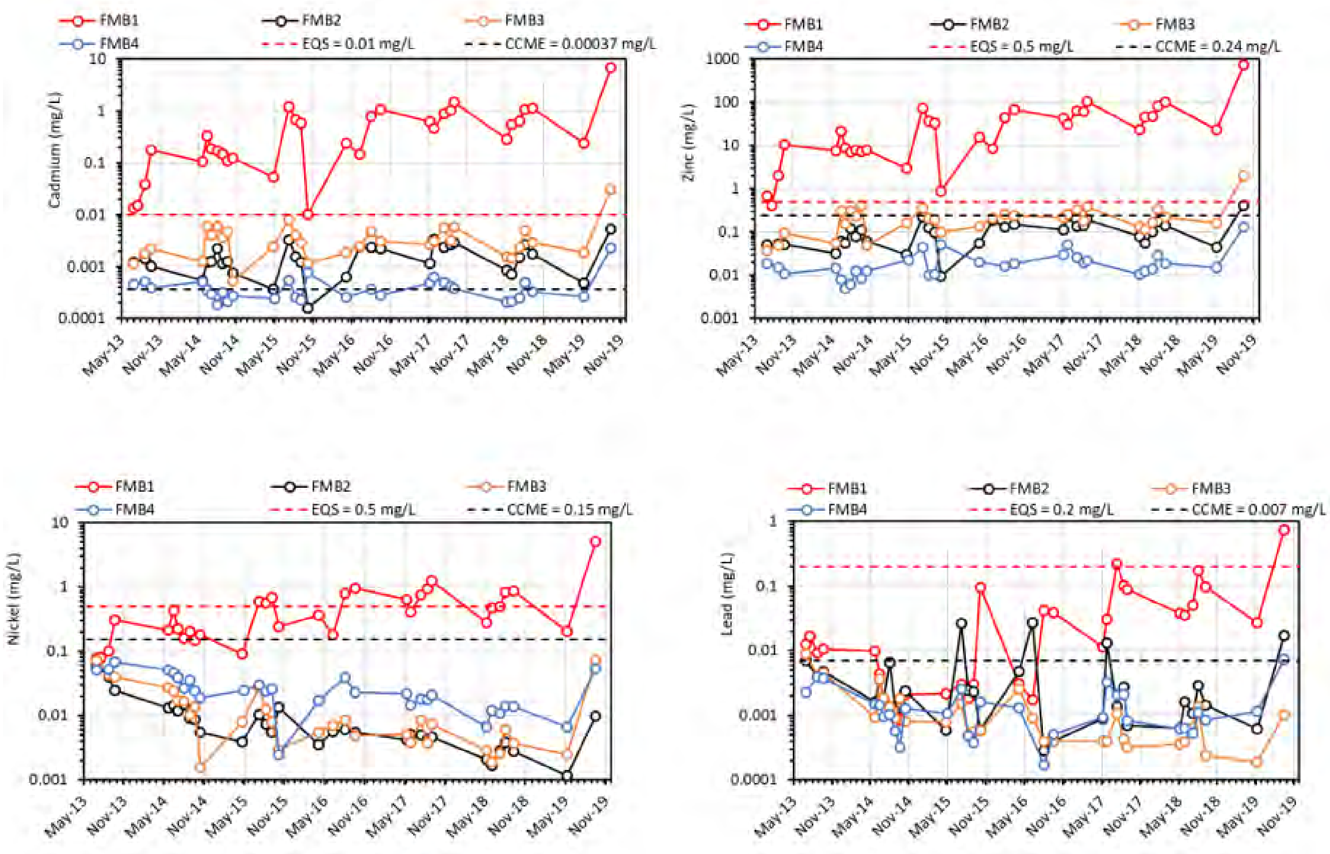


Figure 8-15: Trends of Cadmium, Zinc, Nickel, and Lead Concentration in Flame and Moth Field Barrels

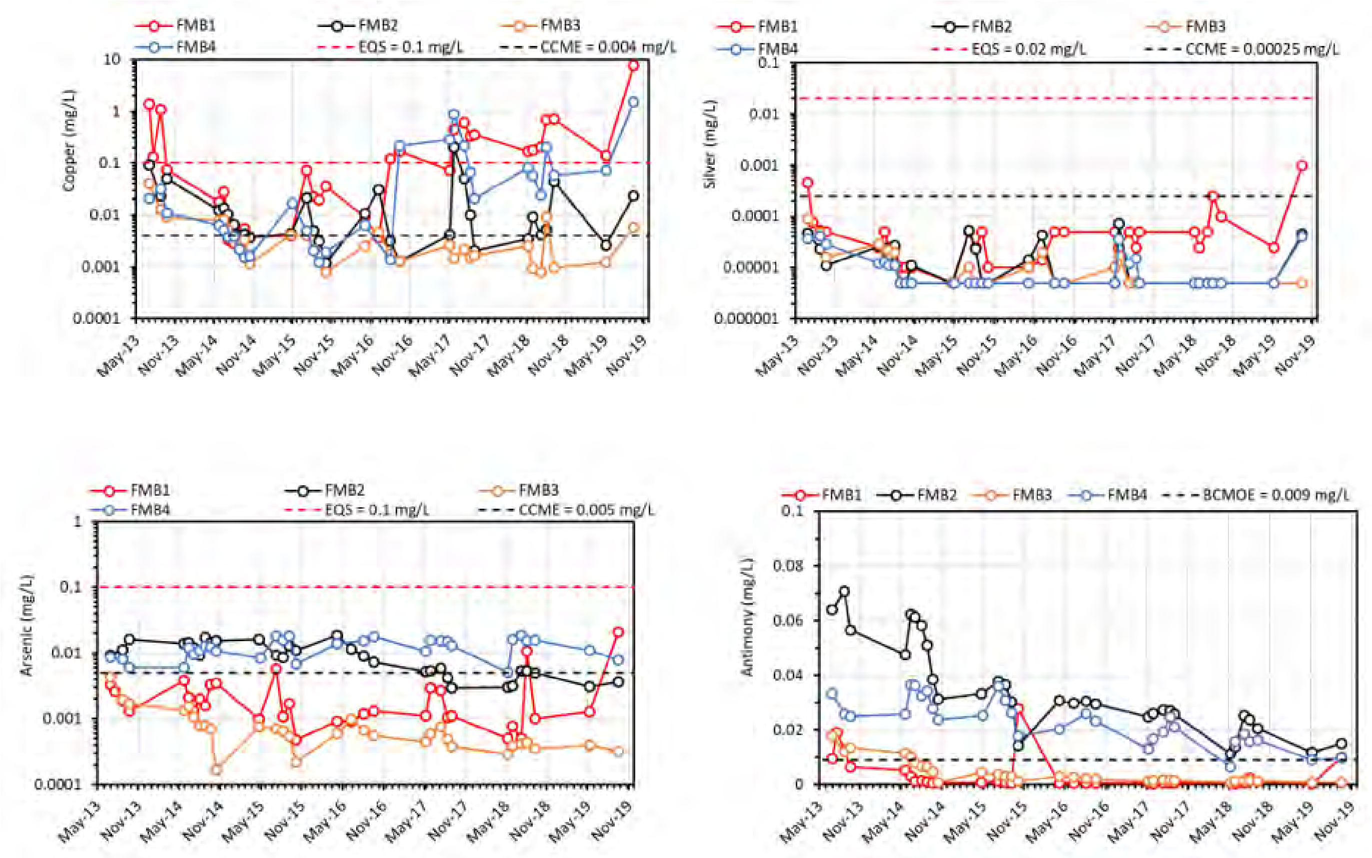


Figure 8-16: Trends Copper, Silver, Arsenic, and Antimony Concentrations in Flame and Moth Field Barrels

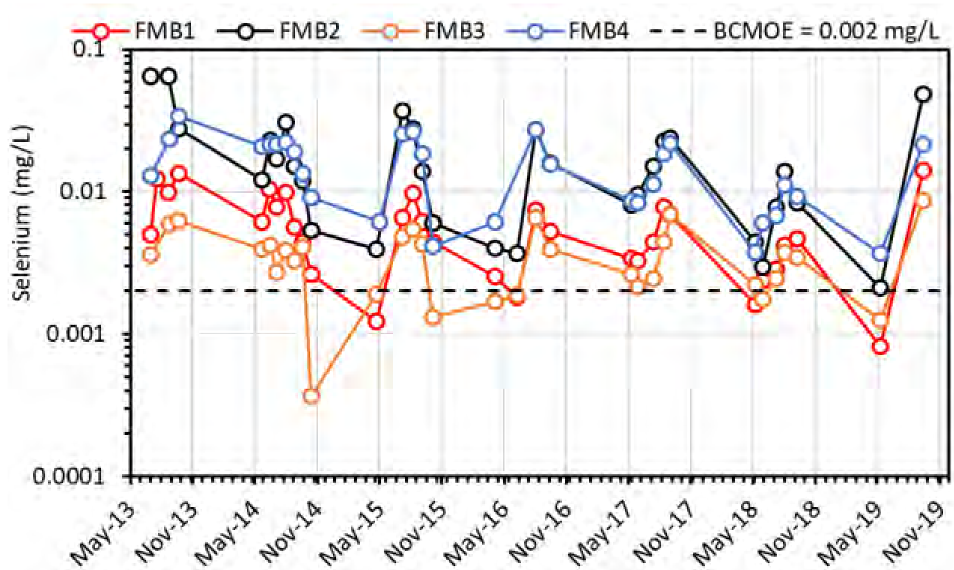


Figure 8-17: Trends of Selenium Concentrations in Flame and Moth Field Barrels

8.3 TAILINGS

AKHM also carried out geochemical characterization of the tailings from each of the mineralized target zones in order to understand their potential ARD/ML). These characterization studies have been ongoing for several years and continue to date. The results of the characterizations were reported in (ACG, 2012, 2015) for the Onek, Lucky Queen and Flame and Moth tailings and in AEG (2019c) for Bermingham and are summarized herein. This section also provides a comparison of the main geochemical characteristics of the tailings from Flame and Moth, Bellekeno, Lucky Queen and Bermingham.

8.3.1 LABORATORY TEST PROGRAM

The laboratory test program included static and kinetic tests. The static testing consisted of:

- Acid-base accounting;
- Elemental analysis;
- Shake flask extraction (MEND SFE);
- Net acid generating (NAG); and
- Mineralogy by X-ray diffraction (XRD) with Rietveld refinement.

The kinetic testing consisted of standard laboratory humidity cell as follow:

- Flame and Moth tailings (113 weeks, completed);
- Bellekeno tailings (208 weeks, completed); and
- Bermingham tailings (67 weeks, ongoing).

8.3.2 RESULTS

Static Testing

Acid-Base Accounting

The results of the ABA testing for Bermingham Locked Cycle (LC), Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, Flame and Moth F4+F5 composite tailings and the average of monthly ABA analyses of composite tailings samples produced from Bellekeno are presented in Table 8-5.

The tailings from the deposits generally have similar ABA characteristics: They had circumneutral to slightly alkaline paste pH (7.8 to 8.1) and high carbonate NP (273 to 389 kg $CaCO_3$/t). Their NP from carbonates was significantly higher than the siderite-corrected bulk NP (100 to 132 kg $CaCO_3$/t) indicating that iron and/or manganese carbonates such as siderite (FeCO3) comprise a substantial portion of the carbonate mineralogy.

ABA shows that the Bermingham LC tailings have a slightly alkaline paste pH (7.6 - 8.15), a very high carbonate neutralization potential (carbonate-NP; 184-204 kg $CaCO_3$/t) and relatively low bulk neutralization potential (bulk NP; 50.5 - 56 kg $CaCO_3$/t). The carbonate-NP was nearly four times higher than the bulk NP due to the anticipated presence of iron and/or manganese carbonates (i.e., siderite and ankerite) that do not contribute to the net acid neutralization. The sulphate content of the tailings samples was at the detection limit of 0.01 wt. % indicating that the bulk of total sulphur (1.29 -1.38 wt.%) consisted of sulphide-sulphur.

The sulphate contents of the tailings from Bermingham, Flame and Moth, Bellekeno, Lucky Queen and Onek were also extremely low (maximum = 0.04 wt. %) indicating that sulphide-sulphur was the sulphur species. The Bellekeno tailings had the highest sulphide-sulphur content (2.21 wt.%), followed by the Bermingham (1.29 -1.38 wt.%). The tailings from the Flame and Moth, Lucky Queen and Onek had sulphide-sulphur concentrations less than 0.5 wt.%; Table 8-5. The NPR, calculated as the ratio of the (siderite-corrected) NP to AP indicates that the Bermingham and Bellekeno tailings were classified as "Uncertain" and had an NPR of 1.3 and 1.9, respectively. Onek, Lucky Queen and Flame and Moth tailings where all non-PAG and had NPR > 7.

ABA data indicate Uncertain potential for ARD for Bermingham and Bellekeno tailings and further testing or expert judgment are needed to provide a final ARD classification of the material. The bulk NP may be underestimated due to the oxidation of Mn (II) during the siderite-corrected NP method, as a s results the NPR for the Bermingham and Bellekeno tailings samples could be much higher and the tailings non-PAG. This is supported by detailed mineralogical examination of historic tailings deposited in the KHSD in which material initially classified as PAG by conventional ABA analysis was found to be non-PAG when its manganese carbonate content was included in the NPR calculation (AEG, 2019c).

Table 8-5: Results of ABA of Bermingham LC, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Sample	Paste pH	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur	CO_2	CO_3-NP	Siderite-Corrected NP	AP	NPR
	pH Units	Wt. %	Wt. %	Wt. %	Wt. %	kg $CaCO_3$/t			Unitless
Berm LCT1	7.6	1.30	0.01	1.29	8.09	184	50.5	40.3	1.3
Berm LCT2	8.2	1.39	0.01	1.38	8.96	204	56.3	43.1	1.3
Onek F7 + F8 average	7.8	0.16	0.04	0.12	n/a	n/a	31.4	3.8	8.4
Lucky Queen F9 + F10 average	7.9	0.19	0.04	0.15	n/a	n/a	19.1	4.5	4.2
Flame & Moth F4+F5 Composite	8.0	0.45	0.02	0.43	17.1	389	100	14.1	7.1
Bellekeno Tailings, Jan 2011- July 2013 Monthly Avg.	8.1	2.3	0.02	2.21	12	273	132	71.7	1.9

Notes:

AP: acid potential: **NP: neutralization potential; NPR: neutralization potential ratio**

Sequential NAG

The NAG test is commonly used to determine the potential for net acid generation of geologic material or as a cross check on the ABA results. During the NAG test, hydrogen peroxide rapidly oxidizes the sulphide minerals in the sample. The NAG test was only done on Bermingham tailings and was performed sequentially such that four successive NAG cycles were conducted on the same sample to ensure the oxidation of all sulphide-sulphur. The pH of the NAG leachate after each cycle provides an indication of the capacity of the acid neutralizing of the sample to buffer the acid produced from sulphide oxidation. The NAG test indicates that a sample is non-PAG if the NAG pH is greater than 4.5 and PAG if the NAG pH is less than 4.5.

Table 8-6 shows that a negligible amount of acidity (i.e., 0.19 kg $CaCO_3$/t) was generated during the test and only during the first cycle suggesting that the sulphides in the tailings are not reactive. The potential for acid generation is considered low because the NAG pH was greater than 4.5 during the four cycles. The sequential NAG provides clarification regarding the "Uncertain" acid generation potential indicated by the ABA work – that is, net acid generation is not expected from Bermingham tailings. The kinetic testing will provide further confirmation of the ARD potential of these tailings.

Table 8-6: Results of Sequential NAG for Bermingham Tailings

Sample ID	Cycle Number	NAG pH	NAG Volume to pH 4.5	NAG Volume to pH 7.0	NAG NaOH Conc.	NAG Acidity pH 4.5	NAG Acidity pH 7.0
		pH Units	mL	mL	N	kg $CaCO_3$/t	kg $CaCO_3$/t
Berm LCT2	Cycle 1	6.56	-	0.1	0.1	-	0.192
	Cycle 2	7.81	-	-	0.1	-	-
	Cycle 3	8.28	-	-	0.1	-	-
	Cycle 4	7.81	-	-	0.1	-	-

Mineralogy

The results of the XRD reported in Table 8-7 show that the Bermingham, Flame and Moth and Bellekeno tailings are mainly composed of quartz (SiO_2; 45.2 to 63.2 wt. %) and calcium rich siderite ($FeCO_3$; 21.2 to 45.3 wt. % as calcian siderite). The Bermingham tailings contain pyrite (FeS_2; 1.6 to 2.2 wt. %) as the main sulphide and sphalerite (ZnS; 0.3 to 0.6 wt. %) and galena (PbS; 0.3 to 0.8 wt. %) as secondary. Bellekeno tailings had similar pyrite content (2.3 wt.%) as Bermingham and Flame and Moth pyrite content were lower (0.7 wt.%). Bellekeno tailings had the highest sphalerite and galena (2.4 wt.% sphalerite; 0.6 wt.% galena), Bermingham tailings had 0.3 to 0.6 wt.% sphalerite and 0.3 to 0.8 wt.% galena, while the Flame and Moth composite tailings were devoid of sphalerite and galena.

Bermingham tailings contained another carbonate mineral with no effective buffering capacity, ankerite (Ca (Fe, Mg, Mn) $(CO_3)2$; 1.0 to 1.4 wt. %). Ankerite was also found in the Bellekeno tailings (0.4 wt.%), but was not in the Flame and Moth composite. Flame and Moth and Bellekeno tailings contained 1.2 and 3.2 wt.% calcite, respectively, but no calcite ($CaCO_3$) was detected in the Bermingham tailings.

These XRD data indicate that the AKHM tailings consist predominantly of geochemically inert silica and iron and manganese carbonate minerals. The major difference between the three tailings is the lack of calcite in the Bermingham tailings and absence of sphalerite and galena in the Flame and Moth tailings. Iron and manganese carbonates have a net neutral buffering capacity under aerobic conditions because the amount of acidity consumed during dissolution is subsequently generated during the oxidation and hydrolysis of ferrous iron. However, the XRD data indicates a calcium rich siderite where substitution of calcium for iron occurs which may result in some neutralization capacity of a portion of the siderite.

The Bermingham potential AP estimated from the pyrite content of the tailings (AP = ~37 kg $CaCO_3$/t) is slightly lower than the AP from the ABA (average 42 kg $CaCO_3$/t) meaning that the sulphide-sulphur from galena and sphalerite, minerals that do not generate acid when oxygen is the only oxidant, may be the source of excess of AP in the ABA test. The XRD data also corroborate the Bermingham tailings ABA showing that the low bulk NP is due to the deficiency in calcite. The higher AP for the Bellekeno sample reflects its elevated pyrite and sphalerite contents and the presence of trace chalcopyrite and wurtzite. The low sulphide mineral content (0.7 wt.% as pyrite) of the Flame & Moth sample confirms its low AP.

Table 8-7: Results of XRD of Bermingham, Flame and Moth and Bellekeno Tailings

Mineral	Bermingham LCT1	Bermingham LCT2	Flame & Moth F4 + F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13
Ankerite – Dolomite	1.4	1.0	-	0.4
Calcite, Magnesian	-	-	1.2	3.2
Cassiterite	-	-	0.5	-
Clinochlore	-	-	1.3	0.4
Dravite	-	-	3.2	-
Galena	0.8	0.3	-	0.6
Illite-Muscovite 2M1	9.6	8.2	2.5	6.6
Kaolinite	1.0	0.9	-	-
Pyrite	1.6	2.2	0.7	2.3
Quartz	63.2	59.3	45.2	52.6
Rutile?	0.6		-	0.3
Siderite, calcian	21.2	27.8	45.3	29.8
Sphalerite	0.6	0.3	-	2.4
Plagioclase	-	-	-	0.8
Gahnite	-	-	-	0.2
Chalcopyrite	-	-	-	0.1
Wurtzite	-	-	-	0.2
K-Feldspar	-	-	-	0.3
Total	100	100	100	100

Elemental Chemistry

The results of the elemental analysis of the Bermingham LC, Flame and Moth F4+F5 composite tailings, Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, and the monthly average of tailings from Bellekeno between July 2012 and August 2013. are presented in Table 8-8.

The screening of the tailings metal content against the 10x their crustal abundance (CRC, 2005) indicates that antimony, arsenic, bismuth, cadmium, lead, manganese, selenium, silver, and zinc were typically high. The elevated metals and metalloids concentration were expected considering the source of the parent material (i.e., ore).

The Bermingham tailings had similar arsenic content as Onek, 1.7 and more than 5 times less arsenic than Flame and Moth tailings and Bellekeno, respectively. Lucky Queen tailings had the lowest; twenty times less than Bermingham and Onek. The highest concentration of antimony was in the Bellekeno (121 ppm), 1.7 and 3 time greater than the Bermingham average and Flame and Moth tailings, respectively. Onek and Lucky Queen had the lowest antimony content below 10 ppm.

Cadmium and zinc concentration in the Bermingham tailings were higher than both Lucky Queen (4- to 11-fold higher) and Flame and Moth (2- to 3-fold higher) tailings, but approximately 2- and 7-fold lower than the Onek tailings and Bellekeno, respectively. Bermingham had the highest lead concentration among all tailings but sample BERM LCT1 (7,460 ppm) was 3 times higher than BERM LCT2. Bellekeno also had very high lead content (6,359 ppm) and Onek, Lucky Queen, and Flame and Moth tailings had concentrations below 800 ppm. The Bellekeno tailings generally had the highest concentration of arsenic, antimony, cadmium, and zinc concentrations.

The Bermingham, Flame and Moth and Bellekeno tailings contained comparable concentrations of selenium. One Bermingham tailings sample LCT2 and Bellekeno also had comparable silver content 50 to 56 ppm, that was higher than Flame and Moth, Onek and Lucky Queen. Bermingham tailings sample LCT1 had a silver concentration double that of Bellekeno.

The elemental concentrations of lead and zinc are particularly elevated in Bellekeno, Lucky Queen and Bermingham tailings because they are the main base metals in sphalerite, galena, chalcopyrite and wurtzite that remained in the tailings after processing as the XRD results suggest. The high concentration of arsenic is likely due to its known presence as trace element in sulphidic ore.

Table 8-8: The results of Metal Analysis of Bermingham LCT, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Element	Unit	Berm LCT1	Berm LCT2	Onek F7 + F8 average	Lucky Queen F9 + F10 average	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite Jul 12 - Aug 13
Aluminum (Al)	%	0.15	0.16	0.36	0.74	0.2	0.2
Antimony (Sb)	ppm	99.8	44.6	<5	9	41	120.6
Arsenic (As)	ppm	369	401	375	17.5	699	2147
Barium (Ba)	ppm	30	30	24	125	11.5	16.4
Bismuth (Bi)	ppm	0.06	0.04	<2	<2	6.59	2.1
Cadmium (Cd)	ppm	46.1	23.4	72.8	3.95	7.19	165.8
Calcium (Ca)	%	0.63	0.73	0.47	0.38	0.59	1.52
Chromium (Cr)	ppm	133	115	174	265.5	185.5	5.5
Cobalt (Co)	ppm	4.3	4.3	2	3	2.7	9.9
Copper (Cu)	ppm	60.8	57.5	377	254	565	242.4
Iron (Fe)	%	6.35	7.07	18.6	6.4	16.3	10.1
Lead (Pb)	ppm	7460	2330	413	555	789	6359
Magnesium (Mg)	%	0.32	0.36	0.47	0.34	0.31	0.31
Manganese (Mn)	%	37900	4.43	5.19	2.47	4.28	3.22
Mercury (Hg)	ppm	0.19	0.13	-	-	0.055	0.19
Molybdenum (Mo)	ppm	2.06	2.02	<1	2	3.74	1.16
Nickel (Ni)	ppm	49.8	49.1	44	51	86.6	19.5
Phosphorus (P)	%	290	0.032	0.014	0.013	0.01	0.02
Potassium (K)	%	0.07	0.08	0.08	0.275	0.03	0.04
Selenium (Se)	ppm	0.9	0.8	-	-	0.1	0.52
Silver (Ag)	ppm	99.6	56.4	6.4	16.4	12.35	50.1
Sodium (Na)	%	<0.01	<0.01	0.02	0.025	0.006	0.014
Strontium (Sr)	ppm	14.3	15	11	15	4.81	24
Thallium (Tl)	ppm	0.78	1.9	17.5	11	0.652	0.129
Tin (Sn)	ppm	2.7	2	-	-	32.9	17.6
Titanium (Ti)	%	<0.005	<0.005	<0.01	0.02	0.001	0.002
Uranium (U)	ppm	0.39	0.38	-	-	0.406	1.052
Vanadium (V)	ppm	6	5	5.5	12.5	9.4	5.18
Zinc (Zn)	ppm	3510	2080	8784	557	1265	12623

Shake Flask Extraction

SFE data was used to screen for potential exceedances of water quality objectives, discharge standards or generic water quality guidelines. The SFE data was here compared to the Keno Hill District Mill Site pond effluent quality standards (EQS) at KV-83. This comparative assessment is not and should not be used as a measure of compliance with site water quality standards and objectives. It rather provides a guide for assessing for constituents of potential concern in drainage from the tailings.

The results of the SFE of all tailings and EQS at KV-83 are reported in Table 8-9. Table 8-9 shows that all tailings had a circumneutral pH (pH= 7.3 - 8.2), within the EQS range and consistent with the ABA paste pH. Bermingham tailings had very low leachable sulphate content (19.1- 46.1 mg/L) and extremely low acidity (often less than the method detection limit of 0.5 mg/L $CaCO_3$). Flame and Moth and Lucky Queen had 4 to 7 times higher leachable sulphate than Bermingham in the order of 140 - 250 mg/L.

The screening of the SFE data against the Mill pond EQS indicates that none of the regulated elements exceeded the Mill pond EQS indication low potential for the release of high concentrations of these elements from the tailings. The solubility of metals and metalloids highlighted as elevated in the tailings in elemental chemistry section did not generate exceedances despite the vigorous condition of the SFE test.

Table 8-9: The Results of SFE of the Bermingham LCT, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Leachable Metals	Unit	Berm LCT1	Berm LCT2	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13	Lucky Queen F9	Lucky Queen F10	KHSD Mill Site EQS (KV-83)
pH	pH units	7.27	8.17	7.90	-	8.1	8.0	6.5-9.5
EC	uS/cm	154.5	97.1	547	-	434	352	
SO_4	mg/L	46.1	19.1	245	-	183	140	
Acidity to pH4.5	mg/L	<0.5	<0.5	-	-	-	-	
Acidity to pH8.3	mg/L	2.1	<0.5	-	-	-	-	
Total Alkalinity	mg/L	11	14	39.9	-	28.2	25.1	
Bicarbonate	mg/L	14	18	-	-	-	-	
Carbonate	mg/L	<0.5	<0.5	-	-	-	-	
Hydroxide	mg/L	<0.5	<0.5	-	-	-	-	
Fluoride	mg/L	0.27	0.2	0.189	-	0.078	0.035	
Hardness $CaCO_3$	mg/L	55.6	35	-	-	204	158	
Aluminum (Al)-Leachable	mg/L	0.00609	0.0214	0.0109	0.0282	<0.0050	<0.0005	
Antimony (Sb)-Leachable	mg/L	0.00419	0.0111	0.0217	0.0387	0.016	0.0116	
Arsenic (As)-Leachable	mg/L	0.000219	0.000331	0.0061	0.0072	<0.0010	<0.0010	0.1
Barium (Ba)-Leachable	mg/L	0.0354	0.0134	0.0253	0.0234	0.037	0.0459	
Beryllium (Be)-Leachable	mg/L	<0.000010	<0.000010	<0.00050	<0.00050	<0.00050	<0.00050	
Bismuth (Bi)-Leachable	mg/L	<0.0000050	<0.0000050	<0.00050	<0.00050	<0.00050	<0.00050	
Boron (B)-Leachable	mg/L	<0.050	<0.050	0.071	0.0942	0.025	0.014	
Cadmium (Cd)-Leachable	mg/L	0.0027	0.000309	0.0024	0.00318	0.00164	0.0509	0.01
Calcium (Ca)-Leachable	mg/L	18.7	12.4	105	138	74.9	59.6	

Leachable Metals	Unit	Berm LCT1	Berm LCT2	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13	Lucky Queen F9	Lucky Queen F10	KHSD Mill Site EQS (KV-83)
Chromium (Cr)-Leachable	mg/L	<0.00010	<0.00010	<0.00050	<0.00050	<0.00050	<0.00050	
Cobalt (Co)-Leachable	mg/L	0.000925	0.000099	0.0004	0.00031	0.0002	0.00702	
Copper (Cu)-Leachable	mg/L	0.000116	0.000334	0.0271	0.0096	0.0303	0.0503	0.1
Iron (Fe)-Leachable	mg/L	0.0022	<0.0010	<0.030	<0.030	<0.030	<0.030	
Lead (Pb)-Leachable	mg/L	0.0607	0.0188	0.0144	0.0593	0.0181	0.112	0.2
Lithium (Li)-Leachable	mg/L	0.00339	0.00294	0.0071	0.0339	<.0.0050	<.0.0050	
Magnesium (Mg)-Leachable	mg/L	2.15	0.988	6.9	6.01	3.96	2.27	
Manganese (Mn)-Leachable	mg/L	2.28	0.445	1.95	0.797	0.765	1.14	
Mercury (Hg)-Leachable	mg/L	<0.000050	<0.000050	0.0001	<0.000050	<0.000050	<0.000050	
Molybdenum (Mo)-Leachable	mg/L	0.000225	0.000928	0.0024	0.0108	0.00318	0.000718	
Nickel (Ni)-Leachable	mg/L	0.00213	0.000368	0.0012	0.0009	0.0006	0.00253	0.5
Phosphorus (P)-Leachable	mg/L	0.0503	0.0414	<0.30	<0.30	<0.30	<0.30	
Potassium (K)-Leachable	mg/L	1.89	1.7	2.04	10.6	3.93	1.87	
Selenium (Se)-Leachable	mg/L	0.000058	0.000041	0.0009	0.00106	0.00871	0.00463	
Silicon (Si)-Leachable	mg/L	0.42	0.45	1.55	3.4	1.91	1.11	
Silver (Ag)-Leachable	mg/L	<0.0000050	0.00003	0.0009	0.0018	0.000144	0.00627	0.02
Sodium (Na)-Leachable	mg/L	0.854	0.596	2.36	24.1	6.19	4.57	
Strontium (Sr)-Leachable	mg/L	0.0261	0.0172	0.38	0.515	0.193	0.141	
Thallium (Tl)-Leachable	mg/L	0.000335	0.000177	0.0001	0.0002	0.00011	<0.00010	
Tin (Sn)-Leachable	mg/L	<0.00020	<0.00020	<0.00050	<0.00050	<0.00050	<0.00050	
Titanium (Ti)-Leachable	mg/L	<0.00050	<0.00050	0.01	0.012	<0.010	<0.010	
Uranium (U)-Leachable	mg/L	<0.0000020	<0.0000020	0.000048	0.00162	0.000011	<0.000010	
Vanadium (V)-Leachable	mg/L	<0.00020	<0.00020	<0.0010	<0.0010	<0.0010	<0.0010	
Zinc (Zn)-Leachable	mg/L	0.142	0.017	0.156	0.051	0.0189	0.0955	0.5

Kinetic Testing

One tailings humidity cell was operated for each of the following deposit: Flame and Moth, Bellekeno and Bermingham. Flame and Moth and Bellekeno have been terminated after 113 and 208 weeks of testing, respectively, and Bermingham tailings cell is still ongoing. Sixty-seven weeks (cycles) of Bermingham humidity cell testing and the Flame and Moth and Bellekeno kinetic data for the same period are discussed herein to allow of a comparison of the geochemical properties of the tailings from the AKHM sites.

Time series plots for pH, alkalinity, acidity, sulphate, and metals and metalloids of potential environmental concern are provided in Figure 8-18 through Figure 8-20 and discussed in order to assess the long-term ARD/ML and the rate of release of the tailings. The Mill pond EQS are also plotted for comparative purposes only rather than an assessment of compliance with site water quality standards.

The results show that only cadmium and zinc in the Bellekeno tailing humidity cell were regularly above their respective EQS. The Bellekeno tailings had the highest concentration release for sulphate, cadmium, lead and zinc (and nickel during the last 31 cycles), Bermingham tailing cell had the highest nickel during the first 31 cycles and the Flame and Moth had the highest concentration release for arsenic, antimony, copper and silver.

The three tailings cells had neutral to slightly alkaline pH within the EQS range (6.5 - 9.5) during the test (Figure 8-18). Bermingham tailings cell had a stable pH ranging between 7.1 to 7.9 , very low acidity (maximum 7.4 mg/L $CaCO_3$; median 0.6 mg/L $CaCO_3$), alkalinity high enough to buffer the acidity released (maximum 29.0 mg/L $CaCO_3$; median 12.4 mg/L $CaCO_3$), and relatively low sulphate concentrations (median 54 mg/L), indicating low sulphide oxidation rate. The acidity, alkalinity and sulphate concentrations showed a first flush effect resulting from the release of readily soluble products followed by a decrease, then stabilization of the concentrations until cycle 43 and 37 for acidity and alkalinity, respectively. However, recurrent spikes of acidity were observed until cycle 21 and an increase was observed after cycle 43 peaking at cycle 55 at 1.9 mg/L $CaCO_3$. Alkalinity gradually increased after cycle 37 from 12 mg/L to 29 mg/L at cycle 61, raising the pH from 7.3 to 7.7 during the same period. The sulphate concentrations showed a slight increase between cycles 2 and 9 (85 mg/L), then decreased over the subsequent two cycles and have stabilized between 45 and 70 mg/L since then.

Flame and Moth and Bellekeno tailings humidity cells had comparable and higher pH and alkalinity levels than Bermingham tailings humidity cell reflecting their higher NP and calcite content, however the pH of the three cells has become comparable during the last three cycles due to the gradual increase of alkalinity in Bermingham cell since cycle 37. The three tailings cells generally had similar sulphate release pattern despite the difference in absolute concentration but showed an early stabilization of the sulphate release from Bermingham and Flame and Moth cells compared to Bellekeno (Figure 8-18).

The sulphate concentrations recorded in the Bermingham cell (38 to 374 mg/L) were markedly lower than those observed in the Bellekeno humidity cell (158 to 1,150 mg/L) during the first 30 cycles then the gap gradually shrank until reaching a comparable level at cycle 55 onward (~58 mg/L). The sulphate concentrations in the Bermingham cell were also lower than in the Flame and Moth cell leachate (120 to 1,130 mg/L) during the first 17 cycles then the sulphate concentration in the Flame and Moth cell decreased sharply below that of the Bermingham cell. The trend of sulphate in Bellekeno is expected since it has higher sulphide-sulphur content (2.2 wt.%) compared to Bermingham tailings (1.4 wt.%). But, the trend of Flame and Moth cell is somewhat unexpected for the early cycles because the Flame and Moth had lower sulphide-sulphur content (0.4 wt.%) than Bermingham. It is likely that sulphide in the Flame and Moth were exposed to leaching early on resulting in higher release rate and a gradual decline thereafter (Figure 8-18).

The plots of arsenic, antimony, cadmium and copper are displayed in Figure 8-19 and lead, nickel, silver and zinc are shown in Figure 8-20. The metals and metalloids time series of the Bermingham cell showed similar patterns characterized by a flush effect during cycle 0 followed by a decrease of concentration during the following two to three weeks and then a short-term increase which peaked between cycles 6 and 8. This was followed by a second decrease and a stabilization as early as cycle 11 onward (antimony and silver) or a continuous decrease during the remainder of the test (arsenic, copper cadmium, lead, nickel and zinc). However, sporadic fluctuations of concentration were visible in the plots of arsenic, silver, lead, and copper.

Aside from the initial flush, the arsenic concentration in the leachate from the Bermingham tailings cell was lower than that of the Bellekeno and Flame and Moth cells likely due to its lower bulk arsenic concentration. Arsenic concentrations in the three cells leachate have been lower than the arsenic EQS (0.1 mg/L). Cadmium and zinc concentrations in the Bermingham tailings cell were comparable to those of Flame and Moth during the first 35 cycles, then their concentrations sharply decreased below the Flame and Moth. Cadmium and zinc concentrations in the Bermingham tailings cell leachate were up to two orders of magnitude lower than those observed from the Bellekeno humidity cell during the same period. Aside from the first cycle, cadmium and zinc in Flame and Moth and Bermingham tailings cells were lower than EQS (0.01 and 0.5 mg/L, respectively) and Bellekeno cell leachates exceeded the cadmium and zinc EQS all the times (Figure 8-19 and Figure 8-20). These differing trends likely reflects the higher concentration of cadmium and zinc in the Bellekeno bulk elemental content.

Bermingham humidity cell lead content was slightly lower than in the Bellekeno tailings cell and comparable to those of Flame and Moth during the first 11 cycles. Then it decreased to levels that were one to three orders of magnitude lower than lead concentrations in the Flame and Moth and Bellekeno tailings leachates. Occasional spikes of lead from the Bermingham tailings cell were observed during the test resulting in peak concentrations above those of the Flame and Moth cell. The Bermingham tailings cell leachate had the highest nickel concentrations among all cells (up to two- to three-fold higher) during the first 35 cycles, then the nickel concentration decreased such that it was below the nickel concentration in the Flame and Moth and Bellekeno cell leachates from cycle 43 onwards. Nickel concentrations in the three cells were orders of magnitude lower than the nickel EQS (0.5 mg/L; Figure 8-20).

Flame and Moth tailing cell leachate had the highest copper release; two orders of magnitude higher than Bermingham tailings cell. Copper concentrations of the latter were slightly lower than the Bellekeno cell leachate during the first 23 cycles after that the gap increased markedly (approximately two orders of magnitude difference at the last cycle) as a result of increasing copper release from the Bellekeno cell. Silver concentrations in the Bermingham and Bellekeno tailings cell leachates were generally similar and below the detection level (i.e., <0.000005 mg/L) although isolated spikes of concentration (0.0001 mg/L) were recurrent in the Bermingham cell. Antimony concentrations in the cell leachate from the Bermingham tailings were lower than the Bellekeno and Flame and Moth humidity cell leachate despite its higher average bulk antimony (72 ppm) compared with the Flame and Moth tailings (41 ppm). The higher antimony release from the Bellekeno can be explained by its high bulk elemental concentration (121 ppm; Table 8-8).

The three cells had similar selenium trends despite the higher selenium release from Bellekeno and Flame and Moths cells during the 20 cycles. The selenium concentrations in the Bellekeno and Flame and Moth cell leachates had similar trend and had remained broadly comparable during the entire test period. Selenium concentrations in the Bermingham tailings cell exhibited a pattern different from all the other parameters of interest (Figure 8-18). The concentration that was up to an order of magnitude lower than the Flame and Moth and Bellekeno leachate selenium at the initial flush decreased and stabilized at 0.00008 mg/L during the next 10 cycles, then it gradually increased to approximately 0.0002 mg/L, surpassing those of the Flame and Moth cell at cycle 49 and Bellekeno at later at cycle 55 (both approximately 0.0001 mg/L).

The humidity cell testing also show that:

- The concentration of ammonia was very low (median = 0.005 mg/L), at or below the detection limit in 76% of the cycles and well below the EQS of 5 mg/L in the Bermingham cell leachate; and
- The concentrations of the following constituents were below the detection limit in all or the majority of cycles of the three tailing cells: aluminum, nitrate, nitrite, beryllium, bismuth, boron, chromium, lanthanum, iron, mercury, silver, tellurium, thorium, tin, titanium, tungsten, vanadium and zirconium.

The neutral pH and lower concentration of metal and metalloids compared to the EQS are evidence of low potential for acid generation and metal release from the tailings. However, elevated concentrations of cadmium and zinc could potentially be released from the Bellekeno tailings. These are considered contaminants of potential concern. The estimation of the lag time to acid generation and NP depletion using humidity cell results indicates that some bulk NP will remain in the tailings after their sulphide has been completely oxidized suggesting that net acid generation is not expected from the tailings.

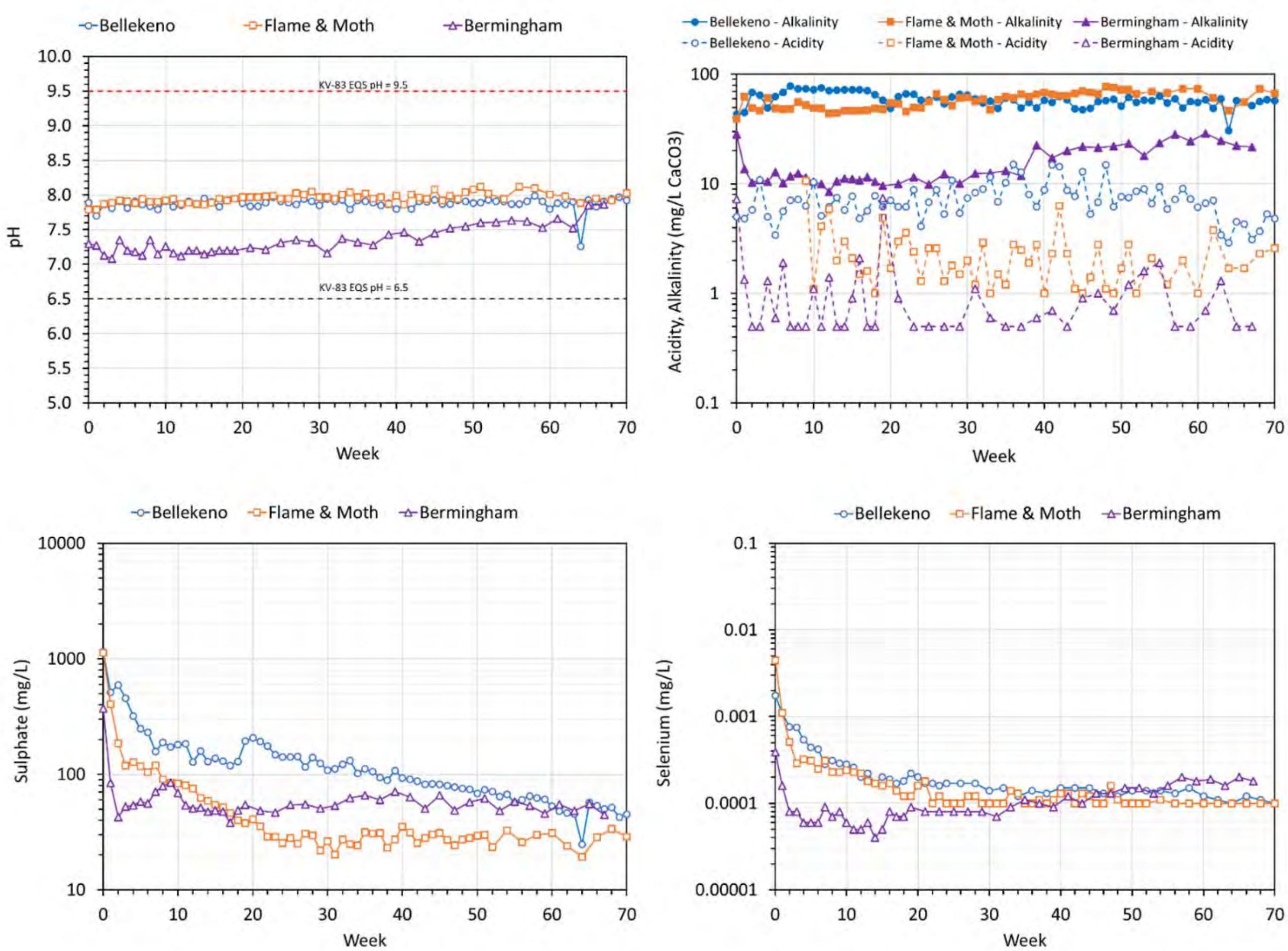


Figure 8-18: pH (top left), Acidity and Alkalinity (top right), Sulphate (bottom left) and Selenium (bottom right) of the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

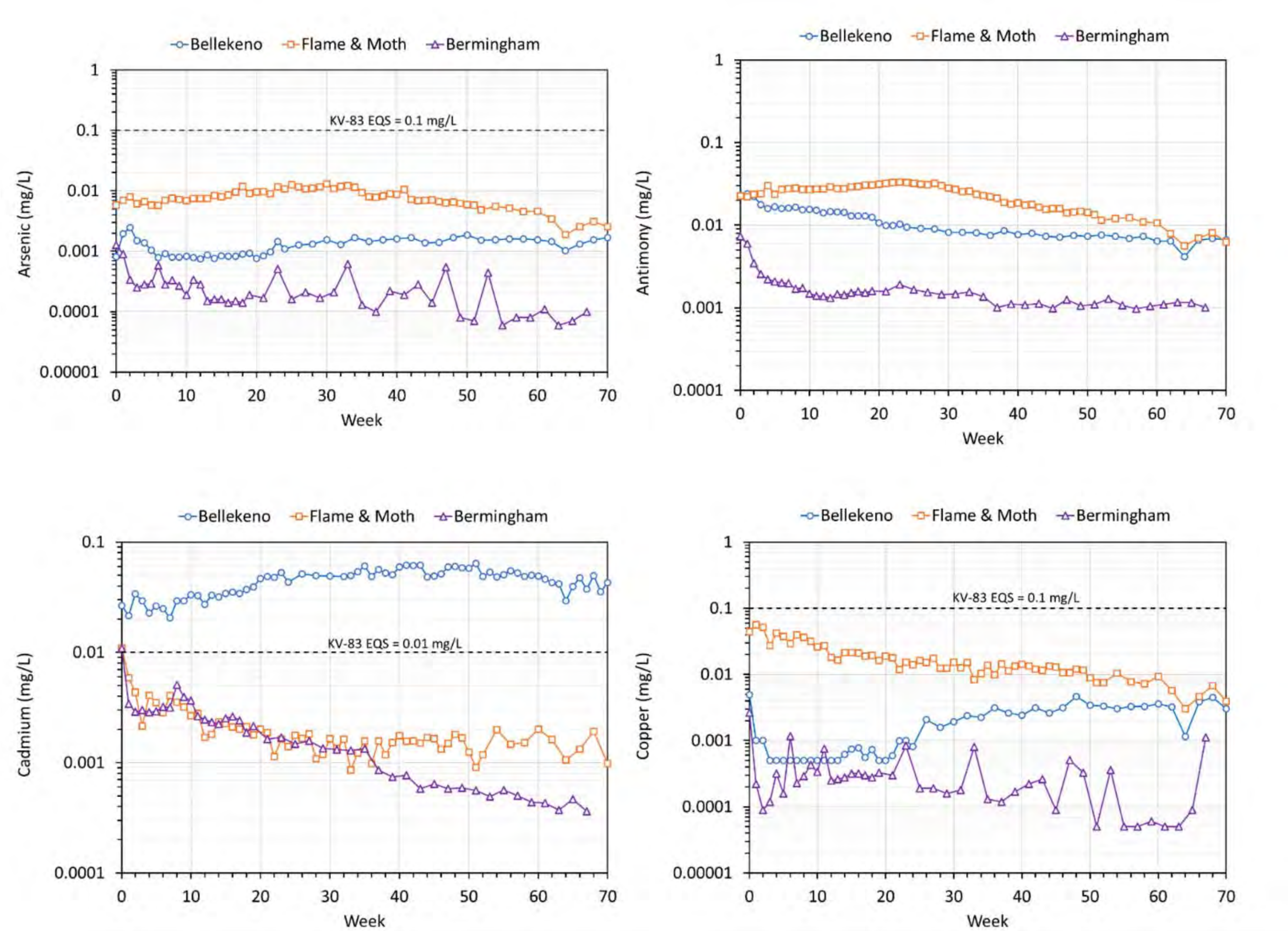


Figure 8-19: Arsenic (top left), Cadmium (bottom left), Antimony (top right), and Copper (bottom right) Trends of the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

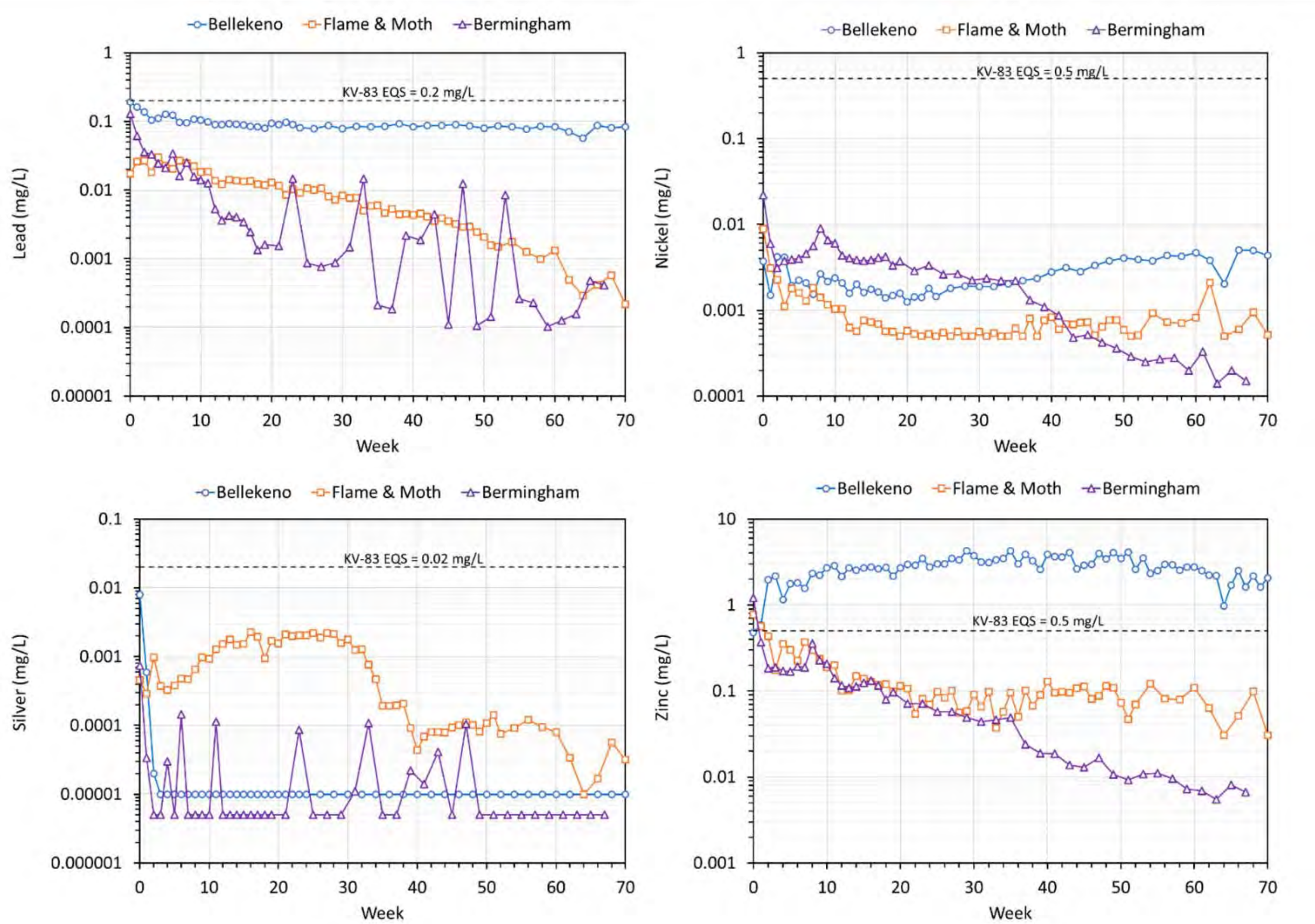


Figure 8-20: Lead (top left), Silver (bottom left), Nickel (top right), and Zinc (bottom right) Trends of the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

9. REFERENCES

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

Access Consulting Group (ACG) (2011a). Geochemical Rock Characterization, Onek. Memorandum prepared for Alexco Keno Hill Mining Corp., December 2011.

Access Consulting Group (ACG) (2011b). Geochemical Rock Characterization, Lucky Queen, Keno Hill District, Yukon. Memorandum prepared for Alexco Keno Hill Mining Corp., December 2011.

Access Consulting Group (ACG) (2011c). Preliminary Geoenvironmental Rock Characterization, Silver King. Memorandum prepared for Alexco Keno Hill Mining Corp., August 2011.

Access Consulting Group (ACG) (2012). Geochemical Characterization of Onek and Lucky Queen Tailings. Memorandum prepared for Alexco Keno Hill Mining Corp., September 05, 2012.

Access Consulting Group. (ACG) (2015). Summary of Geochemical Characterization of Flame & Moth Tailings. Memorandum prepared for Alexco Keno Hill Mining Corp., August 6, 2015.

Alexco Environmental Group Inc. (AEG) (2016a). Environmental Conditions Report, Keno Hill Silver District. Report prepared for Elsa Reclamation and Development Company, June 2016.

Alexco Environmental Group Inc. (AEG) (2016b). Geochemical Rock Characterization, Flame & Moth Project, Keno Hill District, Yukon. Report prepared for Alexco Keno Hill Mining Corp. March 4, 2016.

Alexco Environmental Group Inc. (AEG) (2016c). 041-4 Keno Hill Silver District Chronosequence Development. Prepared for Elsa Reclamation and Development Company Ltd.

Alexco Environmental Group Inc. (AEG) (2018). *Field Protocol: Ambient Air Quality Installation and Sampling Procedure*. Prepared for AEG internal June 22, 2018.

Alexco Environmental Group Inc. (AEG) (2019a). Bermingham Waste Rock Geochemical Characterization. Report prepared for Alexco Keno Hill Mining Corp. November 04, 2019.

Alexco Environmental Group Inc. (AEG) (2019b). Type A Water License QZ09-092 Revewal application QZ18-044 Keno Hills Silver District Mining Operations. July 05, 2019.

Alexco Environmental Group Inc. (AEG) (2019c). Geochemical Characterization of Bermingham Locked Cycle Tailings. Bermingham Report prepared for Alexco Keno Hill Mining Corp. November 07, 2019.

Alexco Environmental Group Inc. (AEG) (2019d). Environmental Effects Monitoring Cycle 3 Interpretive Report. Bermingham Report prepared for Environment and Climate Change Canada on behalf of Alexco Keno Hill Mining Corp. March, 2019.

Altura Environmental Consulting (2008a). Geoenvironmental Rock Characterization, Bellekeno Zone. Report prepared for Access Consulting Group, January 8, 2008.

Access Consulting Group (ACG). 2008b. *Physical Hazard Reduction Program, Keno Hill Property, 2007*, prepared for Yukon Government.

Belfort Instrument. 2013. *Reducing Precipitation Gauge Inconsistencies Using Modern Wind Deflection Methodologies*.

Clearwater Consultants Ltd. (Clearwater), 2008. Memorandum CCL-UHKM-1.

Clearwater Consultants Ltd. (Clearwater), 2009. Memorandum CCL-UHKM-2.

EDI Environmental Dynamic Inc. (EDI). 2005. South McQuesten Water Quality Sampling Program – Year 2.

EDI Environmental Dynamic Inc. 2008. Elsa Tailings Terrestrial Effects Assessment – Phase 1.

EDI Environmental Dynamic Inc. 2009. Elsa Tailings Terrestrial Effects Assessment – Phase 2.

EDI Environmental Dynamic Inc. 2010. Elsa Tailings Terrestrial Effects Assessment – Phase 3.

Environment Canada (EC). 2012. Metal Mining Technical Guidance for Environmental Effects Monitoring. ISBN 978-1-100-20496-3.

Interralogic, Inc. 2011, Technical Memorandum, Draft: 2010/2011. South McQuesten Water Quality Investigation. April 11, 2011.

Interralogic Inc. (ITL), 2012. Keno City Ground Water Evaluation Technical Memorandum March 27, 2012. Prepared for Access Consulting Group.

Interralogic Inc. (ITL), 2013. Natural Attenuation Evaluation Summary Report, United Keno Hill Mines, Elsa, YT. Draft report prepared for Elsa Reclamation and Development Company Ltd, November 2013.

Kwong, Y.T.J., Roots, C. and Kettley, W., 1994. Lithochemistry and aqueous metal transport in the Keno Hill Mining District, Central Yukon Territory. Current Research 1994-E, Geological Survey of Canada, pp 7-15.

Kwong, Y.T.J., Roots, C. and Kettley, W., 1997. Post-mine metal transport and attenuation in the Keno Hill Mining District, central Yukon, Canada. Environmental Geology, 30, 98-107.

LeBarge, W. Bond, J. and Hein, F.J., 2002. Placer gold deposits of the Mayo area, central Yukon Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Bulletin 13

Lipovsky, P., LeBarge, W. Bond, J. and Lowey, G., 2001. Yukon Placer Activity Map (1:1 000 000 scale), 2001. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Open File 1002-34.

Minnow Environmental Inc. (Minnow). 2008. *Water Quality Assessment Report.* Prepared for United Keno Hill Mines.

Minnow Environmental Inc. (Minnow). 2011. *Approach for Developing Water Quality Goals for United Keno Hill Mines*. Prepared for Elsa Reclamation and Development Company Ltd.

Minnow Environmental Inc. (Minnow). 2013. *Evaluation of Contaminants of Concern for the United Keno Hill Mines Long Term Monitoring Program*.

Minnow Environmental Inc. (Minnow). 2015 *Draft Memorandum: Proposed Water Quality Goals for United Keno Hill Complex Watersheds*. February 23, 2015.

Minnow Environmental Inc. (Minnow). 2017 *Updated Water Quality Goals for United Keno Hill Complex Watersheds*. October 30, 2017.

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.

Ontario Ministry of Environment. 2012. *Ontario's Ambient Air Quality Criteria*. Standards Development Branch. PIBS#6570e01. April 2012.

Piteau Associates, 2016. Keno Hill Silver District Preliminary Groundwater Model, Report prepared for Alexco Environmental Group, April 7, 2016.

Public Works and Government Services Canada (PWGSC), 2000. Keno Valley/Dublin Gulch Environmental Assessment. Volume II: Keno Valley Sites #1 to #20. Environmental Services, March 2000

SENES Consultants Ltd. 2011. Human Health and Ecological Risk Assessment for the Historic Keno Hill Mine Site, Yukon. Prepared for Access Consulting Group.

SENES Consultants Ltd. 2014. *Site-Specific Target Levels Keno Hill Mine Site.* Prepared for Elsa Reclamation and Development Company Ltd.)

SRK Consulting. 2007. *Baseline Environmental Report, United Keno Hill Mines Property*, prepared for Elsa Reclamation and Development Company Ltd.

SRK Consulting (Canada) Inc. (SRK), 2014. *Updated Preliminary Economic Assessment for the Keno Hill Silver District Project – Phase 2*, Yukon, Canada. Prepared for Alexco Resource Corp.

Watson K. W. 1986, Silver-Lead-Zinc Deposits of the Keno Hill- Galena Hill Area, Central Yukon. Yukon Geology Vol. 1; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, P 83-88.

Yukon Environment. 2014. *Yukon Ambient Air Quality Standards*. April 2010, updated September 2014.

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	Typical Adit Closure Design
AKHM-13-01-S-0302	Cofferdam Design
AKHM-13-01-S-0303	Shaft/Raise to Surface, Typical Caps
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 Reclaim Measures
AKHM-13-01-C-2402	Bellekeno 625 Reclaim Measures
AKHM-13-01-C-3401	Lucky Queen Reclaim Measures
AKHM-13-01-C-4401	Onek Relcaim Measures
AKHM-13-01-C-5401	Bermingham Reclaim Measures
AKHM-13-01-C-6401	Mill Site Reclaim Measures
AKHM-13-01-C-7401	DSTF Reclaim Measures
AKHM-13-01-C-8401	Sludge Pond Reclaim Measures
AKHM-13-01-C-9401	Flat Creek Camp Reclaim 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.
2021-11-25	Draft for review	B	KAB	--
2018-02-05	Draft for review	A	KAB	--

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-G-0000

Sheet List

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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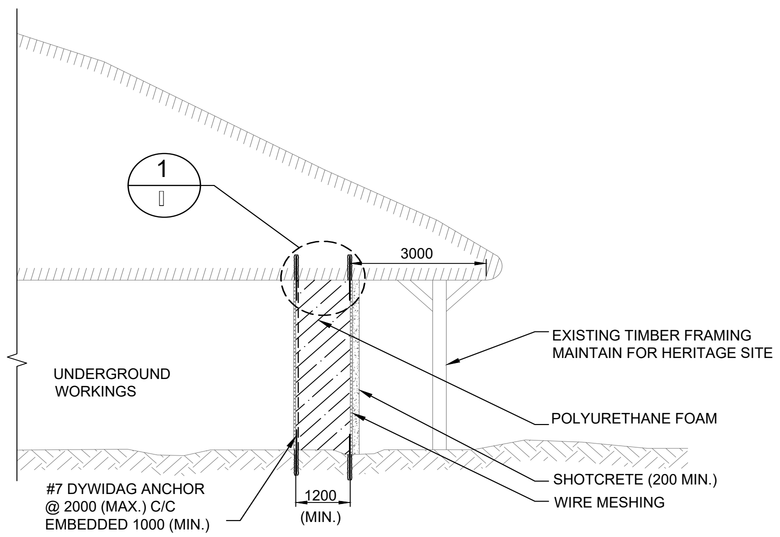

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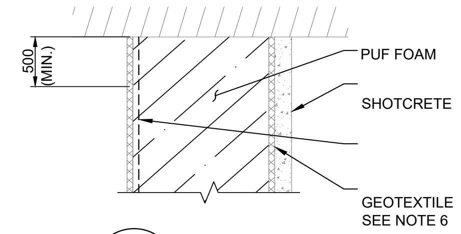

1 DETAIL 1
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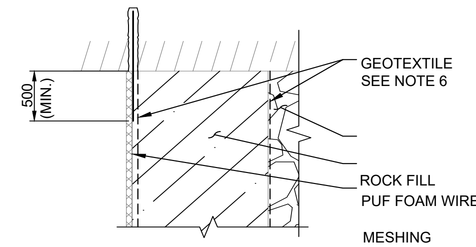
SEE NOTE 7 FOR
CONSTRUCTION SEQUENCE



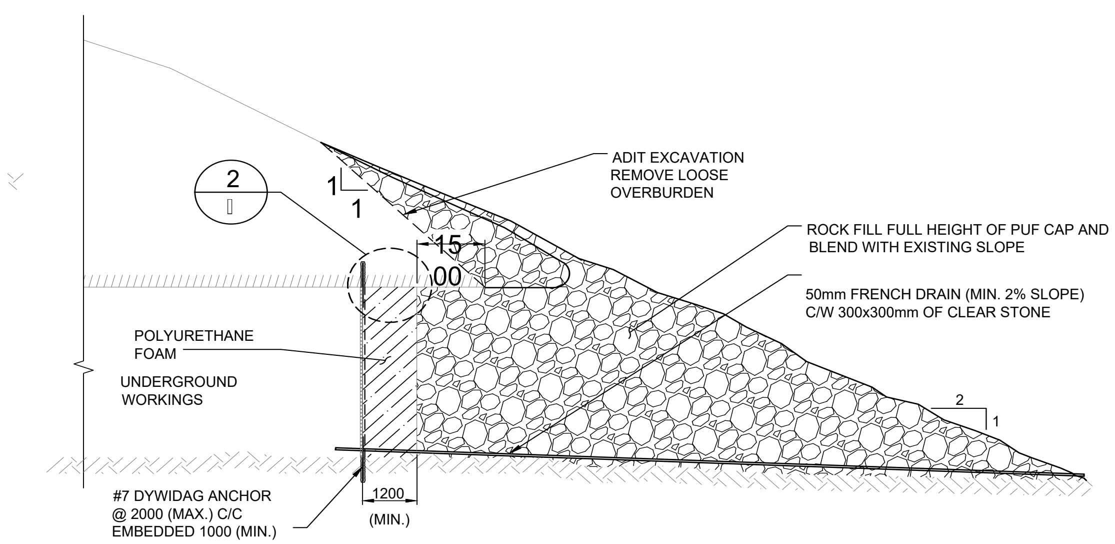
2 DETAIL 2
SEE NOTE 8 FOR
CONSTRUCTION SEQUENCE

NOTES:

1. SEE DRAWING AKHM-13-01-S-0303 FOR GENERAL NOTES.
2. SEE DRAWING AKHM-13-01-S-0303 FOR CONCRETE NOTES
3. SEE DRAWING AKHM-13-01-S-0303 FOR PUF NOTES
4. VERIFY ADIT DIMENSIONS ARE CONSISTENT WITH DRAWING.

