

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

REVISION 3

OCTOBER 2014

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1 INTRODUCTION

Alexco Resource Corp. (Alexco), through its wholly owned subsidiary Alexco Keno Hill Mining Corp., owns and operates the Keno Hill Mine Operations located in the Keno Hill Silver District (the KHSD). The Keno Hill Mine Operations include the developed and producing Bellekeno Mine (suspended operations August 2013), the Lucky Queen and Onek mines which are developed but not yet put into production and the Flame and Moth mine which is scheduled for development and a production decision. The Keno District mill processes ore produced from the Keno Hill Silver District mines. The Bellekeno, Lucky Queen and Onek mines and the Keno District mill are currently licenced for production under Quartz Mining License QML-0009 and Water Use Licence QZ09-092. The Preliminary Bellekeno Mine Decommissioning & Reclamation Plan was submitted in July 2009 as part of the Bellekeno mine licensing process. Section 9.2 of QML-0009 requires that an updated Reclamation and Closure Plan (RCP) be submitted within 12 months of the issuance of that license. Pursuant to that requirement, an updated RCP was submitted to Yukon Government, Energy Mines & Resources, Mineral Resources Branch[1] in January 2011 and was titled: Reclamation and Closure Plan, Bellekeno Mine, Keno Hill Silver District, January 2011. This RCP was approved in August 2011 conditional on a further update to the RCP by November 2011. Alexco submitted a further update to the Reclamation and Closure Plan (November 2011) and this updated RCP was approved by Yukon EMR in January 2012. As part of the licensing process for the Lucky Queen and Onek mines, the RCP was updated in September 2012 and is the most currently approved RCP for mine operations in the Keno Hill Silver District and includes the operations of the Bellekeno, Lucky Queen and Onek mines and the Keno District Mill.

As part of the license amendment process to bring the Flame and Moth deposit into development and production, Alexco has updated the currently approved RCP to include the Flame and Moth deposit. This Keno Hill Mine Operations RCP thus includes the approved reclamation and closure measures for the current Bellekeno, Lucky Queen and Onek mine operations and infrastructure, the Keno District Mill, DSTF Phases I-II as well as measures for closure of the proposed Flame and Moth mine and subsequent changes to current facilities to accommodate development and production of Flame and Moth. The RCP will continue to be updated as new deposits are advanced into the development and operations phase.

Note that the Lucky Queen, Onek and Flame and Moth Production Unit Areas included in this RCP have not been fully delineated pursuant to the Amended and Restated Subsidiary Agreement between Alexco and Aboriginal Affairs and Northern Development Canada (AANDC) as these deposits have not moved into production. The scope of reclamation and closure planning provided in this RCP consequently may be modified. Determination of the final Production Unit Areas will be made during the licencing process. The RCP will be updated accordingly if necessary.

[1] Available at http://www.emr.gov.yk.ca/mining/pdf/mml_bellekeno_reclamation_and_closure_plan_january_2011.pdf

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

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

- Underground mining activities at the Bellekeno, Onek, Lucky Queen and Flame and Moth deposits, surface support infrastructure and activities, miners' dry area, offices, trailers and portals;
- Conventional flotation mill & supporting infrastructure, coarse ore stockpile, plant services, fuel storage area, employee dry area, offices, trailers and mill pond;
- Dry-stack tailings facility (DSTF), Phase I-II;
- Bellekeno, Onek, Lucky Queen and Flame and Moth N-AML waste rock disposal areas (WRDA);
- Bellekeno, Onek, Lucky Queen and Flame and Moth P-AML waste rock storage facilities (WRSF);
- Temporary coarse ore stock piles;
- Site access roads; Bellekeno Haul Road, Christal Lake Haul Road (from Duncan Creek road to the mill), Lightning Creek Bypass Road (including the Lightning Creek bridge), Keno City Bypass Road; Flame and Moth mine haul road;
- Power distribution system (power poles, transformers);
- Water treatment plants and facilities; and,
- 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*, 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 of the sections of the guidance document have been addressed.





ALEXCO KENO HILL MINING CORP.

KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

AKHM

FIGURE 1-1

GENERAL LOCATION MAP

ACCESS

AUGUST 2012

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1.1 ALEXCO'S ACTIVITIES IN THE KHSD

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

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

Table 1-1 Relevant KHSD Assessment and Regulatory Approvals

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

Notes: [a] www.emr.gov.yk.ca/mining/pdf/mml_bk_qml-0009.pdf
[b] www.yukonwaterboard.ca/registers/quartz/QZ09-092/Volume%204/10-1%20Water%20Use%20Licence.pdf
[c] www.yukonwaterboard.ca/registers/quartz/QZ10-060/Licence.pdf
[d] www.yukonwaterboard.ca/registers/quartz/qz08-082/amend_1.pdf

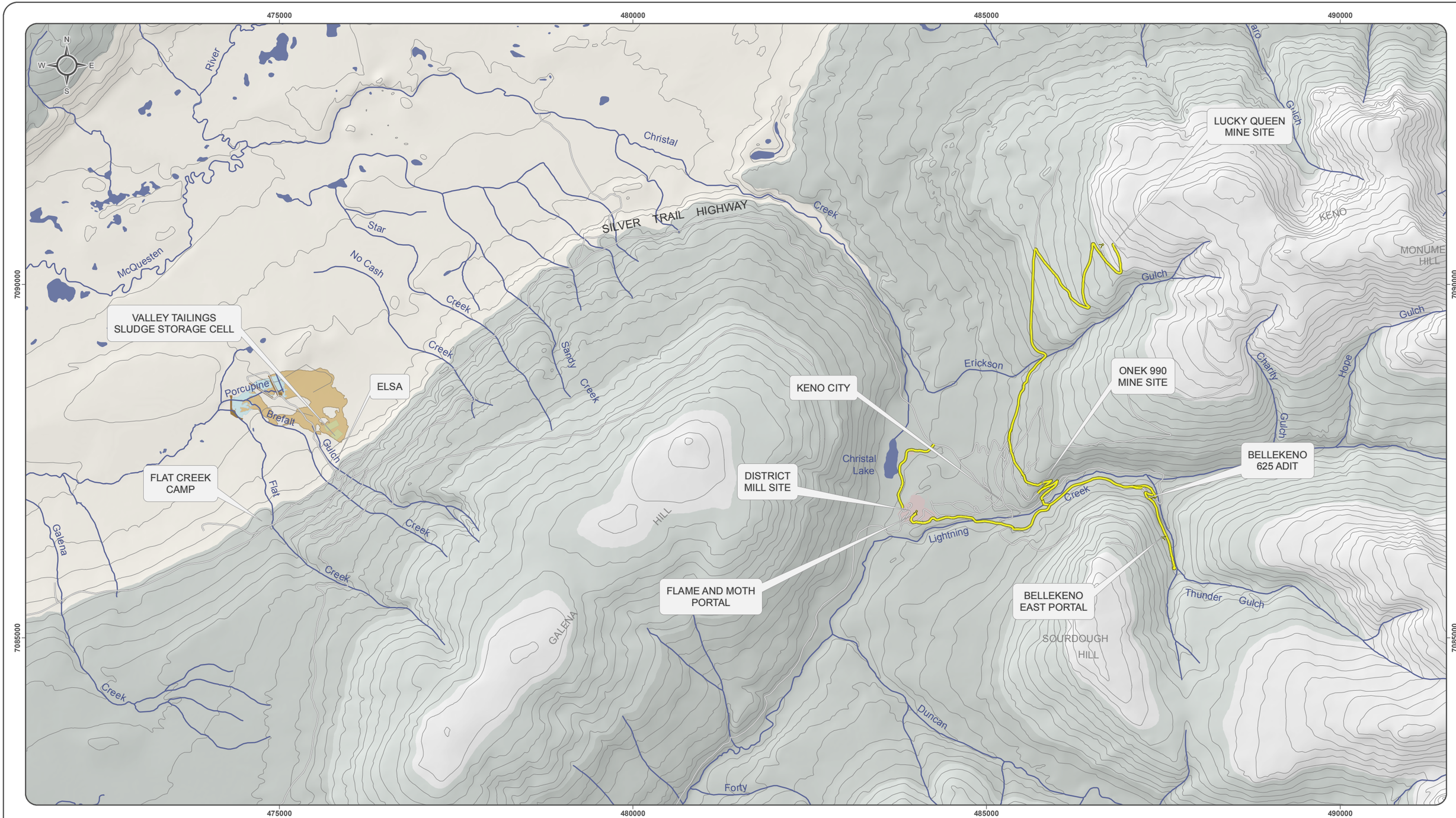
Closure and reclamation planning for the entire KHSD (District Closure Plan) is currently being developed in accordance with the Amended and Restated Subsidiary Agreement (ARSA) between Alexco and AANDC; once approved this plan will be implemented.

