KENO HILL SILVER DISTRICT MINE OPERATIONS

SLUDGE MANAGEMENT PLAN

November 2023

Prepared by:

HECLA YUKON

Prepared for:

Alexco Keno Hill Mining Corp.

VERSION HISTORY

ISSUE DATE	CONCISE DESCRIPTION OF VERSION UPDATES
February 2008	ERDC Keno Hill Water Treatment Systems Sludge Management Plan issued as per requirement of WL QZ06-074 Clause 23 and includes Bellekeno 625, Galkeno 300, Galkeno 900, Silver King and Valley Tailings.
May 2009	ERDC Keno Hill Water Treatment Systems Sludge Management Plan issued as part of AKHM WL QZ09-92 application for Bellekeno Mine Development
February 2011	Initial AKHM Sludge Management Plan based on ERDC plan as per requirement of WL QZ09-092, Part H, Clauses79-80
September 2013	Revisions made as per requirement of WL QZ12-053, Part H, Clauses 84-85
September 2014	Revisions made as per requirement of WL QZ12-053, Part H, Clauses 84-85 to incorporate Flame & Moth Addition details on the water treatment process added, including chemicals used and ammonia treatment
March 2018	Revisions made as per requirement of WL QZ09-092-2, Part G, Clause 93 Updated Flame & Moth Water Management Figure
July 2018	Revisions made as per requirement of WL QZ09-092-2, Part G, Clause 93 to incorporate New Bermingham as part of WL18-044 application
October 2020	Revisions made as per requirement of WL QZ18-044, Part F, Clause 42 to incorporate New Bermingham
June 2022	Format updated to improve ease of use for site operations
November 2023	Updated with removal of tailings being placed into DSTF

NOVEMBER 2023 DOCUMENT REVISIONS

SECTION	SUMMARY OF CHANGES
Entire document	This version of the Sludge Management Plan has been prepared by Alexco Keno Hill Mining Corp (AKHM) to provide guidance to site personnel on roles and responsibilities specific to sludge management.
Version History	Section added to record the complete version history of the AKHM Sludge Management Plan and licence requirements
Document Revisions	Section added to record the revisions as compared to the June 2022 version history for the AKHM Sludge Management Plan
Sludge Management Plan Approach	Section added Roles and Responsibilities of site personnel defined
Background and Previous Studies	Refer to the water treatment facility operations manuals for water treatment chemistry for metal hydroxide precipitation and the treatment for non-metals and ammonia Previous studies on sludge geochemistry relocated and summarized in Sludge Characteristics section
Sludge Disposal	Subsection updated to reflect tailings are not being placed into the DSTF.
Sludge Management at Closure	Details provided in the site Closure and Reclamation Plan summarized

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LIST OF ACRONYMS AND ABBREVIATIONS

ABA	Acid Base Accounting
AKHM	Alexco Keno Hill Mining Corp.
Alexco	Alexco Resource Corp.
DSTF	Dry Stack Tailings Facility
ERDC	Elsa Reclamation and Development Company
FNNND	First Nation of Na-Cho Nyak Dun
KHSD	Keno Hill Silver District
P-AML	Potentially-Acid Metal Leaching
QML	Quartz Mining Licence
TSS	Total Suspended Solids
VTBSSA	Valley Tailings Bellekeno Sludge Storage Area
WL	Water Licence
WTP	Water Treatment Plant

1 INTRODUCTION

1.1 OVERVIEW

This Sludge Management Plan describes how new sludge produced as a by-product of the water treatment plants (WTPs) at the Keno Hill Silver District (KHSD) Mine Operations will be managed. The permits and authorizations in place for mine development, production and mill operation are summarized in Table 1-1. Operational management plans to guide activities and monitoring associated with sludge management are listed in Table 1-2. This plan should be read in conjunction with these documents, permits and licences.

Table 1-1: KHSD Mine Operations Assessment and Regulatory Approvals

Purpose	YESAA Approval	QUARTZ MINING ACT APPROVAL	Water Use Licence
Bellekeno Advanced Exploration	Project #2008-0039 Decision Document	Class 4 Mining Land Use Approval (LQ00476, expires 2028)	Type B Water Licence QZ07- 078/Amendment 1 QZ10-060, licence cancelled in 2015. Replaced by 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 Licence QZ18-044, expires 2037[2]
Onek 990 and Lucky Queen Mine Production	Project#2011-0315 Decision Document	Quartz Mining Licence (QML-0009, Amendment 2, expires 2037)[1]	Use of water and the deposit of waste into water is not authorized
Flame & Moth Mine Production	Project #2013-0161 Decision Document	Quartz Mining Licence (QML-0009, Amendment 2, expires 2037)[1]	Type A Water Licence QZ18-044, expires 2037[2]
Bermingham Mine Production	Project#2017-0176 Decision Document	Quartz Mining Licence (QML-0009, Amendment 2, expires 2037)[1]	Type A Water Licence QZ18-044 issued, Expires 2037[2]

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/

Table 1-2: Related Operational Management Plans

QML-009 PLANS	WL QZ18-044 PLANS
• Adaptive Management Plan[1] • Dry Stack Tailings Facility Construction and Operation Plan[1] • Hazardous Materials Management Plan • Mine Development and Operating Plan • Spill Contingency Plan • Waste Management Plan	• Bioreactor Design and Operation Plan • Environmental Monitoring, Surveillance and Reporting Plan[1] • Groundwater Monitoring Plan • Reclamation and Closure Plan[1] • Water Management Plan • Water Treatment Systems Operating Manuals

Note: 1. Plan required under both the QML and WL

1.2 SITE DESCRIPTION

Alexco Keno Hill Mining Corp. (AKHM), a wholly owned subsidiary of Alexco Resource Corp. (Alexco), owns and operates the KHSD Mine Operations in the central Yukon. The site is 354 km north of Whitehorse, in the vicinity of Keno City. The KHSD Mine Operations comprise a series of small underground mines with a centralized mill as presented in Table 1-3 and Figure 1-1.

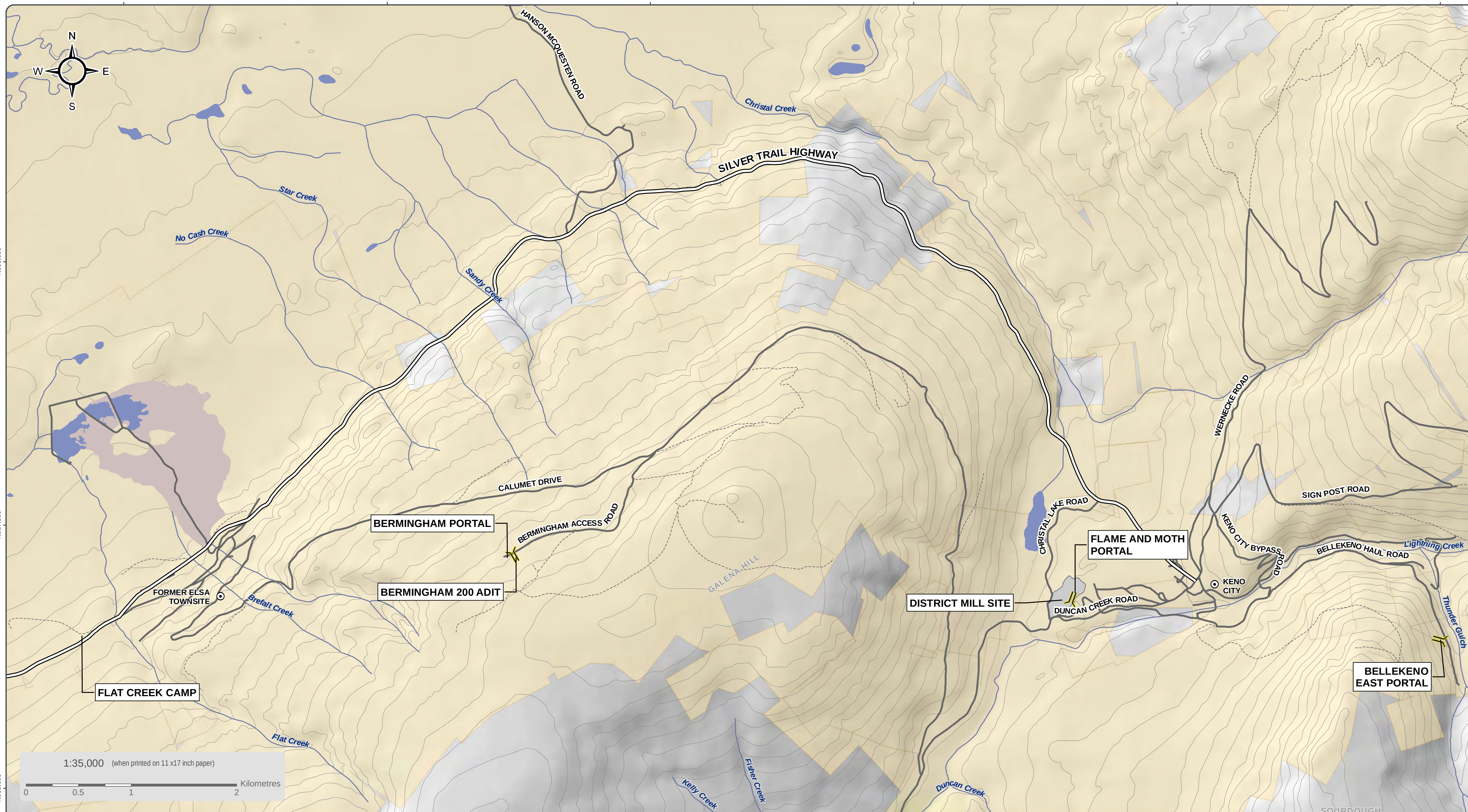
Table 1-3: Keno Hill Silver District Mine Operations Overview