   ALL DEVIATIONS MUST BE REPORTED TO THE PROJECT ENGINEER BEFORE COMMENCING CONSTRUCTION.

5. ALL DIMENSIONS IN MILLIMETERS U.N.O.
6. GEOTEXTILE TO BE ARMTEC 835 WOVEN GEOTEXTILE OR APPROVED ALTERNATE WITH MINIMUM OVERLAP OF 300mm.
7. CONSTRUCTION SEQUENCE TYPE 1:
   - 7.1. INSTALL DYWIDAG ANCHORS ALONG WITH WIRE MESHING AND GEOTEXTILE ON FAR SIDE OF PUF PLUG LOCATION.
   - 7.2. SPRAY PUF PLUG TO DESIRED THICKNESS.
   - 7.3. INSTALL DYWIDAG ANCHORS ON NEAR SIDE OF PLUG.
   - 7.4. INSTALL WIRE MESH AND SPRAY SHOTCRETE OVER ENTIRE AREA OF THE PLUG.
8. CONSTRUCTION SEQUENCE TYPE 2:
   - 8.1. INSTALL DYWIDAG ANCHORS ALONG WITH WIRE MESHING AND GEOTEXTILE ON FAR SIDE OF PUF PLUG LOCATION.
   - 8.2. SPRAY PUF PLUG TO DESIRED THICKNESS.
   - 8.3. FASTEN GEOTEXTILE TO PUFAND BACKFILL TO THE FULL HEIGHT OF THE ADIT WITH ROCKFILL.



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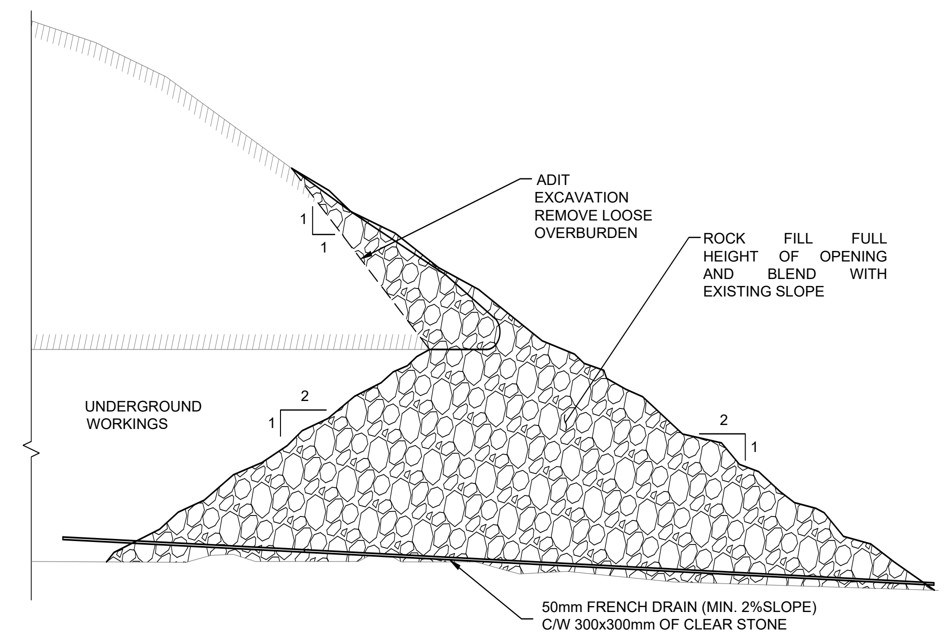


TYPICAL ADIT CLOSURE TYPE 3

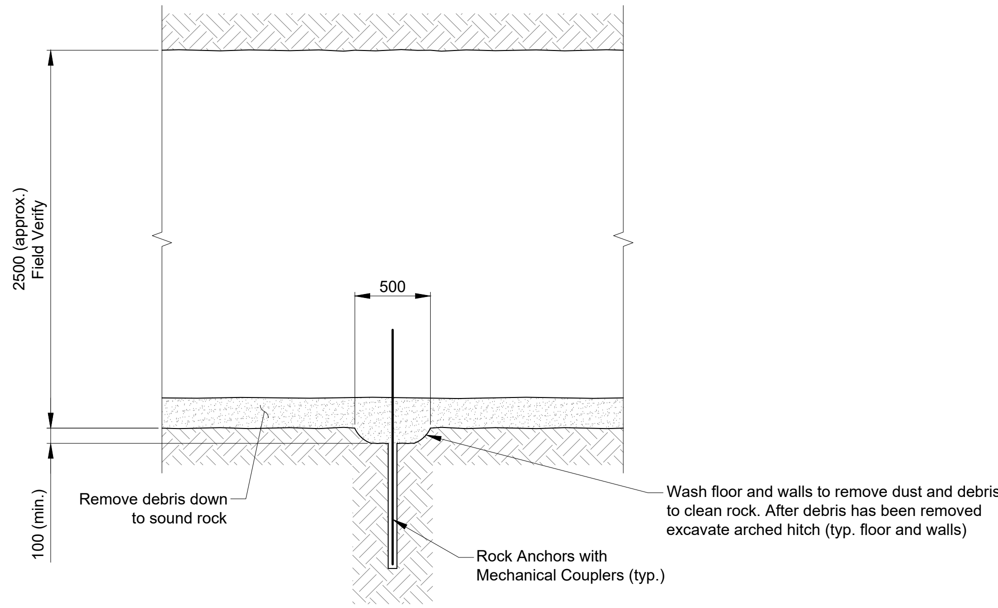
DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-04-23	Draft For Review	0A	TT	--

AKHM
TETRA TECH EBA

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

Portal Closure
Typical Adit Closure Design

REVISION: 0A	2021-04-23	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW



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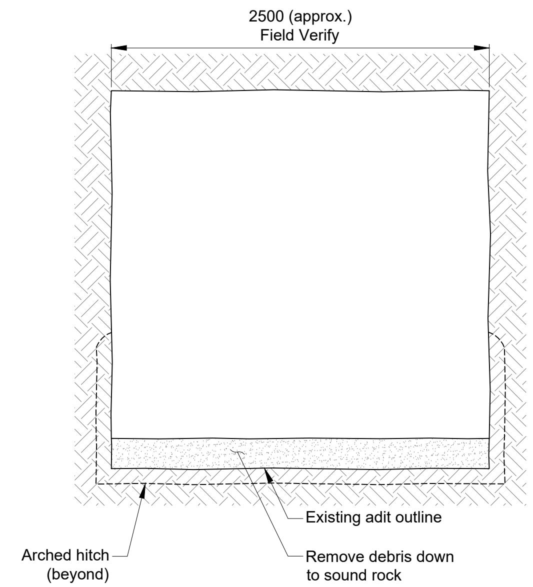

A ADIT CROSS SECTION
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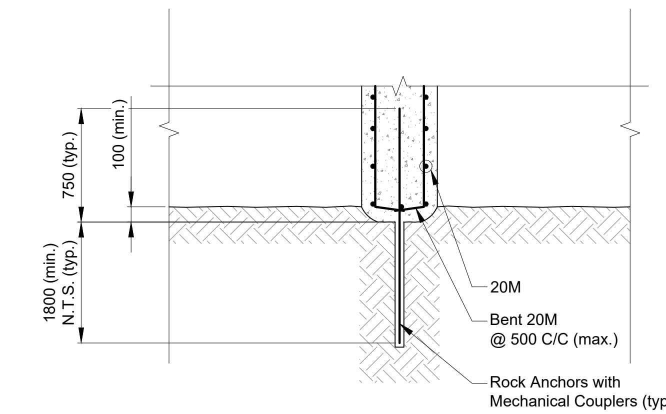

3 ARCHED HITCH DETAIL (TYP. ALL SIDES)
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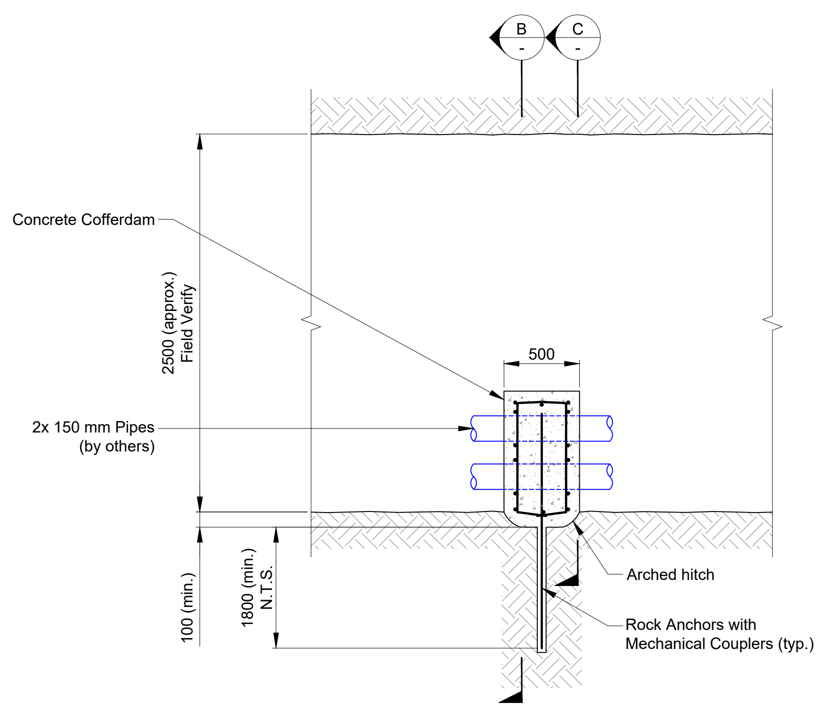

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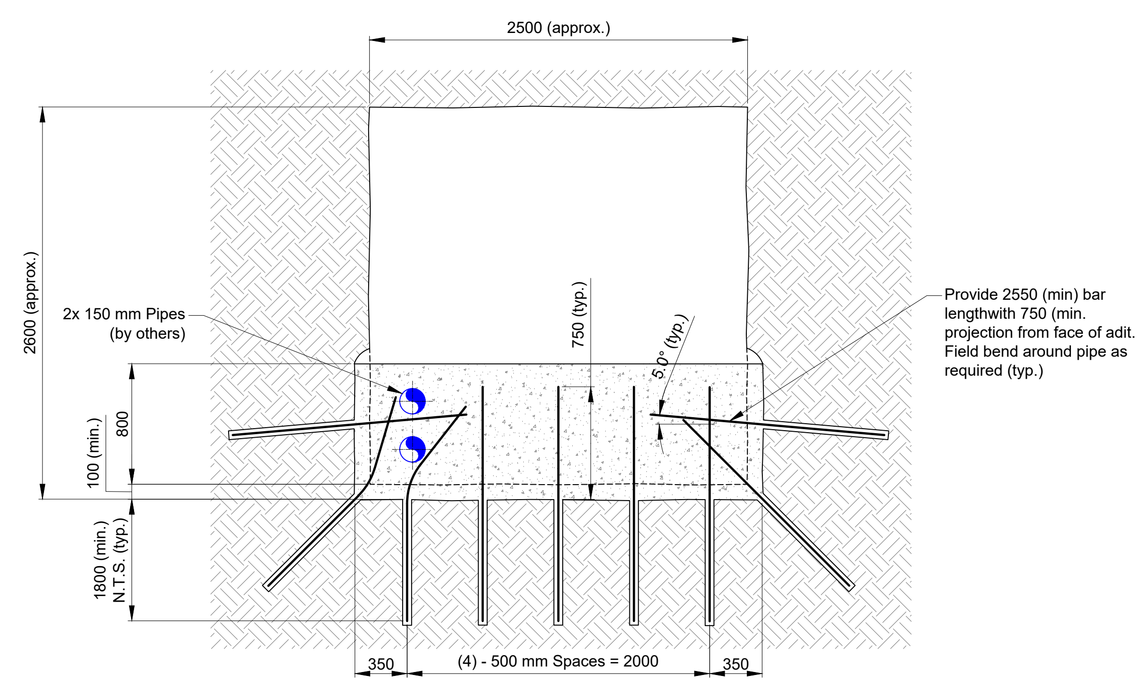

B COFFERDAM - TRANSVERSE SECTION
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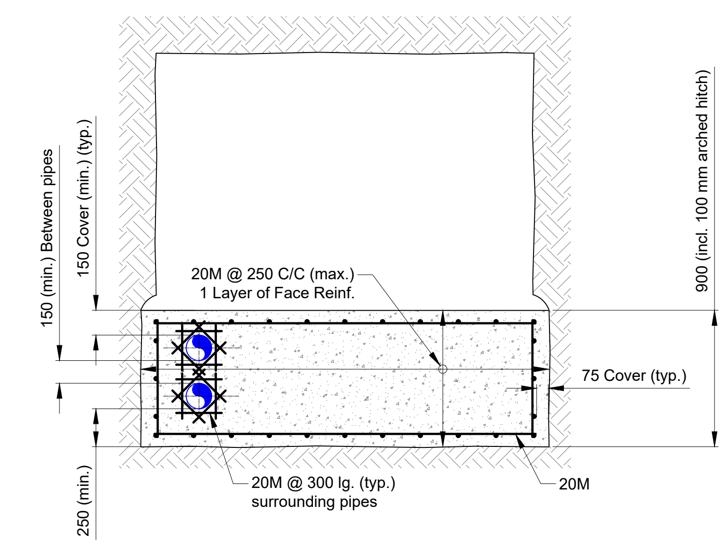
*Reinforcing steel not shown for clarity



C COFFERDAM - TRANSVERSE SECTION
Scale: 1:50
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DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2021-11-18	Draft for review	A	KAB	--

DRAFT
NOT FOR
CONSTRUCTION

ENSERO solutions

AKHM

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

Sections and Details
Concrete Cofferdam
Adit Closure

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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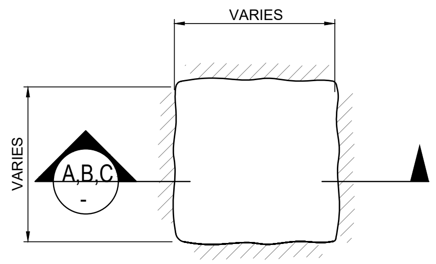
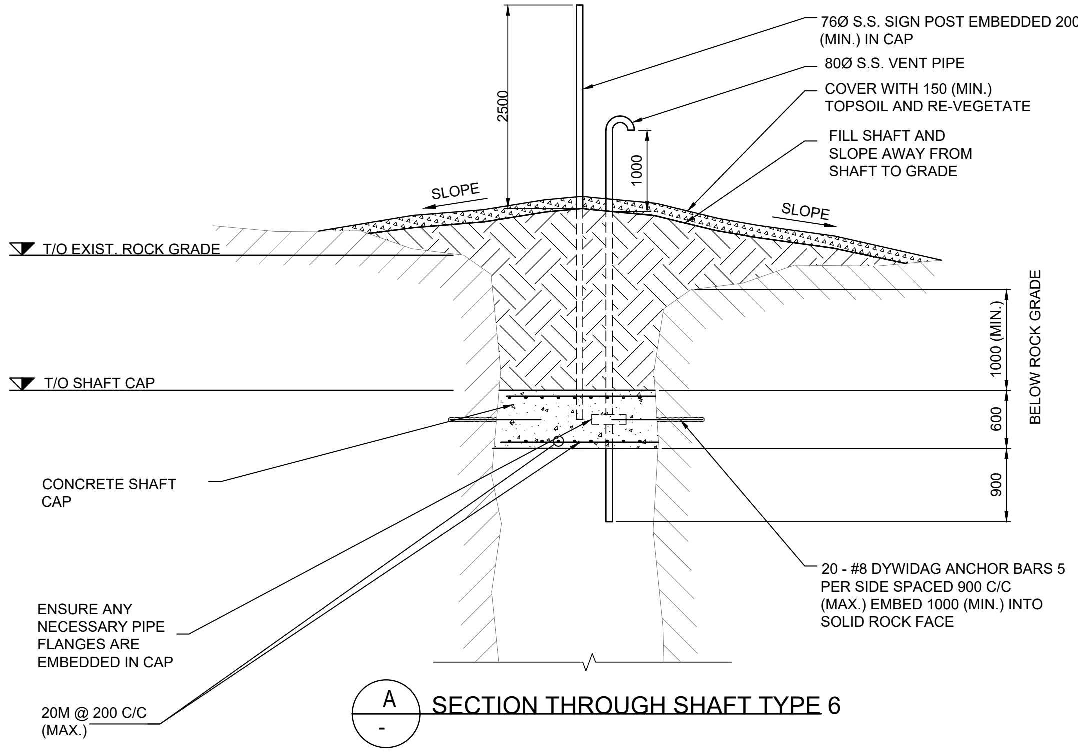
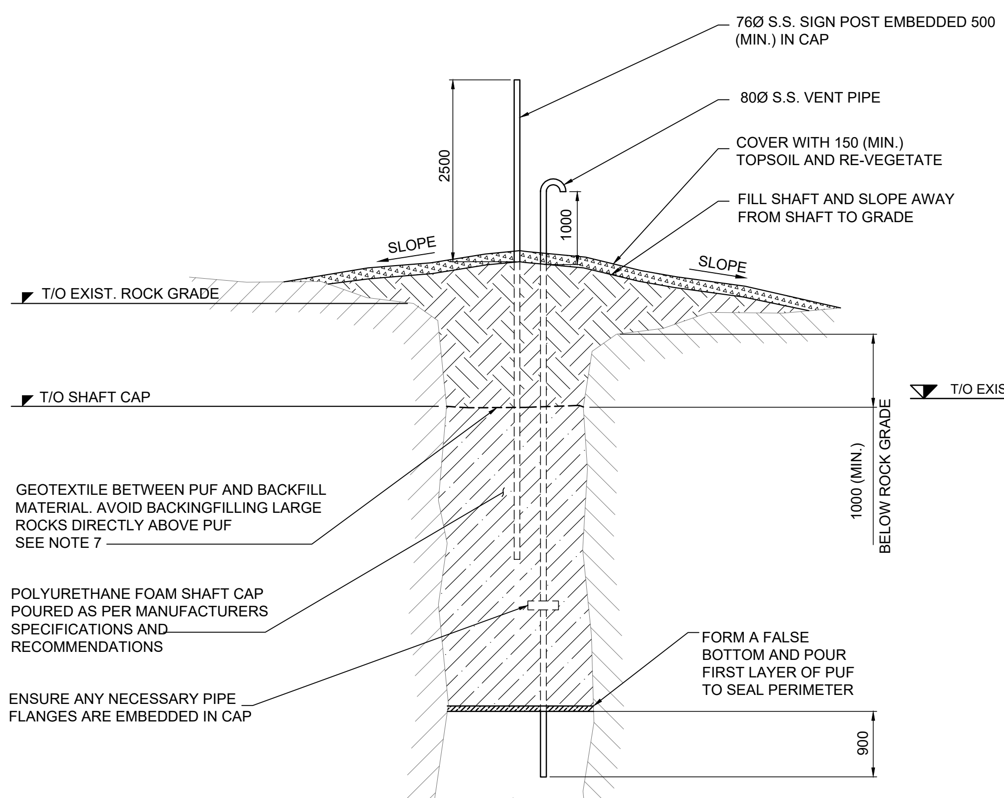


EXISTING SHAFT PLAN VIEW



A
-
SECTION THROUGH SHAFT TYPE 6

CLOSURE TYPE	DESCRIPTION
1	LEVEL AS IS, OR FILL IN MINOR INDENT IN GROUND WHERE PREVIOUS SHAFT WAS BACKFILLED
2	FOR SHALLOW SHAFTS, DEPOSIT ROCK INTO SHAFT UNIT REFUSAL
3	FOR DEEPER SHAFTS, EXTENSIVE AMOUNTS OF ROCK PUSHED INTO SHAFT UNTIL REFUSAL
4	POLYURETHANE FOAM PLUG FOR SMALL SHAFTS (LESS THAN OR EQUAL TO 2 x 2m). FORM AND POUR PUF. MINOR BACKFILL REQUIRED.
5	POLYURETHANE FOAM PLUG FOR LARGER SHAFTS (GREATER THAN 2 x 2m) THAT REQUIRE EXTENSIVE FORMWORK FOR PLACEMENT. FORM AND POUR PUF. MINOR BACKFILL
6	FORM, REINFORCE AND POUR CONCRETE CAP TO PLUG SHAFT. MINOR BACKFILL REQUIRED.



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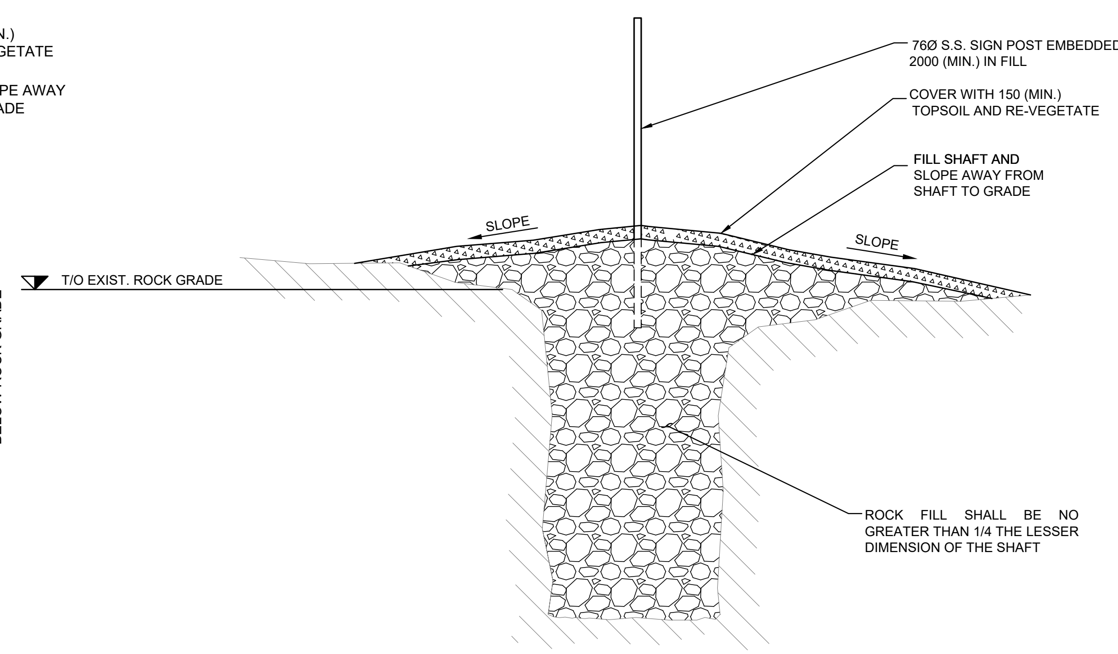

C
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SECTION THROUGH SHAFT TYPE 2 & 3

GENERAL NOTES:

1. ALL SUPPORTS TO BE FOUNDED ON SOUND ROCK. THE DESIGN IS BASED ON A MINIMUM BEARING VALUE OF GOOD QUALITY SEDIMENTARY ROCK (e.g., SHALE) = 600 kPa.
2. COMPETENCY OF THE ROCK AT THE SUPPORTS SHALL BE EXAMINED AND APPROVED BY A QUALIFIED PROFESSIONAL ENGINEER PRIOR TO CONSTRUCTION.
3. ALL LOOSE ROCK SHALL BE REMOVED FROM THE ROCK ANCHORAGES TO COMPETENT ROCK. VERIFY SHAFT DIMENSIONS ARE CONSISTENT WITH DRAWING.
4. ALL DEVIATIONS MUST BE REPORTED TO THE PROJECT ENGINEER BEFORE COMMENCING CONSTRUCTION.
5. THOROUGHLY COMPACT ALL CONCRETE USING VIBRATORS OR OTHER SUITABLE TOOLS DURING THE PLACING OPERATION. THOROUGHLY WORK THE CONCRETE INTO THE CORNERS OF THE FORMS AND ROCK SURFACES AND AROUND THE REINFORCEMENT.
6. SHAFT CAP SHALL NOT BE LOADED UNTIL THE 28-DAY CONCRETE STRENGTH HAS BEEN VERIFIED BY CYLINDER TESTS IN ACCORDANCE WITH CAN/CSA-A23.2.
7. GEOTEXTILE TO BE ARMTEC 835 WOVEN GEOTEXTILE OR APPROVED ALTERNATE WITH MINIMUM OVERLAP OF 300mm.

DESIGN LOADS:

6. LIVE LOAD = 2.0 METERS OF SATURATED SOIL COVER AT 19 kN/cu.m. + THE GREATER EFFECT OF A SPECIFIED 12 kPa UNIFORMLY DISTRIBUTED LOAD, OR 24 kN CONCENTRATED LOAD OVER AN AREA 0.3 m by 0.3 m, ANYWHERE ON THE SLAB.
7. DEAD LOAD = WEIGHT OF CAP

CAST-IN-PLACE CONCRETE:

1. ALL CONCRETE WORK, MIXES, PLACING, CURING, AND TESTING TO BE IN ACCORDANCE WITH CSA-A23.1-19/A23.2-19 "CONCRETE MATERIALS AND METHODS OF CONCRETE CONSTRUCTION/TEST METHODS AND STANDARD PRACTICES FOR CONCRETE".
2. CONCRETE ADMIXTURES CONFORM TO CSA A3000-18 "CEMENTITOUS MATERIALS COMPENDIUM."
3. CONCRETE MIXES TO BE IN ACCORDANCE WITH CSA-A23.1-19 ALTERNATIVE 1.
4. USE COLD WEATHER CONCRETING METHODS WHEN THE MEAN AMBIENT TEMPERATURE FALLS BELOW 41°F (+5°C). ADDITIONAL TEST CYLINDERS WILL BE PREPARED DURING COLD WEATHER CONCRETING
5. TEST CYLINDERS TO BE FIELD CURED UNDER THE SAME CONDITIONS AS THE CONCRETE WHICH THEY REPRESENT.
6. FORMWORK TO BE IN ACCORDANCE WITH CAN/CSA S269.1-16 "FALSEWORK AND FORMWORK". NO COLUMN OR WALL FORMS SHALL BE REMOVED BEFORE CONCRETE HAS REACHED 8MPa.
7. FORM OIL TO BE NON-STAINING, NON-TOXIC AND NON-VOLATILE.
8. BEFORE CONCRETE IS PLACED, REVIEW SHOP DRAWINGS FOR EQUIPMENT, OPENINGS, ANCHOR BOLTS, EMBEDS, INSERTS, ETC. TO ENSURE COMPLETENESS.
9. ALL PIPES, CONDUITS, AND SLEEVES EMBEDDED IN CONCRETE SHALL BE INSTALLED IN ACCORDANCE WITH CSA A23.1-19.
10. TESTING:
    A) QUALITY CONTROL TO BE UNDERTAKEN BY AN INDEPENDENT TESTING AGENCY OBTAINED BY THE CONTRACTOR, RESULTS OF FIELD TESTING WILL BE REPORTED IMMEDIATELY TO THE CONTRACTOR AND ERDC. ERDC MAY ENGAGE AN INDEPENDENT INSPECTION/ TESTING AGENCY TO CONDUCT TESTING; HOWEVER INSPECTION AND TESTING BY ERDC DOES NOT RELIEVE THE CONTRACTOR OF RESPONSIBILITY FOR QUALITY CONTROL AND CONTRACTUAL OBLIGATIONS.
    B) TEST PROCEDURE SHALL INCLUDE, BUT NOT LIMITED TO, THREE TEST CYLINDERS FROM EACH 50m3 OF CONCRETE, OR FRACTION THEREOF, FOR EACH DAY, TYPE OF CONCRETE, OR TYPE OF STRUCTURAL COMPONENT. ONE SLUMP TEST AND ONE ENTRAINED AIR TEST FOR EACH SET OF CYLINDERS.
11. ACCESSORIES SUCH AS HI-CHAIRS, SPACERS ETC., WILL BE SUPPORTED USING PADS OF PLYWOOD OR TEMPERED FIBREBOARD TO PREVENT PUNCTURING. POLYSTYRENE IS NOT AN ACCEPTABLE FORM MATERIAL

CONCRETE REINFORCING:

1. ALL REINFORCING STEEL TO MEET CAN/CSA-G30.18-09 (R2019) "CARBON STEEL BARS FOR CONCRETE REINFORCEMENT", 400 MPa DEFORMED BARS EXCEPT 10M TIES MAY BE 300 MPa.
2. ALL STEEL TO BE DETAILED IN ACCORDANCE WITH CSA A23.1-19 "CONCRETE MATERIALS AND METHODS OF CONCRETE CONSTRUCTION", A23.3-19 "DESIGN OF CONCRETE STRUCTURES" AND THE LATEST EDITION OF THE REINFORCING STEEL MANUAL OF STANDARD PRACTICE BY THE REINFORCING INSTITUTE OF CANADA.

CONCRETE REINFORCING (CONT'D):

3. CLEAR COVER TO REINFORCING WILL BE:
   CONCRETE CAST AGAINST EARTH -
   ALL BARS.. 75mm
   CONCRETE PLACED IN FORMS -
   20M OR LARGER.................................. 50mm
   10M & 15M.. 40mm
4. PROVIDE LAPS TO CSA A23.3 OR THE FOLLOWING MINIMUMS:
   10M - 700mm
   15M - 1000mm
   20M - 1200mm
   25M - 1900mm
5. ALL REINFORCING TO BE HELD IN PLACE AND TIED WITH PROPER ACCESSORIES, HI-CHAIRS AND SPACERS. DETAIL, SUPPLY AND INSTALL ALL ACCESSORIES. HI-CHAIRS TO HAVE 4 LEGS AND TO BE STAPLED OR NAILED TO THE FORMWORK.
6. REINFORCING STEEL SHALL HAVE ADEQUATE SUPPORTS SPACED NOT MORE THAN 1200mm APART IN ANY DIRECTION AND SHALL BE FIRMLY ANCHORED BEFORE CONCRETE IS POURED.
7. ALL REQUIRED OPENINGS NOT SHOWN ON STRUCTURAL DRAWINGS SHALL BE APPROVED BY THE CONSULTANT PRIOR TO CONSTRUCTION.
8. REINFORCING STEEL SHALL BE CLEAN AND FREE OF ALL DIRT, GREASE AND OTHER DELETERIOUS MATERIALS PRIOR TO PLACING CONCRETE.
9. FOR OPENINGS OR INSERTS LESS THAN 450mm, THE REINFORCING STEEL SHALL BE DEFLECTED, NOT CUT.
10. REINFORCING STEEL SHALL NOT BE WELDED, HEATED OR BENT ON-SITE WITHOUT PRIOR APPROVAL OF THE CONSULTANT.
11. DOWELS TO CONCRETE SLABS AND WALLS TO MATCH SLAB REINFORCING UNLESS NOTED OTHERWISE.

ROCK ANCHORS:

1. ROCK BOLTS AND ACCESSORIES TO BE IN ACCORDANCE WITH CAN/CSA M430-90 (R2016) "ROOF AND ROCK BOLTS, AND ACCESSORIES".
2. ROCK ANCHORS TO BE: 'DYWIDAG' THREADBAR, GRADE 75 (517 MPa) OR APPROVED ALTERNATIVE.
3. MINIMUM EMBEDMENT TO BE 2000mm INTO SOUND ROCK UNLESS NOTED OTHERWISE. GROUT FULL DEPTH.
4. INSTALL RESIN AS PER MANUFACTURER'S RECOMMENDATIONS AND INSTRUCTIONS.
5. SCALE ROCK THOROUGHLY PRIOR TO DRILLING ANCHOR HOLES.
6. ANCHOR HOLES SHALL BE CLEAN AND DRY PRIOR TO INSTALLING RESIN.

POLYURETHANE FOAM (PUF) STORAGE AND APPLICATION:

THE CURED PUF MUST MEET THE FOLLOWING SPECIFICATION(S):
COMPRESSIVE STRENGTH 140 kPa

4. PERFORM ALL POLYURETHANE FOAM (PUF) WORK INCLUDING STORAGE AND PLACEMENT TO THE MANUFACTURERS SPECIFICATIONS AND RECOMMENDATIONS.
5. PUF CONTAINERS SHALL BE STORED IN A DRY TEMPERATE LOCATION OUT OF THE SUNLIGHT AND BELOW 30 °C.
6. THE APPLICATION AND MIXTURE OF 2-PART PUF PRODUCTS SHALL BE ACCURATELY METERED AND MIXED TO COMPLY WITH THE MANUFACTURERS SPECIFICATIONS.
7. FORMWORK FOR PUF SHOULD BE SUFFICIENT TO PREVENT THE LEAKAGE OF THE LIQUID DOWN THE SHAFT. THE FIRST LAYER OF PUFF SHOULD BE POURED TO SEAL THE PERIMETER OF THE FORM AND THE VENT. METHOD MAY VARY DEPENDING ON SHAFT CROSS SECTION.
8. ENSURE EACH LAYER OF PUF IS EVENLY APPLIED ACROSS SHAFT OPENING. NO LAYER OF PUF SHALL EXCEED THE LESSER OF THE MANUFACTURERS SPECIFICATIONS OR 450mm.
9. A MINIMUM TIME OF 20 MINUTES SHOULD BE ALLOWED BETWEEN THE POURING OF EACH LAYER OF PUF. THE LAYER SHOULD BE COOL AND REACH A TACK FREE TEXTURE BEFORE POURING THE NEXT LAYER.
10. BACKFILL SHOULD BE COMPLETED NO SOONER THAN 60 MINUTES AFTER THE COOLING OF THE LAST PUF LAYER. THE BACKFILL SHOULD BE NO LESS THAN 1M OF DIRT OVER THE TOP OF THE PUF CAP. THE GRADE SHOULD SLOPE AWAY FROM THE SHAFT CENTER.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-04-23	Draft for Review	0A	TT	--

AKHM
TETRA TECH EBA

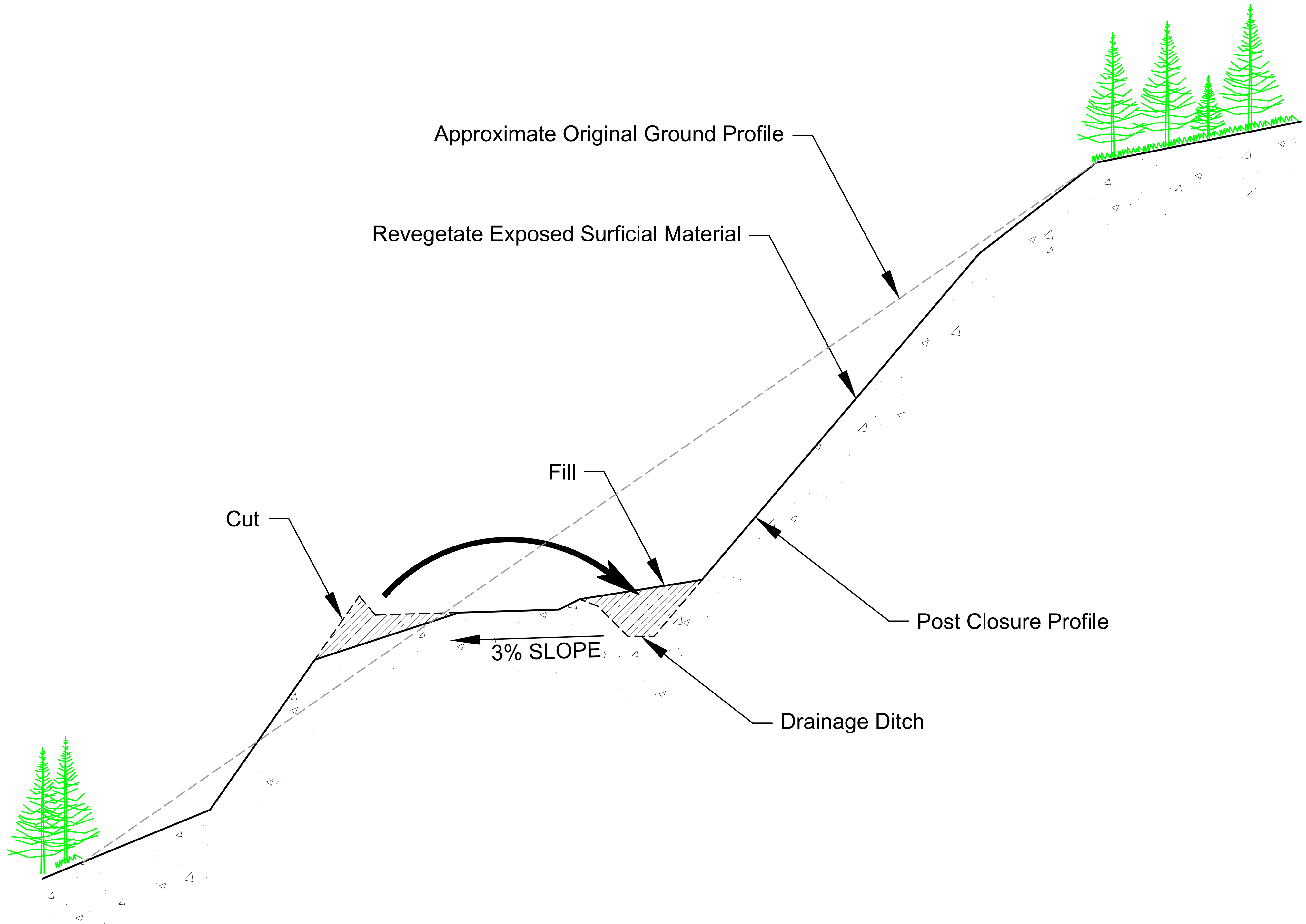
Keno District Mine Operations
Reclamation and Closure Plan
Drawing No:
AKHM-13-01-S-0303

Shaft/Raise to Surface
Typical Concrete, PUF and Backfilled Caps

REVISION: 0A	2021-04-23	PROJECT No.: AKHM-13-01
DRAWN BY: Tetra Tech EBA	DESIGNED BY: Tetra Tech EBA	REVIEWED BY: KSW

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.
2021-11-25	Draft for review	B	KAB	--
2018-01-29	Draft for review	A	KAB	--

Sand & Gravel

Existing Vegetation

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

Haul Road and Site Road Reclamation Typical Section

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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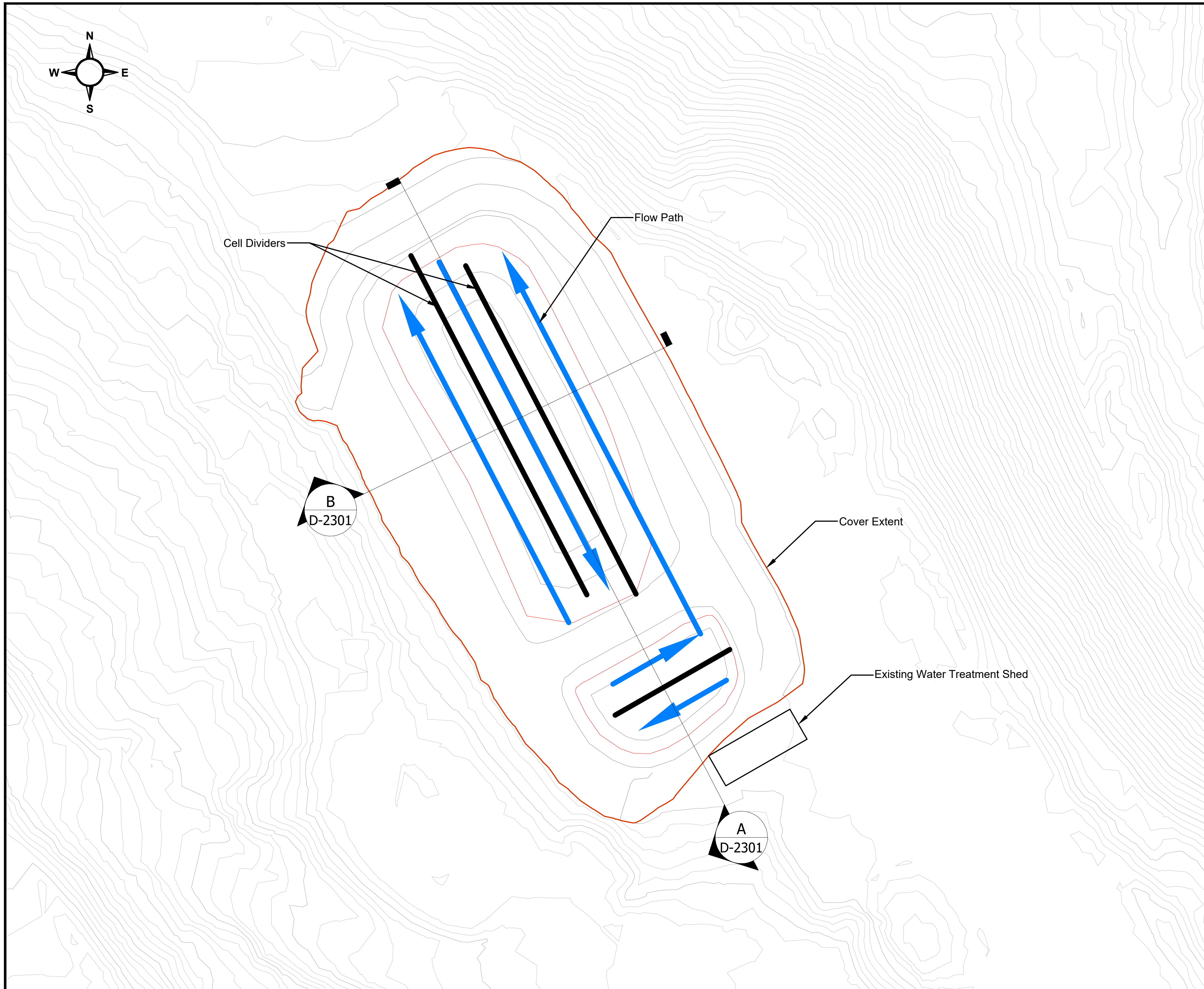

Notes:

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

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
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

Bellekeno 625
Bioreactor Design

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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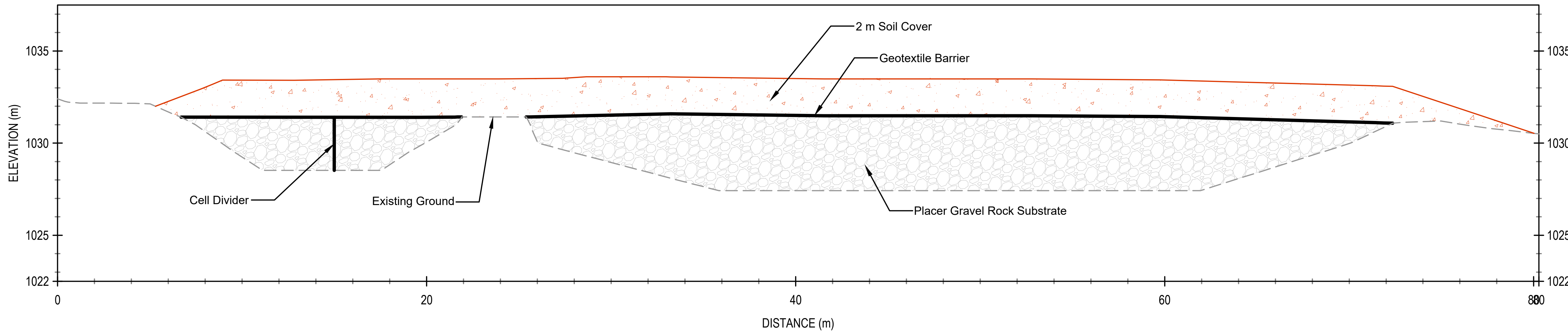
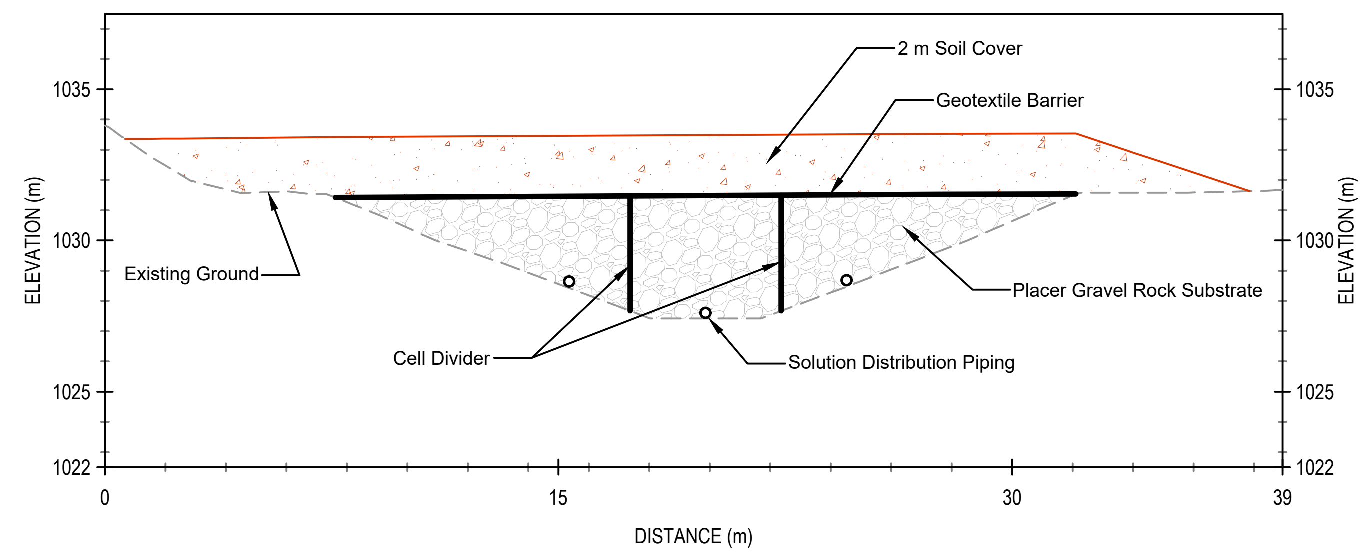


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
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-2301

Bellekeno 625
Bioreactor Design Sections

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: KSW

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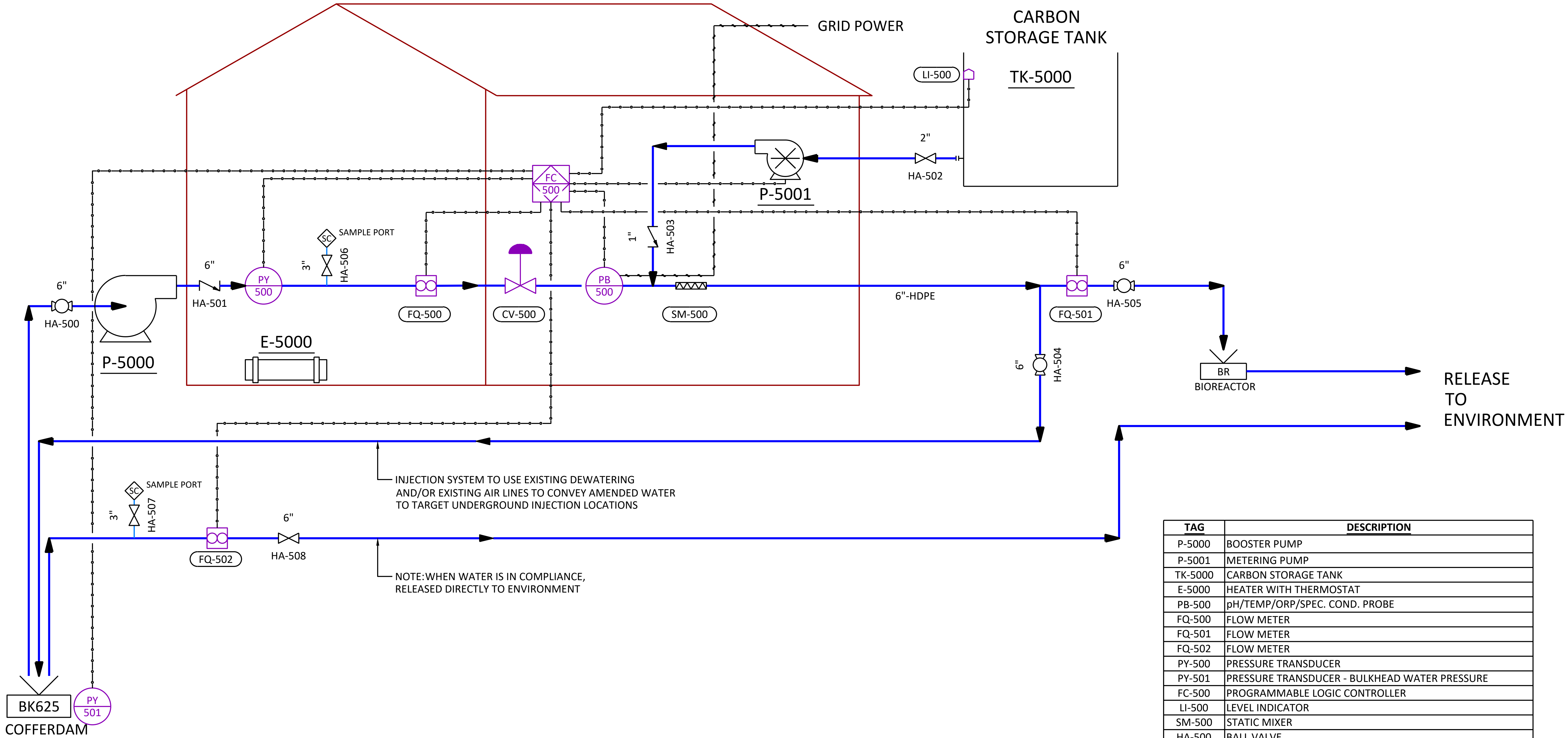

TAG	DESCRIPTION
P-5000	BOOSTER PUMP
P-5001	METERING PUMP
TK-5000	CARBON STORAGE TANK
E-5000	HEATER WITH THERMOSTAT
PB-500	pH/TEMP/ORP/SPEC. COND. PROBE
FQ-500	FLOW METER
FQ-501	FLOW METER
FQ-502	FLOW METER
PY-500	PRESSURE TRANSDUCER
PY-501	PRESSURE TRANSDUCER - BULKHEAD WATER PRESSURE
FC-500	PROGRAMMABLE 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.
2021-11-25	Draft for review	B	KAB	--
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

REVISION B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: EJL	REVIEWED BY: JMH

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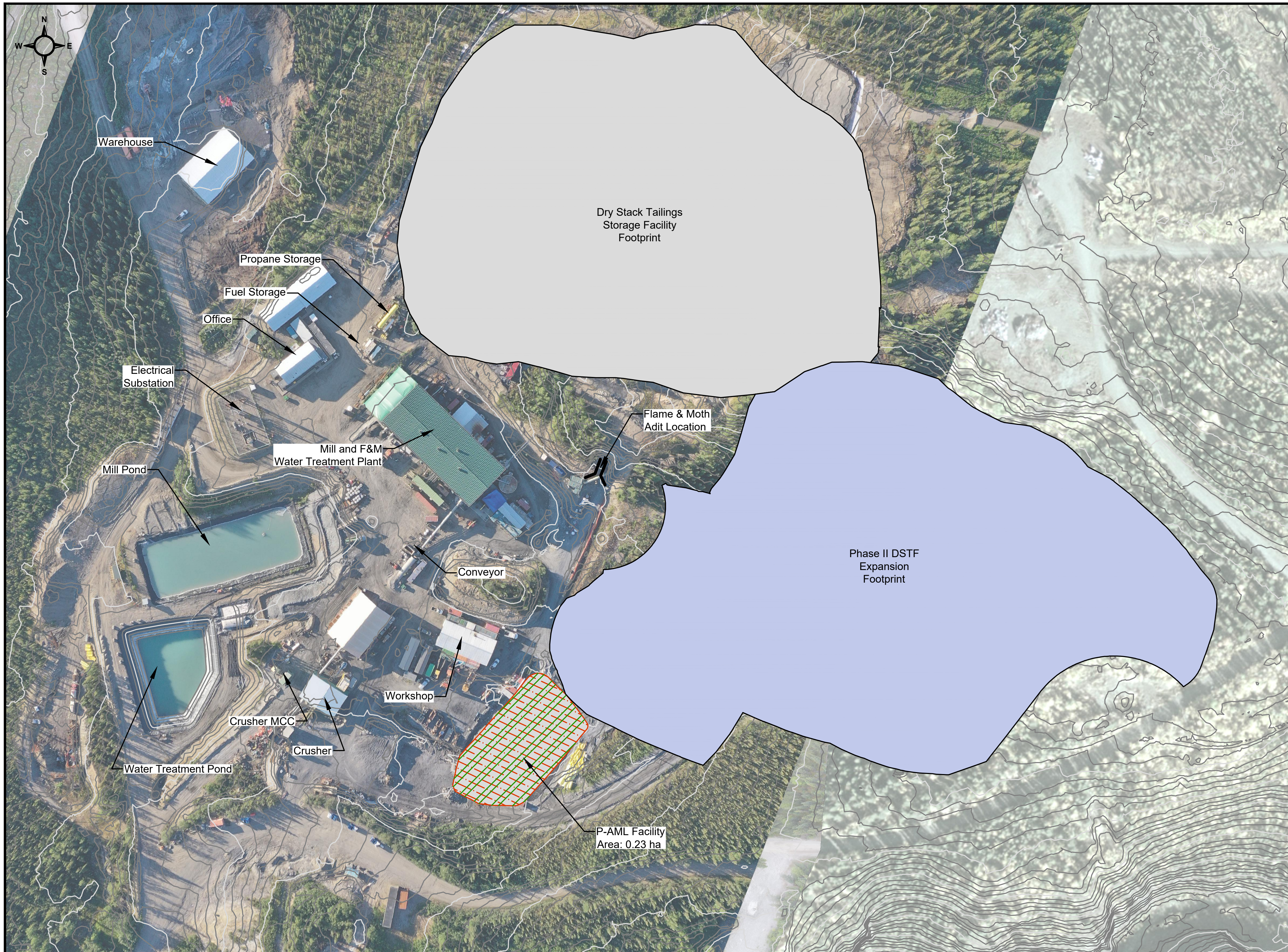

Notes:

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.