1.2 PROJECT SCHEDULE

Active mining and milling operations are currently suspended at the Keno Hill Mine Operations. Table 1-2 summarizes the project schedule from its current status through the completion of the LOM plan.

Table 1-2 Project Schedule

Year	Summary of Main Project Activity
2014	Amend QML-0009 for development and production of Flame and Moth deposit Begin development of Flame and Moth underground decline
2015	Continue development of Flame and Moth Amend WUL 09-092 for milling of Flame and Moth ore Recommence development and production at Bellekeno mine Begin production at Flame and Moth mine
2016	Continue mining at Flame and Moth Recommence development at Lucky Queen mine Bellekeno mine production finishes
2017 - 2020	Continue mining at Flame and Moth and Lucky Queen



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

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

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

0 0.5 1 2 Kilometers

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

AKHM

ACCESS

KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 1-2 PROPERTY OVERVIEW

JANUARY 2014

I:\Keno_Area_Mines\ALL-SITES\Closure\2014\Property_Overview_20140115.mxd
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475000 480000 485000 490000

7090000 7085000

N W E S

KHSD SLUDGE POND
- Truck dewatered sludge to DSTF

FLAT CREEK CAMP
- Downsize camp (remove ATCO traillers) for ongoing use during care & maintenance and exploration activities

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

DRY STACK TAILINGS FACILITY
- Recontour and install evapotranspiration cover
- Ensure adequate run off management
- Decommission ponds and comission bioreactor (if required)
- Truck Mill pond water to BK625 for Treatment

FLAME AND MOTH MINE
- Decommission underground workings
- Remove all site infrastructure
- Re-handle P-AML waste rock from temporary WRSF underground
- Secure adit entrance
- Reclaim portal pad
- Seal vent raise
- Treat mine pool (if required)
- Ensure adequate site run off management

LUCKY QUEEN AND ONEK MINES
-Decommission underground workings
- Remove all site infrastructure
- Secure adit entrance
- Reclaim portal pad
- Recontour and re-vegetate N-AML WRDAs
- Recontour and cover P-AML WRSFs
- Seal vent raise
- Ensure adequate site run off management

ACCESS AND HAUL ROADS
- Remove culverts & Lightning Creek Bridges
- Recontour, scarify, and re-vegetate road surface
- Re-slope banks

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

SEE FIG 7-9 SEE FIG 7-8 SEE FIG 7-11 SEE FIG 7-1

MILL SITE KENO CITY

Wernecke Road SILVER-TRAIL HIGHWAY

Christal Creek Christal Lake Lightning Creek Thunder Gulch Forty Pup Creek Sandy Creek Star Creek No Cash Creek McQuesten River South River Porcupine Creek Brefalt Creek Gulch Flat Creek Galena Creek Creek Gulch Gulch Gulch Eric

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

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

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1:55,000 (when printed on 11 x17 inch paper)

0 0.5 1 2 3 Kilometers

Adit
Haul Road
Road
100 meter contour
Watercourse
Waterbody
Sludge Storage Cell

AKHM ACCESS

KENO HILL SILVER DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 1-3

SITE RECLAMATION AND DECOMMISSIONING PLAN COMPONENTS

JANUARY 2014

I:\Keno_Area_Mines\ALL-SITES\Closure\2014\Site_Reclamation_Plan_20140115.mxd
(Last edited by: jpan; 1/17/2014/4:20 PM)

2 RECLAMATION AND CLOSURE PLANNING

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

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

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

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

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

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

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

2.1 COMPREHENSIVE COOPERATION AND BENEFITS AGREEMENT

Alexco and the First Nation of Nacho Nyak Dun have in place (signed June 2010) a Comprehensive Cooperation and Benefits Agreement (CCBA).

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

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

2.2 CONSULTATION AND ENGAGEMENT

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

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

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

2.3 PROGRESSIVE RECLAMATION

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

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

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

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

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

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

2.4 REVEGETATION

2.4.1 Cover Engineering Design Parameters

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

1. Sufficient growth media will be identified from existing borrow stockpiles in the DSTF and Mill areas and left in place to construct a 0.25 meter storage and release cover over the DSTF.
2. Sufficient growth media will be identified and used to construct the soil/vegetative cover over the waste rock disposal areas containing N-AML material. The volume of material that will be required is yet to be determined as this material will be used for road and other construction purposes insofar as possible over the life of the mine.
3. Sufficient growth media will be identified and used to construct the soil/vegetative cover over the waste rock storage facilities, in the case that additional facilities are required after the rehandling of P-AML to the underground. All P-AML WRSFs will be covered with growth media, the volume of which will be determined upon design and construction of the facilities.
4. Growth media will be spread in those recontoured slopes that do not contain the necessary fines content to promote successful revegetation.
5. The growth media if any that remains in stockpiles will be recontoured and revegetated.

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

2.4.2 Revegetation Design Characteristics

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

50% Violet Wheatgrass

20% Kentucky Bluegrass

20% Red Fescue

10% Alfalfa

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

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

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

2.5 RECLAMATION RESEARCH

Reclamation research is an important part of the closure planning process as the results are used to support the site specific refinement of closure measure designs implemented at sites during final closure. There are currently a number of reclamation research programs underway as part of the District Closure Plan that are co-funded and managed by Alexco. These current programs have direct application to the reclamation and closure of the Keno Hill Mine Operations and Alexco will continue to utilize the research programs underway within the District Closure Plan for planning and optimization of the Keno Hill Mining Operations RCP. The following reclamation research programs

are currently in progress and the results will be utilized for reclamation and closure planning of the Keno Hill Mine Operations:

- progressive reclamation on the DSTF;
- cover system design and field trials;
- site revegetation field trials;
- bioreactor trials;
- natural attenuation studies;
- in situ mine pool demonstration

Alexco will initiate additional reclamation research programs during the ongoing update and optimization to the Keno Hill Mine Operations RCP process progresses. Details on any reclamation research programs will be included in subsequent revisions to this RCP.

2.5.1 Progressive Reclamation DSTF

Progressive reclamation on the DSTF is ongoing with cover and revegetation completed in 2012 and 2014 in areas of the DSTF that have reached their final design footprint (Figure 2-1). Results of the DSTF progressive reclamation provides important reclamation research results on a full scale basis.



Figure 2-1 DSTF Progressive Reclamation – September 2013

2.5.2 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 facilities in the RCP. The cover field trials consists of 12 cells (1 m x 1m).

Once the cover plots have been constructed, a scheduled maintenance program to retain the plots will be ongoing including instrumentation and logging, a biomass sampling program and monitoring activities such as water quality sampling of the infiltration water, seasonal data downloads, and additional reporting.

Typically monitoring tasks will include:

- Regularly scheduled data capture;
- Bi-annual water quality sampling of cover trial discharge (where possible);
- Equipment and site inspection;
- Field observations;
- 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 3 years of monitoring cover and vegetation performance. Sampling will take place at the end of the first growing season and repeated again in years 2 and 3. 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.

2.5.3 Site Revegetation Field Trials

Terrestrial reclamation of mine sites requires an understanding of environmental conditions to develop prescriptions that will have a better chance of success. To date, significant reclamation research has been completed on the ecosystem mapping program at the former UKHM site to

understand successional, soil, and nutrient regimes, data collection on soil metals and metals uptake by vegetation, seed collection workshops, biochar amendment trials in the valley tailings and biomass sampling while continuing to develop a clear understanding of successional relationships with disturbed soils and metals uptake.

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

2.5.4 Bioreactor Trials

Alexco Environmental Group operated a test bioreactor at the Galkeno 900 mine site between October 2008 and May 2011. 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. 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 can be found in the detailed report on the operation and performance of the Galkeno 900 bioreactor (Appendix 4). 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 was slowly released

from the reactor. Conservative elements showed less than 10% change during passage through the bioreactor, including calcium, magnesium, silica, sodium and strontium, demonstrating that dilution was 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.

The results of the Galkeno 900 bioreactor field program have direct correlation to the design and operation of a bioreactor at Bellekeno upon closure. A detailed report on the Galkeno 900 bioreactor trial is included as Appendix 4.