Location	0.5 to 4 km from Keno City, 45 km northeast of Mayo, 354 km north of Whitehorse, YT
Mines/Ore Deposits	Bellekeno (Production 2010 – 2013, suspended 2013 – 2020, production 2020, temporary closure 2020) Flame & Moth (Development 2018, suspended 2018 – 2020, development and production 2020 - present) Bermingham (Advanced exploration 2017 – 2018, development and production 2020 - present) Lucky Queen, Onek 990 (Advanced exploration 2013, not active)
Mining Method	Year round underground cut and fill / longhole stope mining with cemented rock fill and unconsolidated rock fill
Production Rate	400 tonnes/day (Bellekeno, Flame & Moth, Bermingham)
Schedule	Ore mining and milling operations 365 days/year
Mill Recovery Process	Conventional flotation process producing separate lead/silver and zinc concentrates Concentrate is shipped off site for smelting District Mill location at historic Flame & Moth pit area (Constructed 2010) Tailings placed in Dry Stack Tailings Facility (DSTF) or underground as backfill (Established 2010)
Work Force	~ 200 employees and contractors during active mine operations
Airstrip	Village of Mayo, YT
Camp Facilities	Flat Creek camp facilities include a trailer camp, kitchen facility, welcoming center and dry Four refurbished houses and a bunkhouse located nearby in the townsite of Elsa
Power	Hydro grid power Yukon Energy, diesel power backup
Water Supply and Use	Water use and discharge within 3 drainages, Lightning Creek, Christal Creek, and No Cash Creek. Conventional lime precipitation water treatment at Bellekeno 625, Flame & Moth, and New Bermingham. Ammonia treatment via breakpoint chlorination at Flame & Moth and Bermingham. Process water is recycled to the plant for milling.
First Nations	First Nation of Na-Cho Nyak Dun (FNNND)

The KHSD has a long mining history and is a brownfields site. AKHM develops the mineral resources of the KHSD and undertakes receiving environmental monitoring and treatment of mine discharge waters. Alexco's wholly owned subsidiary Elsa Reclamation & Development Company Ltd. (ERDC) undertakes care and maintenance, environmental monitoring and water treatment of historic adit drainages, district-wide closure planning and studies for the historic environmental liabilities. ERDC will commence reclamation of legacy site liabilities upon approval of the Yukon Water Board and receipt of permits.

The placement of water treatment sludge is being performed in watersheds that are impacted by historic mining operations. As the reclamation and closure of historic liabilities is implemented by ERDC in the KHSD, it is expected that changes in the environmental status of the AKHM's KHSD Mine Operations will be observed. In addition, results of the monitoring programs undertaken by ERDC also inform the environmental performance of the KHSD Mine Operations.

Sludge produced as a by-product of the water treatment system at the legacy sites is managed in accordance with the *Keno Hill Water Treatment Systems Sludge Management Plan* (ERDC, 2013) under WL QZ17-076. The legacy sites include Galkeno 300, Galkeno 900, Onek 400, and Silver King 100. A technical memorandum provides an update that includes the use of a dredge and Onek sludge management procedures.



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 September 2020

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

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

Hecla YUKON

ALEXCO KENO HILL MINING CORP.

FIGURE 1-1
KENO HILL SILVER DISTRICT
MINING OPERATIONS OVERVIEW

OCTOBER 2020

2 SLUDGE MANAGEMENT PLAN APPROACH

2.1 OBJECTIVES

The objectives of the Sludge Management Plan are to:

1) Define roles and responsibilities to personnel assigned to manage sludge;
2) Outline appropriate sludge management measures to ensure environmental protection; and
3) Describe procedures required to meet regulatory obligations.

This Sludge Management Plan is intended to be an operational document that will require periodic updates as modifications and improvements are made to the water treatment systems and sludge management.

2.2 ROLES AND RESPONSIBILITIES

2.2.1 Staff and Contractors

All personnel that support the water treatment plant process are required to implement this Sludge Management Plan. Specifically, these responsibilities include:

- Cooperating fully with your supervisor to implement effective sludge management;
- Only carrying out duties and tasks that you are experienced at and trained to perform;
- Where there is uncertainty, asking questions and bringing concerns to the attention of your supervisor when working with products or conducting tasks that may pose potential environmental risks; and
- Recording the volume of each load of sludge pulled from the water treatment retention ponds, and the disposal location in the Vacuum Truck Operator's Logbook.

2.2.2 Site Services Shifters

Site Services Shifters have a responsibility to ensure that staff and contractors have been trained in sludge management procedures, where relevant. Additional responsibilities include:

- Ensuring site-, task- and material-specific training is provided to all site services staff engaged in sludge management activities;
- Recording the number of sludge bags removed and their estimated volume from the WTPs, and their disposal location;
- Ensuring that sludge disposal facility inspections are routinely conducted;
- Conducting corrective action planning and implementation in a timely manner that supports maintaining ongoing site compliance; and

- Maintaining records regarding inspections, personnel training, equipment maintenance, and sludge transport.

2.2.3 Water Treatment Operators

Water Treatment Operators have a responsibility to ensure that the WTPs are managed in accordance with current permits, licences and water treatment system operating manuals including:

- Ensuring that sludge pond and dewatering facility inspections are routinely conducted;
- Collecting annual sludge samples for analytical and grainsize testing; and
- Supporting Site Services Shifters and the Mill Manager in conducting corrective action planning and implementation in a timely manner that supports maintaining ongoing site compliance.

2.2.4 Process Manager

The Process Manager, or their designate, is responsible for Sludge Management Plan implementation and reporting. In addition to overseeing the above tasks undertaken by others, the Mill Manager or their designate is responsible for:

- Ensuring there are appropriate and sufficient supplies, staff and equipment on site to support compliant sludge management;
- Submitting sludge samples for geochemical and geotechnical analysis and obtaining reports by qualified professionals on the results;
- Reporting on sludge management in AKHM's annual reports under the water licence and quartz mining permit; and
- Reviewing the plan annually and updating the plan as needed to ensure alignment with WTP operations and amendments to licence and permit terms and conditions.

3 SLUDGE MANAGEMENT

3.1 SLUDGE GENERATION

Water is collected underground in sumps located in the Bellekeno, Flame & Moth and New Bermingham mines at various elevations and operating areas. The underground sumps settle solids before the water is pumped to surface for treatment in the water treatment plants. The system of sumps and pumping underground advance with mine development. Lime solution is added to the underground mine collected waters and a zinc hydroxide precipitate (sludge) is formed.

The WTPs can be adjusted both automatically and manually by the operators to modify setpoints to achieve target pH, turbidity readings, reagent dosing rates and, at Flame & Moth and New Bermingham, sludge discharge rates. Additional details on the water treatment process are available in the Operations and Maintenance Manual for the Flame & Moth Mine (AKHM, 2018), and Bermingham Water Treatment Facility Operations Manual (AKHM, 2021).

3.2 OPERATIONAL SLUDGE MANAGEMENT FACILITIES

At the Flame & Moth and New Bermingham WTP's a lamella clarifier is the primary liquid/solids separation equipment for removal of the solids, including the zinc (metal) hydroxide precipitate.

- The lamella clarifier is an inclined-plate clarifier. The inlet stream is stilled upon entry into the clarifier. Solid particles begin to settle on the plates and accumulate in collection hoppers at the bottom of the clarifier unit and the underflow. The sludge solution (underflow) is drawn off at the bottom of these hoppers through an automatic electronic control valve and the clarified liquid exits the unit at the top by a weir.