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2021-11-26	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-1401

Flame & Moth
Reclamation Measures

REVISION: B	2021-11-26	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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Notes:

1. The WRSF will be regraded to promote positive drainage and the area will be covered and revegetated.
2. The Bellekeno East portal will receive a rock pile closure. See drawing AKHM-13-01-S-0301.
3. 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
4. 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.
5. All the surface buildings at Bellekeno East are portable structures will be removed and transported offsite for salvage at closure.
6. Sediment ponds at Bellekeno East for the development of the decline will be progressively reclaimed prior to mine closure.
7. Contaminated soil will be removed and treated in a land treatment facility.
8. The Bellekeno East portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
9. 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

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2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Scale: 1:3000

0 20 40 80 Meters

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Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2401

Bellekeno East
Reclamation Measures

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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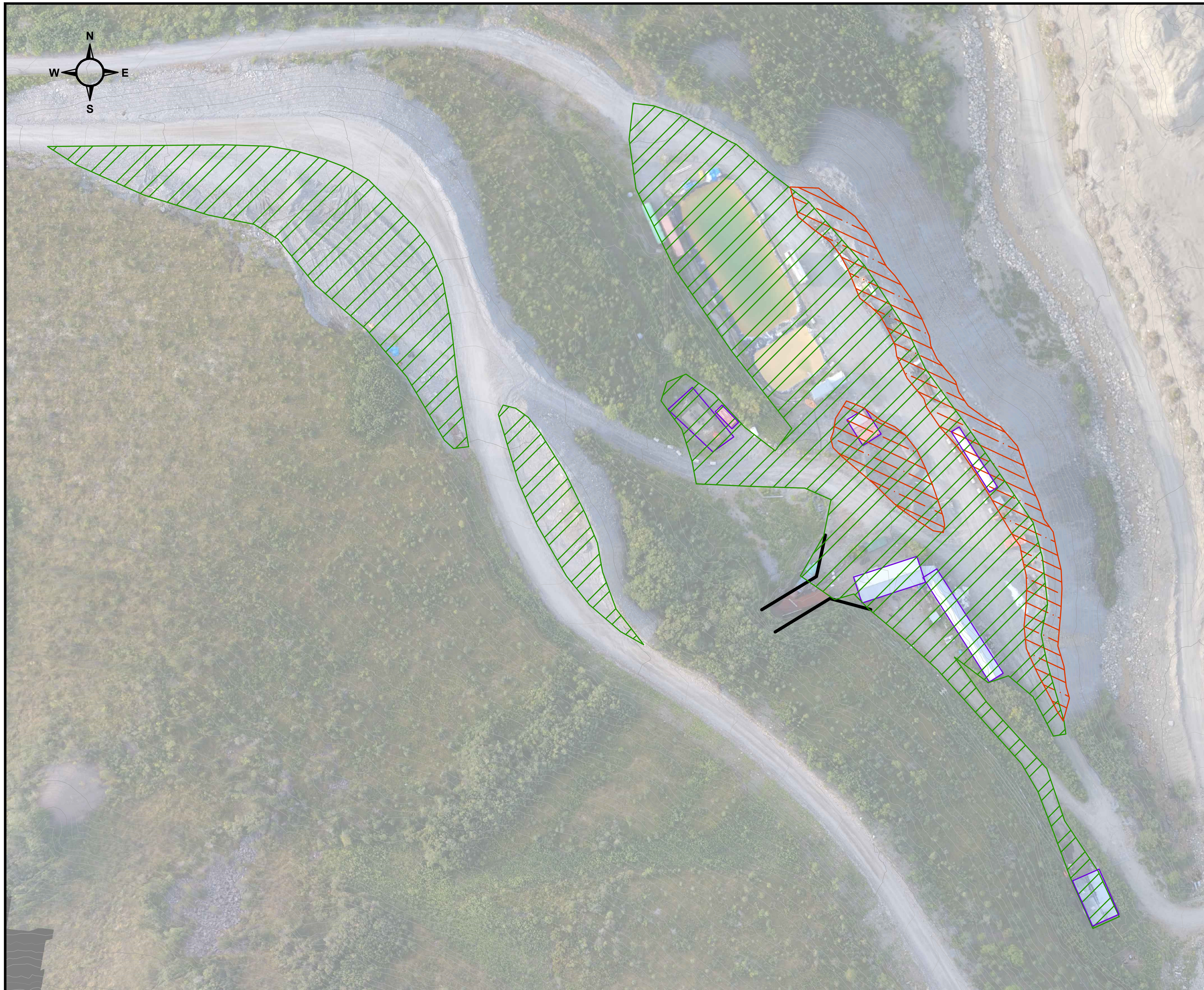

Notes:

1. The Bellekeno 625 adit will be closed with a concrete cofferdam to control water exiting the adit. 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

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2021-11-25	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Scale: 1:1250

0 18.75 37.5 75 meters

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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2402

Bellekeno 625
Reclamation Measures

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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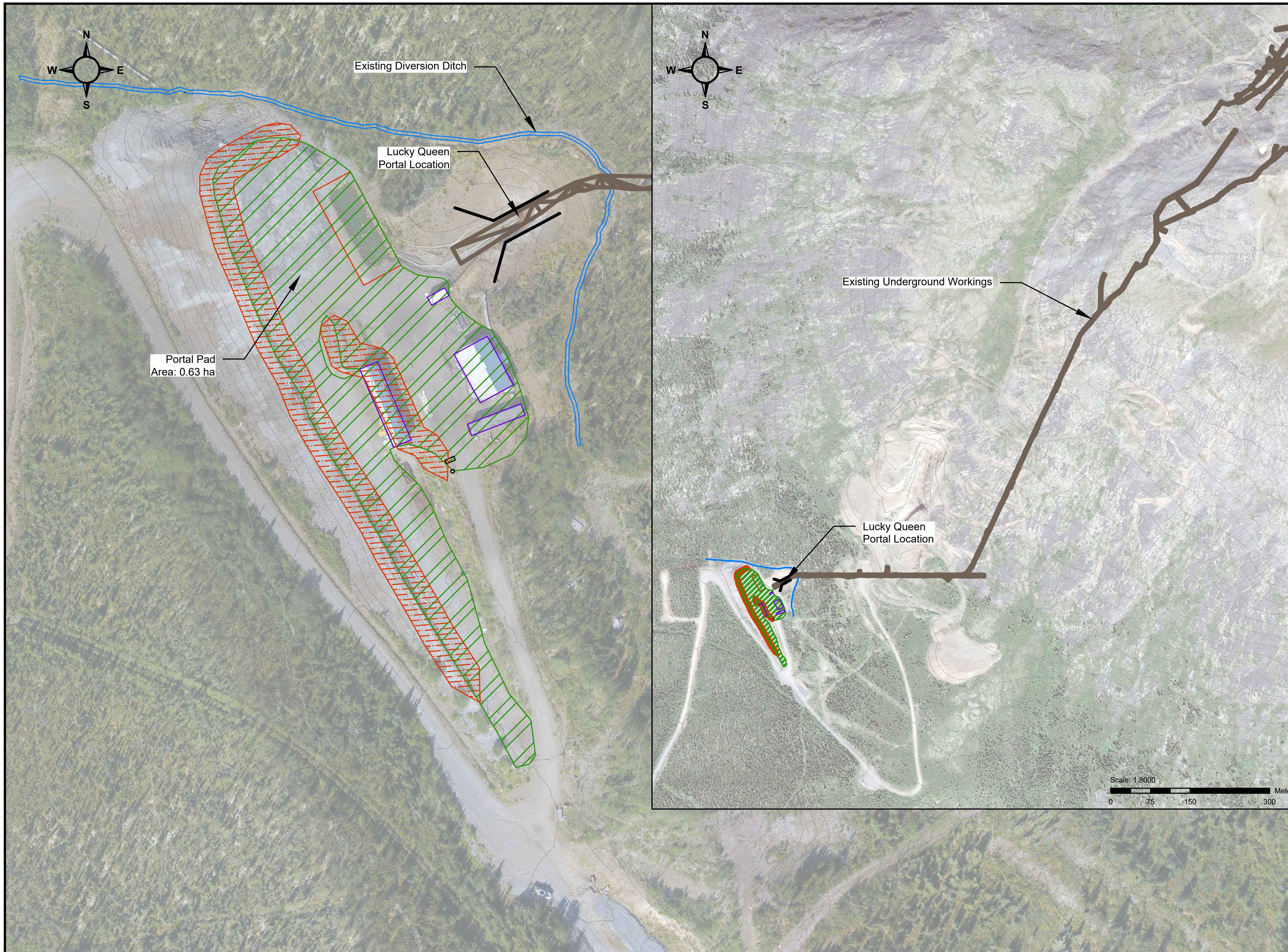

Notes:

1. A rockpile closure will be used to close the portal. See drawing AKHM-13-01-S-0302, Type 3 Closure.
2. Shop and other buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.
4. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
5. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quatities:

Area of recontouring:	2,520 m^2
Area of scarification and revegetation:	6,350 m^2

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2021-11-25	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

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

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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-3401

Lucky Queen
Reclamation Measures

REVISION: B	2021-11-25	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. Shop and other buildings and infrastructure will be removed for salvage or reuse.
4. Contaminated soil will be removed and treated in a land treatment facility.
5. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
6. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	5,600 m^2
Area of scarification and revegetation:	8,300 m^2

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2021-11-25	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Scale: 1:3000

0 25 50 100 Meters

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-4401

Onek
Reclamation Measures

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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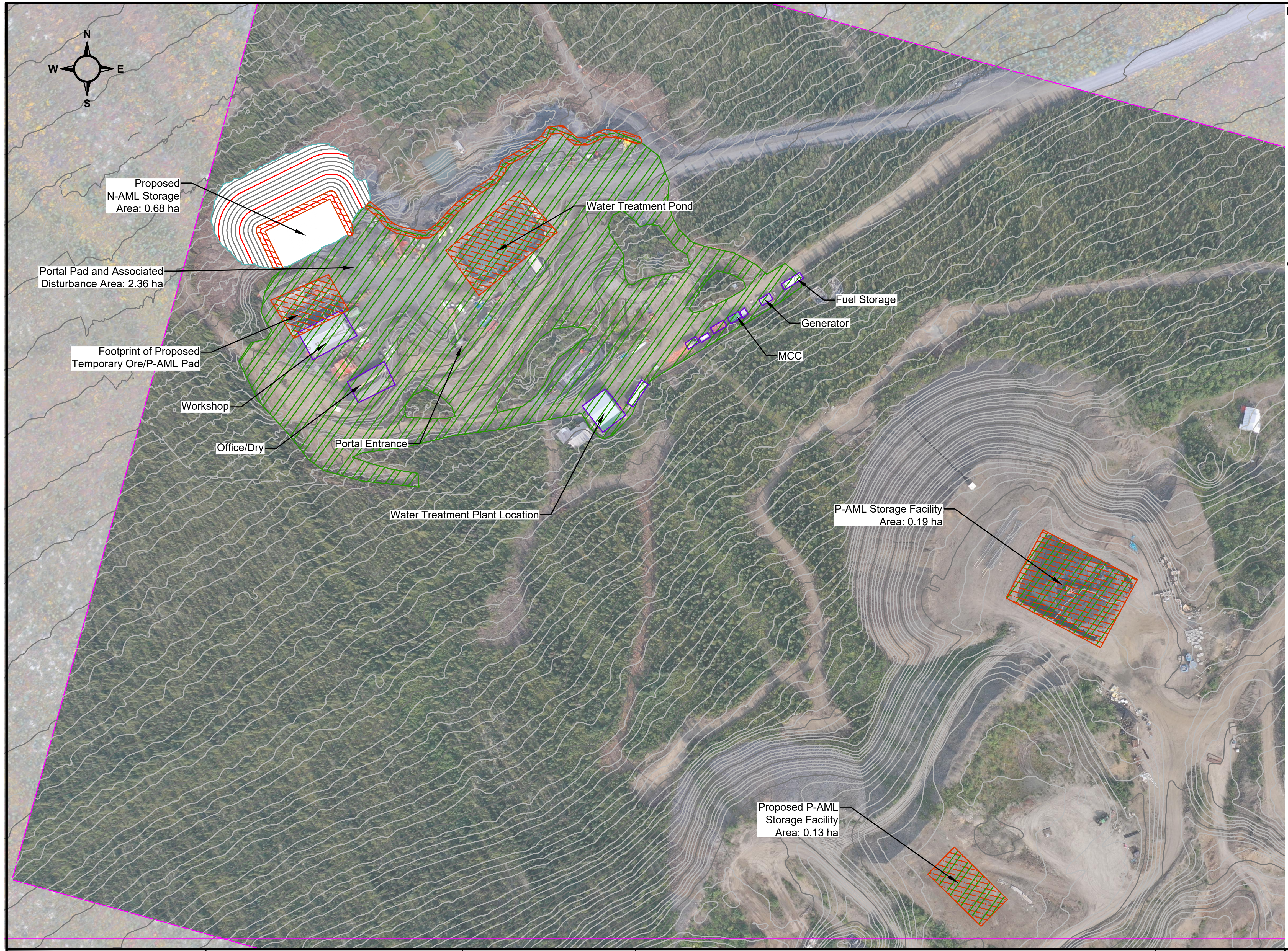

Notes:

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.
9. The vent raise will be capped with an engineered concrete or PUF cap. See Drawing AKHM-13-01-S-0303.

Quantities:

Total area of recontouring: 5,240 m^2
Total area of scarification and revegetation: 26,140 m^2

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2021-11-26	Draft for review	B	KAB	--
2017-12-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Scale: 1:2000
0 15 30 60 Meters

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-5401

Bermingham
Reclamation Measures

REVISION: B	2021-11-26	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: --

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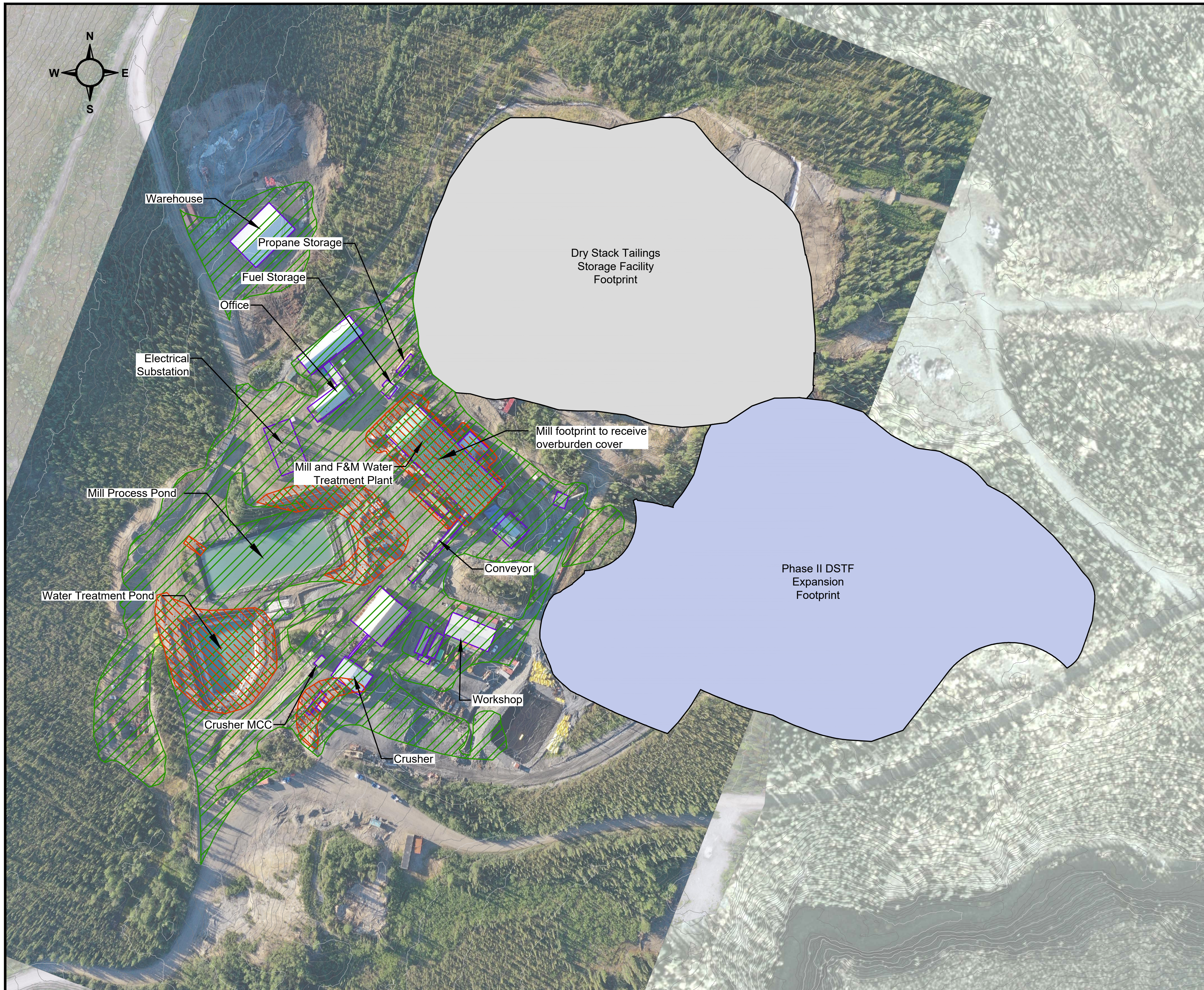

Notes:

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 of the Mill Pond will be scarified and revegetated and it will serve as a sedimentation pond during closure until revegetation is stabilized. A spillway will be cut into the Mill Pond to allow for long term discharge to the environment. The F&M Water Treatment Pond will be recontoured by having the berms pushed in to create a continuous slope.
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:	6,050 m^2
Area of scarification and revegetation:	47,900 m^2
Area to receive overburden cover:	3,150 m^2

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2021-11-26	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to receive overburden cover
- Area to be scarified and revegetated

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-6401

Mill Site Reclamation Measures

REVISION: B	2021-11-26	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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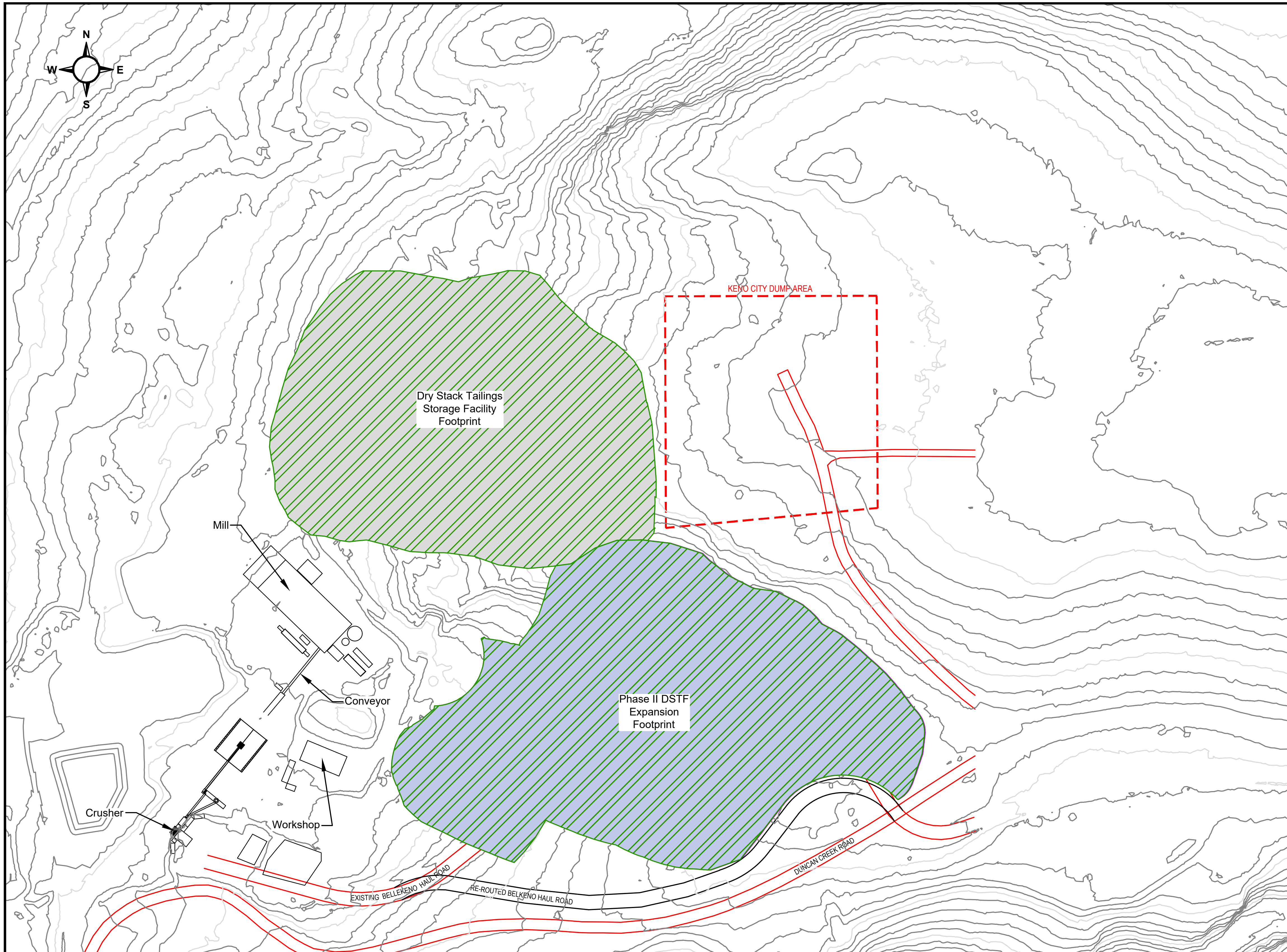

Notes:

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

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2018-01-18	Draft for review	A	KAB	--

Legend

- Area to be recontoured
- Area to be scarified and revegetated

Scale: 1:2500

0 20 40 80 Meters

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-7401

Dry Stack Tailings Facility Reclamation Measures

REVISION: B	2021-11-26	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.

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2018-01-18	Draft for review	A	KAB	--

Scale: 1:5000

0 40 80 160 Meters

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-8401

KHSD Sludge Ponds
Reclamation Measures

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\8-KHSD Sludge Pond\C-Civil\AKHM-13-01-C-8401-SludgePondLayout.dwg (last edited by: KBoldt; 2021/11/26 - 9:42 AM)

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

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2021-11-25	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

Scale: 1:1250

0 17.5 35 70 m

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-9401

Flat Creek Camp Reclamation Measures

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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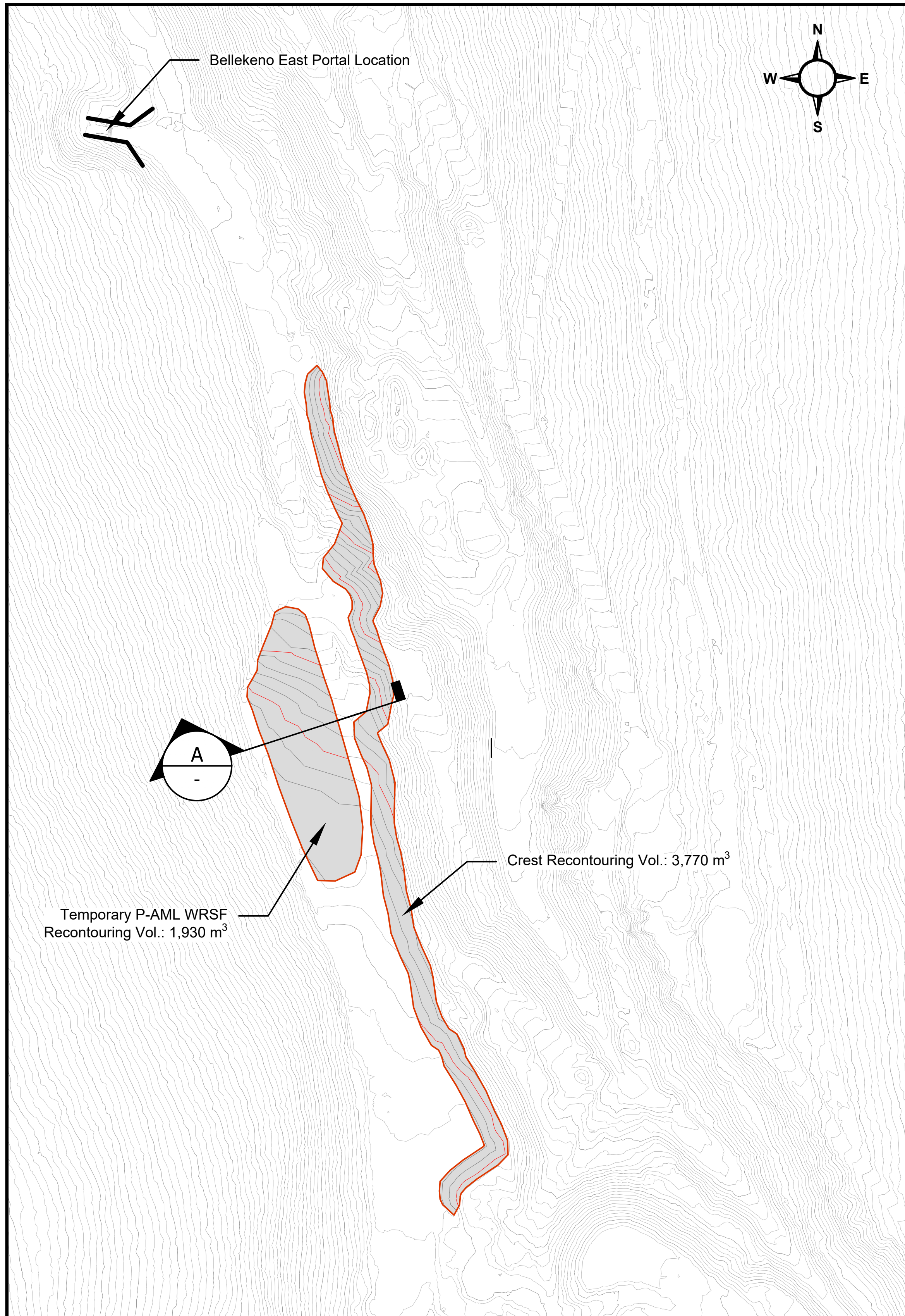
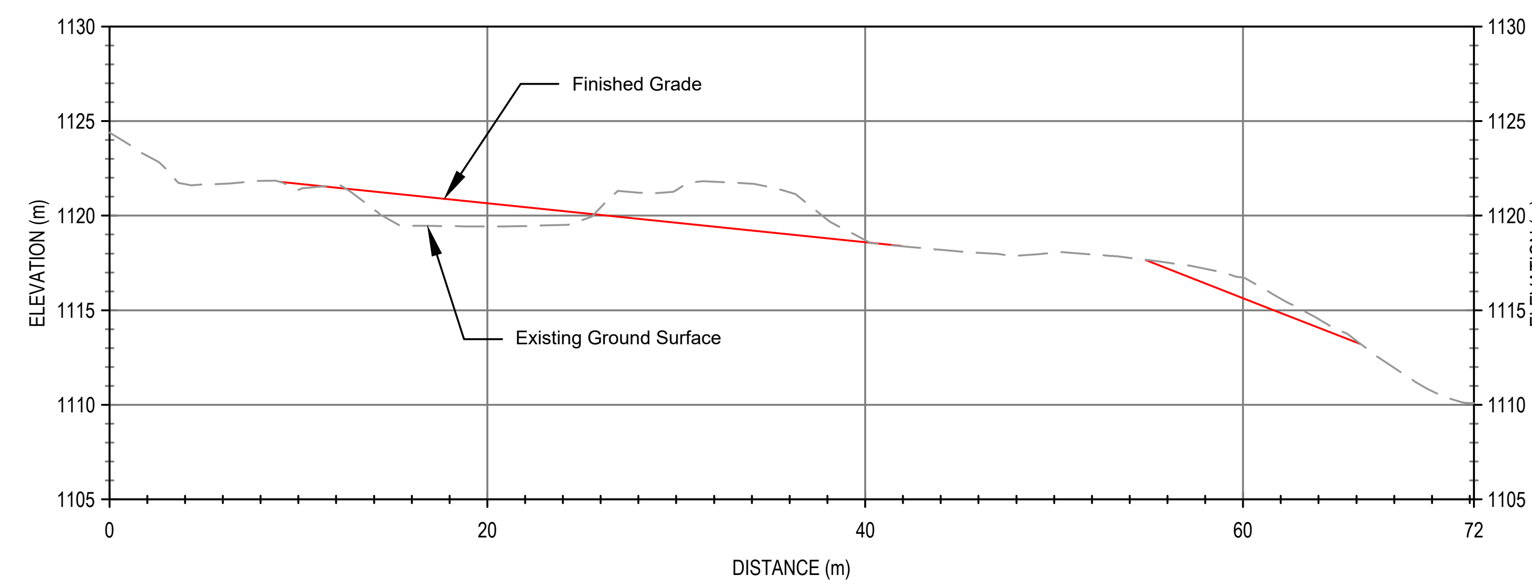


Notes:
1. Remaining P-AML waste rock on surface, stored in the lined storage facility will be backfilled to underground.
2. The WRSF liner will be removed and disposed of in a waste facility.
3. The WRSF will be regraded to promote positive drainage.
4. Portal area crests will be rolled back via excavator.

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

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-2101

Bellekeno East Grading
Plan and Cross Section

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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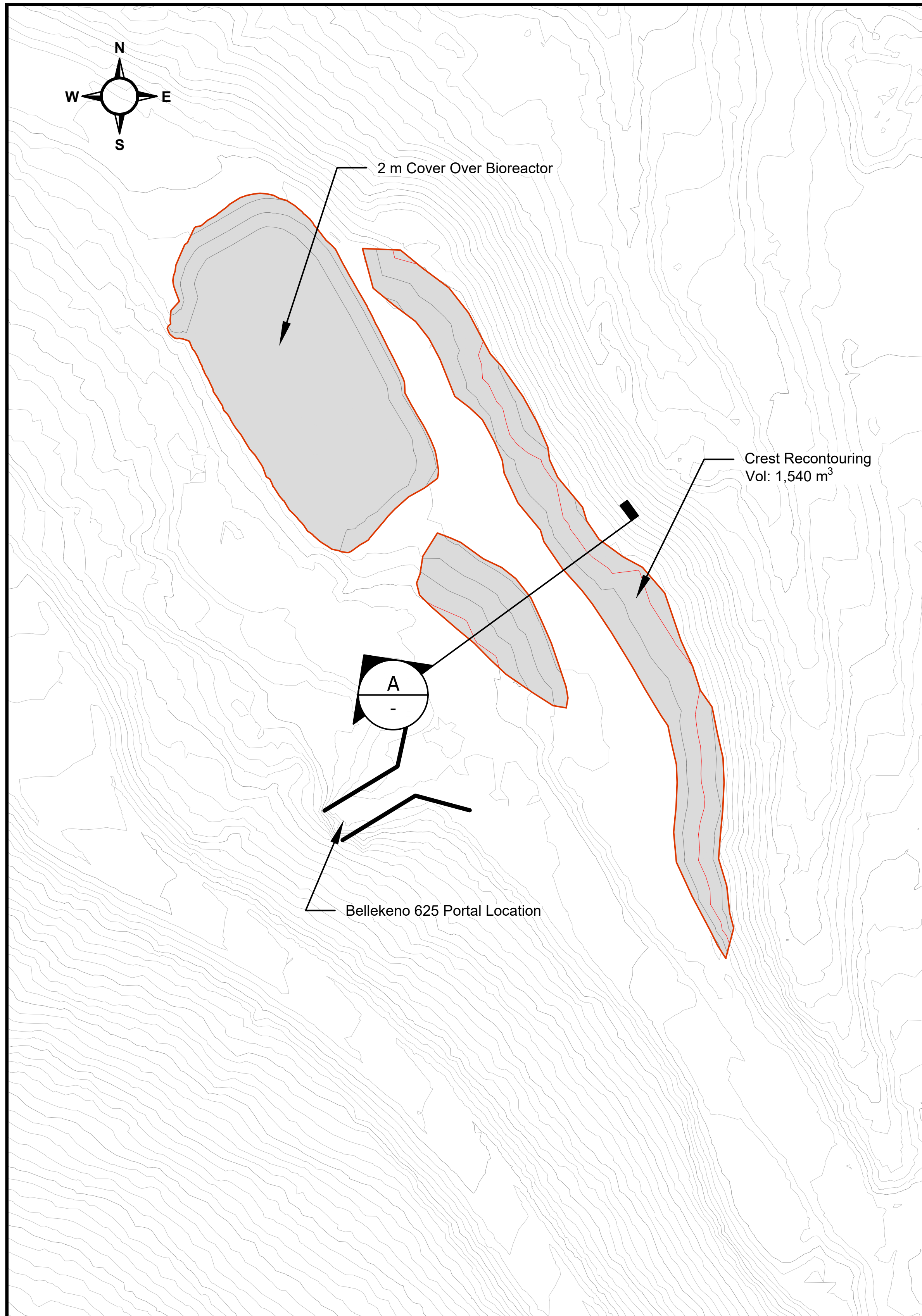
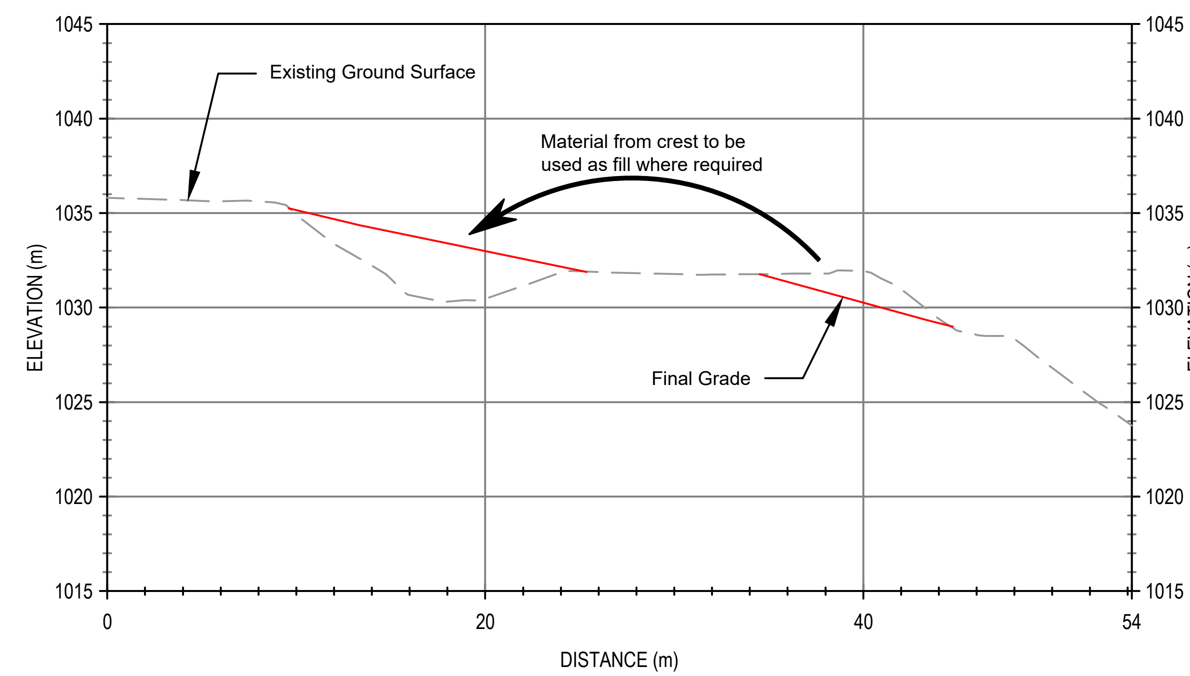


Notes:

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

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

Scale: 1:1250

0 12.5 25 50 m

ENSERO solutions

AKHM

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

Bellekeno 625 Grading
Plan and Cross Section

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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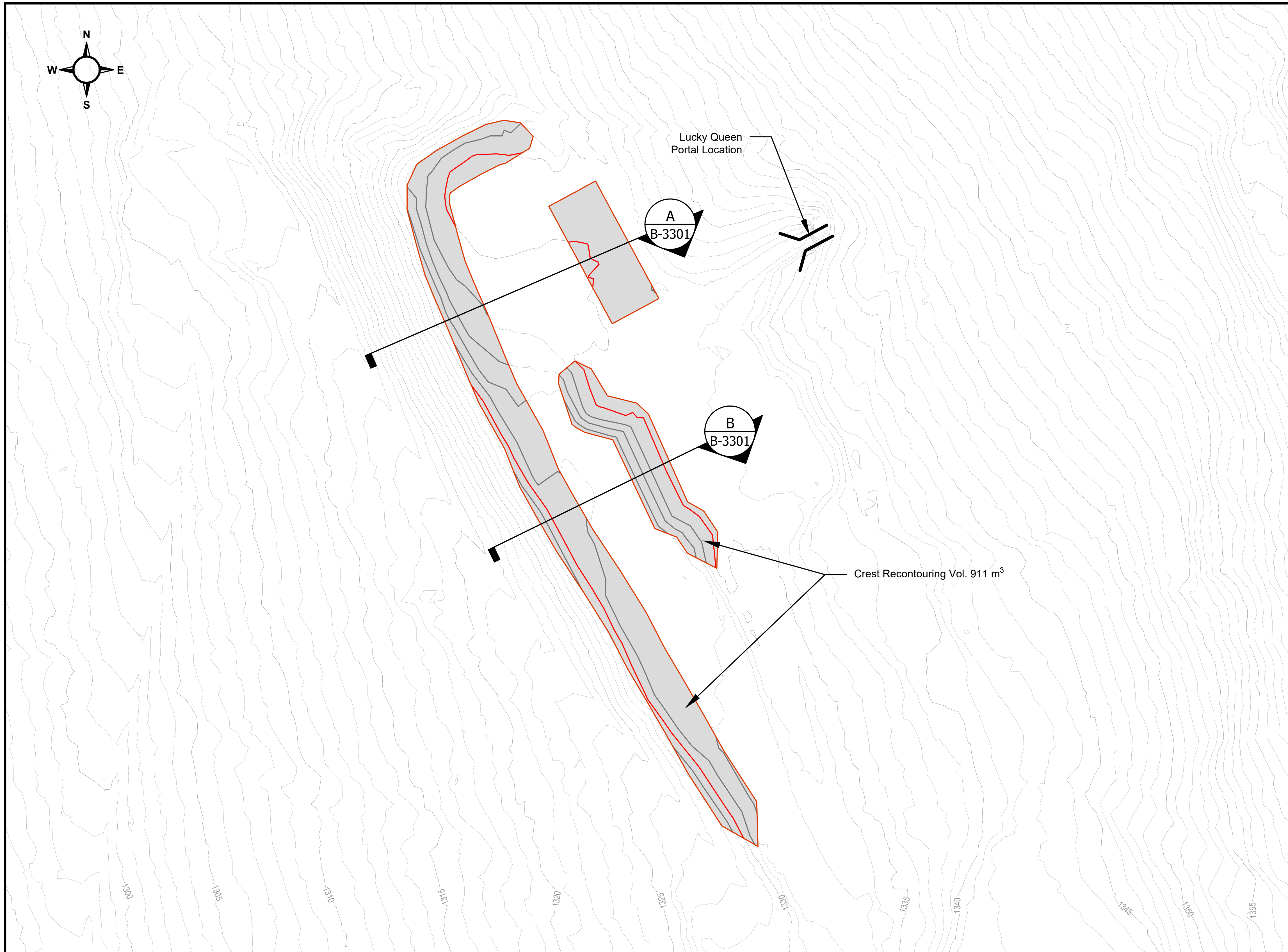

Notes:

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

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Scale: 1:1000

0 10 20 40 m

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3101

Lucky Queen Grading Plan

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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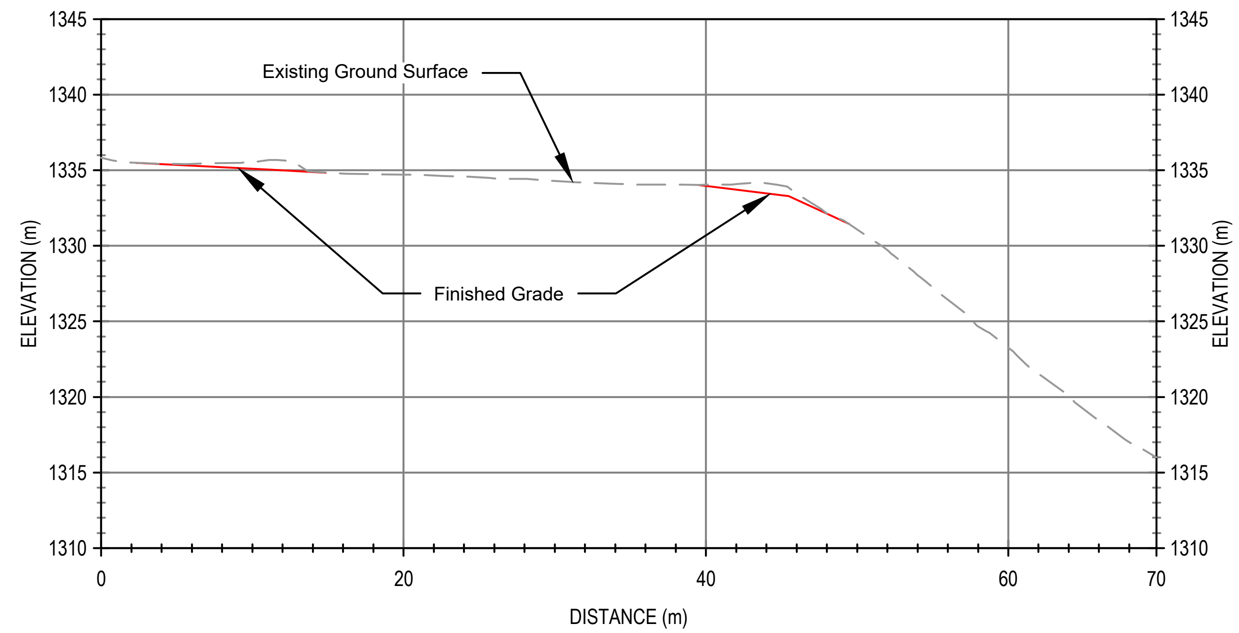
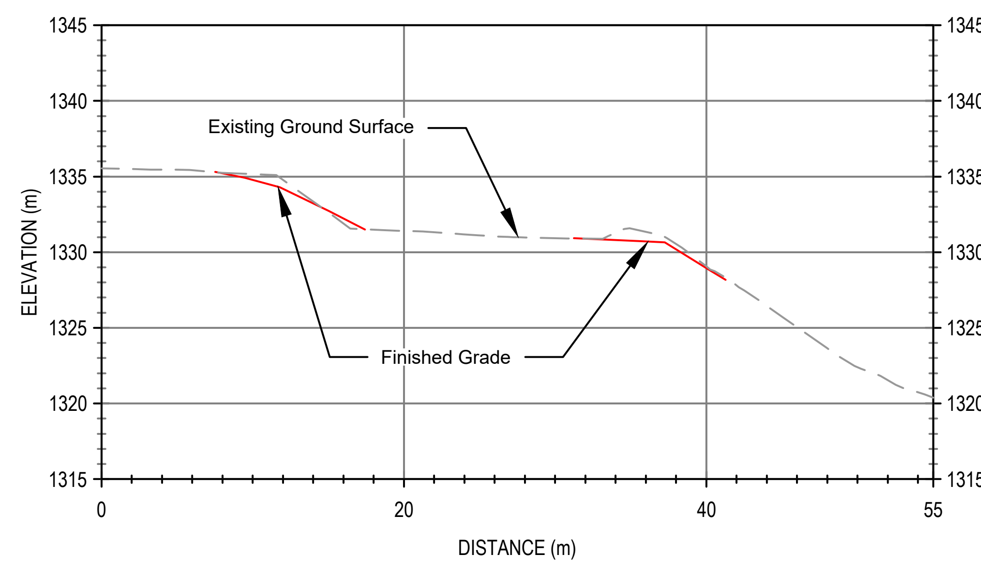


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2018-01-30	Draft for review	A	KAB	--

Scale: 1:500

0 5 10 20 m

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3301

Lucky Queen Grading
Cross Sections

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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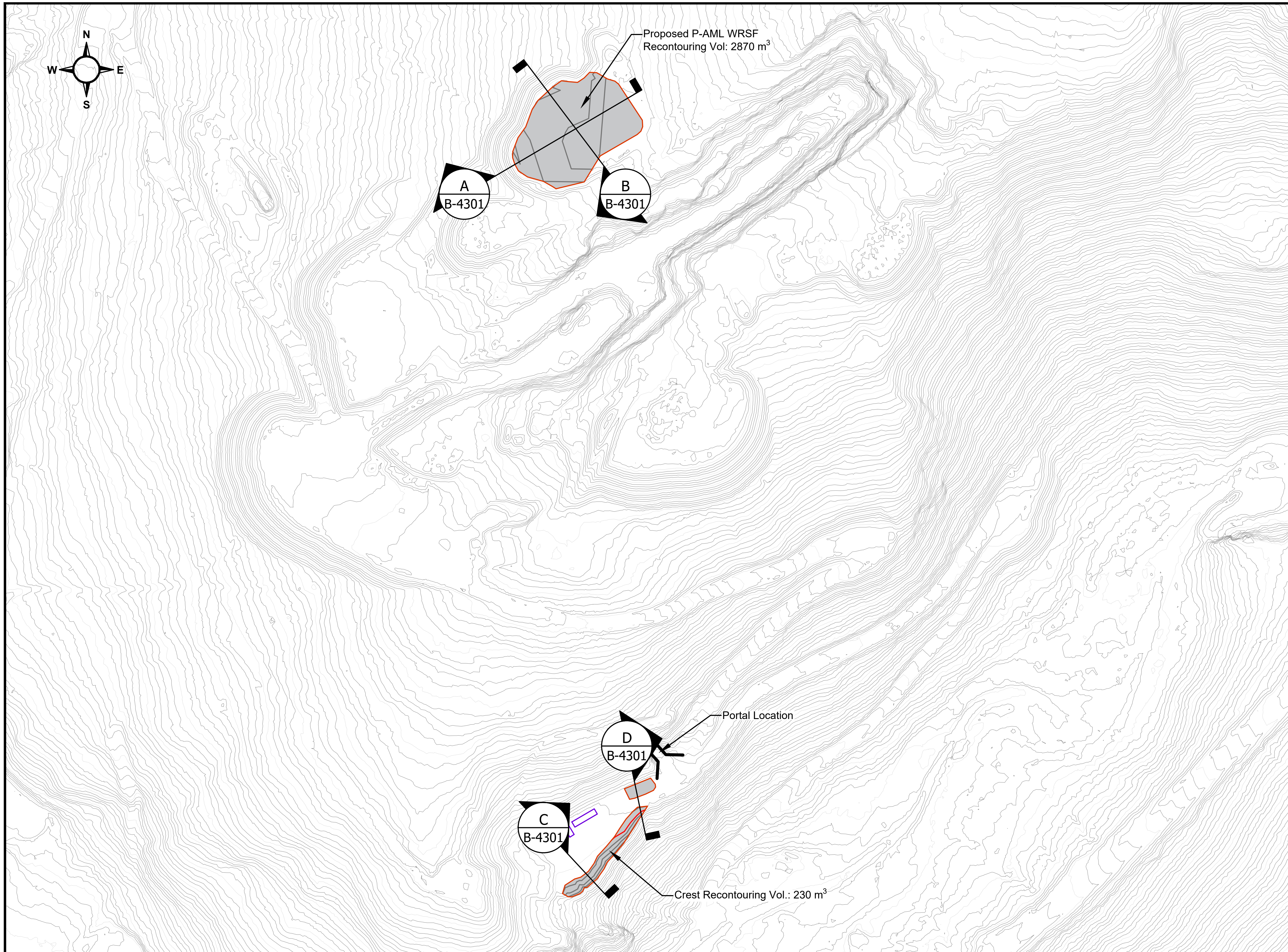

Notes:

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

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2018-01-31	Draft for review	A	KAB	--

Scale: 1:3000

0 25 50 100 Meters

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4101

Onek Grading Plan

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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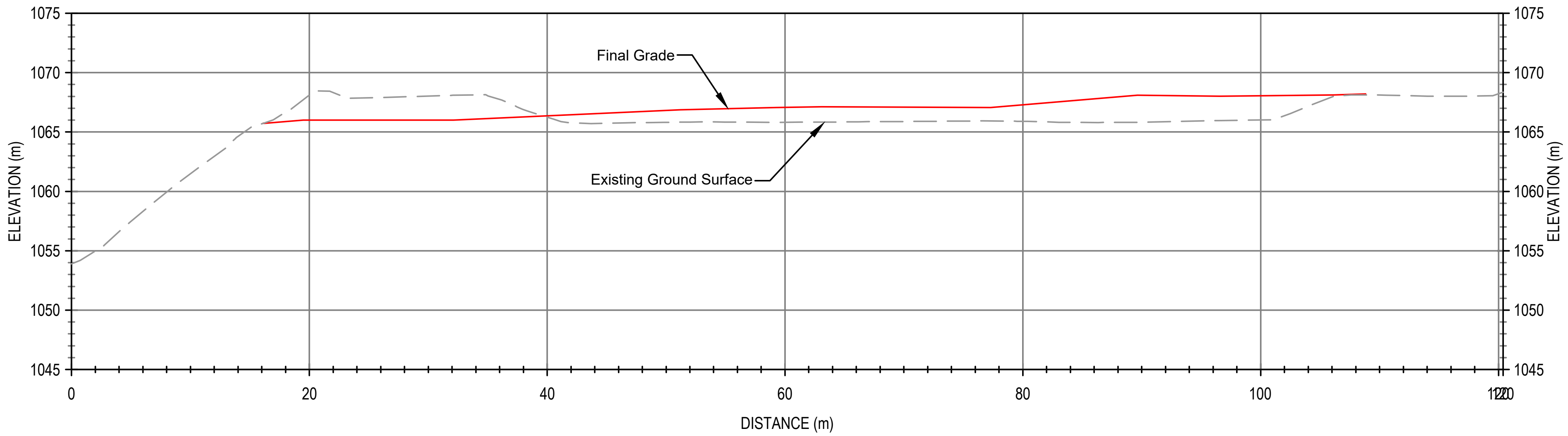
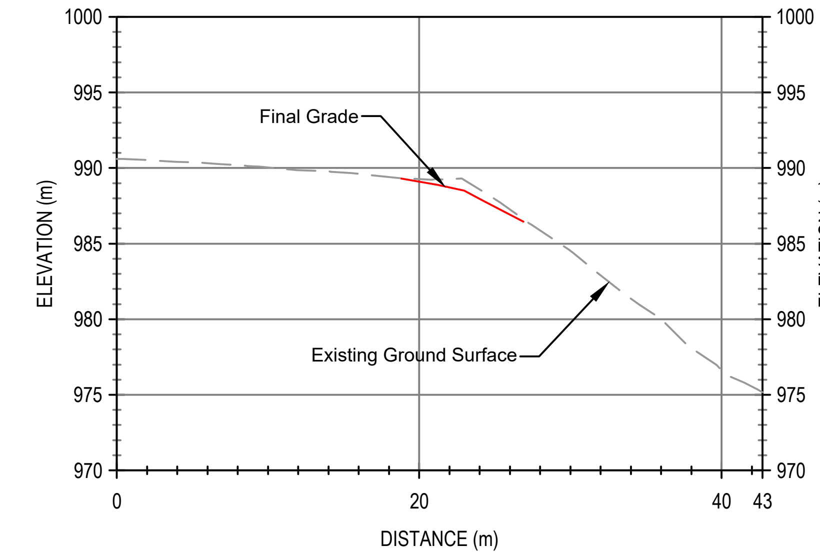


Section A



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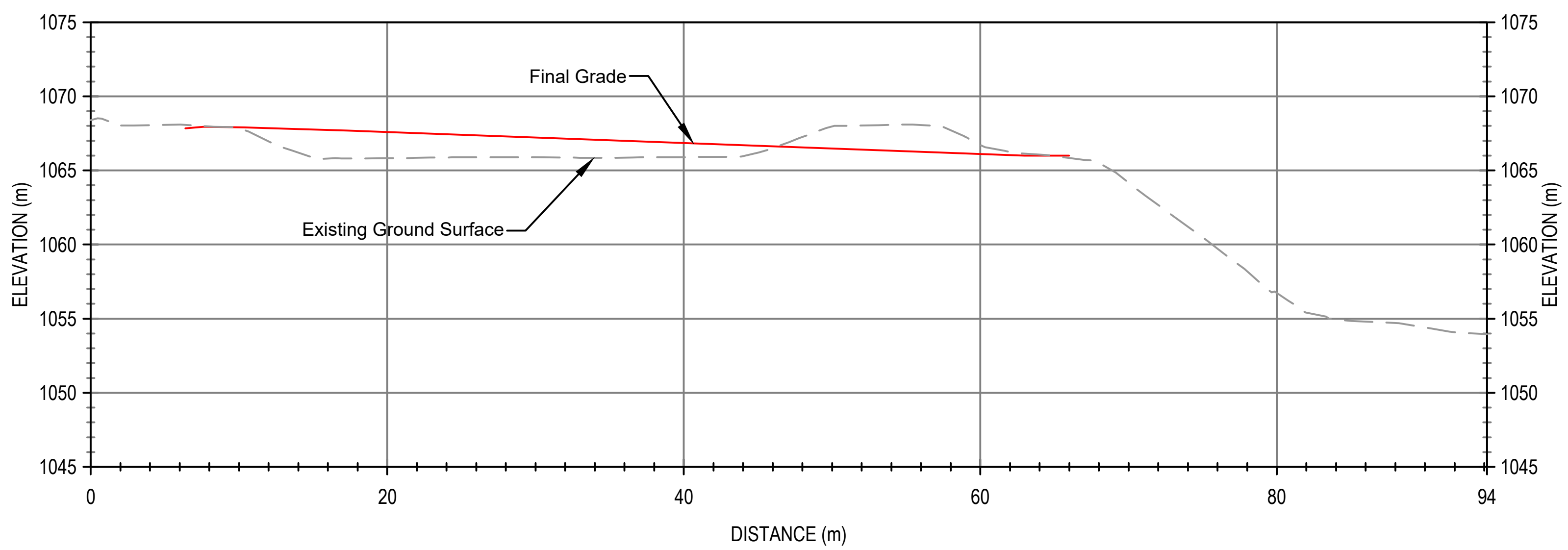
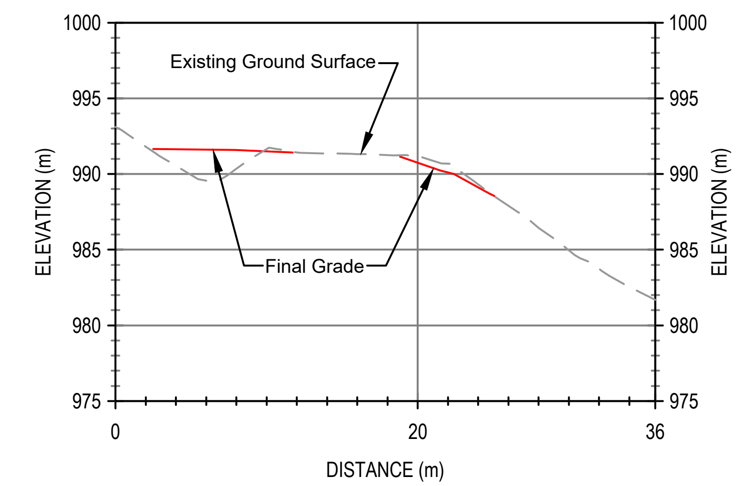


Section B



Section D

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-25	Draft for review	B	KAB	--
2018-01-31	Draft for review	A	KAB	--

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4301

Onek Grading Sections

REVISION: B	2021-11-25	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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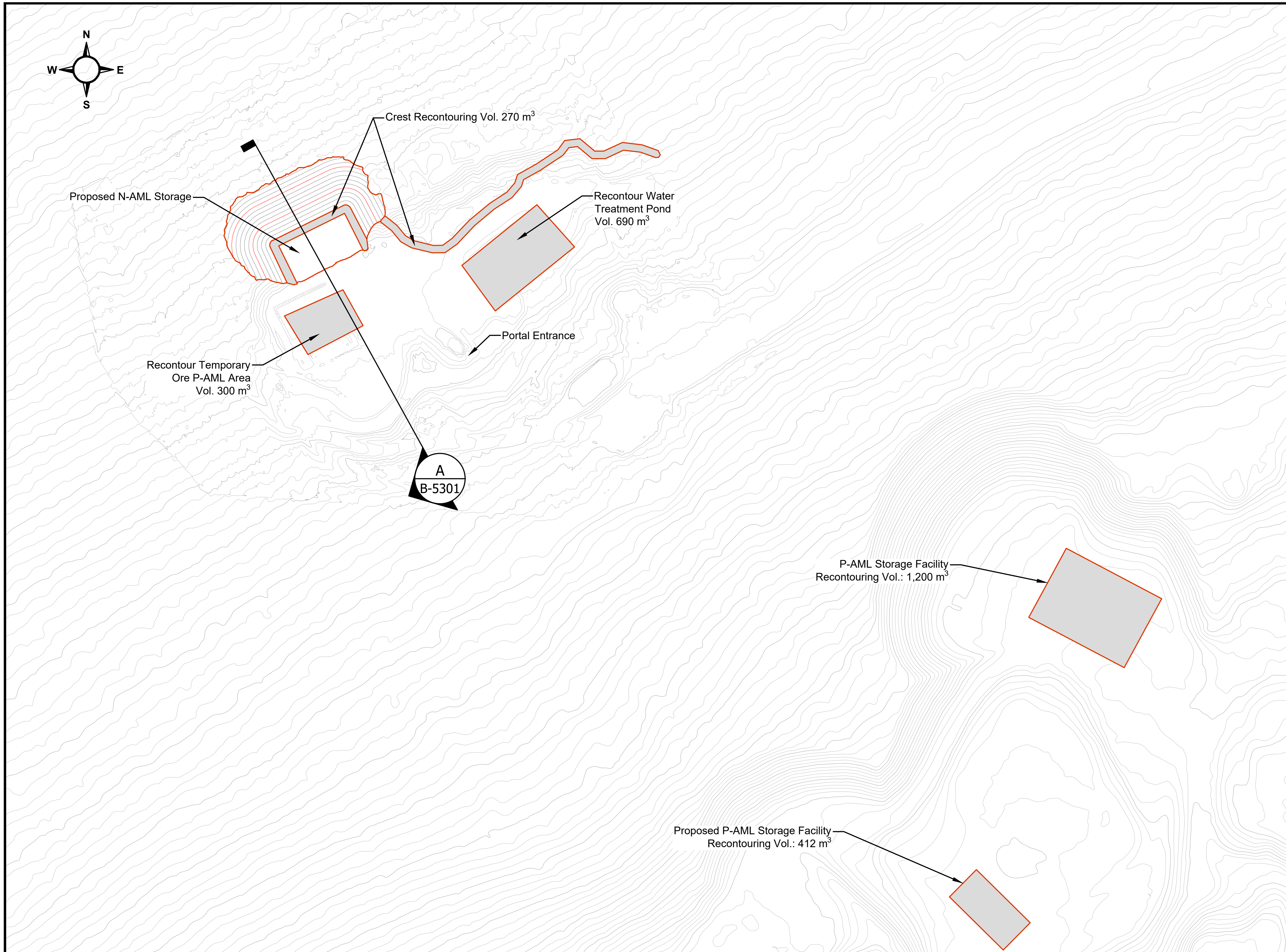

Notes:

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: 3,070 m^3

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2021-11-26	Draft for review	B	KAB	--
2018-02-05	Draft for review	A	KAB	--

Scale: 1:2000
0 12.5 25 50 m

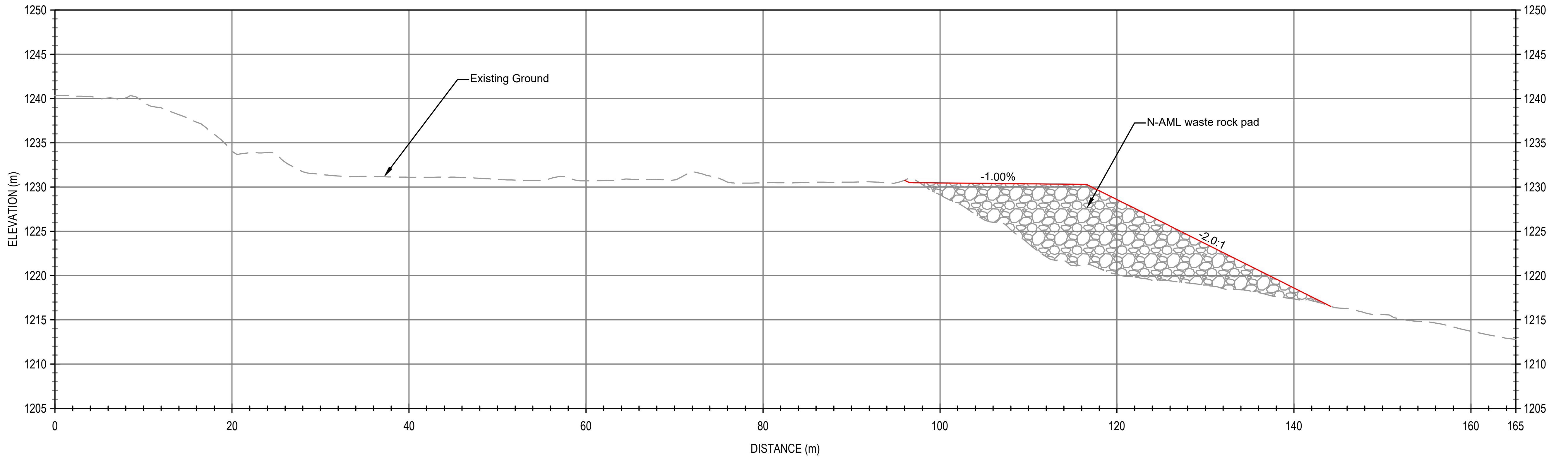
ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5101

Bermingham Grading Plan

REVISION: B	2021-11-26	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW



Section A

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2018-02-05	Draft for review	A	KAB	--

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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5301

Bermingham Grading
Cross Section

REVISION: B	2021-11-26	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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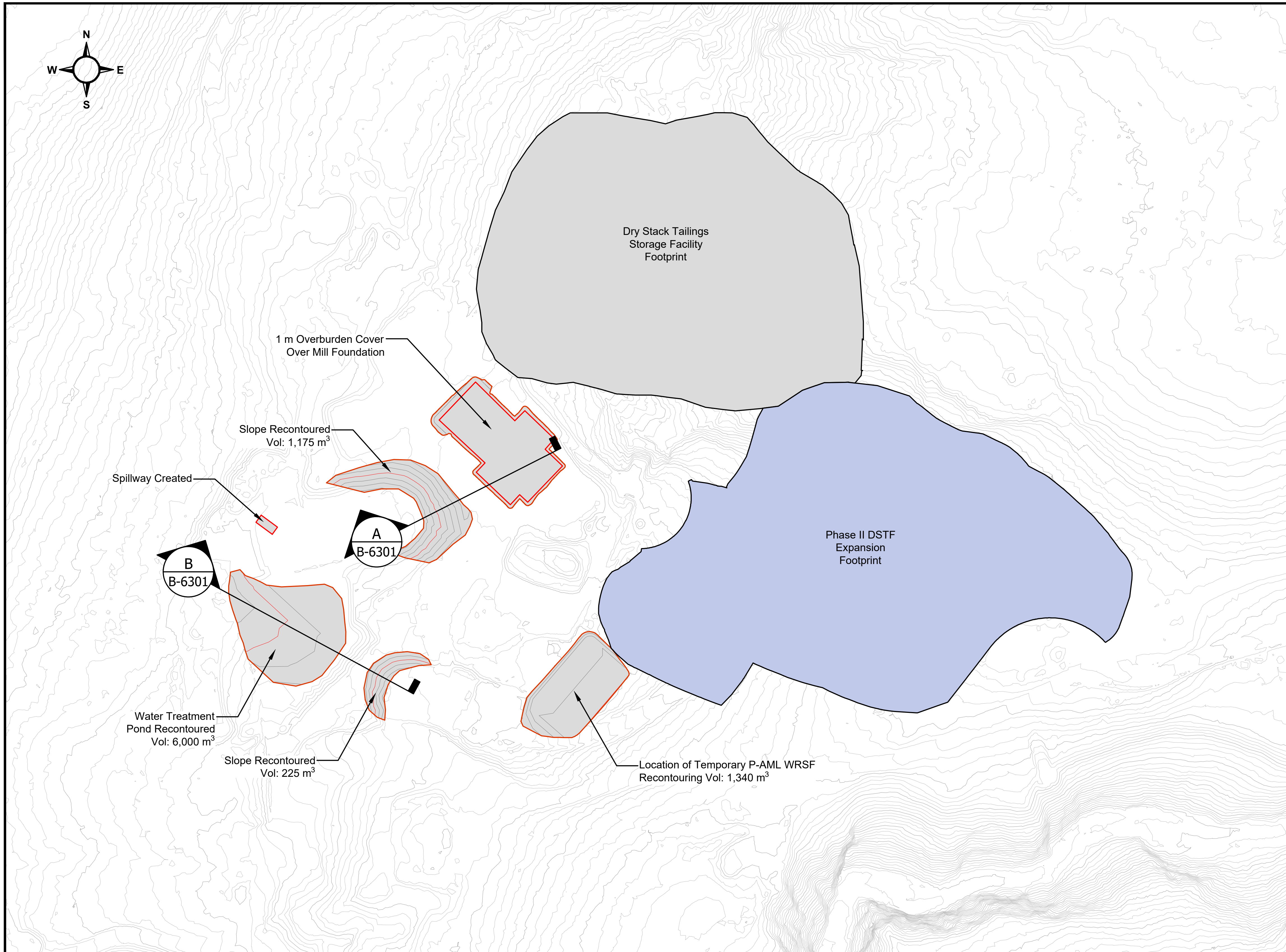

Notes:
1. Concrete slabs and above grade footings and foundations will be broken up and covered with 1 m overburden cover, scarified, and revegetated.
2. The mill process pond will have the liner removed. The slopes will be scarified and revegetated. The pond will serve as a sedimentation pond during closure until revegetation is stabilized. A spillway will be cut into the Mill Pond to allow for long term discharge to the environment.
3. The F&M Water Treatment Pond will be recontoured by having the berms pushed in to create a continuous slope.
4. The mill site will be recontoured and scarified to establish drainage and facilitate revegetation.
5. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured:	8,740 m^3
Volume of overburden cover:	1,800 m^3

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-26	Draft for review	B	KAB	--
2018-02-02	Draft for review	A	KAB	--