2.5.5 Natural Attenuation Studies

Although natural attenuation of metals in native materials (peat and organics) is not a primary treatment technology proposed in the RCP, information and knowledge from the effectiveness of natural attenuation is important research that provides a better estimation and modelling of potential environmental effects from perpetual discharges. Significant field and laboratory work has been completed on the effectiveness of natural attenuation for removal of metals in effluent discharge. The bulk of this work has focused on metal removal observed in No Cash Creek, although mineralogical characterization of metal precipitates in Husky SW and Silver King have also been performed. The metal removal processes identified at No Cash Creek are also thought to occur at Husky SW and Silver King.

Near the No Cash 500 adit, iron, manganese and zinc (oxyhydr)oxide minerals, notably ferrihydrite, birnessite and (hydro)hetaerolite, precipitate out of adit discharge water quickly resulting in significant dark orange sediment near the adit portal. These mineral reactions occur regardless of hydrologic or seasonal variability. Zinc is present as authigenic Zn-bearing mineral phases ((hydro)hetaerolite, hydrozincite), or co-precipitated/sorbed on iron and manganese oxyhydroxides. Cadmium is almost exclusively present as a sorption complex and although the sorbent could not be directly elucidated, the strong correlation between Cd and Zn in the sediments suggests they have similar mineralogical hosts (likely iron and manganese oxyhydroxides). Surficial sediments, as well as buried sediments are of similar mineralogy and environmental stress testing of these sediments has indicated that elevated temperatures, pH and lowered alkalinity do not significantly impact the precipitate stability. A switch to reducing conditions in the stability testing did result in marked Zn and Cd release to solution, however, the low organic carbon content in the adit reach/upper hydrologic area effectively restricts the development of such conditions within the sediment column.

Furthermore, microbiological testing of these sediments indicated they had limited populations of metal- and sulphate-reducing bacteria. Zinc and other metals continue to come out of solution along the cascading reach of No Cash Creek as oxyhydroxide phases. Geochemical mechanisms continue during hydrologic or seasonal variability.

As No Cash Creek transitions to its flatter, lower energy bog reach, similar geochemical reactions continue to sequester metals from solution, however, the transition to a higher organic carbon content in stream and surrounding soil horizons results in increased microbial activity and provides additional potential metals attenuation through sulphate reduction and metal-sulphide precipitation (e.g. sphalerite). Small (1 – 3 µm diameter) sphalerite granules have been identified in association with organic material in sediment thin sections and also in the peat itself. The increase in organic material (peat, wood, grasses, etc) also serve as important potential nucleation sites and micro-environments for supporting manganese and iron mineral precipitation reactions. Column experiments indicated that the peat material that underlies the lower reach of No Cash Creek and which is found throughout the District (including beneath the Valley Tailings and DSTF) is a highly effective sorbent, both in saturated and unsaturated conditions. It removed 99% of zinc and 94% of cadmium from 54 pore volumes of water pumped through peat-filled columns. As such, the peat bog may be viewed as a polishing step to the initial massive metals removal further upstream, adding redundancy to the natural attenuation process. Seasonal and hydrologic variability do not adversely affect the metals attenuation in this reach. Carbon accumulation in the bog is robust and consistent with observations from other comparable bogs, with carbon generation being more than sufficient for sustainable attenuation of all zinc generated from the No Cash Adit.

The natural attenuation studies performed to date have been synthesized into a summary report as part of the District closure program (Interralogic, 2013).

2.5.6 *In Situ* Mine Pool Treatment Demonstration

A site specific large scale technology demonstration project commenced in August 2014 to evaluate the suitability of *in situ* treatment mine pool treatment technology at the Silver King mine. Although the Silver King mine is not subject to the Keno Hill Mine Operations RCP, the results of this test will provide additional support and design criteria for implementation at Bellekeno for closure and treatment of the mine pool.

The first phase of this program was completed in October 2011 when ERDC installed a vertical 110 metre 6" borehole, a 25 hp pump, 584 metres of 4" HDPE pipeline, and controls/monitoring equipment to begin the process of dewatering the Silver King mine.

In late February 2012, ERDC completed the installation of this system and began pumping water from the historical Silver King workings. During that time, preliminary information was gathered about the existing void space found in the Silver King underground workings and tracked as the system dewatered. ERDC installed a flow meter with a data logger as well as a level sensor that could be used to capture and plot this information as it was collected.

Whenever the pump was shut off the backfill mine flooding rate provided information about the recharge rate coming into the underground workings, either from the surrounding aquifer or from

adjacent, connected mine zones. Based on this work, it is possible to estimate a preliminary volume estimate for the mine pool and affected mine workings.

During March 2013, preliminary engineering calculations were performed to determine aspects of the in situ treatment system and treatment strategies.

The results from the initiation of in situ treatment pump testing will be used for the initial evaluation of the appropriate dose of additional in situ treatment reagents to continuously maintain water quality. As results are obtained through the year, this dosage and recirculation strategy will be re-evaluated several times, and pumping rates and injection locations may be changed multiple times. The goal of the treatment for the year is to allow the water that overflows from the mine to be of sufficiently good water quality to achieve direct discharge without subsequent treatment. The reagents selected and the dosing rate of those reagents will be chosen to achieve this goal. A key variable will be the selection of the appropriate carbon source to allow for essentially complete degradation of the added carbon source prior to discharge. This year's work focuses on achieving the carbon source dosage required in the mine pool to maintain a sufficient reduction in metals concentration, and also refining the type of carbon reagent to achieve treatment (planned to be a sugar source followed by an alcohol reagent).

Water from the dewatering well will be pumped to the surface, and amended with a carbon source, and reinjected. There are several injection points that will be considered based on the findings from the 2012-2013 initial treatment and dewatering study. Access to the mine pool can be attained through either the newly installed 6" borehole or the 8" borehole which was installed in the prior mine construction in the 1980s. Additional injection locations may include the open pit area and old shaft areas.

As part of this project, a tracer may be added at one of the listed injection points and then tracked to determine residence time between points or from injection locations to the 100 adit overflow, or from injection points to the pumping borehole. This effort will aid in determining underground flow rates and transport times between different zones which will help in the selection of reagent types. In a general sense, if there is sufficient residence time, a sugar or starch-based reagent is ideal for longer residence type treatment configurations, and alcohol based reagents are ideal for shorter residence treatment configurations.

2.6 DATA COLLECTION PROGRAMS AND DEVELOPMENT OF DESIGN PARAMETERS

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

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

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

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

3 CLOSURE OBJECTIVES AND DESIGN CRITERIA

Yukon Government EMR has developed a Schedule which details specific objectives for the RCP to achieve in closure. The objectives of that schedule are reproduced here and referenced according to where in the RCP they are adhered to (Table 3-1). A schedule outlining requirements for terrestrial performance standards has also been developed and is summarized in Table 3-2.

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

a. (geo)chemical stability;

b. water quality;

c. physical stability; and,

d. land use, aesthetics and public health and safety.

Closure principles and objectives work to ensure both physical stability and chemical stability of the site in the long term and are reflective of the guidelines derived from YG's Reclamation and Closure Policy. The effectiveness of closure measures implemented from this RCP will be the subject of review by regulatory agencies and under the Quartz Mining Act, the company would be able to apply for a certificate of closure from the Yukon Government once there is agreement with their effectiveness. The following primary closure objectives were emphasized during the development of this plan.