- Underflow from the clarifier is gravity fed through pipelines to a series of geotextile filter bags (sludge bags). A valve manifold allows the underflow from the clarifier to be directed to one or more of the sludge bags and flow to each sludge bag can be adjusted according to the overall sludge management requirements.

- The pipelines are insulated, and heat traced to assure that even in extreme cold that sludge will continue to be handled.

- The high surface area sludge bags dewater the underflow solution by passive gravity settling. The geotextile holds back the larger particles and releases treated water to a lined pond.

- The sludge bags are installed within a lined area to collect the filtered water that seeps from the bags and direct it to a lined pond.

- The sludge bags are a single use item. Once a bag is full, the pipeline from the clarifier is disconnected and the sludge within the bag dries and densifies over time. The clarifier underflow is directed to a different bag in the series.

- The sludge bag areas are configured to allow access by a skid steer or front loader for placement and removal of the bags.

- When a dewatered sludge bag is removed for disposal and a new sludge bag is installed and the piping reconnected to it.

At the Bellekeno WTP, the water pumped to the surface reports to a circular rapid mix tank and mixer located underneath a treatment shed that ensures proper mixing of the water as reagents are added to the tank. From the rapid mix tank, the water passes to the first of two lined ponds. It is in the first pond that the majority of total suspended solids (TSS) and metal (zinc) hydroxides settle out in the form of a grey sludge that collects at the bottom.

In addition to the two lined settling ponds at Bellekeno, there are lined ponds at Flame & Moth, New Bermingham and the Mill Pond which support sludge management. Sludge that accumulates in the WTP ponds and the District Mill Pond are removed using a vacuum truck or dredge.

The dredge pumps the sludge solution to a sludge bag located within a lined area adjacent to the ponds to dry and densify the sludge prior to disposal. Unlined dewatering areas are periodically used to dry and densify sludge recovered by the vacuum truck from the ponds. These desludging systems are described further in Section 3.3.

The lined potentially acid metal leaching (P-AML) waste rock storage facilities are periodically used to store dewatered sludge where it is blended with the P-AML waste rock prior to final disposal.

3.3 POND DESLUDGING

Sludge removal and disposal from the first Bellekeno WTP pond to ensure that adequate retention time is available to properly settle the solids or can typically be accomplished without additional drying and densification. Over time the fine-grained clay sized content in the sludge builds up making normal pond desludging difficult and a desludging campaign involving the use of the dredge pump and sludge bag system, or the dewatering area undertaken.

Periodically the other WTP and District Mill ponds also require a desludging campaign be implemented to remove excess solids that have accumulated in the ponds to reduce the TSS in the ponds and to maintain optimal recycled water flow for mill operation.

When a dredge is used to desludge a pond, the sludge solution is pumped to a sludge bag located within a lined area adjacent to the ponds as illustrated in Figure 3-1. The filtered water that seeps from the sludge bag is directed by gravity flow back to the pond. The sludge bag is then disconnected from the pump and the sludge dewaters and densifies prior to being removed for disposal.

Unlined dewatering areas are periodically used to dry and densify sludge recovered by the vacuum truck or dredge from the ponds. The dewatered sludge is then removed by excavator or backhoe and hauled away in a dump truck for disposal.

To maintain effluent discharge water quality during a desludging campaign of the first Bellekeno pond flow from the treatment plant is piped directly to the second pond, bypassing the first pond while it is being desludged. Once the first pond is desludged, flow to the first pond resumes. To maintain effluent discharge water quality while the second pond is desludged the campaign is undertaken while the water level in the second pond is below the discharge elevation. To achieve this state treated water is utilized for dust control on the roads and if required a bypass pipeline installed from the first pond outlet to direct the treated water to the final discharge site.

To maintain effluent discharge water quality during a desludging campaign at the Flame & Moth and District Mill ponds the work can be conducted while there is no discharge to the environment. The use of silt curtains or filter cloth may be required in the Bermingham pond.

3.4 SLUDGE DISPOSAL

Up until 2021, sludge from the Bellekeno WTP was stored in a dedicated cell at the Valley Tailings area, the Valley Tailings Bellekeno Sludge Storage Area (Figure 3-2). The Valley Tailings sludge storage area is not lined to allow water to exfiltrate. Since 2021, sludge removed from the Bellekeno settling ponds has been blended with P-AML waste rock and disposed of underground. The Bellekeno sludge will now be collected in the vacuum truck or dredged transported underground for disposal.

Dewatered sludge from the Flame & Moth WTP is blended with waste rock and disposed of underground.

At the New Bermingham WTP, the densified sludge bag is hauled by truck on average once a month to the historic Bermingham Southwest open pit for final disposal. The pit is located approximately 500 m upgradient of the New Bermingham mine as Figure 3-3.

Sludge stored in P-AML waste rock storage areas will be deposited and blended in accordance with the Waste Rock Management Plan, and sludge relocated underground in accordance with the Mine Development and Operating Plan. These plans specify measures to be taken to comply with WL QZ18-044 and QML-0009 requirements.

AKHM plans to explore options related to the sludge disposal in the DSTF and realizes that additional testing and review is required prior to placement within the facility.

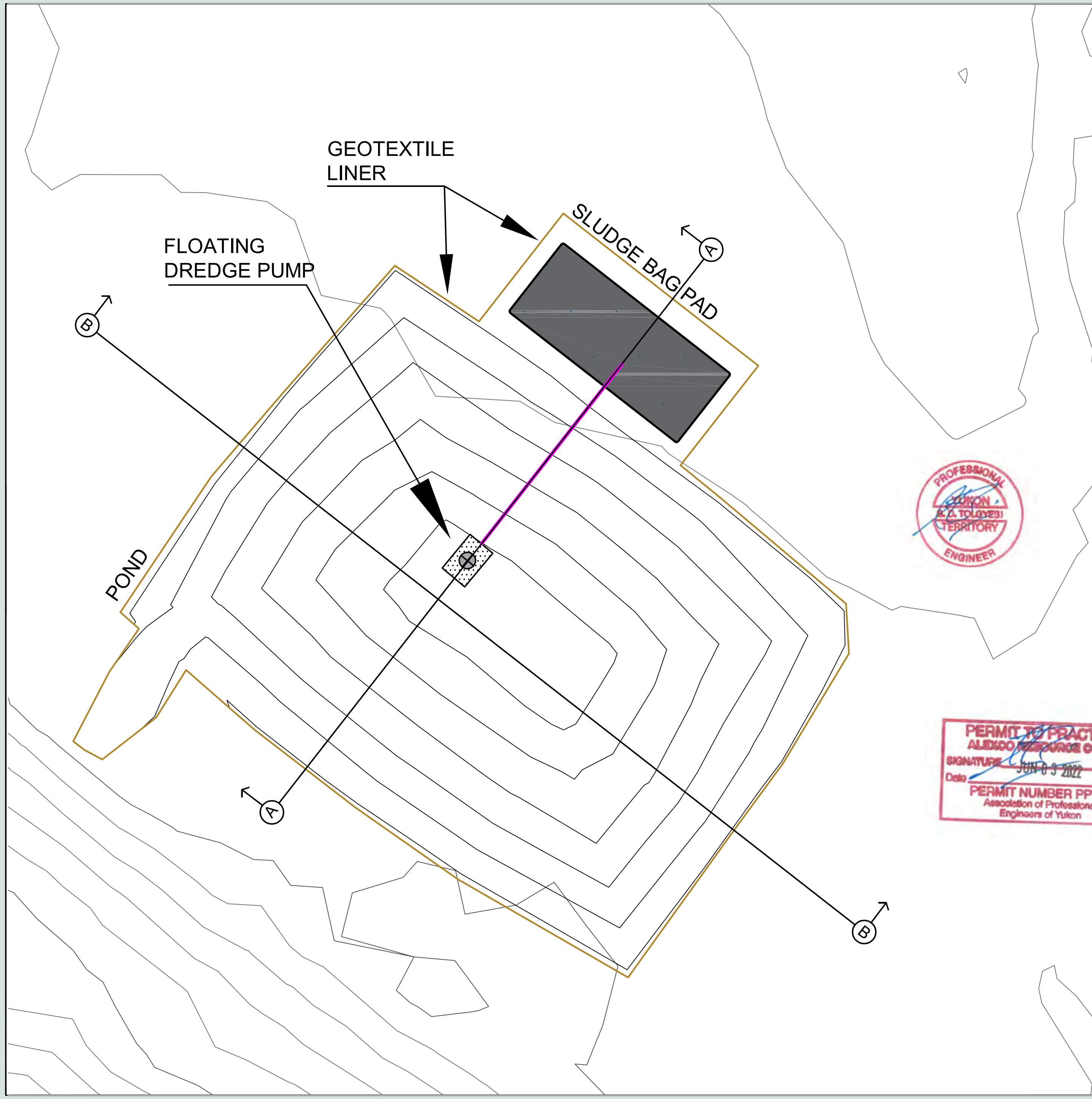
3.5 IN SITU TREATMENT

A semi-passive water treatment system will be operated at the Bellekeno Mine after completion of mining as described in the site Reclamation and Closure Plan. The *in situ* process will generate metal sulphide precipitates as a by-product within the mine workings. These sludges will settle and remain within the underground mine workings. The operating and maintenance plan, *Keno Hill Silver District Mining Operations, Keno Hill In Situ System Operations and Maintenance Plan* (Ensero and AKHM, 2020a) provides a description of the treatment process, safety and emergency preparedness measures, along with operation and maintenance procedures.