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6101

Mill Site Grading Plan

REVISION: B	2021-11-26	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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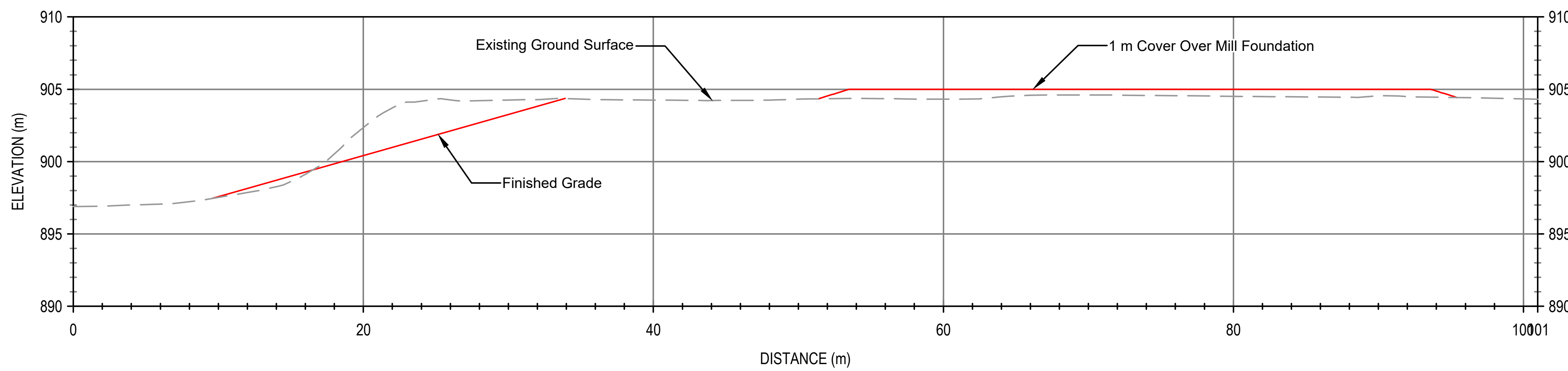
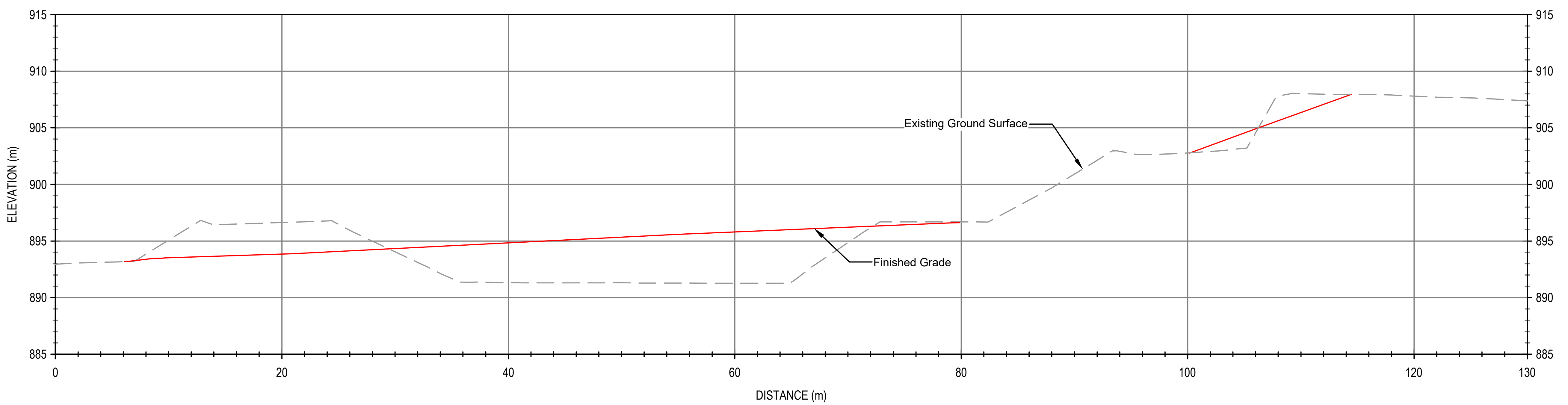


Section A



Section B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-26	Draft for review	B	KAB	--
2018-02-02	Draft for review	A	KAB	--

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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6301

Mill Site Grading
Cross Sections

REVISION: B	2021-11-26	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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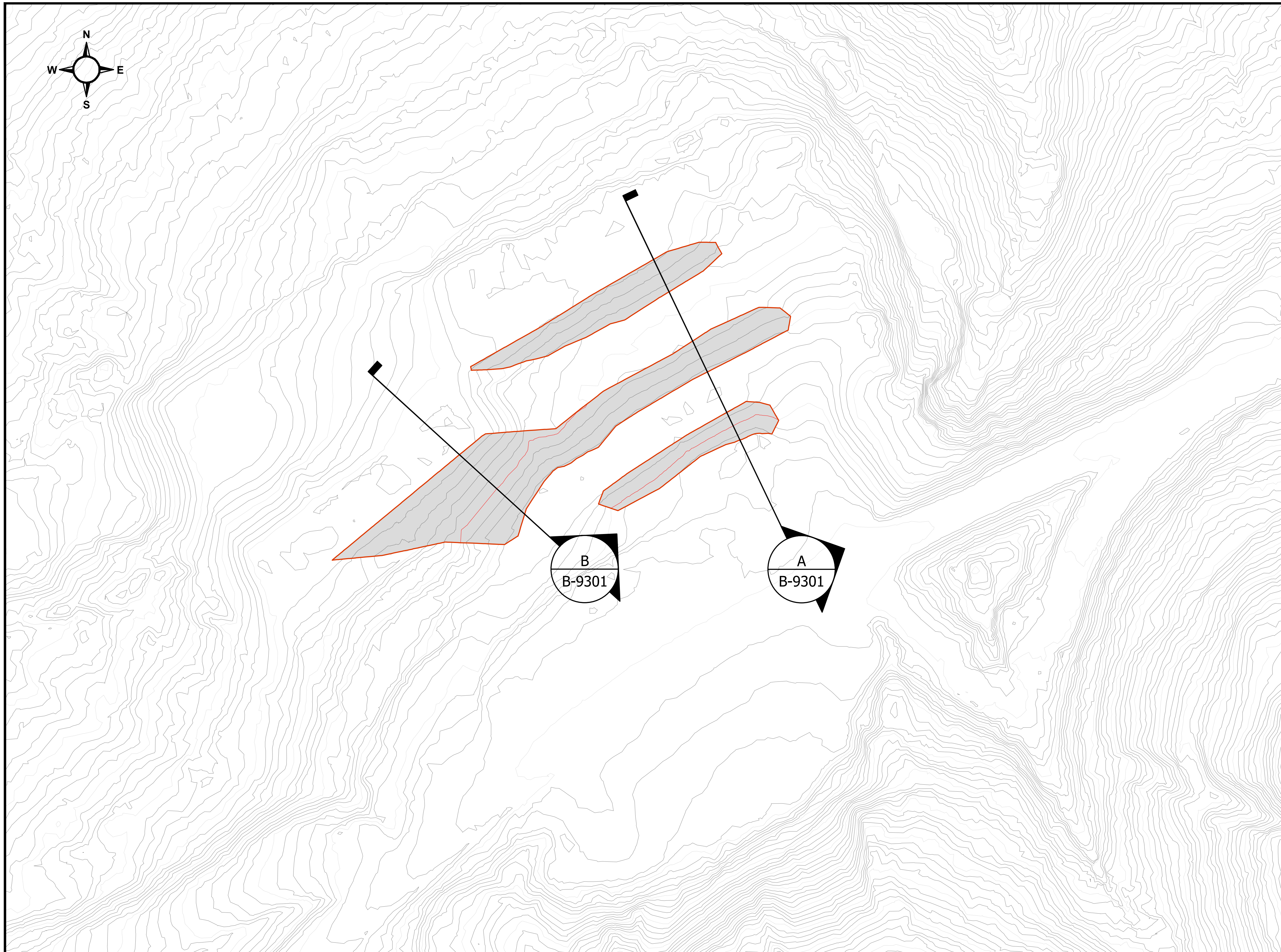

Notes:

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

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2021-11-26	Draft for review	B	KAB	--
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AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9101

Flat Creek Camp
Grading Plan

REVISION: B	2021-11-26	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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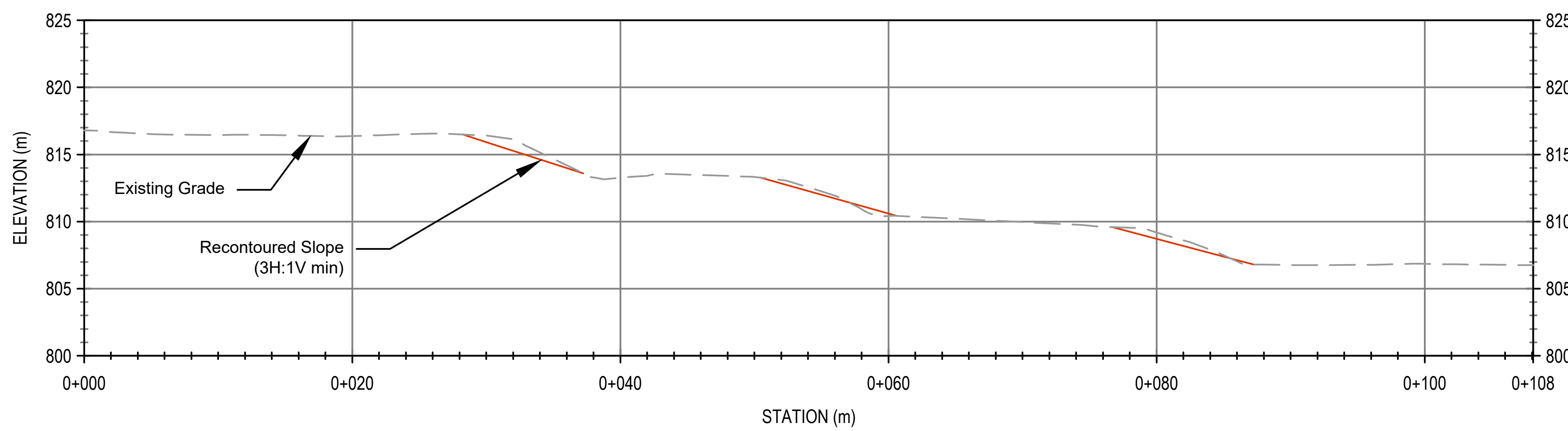
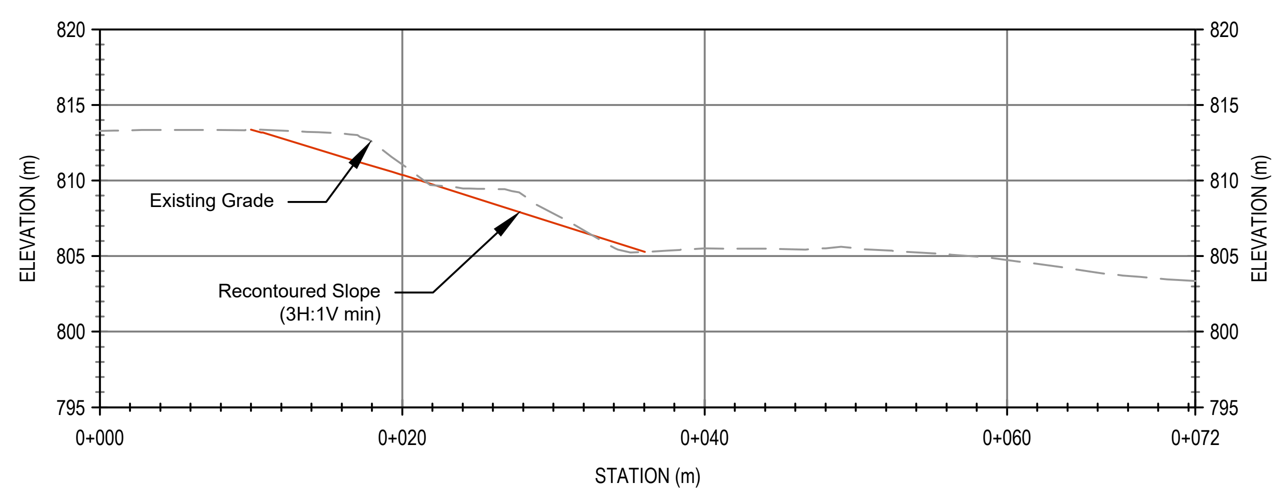
Notes:
1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:



Alignment-A



Alignment-B

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2021-11-26	Draft for review	B	KAB	--
2018-01-18	Draft for review	A	KAB	--

ENSERO solutions

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9301

Flat Creek Camp
Grading Plan - Sections

REVISION: B	2021-11-26	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.

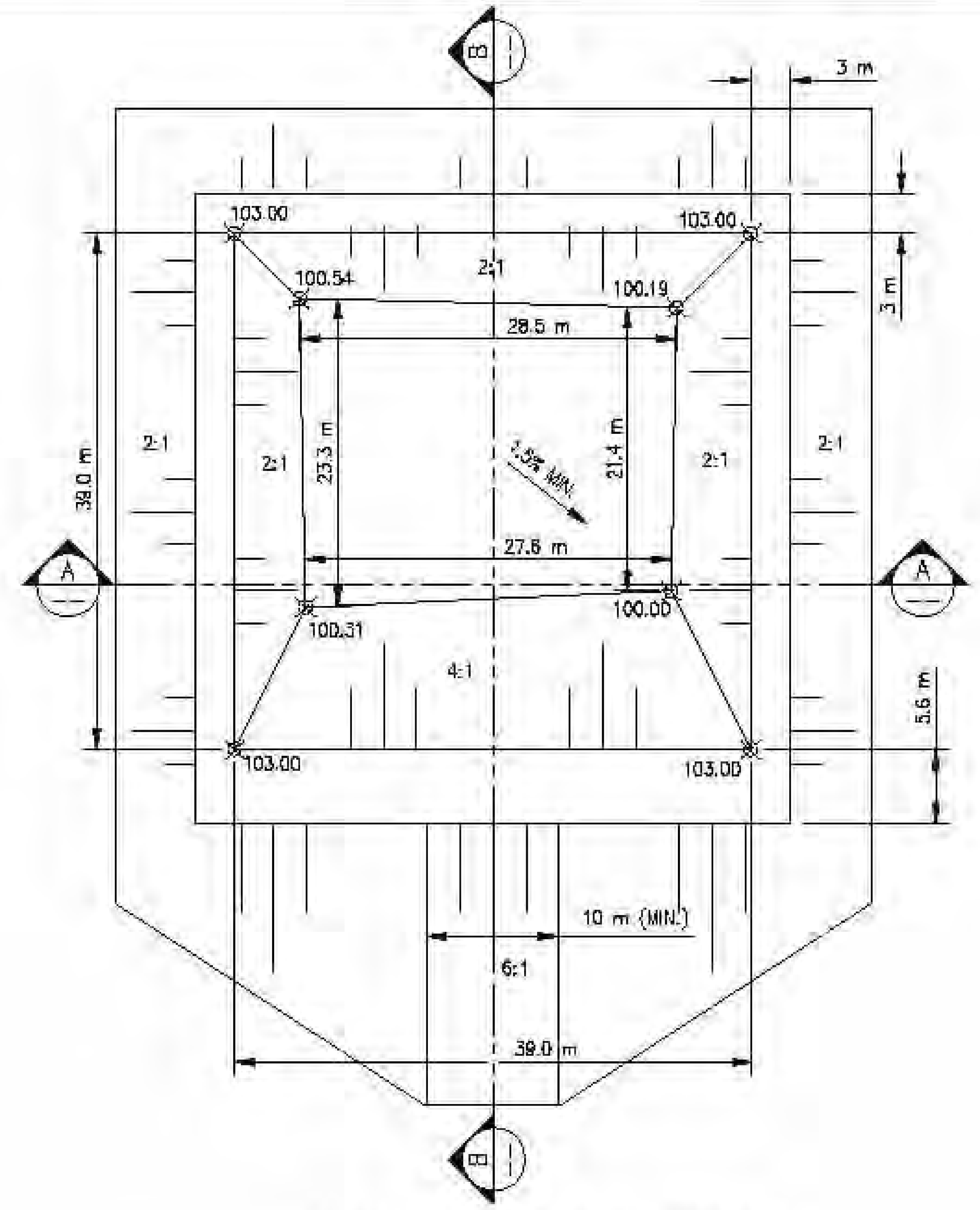
.4 The vegetative cover must have sufficient density and species diversity to stabilize the surface against the effects of long term erosion.

.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

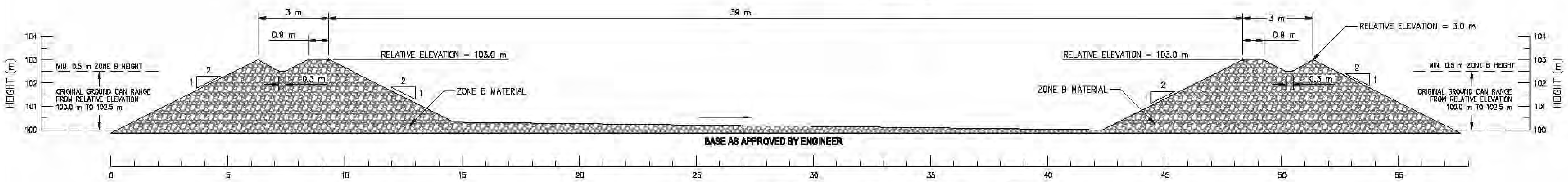
APPENDIX

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 m^2 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.

PERMIT | PROFESSIONAL SEAL

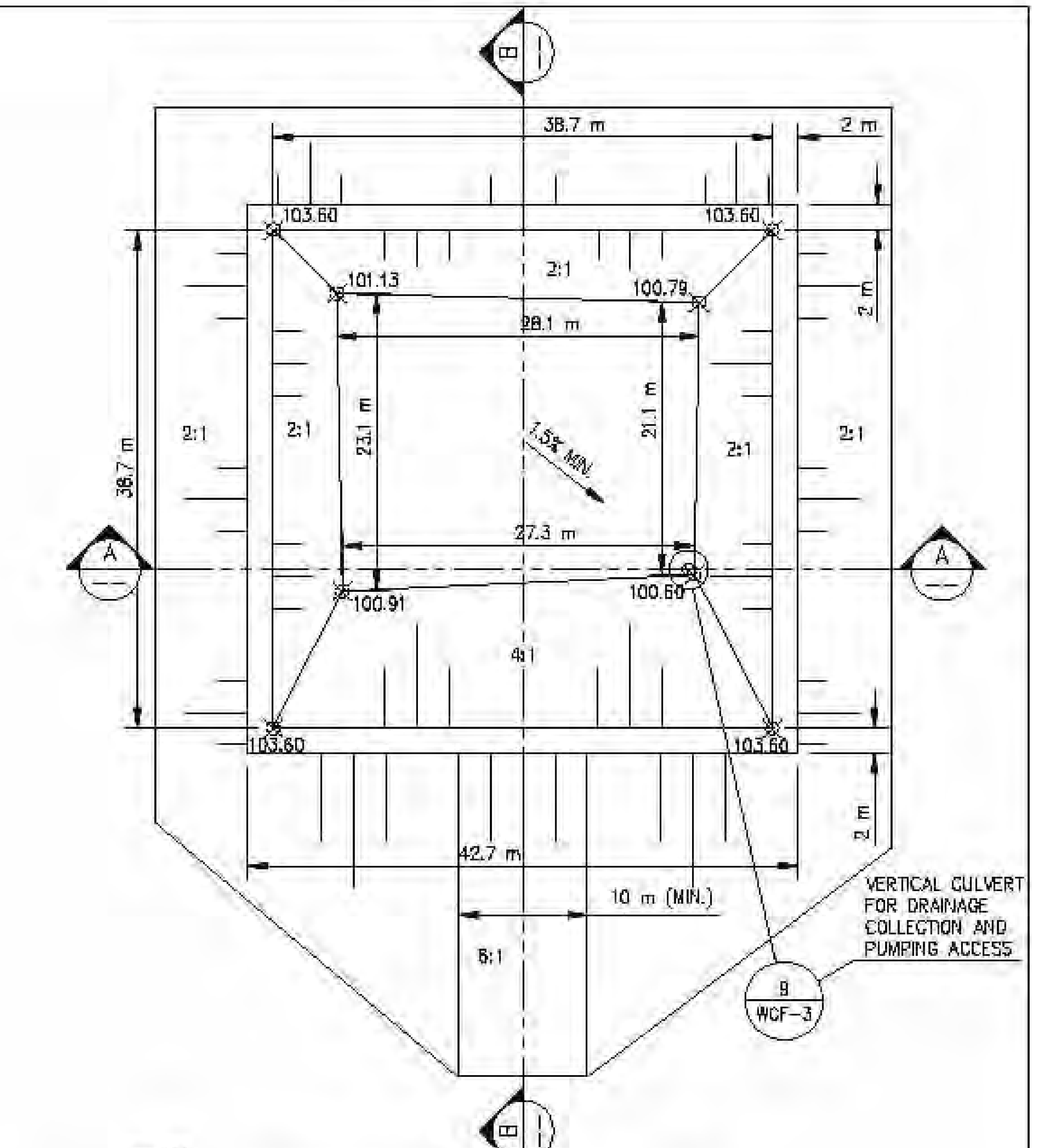
CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

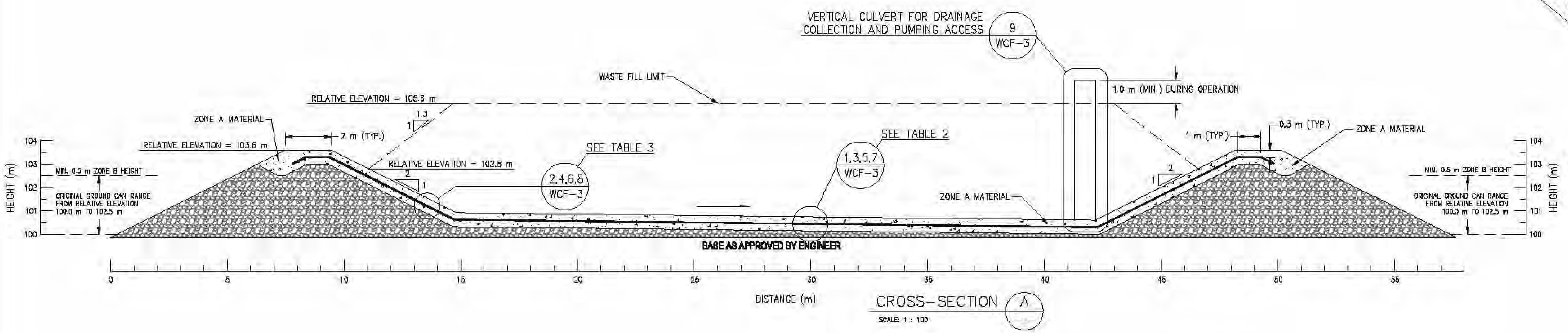
ZONE B MATERIAL PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DSG	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

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 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	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 8, 2008

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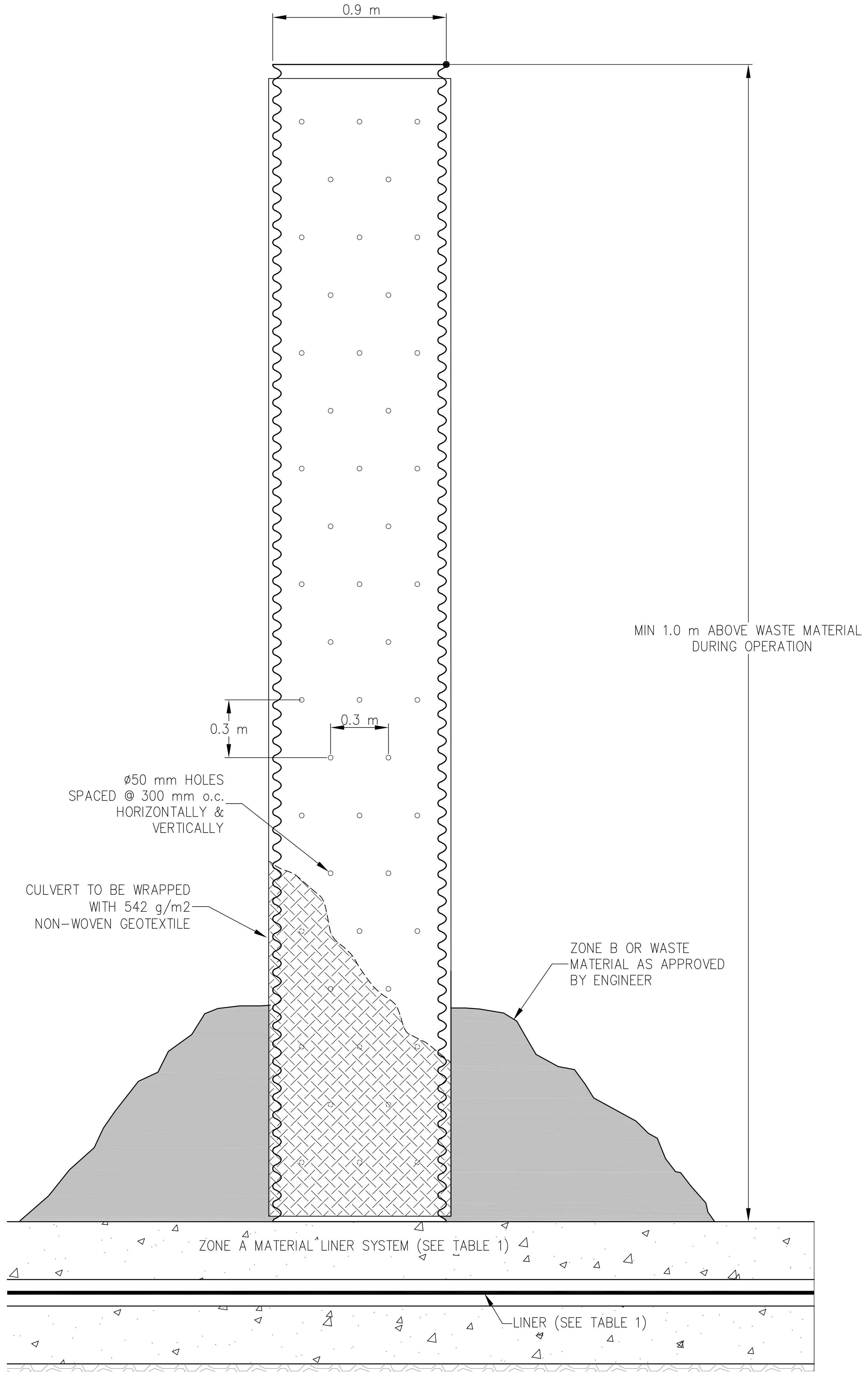
CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE A MATERIAL PLAN & CROSS SECTIONS

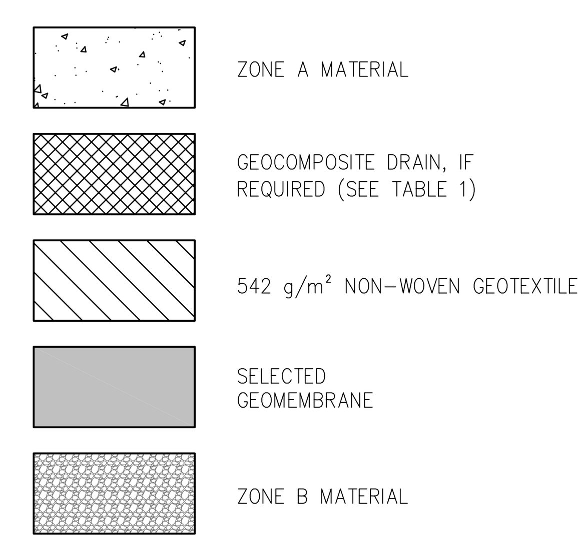
PROJECT No.	OFFICE	DSGN	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPS	0	WCF-2
DATE	SHEET No.	DWN	APP	STATUS	
June 26, 2008	2 of 4	KJT	JRT	B	



DETAIL 1 – VERTICAL CULVERT (9 / WCF-1)

SCALE: 1 : 20

LINER SYSTEM DETAIL KEY



LINER SYSTEM FLOOR & APPROACH BERM

LINER SYSTEM BERMS

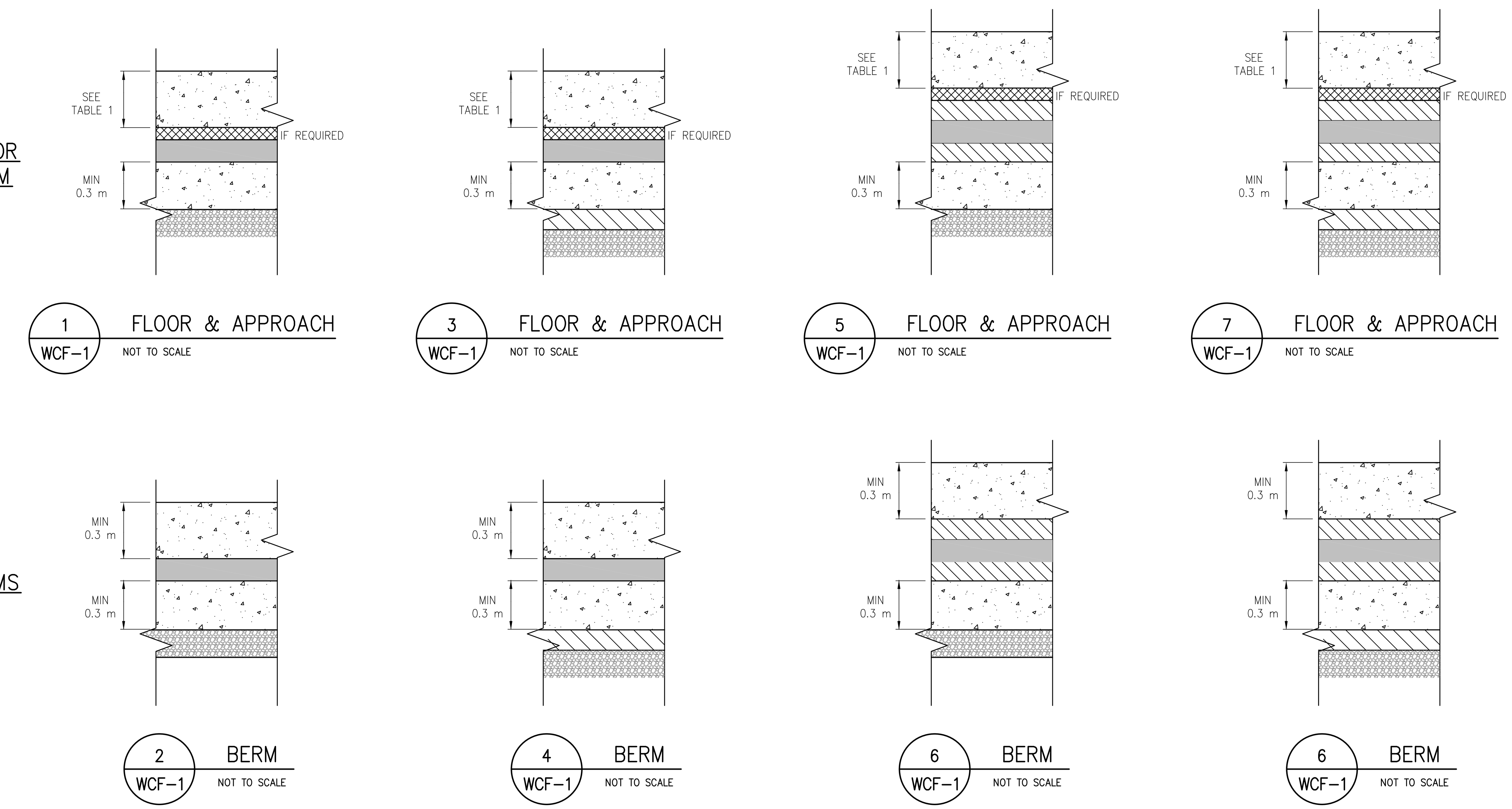


Table 1: Recommended Minimum Cover Thicknesses

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

ISSUED FOR CONSTRUCTION

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

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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CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

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	

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1800 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.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
2	08/07/08	JPS	ISSUED FOR CONSTRUCTION
1	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 8, 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.

PERMIT | PROFESSIONAL SEAL

CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

FACILITY CLOSURE PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DSG	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: Linda Broughton, Alexco Resource Corp.

From: Cheibany Ould Elemine and Andrew Gault, Ensero Solutions Canada, Inc.

Date: September 22, 2021

Re: AKHM Waste Rock ARD/ML Characterization Update 5 – September 2021

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 conducted for the following materials:

- Flame & Moth non-acid generating/metal leaching (N-AML) waste rock composite (98 weeks, completed);
- Bermingham N-AML cover hole waste rock composite HC-01 (57 weeks, completed); and
- Bermingham N-AML advance exploration hole waste rock composite HC-03 (107 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:

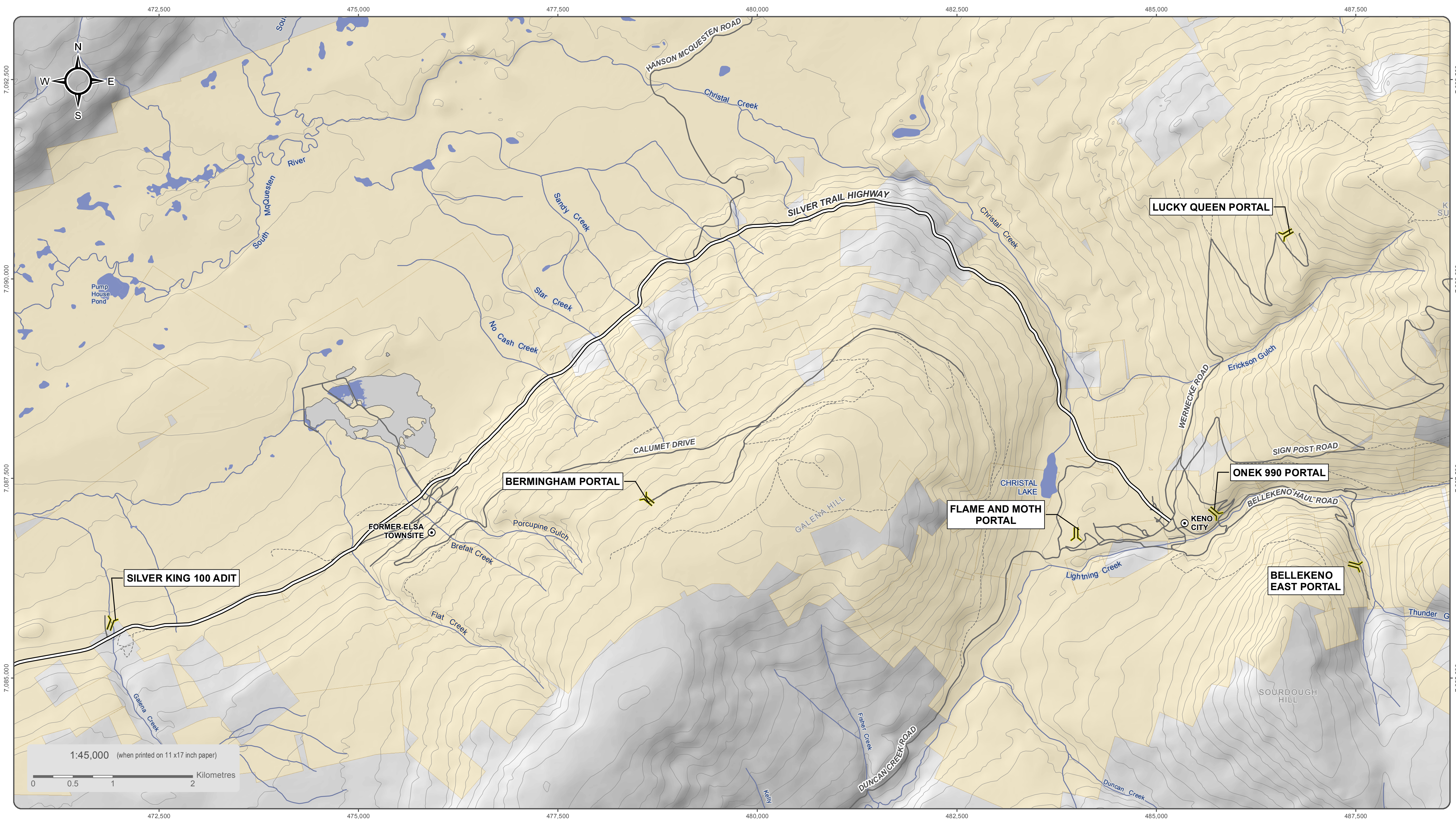
- Bellekeno (Altura, 2008);
- Onek (ACG, 2011a);
- Lucky Queen (ACG, 2011b);
- Silver King (ACG, 2011c);
- Flame & Moth (AEG, 2016b); and
- Bermingham zones (AEG, 2018).

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



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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
- Adit
- Valley Tailings
- Alexco/ERDC Quartz Claims
- Waterbody
- Watercourse
- Silver Trail Highway
- 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

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).

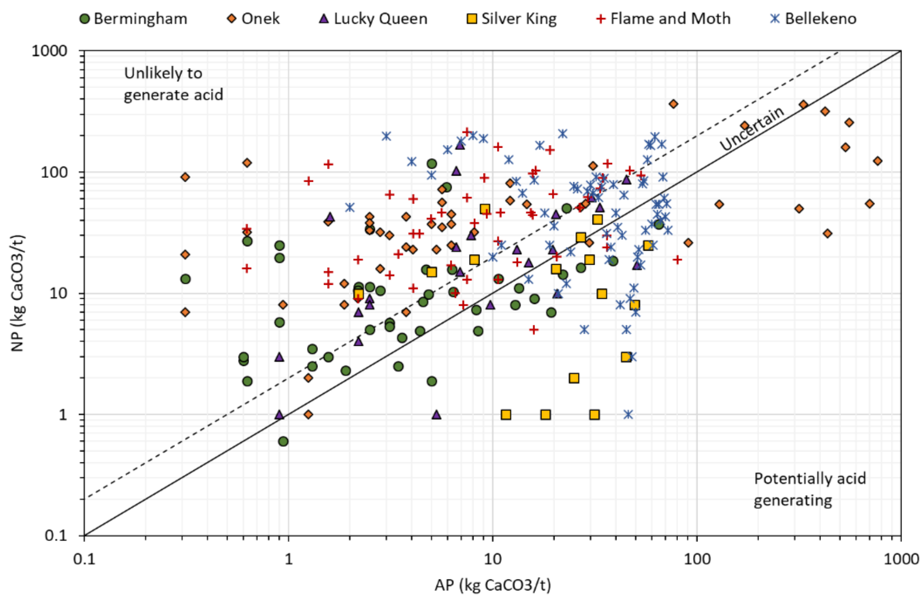
Broken down by major lithology, the QTZT, TQTZT, and GSCH samples broadly reflected the general NPR sample distribution (11% to 31% PAG samples; 44% to 76% non-PAG; Figure 4-3 to Figure 4-5), consistent with the numerical dominance of these lithologies. The GNST and SSCH samples are predominantly non-PAG (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.

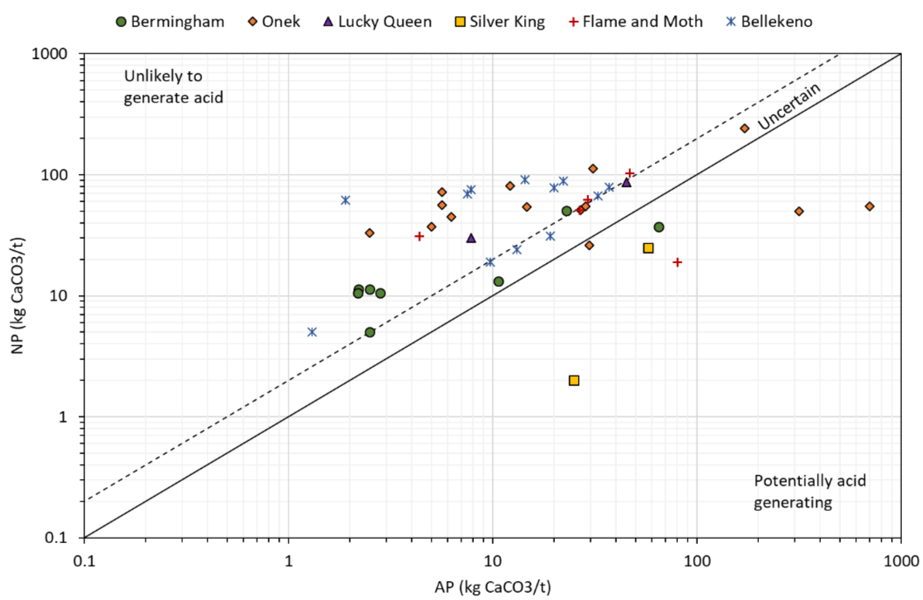
Bulk antimony and silver concentrations were higher than their respective 10x crustal abundance (2 and 0.85 ppm, respectively) for the majority of waste rock samples from Bermingham, Bellekeno, Onek, Lucky Queen, and Silver King. Lower concentrations were observed for Flame & Moth waste rock. Bulk selenium 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.



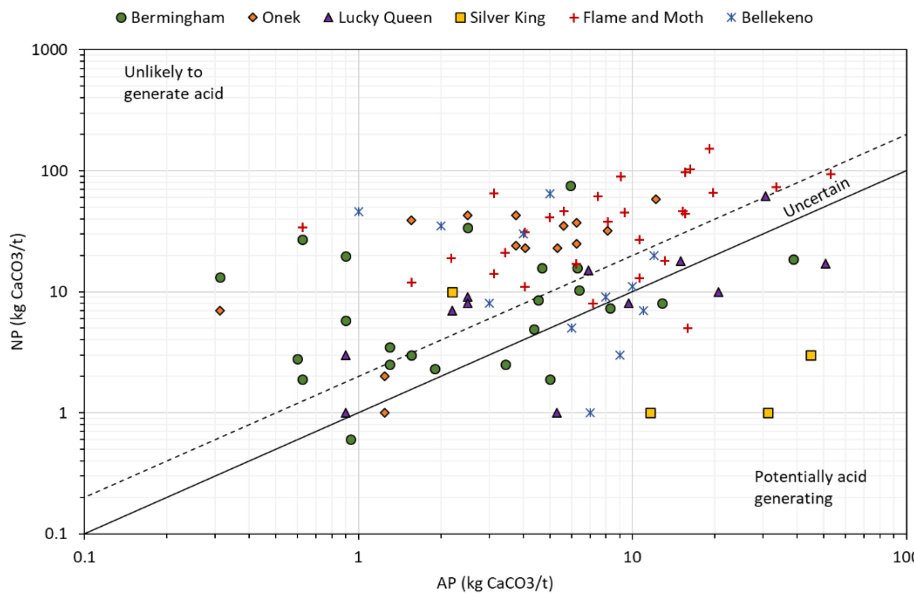
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-2: Variability in NP and AP of Waste Rock Samples from KHSD Deposits



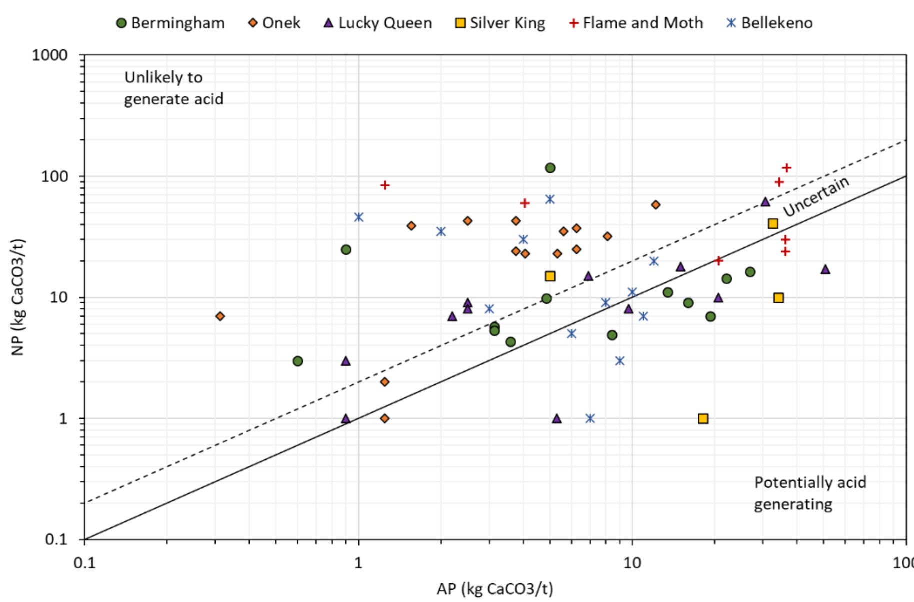
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-3: Variability in NP and AP of GSCH Lithology Waste Rock Samples from KHSD Deposits



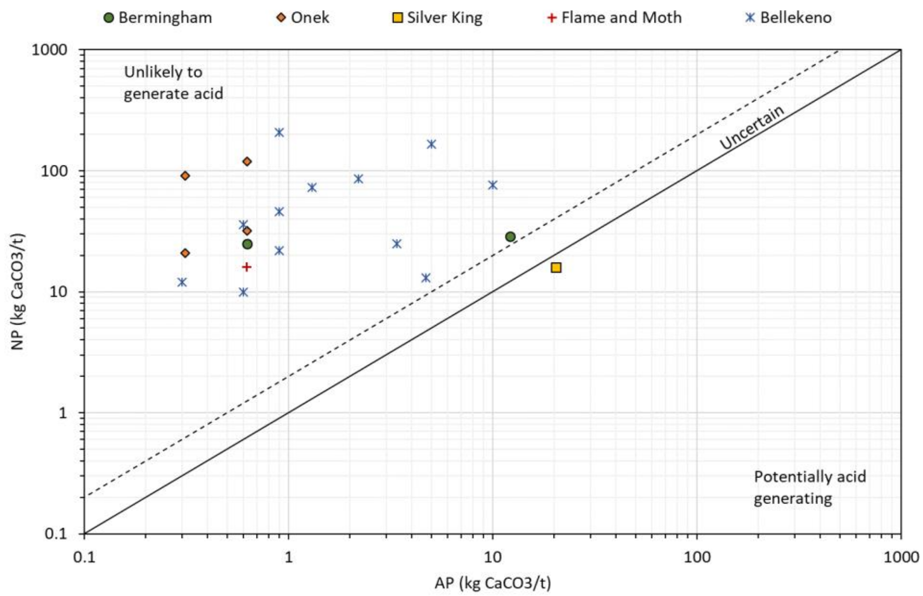
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-4: Variability in NP and AP of QTZT Lithology Waste Rock Samples from KHSD Deposits



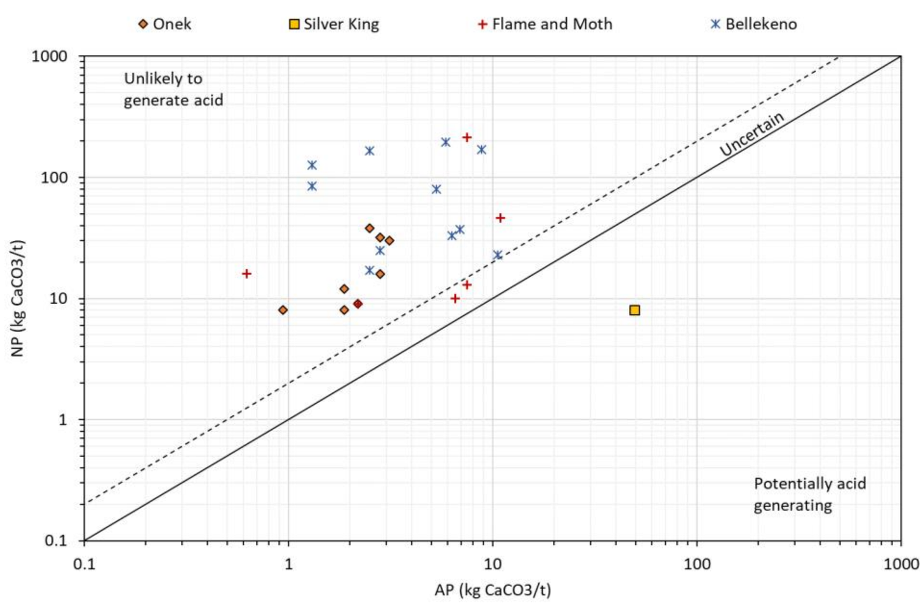
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-5: Variability in NP and AP of TQTZT Lithology Waste Rock Samples from KHSD Deposits



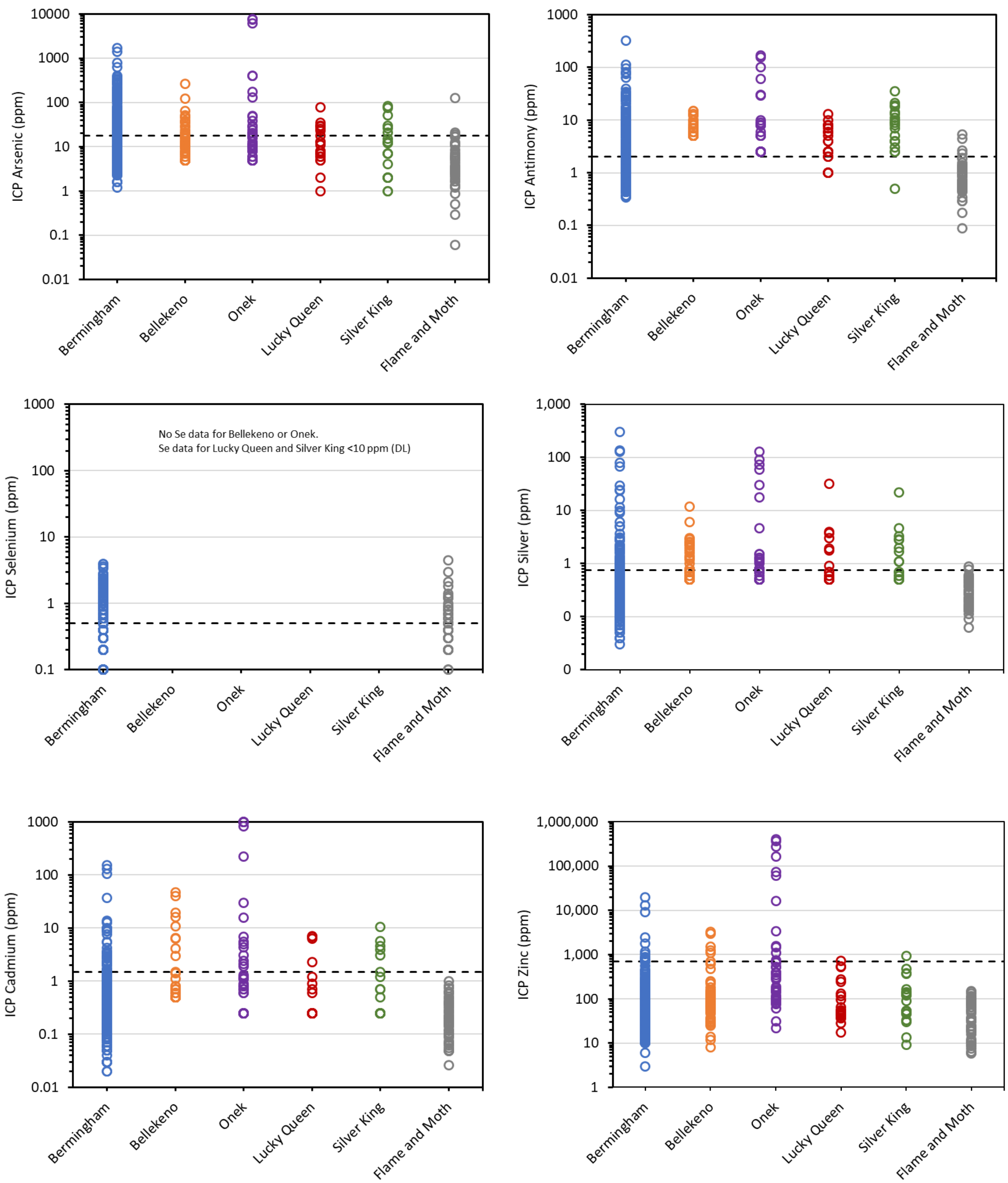
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

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 CCME/BCMOE							

[a] Guideline based on receiving waters with pH>6.5

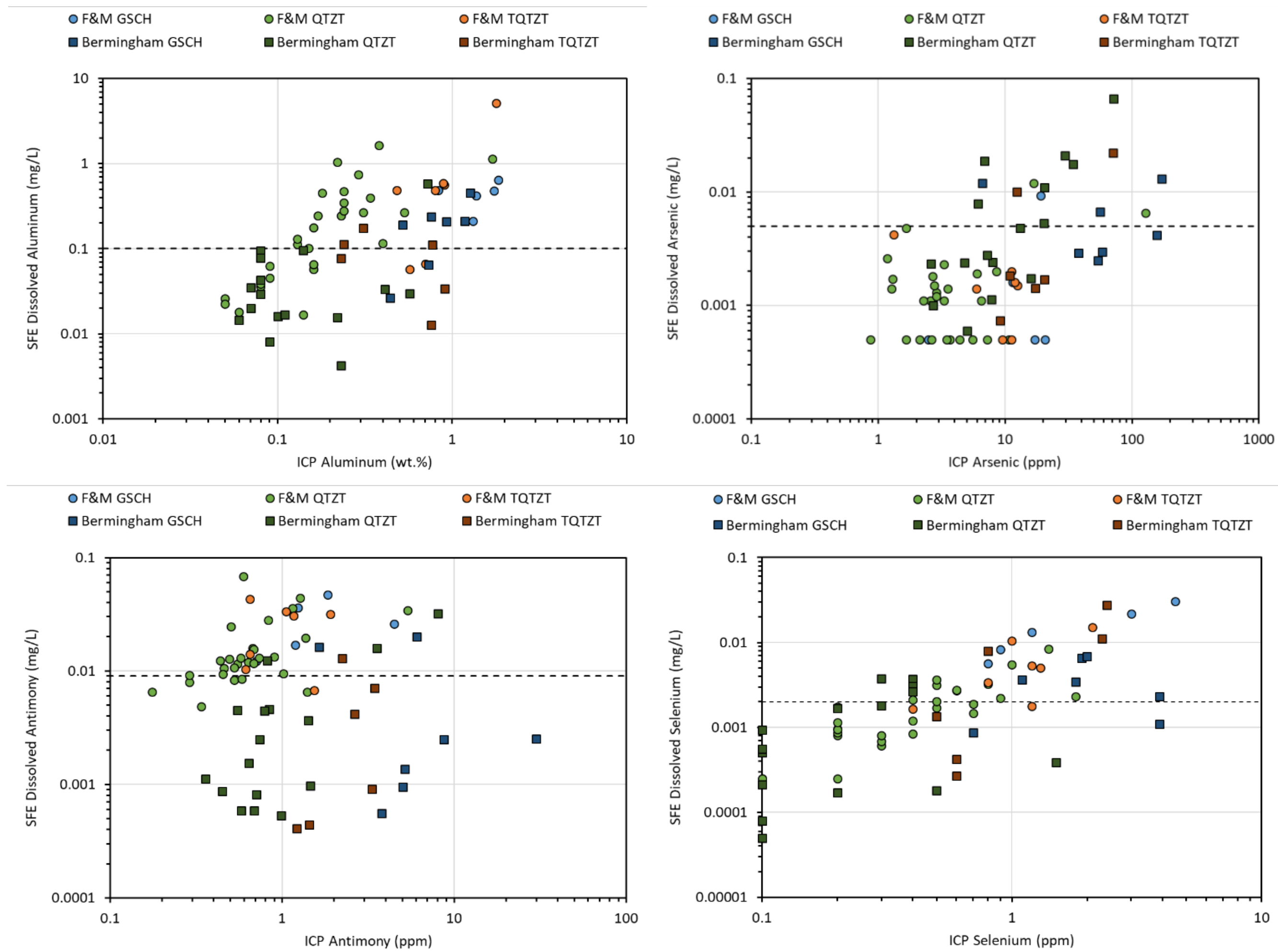


Figure 4-9: Comparison of SFE Leachable and Aqua Regia Bulk Concentrations of Aluminum, Antimony, Arsenic, and Selenium for the main lithologies in Bermingham (squares) and Flame & Moth (circles)

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 and dissolved organic carbon (DOC) and the upper (i.e., 75th) pH 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; 25th percentile DOC 8.6 mg/L and 75th percentile pH 7.3); and
- Station KV-21 in No Cash Creek was used for Bermingham waste rock (25th percentile hardness 327 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 is 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).