1 **Protect Public and Worker Health and Safety**

2 **Protect and Restore the Environment by:**

   i. incorporating progressive reclamation where possible;

   ii. providing slope stabilization and erosion control on linear and non-linear disturbances;

   iii. ensuring long-term chemical stability of the N-AML waste rock disposal areas and components constructed from waste rock to minimize effects to downstream aquatic resources;

   iv. ensuring the long term chemical stability of materials placed into the dry stack tailings facility;

   v. ensuring the long-term physical stability of key structures such as the dry stack tailings facility, Bellekeno, Onek 990 and Lucky Queen portals, P-AML waste rock storage facilities, and access roads; and

   vi. conducting post closure monitoring of the site and adaptive management to assess effectiveness of closure measures for the long term;

3 **Ensure Land Use Commensurate with Surrounding Lands**

4 **Ensure Meaningful Participation of the FNNND**

5 **Ensure Cost Effectiveness**

6 **Realize a Walk-away Closure Scenario**

Table 3-1: EMR RCP Requirements Reference List	
Closure Plan Requirement	**Document Location**
(a) A statement of the objectives to be achieved as a result of reclamation and closure of the site;	**Section 3**
(b) an analysis of the measures required to be implemented to ensure the ongoing physical and chemical stability of the site;	Bellekeno Mine (**Section 7.1**) Onek Mine (**Section 7.1**) Lucky Queen Mine (**Section 7.1**) Flame and Moth Mine **(Section 7.1)** Waste Rock (**Section 7.3**) Roads (**Section 7.6**) Camp (**Section 7.4.6**) Mill and Infrastructure (**Section 7.4**) Dry Stack Tailings Facility (**Section 7.2)** Hazardous Materials (**Section 7.5**)
(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;	Closure Monitoring and Maintenance (**Section 7.8**) Adaptive Management (**Section 7.9.3**)
(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 Lightning Creek bypass road and any other roads at the site, and ore stockpiles	Project Description (**Section 5**) Final Reclamation and Closure Measures (**Section 7**)
(f) a program and implementation schedule for the removal of all infrastructure at the site, including the mill and all infrastructure, camp and roads	**Section 7.4**
(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 (**Section 7.3**)
(h) a program and implementation schedule for progressive reclamation to be carried out during development and production	**Section 8.1**
(i) a program for revegetation of disturbed areas, including a description of how soils will be tested for quality and quantity of nutrients and organic matter to support plant growth and a description of the seed mix to be utilized;	**Section 2.4**
(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 7.2**
(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 7.8**) Adaptive Management (**Section 7.9.3**)
(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, 6.2**
(n) updates on the collection and interpretation of hydrogeological information, related geochemical effects and water discharge from the mine;	**Sections 7.1.2; 7.1.3; 7.8**
(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;	Closure Monitoring and Maintenance (**Section 7.8**) Adaptive Management (**Section 7.9.3**)
(p) description of the quantity and quality of available organic material and borrow material stockpiles for use in reclamation;	**Section 7.7**
(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 6.1**
(r) details of how technological developments and best management practices will be incorporated into the plan over time;	**Section 2.5**
(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, 8**
(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**
(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 8, 6.2**
(iv) a list equipment required to be on-site ensure that any unexpected water flows or levels or other contingencies are properly managed by the Licensee to protect the environment and human safety;	**Section 5.4, 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 6.0; 7.0; 8.0 and 9.0**
(vii) a cost estimate to implement (i) to (vi), as well as any other activities to be undertaken for a temporary closure of five years.	**Section 9**

Table 3-2: Schedule 1 Requirements for Terrestrial Performance Standards			
Technical Guideline #	**Theme**	**Closure Objective**	**Document Reference**
T-01	Water Retention and Sediment Control Structures	Ensure decommissioning of water retention and sediment control structures, and their appurtenances, in such a way that drainage at, and adjacent to the site, is stable in the long term.	Existing water treatment ponds will be decommissioned and reclaimed (see **Section 7.1.3** for the Bellekeno Mine water treatment facility; **Section 7.4.5** for the Mill Pond; **Section 7.4.1.1** for Bellekeno East water storage ponds; **Section 7.4.2** for Onek water storage ponds; **Section 7.4.3** for Lucky Queen water storage 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 7.1.3**). If monitoring indicates seepage from the DTSF requires treatment, a bioreactor will be installed (**Section 7.2.2**)
T-04	Site Contamination	Prevent exposure to and mobilization of substances that pose a risk to human health and the environment through physical and chemical stability	**Section 7**
T-05	Potential Acid Rock Drainage	Walk-away solution	P-AML and AML waste rock is being stored in a temporary lined facility during operations, and will be rehandled back to the underground below the long-term static water level of the mine at closure. Additional permanent P-AML storage facilities will be constructed according to approved engineering designs, if necessary (see **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 iss physically stable and covered with an evapotranspirative cover at closure to prevent infiltration and promote vegetation (**see Section 7.2**)
T-07	Underground Workings and Openings to Surface	Meet water quality objectives Except for authorized access, prevent inadvertent or intentional underground access that may be a hazard to humans and wildlife Prevent subsidence or changes in the topography that may result in a hazard to humans or wildlife	A rock pile will be constructed to close access to the Bellekeno East Adit (**Section 7.1.2**), Onek 990 adit (**Section 7.1.5**) and Flame & Moth adit (**Section 7.1.7**); an adit bulkhead will be installed at the Bellekeno 625 Adit and Lucky Queen Adit to prevent access and provide the ability to manage water discharge (**Sections 7.1.3 and 7.1.6**); an engineered cap will be placed at the 200 Level Vent Raise (**Section 7.1.4**)
T-08	Terrain Hazards	Terrain hazards at the site should be no more significant hazard to people and wildlife than is present in the surrounding vicinity	**Section 7**
T-09	Mine Rock Piles	Rock piles and dumps must be physically and chemically stable in the long term to prevent erosion, subsidence or collapse, and such that dump runoff and surface drainage meet legal requirements	Waste Rock will be stored in approved, engineered facilities and covered and revegetated at closure (see **Section 7.3**)
T-10	Roads and Other Access	Protect public safety. In decommissioning linear infrastructure, enable pre-mining human and wildlife utilization of the area. If however, an alternative future land use is identified, alternative objectives may be identified	Road decommissioning will occur in a manner commensurate with EMR's Yukon Mine Site and Reclamation Closure Policy (see **Section 7.6**)
T-11	Erosion Control	Physical stability such that upon closure, slopes, excavations and other disturbed lands are in a condition that will limit the incidence of soil erosion, slumping and other instabilities that are likely to impede revegetation of a reclaimed site, pose a threat to public safety, lead to wildlife mortality or cause excessive sediment loads to enter nearby water bodies	Slopes will be regraded to at least 2.5H:1V or better, for physical stability
T-12	Re-vegetation	Ensure physical stability and prevent a temporary loss of wildlife habitat utilization from becoming permanent by re-establishing a vegetative mat (food source, hide, etc.) leading to self-sustaining natural revegetation	Revegetation will occur in a manner that meets or exceeds EMR's Yukon Mine Site and Reclamation Closure Policy (see **Section 2.4**)
T-13	Mine Infrastructure	Ensure physical stability and to remove potential threats to public heath and safety, including identification and removal of hazards and hazardous materials	All infrastructural buildings and equipment will be removed and transported offsite for salvage at the end of mine life (see **Section 7.4**)
T-15	Temporary Closure Site Conditions	Ensure public heath and safety and protection of the environment in the event of a temporary closure and to manage risks associated with potential abandonment of the site	**Section 6**
T-16	Geological Values and Heritage	Ensure post-closure access to geological information obtained both leading up to and during mineral development and production at a mine site	Not applicable

3.1 INTEGRATION WITH DISTRICT-WIDE CLOSURE PLANNING

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

1 **Protect Public and Worker Health and Safety**

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

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

2 **Protect and Restore the Environment**

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

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

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

   i. Minimize access restrictions.

   ii. Reclaim disturbed areas to support future community and traditional land use.

   iii. Preserve identified historical resources.

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

   i. Maximize training, capacity building, and employment and business opportunities for First Nation citizens.

   ii. Maximize training, capacity building, and employment and business opportunities for local residents and Yukoners.

5 **Minimize Project Related Liability and Risk**

   i. Minimize risks associated with project implementation.

   ii. Minimize post-closure residual liabilities.

   iii. Minimize post-closure risks.

6 **Minimize Cost**

   i. Minimize project implementation costs.

   ii. Minimize post-closure operations and maintenance costs.

3.2 CLOSURE AND DESIGN CRITERIA

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

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

3.3 SITE CONDITIONS FOR COMPLETION CRITERIA

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

3.3.1 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. This means surface waters and groundwater will be protected against significant adverse environmental effects resulting from discharges. In addition, discharges will not endanger public and wildlife health and safety, nor result in unacceptable deterioration of environmental resources.

Aspects to be monitored closely will include short-term and long-term changes in underground mine pool water quality seepage and runoff from the DSTF and waste rock storage areas and the chemistry

of surface water draining from the site. Potential effects due to any acid rock drainage via surface or ground water will be mitigated. The success of physical reclamation will influence chemical and physical stability.