The existing settling ponds at the Bellekeno WTP will be converted to use as temporary secondary treatment as a bioreactor. This secondary treatment process is discussed further in the *Keno Hill Silver District Mining Operations, Bioreactor Design and Operation Plan* (Ensero and AKHM, 2020b). The existing conventional

Bellekeno WTP system will be retained while the *in situ* treatment system is being commissioned. 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. This process will generate hydroxide sludges that will be deposited in the settling ponds. Solids that build up in the ponds will be removed periodically and hauled to the underground workings.

The design of other *in situ* treatment systems is being advanced as part of the reclamation and closure planning.



PROFESSIONAL
YUKON
S.D. TOLGYESI
TERRITORY
ENGINEER

PERMIT TO PRACTICE
ALEXCO RESOURCE CORP.
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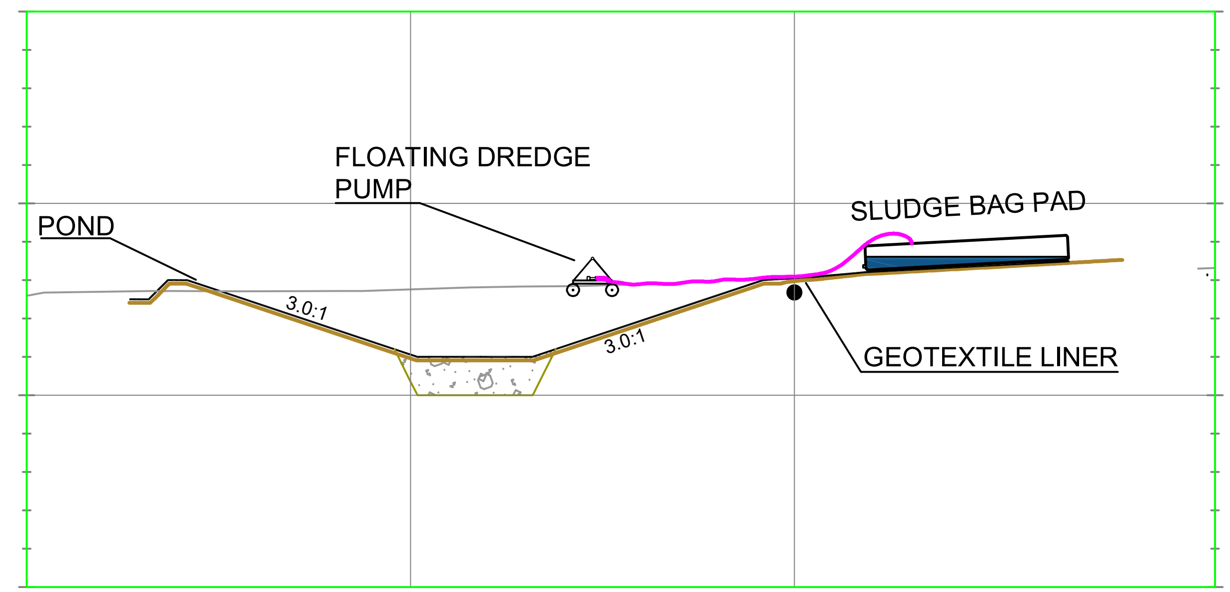
Date JUN 0 3 2022
PERMIT NUMBER PP750
Association of Professional Engineers of Yukon



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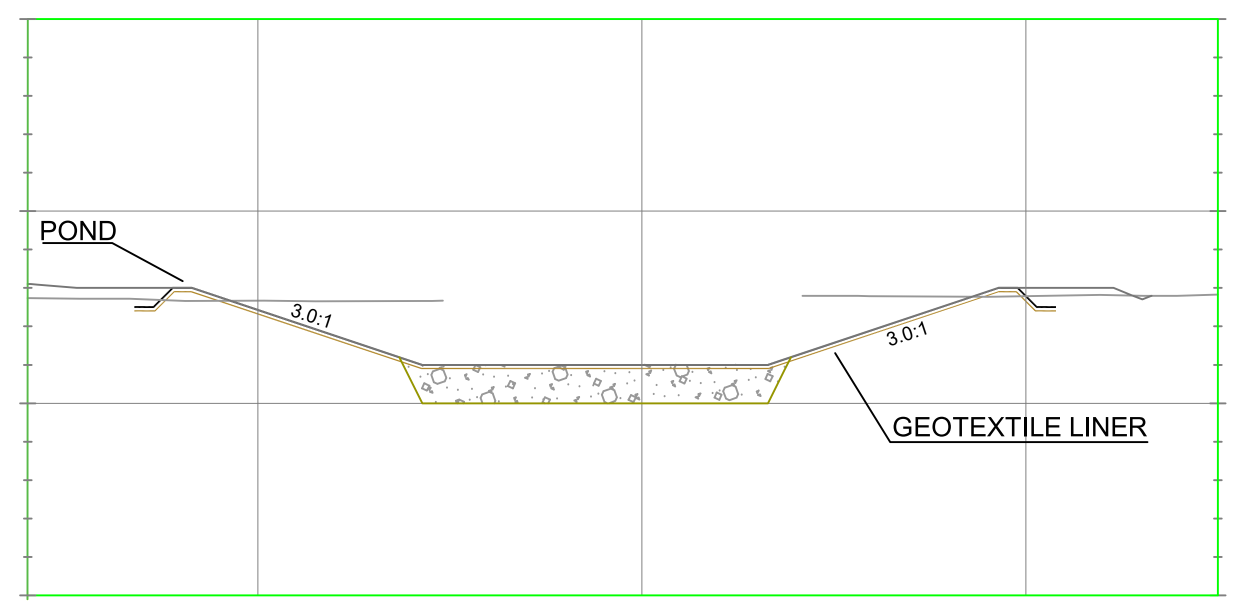