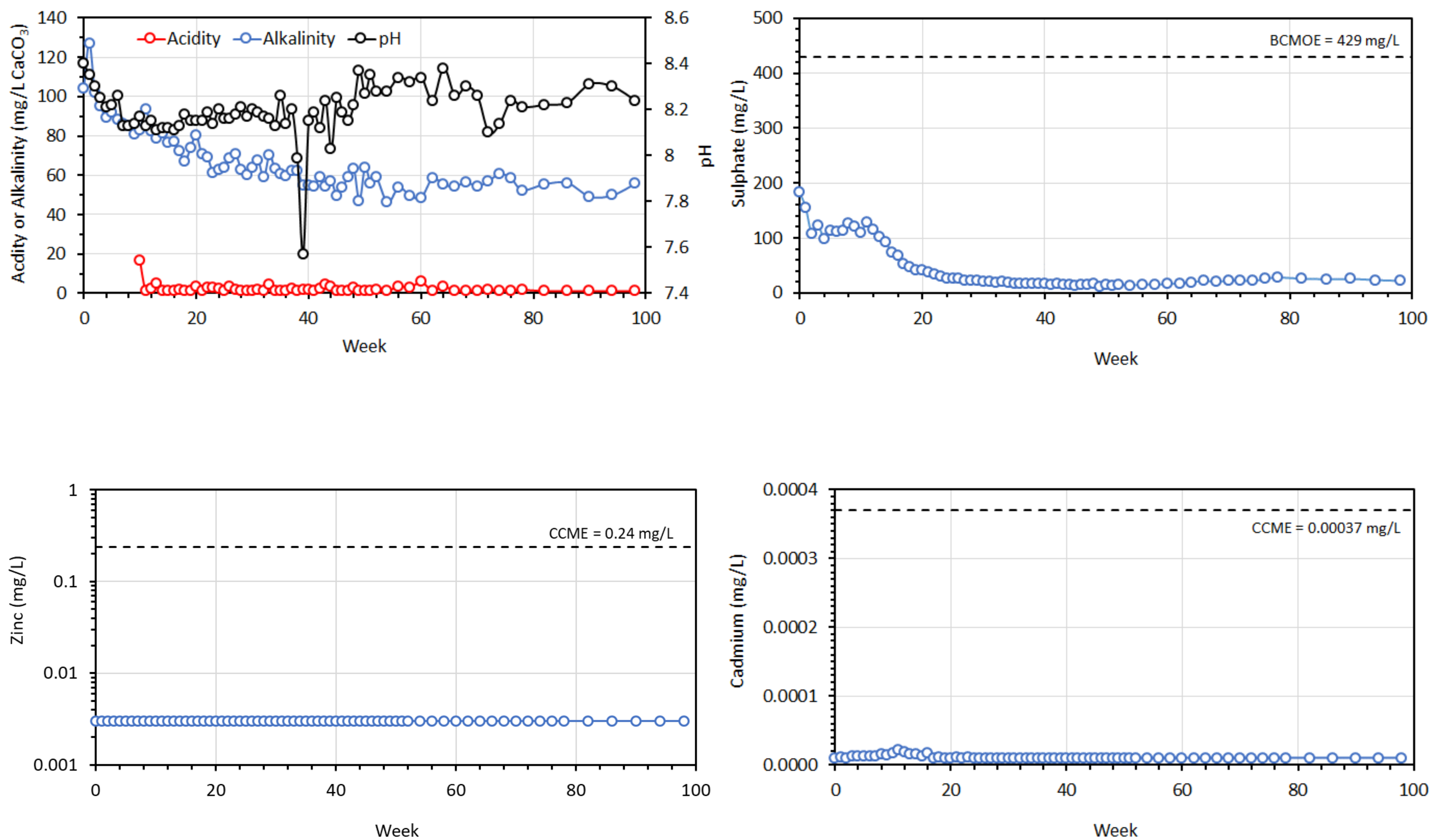


Figure 5-1: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

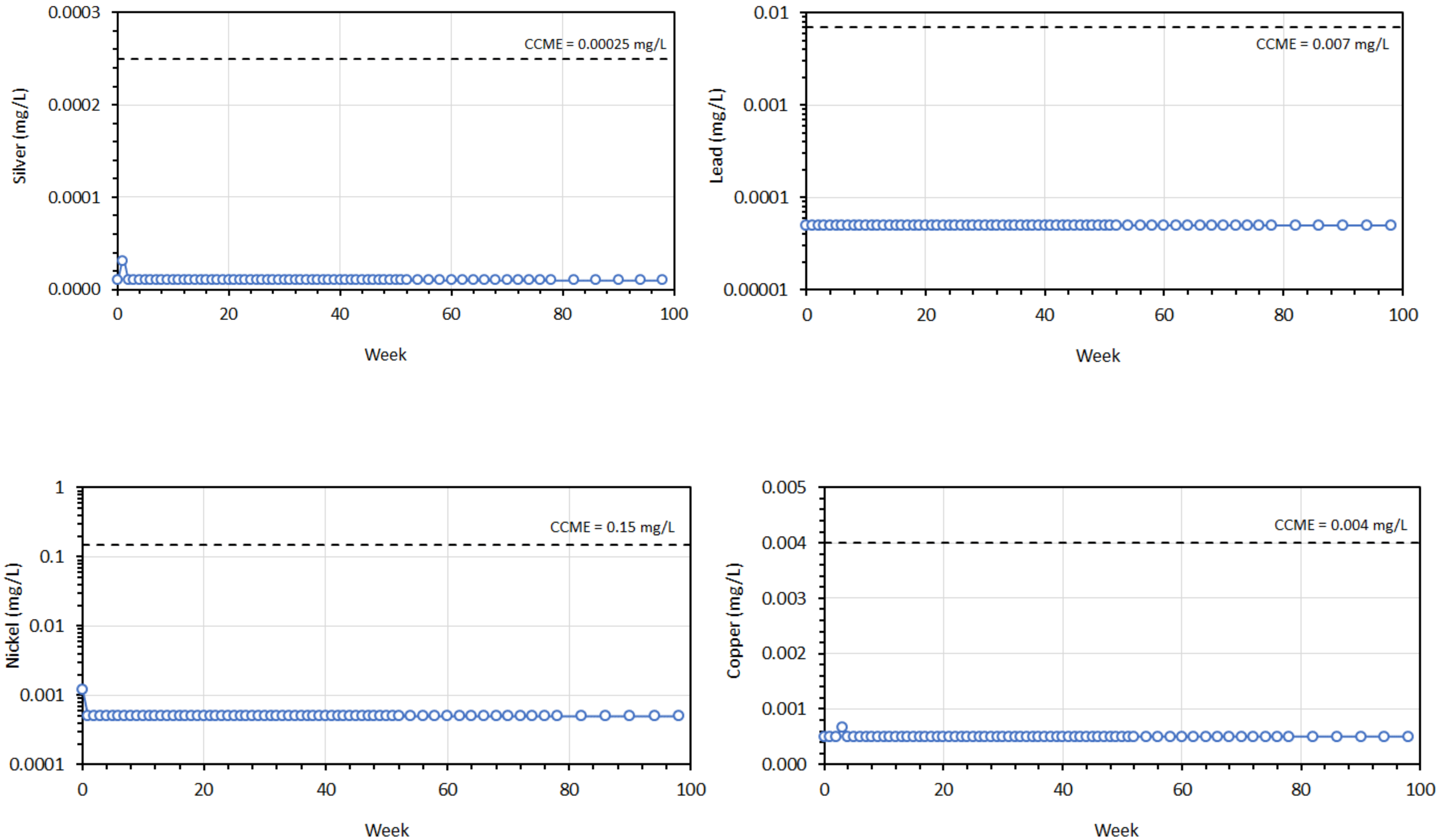


Figure 5-2: Silver, Lead, Nickel, and Copper Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

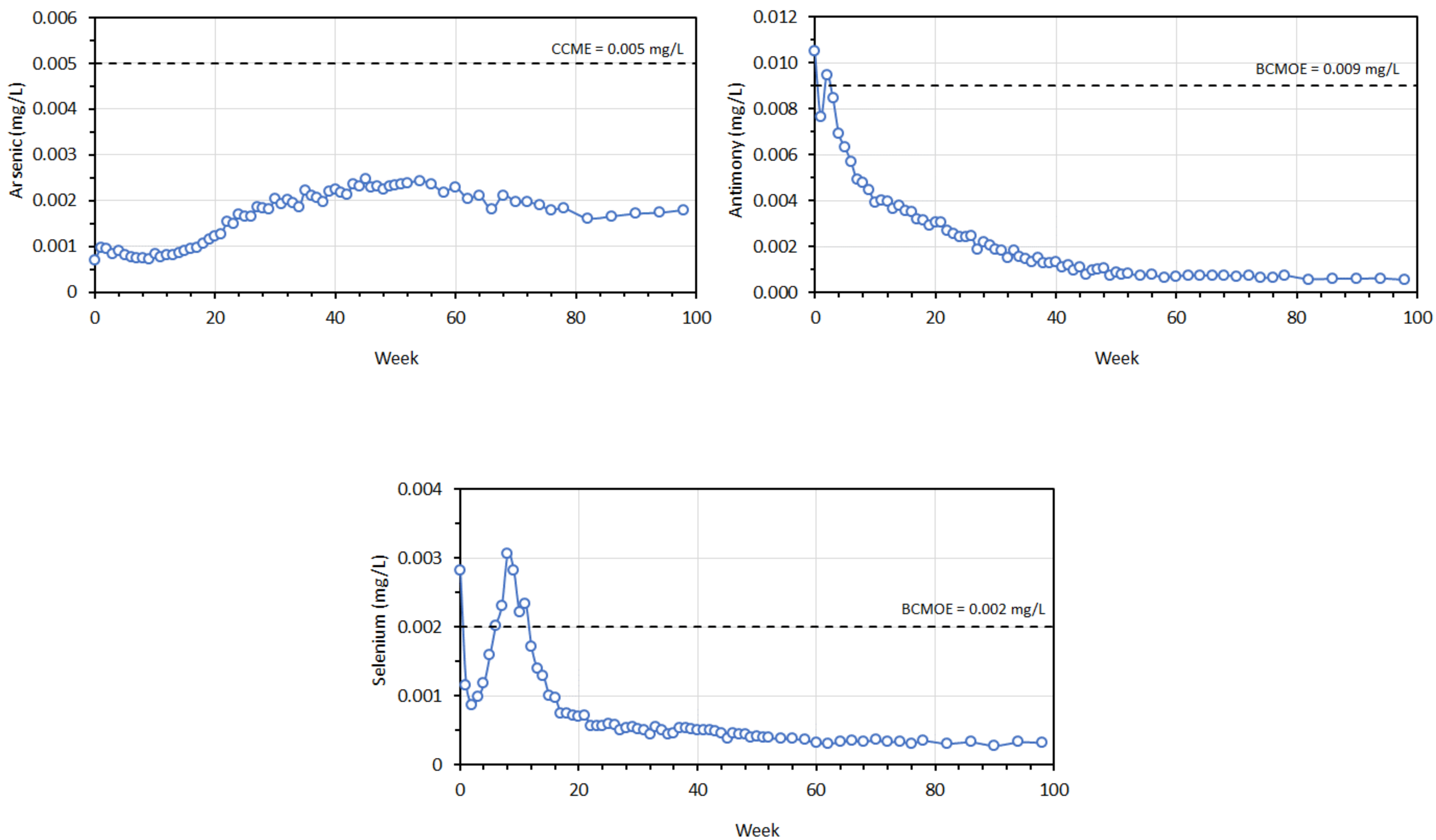


Figure 5-3: Arsenic, Antimony and Selenium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

5.1.2 Bermingham

Two waste rock humidity cells were operated to understand the potential for acid rock drainage and metal release rates from the Bermingham N-AML waste rock. The first humidity cell (HC-01) was constructed using a composite of N-AML Bermingham waste rock from cover holes with total sulphur and NP closer to the lower percentile (36%), NP close to the median (51%) of ABA data and an NPR of 4.1 (Total sulphur = 0.09 Wt.%; NP= 10.3 kg $CaCO_3$/t; AP= 2.5 kg $CaCO_3$/t). The cell also had elevated trace metal contents close to the 70th percentile and was operated for 57 weeks (Table 5-1). The second humidity cell (HC-03) was constructed using a composite of N-AML Bermingham waste rock from advanced exploration drill holes with total sulphur close to the 78th percentile, NP close to the 87% percentile, AP close to the 79% of ABA data and an NPR of 2.6 (Total sulphur = 0.36 Wt.%; NP= 29.0 kg $CaCO_3$/t; AP= 11.3 kg $CaCO_3$/t). The second cell also had elevated trace metal content close to the 90th percentile of the elemental data and was operated for 107 weeks (Table 5-2). Figure 5-4 to Figure 5-6 present the humidity cell leachate data collected for constituents of interest.

Table 5-1: Select ABA and Trace Element Composition of N-AML Humidity Cell Material HC-01

	Paste pH	Total Inorganic Carbon	Carbonate NP	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur	AP	NP	Neutralization Potential Ratio
	pH Units	wt%	kg $CaCO_3$/t	wt%	wt%	wt%	kg $CaCO_3$/t	kg $CaCO_3$/t	N/A
	8.00	0.21	4.8	0.09	0.01	0.08	2.5	10.3	4.1
Percentile:	37%	63%	53%	36%	48%	36%	36%	51%	68%
	Arsenic	Antimony	Cadmium	Copper	Lead	Nickel	Selenium	Silver	Zinc
	ppm	ppm	ppm	ppm	Ppm	ppm	ppm	ppm	ppm
	41	2.4	0.39	12	12	15	1.1	0.38	76
Percentile:	81%	66%	65%	69%	66%	54%	80%	69%	69%

Table 5-2: Select ABA and Trace Element Parameter Composition of High Sulphide N-AML Humidity Cell Material HC-03

	Paste pH	Total Inorganic Carbon	Carbonate NP	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur	AP	NP	Neutralization Potential Ratio
	pH Units	wt%	kg $CaCO_3$/t	wt%	wt%	wt%	kg $CaCO_3$/t	kg $CaCO_3$/t	N/A
	8.58	1.25	28.4	0.36	0.01	0.36	11.3	29.0	2.6
Percentile:	82%	95%	92%	78%	48%	79%	79%	87%	60%
	Arsenic	Antimony	Cadmium	Copper	Lead	Nickel	Selenium	Silver	Zinc
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	17	2.2	1.03	16	32	13	0.6	0.61	115

	Paste pH	Total Inorganic Carbon	Carbonate NP	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur	AP	NP	Neutralization Potential Ratio
Percentile:	59%	62%	89%	77%	90%	47%	61%	79%	84%

pH, Acidity, Alkalinity and Sulphate

The Bermingham humidity cell HC-01 leachate was circumneutral (pH 6.7 to 7.6; Figure 5-4), with relatively low levels of alkalinity (4.5 to 16 mg/L $CaCO_3$) and negligible acidity (below or at the detection limit of 0.5 mg/L $CaCO_3$;). Sulphate concentrations were also low, ranging between 2.5 and 15.3 mg/L, over an order of magnitude lower than the sulphate WQO (524 mg/L; Figure 5-4).

The leachate from the higher sulphur cell HC-03 was also neutral to slightly alkaline (pH 7.3 to 8.1; Figure 5-4) with relatively low levels of alkalinity (9.0 to 42.1 mg/L $CaCO_3$) and acidity mostly below the detection limit except in a few cases (<0.5 to 1.1 mg/L $CaCO_3$). These parameters reflect the higher sulphide-sulphur and NP content of this cell compared to HC-01. Sulphate concentrations from HC-03 were also higher than HC-01, ranging between 10.9 and 42.8 mg/L, reflecting its elevated sulphur content. The sulphate concentration difference between the two cells has gradually widened after cycle 16. Sulphate concentration of the HC-03 was also several times lower than WQO (524 mg/L; Figure 5-4).

The sulphate release trends of the Bermingham cells were comparable to that of Flame & Moth but the concentrations released were different. Sulphate content of HC-01 was an order of magnitude lower due to its lower sulphide content compared to the Flame & Moth humidity cell composite sample. Bermingham HC-03 also had lower sulphate than Flame & Moth during the first 20 cycles, then the sulphate release rate increased resulting in higher sulphate in HC-03 over Flame & Moth after the 25th week until week 65 after which the concentration decreased below the Flame & Moth. Sulphate leached from HC-03 has decreased gradually since week 35 (37 mg/L) reaching sulphate level of 14.5 mg/L at the last week of testing.

Trace Elements of Interest

Aside from selenium in HC-01, antimony and copper in HC-03 the concentrations of all constituents of interest in the leachates of Bermingham N-AML humidity cells were consistently well below their respective WOQ, EQS, CCME or BCMOE values (Figure 5-4 to Figure 5-6). Selenium in HC-01 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 BCMOE (0.002 mg/L). Selenium concentration in HC-03 had a similar pattern as HC-01, but with concentrations constantly below HC-01 and the WQO. Selenium concentrations in HC-03 gradually decreased since the peak measured at week 03. It is worth nothing that among all constituents of interested analyzed only selenium concentrations were regularly higher in the Bermingham HC-01 leachate compared to Flame & Moth, except during weeks 8-9. Selenium concentrations in HC-03 were comparable to the Flame and Moth except between cycles 6 and 16 when the concentration in the Flame & Moth peaked. Copper concentration in HC-01 and HC-03 where consistently more than one order of magnitude below the WQO except for two isolated peaks at weeks 83 and 87 (0.0147 – 0.0175 mg/L) where the concentration exceeded the WQO. Copper concentration was consistently below the detection limit (0.0005 mg/L) in the Flame & Moth. Cadmium concentration in HC-01 and HC-03 were two to three orders of magnitude lower than the Bermingham EQS. Cadmium concentrations were higher in the Bermingham leachates than Flame & Moth during the first ~40 weeks before declining and becoming comparable with Flame & Moth concentrations then lower during the last weeks of testing for HC-01 and HC-03. Arsenic concentrations in HC-01 and HC-03 were also more than an order of magnitude lower than the WQO. The arsenic concentrations were also higher in the Bermingham leachates than Flame & Moth during the first ~20 weeks, before gradually declining below the Flame & Moth concentrations thereafter (Figure 5-6)

The concentrations of arsenic, cadmium, zinc, lead, nickel, and copper in the Bermingham N-AML humidity cell HC-01 and HC-03 were relatively low and more than an order of magnitude below their water quality guidelines (Figure 5-4 through Figure 5-6). The concentrations of these elements in the Bermingham humidity cell leachates were initially lower or became lower during the last cycles than those observed in the Flame & Moth humidity cell; however, this is largely due to the better detection limits available for the Bermingham test work and the high detection limit used in Flame & Moth. Silver was below the detection limit in all humidity cells.

Aside from selenium, HC-03 had higher (pH, sulphate, zinc, cadmium, nickel, antimony, and molybdenum) or comparable (copper) leachate concentrations compared to HC-01 reflecting its higher sulphur and bulk metal contents. HC-03 had lower lead, arsenic and selenium at during the last 20 weeks of operation of HC-01.

The time to sulphide and NP depletion in the Bermingham N-AML waste rock humidity cell HC-01 was calculated to be 21 and 39 years, respectively, while HC-03 provided shorter sulphide depletion times (18 years) and NP depletion time (21 years). This indicates that a significant portion of NP will remain in HC-01 after the sulphide minerals have been depleted but only a limited amount of NP will remain after HC-03 is depleted from its sulphide sulphur. Both humidity cells were terminated after the concentrations of constituents of interest had stabilized. Closedown static test data for HC-01 and HC-03 indicated that the acidity potentially from the remaining sulphides was less than 2 and 8.8 kg $CaCO_3$/t, respectively, significantly lower than the remaining NP (7.3 and 49 kg $CaCO_3$/t, respectively), consistent with the sulphide and NP depletion calculations. The results are also consistent with the mineralogical data showing low sulphides (0.6 - 0.7wt.%) and the presence of reactive carbonates (0. 4 -2.0 wt.%) in the cell residues

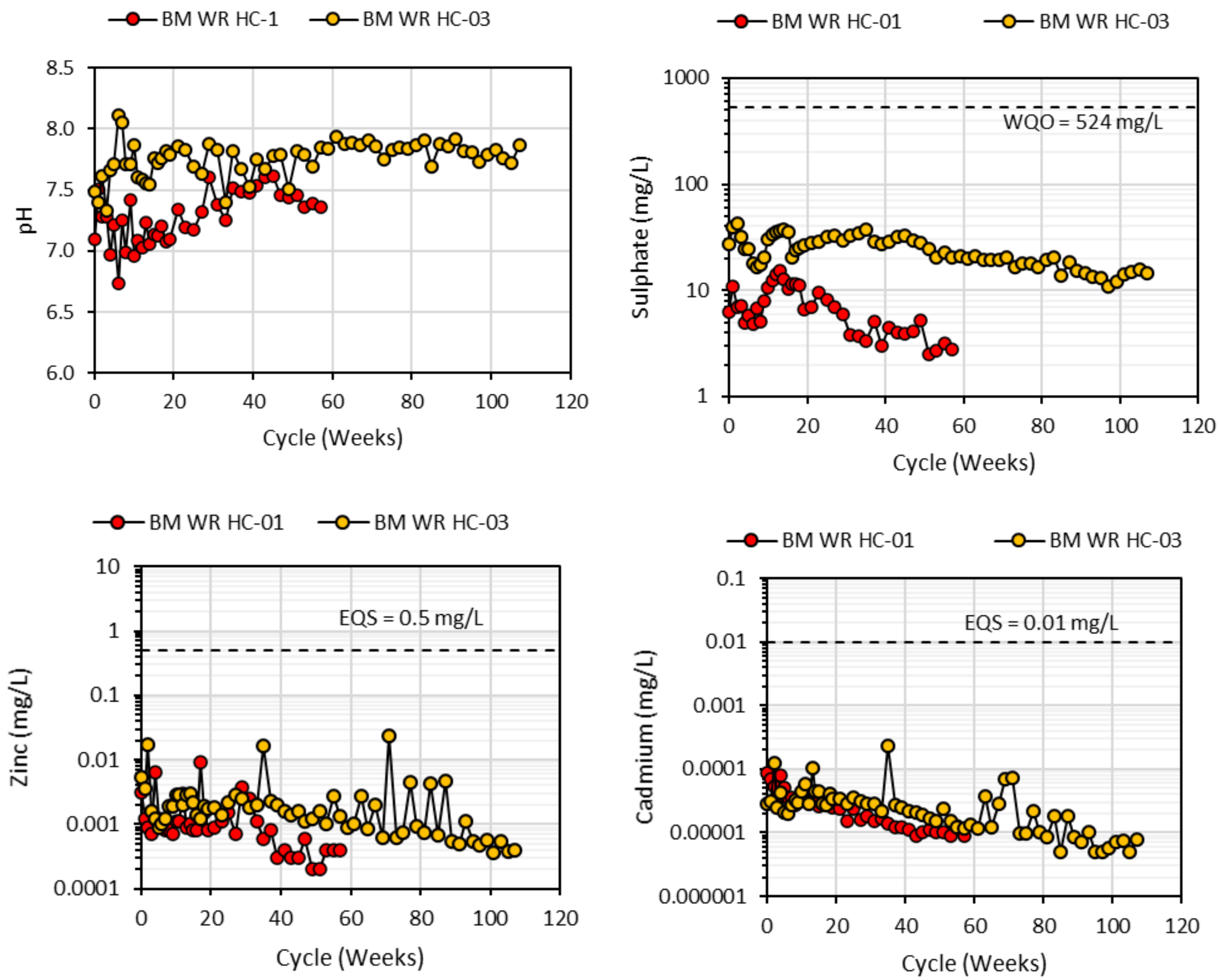


Figure 5-4: pH, Sulphate, Zinc and Cadmium Trends within the Bermingham N-AML Waste Rock Humidity Cells

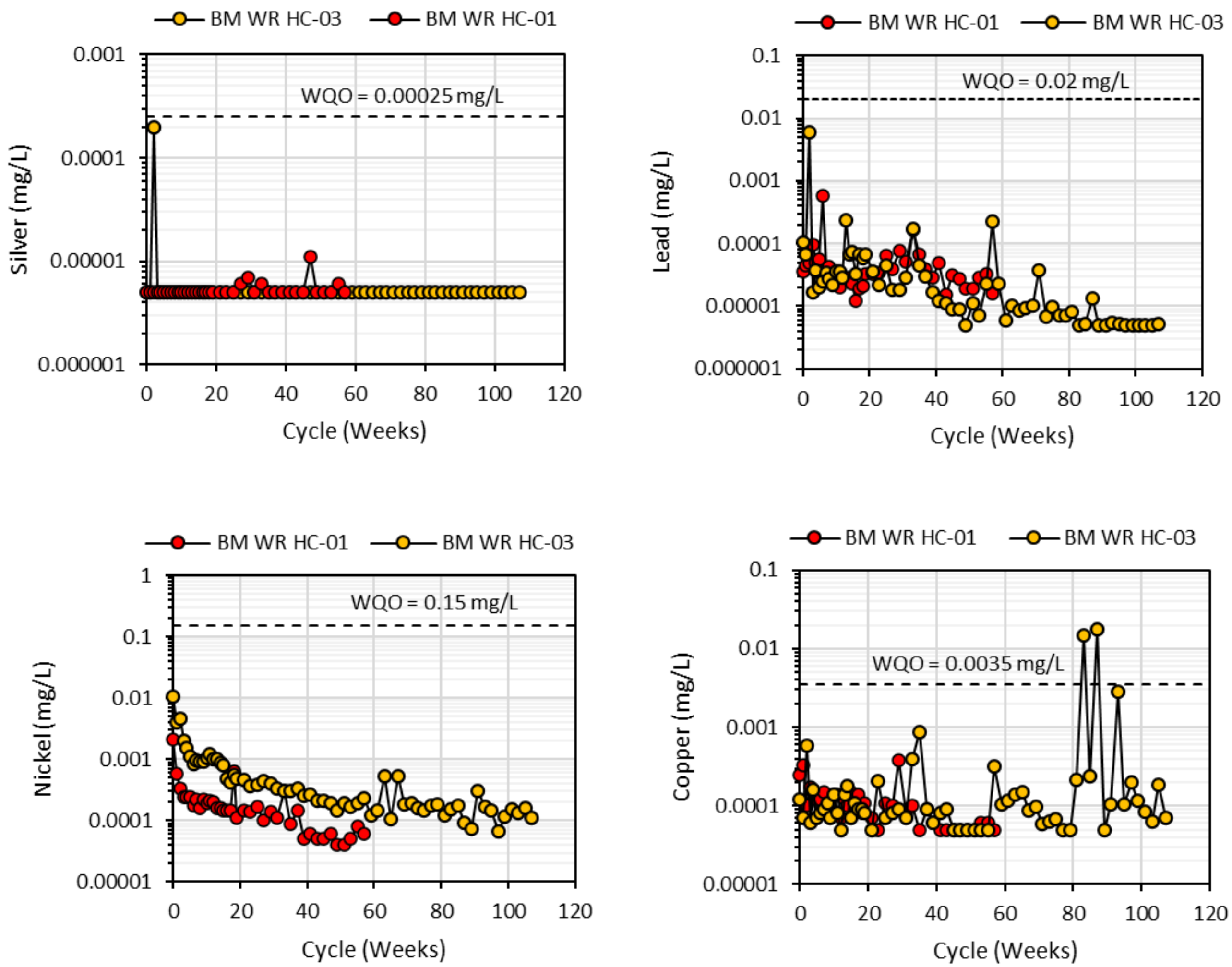


Figure 5-5: Silver, Lead, Nickel, and Copper Trends within the Bermingham N-AML Waste Rock Humidity Cells

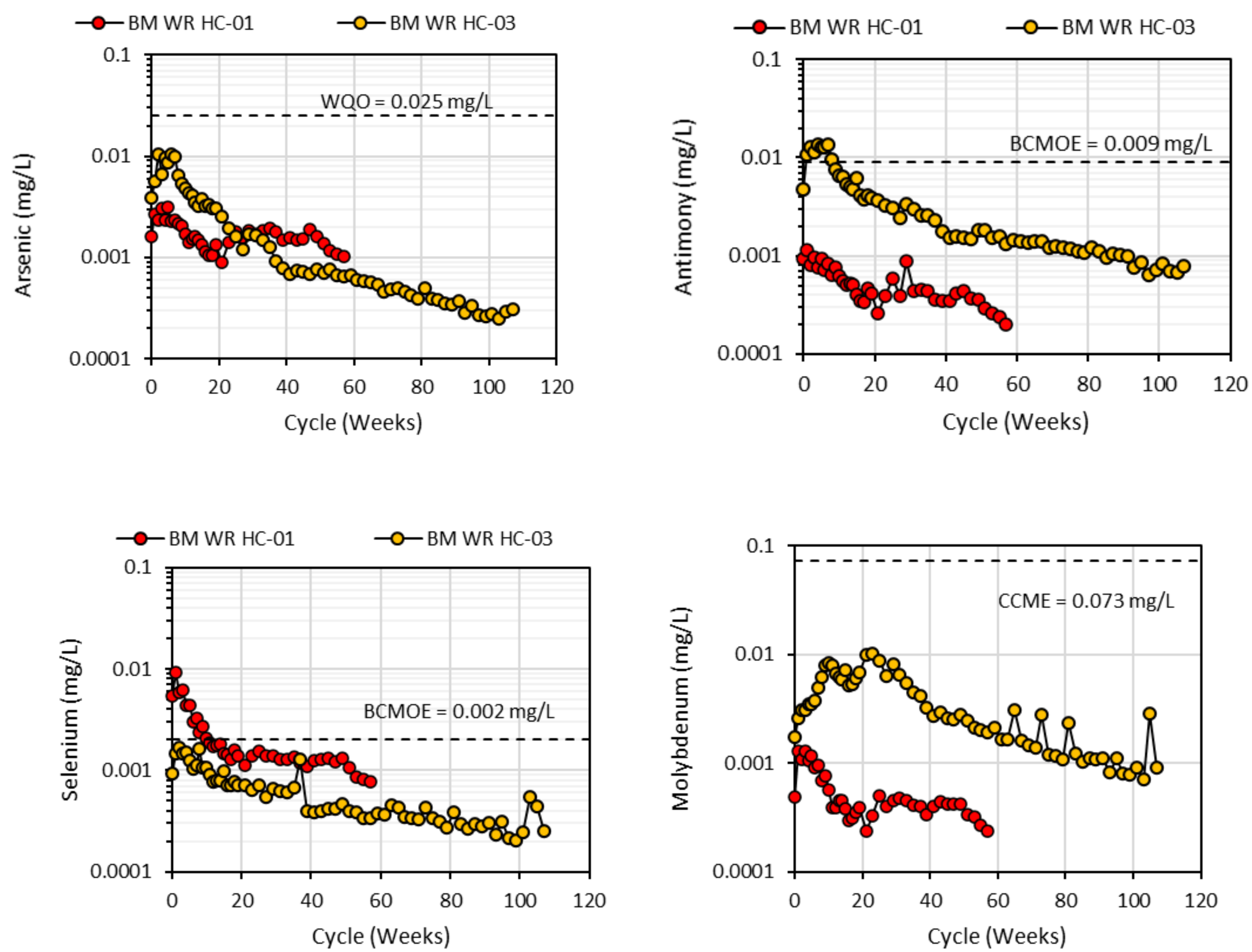


Figure 5-6: Arsenic, Antimony Selenium and Molybdenum Trends within the Bermingham N-AML Waste Rock Humidity Cells

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 leach 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). All the barrels are generally sampled at least four times a year except in 2019 when they were only sampled twice due to dry conditions and lack of leachate in the collection bins.

pH, Acidity, Alkalinity and Sulphate

The field barrel leachate pH fluctuated but has remained circumneutral to slightly alkaline during most of the monitoring period until 2016. Since 2016, leachate pH below 6.5 was constantly observed in FMB1 and occasionally observed (three times) in FMB2. FMB1 generally displayed the lowest pH values (below pH 6.0 since September 2017) consistent with its P-AML designation, whereas the highest pH values were often recorded in the leachate from FMB3 although its pH decreased below 6.5 during the September 2018 and 2019 samplings events. All N-AML barrels had leachate pH <6.5 during the September 2018 and 2019 sampling events except FMB4 that had a pH of 7.6 in 2019.

This trend was reversed for the acidity levels, where FMB1 consistently exhibited significantly higher acidity (<1.0 – 226 mg/L $CaCO_3$) than observed for FMB2, FMB3 and FMB4 (<1.0 – 4.8 mg/L $CaCO_3$; Figure 5-7). The acidity difference between FMB1 and the N-AML barrels increased significantly as the test progressed reaching about 200 mg/L $CaCO_3$ during the 2018 last two sampling events then the gap decreased to 40 mg/L in May 2019. The September 2019 acidity result for FMB1 was unusually high as the concentration reached 1560 mg/L $CaCO_3$. Since the cell had remained undrained since May 2019, it is believed that soluble products had accumulated in the barrel between May and July and were flushed out in September 2019. Alkalinity levels showed some limited correlation with pH, as FMB1, which was had the lowest 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 and declined gradually as the test progressed. FMB1 alkalinity was below the detection limit during the last six sampling events indicating a depletion of buffering capacity and explaining the acidic leachate pH observed.

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 (July-September) and lowest for the spring and fall sampling events, except for the 2017 and 2018 datasets, 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 concentration to date (4,930 mg/L) in the September 2019 sampling event. FMB1 sulphate concentrations always exceeded the BCMOE guideline (429 mg/L), leachate from FMB3 generally had sulphate concentrations below the BCMOE guideline, whereas the sulphate concentration in FMB2 and FMB4 oscillated about the BCMOE guideline. All field barrel samples exceeded the BCMOE sulphate guidelines in September 2019 likely due to the build up of soluble products in the field barrels between May and July and subsequent flushing in September.

Trace Elements of Interest

The trace element leaching trends were broadly consistent 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 and nickel and copper in exceedance since August 2016. 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 except six copper exceedances in FMB4 between 2016 and 2019, one copper exceedance in FMB2 in 2017, and one cadmium and zinc exceedance in FMB3 in 2019 (Figure 5-8 and Figure 5-9).

Zinc

Leachate from the N-AML rock-bearing materials found within FMB4 had the lowest zinc concentrations, which were consistently below the CCME guideline (0.24 mg/L; Figure 5-8). Leachate zinc concentrations from FMB2 were also typically lower than the CCME guideline although higher than FMB4. Leachate zinc concentrations from FMB3 were higher than FMB2 and FMB4, recurrently higher than the CCME guideline but constantly lower than the EQS for zinc (0.5 mg/L) except during the last sampling event when unusually high sulphate and low pH were observed. FMB1 consistently showed the highest zinc concentrations (0.4 – 105 mg/L) between 2013 and 2018 and an unusually high zinc release in September 2019 (722 mg/L). Almost all the FMB1 samples exceeded the EQS for zinc and were one to two orders of magnitude higher than the zinc levels recorded in the other field barrels. Zinc concentrations observed in 2017 and 2018 in FMB1 had comparable patterns and the leachate zinc levels were generally higher than in previous years, consistent with the higher sulphate (2017) and acidity levels (2017 and 2018). This metal leaching behaviour is in line with the predominantly P-AML rock that comprises FMB1. The zinc concentration in leachates collected from the N-AML field leach barrels FMB1, FMB2, and FMB3 have not exceeded the EQS to date except for the last sampling event for FMB3 (September

2019). The high zinc release in 2019 coincided with the highest sulphate release indicating a common source, likely the flushing of soluble weathering products stored in the field barrels since May 2019 sampling event.

Cadmium

Cadmium concentrations followed remarkably similar trends to those of zinc (Figure 5-8). The cadmium concentration in the leachate for all the field barrels FMB1 and FMB3 exceeded the CCME guideline (0.00037 mg/L) for all samples collected to date. FMB2 leachate cadmium concentrations also regularly exceeded the CCME guideline with one decrease below the CCME guideline in 2015. FMB4 cadmium concentrations were regularly lower or slightly higher than CCME (Figure 5-8) except in September 2019 when the concentration was almost one order of magnitude higher than CCME guideline. 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. Like zinc, cadmium concentrations observed in 2017 and 2018 in FMB1 leachate had similar patterns and were generally higher than in previous years, consistent with the higher sulphate (2017 and 2019) and acidity levels (2017 – 2019) observed. Leachate from the other three N-AML rock filled field barrels contained cadmium levels that were below the EQS except the last sampling event of FMB3 where the concentration exceeded the EQS (0.0315 mg/L) Like zinc and sulphate, unusually high cadmium concentrations were recorded in all field barrels in September 2019.

Nickel

Nickel concentrations were highest in the leachate 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 nickel 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. Like zinc and cadmium. nickel concentrations observed in 2017 and 2018 in FMB1 leachate were generally higher than in previous years, consistent with higher sulphate (2017 and 2019) and acidity levels (2017 – 2019). 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 until September 2019 when relatively high nickel concentrations were recorded. Nickel concentrations in leachate from FMB2, FMB3 and FMB4 never exceed the CCME guideline or the EQS (Figure 5-8). Like zinc, sulphate, and cadmium, unusually high nickel concentrations were measured in all field barrels in September 2019 likely due to accumulation of soluble nickel-bearing weathering products over the summer.

Lead

The leachate from FMB1 generally contained the highest lead concentrations (0.0013 – 0.74 mg/L), which constantly exceeded the CCME threshold (0.007 mg/L; Figure 5-8) since August 2016, and hence confirmed the P-AML nature of the rock materials used in this field barrel. Like other metal(loids), lead concentrations observed in 2017, 2018, and 2019 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate (2017 and 2019) and acidity levels (2017,2018 and 2019). Lead concentrations in FMB1 exceeded the EQS (0.2 mg/L) in July 2018 and September 2019. 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 (June and July sampling events of 2015 – 2017 and September 2019) and one instance for FMB4 (September 2019). Like previous elements of interest and sulphate, the highest lead concentrations observed to date were recorded in September 2019, likely related to flushing of soluble lead-bearing minerals that accumulated during weathering of the P-AML material over the summer. The lead concentrations from the N-AML field barrels in September 2019 was largely consistent with historical levels.

Copper

Copper concentrations followed a similar trend to those observed for lead except there was a higher rate of exceedances of the CCME copper guideline and EQS in leachates from N-AML barrels. The P-AML rock-bearing field leach barrel FMB1 (0.003 – 7.7 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 or all of the 2017 – 2019 sampling events (Figure 5-9). Copper concentrations in leachate from N-AML FMB3 remained below both the EQS and CCME guideline (0.004 mg/L) for the majority of sampling events since late 2014 except in August 2018 and September 2019 when the leachate concentration surpassed the CCME guideline. Conversely, FMB2 exceeded the copper EQS once in 2017 and FMB4 periodically exceeded the EQS since 2016. Leachate copper concentrations from both FMB2 and FMB4 frequently exceeded the CCME threshold since the beginning of each test (Figure 5-9). Like other metals, an unusually high copper concentration was measured in FMB1 in September 2019 due to flushing of accumulated secondary weather products. The copper concentrations observed in the leachate from the N-AML field barrels in September 2019 were broadly consistent with historical levels.

Silver

The P-AML FMB1 displayed the highest silver concentration in its leachate (<0.00005 – 0.001 mg/L). It was not particularly elevated compared to the other N-AML field barrels (<0.00001 - 0.0001 mg/L; Figure 5-9) until September 2017 after which the silver concentration in the leachate from N-AML field barrels was typically below the detection limit whereas the P-AML silver concentration remained an order of magnitude higher. Only the initial sampling event and the September 2019 sample (0.00046 and 0.001 mg/L, respectively) exceeded the silver CCME guideline (0.00025 mg/L). The silver levels in leachate from 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 comparable levels of arsenic (typically 0.0005 – 0.012 mg/L), which were below the CCME threshold (0.005 mg/L) for all but three FMB1 samples collected to date (Figure 5-9). Arsenic concentrations in leachate from FMB2 and FMB4 were also comparable (0.006 – 0.019 mg/L), higher than FMB1 and FMB3, and exceeded or were comparable to the CCME limit for the majority of samples collected to date (Figure 5-9). The arsenic concentrations in all the field barrel leachates were well below the EQS (0.1 mg/L). Unlike all elements of interests discussed thus far, no increase of arsenic concentration was observed in any of the N-AML field barrels in September 2019.

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 – 0.026 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 5-9). The antimony levels in the leachate from FMB4 and FMB2 were all above or comparable to the BCMOE guideline, with the latter field barrel showing the highest antimony concentrations (0.012 – 0.071 mg/L). A declining trend in the leachate antimony concentration from the field barrels was broadly observed for all barrels. Like arsenic no increase of antimony concentration was observed in any of the N-AML field barrels in September 2019.

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 – 0.0087 mg/L) and highest (FMB2: 0.002 – 0.065 mg/L; FMB4: 0.0037 – 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. It is however worth noting that an identical selenium pattern was observed for all field barrels since June 2016 despite the difference in selenium absolute concentrations. Also, an increase in leachate selenium concentration was observed in all field barrels in September 2019.

The similar patterns of zinc, cadmium, nickel, copper, and lead and their high concentration in the P-AML leach barrel FMB1, coincident with high sulphate and acidity levels, indicate a common source via sulphide oxidation. Conversely, the low concentrations of arsenic, antimony, and selenium in FMB1 leachate compared with the N-AML field barrels may suggest lower release rate of oxyanions under acidic conditions of the P-AML rock drainage compared with circumneutral N-AML drainage. A decrease of pH below 6.5 was observed in FMB3 in September 2018 and 2019. This tendency toward acidic pH may explain the low concentrations of arsenic, antimony and selenium in this barrel similar to that observed for the P-AML FMB1.

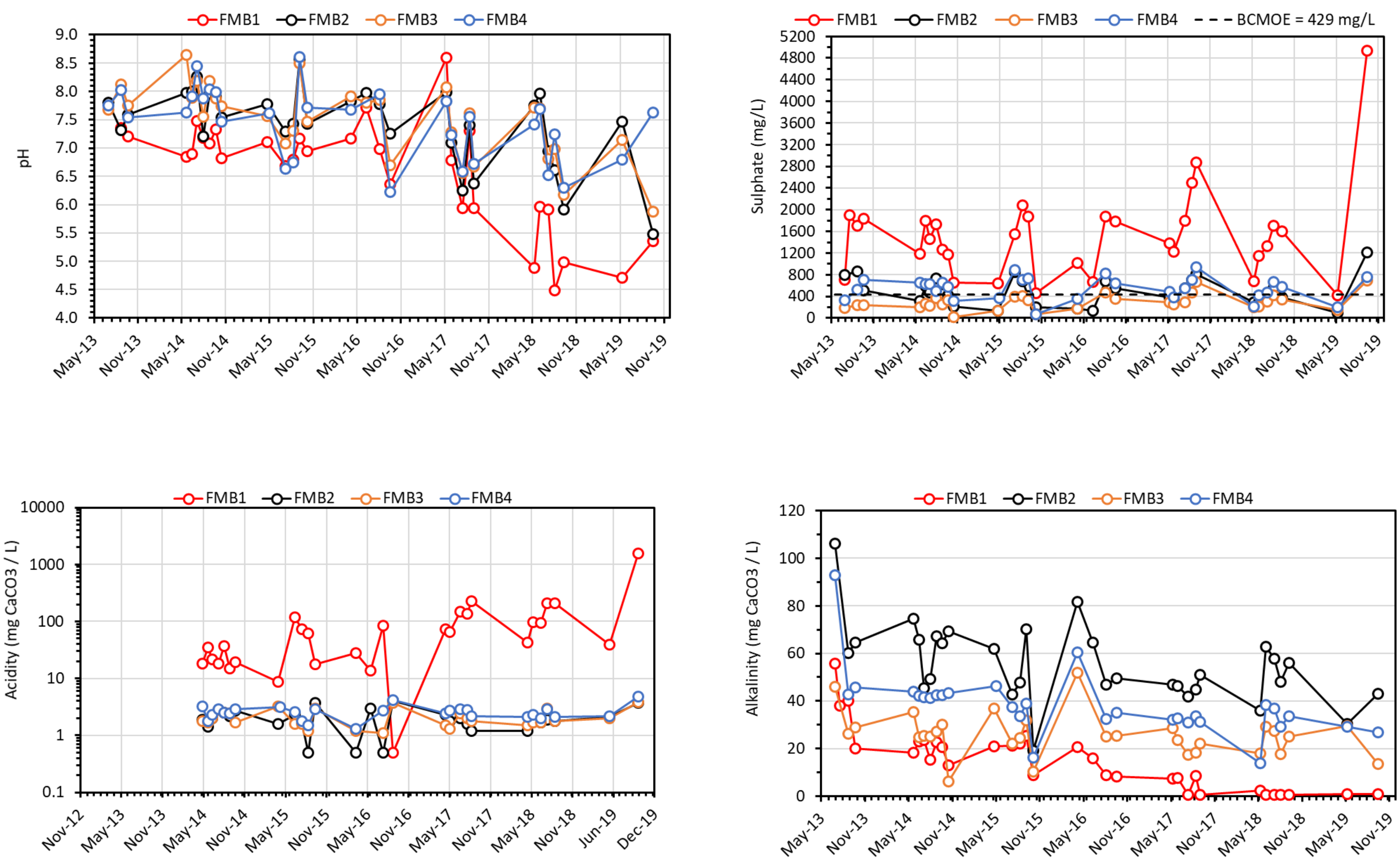


Figure 5-7: Trends in Flame & Moth Waste Rock Field Barrel pH, Sulphate, Alkalinity and Acidity Levels

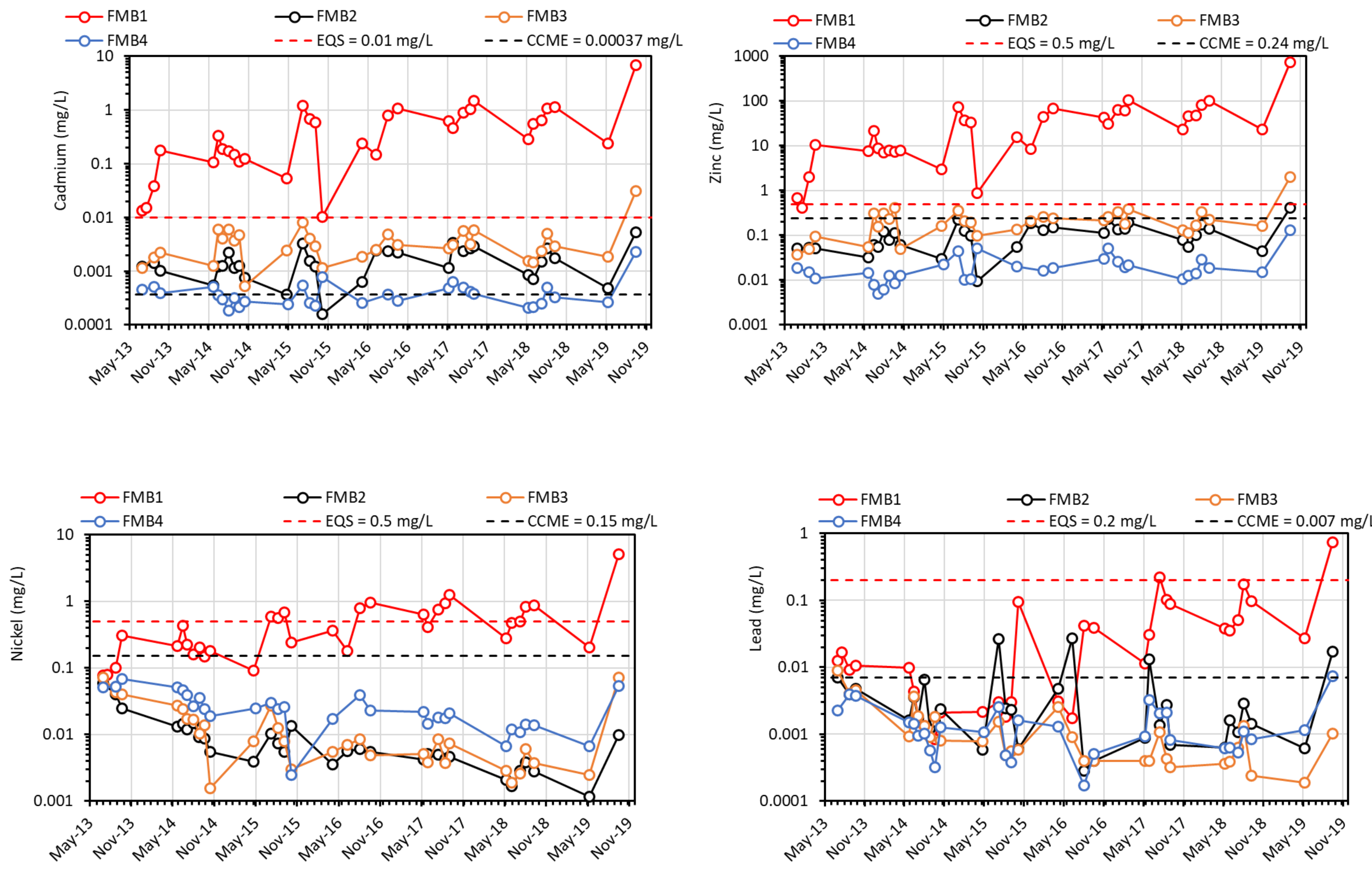


Figure 5-8: Trends in Flame & Moth Waste Rock Field Barrel Cadmium, Zinc, Nickel, and Lead Concentration

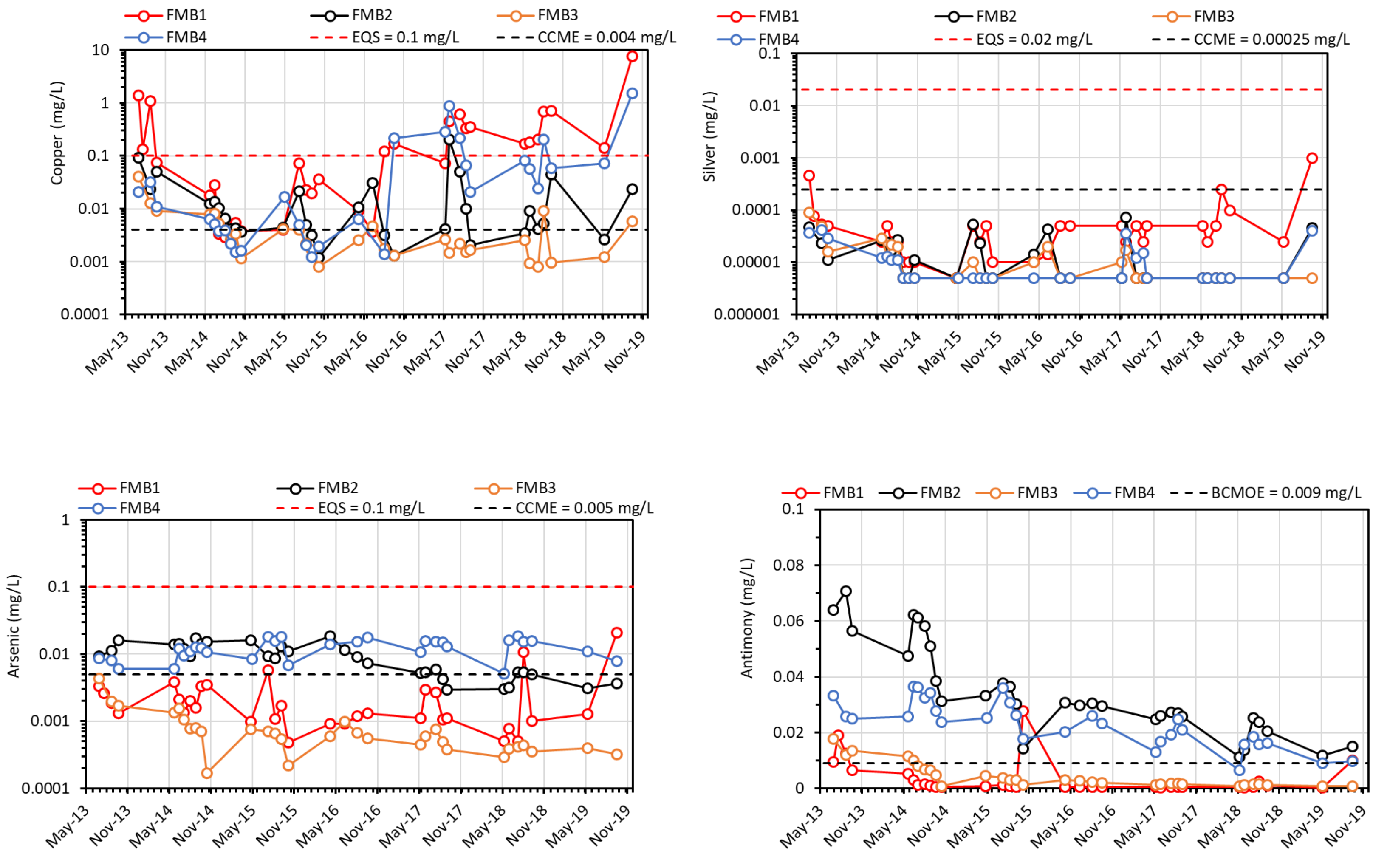


Figure 5-9: Trends in Flame & Moth Waste Rock Field Barrel Copper, Silver, Arsenic, and Antimony Concentrations

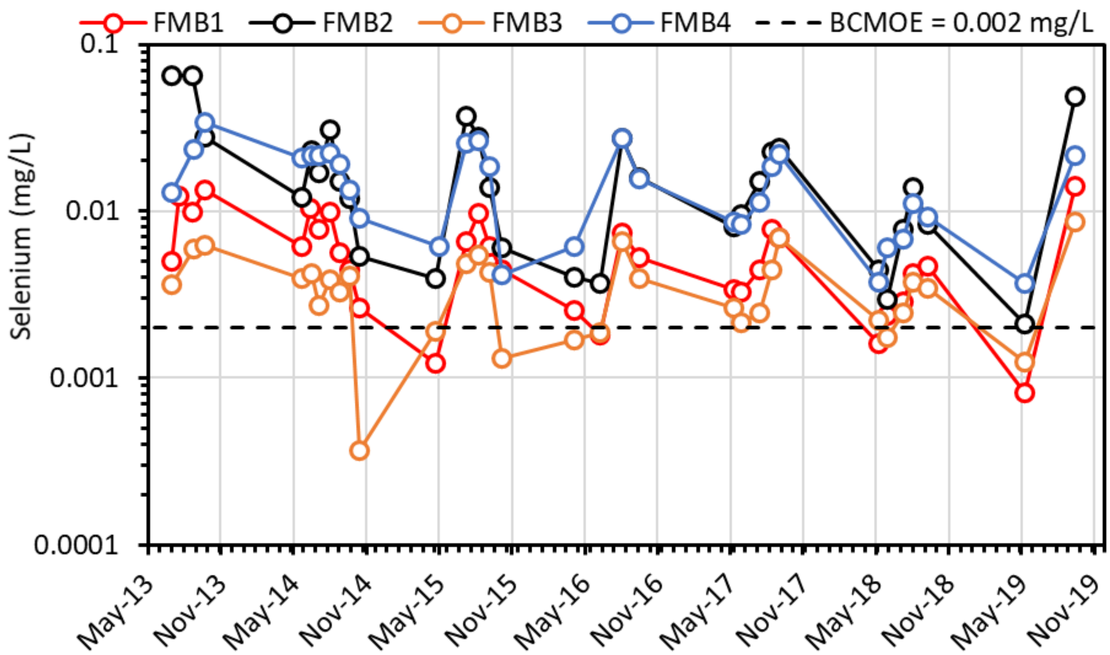


Figure 5-10: Trends in Flame & Moth Waste Rock Field Barrel Selenium Concentrations

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 test 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 were more recurrent at Bermingham;

- Humidity cell testing indicated higher pH and higher concentration release from the Flame & Moth compared to Bermingham waste rock cells except for arsenic (first 20 cycles only), antimony and cadmium with only antimony and selenium potentially exceeding the generic guidelines during early flushing events. Unlike HC-01, the high sulphur Bermingham cell HC-03 exceeded the sulphate released from the Flame & Moth after 5 months of testing then declined to half of Flame & Moth during the last cycles.

- 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 acidity and concentrations of sulphate, cadmium, nickel, lead, copper and zinc in excess of water quality guidelines. Abnormally elevated leachate acidity, sulphate, and metal concentrations were observed in most of the field barrels, especially in P-AML FMB1, for the September 2019 sampling event. This is a sporadic release likely due to poor flushing conditions during this dry year resulting in the storage of weathering products in the barrels following the May 2019 sampling event and their subsequent flushing in September.

7 REFERENCES

Access Consulting Group (ACG) (2011a). Geochemical Rock Characterization, Onek. Memorandum prepared for Alexco Keno Hill Mining Corp., December 2011.

Access Consulting Group (ACG) (2011b). Geochemical Rock Characterization, Lucky Queen, Keno Hill District, Yukon. Memorandum prepared for Alexco Keno Hill Mining Corp., December, 2011.

Access Consulting Group (ACG) (2011c). Preliminary Geoenvironmental Rock Characterization, Silver King. Memorandum prepared for Alexco Keno Hill Mining Corp., August, 2011.

Alexco Environmental Group Inc. (AEG) (2016a). Environmental Conditions Report, Keno Hill Silver District. Report prepared for Elsa Reclamation and Development Company, June 2016.

Alexco Environmental Group Inc. (AEG) (2016b). Geochemical Rock Characterization, Flame & Moth Project, Keno Hill District, Yukon. Report prepared for Alexco Keno Hill Mining Corp. March 4, 2016.

Alexco Environmental Group Inc. (AEG) (2018). Bermingham Waste Rock Geochemical Characterization. Report prepared for Alexco Keno Hill Mining Corp. October 31, 2018.

Altura Environmental Consulting (2008a). Geoenvironmental Rock Characterization, Bellekeno Zone. Report prepared for Access Consulting Group, January 8, 2008.

British Columbia Ministry of Environment (BCMoE) (2016) British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture. Summary Report. Water Protection & Sustainability Branch, Ministry of Environment, March 2016.

Canadian Council of Ministers of the Environment (CCME) (2017) Canadian Water Quality Guidelines for the Protection of Aquatic Life. Accessed at http://st-ts.ccme.ca/, September 2017.

CRC (2005) *Handbook of Chemistry and Physics, 85th Edition.* CRC Press. Boca Raton, Florida.

Minnow Environmental Inc. (2015) Draft Memorandum: Proposed Water Quality Goals for United Keno Hill Complex Watersheds. February 23, 2015.

Price, W. (2009). Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. MEND Report 1.20.1. CANMET – Mining and Mineral Science Laboratories, Smithers, BC.

Roscoe Postle and Associates Inc. (2017). Technical Report Preliminary Economic Assessment of the Keno Hill Silver District Project, Yukon Territory, Canada.

Skousen, J., Renton, J., Brown, H., Evans, P., Leavitt, B., Brady, K., Cohen, L. and Ziemkiewicz (1997) Neutralization Potential of Overburden Samples Containing Siderite. Journal of Environmental Quality, 26, 673-681.

Memorandum

To: Alexco Keno Hill Mining Corp.

From: Cheibany Ould Elemine, P.Geo., Ensero Solutions Canada, Inc.

Date: September 9, 2020

Re: Geochemical Characterization of Bermingham Locked Cycle Tailings

1 INTRODUCTION

The Bermingham Mine Development and Production Project has received Water Licence QZ18-044 and amended Quartz Mining License QML-0009 authorizing the development and production of the deposit in addition to the Flame and Moth and Bellekeno deposits. This memorandum has been updated to satisfy the requirements of the Water Licence and Quartz Mining License.

The scope of the Bermingham Project includes the development of underground workings and ventilation/escape raise, construction of surface and underground infrastructure, underground definition drilling, development of ore accesses, mining and processing ore through the Keno District Mill, deposition of waste rock on surface, treatment and release of water and deposition of tailings in the licenced Dry Stack Tailings Facility (DSTF).

To characterize the acid rock drainage and metal leaching (ARD/ML) potential related to the tailings when exposed to oxidizing surface conditions, two large tailings samples were collected from the locked cycle (LC) metallurgical testing of Bermingham ore, and tested for their geochemical composition and properties. This technical memorandum summarizes the results of the geochemical static and kinetic tests conducted on these tailings material and provide a comparison with the tailings from Flame and Moth, Bellekeno, Lucky Queen, and Onek deposits in the Keno Hill District (KHSD).

2 TAILINGS SAMPLE PREPARATION

Two representative 5.5 kg tailings samples (Berm LCT1 and LCT2) were obtained from the LC metallurgical testing and sent to Maxxam Analytics, Burnaby, British Columbia for static and kinetic testing. Each tailings sample was homogenized without any further crushing prior to shake flask extraction analysis and kinetic testing. Two subsamples of the tailings were crushed further to 85% passing 200 mesh (75 µm) for acid base accounting, elemental, and X-ray diffraction analyses.

3 LABORATORY GEOCHEMICAL TESTING

The acid base accounting (ABA) test included: paste pH, total inorganic carbon, bulk neutralization potential by the siderite-corrected method, and sulphur speciation with the sulphide sulphur determined by difference between total sulphur (Leco) and sulphate sulphur (HCl extraction). A sequential net acid generation (NAG) test was done as a cross-check on the ABA test work. The metal content of the tailings samples was determined by *aqua regia* digestion followed by inductively coupled plasma mass spectrometry (ICP-MS) analysis, and the mineralogical composition determined by X-ray diffraction (XRD) with Rietveld refinement. A standard shake flask extraction (MEND SFE) test was also performed using a 3:1 liquid to solid ratio using deionized water as leaching fluid. Kinetic testing using the standard humidity cell (HC) was also performed using the LCT2 sample. The HC analysis was started in July 2018 and terminated on June 23, 2020 after operating for 103 weeks. The cell was terminated as per standard closedown procedure and its residue subjected to ABA, bulk elemental, and XRD analyses similar to the head sample. Detailed descriptions of each of the above analytical methods can be found in Price (2009).

4 RESULTS

4.1 ACID BASE ACCOUNTING

The results of the Bermingham ABA testing are presented Table 4-1 alongside those of the Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, Flame & Moth F4+F5 composite tailings and the average of monthly ABA analyses of composite tailings samples produced from Bellekeno ore between January 2011 and July 2013 (ACG, 2015). These results show that the Bermingham LC tailings have a slightly alkaline paste pH (7.6-8.15), a very high carbonate neutralization potential (carbonate-NP; 184-204 kg $CaCO_3$/t) and relatively low bulk neutralization potential (bulk NP; 50.5-56 kg $CaCO_3$/t). The carbonate-NP was significantly (3.6 times) higher than the bulk NP due to the anticipated presence of a large proportion of iron and/or manganese carbonates such as siderite and ankerite that do not contribute to the net acid neutralization under oxidizing conditions. The sulphate content of the tailings samples was extremely low (at the detection limit of 0.01 wt. %) indicating that the bulk of sulphur (1.29-1.38 wt.%) of the tailings consists of sulphide-sulphur.

The tailings from other four deposits generally have similar ABA characteristics as Bermingham tailings: They had circumneutral to slightly alkaline paste pH (7.8 to 8.1) and high carbonate NP (273 to 389 kg $CaCO_3$/t). Their carbonate-NP was significantly higher than the siderite-corrected bulk NP (100 to 132 kg $CaCO_3$/t) indicating that ferrous and or manganese carbonates such as siderite ($FeCO_3$) comprise a substantial portion of the carbonate mineralogy in the tailing like at Bermingham. The sulphate contents of the tailings from Flame & Moth, Bellekeno, Lucky Queen and Onek were also extremely low (maximum = 0.04 wt. %) indicating that the bulk of sulphur consists of sulphide-sulphur. The Bellekeno tailings contained the highest sulphide-sulphur content (2.21 wt.%), followed by the Bermingham tailings (1.29 and 1.38 wt.%). The tailings from the other three sites had sulphide-sulphur concentrations less than 0.5 wt.%; Table 4-1. The neutralization potential ratio (NPR), defined as the ratio of the (siderite-corrected) neutralization potential to the acid potential, provides an indication of acid generation over the long-term. A sample with an NPR less than one is termed "potentially acid generating (PAG), a sample with NPR greater than two is considered not potentially acid generating (non-PAG) and a sample with NPR between 1 and 2 is considered "Uncertain" with respect to acid generation and require further testing to confirm the potential ARD/ML classification.

The Bermingham tailings returned an NPR of 1.3 and was classified as "Uncertain" The other tailings had NPR greater than 2 except Bellekeno tailings which was classified as Uncertain (NPR = 1.9). Onek, Lucky Queen and Flame and Moth tailings where all non-PAG (calculated NPR > 7).

As indicated above, an NPR between 1 and 2 indicates that the potential to generate acid is Uncertain and further testing or expert judgment of the data available are needed to provide a final classification of the material. Given that the bulk NP available for acid neutralization may be underestimated due to the oxidation of Mn (II) during the siderite-corrected NP method, the NPR calculated for the Bermingham and Bellekeno tailings samples could be considerably higher. This is supported by detailed mineralogical examination of historic tailings deposited in the KHSD in which material initially classified as potentially acid generating by conventional ABA analysis but was found to be not potentially acid generating when its manganese carbonate content was included in the NPR calculation (SRK, 2009). Also, it is likely that the siderite calcian end-member will contribute some effective NP for acid neutralization.

Table 4-1: ABA Data for Bermingham LCT, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Sample	Paste pH	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur	CO_2	CO_3-NP	Siderite-Corrected NP	AP	NPR
	pH Units	%	%	%	%	kg $CaCO_3$/t			Unitless
Berm LCT1	7.6	1.30	0.01	1.29	8.09	184	50.5	40.3	1.3
Berm LCT2	8.2	1.39	0.01	1.38	8.96	204	56.3	43.1	1.3
Onek F7 + F8 average	7.8	0.16	0.04	0.12	n/a	n/a	31.4	3.8	8.4
Lucky Queen F9 + F10 average	7.9	0.19	0.04	0.15	n/a	n/a	19.1	4.5	4.2
Flame & Moth F4+F5 Composite Tailings	8.0	0.45	0.02	0.43	17.1	389	100	14.1	7.1
Bellekeno Tailings, Jan 11- July 13 Monthly Avg.	8.1	2.3	0.02	2.21	12	273	132	71.7	1.9

AP: acid potential:
NP: neutralization potential
NPR: neutralization potential ratio

4.2 SEQUENTIAL NAG

The NAG test is often used as a cross check on the ABA results regarding potential for net acid generation. The NAG test rapidly oxidizes the sulphide in the sample by reacting it with an excess of hydrogen peroxide. In this work, the NAG test was performed sequentially such that four successive NAG cycles were conducted on the same sample to ensure all of the available sulphide-sulphur was oxidized. The pH of the NAG leachate after each cycle provides an indication of the capacity of the acid neutralizing minerals in the sample to buffer the acid produced from sulphide oxidation and therefore the overall net acid generation potential of the sample.

The results of the sequential NAG reported in Table 4-2 show that a negligible amount of acidity (i.e., 0.19 kg $CaCO_3$/t) was generated during the test and only during the first cycle suggesting a very low oxidation rate or that the sulphides content of the tailings is not reactive. The potential for acid generation is considered low because the NAG pH was circumneutral during the four cycles; the NAG test indicates a sample is non-PAG if the NAG pH is greater than 4.5. In short, the sequential NAG provides clarification regarding the "Uncertain" acid generation potential indicated by the ABA work – that is, net acid generation is not expected from these tailings. Ongoing kinetic testing will provide further confirmation of the ARD potential of the Bermingham tailings. The NAG test was not conducted on tailings from other sites to provide a site wide comparative assessment.