3.3.3 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 AREA COMPONENTS

Each of the Mine Area Components will reach their completion criteria at varying times in the operations and post-mining period, but all will follow the same three stages of reclamation in systematic order. In addition, adjustments to the reclamation schedule will be expected due to modifications made from new innovations in reclamation practices, seasonal climate variability and/or geotechnical setbacks. Table 3-3 Table 3-3 provides a general overview of each Mine Area Component and the site conditions associated with meeting completion criteria.

Table 3-3 Keno Hill Mining Operations Reclamation Units Completion Criteria

Reclamation Units	Completion Criteria Conditions		
	Physical Stability Requirements	Chemical Stability Requirements	Biological Stability Requirements
Underground Mines			
Bellekeno Onek Lucky Queen Flame and Moth	Salvageable equipment removed. All other equipment cleaned of hydrocarbons. Infilling of underground stopes with P-AML waste rock and tailings material Mine openings stabilized, barricaded and free-flowing with respect to water, where applicable	All chemicals and contaminants remediated or removed	N/A
Waste Rock Storage Facilities			
Bellekeno Benched N-AML WRSF Bellekeno Temporary P-AML Facility Onek Permanent P-AML Facility Lucky Queen P-AML Facility Flame and Moth Temporary P-AML Facility	Stable slopes WRSFs covered where applicable No significant wind or water erosion	No ARD or metal leachate seepage concerns	Safe wildlife access
Water Management Structures			
Treatment Facility Settling Ponds Mill Process Pond	All impediments to normal hydrologic conditions broken down to re-establish hydrologic flow BK 625 ponds converted to geotechnically-stable bioreactors; mill pond liner removed and stable	All chemicals and contaminants remediated or removed	Safe ingress/egress for wildlife
Water Diversion Structures			
DSTF diversion berms	No significant erosion along channel banks and banks of dam structures Permanent, stable channel for Bellekeno 625 ongoing discharge from bioreactor decant pipe to Lightning Creek	All chemicals and contaminants removed	
Sedimentation Pond			
	No exposed sedimentation areas No significant wind erosion	Effluent quality requirements as required by the Water License	
Mill Site			
Mill Building Mill Office and Dry Electrical Substation Crushing Plant Fine Ore Stockpile Crusher MCC Assay Lab Mill Motor Control Centre Fresh Water Tank Diesel Storage Tanks Propane Tank Mill Wastes Buried Infrastructure	All infrastructure disassembled and removed Infrastructure supports and foundations removed or buried and berms broken down	All processing chemicals, contaminants and ore stockpiles removed	Sustainable vegetation cover
Dry Stack Tailings Facility			
DSTF Phase 1 DSTF Phase II	DSTF covered with an evapo-tranpirative cover and vegetation No significant erosion or infiltration Tailings geotechnically stable	Any seepage reporting to Christal Creek watershed will not exhibit an adverse (measureable?) impact	Wildlife access
Bridges and Culverts			
Lightning Creek Bridge (Keno City Bypass Road) Lightning Creek Bridge (Onek 990) Culverts	Stream and cut banks are stable and have no significant erosion Lightning Creek bridge is removed	All chemicals and contaminants remediated or removed	
Flat Creek Camp			
	Camp downsized to pre-production level Areas where camp buildings have been removed stable with no significant wind or water erosion	All chemical spills and contaminants remediated or removed	Sustainable vegetation cover
Linear Disturbances			
Roads Transmission Lines	No significant erosion along road banks and areas where culverts have been removed	All chemical spills and contaminants remediated or removed	Sustainable vegetation cover

4 ENVIRONMENTAL AND SOCIO-ECONOMIC DESCRIPTION

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

Table 4-1 summarizes existing environmental conditions in the Keno Hill Mine Operations project area. The Keno Hill Silver District lies within the Yukon Plateau – North Ecoregion, just south of the Wernecke Mountains. The terrain consists of concordant, rolling, upland areas separated by wide valleys. Alpine mountain peaks extend above the uplands locally. Many valleys include peatlands, palsas, fens and meadows of sedge tussocks. Upper slopes may be covered with scree material, with treeline occurring at 1,350 to 1,500 m. The area has been influenced by the latest glaciation but shows more subtle evidence of an earlier event as well.

Table 4-1 Keno Hill Silver District Environmental Setting Summary

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

4.1 CLIMATE

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

Because of its northern latitude, winter days are short with the sun low on the horizon such that north facing slopes can experience ten weeks without direct sunlight around the winter solstice. Conversely, summer days are very long, especially in early summer around the summer solstice. Annual

precipitation averages 28 centimetres (cm); half of this amount falls as snow, which starts to accumulate in October and remains into May or June.

Meterological data is collected at a meteorological station located adjacent to the District Mill and DSTF (at an elevation of 935 masl). The sensors on this station include air temperature, relative humidity, rainfall, pyranometer, and wind speed and direction. Table 4-2 summarizes data collected to date at the Keno District Mill.

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

Month	Extreme Maximum Temp (ºC)	Average Maximum Temp (ºC)	Average Temp (ºC)	Average Minimum Temp (ºC)	Extreme Minimum Temp (ºC)	Average Relative Humidity (%)	Total Rain (mm)	Average Wind Speed (m/s)	Extreme Maximum Wind Speed (m/s)	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)
Jun -11	24.72	18.59	11.96	6.30	-2.56	n/a	n/a	1.35	9.14	n/a	n/a
Jul-11	25.67	18.50	12.91	8.00	5.09	n/a	n/a	1.15	8.02	n/a	n/a
Aug-11	22.32	15.58	9.78	5.37	1.93	n/a	n/a	1.18	9.15	n/a	n/a
Sep-11	17.97	11.29	6.07	1.85	-2.47	n/a	n/a	1.43	11.36	n/a	n/a
Oct-11	7.20	0.20	-2.74	-5.41	-9.84	n/a	*2.60*[3]	0.94	13.12	n/a	n/a
Nov-11	-4.23	-16.79	-19.54	-22.47	-34.99	n/a	0.00	0.58	12.05	n/a	n/a
Jan-12	-0.96	-19.10	-23.13	-26.79	-37.32	n/a	0.00	*0.59*	*9.51*	n/a	n/a
Feb-12	2.77	-6.77	-10.00	-13.07	-26.78	n/a	0.10 [4]	*1.38*	*15.62*	n/a	n/a
Mar-12	5.33	-7.69	-13.37	-18.00	-27.80	n/a	0.00	*0.97*	*9.24*	n/a	n/a
Apr-12	9.69	6.13	0.96	-3.87	-15.92	n/a	0.60 [4]	1.37	10.27	n/a	n/a
May-12	17.78	10.73	6.31	1.91	-3.47	*51.81*	18.30	1.78	10.60	n/a	n/a
Jun-12	27.62	18.41	13.46	8.29	4.42	56.35	21.70	1.44	10.26	n/a	n/a
Jul-12	25.14	18.07	12.75	7.73	1.64	69.26	85.80	1.36	12.99	n/a	n/a
Aug-12	21.72	16.31	11.25	6.56	-0.89	67.79	47.00	1.62	9.41	n/a	n/a
Sep-12	20.24	10.33	5.90	2.08	-5.22	69.51	36.40	1.84	14.27	n/a	n/a
Oct-12	7.60	-3.95	-7.35	-10.32	-20.62	79.54	7.60	1.13	10.37	n/a	n/a
Nov-12	-8.98	-19.55	-21.90	-24.32	-33.36	81.43	0.00	0.94	9.36	n/a	n/a
Dec-12	-3.36	-21.30	-23.44	-25.58	-36.32	81.34	0.00	*0.26*	*5.93*	*1.01*	*0.05*
Jan-13	-1.59	-17.06	-20.01	-23.08	-41.48	82.92	0.00	*0.76*	*14.48*	1.06	0.81