Section B

Hecla YUKON

SLUDGE BAG GENERAL ARRANGEMENT FOR DREDGING

June 3, 2022

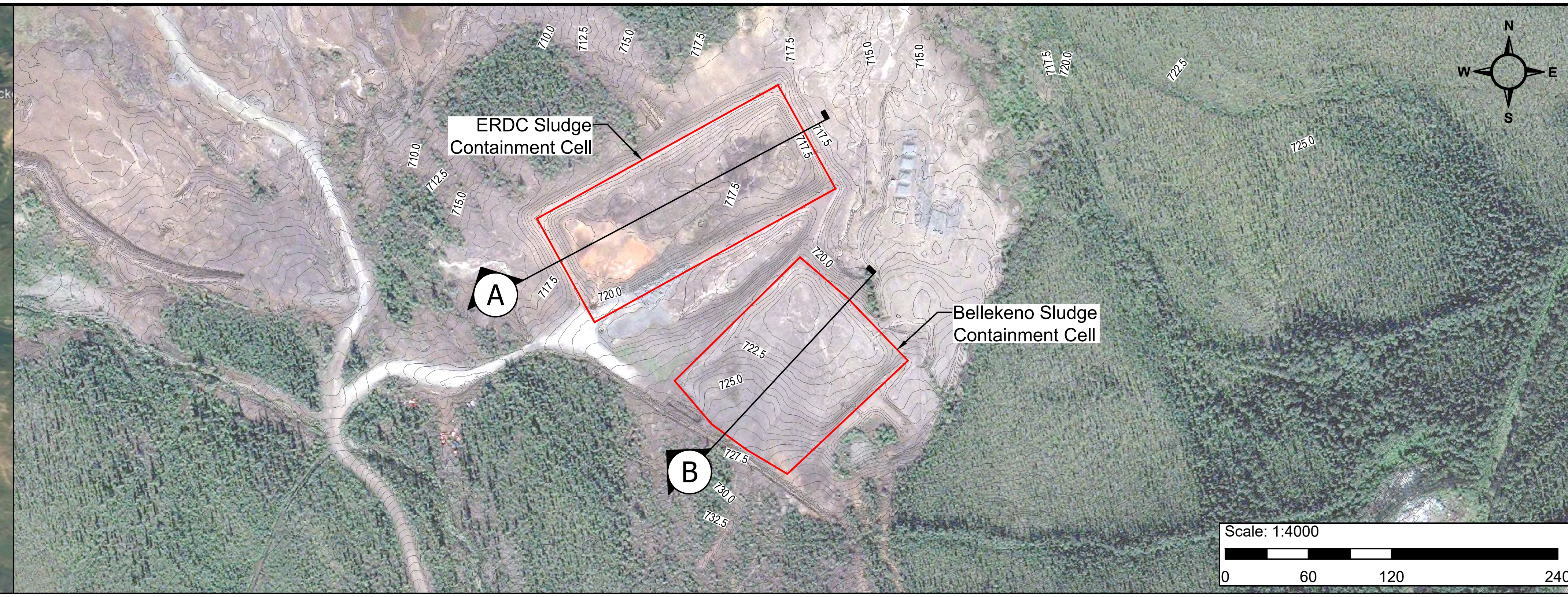
REVISIONS

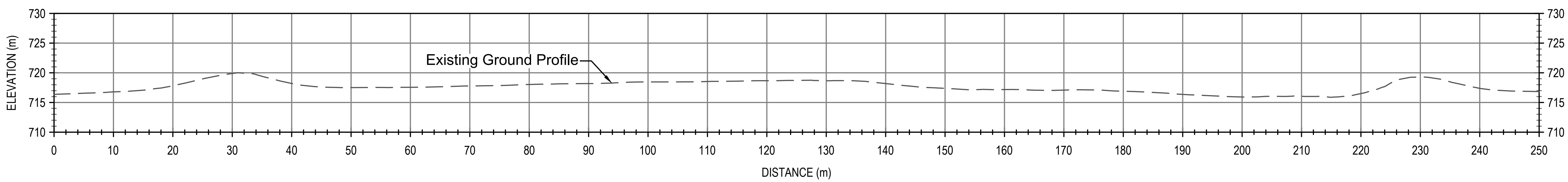
NO.	BY	DATE	DESCRIPTION
A	B.G	2022/06/02	Draft for review
B	B.G	2022/06/02	Draft for review
C	B.G	2022/06/03	Sludge pump and liner configuration correction

Contact: SD Tolgyesi

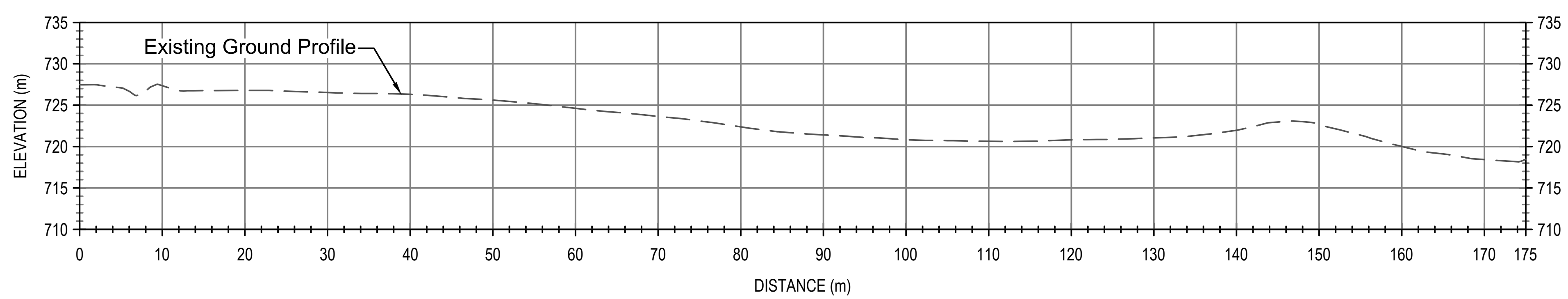
Phone: 867-995-3113

ERDC-002-7-GENERAL





Section A



Section B

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Notes:

1. Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2020-10-22.
2. Topographic contours and profiles derived from LiDAR data acquired by Eagle Mapping Ltd., September 25th, 2014

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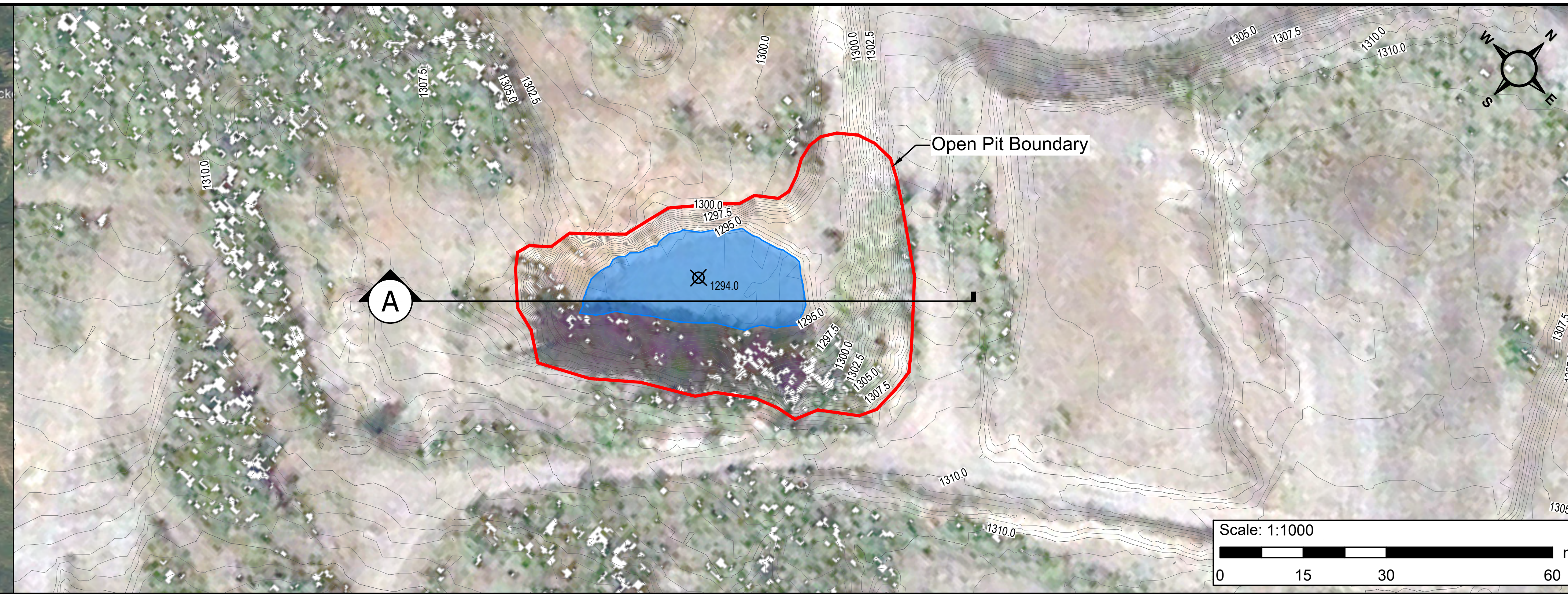
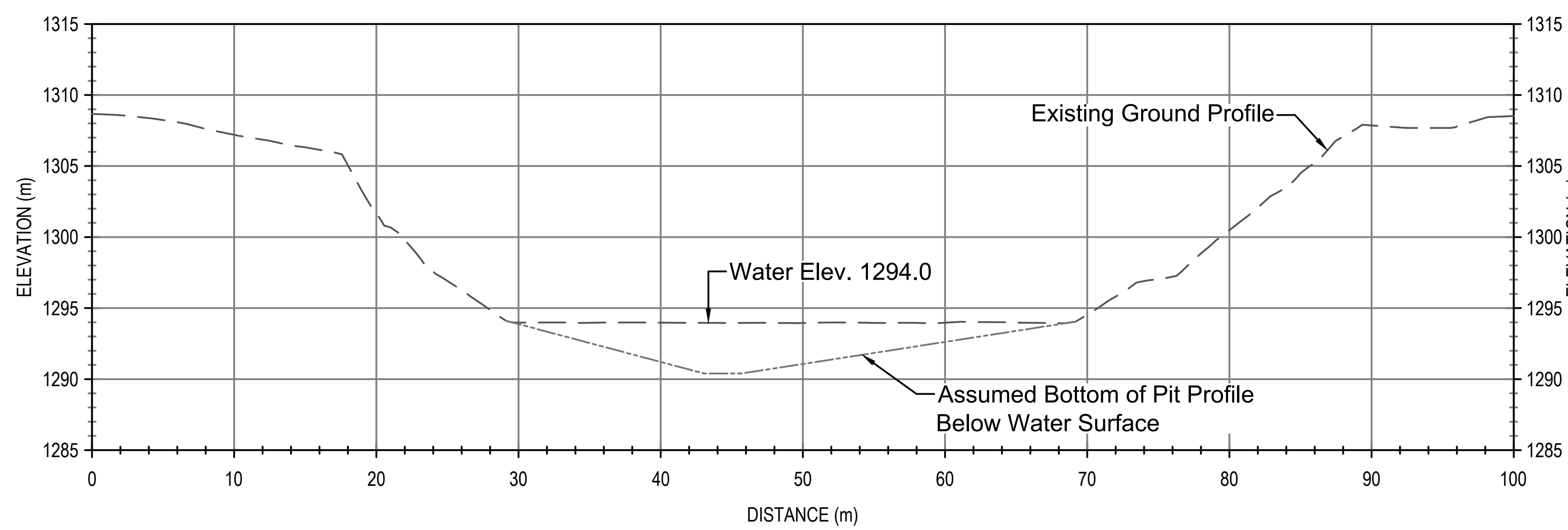
Keno QZ18-044 Management Plans
Sludge Containment