Table 4-2: Sequential NAG Data for Bermingham Locked Cycle Tailings

Sample ID	Cycle Number	NAG pH	NAG Volume to pH 4.5	NAG Volume to pH 7.0	NAG NaOH Conc.	NAG Acidity pH 4.5	NAG Acidity pH 7.0
		pH Units	mL	mL	N	kg $CaCO_3$/t	kg $CaCO_3$/t
Berm LCT2	Cycle 1	6.56	0.0	0.1	0.1	0.000	0.192
	Cycle 2	7.81	0.0	0.0	0.1	0.000	0.000
	Cycle 3	8.28	0.0	0.0	0.1	0.000	0.000
	Cycle 4	7.81	0.0	0.0	0.1	0.000	0.000

4.3 MINERALOGY

The mineralogical composition of the tailings was determined by XRD and the results of the test are reported in Table 4-3. These results show that the Bermingham tailings are mainly composed of quartz (SiO_2; 59.3 to 63.2 wt. %) and calcium rich siderite ($FeCO_3$; 21.2 to 27.8 wt. % as calcian siderite) similar to the Flame & Moth and Bellekeno tailings. The Bermingham tailings contain sulphide minerals, the main source of acidity, as pyrite (FeS_2; 1.6 to 2.2 wt. %), sphalerite (ZnS; 0.3 to 0.6 wt. %) and galena (PbS; 0.3 to 0.8 wt. %). Pyrite content was similar to the concentration in the Bellekeno tailings (2.3 wt.%) but Flame and Moth pyrite content were low (0.7 wt.%). Sphalerite and galena were less abundant or comparable in the Bermingham tailings samples than in the Bellekeno tailings (2.4 wt.% sphalerite; 0.6 wt.% galena) and completely absent from the Flame and Moth composite tailings.

In addition to calcian siderite, the Bermingham tailings contained another carbonate mineral, ankerite (Ca (Fe, Mg, Mn) (CO_3)2; 1.0 to 1.4 wt. %), with no effective buffering capacity. Ankerite was also identified in the

Bellekeno tailings (0.4 wt.%), but was not detected in the Flame & Moth composite. No calcite ($CaCO_3$) was detected in the Bermingham samples, which differed from the 1.2 and 3.2 wt.% calcite content in the Flame & Moth and Bellekeno tailings, respectively. These data indicate that the Bermingham tailings consist predominantly of geochemically inert silica (~ 60 wt. %) and iron and manganese carbonate minerals (28 wt. %) like other tailings. The major difference between the three is the lack of calcite in the Bermingham tailings, the lack of sphalerite and galena in the Flame and Moth tailings and the presence of trace chalcopyrite (0.1 wt. %) and wurtzite (0.2 wt. %) in Bellekeno tailings.

Iron and manganese carbonates have a net neutral buffering capacity under aerobic conditions because the amount of acidity consumed during dissolution is subsequently generated during the oxidation and hydrolysis of ferrous iron. However, the XRD data indicates a calcium rich siderite where substitution of calcium for iron occurs which may result in some neutralization capacity of a portion of the siderite.

The Bermingham potential AP estimated from the pyrite content of the tailings (AP = ~37 kg $CaCO_3$ /t) is slightly lower than the AP from the ABA meaning that the sulphide-sulphur from galena and sphalerite, minerals that do not generate acid when oxygen is the only oxidant, may be the source of excess of AP in the ABA test. The XRD data corroborate the Bermingham sample ABA showing that the lower siderite-corrected NP is likely due to the deficiency of calcite content relative to the other tailings. Although both the Bermingham and Bellekeno tailings samples share similar pyrite concentrations (1.6 to 2.2 and 2.3 wt.%, respectively), the higher AP for the Bellekeno sample mainly reflects its higher sphalerite content and the presence of trace chalcopyrite and wurtzite compared to that of the Bermingham samples. The low AP of the Flame & Moth sample is due to its low pyrite content (0.7 wt.%) and absence of other sulphides.

Table 4-3: Mineralogy of Bermingham LCT, Flame and Moth and Bellekeno Tailings

Mineral	Bermingham LCT1	Bermingham LCT2	Flame & Moth F4 + F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13
Ankerite – Dolomite	1.4	1.0	-	0.4
Calcite, Magnesian	-	-	1.2	3.2
Cassiterite	-	-	0.5	-
Clinochlore	-	-	1.3	0.4
Dravite	-	-	3.2	-
Galena	0.8	0.3	-	0.6
Illite-Muscovite 2M1	9.6	8.2	2.5	6.6
Kaolinite	1.0	0.9	-	-
Pyrite	1.6	2.2	0.7	2.3
Quartz	63.2	59.3	45.2	52.6
Rutile ?	0.6		-	0.3
Siderite, calcian	21.2	27.8	45.3	29.8
Sphalerite	0.6	0.3	-	2.4
Plagioclase	-	-	-	0.8
Gahnite	-	-	-	0.2

Mineral	Bermingham LCT1	Bermingham LCT2	Flame & Moth F4 + F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13
Chalcopyrite	-	-	-	0.1
Wurtzite	-	-	-	0.2
K-Feldspar	-	-	-	0.3
Total	100	100	100	100

4.4 METALS CONTENT

The bulk metal concentration of an element provides a preliminary indication of constituents that are elevated or depleted in a geologic material and should be monitored during leaching tests. However, the enrichment or depletion of a constituent in a sample is not a direct measure of their potential mobility or bioavailability (or lack thereof) because several parameters, including but not limited to, site hydrogeology, biogeochemistry, climate, pH and redox conditions ultimately determine the mobility and bioavailability of an element.

The results of the solid-phase metals analysis of the Bermingham LC tailings are presented in Table 4-4 alongside that of the Flame & Moth F4+F5 composite tailings, Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, and the monthly average of tailings from Bellekeno between July 2012 and August 2013.

A premilitary screening of the tailings metal content against the 10x their crustal abundance (CRC, 2005) was done and revealed that antimony, arsenic, bismuth, cadmium, lead, manganese, selenium, silver, and zinc were typically high. The elevated metals and metalloids concentration were expected considering the source of the parent material (i.e., ore). The enrichment or depletion of metals in the Bermingham tailings was assessed by comparison with the tailings from other deposits and focused on a few of those identified during preliminary screening because of their potential for environmental concern namely; antimony, arsenic, cadmium, lead, selenium, silver and zinc.

The Bermingham tailings contained similar arsenic content to the Onek, ,1.7 and more than 5 times lower than Flame and Moth tailings and Bellekeno, respectively, and twenty times higher than the arsenic concentration in the Lucky Queen tailings. The highest antimony was in the Bellekeno (121 mg/L) and was nearly three times greater than the Bermingham (BERM LCT2) and Flame and Moth tailings and more than thirteen times that of Onek and Lucky Queen.

The cadmium and zinc concentration in the Bermingham tailings were higher than that of both the Lucky Queen (*ca.* 4- to 11-fold higher) and Flame and Moth (*ca.* 2- to 3-fold higher) tailings, but approximately 2- to 7-fold lower than the Onek tailings and Bellekeno, respectively. Lead content of the Bermingham tailings sample BERM LCT1 was 3 times higher than BERM LCT2 and was the highest among the all tailings. The lead content of BERM LCT2 was approximately 3 to 6 times higher than the Onek, Lucky Queen, and Flame and Moth tailings but 2.7 lower than Bellekeno tailings. The Bellekeno tailings generally had the highest concentration of these elements, with arsenic, antimony, cadmium, and zinc concentrations present at levels three- to seven-fold higher levels than those in the Bermingham tailings.

The Bermingham, Flame and Moth and Bellekeno tailings contained comparable concentrations of selenium concentrations. Bermingham tailings sample LCT2 and Bellekeno also had comparable silver content 50 to 56 ppm, that was four to seven time higher than Flame and Moth, Onek and Lucky Queen. But Bermingham tailings sample LCT1 had a silver concentration nearly twice that of Bellekeno.

The metal concentrations of lead and zinc are particularly elevated in Bellekeno, Lucky Queen and Bermingham tailings because they are the main base metals in sphalerite, galena chalcopyrite and wurtzite remaining in the tailing after processing as indicated by the results of XRD. The high concentration of arsenic is likely due to its known presence as trace element in sulphidic ore. The potential for leachability and solubility of these metals and metalloids is assessed in the SFE and HC tests.

Table 4-4: Elemental Content of Bermingham LCT, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Element	Unit	Berm LCT1	Berm LCT2	Onek F7 + F8 average	Lucky Queen F9 + F10 average	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite Jul 12 - Aug 13
Aluminum (Al)	%	0.15	0.16	0.36	0.74	0.2	0.2
Antimony (Sb)	ppm	99.8	44.6	<5	9	41	120.6
Arsenic (As)	ppm	369	401	375	17.5	699	2147
Barium (Ba)	ppm	30	30	24	125	11.5	16.4
Bismuth (Bi)	ppm	0.06	0.04	<2	<2	6.59	2.1
Cadmium (Cd)	ppm	46.1	23.4	72.8	3.95	7.19	165.8
Calcium (Ca)	%	0.63	0.73	0.47	0.38	0.59	1.52
Chromium (Cr)	ppm	133	115	174	265.5	185.5	5.5
Cobalt (Co)	ppm	4.3	4.3	2	3	2.7	9.9
Copper (Cu)	ppm	60.8	57.5	377	254	565	242.4
Iron (Fe)	%	6.35	7.07	18.6	6.4	16.3	10.1
Lead (Pb)	ppm	7460	2330	413	555	789	6359
Magnesium (Mg)	%	0.32	0.36	0.47	0.34	0.31	0.31
Manganese (Mn)	%	37900	4.43	5.19	2.47	4.28	3.22
Mercury (Hg)	ppm	0.19	0.13	n/a	n/a	0.055	0.19
Molybdenum (Mo)	ppm	2.06	2.02	<1	2	3.74	1.16
Nickel (Ni)	ppm	49.8	49.1	44	51	86.6	19.5
Phosphorus (P)	%	290	0.032	0.014	0.013	0.01	0.02
Potassium (K)	%	0.07	0.08	0.08	0.275	0.03	0.04
Selenium (Se)	ppm	0.9	0.8	n/a	n/a	0.1	0.52
Silver (Ag)	ppm	99.6	56.4	6.4	16.4	12.35	50.1
Sodium (Na)	%	<0.01	<0.01	0.02	0.025	0.006	0.014
Strontium (Sr)	ppm	14.3	15	11	15	4.81	24
Thallium (Tl)	ppm	0.78	1.9	17.5	11	0.652	0.129
Tin (Sn)	ppm	2.7	2	n/a	n/a	32.9	17.6
Titanium (Ti)	%	<0.005	<0.005	<0.01	0.02	0.001	0.002
Uranium (U)	ppm	0.39	0.38	n/a	n/a	0.406	1.052
Vanadium (V)	ppm	6	5	5.5	12.5	9.4	5.18
Zinc (Zn)	ppm	3510	2080	8784	557	1265	12623

4.5 SHAKE FLASK EXTRACTION

SFE provides preliminary indication of the leachability, solubility and potential mobility of metals and metalloids during short-term leaching by meteoric water under oxidizing conditions. SFE is also used to screen for potential exceedances of water quality objectives, discharge standards or generic water quality guidelines.

The results of the SFE of all tailings are reported in Table 4-5 alongside the Keno Hill District Mill Site pond effluent quality standards (EQS) at KV-83. Table 4-5 shows that Bermingham tailings had a circumneutral pH (pH= 7.3-8.2) consistent with the ABA paste pH, low leachable sulphate content (19.1-46.1 mg/L) and no measurable acidity (less than the method detection limit of 0.5 mg/L $CaCO_3$). Table 4-5 also show that SFE was also circumneutral for those tailings (i.e., Lucky Queen) for which the SFE pH data was available.

To screen for potential water quality exceedances, the SFE data were compared with the Mill pond EQS as any seepage would report to the mill pond. No exceedance of the Mill pond EQS were found in any of the tailings. The solubility of metals and metalloids highlighted in Section 4.4 as elevated in the tailings did not generate exceedances despite the vigorous condition of the SFE test. Note that the comparison of result of SFE data with the EQS is not and should not be used as a measure of compliance with site water quality standards and objectives. Rather, the comparison provides a guide for potential constituents of concern in drainage from the tailings, which should be confirmed by kinetic testing.

Table 4-5: SFE Results for the Bermingham LCT, Flame and Moth, Bellekeno, Lucky Queen and Onek Tailings

Leachable Metals	Unit	Berm LCT1	Berm LCT2	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13	Lucky Queen F9	Lucky Queen F10	KHSD Mill Site EQS (KV-83)
pH	pH units	7.27	8.17	7.90	-	8.1	8.0	6.5-9.5
EC	uS/cm	154.5	97.1	547	-	434	352	
SO_4	mg/L	46.1	19.1	245	-	183	140	
Acidity to pH4.5	mg/L	<0.5	<0.5	-	-	-	-	
Acidity to pH8.3	mg/L	2.1	<0.5	-	-	-	-	
Total Alkalinity	mg/L	11	14	39.9	-	28.2	25.1	
Bicarbonate	mg/L	14	18	-	-	-	-	
Carbonate	mg/L	<0.5	<0.5	-	-	-	-	
Hydroxide	mg/L	<0.5	<0.5	-	-	-	-	
Fluoride	mg/L	0.27	0.2	0.189	-	0.078	0.035	
Hardness $CaCO_3$	mg/L	55.6	35	-	-	204	158	
Aluminum (Al)-Leachable	mg/L	0.00609	0.0214	0.0109	0.0282	<0.0050	<0.0005	
Antimony (Sb)-Leachable	mg/L	0.00419	0.0111	0.0217	0.0387	0.016	0.0116	
Arsenic (As)-Leachable	mg/L	0.000219	0.000331	0.0061	0.0072	<0.0010	<0.0010	0.1
Barium (Ba)-Leachable	mg/L	0.0354	0.0134	0.0253	0.0234	0.037	0.0459	

Leachable Metals	Unit	Berm LCT1	Berm LCT2	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13	Lucky Queen F9	Lucky Queen F10	KHSD Mill Site EQS (KV-83)
Beryllium (Be)-Leachable	mg/L	<0.000010	<0.000010	<0.00050	<0.00050	<0.00050	<0.00050	
Bismuth (Bi)-Leachable	mg/L	<0.0000050	<0.0000050	<0.00050	<0.00050	<0.00050	<0.00050	
Boron (B)-Leachable	mg/L	<0.050	<0.050	0.071	0.0942	0.025	0.014	
Cadmium (Cd)-Leachable	mg/L	0.0027	0.000309	0.0024	0.00318	0.00164	0.0509	0.01
Calcium (Ca)-Leachable	mg/L	18.7	12.4	105	138	74.9	59.6	
Chromium (Cr)-Leachable	mg/L	<0.00010	<0.00010	<0.00050	<0.00050	<0.00050	<0.00050	
Cobalt (Co)-Leachable	mg/L	0.000925	0.000099	0.0004	0.00031	0.0002	0.00702	
Copper (Cu)-Leachable	mg/L	0.000116	0.000334	0.0271	0.0096	0.0303	0.0503	0.1
Iron (Fe)-Leachable	mg/L	0.0022	<0.0010	<0.030	<0.030	<0.030	<0.030	
Lead (Pb)-Leachable	mg/L	0.0607	0.0188	0.0144	0.0593	0.0181	0.112	0.2
Lithium (Li)-Leachable	mg/L	0.00339	0.00294	0.0071	0.0339	<.0.0050	<.0.0050	
Magnesium (Mg)-Leachable	mg/L	2.15	0.988	6.9	6.01	3.96	2.27	
Manganese (Mn)-Leachable	mg/L	2.28	0.445	1.95	0.797	0.765	1.14	
Mercury (Hg)-Leachable	mg/L	<0.000050	<0.000050	0.0001	<0.000050	<0.000050	<0.000050	
Molybdenum (Mo)-Leachable	mg/L	0.000225	0.000928	0.0024	0.0108	0.00318	0.000718	
Nickel (Ni)-Leachable	mg/L	0.00213	0.000368	0.0012	0.0009	0.0006	0.00253	0.5
Phosphorus (P)-Leachable	mg/L	0.0503	0.0414	<0.30	<0.30	<0.30	<0.30	
Potassium (K)-Leachable	mg/L	1.89	1.7	2.04	10.6	3.93	1.87	
Selenium (Se)-Leachable	mg/L	0.000058	0.000041	0.0009	0.00106	0.00871	0.00463	
Silicon (Si)-Leachable	mg/L	0.42	0.45	1.55	3.4	1.91	1.11	
Silver (Ag)-Leachable	mg/L	<0.0000050	0.00003	0.0009	0.0018	0.000144	0.00627	0.02
Sodium (Na)-Leachable	mg/L	0.854	0.596	2.36	24.1	6.19	4.57	
Strontium (Sr)-Leachable	mg/L	0.0261	0.0172	0.38	0.515	0.193	0.141	
Thallium (Tl)-Leachable	mg/L	0.000335	0.000177	0.0001	0.0002	0.00011	<0.00010	
Tin (Sn)-Leachable	mg/L	<0.00020	<0.00020	<0.00050	<0.00050	<0.00050	<0.00050	
Titanium (Ti)-Leachable	mg/L	<0.00050	<0.00050	0.01	0.012	<0.010	<0.010	
Uranium (U)-Leachable	mg/L	<0.0000020	<0.0000020	0.000048	0.00162	0.000011	<0.000010	
Vanadium (V)-Leachable	mg/L	<0.00020	<0.00020	<0.0010	<0.0010	<0.0010	<0.0010	
Zinc (Zn)-Leachable	mg/L	0.142	0.017	0.156	0.051	0.0189	0.0955	0.5

Note: EQS: effluent discharge standards at KV-83 for the KHSD

4.6 HUMIDITY CELL

The HC test provides an indication of the long-term acid generation and rate of release of constituents (i.e., acidity, alkalinity, sulphate, major and trace elements) and constitutes robust evidence on the ARD/ML potential of a geologic material.

The results of 103 weeks (cycles) of Bermingham HC testing are discussed herein. Time series of selected constituents of interest are provided and discussed below to assess the rate of release and the long-term ARD/ML potential of the Bermingham tailings. The HC data were plotted with HC results for Bellekeno and Flame and Moth tailings to provide a site wide comparison. The Mill pond EQS are also plotted for comparative purposes only rather than an assessment of compliance with site water quality standards.

4.6.1 pH, Sulphate, Acidity and Alkalinity

The pH, acidity, alkalinity and sulphate released from the Bermingham tailings during the tests are plotted in Figure 4-1. The plot shows a stable neutral pH of between 7.1 and 8.0 (median = 7.4) within the EQS range (6.5 - 9.5), very low acidity (maximum 7.4 mg/L $CaCO_3$; median equivalent to the detection limit 0.5 mg/L $CaCO_3$), alkalinity high enough to buffer the acidity released (maximum 39.6 mg/L $CaCO_3$; median 20.8 mg/L $CaCO_3$), and relatively low sulphate concentrations (median 51 mg/L), indicating a low sulphide oxidation rate. The acidity, alkalinity and sulphate concentrations showed a first flush effect resulting from the release of readily soluble products followed by a decrease then stabilization of the concentrations until cycle 43 and 37 for acidity and alkalinity, respectively, although recurrent spikes of acidity were observed until cycle 69 after which the acidity was typically below the detection limit. Alkalinity gradually increased after cycle 37 from 12 mg/L to 40 mg/L at cycle 99, coincident with an increase in pH from 7.3 to 8.0. The sulphate concentrations showed a slight increase between cycles two and nine (85 mg/L), then decreased and continued to decline during the test reaching 29 mg/L during the last two cycles.

The pH and alkalinity levels in the leachate from the Bermingham tailings humidity cell were lower than those observed in the Flame and Moth and Bellekeno tailings HCs (Figure 4-1), reflecting its lower NP and lack of calcite, however the pH was comparable to that observed for Bellekeno and Flame and Moth during the last three cycles due to the gradual increase observed since cycle 37. The Bermingham sulphate concentrations recorded during the test (29 to 374 mg/L) were markedly lower than those observed in the Bellekeno HC (158 to 1,150 mg/L) during the first 30 cycles then the gap gradually shrank until reaching a comparable level at cycle 55 onward. The Bermingham sulphate concentrations were also lower than in the Flame and Moth HC leachate (120 to 1130 mg/L) during the first 17 cycles after which the sulphate concentration in the HC leachate from the Bermingham tailings increased and remained above that of the Flame and Moth HC during the remainder of the test. This trend is expected for Bellekeno, which has a higher sulphide-sulphur content (2.2 wt.%) than the Bermingham tailings (1.4 wt.%), but is somewhat unexpected for the early cycles of the test for Flame and Moth because of its lower sulphide-sulphur content (0.4 wt.%). Sulphides in the Flame and Moth tailings were likely exposed to leaching at the onset of the test resulting in higher release rate early on and gradual decline thereafter. However, the three tailings generally showed a similar sulphate release pattern despite the difference in absolute concentration, although the sulphate released from the Flame and Moth HC stabilized whereas sulphate concentrations in the Bermingham and Bellekeno HCs continued to slowing decrease (Figure 4-1).

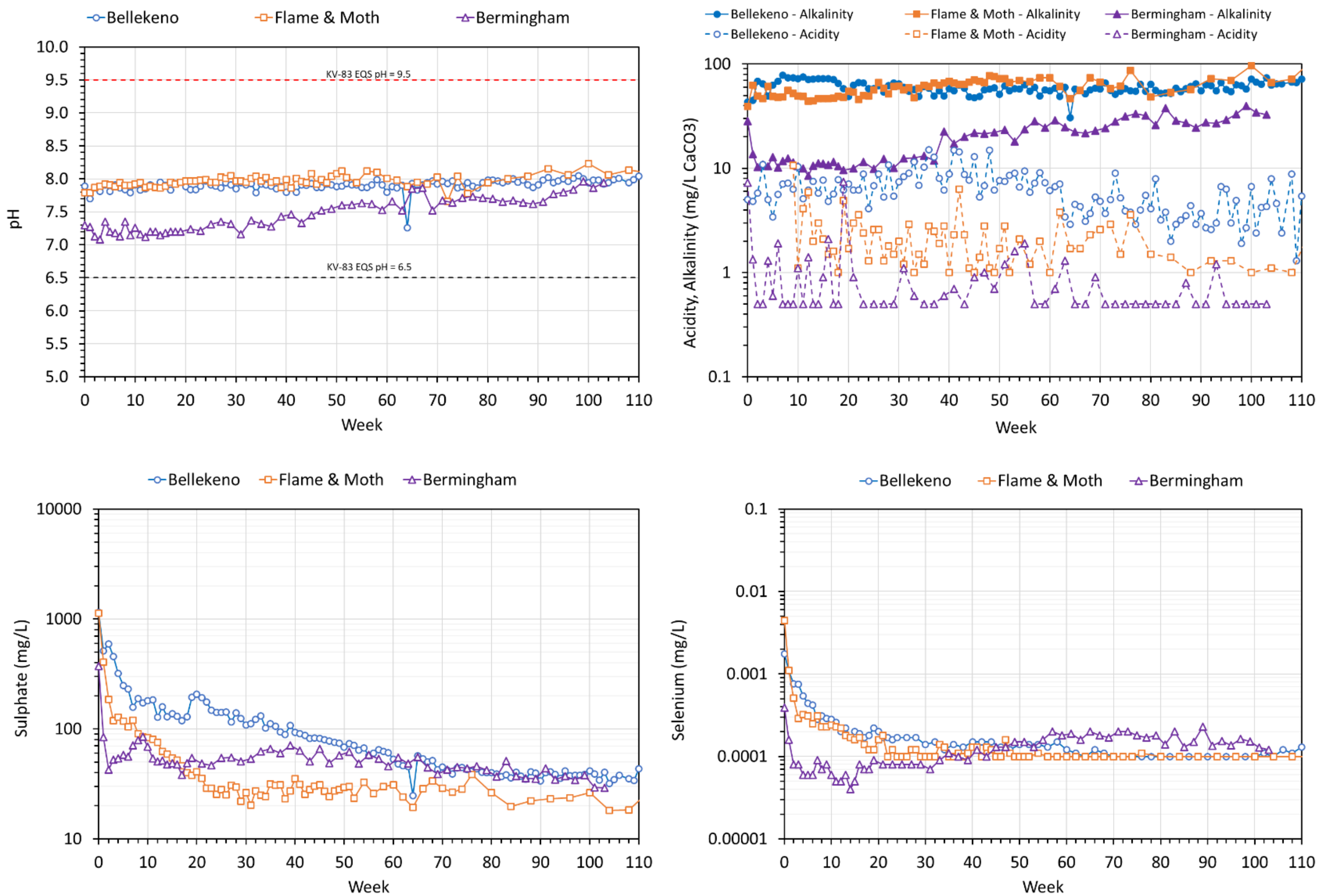


Figure 4-1: pH (top left), Acidity and Alkalinity (top right), Sulphate (bottom left) and Selenium (bottom right) Trends within the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

4.6.2 Constituents of Potential Concern

The times series of metals and metalloids of potential environmental concern in the Bermingham tailings HC are plotted in Figure 4-2 and Figure 4-3 alongside those of Bellekeno and Flame and Moth.

The time series of arsenic, antimony, cadmium, and copper are displayed in Figure 4-2 and lead, nickel, silver, and zinc are shown in Figure 4-3. Analysis of the Bermingham tailings metals and metalloids time series showed similar patterns characterized by a flush effect during cycle 0 followed by a decrease of concentration during the following two to three weeks and then a short-term increase which peaked between cycles six and eight. This was followed by a second short or extended decrease and a stabilization as early as cycle 11 onward (antimony and silver) or later (cycle 55 onward for arsenic, copper; cycle 81-89 onward for cadmium, lead and nickel; cycle ~95 for zinc.). However, sporadic fluctuations of concentration were visible in the plots of arsenic, nickel, silver, lead, and copper.

Aside from the initial flush, the arsenic concentration in the HC leachate from the Bermingham tailings was lower than that of the Bellekeno and Flame and Moth HC leachates, likely due to its lower bulk arsenic concentration. Arsenic concentrations in the HC leachate from the Bermingham HC were an order of magnitude or more lower than those of the Bellekeno and Flame and Moth HCs since cycle 35 and no exceedance of the arsenic EQS (0.1 mg/L) was observed in any of the cells. Cadmium and zinc concentrations in the Bermingham tailings HC leachate were comparable to those of Flame and Moth during the first 35 cycles, then their concentrations sharply decreased below Flame and Moth. Cadmium and zinc concentrations in the Bermingham tailings HC leachate were markedly lower (up to two orders of magnitude) than those observed from the Bellekeno humidity cell during the same period. Besides the first cycle, exceedances of the cadmium and zinc EQS (0.01 and 0.5 mg/L, respectively) were only observed in the Bellekeno HC leachate. The Bermingham tailings cadmium and zinc trends likely reflects the lower concentration of these elements in the Bermingham tailings relative to Bellekeno but somewhat expected compared to Flame and Mock considering its higher cadmium and zinc (Table 4-4). Lead concentrations in the Bermingham humidity cell leachate were almost comparable to the Bellekeno tailings cell during the initial flush, then the concentration markedly decreased to levels that were one order of magnitude lower at cycle 11 and more than two orders of magnitude during the last cycles. Lead concentrations in the Bermingham humidity cell leachate were generally comparable to those of Flame and Moth during the first 11 cycles, then decreased to levels that were one order of magnitude lower than lead concentrations measured in the Flame and Moth HC leachates. Lead concentrations increased again after cycle 59 surpassing and remaining above the Flame and Moth HC after the 79th cycle. Occasional high releases of lead from the Bermingham tailings HC were observed during the test resulting in peak concentrations above those of the Flame and Moth HC. The Bermingham tailings HC leachate generally had the highest nickel concentrations during the first 35 cycles, then the nickel concentration decreased sharply such that it was below the nickel concentration in the Flame and Moth and Bellekeno HC leachates from cycle 43 onwards and generally stabilized after cycle 89. Note that nickel concentrations in the three cells were orders of magnitude lower than the nickel EQS (0.5 mg/L; Figure 4-3).

Aside from sulphate, selenium (last phase of the test), and nickel (early phase of the test), the Bellekeno and Flame and Moth tailings HCs had higher constituent concentrations than the Bermingham HC during the test period. The Bellekeno tailings had the highest concentration release for sulphate during the first half of the test, and the highest cadmium, lead, zinc, and nickel concentrations during the last 68 cycles. The Flame and Moth HC had the highest concentration release for arsenic, antimony, copper, and silver during the first 50 to 70 cycles then their concentrations become comparable or decreased below those in the Bellekeno cell. Copper concentrations in the Bermingham tailings HC leachate were slightly lower than the Bellekeno HC leachate during the first 23 cycles after which time the gap increased markedly (approximately two orders of magnitude difference at the last cycle). Silver concentrations in the Bermingham tailings cell leachate were generally below the detection level (i.e., <0.000005 mg/L) similar to the silver release from the Bellekeno cell although spikes of concentration (0.0001 mg/L) were recurrent during the test. Antimony concentrations in the HC leachate from the Bermingham tailings were lower than that of the Bellekeno and Flame and Moth HC leachate despite a bulk antimony concentration (44.6 ppm) that was comparable with the Flame and Moth tailings (41 ppm; Table 4-4).

Selenium concentrations in the Bermingham tailings HC exhibited a pattern different from all the parameters of interest (Figure 4-1). The concentration decreased after the first flush and was up to an order of magnitude lower than the Flame and Moth and Bellekeno leachate selenium levels during the first 20 cycles. After a stabilization at 0.00008 mg/L during the next 10 cycles, selenium concentrations in the Bermingham tailings cell leachate gradually increased to approximately 0.0002 mg/L, surpassing and remaining slightly above those of the Flame and Moth cell at cycle 49 and Bellekeno at cycle 55 (both approximately 0.0001 mg/L). The selenium concentration then decreased to levels that were comparable to the other cells during the last three cycles.

The tailings kinetic test results indicate that the trace element release rates for Bermingham were lower than the effluent quality standards at KV-83, the KHSD Mill Site. The data also suggest that the trace element release rates for the last ten cycles observed for the Bellekeno and Flame and Moth tailings may be used as a conservative proxy (upper boundary) for most constituents, except selenium, for the Bermingham tailings under the circumneutral conditions expected in the tailings storage facility.

It is worth noting that trace element concentrations released from the Bellekeno and Flame and Moth tailings cells were also lower than the effluent quality standards at KV-83, the KHSD Mill Site with the exception of zinc and cadmium in Bellekeno (Figure 4-2 and Figure 4-3). This is likely related to the elevated bulk zinc and cadmium concentrations in the Bellekeno tailings compared to the other tailings.

Additional information derived from the analysis of Bermingham HC data included:

- The concentration of ammonia was very low (median = 0.005 mg/L), at or below the detection limit in 76% of the cycles and well below the EQS of 5 mg/L;
- The concentrations of the following constituents were below the detection limit in all or the majority of leachates since cycle four: nitrate, nitrite, ammonia, beryllium, bismuth, boron, cesium chromium, lanthanum, iron, mercury, silver, sodium, tellurium, thorium, tin, titanium, tungsten, vanadium and zirconium; and
- The concentration of molybdenum was below the detection limit in the second half of the test.

The neutral pH, significant alkalinity, low acidity and sulphate releases, and lower concentration of metal and metalloids compared to the EQS are evidence of low potential for acid generation and metal release from the Bermingham (and other) tailings consistent with the sequential NAG and SFE results.

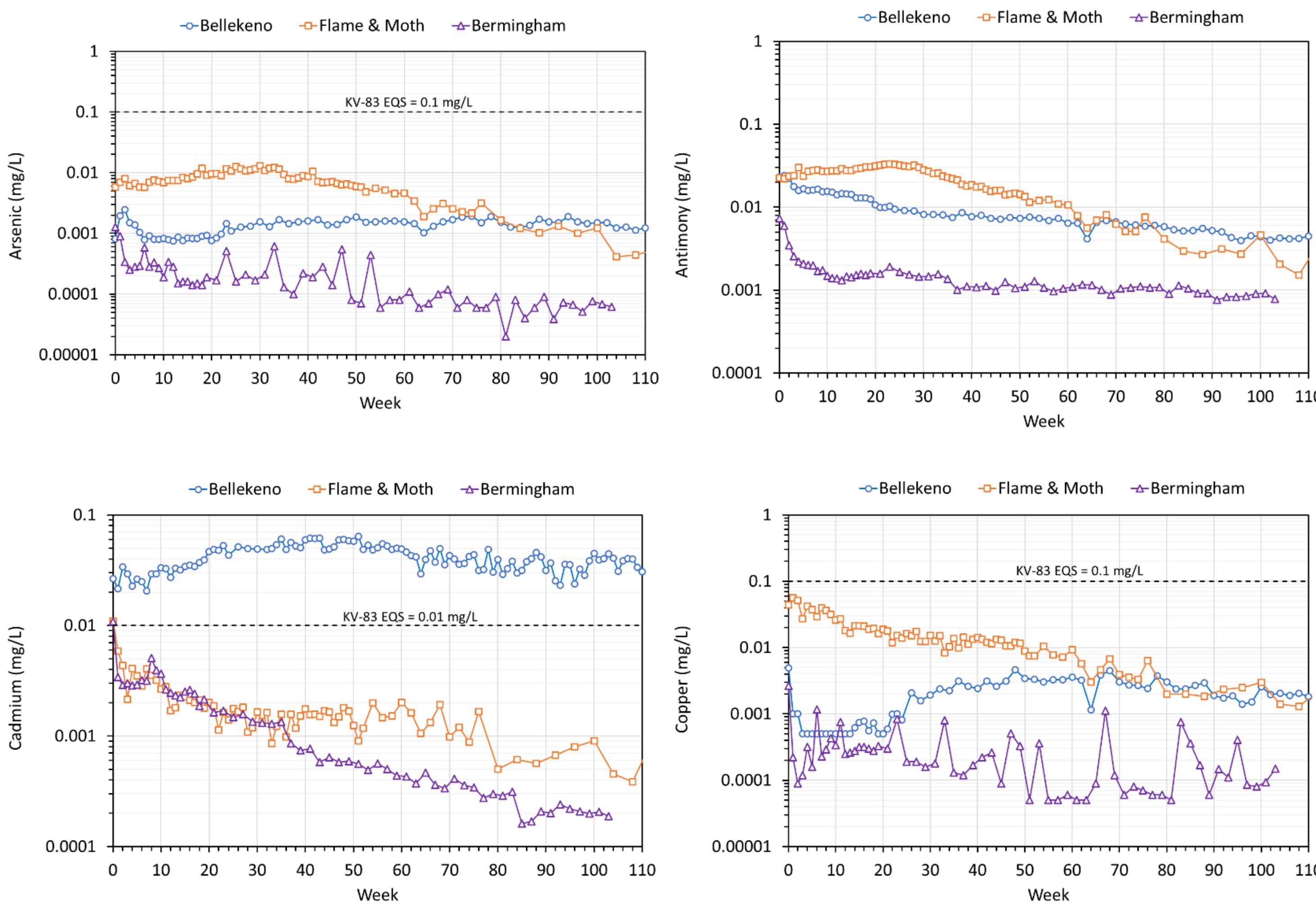


Figure 4-2: Arsenic (top left), Cadmium (bottom left), Antimony (top right), and Copper (bottom right) Trends within the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

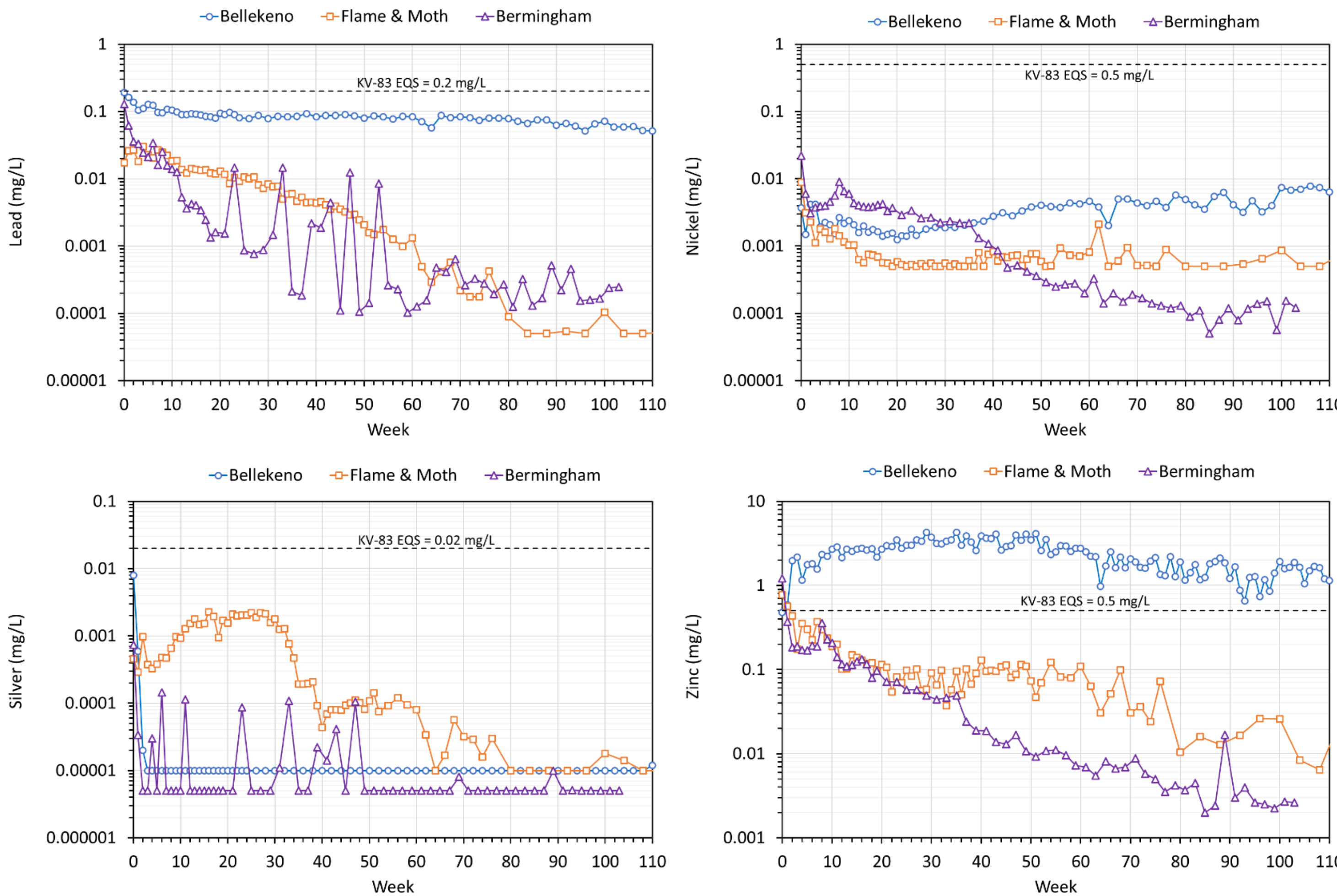


Figure 4-3: Lead (top left), Silver (bottom left), Nickel (top right), and Zinc (bottom right) Trends within the Bermingham LC, Flame and Moth and Bellekeno Tailings Humidity Cells

The estimation of the lag time to acid generation for the Bermingham tailings HC indicates that the times to sulphide and bulk NP depletion are approximately 31 and 40 years, respectively (Figure 4-4). Therefore, some bulk NP will remain in the tailings after the sulphide has been depleted, suggesting that net acid generation is not expected from the tailings. This is consistent with the sequential NAG results.

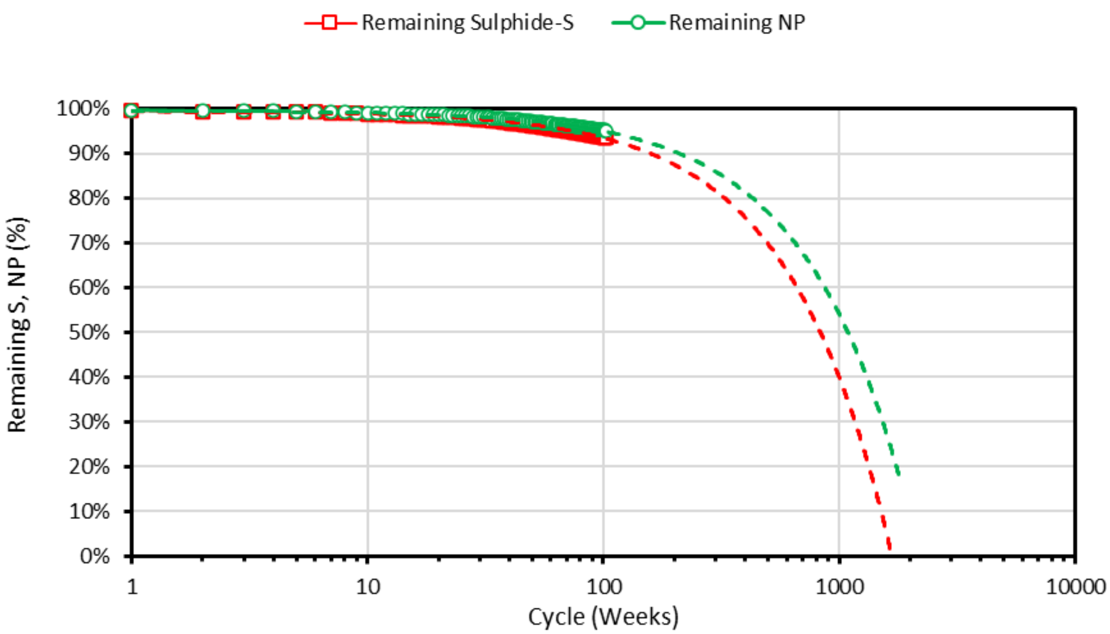


Figure 4-4: Calculations of Sulphide Sulphur and NP Depletion in Bermingham Tailings Humidity Cell

4.6.3 Humidity Cell Closedown

The purpose of the closedown procedure is to help in the interpretation of humidity cell test results by identifying and estimating the changes that may have occurred during the test. The results of the closedown tests on HC residue are reported in Table 4-6 to Table 4-9. The results of the ABA, metal, and XRD analyses on the tailings sample before the HC test are also included for comparison.

The XRD results suggest that weathering and leaching of sulphides (i.e., pyrite, sphalerite, and galena) and carbonate minerals (i.e., ankerite-dolomite and calcian siderite) identified in the head (pre-kinetic) samples occurred. The weathering process resulted in the reduction of the sulphides by 27% to 67% and of carbonates by 10% to 60% (Table 4-6). The changes induced by the leaching and weathering process and the loss of readily soluble minerals resulted in a higher percentage of less soluble minerals (i.e., quartz and aluminosilicates). Sample heterogeneity and/or normalization of the XRD results are the likely explanation for the appearance of paragonite and rutile. The ABA results confirm these changes as indicated by a decrease in total sulphur and carbonate NP by 15% and 16%, respectively (Table 4-7). However, the cell residue still contains enough carbonate and bulk NP to prevent the onset of ARD. The bulk NP apparent increase in the residue by 4% is likely due to the heterogeneity of the sample.

Table 4-6: Mineralogy of Original Tailings and Residue of Tailings Humidity Cell

Mineral	Bermingham LCT2 Tailing	
	Pre-kinetic (%)	Post-kinetic (%)
Ankerite – Dolomite	1	-
Dolomite	-	0.4
Galena	0.3	0.1
Illite-Muscovite 2M1	8.2	7.8
Kaolinite	0.9	1.4
Pyrite	2.2	1.6
Quartz	59.3	61.2
Rutile?	-	0.4
Siderite, calcian	27.8	25.1
Sphalerite	0.3	0.2
Paragonite	-	1.8
Total	**100**	**100**

Table 4-7: ABA Results for Original Tailings and Residue of Tailings Humidity Cell

Sample	pH Units	Bermingham LCT2 Tailing	
		Pre-kinetic	Post-kinetic
Paste pH	-	8.2	8.2
Total Sulphur	%	1.39	1.18
Sulphate Sulphur	%	0.01	<0.01
Sulphide Sulphur	%	1.38	1.18
Total Inorganic Carbon	%	8.96	7.52
Carbonate-NP	kg $CaCO_3$/t	204	170.9
Siderite-Corrected NP	kg $CaCO_3$/t	56.3	58.5
AP	kg $CaCO_3$/t	43.1	36.9
NPR	-	1.3	1.6

No marked change of concentration was observed for the majority of elements. Aside from antimony, calcium, magnesium, selenium, sodium, and thallium, the decreases of metal concentration was less than 16%. Aluminum, barium, molybdenum, nickel uranium, and vanadium reported concentrations higher than the pre-kinetic test. Likely due to sample heterogeneity.

Table 4-8: Elemental Content of Original Tailings and Residue of Tailings Humidity Cell

Element	Unit	Bermingham LCT2 Tailing	
		Pre-kinetic	Post-kinetic
Aluminum (Al)	%	0.16	0.17
Antimony (Sb)	ppm	44.6	30.9
Arsenic (As)	ppm	401	371
Barium (Ba)	ppm	30	34
Bismuth (Bi)	ppm	0.04	<0.1
Cadmium (Cd)	ppm	23.4	20.6
Calcium (Ca)	%	0.73	0.54
Chromium (Cr)	ppm	115	114
Cobalt (Co)	ppm	4.3	3.9
Copper (Cu)	ppm	57.5	54.7
Iron (Fe)	%	7.07	6.01
Lead (Pb)	ppm	2330	2230
Magnesium (Mg)	%	0.36	0.35
Manganese (Mn)	%	4.43	>1
Mercury (Hg)	ppm	0.13	0.12
Molybdenum (Mo)	ppm	2.02	2.5
Nickel (Ni)	ppm	49.1	51.1
Phosphorus (P)	%	0.032	0.028
Potassium (K)	%	0.08	0.07
Selenium (Se)	ppm	0.8	<0.5
Silver (Ag)	ppm	56.4	48.8
Sodium (Na)	%	<0.01	0.003
Strontium (Sr)	ppm	15	13
Thallium (Tl)	ppm	1.9	0.7
Tin (Sn)	ppm	2	-
Titanium (Ti)	%	<0.005	<0.001
Uranium (U)	ppm	0.38	0.4
Vanadium (V)	ppm	5	7
Zinc (Zn)	ppm	2080	1790

The closedown SFE results generally returned lower constituent concentrations than those observed for the pre-humidity cell sample except for some major elements (Table 4-9). Electric conductivity, sulphate, alkalinity, calcium, magnesium, potassium, sodium, strontium, copper, and cadmium returned leachable concentrations higher (1.6 to 10 times higher) than the pre-humidity cell sample indicating the accumulation of some soluble products in the cell. However, no leachable concentrations exceeded the EQS.

To determine and estimate the load of constituents that may have accumulated in the HC, the closedown SFE concentrations were normalized by the weight of the tailing cell residue and compared with the normalized data for the last cycle of the humidity cell (Table 4-10). The load released from the closedown SFE was more than six-fold higher than that observed for the final humidity cell cycle for the majority of constituents. Several metals (i.e., aluminum, arsenic, barium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, potassium, silicon, sodium, uranium, tin, and zinc) were twenty to more than hundred times higher. This confirms the accumulation of constituents during the humidity cell testing and redistribution of the closedown SFE load evenly over all weeks of the test is likely to increase the loading of each cycle by at least 6%. However, the redistribution of the closedown SFE concentration evenly over all weeks of the test will result in a modest increase of the weekly concentration released and unlikely to result in weekly or steady-state concentrations higher than the Bellekeno, Flame and Moth or EQS. Thus, the trace element release rates for the last ten cycles observed for the Bellekeno and Flame and Moth tailings are still a valid conservative proxy for most constituents, except selenium, for the Bermingham tailings.

Table 4-9: Comparison of Pre-Humidity Cell SFE, Closedown SFE and Humidity Cell Last Cycle

Leachable Metals	Unit	Bermingham LCT2 Tailing			KHSD Mill Site EQS (KV-83)
		Pre-kinetic SFE	Closedown SFE	Last Kinetic Cycle	
pH	pH units	8.17	8.02	7.94	6.5-9.5
EC	uS/cm	97.1	180	131	-
SO_4	mg/L	19.1	31	29.1	-
Acidity to pH4.5	mg/L	<0.5	<0.5	<0.5	-
Acidity to pH8.3	mg/L	<0.5	<0.5	<0.5	-
Total Alkalinity	mg/L	14	65.3	32.7	-
Fluoride	mg/L	0.2	0.05	<0.05	-
Hardness $CaCO_3$	mg/L	35	132	60.8	-
Aluminum (Al)-Leachable	mg/L	0.0214	0.00438	0.00101	-
Antimony (Sb)-Leachable	mg/L	0.0111	0.0019	0.000783	-
Arsenic (As)-Leachable	mg/L	0.000331	0.000264	0.000062	0.1
Barium (Ba)-Leachable	mg/L	0.0134	0.005	0.000264	-
Beryllium (Be)-Leachable	mg/L	<0.000010	<0.000010	<0.000010	-
Bismuth (Bi)-Leachable	mg/L	<0.0000050	<0.0000050	<0.0000050	-
Boron (B)-Leachable	mg/L	<0.050	<0.050	<0.050	-
Cadmium (Cd)-Leachable	mg/L	0.000309	0.000526	0.000189	0.01
Calcium (Ca)-Leachable	mg/L	12.4	40.3	14	-
Chromium (Cr)-Leachable	mg/L	<0.00010	<0.00010	<0.00010	-
Cobalt (Co)-Leachable	mg/L	0.000099	0.0000783	0.0000089	-
Copper (Cu)-Leachable	mg/L	0.000334	0.0026	0.00015	0.1
Iron (Fe)-Leachable	mg/L	<0.0010	0.006	0.0016	
Lead (Pb)-Leachable	mg/L	0.0188	0.00119	0.000247	0.2
Lithium (Li)-Leachable	mg/L	0.00294	0.00284	0.00062	-
Magnesium (Mg)-Leachable	mg/L	0.988	7.52	6.24	-
Manganese (Mn)-Leachable	mg/L	0.445	0.343	0.0211	-
Mercury (Hg)-Leachable	mg/L	<0.000050	<0.000050	<0.000010	-
Molybdenum (Mo)-Leachable	mg/L	0.000928	0.00105	<0.000050	-
Nickel (Ni)-Leachable	mg/L	0.000368	0.000335	0.000121	0.5
Phosphorus (P)-Leachable	mg/L	0.0414	0.0074	0.0041	-
Potassium (K)-Leachable	mg/L	1.7	3.41	0.192	-
Selenium (Se)-Leachable	mg/L	0.000041	0.000117	0.00012	-
Silicon (Si)-Leachable	mg/L	0.45	0.88	0.15	-
Silver (Ag)-Leachable	mg/L	0.00003	0.0000131	<0.0000050	0.02
Sodium (Na)-Leachable	mg/L	0.596	2.44	<0.050	-
Strontium (Sr)-Leachable	mg/L	0.0172	0.183	0.0143	-
Thallium (Tl)-Leachable	mg/L	0.000177	0.000105	0.0000808	-
Tin (Sn)-Leachable	mg/L	<0.00020	0.00077	<0.00020	-
Titanium (Ti)-Leachable	mg/L	<0.00050	<0.00050	<0.00050	-
Uranium (U)-Leachable	mg/L	<0.0000020	0.00019	0.0000071	-
Vanadium (V)-Leachable	mg/L	<0.00020	<0.00020	<0.00020	-
Zinc (Zn)-Leachable	mg/L	0.017	0.0152	0.00263	0.5

Table 4-10: Comparison of Tailing Cell Last Cycle and Closedown SFE Loadings

Leachable Metals	Unit	Last Kinetic Cycle	Closedown SFE
pH	pH units	7.9	8.0
EC	uS/cm	-	-
SO_4	mg/kg	13.8	93
Acidity to pH4.5	mg/kg	0.24	1.5
Acidity to pH8.3	mg/kg	0.24	1.5
Total Alkalinity	mg/kg	15.53	195.9
Fluoride	mg/kg	0.024	0.15
Hardness $CaCO_3$	mg/kg	28.9	396
Aluminum (Al)-Leachable	mg/kg	0.00048	0.01314
Antimony (Sb)-Leachable	mg/kg	0.00037	0.0057
Arsenic (As)-Leachable	mg/kg	0.0000295	0.000792
Barium (Ba)-Leachable	mg/kg	0.000125	0.015
Beryllium (Be)-Leachable	mg/kg	0.0000047	0.00003
Bismuth (Bi)-Leachable	mg/kg	0.0000024	0.000015
Boron (B)-Leachable	mg/kg	0.0237	0.15
Cadmium (Cd)-Leachable	mg/kg	0.000089	0.001578
Calcium (Ca)-Leachable	mg/kg	6.65	120.9
Chromium (Cr)-Leachable	mg/kg	0.000047	0.0003
Cobalt (Co)-Leachable	mg/kg	0.00000423	0.0002349
Copper (Cu)-Leachable	mg/kg	0.000071	0.0078
Iron (Fe)-Leachable	mg/kg	0.00076	0.018
Lead (Pb)-Leachable	mg/kg	0.00012	0.00357
Lithium (Li)-Leachable	mg/kg	0.000295	0.00852
Magnesium (Mg)-Leachable	mg/kg	2.96	22.56
Manganese (Mn)-Leachable	mg/kg	0.01	1.029
Mercury (Hg)-Leachable	mg/kg	0.0000047	0.00015
Molybdenum (Mo)-Leachable	mg/kg	0.000024	0.00315
Nickel (Ni)-Leachable	mg/kg	0.000057	0.001005
Potassium (K)-Leachable	mg/kg	0.09	10.23
Selenium (Se)-Leachable	mg/kg	0.000057	0.000351
Silver (Ag)-Leachable	mg/kg	0.0000024	0.0000393
Sodium (Na)-Leachable	mg/kg	0.024	7.32
Strontium (Sr)-Leachable	mg/kg	0.0068	0.549
Thallium (Tl)-Leachable	mg/kg	0.000038	0.000315
Tin (Sn)-Leachable	mg/kg	0.000095	0.00231
Titanium (Ti)-Leachable	mg/kg	0.00024	0.0015
Uranium (U)-Leachable	mg/kg	0.0000034	0.00057
Zinc (Zn)-Leachable	mg/kg	0.00125	0.0456

4.7 DISCUSSION AND TAILINGS MANAGEMENT

The comparison of the results of geochemical testing of the Bermingham tailings sample with Onek, Lucky Queen, Flame and Moth, and Bellekeno tailings indicates that the tailings share similar geochemical characteristics with respect to ARD/ML. All the tailings had low potential for ARD/ML, with lower SFE-leachable metal(loid) concentrations observed for the Bermingham tailings compared to other tailings. Also, the Bermingham tailings HC data indicated that most metal(loid) concentrations release rates were comparable or markedly lower than those observed from Flame and Moth and Bellekeno tailings. One exception was the slightly elevated nickel concentration compared to those observed in the Flame and Moth and Bellekeno tailings humidity cell leachate during the first thirty cycles of the test but nickel concentrations later decreased mirroring the other metal(loid)s. The other exception was the higher selenium concentration above that of the Flame and Moth and Bellekeno HC during the second half of the test. Aside from the first flush cadmium and zinc concentrations, no exceedance of the Mill site EQS were observed in the Bermingham SFE or HC test indicating low potential for metal leaching.

While ABA work indicated that the Bermingham tailings had an Uncertain potential for acid generation, the sequential NAG and the kinetic results confirmed their low potential for acid generation. The Uncertain acid potential based on calculated NPR could be explained by the following:

1. The siderite-corrected NP method likely underestimated the effective NP available for acid neutralization. A portion of the iron and manganese carbonate material will likely contribute to net acid neutralization given the slow oxidation kinetics of manganese at circumneutral pH and siderite calcian end-member.

2. XRD analysis identified sphalerite (0.3 to 0.6 wt.%), galena (0.3 to 0.8 wt.%), and pyrite (1.6 to 2.2 wt.%) in the Bermingham tailings sample. Under oxic weathering conditions, the oxidation of galena and sphalerite by oxygen is not an acid generating process. Both these minerals constitute approximately 20% to 47% of the XRD-measured sulphide mineralogy, indicating that the AP was likely overestimated.

Furthermore, sequential NAG testing revealed that there is sufficient NP in the Bermingham tailings to buffer the acid generated from sulphide oxidation. Sulphide and NP depletion calculations for the Bermingham tailings humidity cell also confirmed that the NP will outlast the AP generated from sulphide, indicating that net acid generation is not anticipated from the Bermingham tailings.

The results of the humidity cell closedown tests indicated that geochemical changes consisting of the removal of some constituents from the sample and the accumulation of others in the residue occurred during the kinetic test. Despite these changes, the tailings material remains low potential for long-term acid generation and metal leaching.

The tailings deposited in the DSTF or underground as cemented tailings backfill at Bermingham will either be standalone Bermingham tailings or a combination of tailings originating from the mines currently permitted in the KHSD. Blending and/or co-disposal of the Bermingham tailings with high effective NP (high in fast reactive calcite) tailings from the Flame and Moth and Bellekeno in the DSTF would significantly increase the bulk NP of the tailings mix, thus the net long-term acid generation is not anticipated. The geochemical testwork completed on the Bellekeno tailings stored on the DSTF and their performance indicate that the tailings are not a concern from an acid generating potential perspective.

5 SUMMARY

The results of static and kinetic tests conducted on the Bermingham tailings indicate that the tailings were mainly composed of silica, calcian iron and manganese carbonates and minor sulphides. They had low potential for long-term acid generation due to an adequate NP buffering the acidity released from sulphide oxidation. The tailings had elevated bulk concentrations of several metals and metalloids but laboratory simulated short- and long-term leaching tests (SFE and HC) suggests that relatively low levels of metal leaching may be expected from the Bermingham tailings. Similar geochemical characteristics were observed for the tailings humidity cell residue.

The Bermingham tailings had similar geochemical characteristics as the tailings from other deposits. Their lower bulk metal composition might be in part due to spatial variability in mineralization between the deposits. The SFE leachable metal(loid)s and HC metal(loid) release rates were comparable or markedly lower than those observed from other tested tailings, except for nickel and selenium, with leachate constituent concentrations well below the EQS at the Mill site pond. Their low fast reactive carbonate content (e.g., low readily available NP) will be compensated by NP from calcian siderite and by NP from other tailings with high NP during co-disposal or blending. Overall, the Bermingham tailing have low potential for acid and metal release.

6 REFERENCES

Access Consulting Group. (2015) Summary of Geochemical Characterization of Flame & Moth Tailings. Memorandum prepared for Alexco Keno Hill Mining Corp., August 6, 2015.

CRC (2005). CRC *Handbook of Chemistry and Physics, 85th Edition.* CRC Press. Boca Raton, Florida.

Price, W.A. (2009) *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials*. MEND Report 1.20.1. CANMET – Mining and Mineral Science Laboratories, Smithers, BC.

APPENDIX 3.4
FLAME & MOTH WASTE STORAGE FACILITY DESIGN

TETRA TECH EBA

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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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
YUKON
JUSTIN PIGAGE
TERRITORY
Oct. 2/14
ENGINEER

Justin Pigage, P.Eng.
Geotechnical Engineer, Arctic Region
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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).

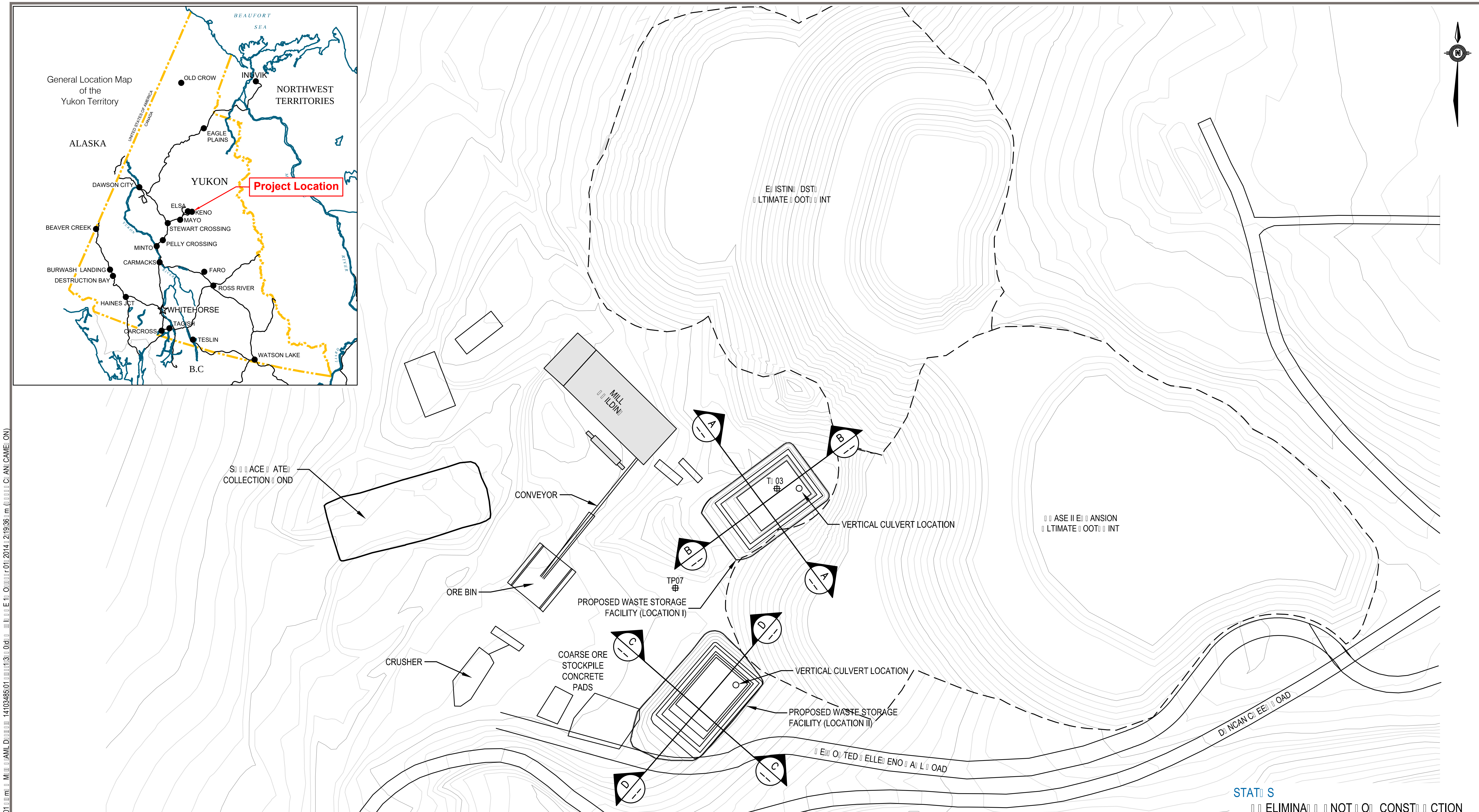
REFERENCES

EBA, A Tetra Tech Company “Dry Stacked Tailings Facility – Risk Assessment Stability Model Update, Keno Hill District Mill Site, Yukon” February 2013.