Month	Extreme Maximum Temp (ºC)	Average Maximum Temp (ºC)	Average Temp (ºC)	Average Minimum Temp (ºC)	Extreme Minimum Temp (ºC)	Average Relative Humidity (%)	Total Rain (mm)	Average Wind Speed (m/s)	Extreme Maximum Wind Speed (m/s)	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)
Feb-13	1.54	-9.10	-12.52	-15.46	-23.74	88.36	0.30 [4]	*0.85*	*12.25*	10.26	1.27
Mar-13	3.26	-7.52	-13.16	-17.99	-29.96	64.08	3.90	1.59	12.47	95.82	6.33
Apr-13	6.07	-2.76	-7.94	-13.69	-25.07	54.50	8.20	2.44	12.93	190.02	14.48
May-13	23.31	10.20	5.27	0.23	-9.46	61.83	39.60	1.77	11.76	215.44	21.70
Jun-13	30.51	19.97	14.27	8.30	1.84	58.72	57.30	1.82	12.87	234.69	29.79
Jul-13	24.93	19.40	14.01	8.60	2.25	62.67	46.90	1.75	16.14	211.00	27.10
Aug-13	27.34	18.54	12.98	8.01	-0.38	66.30	51.90	1.49	11.05	156.25	21.38
Sep-13	16.11	9.69	5.81	2.26	-3.74	77.52	59.70	1.54	10.99	79.69	10.88
Oct-13	8.25	1.61	-1.32	-4.21	-10.10	86.75	44.60	1.11	11.62	35.75	4.26
Nov-13	0.18	-13.41	-16.68	-20.08	-37.96	84.26	10.60	*1.02*	*10.96*	4.93	*1.08*
Dec-13	-1.73	-21.23	-23.91	-26.70	-35.29	78.77	4.90	*0.75*	*9.47*	0.57	*0.62*
Jan-14	3.74	-9.33	-12.16	-15.10	-32.22	89.44	24.9	*0.72*	*10.03*	2.42	*0.64*
Feb-14	-1.93	-15.25	-19.40	-23.02	-33.55	75.20	2.9	0.87	10.85	31.34	1.99
Mar-14	4.57	-5.31	-11.29	-16.16	-26.79	54.77	0.7	1.57	11.98	115.54	9.17
Apr-14	10.93	4.09	-0.96	-5.78	-17.33	57.54	5.1	1.64	12.05	171.28	15.77
May-14	21.30	12.70	7.64	2.03	-3.03	52.18	12.8	2.09	19.21	217.91	29.81
Jun-14	24.93	16.21	11.39	5.95	-0.13	56.14	40.4	1.78	10.43	217.90	28.58
Jul-14	23.44	18.49	13.68	8.73	-0.04	65.01	31.0	1.63	13.38	187.31	23.84
Aug-14	22.09	15.57	10.87	6.93	0.06	74.59	67.7	1.44	11.85	139.84	15.72

4.2 SURFACE WATER

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

4.2.1 Christal Creek

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

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

Table 4-3 Christal Creek Catchment Surface Water Monitoring Stations

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

4.2.2 Lightning Creek

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

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

Table 4-4 Lightning Creek Catchment Surface Water Monitoring Stations

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

Alexco provides regular monitoring data, analysis and discussion of trends in our monthly and annual reports submitted as a condition of WUL 09-092 and QML-0009.

4.3 GROUNDWATER

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

A district wide groundwater investigation was initiated in 2013, with single monitoring wells installed at a Keno 700, Sadie Ladue, Onek, Galkeno 900, Galkeno 300, Birmingham, Ruby 400, Husy, Husky SW, and Silver King. Groundwater quality data were collected from these wells which showed elevated concentrations of constituents related to mineralization (sulphate, cadmium, zinc, and arsenic). Further well installation is planned at each site in order to determine hydraulic conductivity and groundwater flow direction.

4.4 VEGETATION AND WILDLIFE

The Keno Hill Silver District supports a variety of wildlife including ungulates, fur-bearers, small mammals, upland game birds and waterfowl. Moose are the most important subsistence animal in the area. Repeated survey work over the last 15 years indicates a healthy, stable moose population that has in recent years reached a maximum level of harvest (Lortie, 2009). Woodland caribou are not presently found in the immediate study area with the exception of the appearance in summer of fewer than 10-12 caribou scattered in very small groups in the Mt. Hinton and Bunker Hill areas. Sheep are not known to inhabit the Keno Hill area.

4.5 SOIL AND BEDROCK

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

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

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

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

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

5 PROJECT DESCRIPTION

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

The Keno Hill Silver District and 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 and Flame and Moth. The RCP incorporates underground mines and deposits that are in a variety of phases including active mines (Bellekeno), permitted and developed (Lucky Queen, Onek) and future mines that are in the permitting and development phase (Flame and Moth). Table 5-1 presents an overview of the Keno Hill Mine Operations project that is subject to this RCP.

Table 5-1 Keno District Mine Operations Overview

Location	0.5 to 4 km from Keno City, 45 km northeast of Mayo, 354 km north of Whitehorse, YT.
Land Position	Alexco Resource Corp. and its wholly owned subsidiary Elsa Reclamation and Development Corp. owns 1,563 claims and leases covering an area of approximately 24,262 ha within the Keno Hill Silver District including the Bellekeno, Onek and Lucky Queen deposit Production Unit Areas. Two Fee Simple lots within KHSD total 59 ha (Lot 960 and Lot 956)
Mines/Ore Deposits	Bellekeno (Active 2010 – 2013, suspended 2013) Lucky Queen, Onek (developed, not active) Flame and Moth (late stage exploration, permitting/development phase)
Mining Method	Year round underground narrow vein cut and fill/ shrinkage/ long hole mining
Current Mine(s) Plan Life	6 years
Current Total Project Life	8 years construction/development/operations/progressive reclamation 1 year final decommissioning and reclamation 5 years closure monitoring and maintenance.
Ore Production Rate	400 tonnes/day (annual average), across 3 mines/deposits (Bellekeno, Lucky Queen, Onek) ~660,000 tonnes of ore in LOM plan
Mine Waste Rock	309,000 tonnes of waste rock produced from underground development
Ore Mining Schedule	Ore mining for 365 days/year Milling operations 365 day/year

Mill Recovery Process	Conventional flotation process producing separate lead/silver concentrate and zinc concentrate shipped off site for smelting. District Mill location at historic Flame and Moth pit area. Tailings placed in Dry Stack Tailings Facility or underground as paste backfill.
Work Force	~ 200 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 2 drainages, Lightning Creek and Christal Creek. Conventional lime precipitation water treatment at Bellekeno 625 Water treatment plant at Flame and Moth
First Nations	First Nation of Na-Cho Nyak Dun

5.1 HISTORY

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

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

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

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

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

In June 2005, Alexco was selected as the preferred purchaser of the assets of UKHM by PricewaterhouseCoopers Inc. In February 2006, Alexco's purchase of UKHM's assets through a wholly-owned subsidiary, Elsa Reclamation & Development Company Ltd. (ERDC), was approved. Under the Keno Hill Amended and Restated Subsidiary Agreement, Alexco and ERDC are indemnified against all

historical liability, has property access for exploration and future development, and is not required to post security against pre-existing liabilities. ERDC received a water license from the Yukon government in November 2007, giving Alexco free and clear title to surface and subsurface claims, leases, free-hold land, buildings and equipment at Keno Hill. Since Alexco acquired the assets of the Keno Hill Silver District, the following major milestones have been achieved:

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

2009: Underground development and construction at Bellekeno begins;

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

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

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

2013: Temporary suspension of Bellekeno mine operations and milling;

2014: Permitting and development of Flame and Moth mine

5.2 MINING AND MILLING OPERATIONS

5.2.1 Project Schedule

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

The historic mine operations that operated in the Keno Hill Silver District consisted of multiple smaller underground narrow vein mines that provided ore to a centralized mill. Alexco is operating in a similar approach whereby more than one underground mine is necessary to provide ample mill feed to a centralized mill (Keno District Mill). The Keno District Mill is designed for 400 tpd and the current LOM mine plan includes a combination of Bellekeno, Flame and Moth, and Lucky Queen operating over a 6 year period. Table 5-2 presents the current LOM plan that is the basis for the RCP. Table 5-3 summarizes the overall LOM project schedule from development/production through final reclamation and closure.