Figure 3-2

Valley Tailings
Sludge Containment Area

PROJECT No.: ECA20YT00030-223		2020-10-22
DRAWN BY: KB	DESIGNED BY: KW	REVIEWED BY: KW





Section A

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Notes:

1. Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2020-10-22.
2. Topographic contours and profiles derived from LiDAR data acquired by Eagle Mapping Ltd., September 25th, 2014

ENSERO solutions

Keno QZ18-044 Management Plans
Sludge Containment

Figure 3-3

Bermingham SW
Sludge Containment Area

PROJECT No.: ECA20YT00030-223	2020-10-22

DRAWN BY: KB	DESIGNED BY: KW	REVIEWED BY: KW

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4 SLUDGE CHARACTERISTICS

A memorandum summarizing the results of acid base accounting (ABA), trace metal content, leachable metals, moisture content and particle size distribution analysis on sludge samples collected from the Bellekeno, Flame & Moth, and Bermingham WTPs is included as Appendix A. The results of similar geochemical tests conducted on sludge samples collected from the same mines in 2018, 2019, 2020, and 2021 are compared. The sludge disposal in the underground workings, and open-pit disposal combined with the elevated neutralization potential of the sludge are expected to prevent the onset of metal re-mobilizing or acidic conditions.

5 SLUDGE MANAGEMENT AT CLOSURE

The KHSD Reclamation and Closure Plan is updated every two years in accordance with QML-0009 and WL QZ18-044. Specific measures for sludge management at closure are described in the Reclamation and Closure Plan. In summary, current closure measures for sludge management include the following:

- Reclamation tasks include removal of pond sludges, removal and burial of the pond liners, pipelines, rip rap discharge channels, pond recontouring, revegetation and remediation of any contaminated soils.
- The sludge in the Valley Tailings Bellekeno Sludge Storage Area will be either relocated underground in accordance with engineering design conditions.
- At mine closure, the sludge disposed of in the Bermingham Southwest pit will be covered with waste rock and till material.
- Any sludge disposed of in the DSTF will be managed in accordance with the DSTF closure measures.
- The Bellekeno WTP will be decommissioned, and the lined ponds and tanks used for the construction of the underground *in situ* treatment system. As a contingency treatment system, the Bellekeno treatment pond is planned to be converted into a biological treatment cell, in addition to the in-situ treatment of the mine pool.
- Approximately 10 cm of soil from below the Bellekeno sludge dewatering area with be removed and disposed of underground, and area recontoured.
- The Valley Tailings Bellekeno Sludge Storage Area is distinct and is a physically separate facility from the ERDC sludge storage area. During reclamation, sludge will be excavated from the storage cell in the valley tailings and transported for final disposal underground or in a DSTF.

6 MONITORING AND REPORTING

The following measures will be implemented during the duration of water treatment and sludge generation at Bellekeno, Flame & Moth and New Bermingham WTPs:

- Sludge volumes will be recorded in the Operator's Logbook for each load of sludge pulled from the Water Treatment retention ponds;
- Sludge samples will be collected annually and tested for grain size, metals and ABA; and
- Groundwater will be monitored around the Bermingham Southwest open pit at three location KV-122, KV-123 and KV-124. Surface water will be monitored in No Cash Creek at KV-21, KV-111 and KV-118.
- No additional sludge will be placed in the Valley Tailings Bellekeno Sludge Area.

The template used for sludge disposal tracking is included for reference in Appendix B.

Sludge stored in P-AML waste rock storage areas will be evaluated by waste rock management programs, and sludge relocated underground in accordance with the mines operating plan.

Annual reports are submitted as part of WL QZ18-044 and QML-009. The annual WL reports will include a monthly summary of the volume of sludge removed from each WTP and the disposal destination, sludge testing results, surface and groundwater monitoring details, and an updated water balance that considers any disposal of sludge with the mine workings.. All monthly and annual reports are provided to the FNNND.

7 REFERENCES

Alexco Keno Hill Mining Corp. (2018). *Alexco Keno Hill Mining Corp. – Keno Hill Operations, Operations and Maintenance Manual – Flame & Moth IWTP*, December 2018.

Alexco Keno Hill Mining Corp. (2021). *Bermingham Water Treatment Facility Operations Manual – Rev. 0, Keno Hill Silver District, Yukon Territory, Canada*, July 13, 2021.

Elsa Reclamation and Development Company Ltd. (2013). *Keno Hill Water Treatment Systems Sludge Management Plan, QZ12-057, Revision No. 4.* September 2013.

Ensero and AKHM, 2020a. *Keno Hill Silver District Mining Operations, Keno Hill In Situ System Operations and Maintenance Plan.* October 2020.

Ensero and AKHM, 2020b. *Keno Hill Silver District Mining Operations, Bioreactor Design and Operation Plan*. October 2020.

APPENDIX A:

SLUDGE CHARACTERIZATION MEMO

Memorandum

To: Arlene Stearman, Alexco Keno Hill Mining Corp.

From: Cheibany Ould Elemine and Andrew Gault, Ensero Solutions Canada, Inc.

CC: Kai Woloshyn, Ensero Solutions Canada, Inc.

Date: March 28, 2022

Re: Geochemical Assessment of KHSD Water Treatment Sludge – 2021 Update

1 INTRODUCTION

Alexco Keno Hill Mining Corp. (AKHM) currently operates and maintains water treatment plants (WTPs) under Type "A" Water License QZ18-044 at the Bellekeno, Flame & Moth, and Bermingham mines. Elsa Reclamation and Development Company Ltd. (ERDC) also operates care and maintenance WTPs under Type B Water Licence QZ17-076 which treat water that discharges from the Galkeno 300, Galkeno 900, Onek 400, and Silver King 100 adits. The treatment systems operated comprise one or more of the following processes:

- Metals removal with the addition of air, lime for pH adjustment, flocculant, coagulant; and
- Particle removal via a multimedia filter, clarifier/thickener, and/or settling pond.

The Sludge Management Plan for the Keno Hill Silver District (KHSD) mining operations (Ensero, 2020) stipulates that the measures listed below will be implemented during the duration of water treatment and sludge generation at the Bellekeno, Bermingham, and Flame & Moth WTPs:

- Recording of the volume of each load of sludge pulled from the water treatment retention ponds in the Operator's Log Book;
- Collection and testing of sludge samples annually. The tests will at least include acid-base accounting (ABA) and elemental analysis; and
- Provision of the information above in AKHM's Annual Report to the Yukon Water Board.

The Sludge Management Plan (ERDC, 2013) for the ERDC care and maintenance water treatment systems requires that sludge volumes produced are recorded. Solid phase characterization of the sludge from the care and maintenance WTPs is not a requirement. Nevertheless, such data have been collected in previous years and are provided in past technical memorandums.

This memorandum summarizes the results of static testing on sludge samples collected on October 12, 2021. The results of samples collected in previous years from AKHM WTPs are also provided, and a comparative assessment done, where appropriate. The memorandum includes results for the following samples:

- October 2021 sludge samples collected from the Bellekeno, Flame & Moth, and Bermingham WTPs.

2 SAMPLING AND LABORATORY TESTING

One sludge sample was collected from the treatment pond at Bellekeno, and from the clarifier valve at each of the Flame & Moth and Bermingham WTPs. All three (3) samples were sent to ALS laboratories in Vancouver, BC, for testing (Table 2-1). The geochemical laboratory tests were based on methods outlined in Price (2009) and consisted of:

- ABA including: paste pH, total inorganic carbon, bulk neutralization potential by the Modified Sobek neutralization potential method, and sulphur speciation with the sulphide sulphur determined by difference between total sulphur (Leco) and sulphate sulphur (HCl extraction);

- Ultra trace elemental analysis by *aqua regia* digestion followed by inductively coupled plasma mass spectrometry (ICP-MS); and

- Shake Flask Extraction (MEND SFE) test on the Bermingham sludge sample at 3:1 water-solid ratio.