EBA Engineering Consultants Ltd. “Typical Waste Containment Facility Design, Keno Hill Silver District, YT – Construction Specifications” July 2008.

Piteau Associates Engineering Ltd. “Investigation and Design of Mine Dumps – Interim Guidelines.” Prepared for British Columbia Mine Waste Rock Pile Research Committee, May 1991.

FIGURES



STATUS

PRELIMINARY – NOT FOR CONSTRUCTION

LEGEND

TEST PIT LOCATION (2009)

0 — 100 m

CLIENT

ALEXCO

TETRA TECH EBA

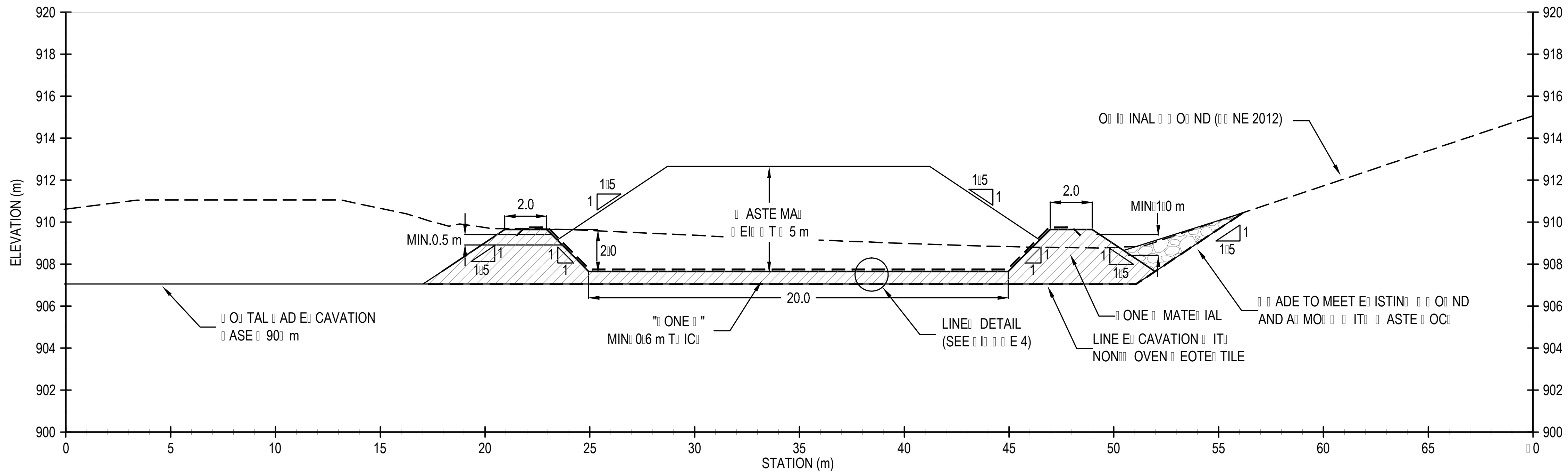
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

SITE PLAN

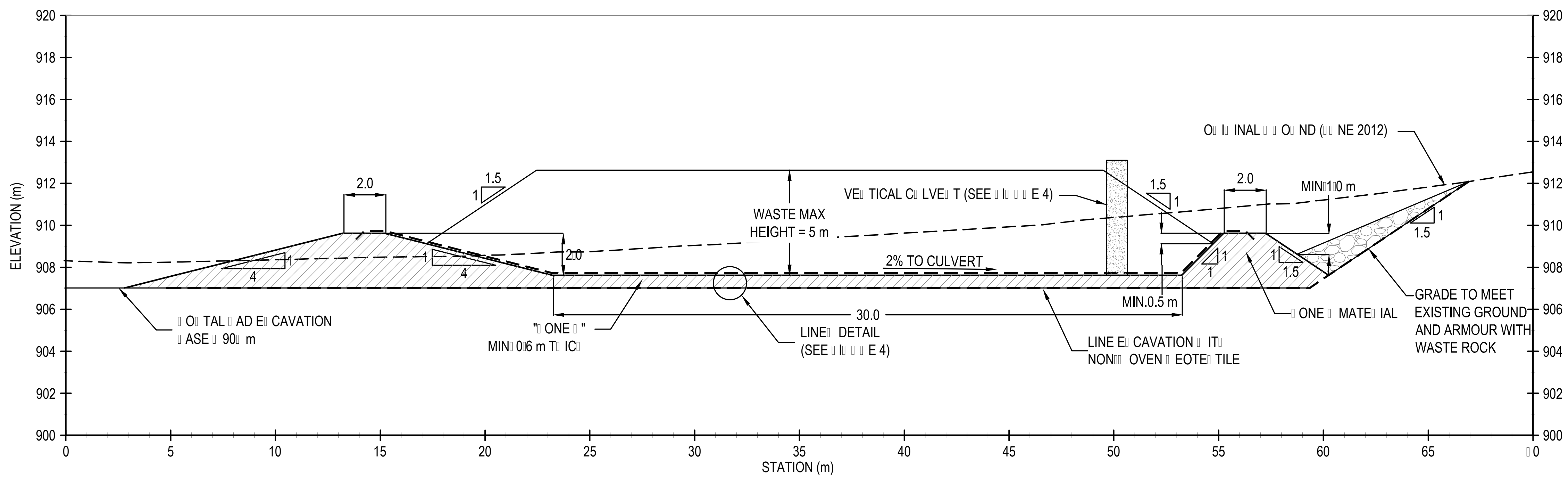
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0

OFFICE	DATE
EBA-WHSE	September 25, 2014

Figure



SECTION A A



SECTION B B

STATUS
PRELIMINARY NOT FOR CONSTRUCTION

0 10 m
SCALE 1:250

CLIENT
ALEXCO

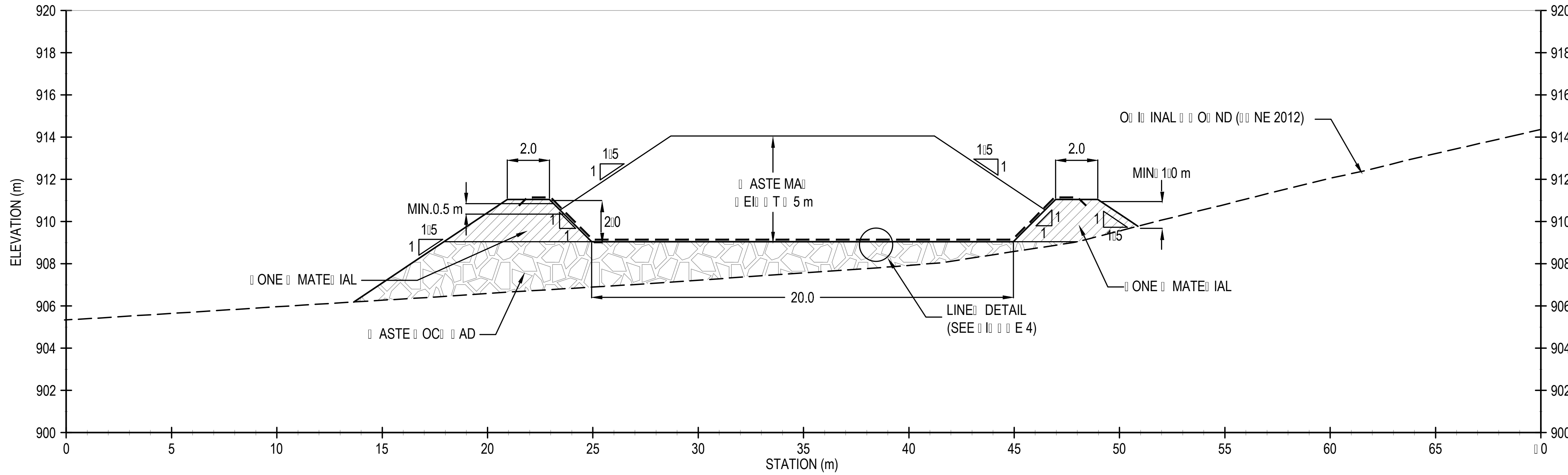
TETRA TECH EBA

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

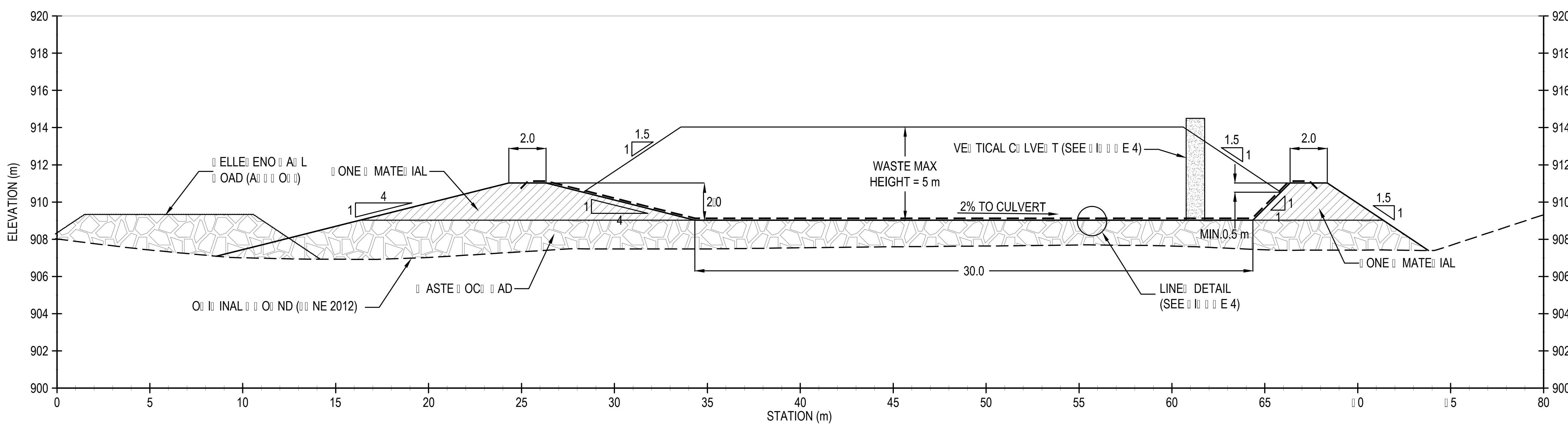
LOCATION I CROSS SECTIONS

PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE	DATE		
EBA-WHSE	September 25, 2014		

Figure



SECTION C – C'



SECTION D – D'

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 II CROSS SECTIONS

PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE	DATE		
EBA-WHSE	September 25, 201		

Figure 3

NOTES▯

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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.

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The fill materials shall be placed in lifts not exceeding 0.5 m in uncompacted thickness and compacted to at least 95% of maximum dr▯ d▯▯▯▯▯ ▯▯▯▯ ▯▯▯d▯rd ▯▯▯r▯▯▯ ▯▯r 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.

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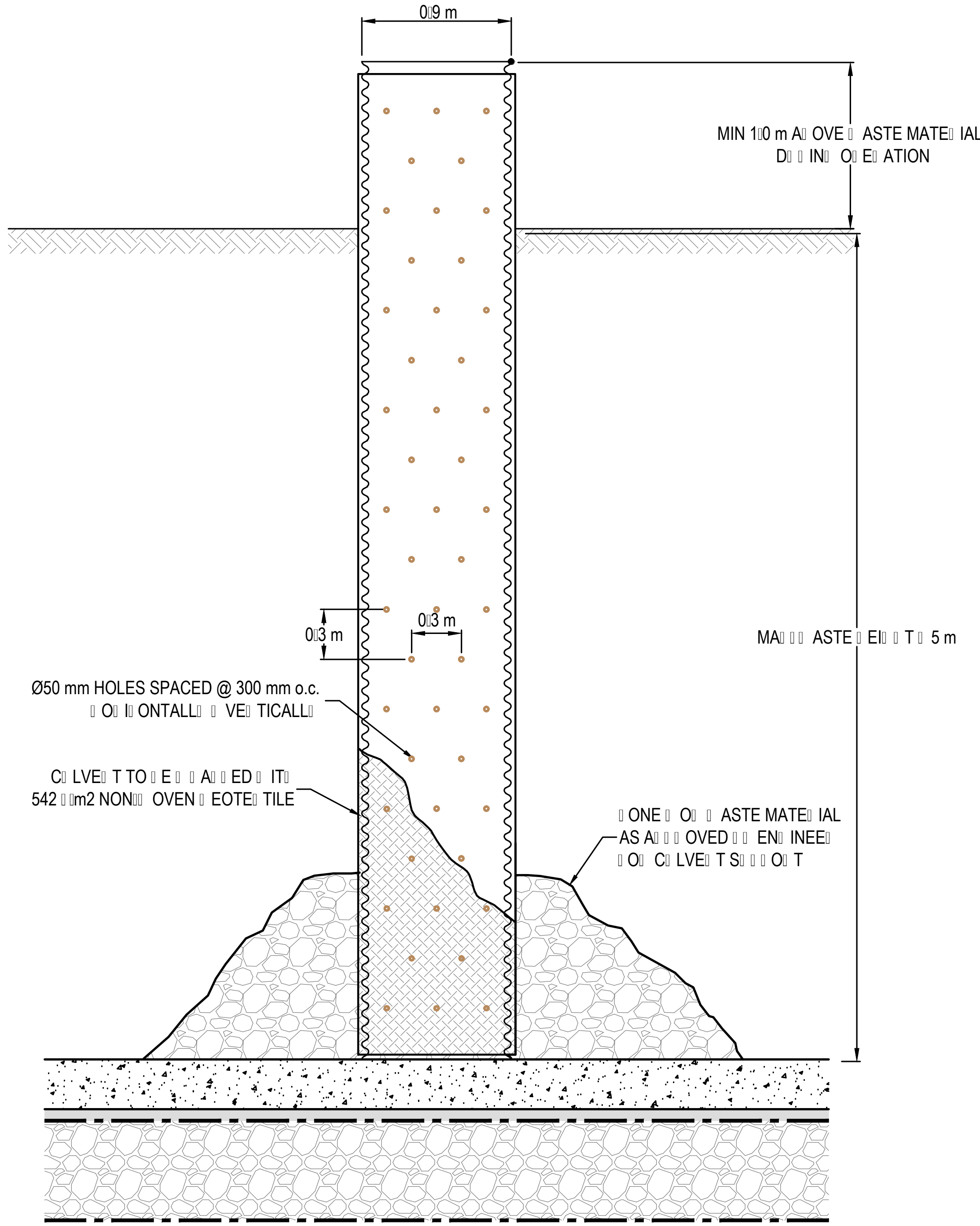

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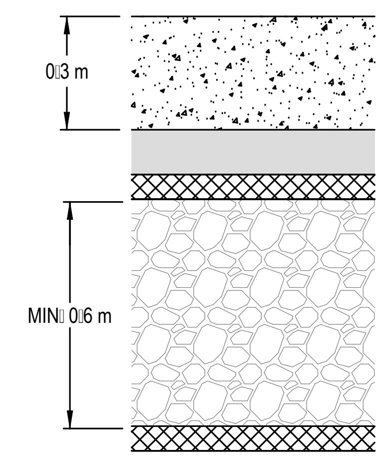
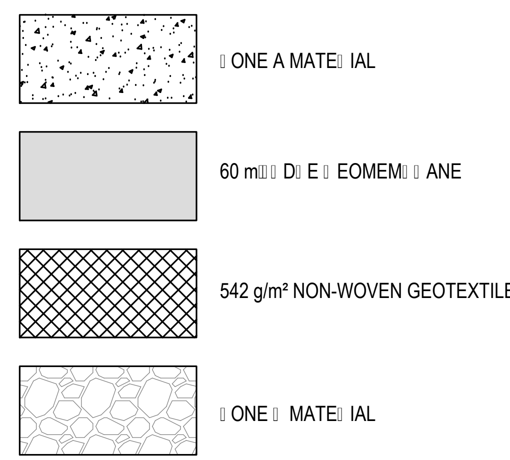


DETAIL 2 ▯ ▯ ACILIT▯ ▯ LOO▯ AND ▯ E▯ MS



LINE▯ S▯ STEM DETAIL ▯ E▯

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

STAT▯ S
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NOTE
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CLIENT
ALEXCO
TETRA TECH EBA

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

DETAILS AND NOTES

▯ ▯ O▯ ECT NO▯	D▯ N	C▯ D	▯ EV
W1▯103▯85-01	CB	JTP	0
O▯ ▯ ICE	DATE		
EBA-WHSE	September 26, 201▯		

Figure 4

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
		Disturbed	SA01		354		
1							
							906.0
		Disturbed	SA02		1158		
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	Plastic–liquid range (~12–20)	Vx, Vc (<5%)	
						Unfrozen	903.0
4							
		Disturbed	SA04	1.5	Pocket pen. (~200 kPa)		902.0
5							
	EOH - refusal at probable bedrock (quartzite)						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
DSTF RISK ASSESSMENT

Bellekeno Mine - Dry Stack Failure Modes and Effects Analysis
Final Draft

Prepared for

Alexco Resource Corp.

Prepared by

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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Project No:	1CA009.006

File Name: BellekenoMine_DryStackFMEA_Report_1CA009.006_dvz_ccs_20130703_FNL DRAFT.docx

srk consulting

[illegible]

[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 [illegible]

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]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[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

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.

Appendix A: Introductory PowerPoint Presentations

DSTF Risk Assessment

ALEXCO

- Introductions
- Participants
- Objectives
- Risk Assessment Process Overview
- DSTF Overview
- DSTF Risk Assessment

Keno District Timeline

- **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

- **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

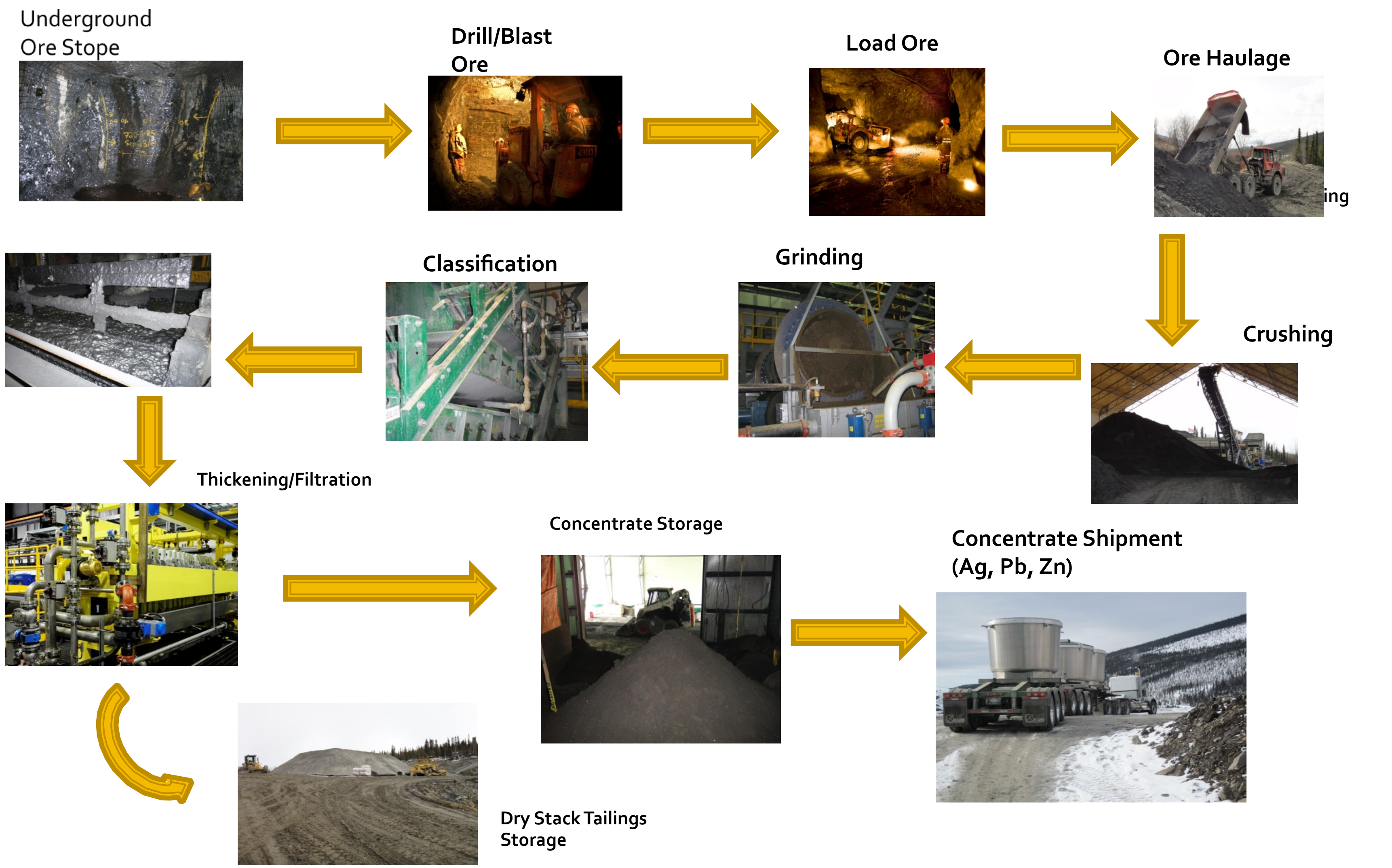
ALEXCO

- **Disadvantages**
  - Increased capital and operating costs
  - Increased process bottlenecks – decreased operating flexibility
  - Potential dust migration due to lower moisture content

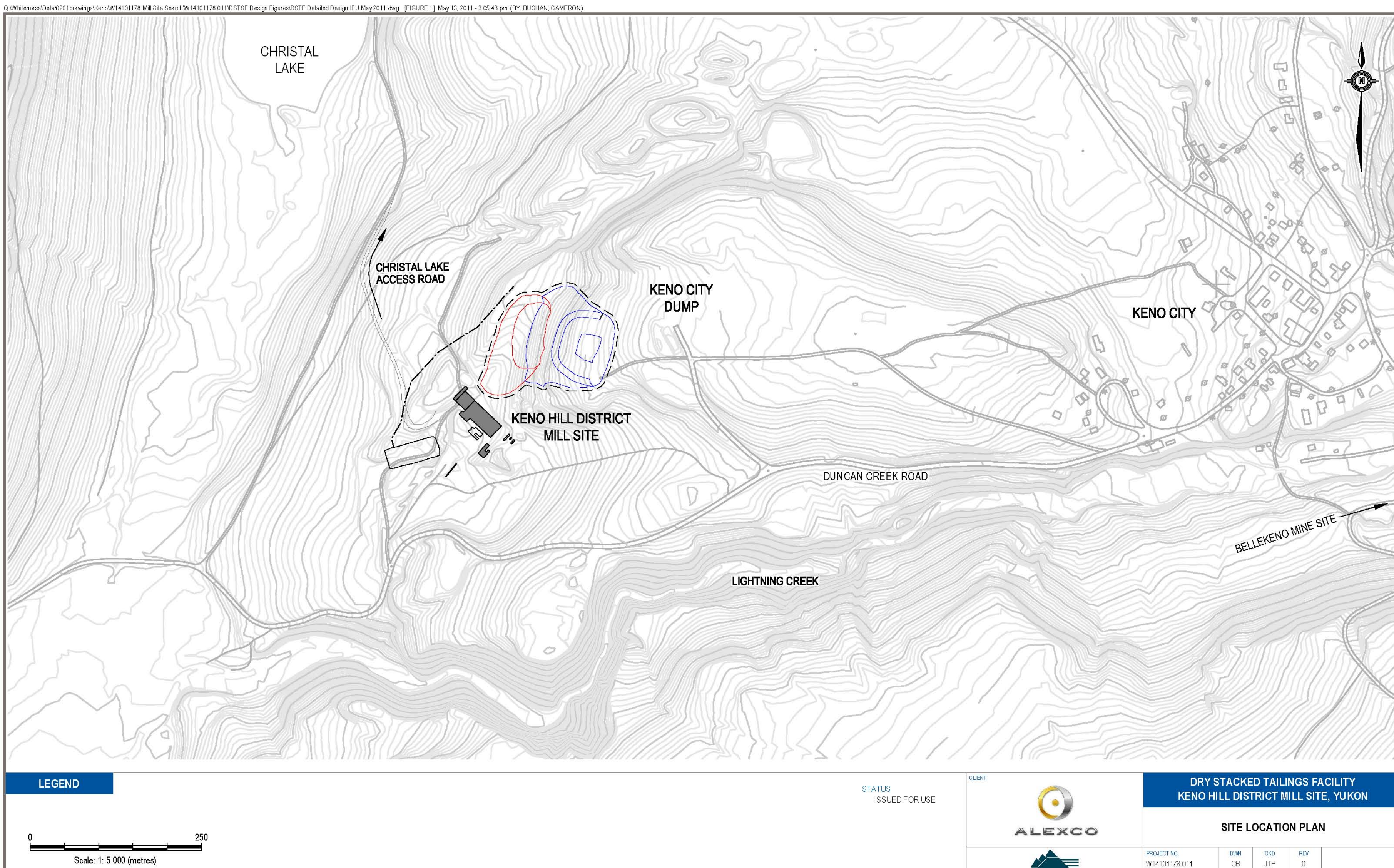
Mill Area Layout

Mill Process Flowsheet

ALEXCO

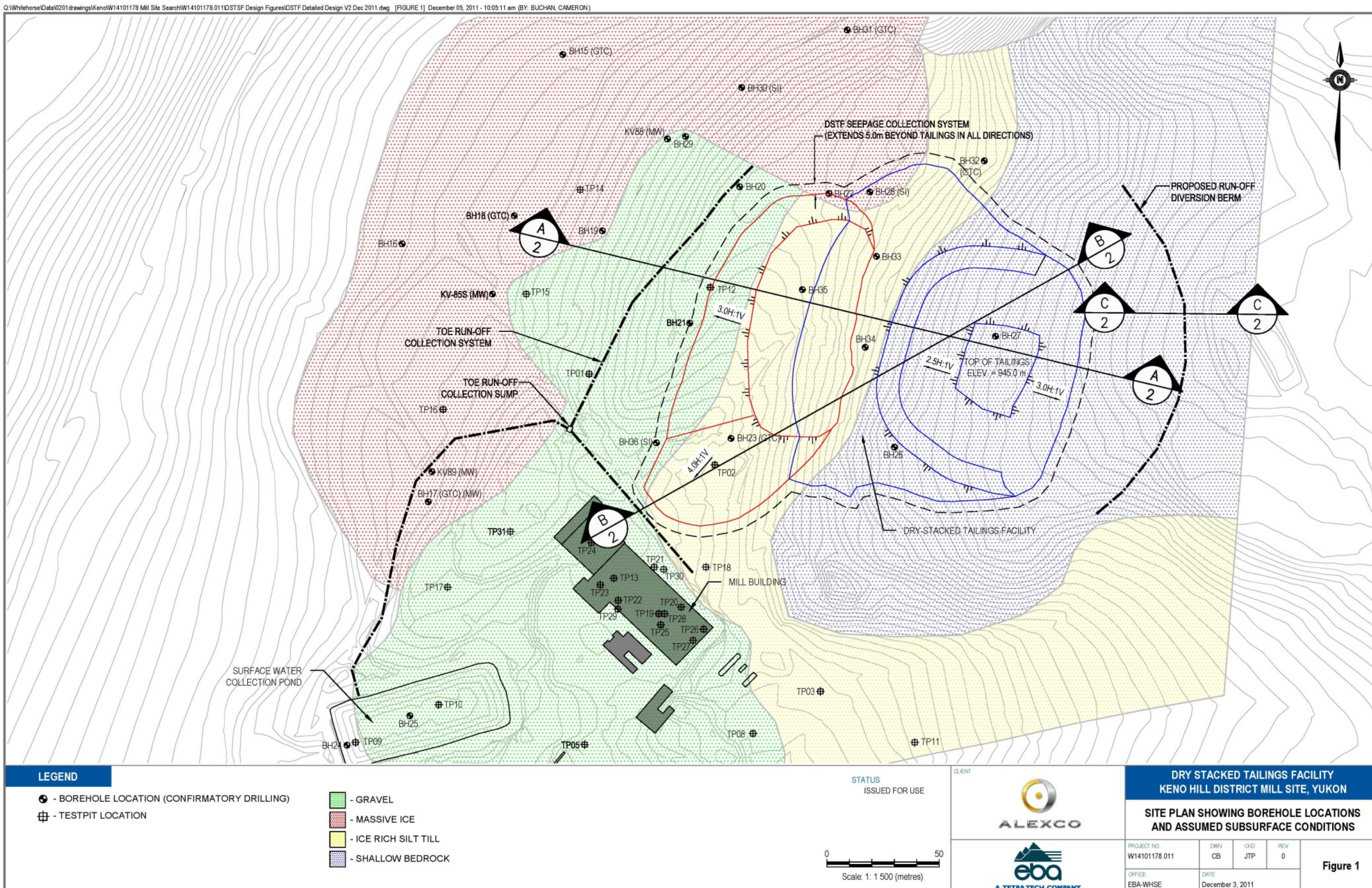


DSTF Design



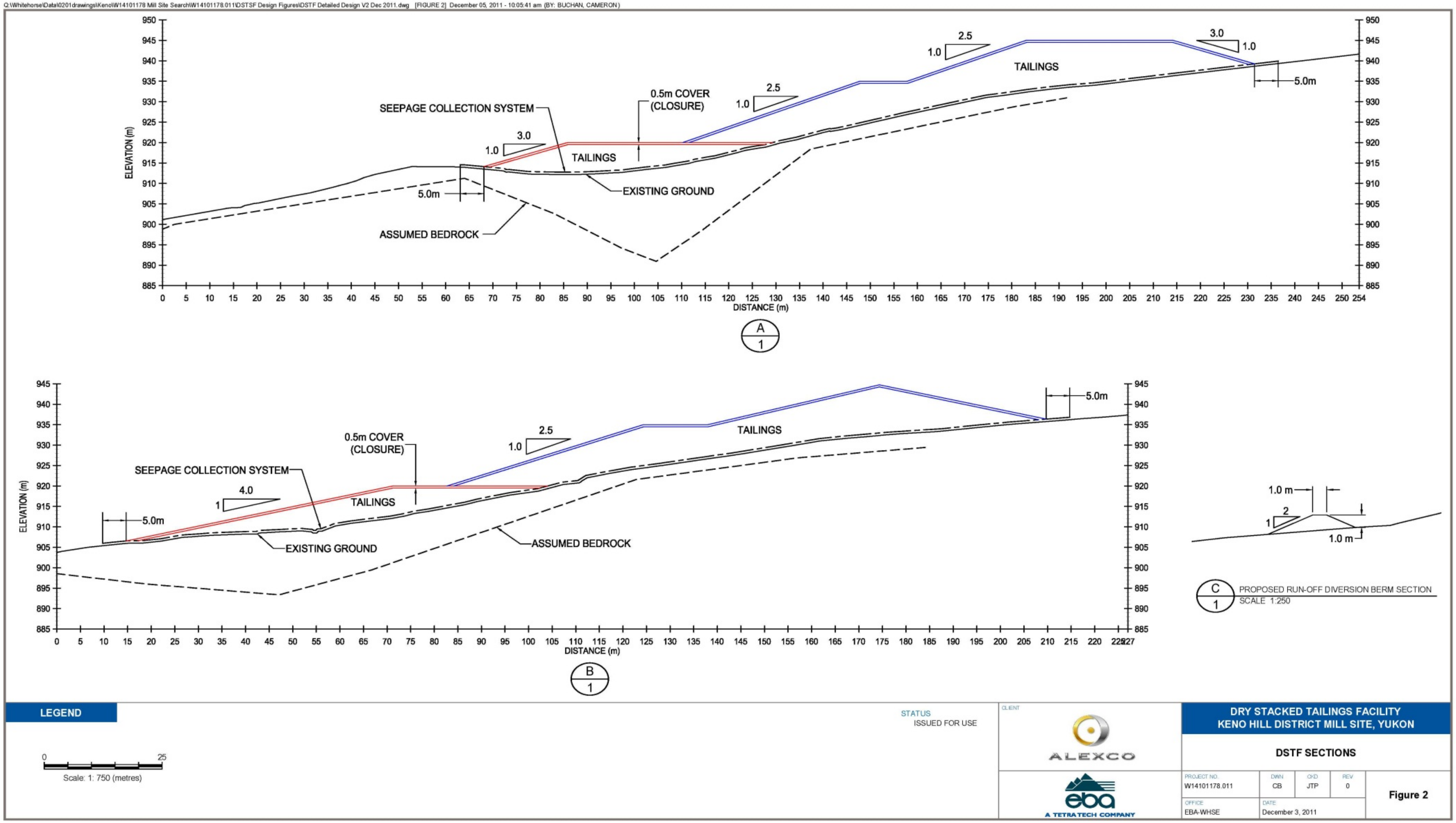
Q:\Whitehorse\Data\0201drawings\Keno\W14101178 Mill Site Search\W14101178.011\DSTSF Design Figures\DSTF Detailed Design IFU May2011.dwg [FIGURE 1] May 13, 2011 - 3:05:43 pm (BY: BUCHAN, CAMERON)
CHRISTAL LAKE
CHRISTAL LAKE ACCESS ROAD
KENO CITY DUMP
KENO CITY
KENO HILL DISTRICT MILL SITE
DUNCAN CREEK 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



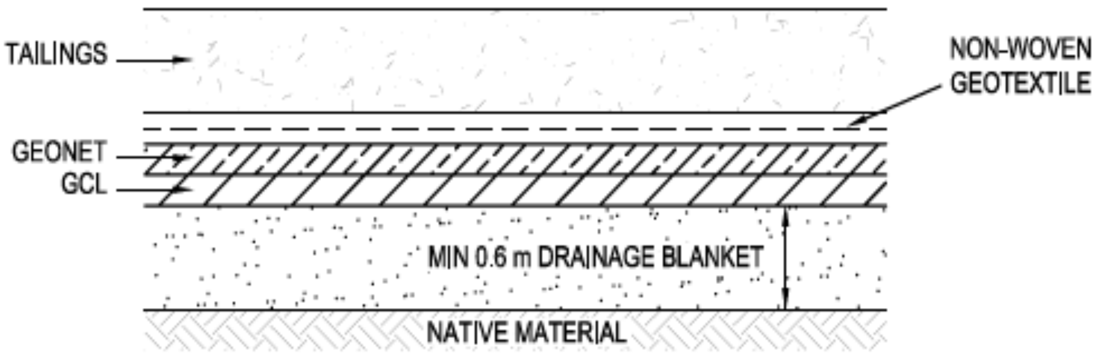
Q:\Whitehorse\Data\0201drawings\Keno\W14101178 Mill Site Search\W14101178.011\DSTF Design Figures\DSTF Detailed Design V2 Dec 2011.dwg [FIGURE 1] December 05, 2011 - 10:05:11 am (BY: BUCHAN, CAMERON)
BH31 (GTC)
BH15 (GTC)
BH30 (SI)
KV88 (MW)
BH29
DSTF SEEPAGE COLLECTION SYSTEM
(EXTENDS 5.0m BEYOND TAILINGS IN ALL DIRECTIONS)
BH32 (GTC)
TP14
BH20
BH22
BH28 (SI)
PROPOSED RUN-OFF DIVERSION BERM
BH18 (GTC)
BH19
BH16
BH33
KV-85S (MW)
TP15
TP12
BH35
3.0H:1V
BH21
TOE RUN-OFF COLLECTION SYSTEM
BH34
BH27
TOP OF TAILINGS ELEV. = 945.0 m
2.5H:1V
3.0H:1V
TP01
TOE RUN-OFF COLLECTION SUMP
TP16
BH36 (SI)
BH23 (GTC)
BH26
4.0H:1V
KV89 (MW)
TP02
BH17 (GTC) (MW)
DRY-STACKED TAILINGS FACILITY
TP31
TP24
TP21
TP30
TP18
TP13
MILL BUILDING
TP17
TP23
TP22
TP20
TP29
TP19
TP28
TP25
TP26
TP27
SURFACE WATER COLLECTION POND
TP03
TP10
BH25
TP09
BH24
TP05
TP08
TP11
A 2
B 2
C 2
LEGEND
- BOREHOLE LOCATION (CONFIRMATORY DRILLING)
- TESTPIT LOCATION
- GRAVEL
- MASSIVE ICE
- ICE RICH SILT TILL
- SHALLOW BEDROCK
STATUS
ISSUED FOR USE
0 50
Scale: 1: 1 500 (metres)
CLIENT
ALEXCO
eba
A TETRA TECH COMPANY
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



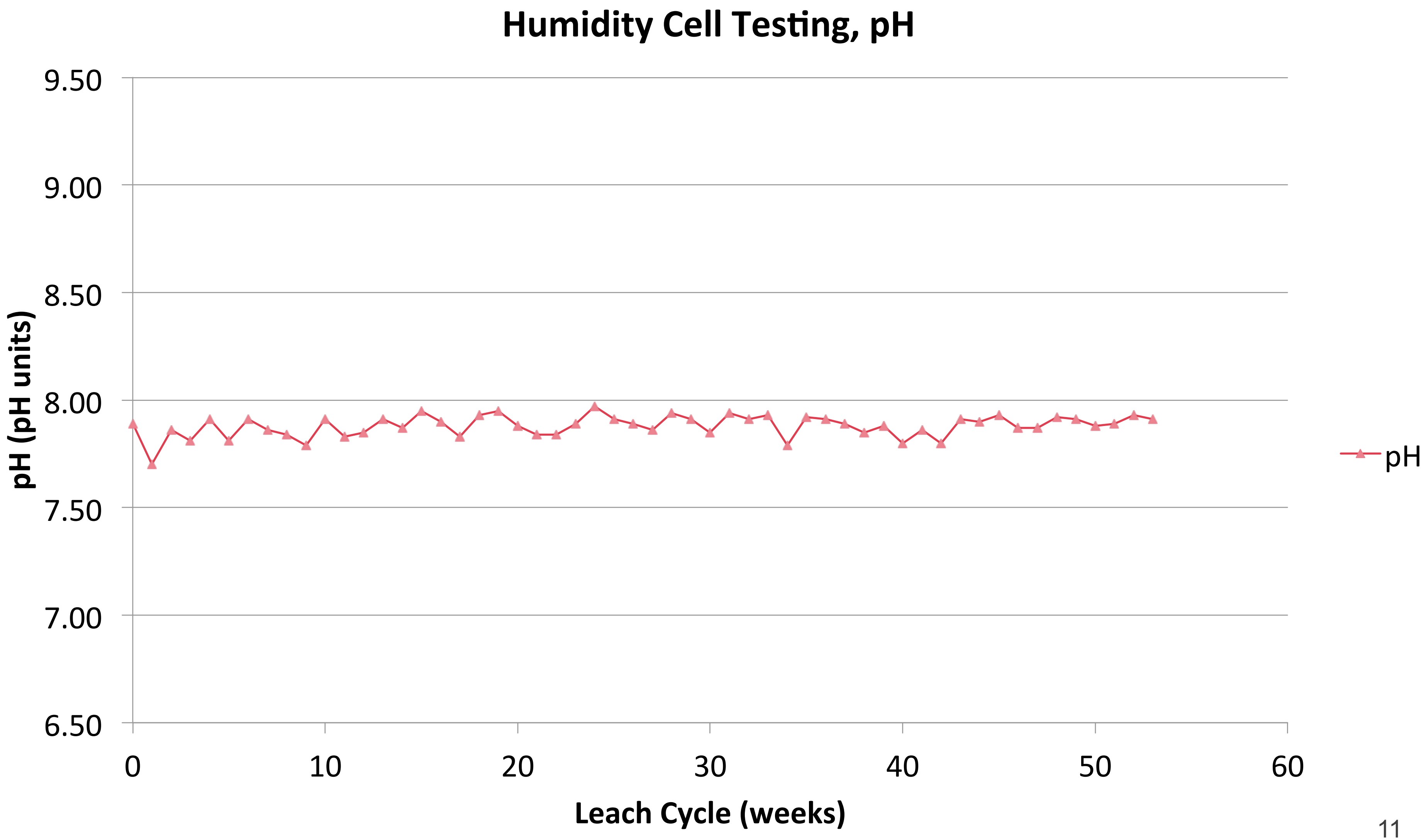
SEEPAGE COLLECTION SYSTEM
0.5m COVER (CLOSURE)
TAILINGS
EXISTING GROUND
ASSUMED BEDROCK
5.0m
ELEVATION (m)
DISTANCE (m)
A 1
B 1
C 1
PROPOSED RUN-OFF DIVERSION BERM SECTION
SCALE 1:250
LEGEND
Scale: 1: 750 (metres)
STATUS
ISSUED FOR USE
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
DSTF SECTIONS
PROJECT NO. W14101178.011
DWN CB
CKD JTP
REV 0
OFFICE EBA-WHSE
DATE December 3, 2011
Figure 2

DSTF Design

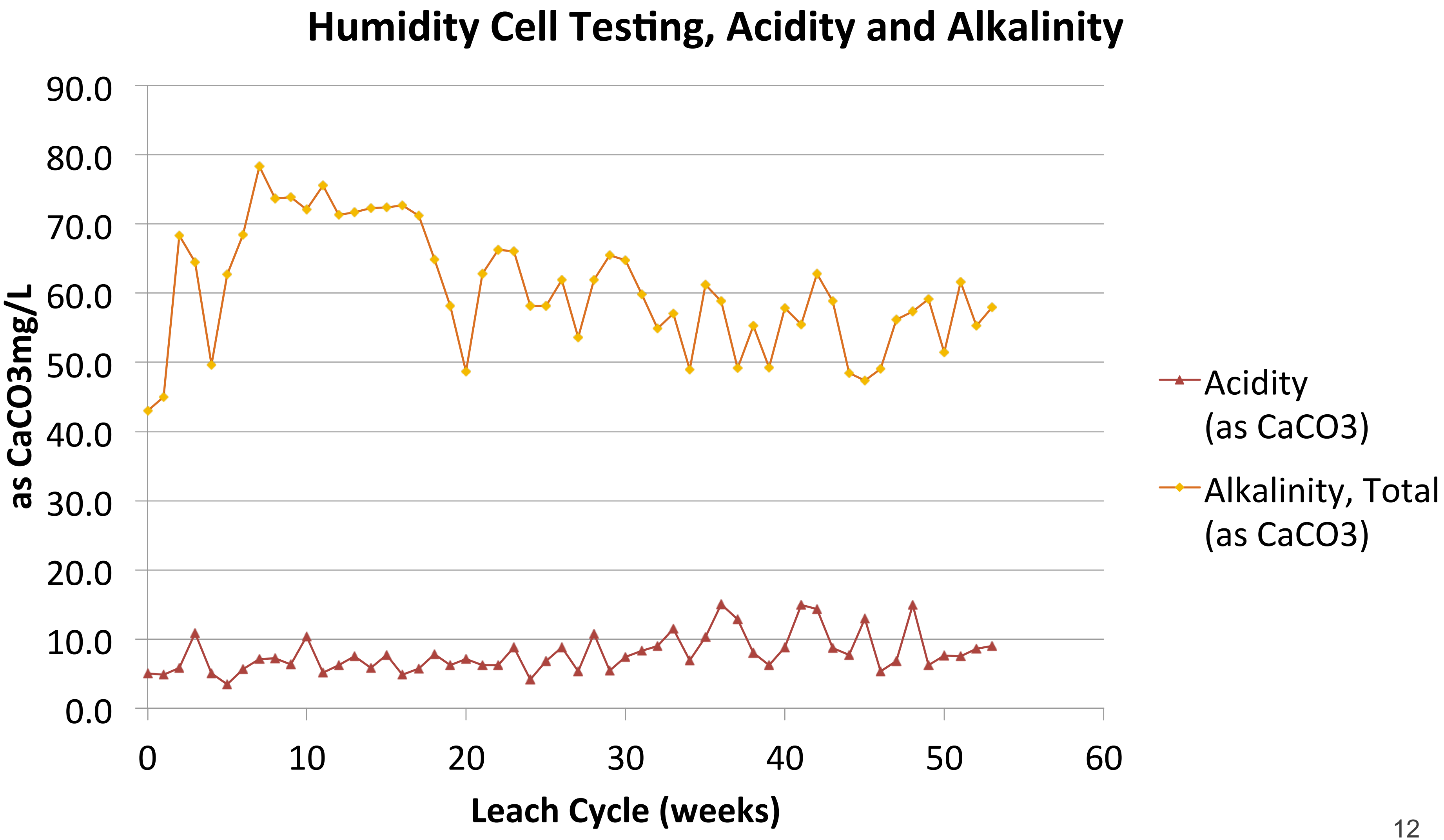


SEEPAGE COLLECTION SYSTEM DETAIL

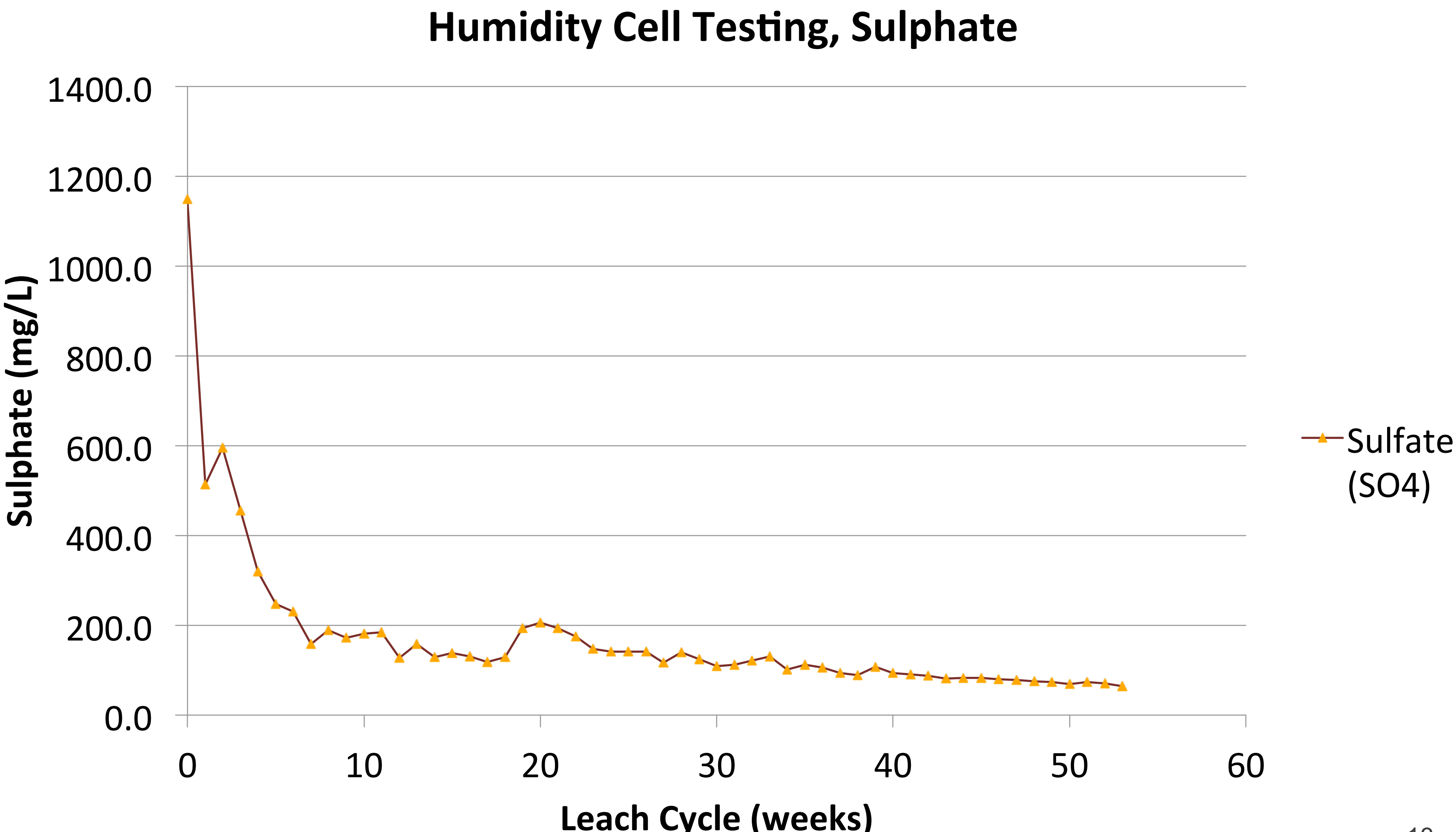
DSTF Performance



DSTF Performance

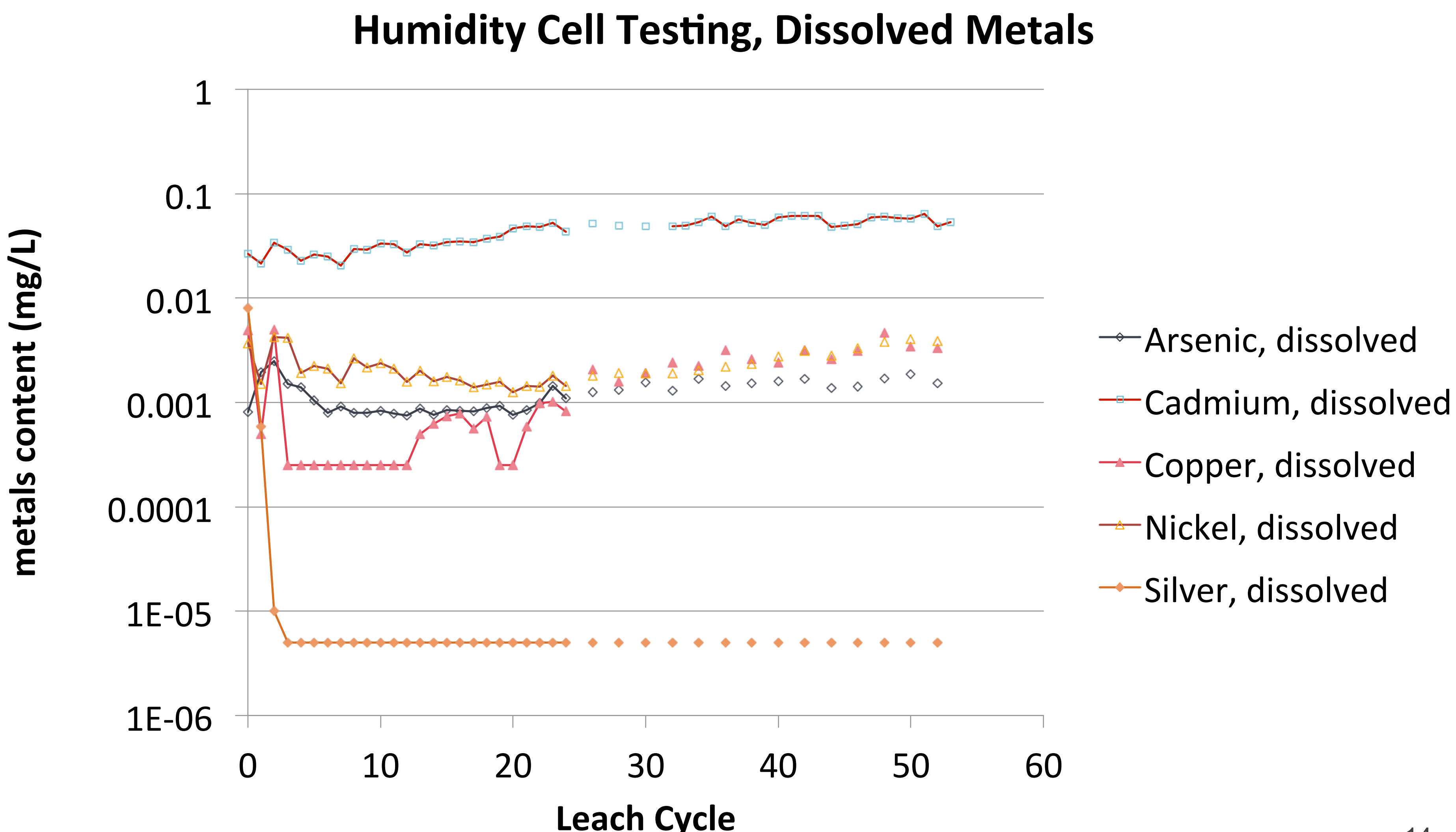


DSTF Performance

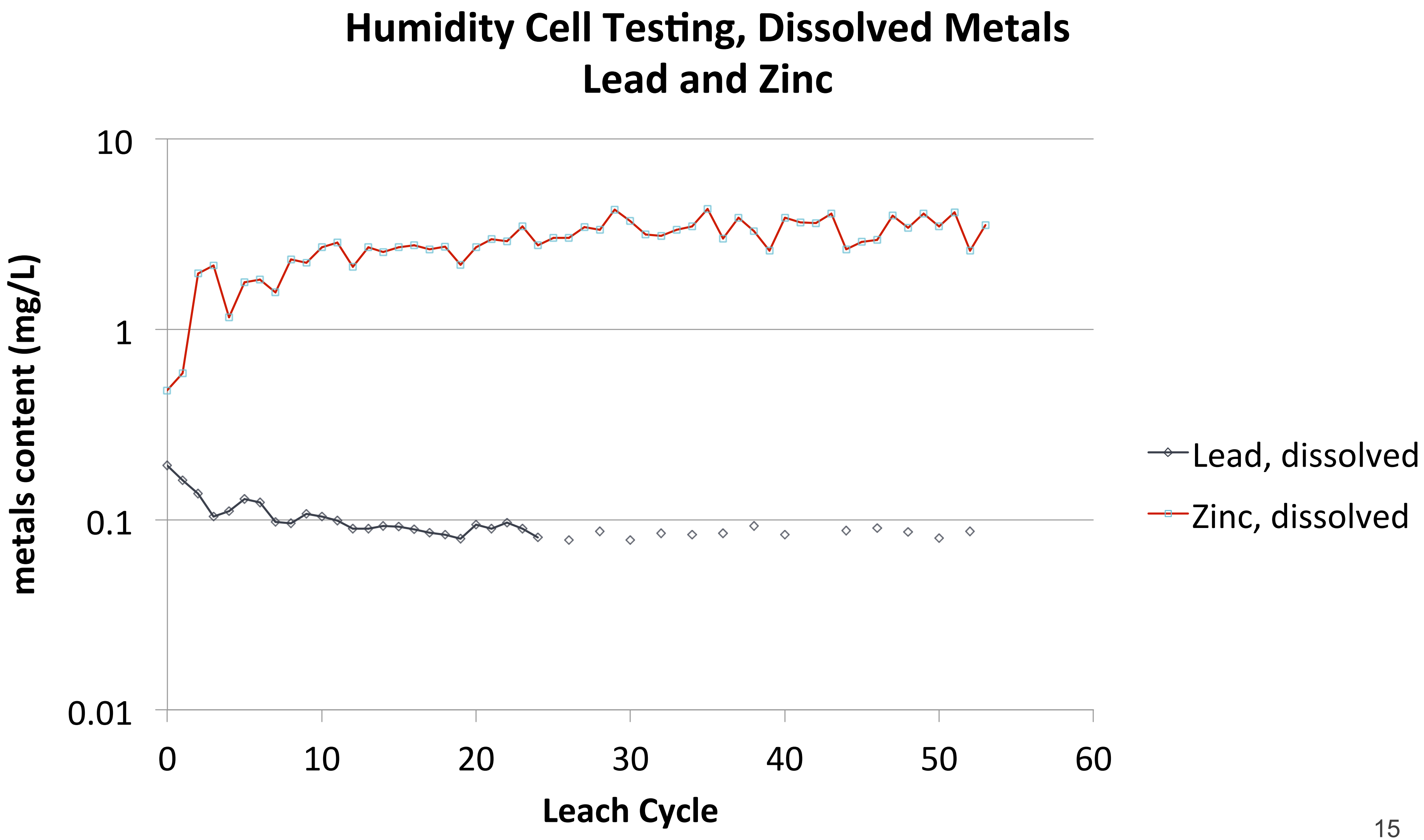


DSTF Performance

ALEXCO



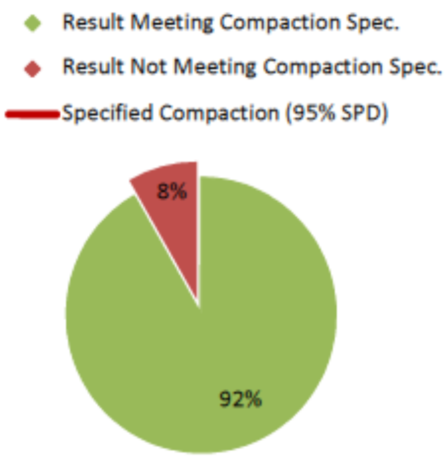
DSTF Performance



DSTF Performance - Compaction

ALEXCO

Summary of DSTF Compaction Results



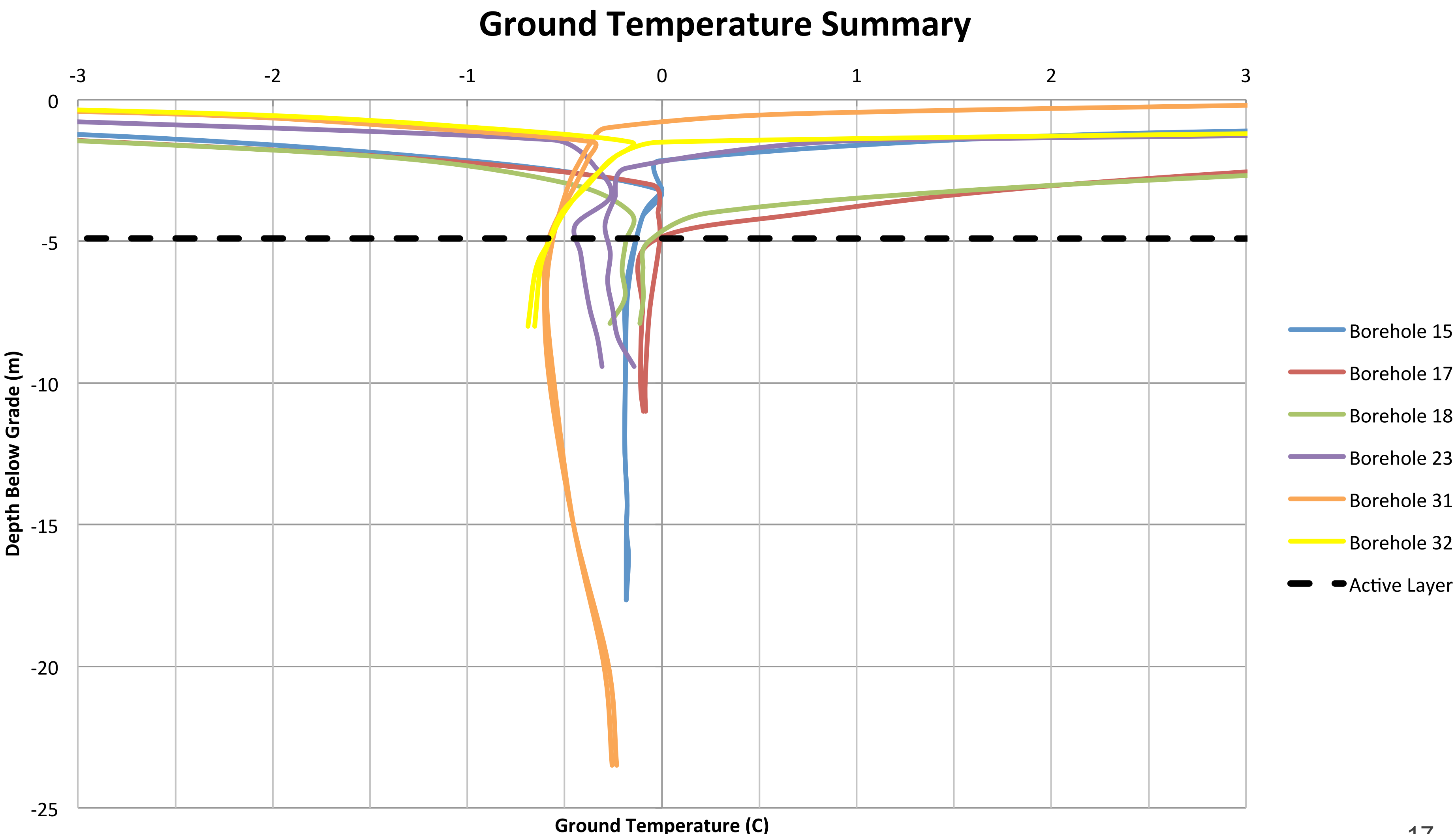
120 Compaction Tests To Date

<u>Notes</u>

Compaction based on maximum dry density for tailings of 2080 kg/m^3 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

ALEXCO

APPENDIX 3.6

KENO HILL IN SITU SYSTEM OPERATIONS AND MAINTENANCE PLAN

KENO HILL SILVER DISTRICT MINING OPERATIONS

KENO HILL IN SITU SYSTEM OPERATIONS AND MAINTENANCE PLAN

October 2020

Prepared for:

ALEXCO KENO HILL MINING CORP.

Prepared by:

TABLE OF CONTENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

AKHM	Alexco Keno Hill Mining Corp.
BDOP	Bioreactor Design and Operation Plan
DOC	Dissolved Organic Carbon
EQS	Effluent Quality Standard
HRT	Hydraulic Retention Time
OMP	Operations and Maintenance Plan
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
SDS	Safety Data Sheets
TSS	Total Suspended Solids
WTP	Water Treatment Plant

1. INTRODUCTION

1.1 PURPOSE

Alexco Keno Hill Mining Corp. (AKHM) will be operating a semi-passive water treatment system at the Bellekeno Mine after completion of mining. This document has been prepared to fulfill the requirements of Clause 63.(a) of Water Licence QZ18-044 relating to this treatment circuit as follows:

63. The Licensee must submit to the Board and implement an updated Operating and Maintenance Plan (OMP) for the Keno Hill Silver District:

    a) within 90 days of the effective date of this Licence to reflect the operating conditions of this Licence;

    b) 90 days prior to mine pool treatment commencing at the Bellekeno Mine; and

    c) provide any subsequent updates as part of the annual report.