Table 5-2 Keno Hill Mine Operations LOM Plan

Category	2014	2015	2016	2017	2018	2019	2020
Metres Development	885	2690	995	678	887	784	750
Tonnes Ore Mined/Milled		58,312	133,868	121,797	115,403	115,321	115,000
Average Silver Grade (g/t)		719	736	758	673	602	601
Average Lead Grade (%)		2.59	2.46	2.29	1.97	1.58	2.41
Average Zinc Grade (%)		6.10	6.07	5.42	4.82	4.89	6.36
Tonnes Waste Rock Broken	38,711	151,826	23,274	40,832	30,733	31,086	31,000
Tonnes Tailings Generated	-	53,247	122,653	112,382	107,649	108,605	108,300
Tonnes Backfill Required	-	32,566	68,824	69,151	69,284	69,038	64,107

Table 5-3 Keno Hill Mine Operations Production, Reclamation and Closure Schedule

Mine/Activity	2014				2015				2016				2017				2018				2019				2020				2021				2022-2026
	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	
Bellekeno																																	
Development																																	
Ore Production																																	
Reclamation																																	
Flame and Moth																																	
Development																																	
Ore Production																																	
Reclamation																																	
Lucky Queen																																	
Development																																	
Ore Production																																	
Reclamation																																	
Onek																																	
Development																																	
Ore Production																																	
Reclamation																																	
DSTF																																	
Phase 1 Operations																																	
Phase 2 Operations																																	
Progressive Reclamation																																	
Final Reclamation																																	
Facilities																																	
Mill Operations																																	
Reclamation																																	
Post Closure Monitoring & Maintenance																																	

5.2.2 Mining Methods

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

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

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

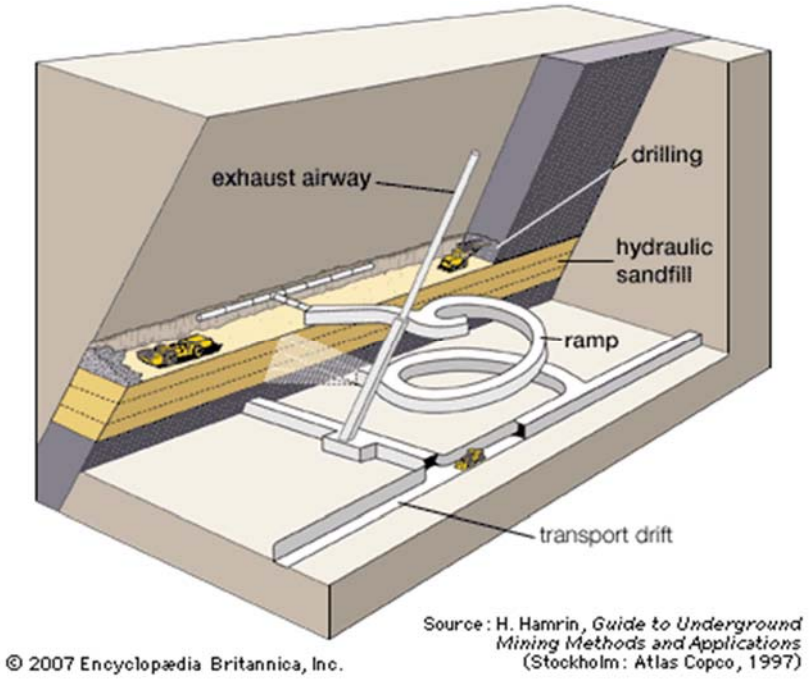


Figure 5-1 Overhand, Mechanized Cut & Fill Mining Methods (Source: Atlas Copco)

Long hole stoping ("LH") is normally used where large blocks of continuous mineralization can be identified and the surrounding rock is reasonably strong (Figure 5-2). Access to the top and bottom of the mineralized

block is provided with drifts. A vertical opening (slot raise) is created within the stope block from the top of the block to the bottom. Long holes are drilled to blast vertical slabs off the mineralized block which is then scooped from a lower drawpoint by an LHD loader.

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

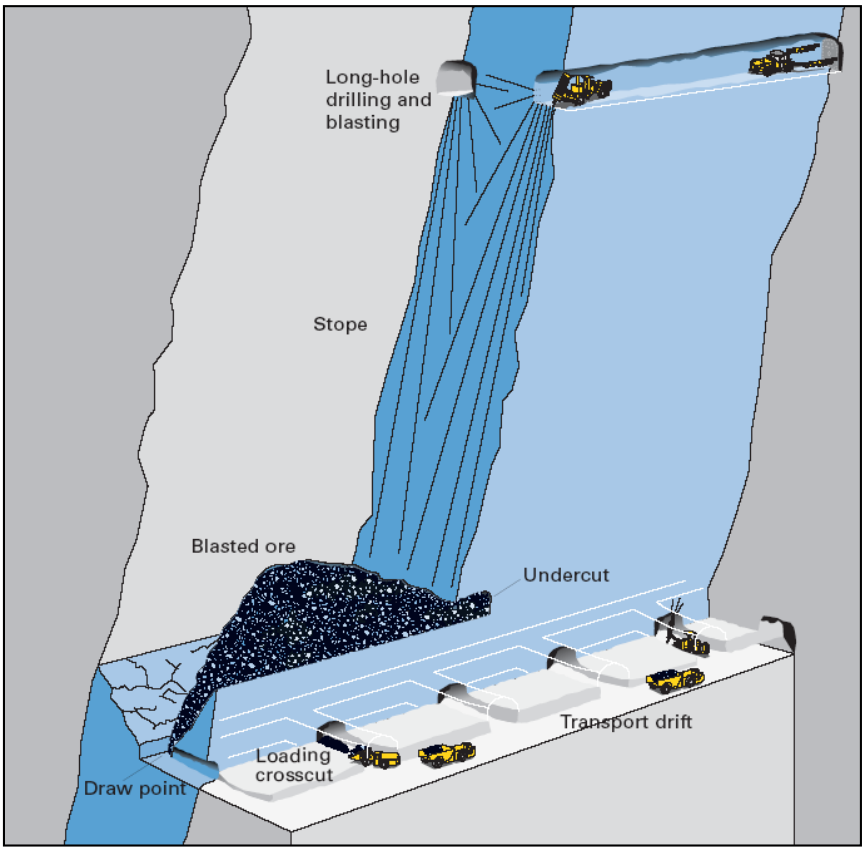


Figure 5-2 Long Hole Mining Method (Source: Atlas Copco)

5.2.3 MILLING PROCESS DESCRIPTION

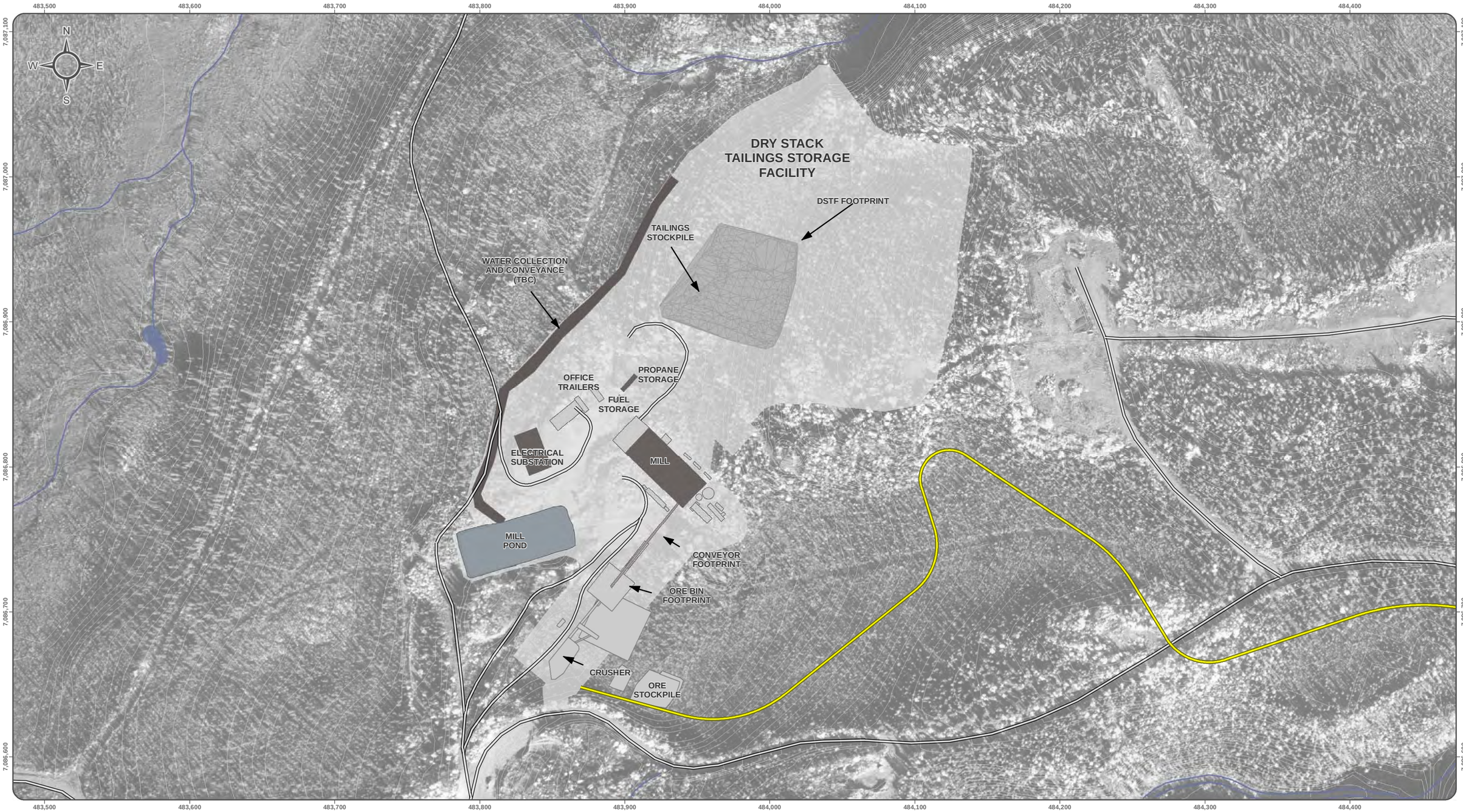
The Keno District Mill is a conventional differential flotation facility producing two separate metal concentrates that are shipped offsite for final processing. Preparatory construction including the mill concrete foundation began in September 2009 while full scale construction of the mill facilities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