Other tests performed on the samples included moisture content (Bermingham sludge only) and particle size distribution.

Table 2-1: Description of WTP Sludge Samples

Sample ID	Location	Sample weight (kg)	Laboratory Test
BK_2021	Bellekeno	0.56	ABA, Elemental Analysis and Particle Size Distribution
F&M_2021	Flame & Moth	0.44	ABA, Elemental Analysis and Particle Size Distribution
BH_2021	Bermingham	0.44	ABA, Elemental Analysis Shake Flask Extraction, Moisture Content and Particle Size distribution

3 RESULTS

The results of laboratory test results are summarized in Table 3-1 to Table 3-4 and laboratory reports are provided in Appendix A. For comparison purposes, the results of similar geochemical tests conducted on sludge samples collected from the same mines in 2018, 2019, and 2020, and reported in AEG (2019 and 2020) and Ensero (2021) are also provided.

3.1 PARTICLE SIZE DISTRIBUTION

The results of particle size distribution (PSD) show that the samples consist mostly of silt (73% to 81%) and clay (17.7% to 26.6%) with trace amount of sand and gravel material (Table 3-1).

Table 3-1: Results of PSD Test of WTP Sludge Samples

Grain Size	Units	Detection Limit	BK	F&M	BH
Sampling Year:			**2021**	**2021**	**2021**
Clay (<0.004mm)	%	1.0	22.4	26.6	17.7
Silt (0.063mm - 0.004mm)	%	1.0	75.5	73.0	81.0
Sand (0.2mm - 0.063mm)	%	1.0	1.3	<1.0	<1.0
Sand (2.0mm - 0.2mm)	%	1.0	<1.0	<1.0	<1.0
Sand (2.0mm - 0.063mm)	%	1.0	2.1	<1.0	1.3
Gravel (>2mm)	%	1.0	<1.0	<1.0	<1.0

Notes:
BK: Bellekeno 625
F&M: Flame & Moth
BH: Bermingham

3.2 ACID BASE ACCOUNTING

ABA provides an indication of the acid generation and neutralization potentials of geologic materials by determining the content and ratio of potentially acid producing and consuming minerals in a sample. The results of the ABA testing of the 2021 sludge samples are presented in Table 3-2 along with the results of the 2018, 2019, and 2020 tests.

The 2021 results show that the samples had neutral paste pH (8.6 – 8.9). The Bellekeno and Flame & Moth sludge samples had paste pH values of up to 0.2 to 0.6 pH units higher than the previous two years, respectively.

The carbonate neutralization potential (carbonate-NP) was very high in the Bellekeno sludge (615 kg $CaCO_3$/t), consistent with historical data (700 – 835 kg $CaCO_3$/t; Table 3-2). The carbonate-NP was moderately high and comparable in the sludge samples from Flame & Moth and Bermingham (both 201 kg $CaCO_3$/t). These carbonate-NP values reflect the addition of lime during treatment. A marked continuous decrease of carbonate-NP (from 870 to 201 kg $CaCO_3$/t) was observed in the Flame & Moth WTP sludge from 2019 to 2021, likely due to lower lime addition over the years. The carbonate-NP remained the main contributor to the bulk neutralization potential for all samples, suggesting that most NP is from reactive carbonates.

The sulphate content of the Bellekeno sample made up 38% of total sulphur, which was a significant change from previous years when total sulphur consisted primarily of sulphate (more than 59% to 100%). The sulphate content of the Flame & Moth sludge was much lower than in 2019 and 2020 and only represented 4% of total sulphur compared to 66% in 2020 and 100% in 2019. This is likely due lower addition of lime (i.e., less precipitation of the calcium sulphate mineral gypsum that forms as calcium from the lime reacts with sulphate in the mine water) coupled with higher sulphide sulphur content in the 2021 samples compared to 2018, 2019, and 2020. The Bermingham sludge sample contained no sulphate (<0.01 wt.%).

The elevated carbonate-NP coupled with a very low acid generation potential (14.1 to 32.2 kg $CaCO_3$/t) suggests that the potential for acid generation from the sludge is low. The carbonate neutralization potential ratio (NPR) was calculated conservatively as a ratio of carbonate-NP to acid potential and confirmed this (i.e., NPR greater than 2).

All the sludge samples had an NPR greater than 2 consistent with previous years and were classified as non-potentially acid generating (non-PAG).

3.3 METAL CONTENT

The bulk metal concentration of an element provides a preliminary indication of constituents that could be solubilized and remobilized when exposed to leaching, depending on the speciation of the metal. However, the enrichment (or depletion) of a constituent in a sample is not a direct measure of its potential mobility or bioavailability because several factors including hydrogeology, biogeochemistry, climate, pH, and redox conditions which together ultimately determine the mobility and bioavailability of an element in the environment. In the case of sludge, climate, pH, and redox conditions are the primary controls on the potential elemental mobility.

The results of the trace elemental analysis of the WTP sludge samples are presented in Table 3-3. The discussion herein is focused on the metal(loid)s related to the KHSD mineralization such as arsenic, cadmium, copper, lead, nickel, manganese, iron, silver, and zinc. The results of the elemental analysis showed high metal(loid) concentrations in the sludges as expected from a treatment system (Table 3-3 and Table 3-4). The metalloid content of the Bellekeno sludge largely reflects the metal(loid) load supplied by the adit discharge to the WTP. The elevated manganese (7,800 ppm), lead (>10,000 ppm), and zinc (>10,000 ppm) concentrations in the Bellekeno sludge compared to the Flame & Moth and Bermingham sludge reflect the high loading of these metal(loid)s supplied by the adit (Table 3-3). The Bermingham sludge also contained elevated silver, arsenic, cadmium, manganese, and lead. The high acid buffering capacity of the sludges create favorable conditions for the precipitation of metal oxyhydroxides that scavenge and coprecipitate these metals(loids), limiting their solubility and mobility in the environment.

The sludge metal data collected to date also showed some variation of the concentration of metal(loid)s at each mine site. For example, the concentrations of many metal(loids) including arsenic, cadmium, copper, lead, silver, and zinc in the Bellekeno sludge increased significantly from 2019 to 2021 (Table 3-3). This behaviour reflected changes to the concentration of these metal(loid)s in the Bellekeno 625 adit discharge, with mining activity likely responsible for the higher metal(loid) concentrations in both the adit discharge and associated sludge in 2021. The concentrations of some metals (e.g., silver, copper, nickel, lead) in the Flame & Moth sludge also increased modestly in 2021 compared to 2019 and 2020 (Table 3-3), while arsenic and manganese decreased.

3.4 LEACHABLE METALS

The results of the SFE conducted on the Bermingham sludge sample are provide in Table 3-4. The results show that aside from major elements, the concentration of most constituents in the leach solution were very low or below the detection limit. The leach pH was mildly alkaline (pH 8.25) and leachable sulphate was low (120 mg/L), consistent with the ABA results. Metal(loid)s that exhibited elevated concentrations in the Bermingham sludge (e.g., silver, arsenic, cadmium, manganese, and lead) did not show similarly elevated SFE leachate concentrations. For example, the SFE leachate concentrations were between 2.2- and 215-fold lower than the effluent quality standards (EQS) for those parameters with an EQS (arsenic, cadmium, copper, lead, nickel, silver, zinc).