The Reasons for Decision document that supports this Water Licence provides more explanation of the specific requirement of this Clause; this OMP update is specific to the proposed post-closure *in situ* semi passive water treatment for the underground mine water.

The treatment system will be implemented upon completion of mining as documented in the site Reclamation and Closure Plan. Based on the current mine plan, mining would be completed in Q1 of 2020. The estimated time to retreat from the mine workings and for the mine to completely flood following mining is at minimum 6 months, or Q4 of 2021. Subclauses (b) and (c) would be triggered at that time.

1.2 SCOPE OF THIS DOCUMENT

This OMP will provide the necessary information for the operation, maintenance and trouble-shooting of the systems to ensure they operate to design standards and criteria. It is important that all operators, technicians, and maintenance personnel understand and follow the guidelines and procedures described in this OMP. A copy of this plan, as well as any applicable supplements, shall always be maintained on site and available for review once the treatment system is in operation.

The OMP will also include the necessary safety procedures and emergency action plans required, as part of the operations and monitoring activities. The treatment plant system will be operated and monitored in compliance with the Yukon's Occupational Health and Safety regulations. Environmental monitoring and surveillance are addressed in a separate document.

2. LOCATION AND DESCRIPTION

The Bellekeno mine area is located approximately 3 km east of Keno City within the Keno Hill Silver District. The water management and treatment ponds for the Bellekeno Mine are shown in Photo 2-1. 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.

Photo 2-1: Bellekeno 625 WTP Area Overview

3. PROCESS DESCRIPTION

3.1 TREATMENT PERFORMANCE

The expected performance of the Bellekeno 625 water treatment for operations is specified in Part G, Clause 64 of Water Licence QZ18-044 for station KV-43. During operations, Clause 2 of the Water Licence also limits the effluent discharge rate from the mine to 864 m^3/day, or the equivalent of continuous discharge at 10 L/s. The semi-passive *in situ* treatment system is currently designed to achieve those Effluent Quality Standard (EQS) values in post closure despite the significantly lower flow rates which are expected once mining ceases.

3.2 PROCESS OVERVIEW

In situ treatment is a water treatment approach with two main objectives; to create anaerobic (oxygen deficient) conditions within the underground mines to limit further oxidation and to reprecipitate the metals within the mine workings by in situ sulphate reduction. This anaerobic process essentially reverses the process that originally created the metals in the mine discharge. These are naturally occurring reactions.

This naturally occurring process is enhanced within the workings by supplying an organic carbon (alcohols, sugars, syrups, starches, or cellulosic materials) into the flooded mine workings. These materials are consumed by naturally occurring microorganisms native to the mining environment, and the anaerobic environment is then created and sustained by these microbial processes. The concentration and type of organic carbon used is selected to control the amount and rate of sulphate reduction, thus ensuring that sufficient sulphate reduction is accomplished to achieve metals precipitation. These biogeochemical reactions occur over a wide range of temperature conditions.

The required residence time to allow for the biogeochemical treatment processes to precipitate metals from the solution to ensure treatment and compliant discharge has been designed from experience with pilot testing on site and laboratory testing. The residence time can be managed by installation of hydraulic bulkheads to retain water underground.

The Bellekeno Mine *in situ* system consists of carbon amendment equipment to periodically inject a dose of dissolved organic carbon (DOC) into the mine workings to facilitate microbe growth and fuel *in situ* treatment. During carbon amendment, circulation water is drawn with a well pump, dosed with glycerol and then distributed to three separate injection locations. A hydraulic bulkhead will be installed at the portal to both limit access to the mine, and, to retain water underground and control the discharge rate. The mine discharge adit is also designed with equipment to control and monitor the adit discharge pressure and monitor effluent pH and turbidity.

3.3 DESIGN BASIS

The design basis for the Bellekeno treatment is discussed in detail in the Reclamation and Closure Plan (AKHM 2019). A summary of the key design parameters for in situ treatment of Bellekeno mine water is presented in Table 3-1. Based on the design flow of 4 L/s 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.

Table 3-1: Bellekeno In Situ Treatment Design Parameters

Design Parameter	Unit	
Mine Inflow	Base Flow: 4 L/s	Max Flow: 6 L/s
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

The Bellekeno mine post closure water treatment system includes two stages of treatment; the primary treatment in the underground workings followed by a contingency for secondary treatment at surface in the existing settling ponds. This approach is currently used at the pilot *in situ* water treatment at the Silver King. In that case, the second stage of "treatment" is for minor pH adjustment and settling of solids prior to discharge. The pilot *in situ* treatment system has worked effectively for several years, and no secondary biological treatment is required to augment or replace the underground *in situ* treatment, as proposed for Bellekeno. This secondary treatment is discussed further in the Bioreactor Design and Operation Plan (BDOP) as required under Clause 55 of the Water Licence.

3.4 PLANT LAYOUT AND EQUIPMENT

3.4.1 UNDERGROUND IN SITU TREATMENT SYSTEM

The following summarizes the main design features of the Bellekeno in situ treatment system. The process flow and instrumentation diagram for the Bellekeno *in situ* treatment system is shown in Figure 3-1 which is extracted from the Reclamation and Closure Plan (Alexco, 2019).

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. 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. The final flooded water elevation is expected to be below any other openings to surface (i.e. Bellekeno East), thus no other bulkheads are required.

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. Existing pipelines for operational mine water management will be utilized and twinned where required for recirculation. The discharge location of the injection pipe is planned to be in the stopes on the 850 level of the Southwest Zone. Water from the 625 level will be collected, amended with the design dose of reagents, and injected in the underground workings, 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.

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.

Programmable Logic Controller (PLC) will be located in the process control and monitoring shed. This system is capable of monitoring inputs from pressure gauges, flow meters, level sensors, and other monitoring equipment. In addition, it 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.

3.4.2 SECONDARY TREATMENT

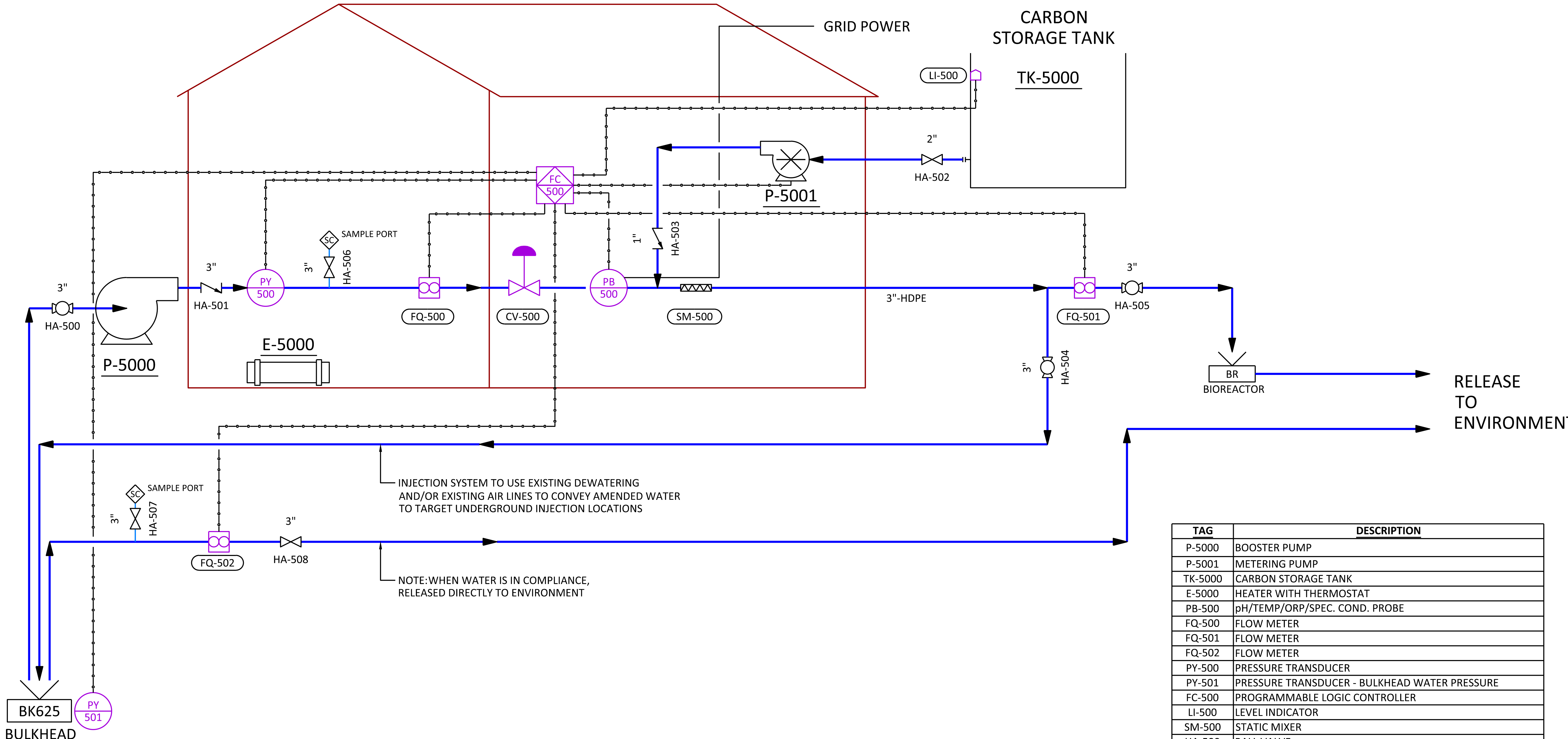
The existing settling ponds at the Bellekeno 625 mine site will be retained at closure and will be converted to use as secondary treatment as a bioreactor. This secondary treatment is discussed further in the BDOP as required under Clause 55 of the Water Licence.

Briefly; the existing conventional water treatment system for addition of lime and flocculant would be retained during the commissioning period (active reclamation) of the underground water treatment process. This is to provide a contingency for final polishing of effluent as steady state conditions are being established in the underground *in situ* treatment system.

Once treatment is established underground and the site moves into post closure, the setting ponds will be converted to a bioreactor treatment system, to allow for a more passive final polishing step. Water quality will be monitored at both the outlet from the underground for assessment of treatment effectiveness, as well as the final point of discharge from the pond.

In the Reclamation and Closure Plan, it was proposed to convert the ponds to bioreactors while the mine is flooding. As part of advancing this design, and the design of other *in situ* treatment systems across the District, it is being considered that it may be prudent to retain conventional water treatment capability while the mine is flooding and the conditions for the biological treatment are being established, perhaps one to two years. Based on experience at Silver King, the amount of reagent that could be required is minimal. There is no material change to operator time (labour) as this would be done as part of routine monitoring and maintenance.

The construction of the bioreactor in one of the ponds can be done while using the other for treatment, followed by the second pond once the underground treatment is operating at steady conditions. The decisions on timing for conversion of the ponds to bioreactors would be based on water flow and water chemistry. The specifics of this change will be documents in the update to the Reclamation and Closure Plan, due by November 27, 2021.



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

Figure 3-1

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

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4. PLANT OPERATION

4.1 IN SITU SYSTEM

The following defines the key process indicators that indicate the system is functioning as designed:

- Adit discharge water is to be sampled weekly and analyzed for DOC, and total and dissolved metals to inform target setting of future carbon amendment campaigns; and
- Molasses will be used as the carbon source for the commissioning stage. The duration of treatment between injections should progressively increase throughout the commissioning stage until it reaches greater than 6 months between injection events and the EQS/load reduction targets for zinc and cadmium are met.

The following parameters will be used to determine the end of the commissioning phase as basis for confirming the treatment system is meeting design specifications:

- The effluent being discharged into the environment meets the commissioning threshold for cadmium and zinc for more than 6-month period between carbon injections. The commissioning threshold is defined as 20% below the EQS/50% load reduction, which is an estimate of the expected future EQS defined in the WUL. At this point the carbon source will be switch from molasses to glycerol; and
- No major electrical, mechanical, instrumentation/process control or civil failures for at least 3 months.

4.2 START-UP PROCEDURE – CARBON AMENDMENT

Prior to starting any carbon amendment procedure, ensure there is adequate inventory of carbon source available in the tank. If not, perform makeup procedures as required as outlined in Section 4.5.1.

Startup of the carbon amendment system is performed as follows:

1. Inspect and ensure all valves on the circulation line are open allowing an unobstructed flow path of water to the injection locations;
2. Start the circulation pump from its variable frequency drive and set the flow rate to the circulation target;
3. Throttle the hand valves as required to balance flow between them. Verify the flow rates in each line with a portable doppler flow meter as required;
4. Ensure carbon pump isolation valves are open to allow carbon input into the circulation line; and
5. Start the carbon pump from its variable frequency drive and set the injection flow rate to the carbon input target. Verify the carbon flow with a graduated cylinder and stopwatch timer.

4.3 SHUTDOWN PROCEDURE – CARBON AMENDMENT

Shutdown of the carbon amendment system is performed as follows:

1. Stop the carbon pump from its variable frequency drive. Shut isolation valves;

2. If the shutdown is going to for an extended period (for the season), disconnect the suction and discharge lines of the carbon pump and run it for a short period to ensure all fluid is drained from the pump and lines. Direct these small flows into a bucket to avoid a mess on the floor;

3. Stop the circulation well pump from its variable frequency drive; and

4. If the shutdown is going to last for an extended period or may persist through freezing outside temperatures, drain all water from the circulation line by first opening vent line valves and drain valves to drain water from the well injection lines.

4.4 ROUTINE CHECKS AND SAMPLES

In future revisions of this document, a detailed table will be prepared of the required checks and frequency for operation of the in situ treatment systems. In addition to standard system operations, the key parameter is the adit discharge water chemistry, to be analysed both at the onsite laboratory on at least a weekly basis, with monthly samples at an accredited analysis laboratory.

4.4.1 MAINTENANCE INJECTIONS

Total and dissolved cadmium and zinc concentrations in the effluent water should be plotted as a function of time to monitor changes in response to carbon addition. These should also be compared with plots of adit discharge to evaluate the effects of seasonal changes in flow on cadmium and zinc concentrations. For purposes of design, the following events were evaluated as triggers for a regular maintenance injection of glycerol:

- Total cadmium or zinc concentrations equal to or greater than 80% of the EQS; or
- Increasing trend (accounting for any documented seasonality) is evident in the total cadmium or zinc concentration data that indicates the 50% load reduction target or EQS will be exceeded within 3 months; or
- The seasonal behaviour of total cadmium and zinc concentrations in the adit discharge indicates that exceedance of the 50% load reduction target or EQS may be reasonably expected during the next seasonal high flow event (e.g., spring freshet) that is due within the next 3 months.

4.4.2 UPSET CONDITIONS

The following examples constitute upset conditions that may be encountered during routine operations:

1. Sharp increase in adit discharge that is equal to or greater than the 95th percentile adit discharge rate;

2. Insufficient flow from for reagent injection e.g., pipeline blockage due to frozen water or precipitate scaling;

3. Total cadmium or zinc concentrations increase sharply to greater than or equal to the EQS; and

4. Total suspended solids (TSS) exceeds the EQS of 25 mg/L (e.g., during high flow periods such as spring freshet which lower the HRT in the ponds for settling to occur).

Responses to the above conditions will be detailed as part of the next revision of the OMP, closer to implementation. Responses would include:

1. Although there should still be adequate HRT to maintain treatment at higher flow, the following precautionary measures should be undertaken:
    a. Collect a sample of the adit discharge water and submit to site lab for total zinc analysis.
    b. Prepare for maintenance carbon injection between May and October or possible batch alkali addition in settling pond. If high flow conditions persist, consider implementation of surface reclamation to divert significant inflows to mine workings.
2. Inspect injection pipeline and steam flush/de-scale if needed;
3. Implement short-term batch addition of lime to the settling pond(s) to treat water and perform a maintenance carbon injection;
4. Implement short-term batch addition of lime to the settling pond(s) to raise pH above 6.5 until high flows abate; and
5. Implement short-term batch addition of flocculant to lower TSS within settling pond.

4.5 CHEMICAL REAGENT PROCEDURES

4.5.1 IN SITU CARBON TANK MAKEUP

Makeup of carbon amendment reagent is similar across all three *in situ* installations. The general procedure is outlines as follows:

For molasses makeup:

1. Molasses is highly viscous and needs to be diluted 1:1 with water. Water should always be added to the storage tank first. Determine the tank level that needs to be made up and divide by two to determine the water level addition required;
2. Connect the water delivery truck discharge line to the tank offloading line. Pump water into the tank to add the target level to the tank;
3. Connect the molasses delivery truck discharge line to the offloading line. Pump molasses into the tank to add the target level to the tank; and
4. Reconnect the water delivery truck discharge line to the offloading line and flush the line with water as required to clear residual molasses.

For glycerol makeup:

1. Glycerol is a viscous fluid which freezes at approximately 18°C in its pure form. It requires dilution to improve its flowing properties and lower its freezing point (approximately -45°C). Water should always be added to the storage tank first;

2. Connect the water delivery truck discharge line to the tank offloading line. Pump water into the tank to add the target level to the tank;

3. Connect the glycerol delivery truck discharge line to the offloading line. Pump glycerol into the tank to add the target level to the tank; and

4. Reconnect the water delivery truck discharge line to the offloading line and flush the line with water as required to clear residual glycerol.

4.5.2 SECONDARY TREATMENT LIME TANK MAKEUP

During active reclamation, makeup of lime for secondary treatment is performed as follows:

1. Connect the lime slurry truck to the tank offloading line and begin pumping lime into the tank;

2. If the lime tank is being filled from empty, do not start the agitator until the level in the tank reaches at least 50%. Damage to the agitator drive hub can occur if it is run without adequate level in the tank; and

3. Flush the offloading line with water to remove any potential for line plugging.

4.5.3 SECONDARY TREATMENT POLYMER TANK MAKEUP

During active reclamation, makeup of polymer for secondary treatment is performed as follows:

1. If the polymer tank is being filled from empty, do not start the agitator until the level in the tank reaches at least 50%. Damage to the agitator drive hub can occur if it is run without adequate level in the tank. Otherwise start the agitator, 102-AG-406;

2. Add water to the tank by opening HV-403 and throttling HV-401 to provide backpressure. Fill the tank to the target level as per the plant target sheet;

3. Add concentrated polymer to the tank by turning on the polymer tote pump 102-PP-407. Run the pump for the duration specified in the plant target sheet; and

4. Allow the polymer to mix for one hour before shutting down the agitator, 102-AG-406.

5. ROUTINE PLANT MAINTENANCE

Continued reliability of the *in situ* and secondary treatment systems requires routine maintenance of the process equipment and instrumentation. Operating and maintenance plans for all installed equipment and instrumentation will be appended to a future revision of this plan closer to implementation. Maintenance and calibration of equipment should be performed as per instructions and frequency prescribed in these manual.

6. PLANT SAFETY AND EMERGENCY PREPAREDNESS

6.1 PERSONAL PROTECTIVE EQUIPMENT

Refer to the Emergency Response Plan for details on the emergency contact list. Contact the water treatment superintendent for immediate assistance.

Personal protective equipment (PPE) will always be used within the Water Treatment Plant (WTP). Standard PPE to be worn at all times when working in *in situ* treatment buildings:

- Hardhat;
- CSA approved safety footwear;
- Safety glasses;
- Long sleeve shirt and pants;
- High visibility vest; and
- Ear plugs (where designated with signage).

There are additional PPE requirements for working with and handling the various chemicals used, outlined in Section 6.2 below.

6.2 CHEMICAL SAFETY

This section outlines general safety precautions, PPE, and spill response to be used when working with the various plant chemicals that are currently specified. A comprehensive summary of chemical safety, toxicological information and handling guidelines can be found on the Safety Data Sheets (SDS) in Appendix 1 (for future revision of this document). Should the chemical change the safety procedures will be revised accordingly

The locations of eyewash bottles in the various *in situ* and secondary treatment areas are denoted on general arrangement drawings attached in Appendix 2 (for future revision of this document). Ensure the eyewash bottle is in the designated location before any chemical handling occurs. Inspect the eyewash bottle on a monthly basis for expiry.

6.2.1 HYDRATED LIME

Hydrated lime (calcium hydroxide) is an insoluble white powder and a strong base when combined with water. Lime is a respiratory and skin/eye irritant. In addition to the standard PPE, the following additional PPE should be worn when handling hydrated lime:

- Nitrile or otherwise chemical resistant gloves;
- Respirator with purple dust cartridges installed (if contact with airborne dry lime powder is expected);
- Face shield (if risk of chemical splash is present); and
- Chemical resistant footwear (if risk of walking through pooled slurry is present).

In the event of a spill of hydrated lime, collect slurry in a contained area and transfer to an appropriate container for reuse or disposal.

6.2.2 DREWFLOC 2499 OR EQUIVALENT

Drewfloc 2499 is a soluble emulsion polymer and is an eye irritant. In addition to the standard plant PPE, the following additional PPE should be worn when handling polymer solution:

- Nitrile or otherwise chemical resistant gloves; and
- Face shield (if risk of chemical splash is present).

Polymer spills can be very slippery, so it is advised to wear slip resistant footwear if risk of walking through floor where polymer may be present or have spilled. In the event of a spill of polymer, cover the spill in absorbent material to absorb all moisture and then clean up with a shovel.

6.2.3 GLYCEROL

Glycerol is a colourless, odourless, viscous liquid. Glycerol is a slight skin and eye irritant. In addition to the standard PPE, the following additional PPE should be worn when handling glycerol solution:

- Nitrile or otherwise chemical resistant gloves.

In the event of a glycerol spill use absorbent material to contain the spill and then collect in an appropriate container for disposal or reuse. Small amounts can be diluted with water to rinse clean.

6.2.4 MOLASSES

Molasses is a dark coloured, viscous sweet-smelling liquid. Molasses is a slight skin and eye irritant. In addition to the standard PPE, the following additional PPE should be worn when handling molasses solution:

- Nitrile or otherwise chemical resistant gloves.

In the event of a molasses spill use absorbent material to contain the spill and then collect in an appropriate container for disposal or reuse. Small amounts can be diluted with water to rinse clean.

6.3 FIRE

The locations of fire extinguishers within the various *in situ* and secondary treatment areas are shown in general arrangement drawings attached in Appendix 2. In the event of a fire, workers may extinguish the fire if they are trained on using fire extinguishers and the fire is small (generally no larger than a small waste-paper basket). If the fire is too big to extinguish, all workers will evacuate the building.

In the event of fire, site security should be contacted immediately to communicate with emergency dispatch.

6.4 WINTER CONDITIONS

Winter conditions including snow and ice accumulation will be present around the *in situ* and secondary treatment buildings several months of the year. Weather appropriate clothing and slip resistance footwear should always be worn when working outside. Snow and ice accumulation from doorways should be cleared within 24 hours.

7. REFERENCES

Alexco Keno Hill Mining Corp. (AKHM), 2019. *Reclamation and Closure Plan Keno District Mine Operations Keno Hill Silver District, Rev 5.1*.

APPENDIX A.
SDS Sheets

For future revision of this document

APPENDIX B.
Drawings

For future revision of this document

APPENDIX C.
Process Control Narrative

For future revision of this document

APPENDIX 3.7

BIOREACTOR DESIGN AND OPERATION PLAN

KENO HILL SILVER DISTRICT MINING OPERATIONS

BIOREACTOR DESIGN AND OPERATION PLAN

October 2020

Prepared for:

ALEXCO KENO HILL MINING CORP.

Prepared by:

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 PURPOSE OF THE PLAN

Alexco Keno Hill Mining Corp. (AKHM) will be operating a semi-passive water treatment system at the Bellekeno Mine after completion of mining. This document has been prepared to fulfill the requirements of Clause 55 of Water Licence QZ18-044 relating to the secondary treatment as follows:

> 55. Within 90 days of the effective date of this Licence, the Licensee must submit to the Board and implement an updated Bioreactor Design and Operation Plan (BDOP) which addresses the proposed Bellekeno and Flame and Moth bioreactors.

1.2 SCOPE OF THIS DOCUMENT

This document provides the preliminary design for the Bellekeno bioreactor, and the plan for detailed design, commissioning, and operations.

The Flame & Moth bioreactor is discussed conceptually. Drawings of the two ponds which would be used as the bioreactor are provided and discussed. At this time, there is no flow of water from the mine or mill site that would require bioreactor. Therefore, it is not possible to size and design a bioreactor treatment system at this time.

2. LOCATION AND DESCRIPTION

2.1 BELLEKENO

The Bellekeno mine area is located approximately 3 km east of Keno City within the Keno Hill Silver District. The water management and treatment ponds for the Bellekeno Mine are shown in Photo 2-1. 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.

Photo 2-1: Bellekeno 625 WTP Area Overview

2.2 FLAME & MOTH

The Flame & Moth mine area is located adjacent to the District Mill. Water treatment for Flame & Moth is done in the mill facility. There are two ponds at the Mill: one for mill process water (bottom, centre of photo), and the second for the water treatment circuit effluent which is called the Flame & Moth pond (above and left on photo). The District Mill, the Flame & Moth portal, and the ponds are shown in Photo 2-2.

Photo 2-2: Flame & Moth and District Mill Area Overview

3. PREVIOUS STUDIES

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 were included as Appendix 1.3 of the site Reclamation and Closure Plan (AKHM, 2019). That information supports this approach in closure of the Bellekeno mine and the design.

The treatment mechanism in the bioreactor is essentially the same as in the mine workings (the *in situ* treatment). The primary mechanism is reductive precipitation under anaerobic conditions. In addition, in the proposed bioreactor ponds, there can be some (seasonal) treatment of parameters such as ammonia by oxidation. Longer term studies in larger ponds and open pits following closure have shown that there are additional treatment mechanisms that can be effective at the surface of the bioreactor, such as sorption and chelation reactions with biological material. At this time, the biologically driven processes under anaerobic conditions such as sulphate reduction are the only mechanisms relied upon for metal removal in these bioreactors. These bioreactors are simply polishing processes and contingency measures.

4. PROCESS DESCRIPTION

4.1 BELLEKENO

4.1.1 DESIGN BASIS

The proposed bioreactor treatment is a final polishing step for the treated mine water from the Bellekeno underground mine workings, post closure. 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 compliant 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.

However, as discussed in the Operations and Maintenance Plan for the Bellekeno In Situ Treatment System (AKHM 2020a), the existing conventional water treatment system for addition of lime and flocculant would be retained during the commissioning period (active reclamation) of the underground water treatment process. This is to provide a contingency for final polishing of effluent as steady state conditions are being established in the underground *in situ* treatment system. Once treatment is established underground and the site moves into post closure, the settling ponds will be converted to a bioreactor treatment system to allow for a more passive final polishing step.

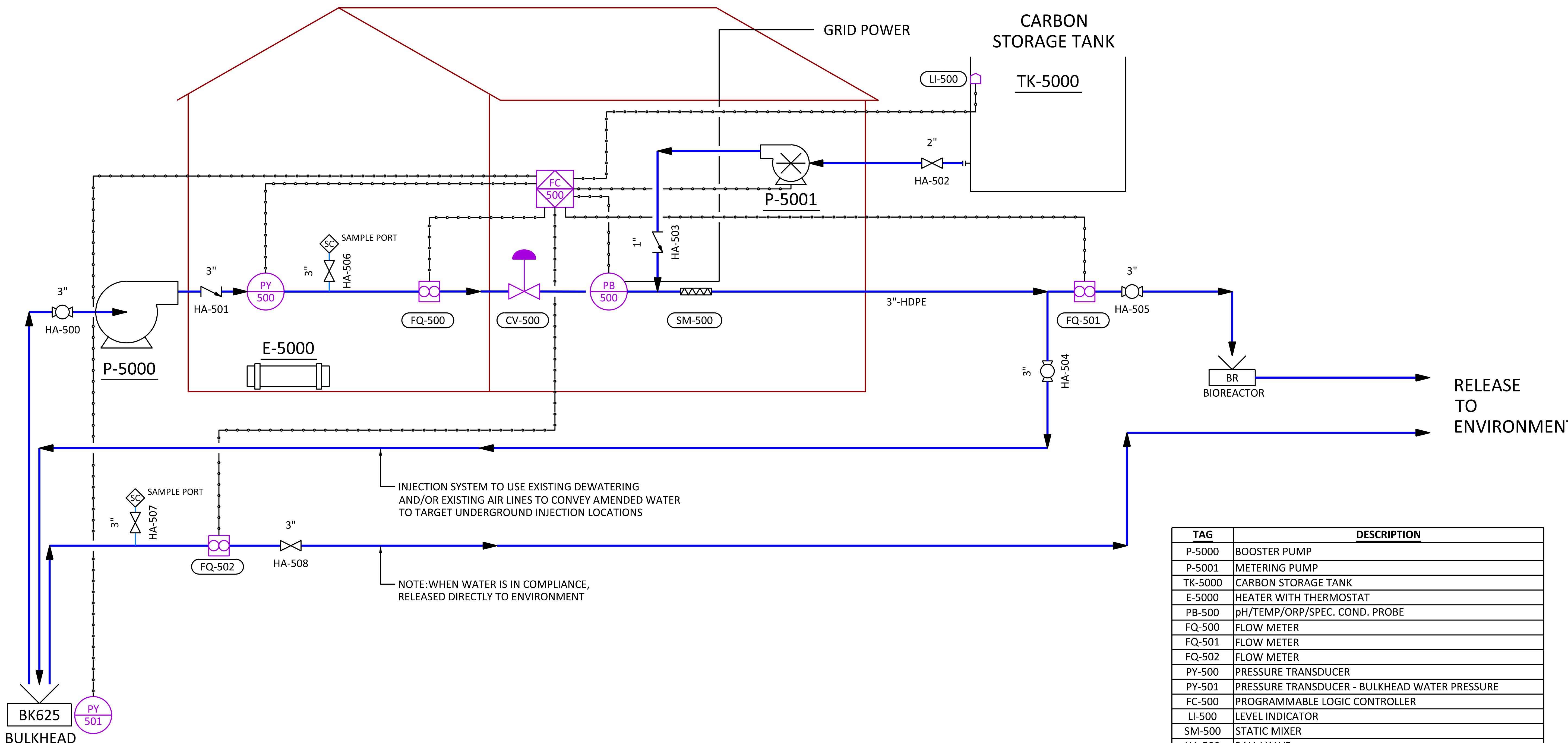
Water quality will be monitored at both the outlet from the underground for assessment of treatment effectiveness, as well as the final point of discharge from the pond.

4.1.2 PRELIMINARY DESIGN

The Bellekeno post closure water treatment system is shown in Figure 4-1. The bioreactor is also shown on this figure. The next two drawings show specifics of the bioreactor, Figure 4-2 and Figure 4-3. These figures are extracted from the current Alexco Reclamation and Closure Plan (AKHM, 2019).

The bioreactor construction is a relatively simple process, since the existing ponds will be used. The construction of the adit plug and piping is included in the design of the underground mine water *in situ* system and not repeated herein. The steps for bioreactor construction include:

1. Complete detailed water chemistry analyses of the underground water chemistry and reagent requirements to determine the schedule for conversion of ponds to bioreactors. Confirm transition plan for managing water quality in the interim;
2. Remove (vacuum truck) remaining sludge in Bellekeno lined ponds;
3. Install piping distribution system in bottom of ponds;
4. Fill ponds with clean gravel sourced from adjacent placer mine. Install geotextile barrier over surface of gravel;
5. Place 2 meter soil cover over top of geotextile;
6. Complete tie-ins with the existing water management piping and instrumentation; and
7. Use underground mine water to flow through bioreactor, and commission.



TAG	DESCRIPTION
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E-5000	HEATER WITH THERMOSTAT
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HA-505	BALL VALVE
HA-506	GATE VALVE
HA-507	GATE VALVE
HA-508	GATE VALVE
CV-500	THROTTLING VALVE

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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

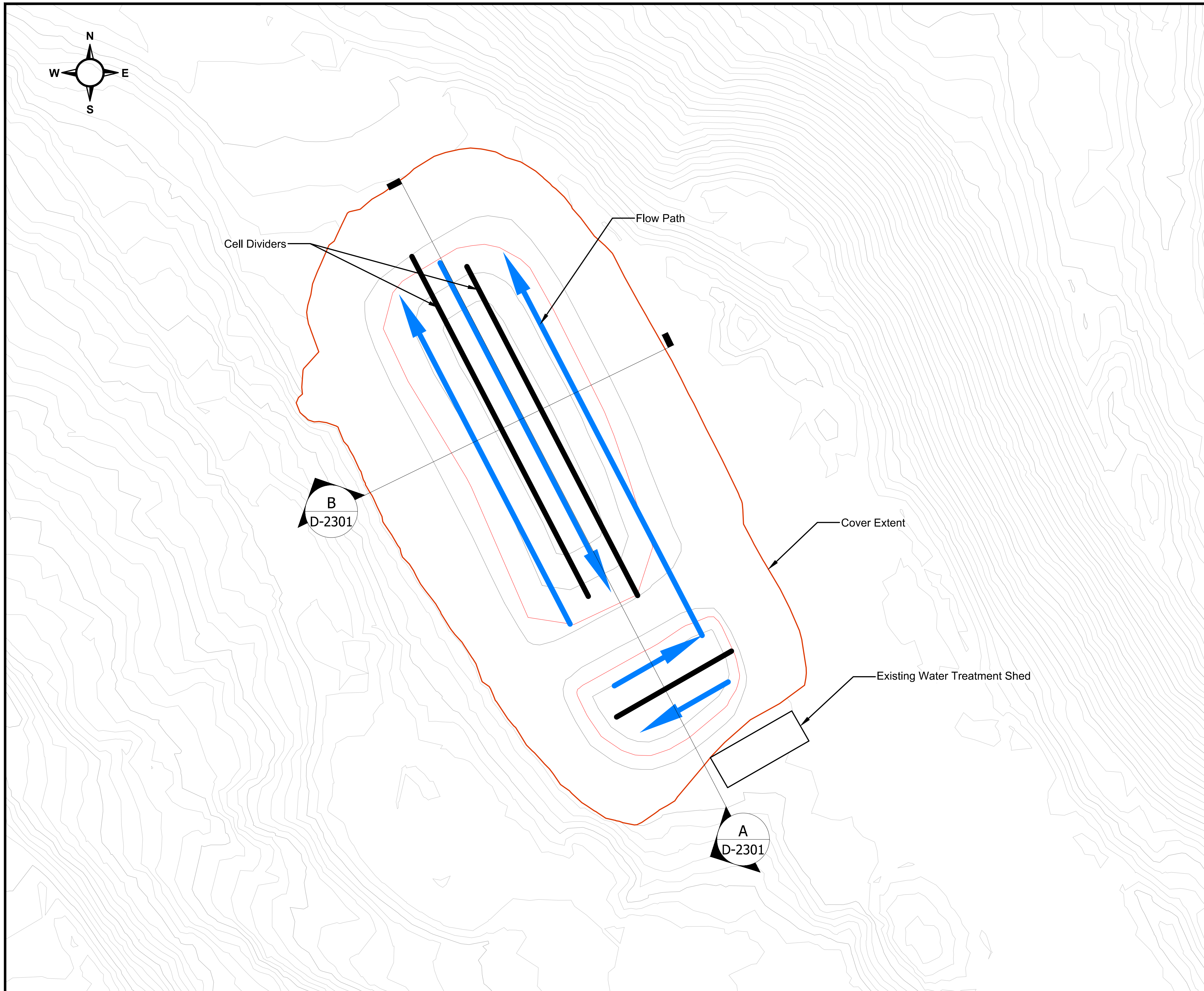
Keno District Mine Operations
Reclamation and Closure Plan
Drawing No.: AKHM-13-01-D2601

Bellekeno Closure Treatment System

Piping & Instrumentation Diagram

Figure 4-1

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



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

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

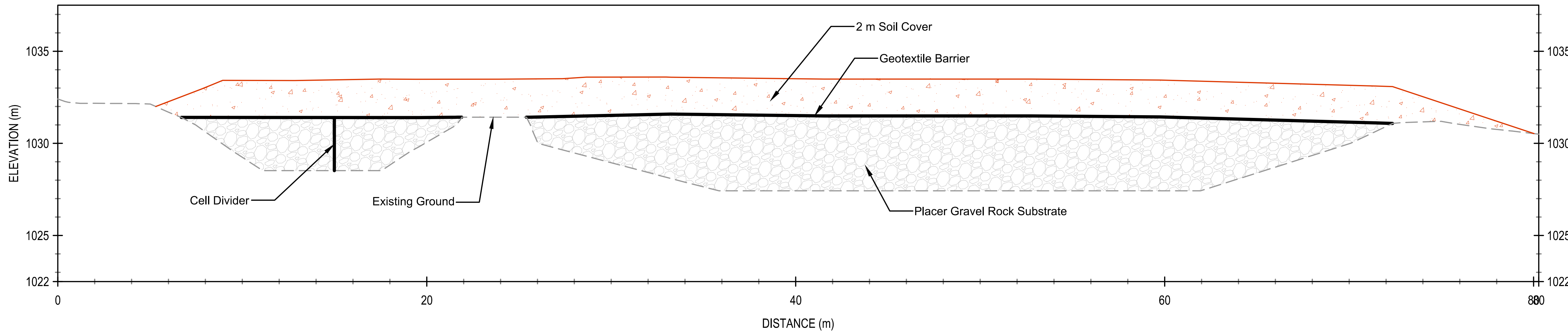
Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-D-2102

Figure 4-2

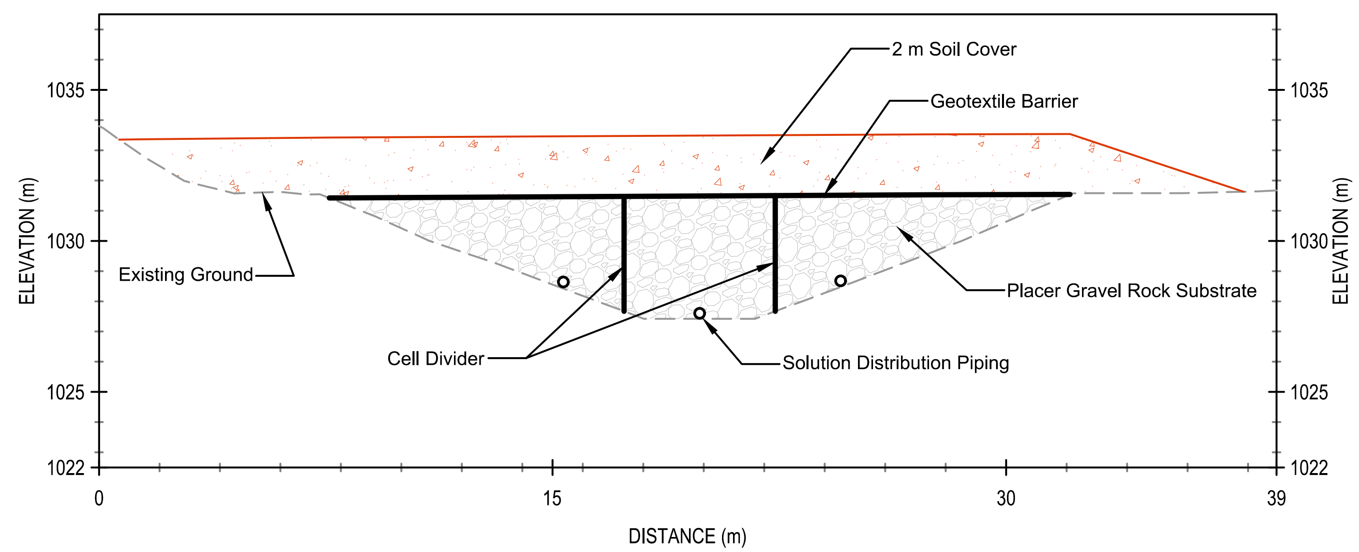
Bellekeno 625
Bioreactor Design

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; 2018/02/15 - 2:17 PM



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 4-3

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; 2018/02/15 - 2:17 PM

4.1.3 DETAILED DESIGN AND SCHEDULE

While the design of the bioreactor is relatively simple, a detailed equipment list, cost and construction plan will be completed as part of the mine projects planning process for 2021. As noted in other documents, it is anticipated that the existing ponds may be retained as conventional water treatment facilities for up to two years following cessation of mining. The anticipated program is as follows:

- Once safe access to the Bellekeno underground is established and mine dewatering advances, sample underground water chemistry;
- Update calculations of time to flooding, hydraulic residence time, and underground mine water quality;
- Using experience from elsewhere on site (Silver King), estimate the range of water chemistry and time period to reach "steady state" of the underground *in situ* biological treatment (equivalent to the commissioning period for the underground treatment system);
- From those data, assess requirements for secondary treatment during active reclamation. This would include:
    - Requirements for conventional lime/flocculant treatment; and
    - Residence time required in ponds and therefore schedule to convert ponds to bioreactors.
- Revise design of bioreactor and plan schedule for construction, to provide residence time to treat effluent water and achieve compliance for discharge;
- Update Reclamation and Closure Plan;
- Update design report and submit to Yukon Water Board; and
- Construct and commission.

4.1.4 PLANT COMMISSIONING AND OPERATION

The following procedures are described for the operation of the bioreactors. This is based on the current assumption under the Water Licence that no conventional water treatment is required during active reclamation or post closure. This would be amended as required as a result of the detailed design that will be completed during mining at Bellekeno (anticipated for Q4 2020 and Q1 2021).

4.1.4.1 *Commissioning*

Water from the flooded underground would be piped to the settling ponds currently in place at 625 for commissioning and optimization of the bioreactor. Flow would be controlled to prevent disturbance of the soil layer. Once the flooded underground 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.

4.1.4.2 *Reagent Makeup and Addition*

Reagents are required for the commissioning of this system to provide a carbon source to develop the biomass. Periodic reagent addition may be required for ongoing operation of the bioreactor. However, the specific reagent addition requirements will depend on the required biomass which, in turn, is based on the influent water chemistry. This will be defined as noted above in Section 3.1.3.

The reagent makeup and handling systems will be the same systems used for the *in situ* treatment underground. The carbon sources that can be used are molasses or an alcohol such as ethanol or glycerol.

4.1.4.3 *Start-Up Procedures*

There are no start-up procedures required for this passive treatment system, in the traditional sense of plant operation "start-up" and "shutdown". Reagents will be added periodically to provide nutrition for development of the biomass.

Water flow to the bioreactors is managed as part of the Bellekeno mine water management and treatment systems and controls (AKHM 2020a).

4.1.4.4 *Shutdown Procedures*

There are no shutdown procedures required for this passive treatment system, in the traditional sense of active water treatment plants.

Water flow from the bioreactors will be managed to maintain design freeboard requirements. The piping and discharge systems between and from the ponds will be designed to allow control of non-compliant discharge. However, this is a polishing system and not primary treatment. The primary control is managing discharge from the underground mine at the Bellekeno 625 adit (AKHM 2020).

4.1.4.5 *Monitoring and Inspections*

Water chemistry will be monitored within the ponds and at the influent and effluent points, during the initial period of operation to confirm effective performance. The permitted effluent point at the outlet from the final pond will be monitored as prescribed for active reclamation and closure. The mine water chemistry (which is the pond influent) will be monitored in parallel with the effluent monitoring. Samples will be collected both for analysis on site (general parameters and zinc total and dissolved), as well as for analysis at external laboratories as described in the AKHM Monitoring, Surveillance and Reporting Plan (AKHM 2020b).

Monitoring for physical stability would continue to be done as part of the AKHM site inspection procedures. The ponds would continue to be included in the AKHM annual inspections by a qualified third party.

4.1.4.6 *Maintenance*

Maintenance of these facilities will be included in the operations and maintenance plans for the Bellekeno site, as documented in part in the Bellekeno In Situ OMP (AKHM 2020a).

4.2 FLAME & MOTH

4.2.1 DESIGN BASIS

The contingency for a bioreactor at the Flame & Moth site is proposed for the potential requirement post-closure to treat either:

- Potential seepage from the dry stack tailings facility (the DSTF); and
- Potential discharge from the Flame & Moth underground mine.

During operations, any seepage from the DSTF is collected in a sump at the toe of the dry stack and piped to the mill pond. The physical system of drainage around the DSTF is specifically designed to identify any seepage and to monitor the flow and quality of that seepage. To date, there has been no seepage from the DSTF identified and only runoff from rain and snow melt conveyed to the Mill pond.

Tailings are filtered to approximately 10% moisture, placed in layers on the dry stack, compacted and then covered with up to 0.5 me of soil and vegetated. The final tailings surface is graded to shed precipitation and revegetated to encourage evapotranspiration. Thus, there is surface runoff from the facility, as intended by design. This, in turn, minimizes infiltration and the potential for seepage in the long-term.

Therefore, treatment after closure of the mine operations is not expected to be required for either based on:

- The DSTF is designed to “shed” water rather than collect water. There has been no seepage draining from the DSTF since it was constructed and commissioned in 2010; and
- The natural groundwater table at the Flame & Moth mine is approximately 20 m below the portal elevation. This has been confirmed by ongoing groundwater level monitoring. In fact, the mine was designed such that the portal would be above the final flooded elevation and there would be no discharge from the mine.

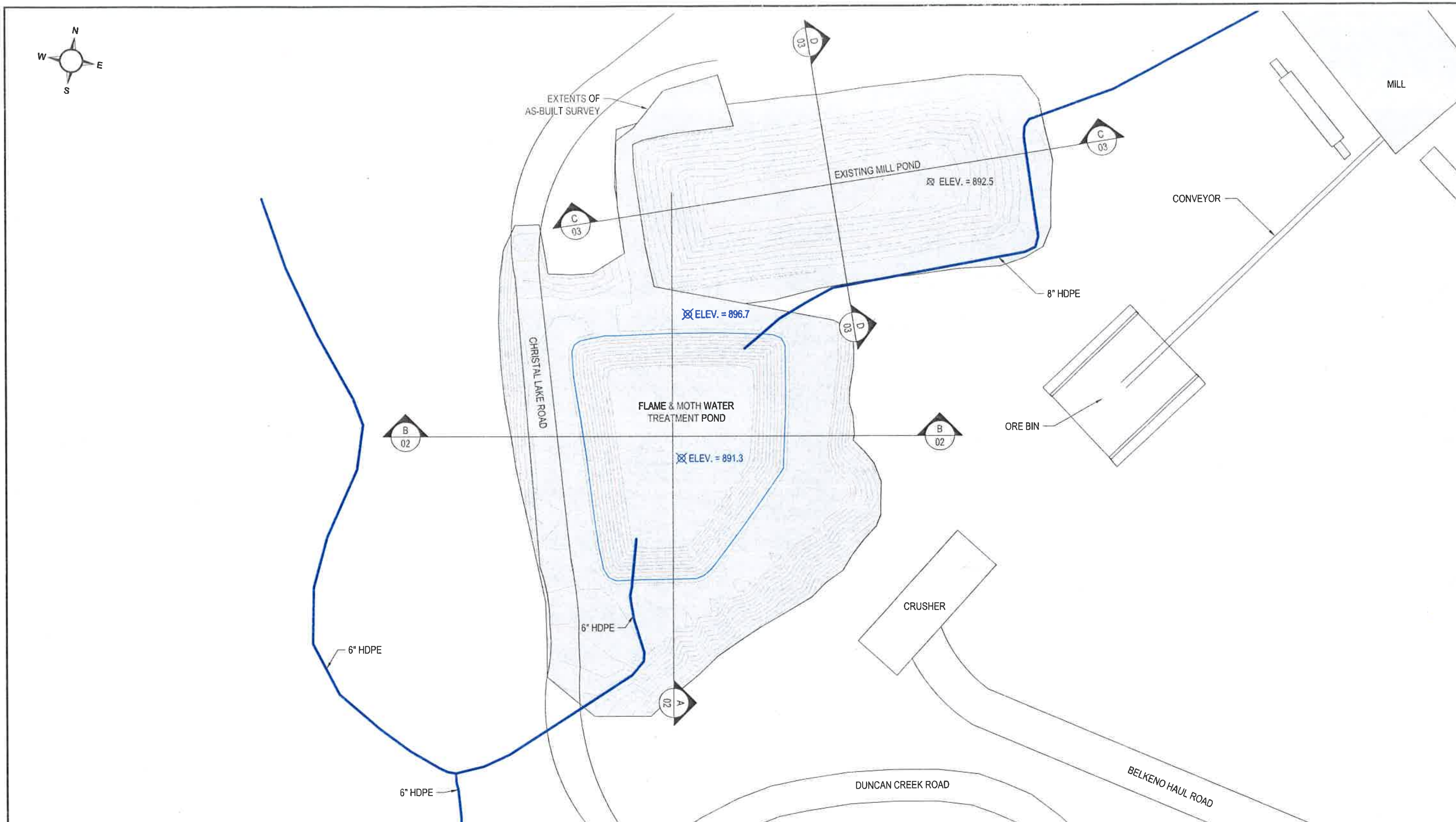
4.2.2 SCHEDULE

There is ongoing water management and water treatment at the mill area during operations, as there was during the temporary closure from 2013 till 2020. The pond levels are also actively managed to provide storage for design events. AKHM is currently resuming production, and will continue to use both of these ponds for active water management during operations.

The planned mine life for AKHM at this time is seven years from start of production (~Q4 2020). Therefore, none of the ponds would be converted to a bioreactor in the near future.

4.2.3 CONCEPTUAL DESIGN

As shown in Photo 2.2, there are two ponds in the area of the Flame & Moth portal. A plan and sections of each of these ponds are provided in Figure 4-4, Figure 4-5 and Figure 4-6.



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

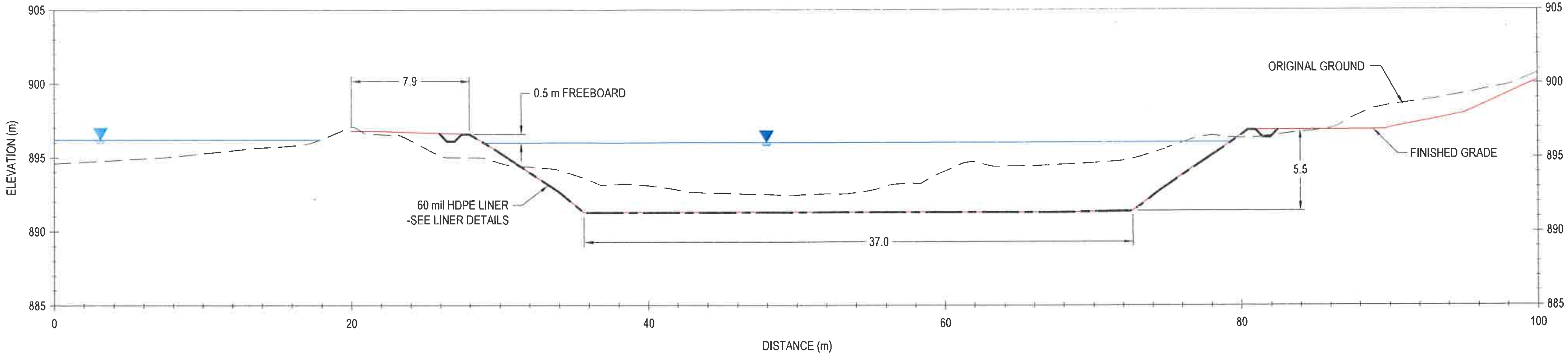
Drawing No: ALEX-13-NMP-02-0C102.01

Figure 4-4

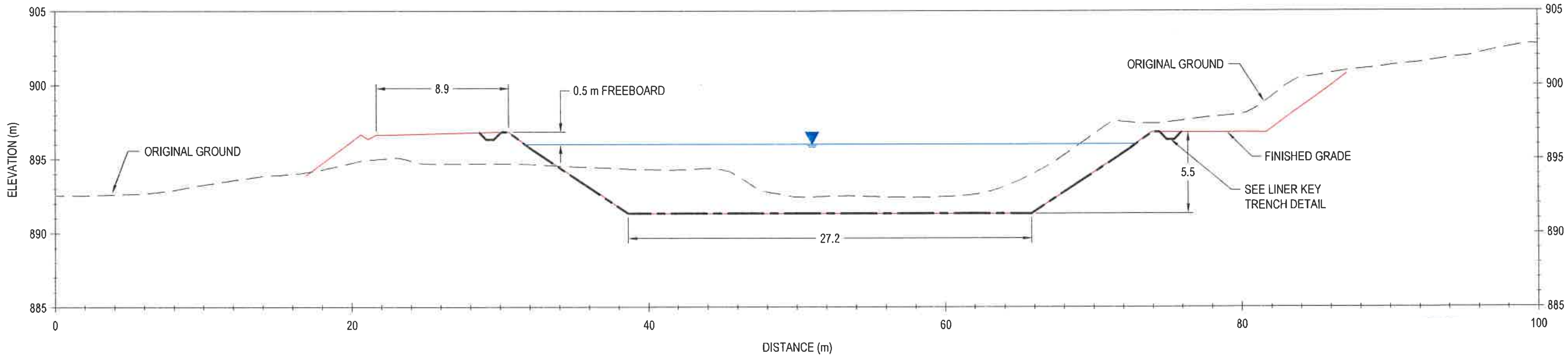
Flame & Moth and Mill Ponds As-Built

Site Plan

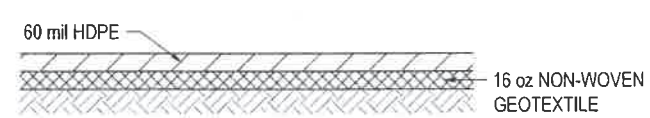
REVISION: 0	2019-04-18	PROJECT No.: ALEX-13-NMP-02
DRAWN BY: KAB	DESIGNED BY: JP (EBA)	REVIEWED BY: NC



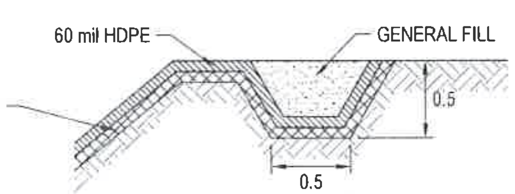
SECTION A - A'



SECTION B - B'



LINER DETAIL



LINER KEY TRENCH DETAIL

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2019-04-18	Stamped	0	KB	NC
2019-04-18	Draft for review	B	KB	KW
2019-04-17	Draft for review	A	KB	KW

0 15m

Scale: 1:300 @ 11"x17"

NOTE: DETAILS NOT TO SCALE
ALL DIMENSIONS IN METERS UNLESS OTHERWISE DENOTED

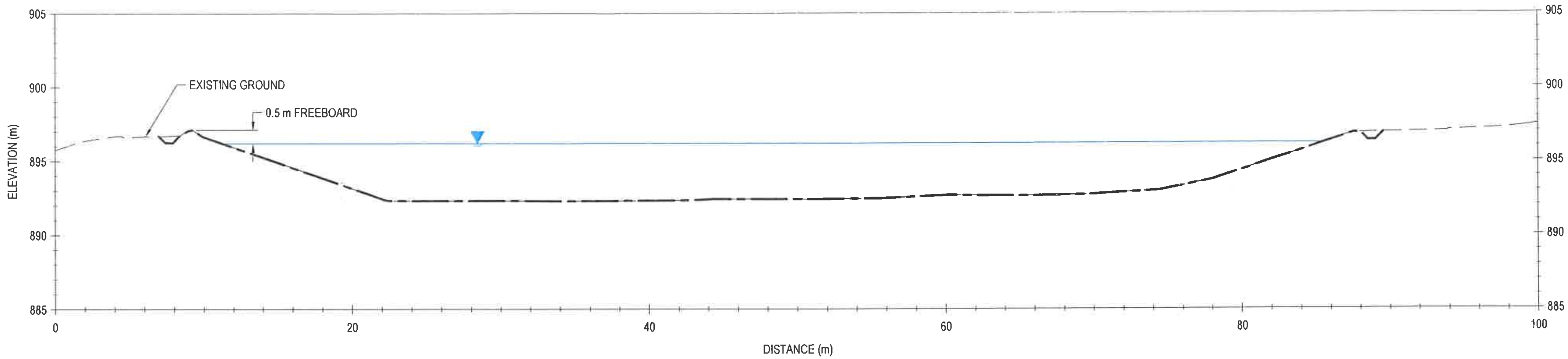
ALEXCO

Flame & Moth
Water Use License
Drawing No: ALEX-13-NMP-02-0C102.02

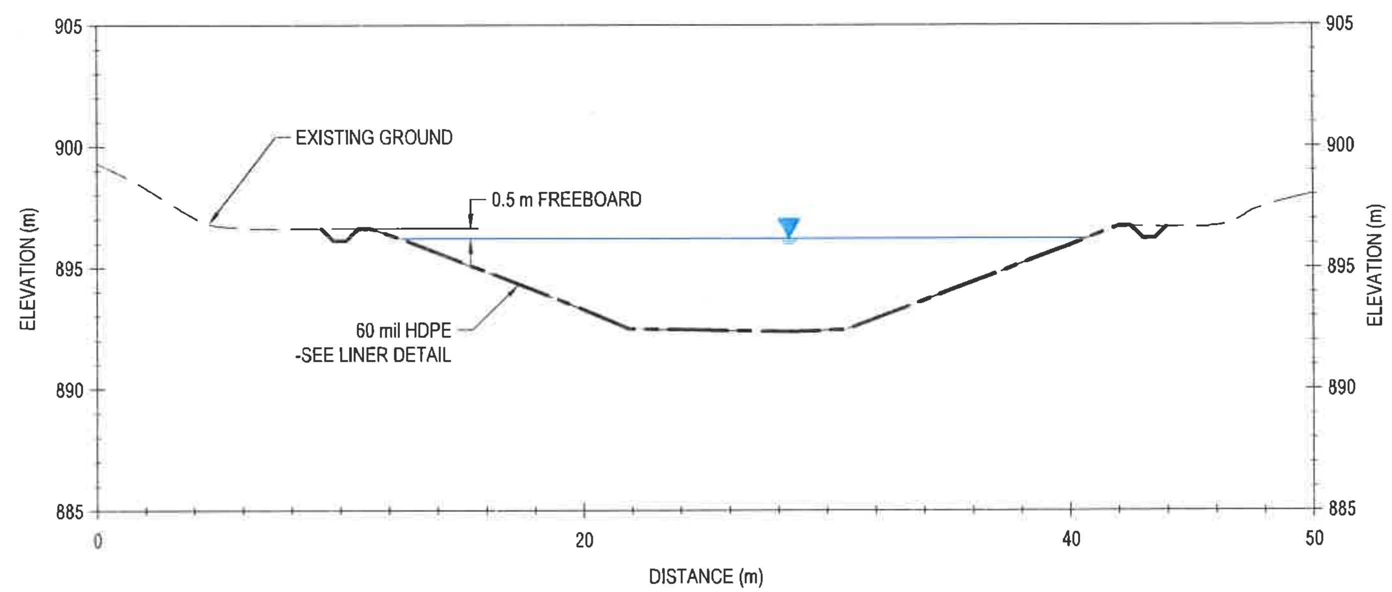
Figure 4-5

Flame & Moth Water Treatment Pond As-Built Cross Sections

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



SECTION C - C'



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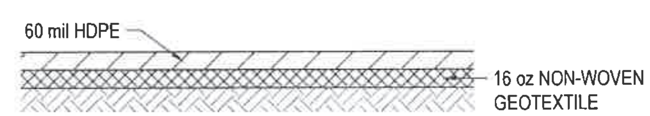

LINER DETAIL

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

0 15m

Scale: 1:300 @ 11"x17"

ALEXCO

Flame & Moth
Water Use License
Drawing No: ALEX-13-NMP-02-0C102.03

Figure 4-6

Mill Pond As-Built
Cross Sections

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

The pond that is proposed to be used as the potential bioreactor is the smaller of the two, the "Mill" pond. The design storage volume of that pond is approximately 5,242 m^3., whereas the whereas the Flame and Moth pond has a storage volume of 6,993 m^3. Clearly both are much larger ponds than would be required for managing seepage from the DSTF. The conceptual design is to reduce the active storage volume by partitioning the pond and/or filling with gravel, to allow flow through the system and prevent stagnation. Input from other operations and designers of such systems is being sought.

4.2.4 DETAILED DESIGN AND SCHEDULE

At this time, there is no requirement for a bioreactor for Flame & Moth. However, it is prudent to regularly test the assumptions and field conditions on which that is based. This can be done with data and studies that are required under other management plans. More specifically, for seepage from the DSTF, the following steps will be done to advance to detailed design of the bioreactor:

- Continue to monitor seepage flow and seepage chemistry from the dry stack;
- Collect the laboratory data on tailings geochemistry (static and kinetic testing) as documented in the Tailings Characterization Plan (AKHM 2020c);
- Annually review these data (the DSTF and the laboratory testing), to assess the potential for the DSTF to generate drainage water chemistry that would not be compliant for discharge in the longer term. This assessment includes consideration of both flow and chemistry. It would be done in conjunction with the physical characterization of tailings and the conditions of the cover, as completed under other studies; and
- At each update of the Reclamation and Closure Plan (RCP), consider the design size of a bioreactor for the "worst reasonable case" and update the RCP accordingly.

5. REFERENCES

Alexco Keno Hill Mining Corp. (AKHM), 2019. *Reclamation and Closure Plan Keno District Mine Operations Keno Hill Silver District, Rev 5.1*.

Alexco Keno Hill Mining Corp. (AKHM), 2020a. *Keno Hill In Situ System Operations and Maintenance Plan October 2020,* prepared by AKHM and Ensero Solutions*.*

Alexco Keno Hill Mining Corp. (AKHM), 2020b. *Keno Hill October 2020 Monitoring, Surveillance and Reporting Plan October 2020,* prepared by AKHM and Ensero Solutions.

Alexco Keno Hill Mining Corp. (AKHM), 2020c. *Keno Hill October 2020 Tailings Characterization Plan October 2020,* prepared by AKHM and Ensero Solutions.