Table 3-2: Results of ABA of WTP Sludge Samples

Parameter	Units	Detection Limit	BK		F&M-B		F&M-A		F&M		BH	
Sampling Year			**2018**	**2019**	**2020**	**2021**	**2018**	**2018**	**2019**	**2020**	**2021**	**2021**
Paste pH	pH unit	0.1	9.0	8.5	8.6	8.8	8.6	8.5	8.3	8.0	8.6	8.9
Inorganic Carbon (C)	wt.%	0.05	10.05	9.91	8.39	7.38	3.63	6.7	10.4	6.62	2.41	2.41
Inorganic Carbon Dioxide (CO_2)	wt.%	0.2	36.7	36.3	30.8	27	13.3	24.6	38.2	24.2	8.8	8.9
Total Sulphur	wt.%	0.01	1.01	1.11	1.22	1.67	0.72	0.80	0.75	0.68	0.47	0.46
HCl Extractable Sulphur	wt.%	0.01	0.98	1.09	0.72	0.64	0.34	0.62	0.77	0.45	0.02	<0.01
Sulphide Sulphur (by diff.)	wt.%	0.01	0.03	0.02	0.5	1.03	0.38	0.18	<0.01	0.23	0.45	0.46
Carbonate Equivalent Neutralization Potential (NP)	kg $CaCO_3$/t	1	835	826	700	615	302	559	869	550	201	201
Acid Generation Potential (AP)	kg $CaCO_3$/t	0.3	0.9	0.6	15.6	32.2	11.9	5.6	0.3	7.2	14.1	14.4
Modified Sobek Neutralization Potential (NP)	kg $CaCO_3$/t	1	837	868	695	600	320	562	902	520	195	202
Neutralization Potential Ratio (NPR)	NA	0.1	890	1321	45	19	25	99	2780	77	14	14
ARD Classification	NA	-	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG	non-PAG

Notes:
BK: Bellekeno 625
F&M: Flame & Moth
BH: Bermingham
NP: neutralization potential
NA: not available

Table 3-3: Results of Elemental Analysis of WTP Sludge Samples

Parameter	Units	BK				F&M				Bermingham
		2018	2019	2020	2021	2018	2019	2020	2021	2021
Silver (Ag)	ppm	0.86	0.46	102	>100	0.99	0.06	1.21	4.18	>100
Aluminum (Al)	%	0.03	0.03	0.18	0.18	0.67	0.03	0.68	0.73	0.83
Arsenic (As)	ppm	36.3	21.9	242	308	38.6	89.2	73	30.8	248
Boron (B)	ppm	10	<10	<10	<10	<10	<10	<10	10	10
Barium (Ba)	ppm	20	20	30	30	70	10	40	120	90
Beryllium (Be)	ppm	<0.05	<0.05	0.06	0.11	0.59	<0.05	0.24	0.45	0.64
Bismuth (Bi)	ppm	0.03	0.02	1.75	3.32	0.34	0.01	0.36	0.74	0.18
Calcium (Ca)	%	>25.0	>25.0	>25.0	22.7	12.9	>25.0	22.6	7.96	8.04
Cadmium (Cd)	ppm	21.9	10.25	100.5	140.5	0.67	0.13	2.24	2.81	21.1
Cobalt (Co)	ppm	19.2	13.1	12.1	11.6	3.8	3.1	3.2	5.1	8.1
Chromium (Cr)	ppm	6	<1	4	5	19	2	15	19	18
Copper (Cu)	ppm	12.1	2.8	109	210	16	3	15.1	33	55.3
Iron (Fe)	%	2.46	1.86	2.72	2.89	1.6	1.31	1.94	1.71	2.36
Mercury (Hg)	ppm	0.01	<0.01	0.14	0.25	0.02	<0.01	0.04	0.05	0.09
Potassium (K)	%	0.01	0.01	0.03	0.02	0.04	<0.01	0.04	0.04	0.06
Lithium (Li)	ppm	1.3	1.5	1.5	2.3	9.9	1.4	8	14	11.4
Magnesium (Mg)	%	1.13	0.6	0.77	0.49	0.67	0.37	0.44	0.5	0.44
Manganese (Mn)	ppm	7130	4980	7030	7800	759	1220	1150	595	4280
Molybdenum (Mo)	ppm	1.07	0.12	0.95	1.57	1.96	0.12	0.86	4.84	3.07
Sodium (Na)	%	0.03	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.01
Nickel (Ni)	ppm	68.1	46.4	44.3	34.2	20.6	8.9	16.2	25.4	30.6
Phosphorus (P)	ppm	50	40	160	180	640	40	510	500	660
Lead (Pb)	ppm	111	52.1	9750	>10000	50.4	7.7	116	523	1815

Parameter	Units	BK				F&M				Bermingham
		2018	2019	2020	2021	2018	2019	2020	2021	2021
Sulfur (S)	%	1.07	1.14	1.38	1.73	0.69	0.78	0.79	0.49	0.48
Antimony (Sb)	ppm	2.14	1.06	95.4	174	3.44	2.83	4.57	4.68	66.1
Selenium (Se)	ppm	0.4	0.7	1.3	1.4	0.5	0.4	0.7	0.9	0.7
Tin (Sn)	ppm	1	<0.2	8.9	14.8	2.2	9.5	1.9	2.2	3.5
Strontium (Sr)	ppm	758	683	655	520	310	730	578	188	129
Thallium (Tl)	ppm	0.13	0.04	0.14	0.15	0.06	0.02	0.21	0.1	0.2
Uranium (U)	ppm	13.7	12.65	10.2	7.07	5.71	7.86	5.3	3.56	2.17
Vanadium (V)	ppm	8	9	31	15	11	7	15	13	18
Zinc (Zn)	ppm	8380	5150	>10000	>10000	133	169	361	331	1500
Zinc (Zn)*	%	-	-	1.195	-	-	-	-	-	-

Notes:
BK: Bellekeno 625
F&M: Flame & Moth
BH: Bermingham
**: ore grade aqua regia*

Table 3-4: Results of Shake Flask Extraction on Bermingham Sludge

Parameter	DL	Units	Bermingham
pH	0.1	pH units	8.25
Sulphate	0.5	mg/L	120
Dissolved hardness (as CaCO3)	0.6	mg/L	237
Aluminum	0.005	mg/L	0.0546
Antimony	0.0001	mg/L	0.153
Arsenic	0.001	mg/L	0.0279
Barium	0.001	mg/L	0.0488
Beryllium	0.0005	mg/L	<0.00050
Bismuth	0.0005	mg/L	<0.00050
Boron	0.01	mg/L	0.279
Cadmium	0.00005	mg/L	0.000136
Calcium	0.1	mg/L	46.8
Chromium	0.0005	mg/L	<0.00050
Cobalt	0.0001	mg/L	0.00033
Copper	0.001	mg/L	<0.0010
Iron	0.03	mg/L	0.083
Lead	0.0001	mg/L	0.0149
Lithium	0.005	mg/L	0.106
Magnesium	0.05	mg/L	29.2
Manganese	0.0005	mg/L	0.10
Mercury	0.00005	mg/L	0.015
Molybdenum	0.0001	mg/L	0.00833
Nickel	0.0005	mg/L	0.00172
Phosphorus	0.3	mg/L	<0.30
Potassium	0.05	mg/L	4.08
Selenium	0.0005	mg/L	0.00188
Silicon	0.05	mg/L	11
Silver	0.00005	mg/L	<0.000050
Sodium	0.05	mg/L	6.18
Strontium	0.0005	mg/L	0.509
Sulphur	0.5	mg/L	41.1
Thallium	0.0001	mg/L	<0.0001
Tin	0.0005	mg/L	<0.0005
Titanium	0.01	mg/L	<0.01
Uranium	0.00001	mg/L	0.00698

Parameter	DL	Units	Bermingham
Vanadium	0.001	mg/L	0.0012
Zinc	0.01	mg/L	<0.01

Notes:
DL: detection limit

4 SUMMARY

The results of static tests on KHSD 2021 sludge samples from Bellekeno, Flame & Moth, and Bermingham WTPs indicated that the sludges had low potential for long-term acid generation due to their high carbonate buffering capacity and low sulphide sulphur contents. The sludges contained elevated concentration of metal(loid)s typical of a water treatment sludge, with metals precipitated as metal oxyhydroxides, carbonates, and sulphates following the lime-based pH adjustment treatment and settling in ponds and clarifiers.

Tessier Sequential Extraction testing conducted in 2018 (AEG, 2019) showed that the precipitated metal(loid)s were largely bound to the residual and reducible phases. The precipitated metal(loid)s were predominantly in stable forms and unlikely to be re-mobilized unless exposed to acidic or reducing conditions. The current management practices outlined in the sludge management plan (Ensero, 2020) including underground disposal, co-disposal with dry stack tailings, and in open-pit disposal combined with the elevated NP are expected to prevent the onset of these metal re-mobilizing conditions.

5 REFERENCES

AEG (Alexco Environmental Group Inc.). (2019). Geochemical Assessment of KHSD Water Treatment Sludge Keno Hill Silver District Mining Operations, Yukon. Report prepared for Alexco Keno Hill Mining Corp. March 2019.

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Ensero (Ensero Solutions Canada, Inc.). (2020). Sludge Management Plan, Keno Hill Silver District Mining Operations, Yukon. Report prepared with Alexco Keno Hill Mining Corp. October 2020.

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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 B:

SLUDGE LOGBOOK TEMPLATE

Sludge Tracking Log

Sludge Removal

Removed From	January		February		March		April		May		June		July		August		September		October		November		December		Total Litres
	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	
Bermingham																									0
F&M																									0
BK																									0

Sludge Deposit m^3

Deposited At	January		February		March		April		May		June		July		August		September		October		November		December		Total Litres
	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	Loads	Bags	
Mill/DSTF																									0
Berm SW Pit																									0
BK u/g																									0
F&M u/g																									
Berm u/g																									
F & M P-AML																									
Berm P-AML																									0