Figure 5-3 Mill Infrastructure Overview

5.2.3.1 Mill Design Criteria

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



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

Datum: NAD 83; Projection: UTM Zone 8N

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

0 50 100 150 200 Meters

AKHM
ACCESS

KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 5-4
MILL SITE LAYOUT

AUGUST 2012

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(Last edited by: mducharme;03/08/2012/15:14 PM)

Table 5-4 Mill Design Criteria

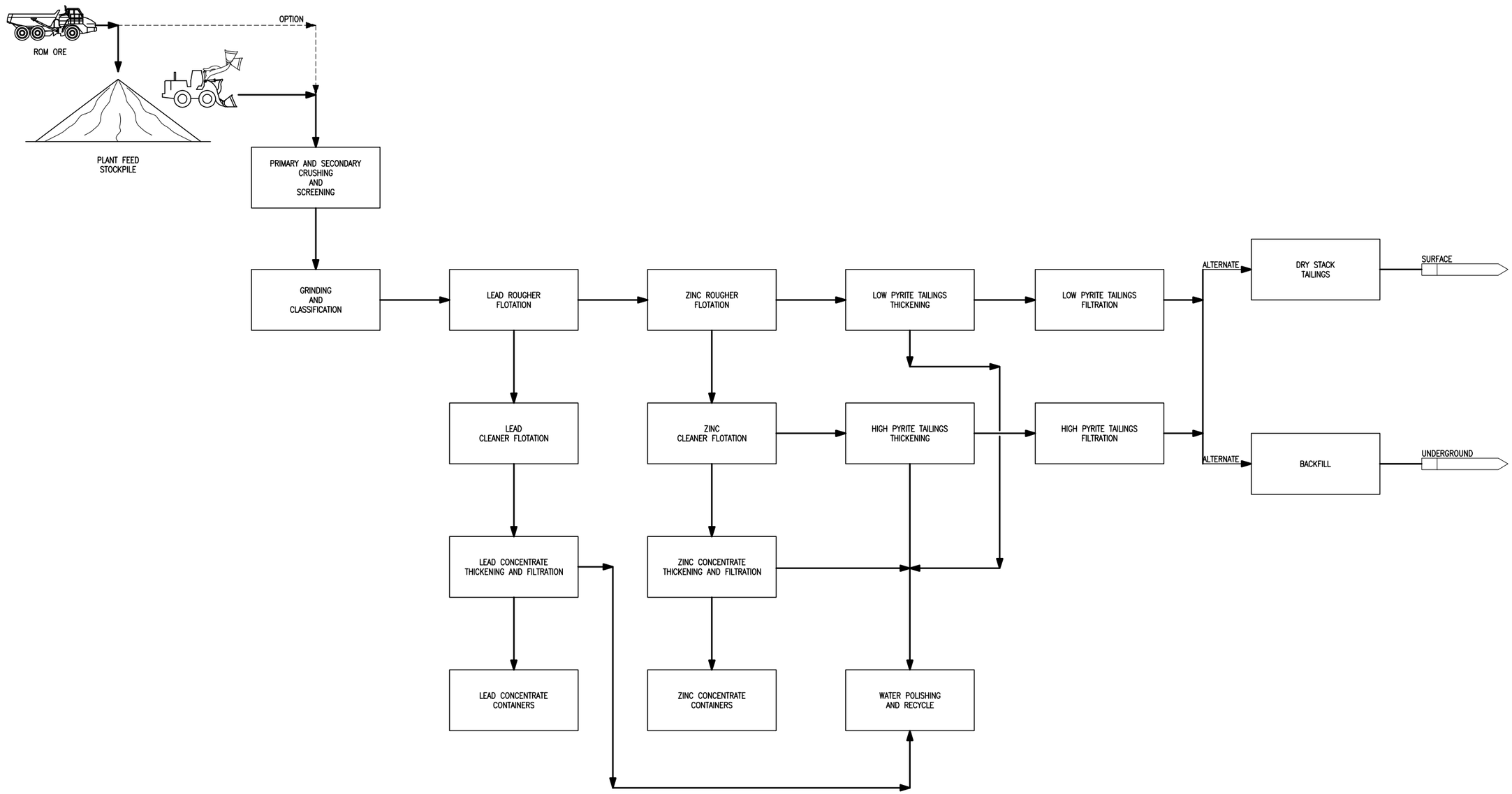
Description	Unit	Value
Type Of Ore Processed		
Silver/Lead/Zinc sulphide mineralization Bellekeno/Lucky Queen/ Onek Mines		
Ore Characteristics		
Specific Gravity	g/cm³	3.46
Bulk Density	t/m³	2.1
Moisture Content	%	3-5
Operating Schedule		
Crusher Plant		
Shift/Day		1
Hours/Shift	h	12
Hours/Day	h	12
Grinding and Flotation Plant		
Shift/Day		2
Hours/Shift	h	12
Hours/Day	h	24
Days/Year	day	365
Plant Availability/Utilization		
Overall Plant Feed	mt/a	149,000
Overall Plant Feed	mt/d	250 - 400
Crusher Plant Availability	%	80.0
Grinding and Flotation Plant Availability	%	92.0
Crushing Process Rate	mt/h	63.8
Grinding/Flotation Process Rate	mt/h	18.5
Head Grades (LOM)	% Pb	4 - 10
	% Zn	5 -12
	g/t Au	0.42
	g/t Ag	500 – 1,000
Recovery (LOM)	Pb %	93
	Zn %	75
Recovery (LOM) including in Pb & Zn concentrates	Au %	70
Recovery (LOM) including in Pb & Zn concentrates	Ag %	92
Silver-Lead Concentrate Grade (LOM)	% Pb	65
	% Zn	2.3
	g/t Au	1.5
	g/t Ag	5,500
Zinc Concentrate Grade (LOM)	% Pb	0.5
	% Zn	45
	g/t Au	1.1
	g/t Ag	300
Silver-Lead Concentrate Mass Recovery (LOM)	%	13
Silver-Lead Concentrate Production (LOM)	t/a	19,000
Zinc Concentrate Mass Recovery (LOM)	%	9
Zinc Concentrate Production (LOM)	t/a	8,000

5.2.4 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 ball milling in a closed circuit with a high frequency screen to produce a grinding product of 80% passing 174 μm;
- the ground high frequency screen underflow feeding to lead rougher scavenger flotation circuit to recover lead and silver minerals; the lead rougher flotation concentrate being upgraded in three stages of cleaner flotation;
- the zinc rougher flotation concentrate being upgraded in three stages of cleaner thickening and pressure filtration of the lead and zinc concentrates
- thickening and pressure filtration of tailings, disposed either at underground as backfill or at the surface dry stack tailings facility.

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



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C	1	ISSUED FOR CLIENT APPROVAL	29JAN10	CC
B	1	ISSUED FOR INFORMATION	09JUL09	AKF
A	1	ISSUED FOR CLIENT REVIEW	21MAY09	CC

CLIENT, PROJMNG, PROLDNG, PROCESS, ELECTR., INSTR., PIPING, MECH., STRUCT., SEISMOS, ARCH., LAYOUT

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

YUKON TERRITORY

ALEXCO

WARDROP | Engineering Inc.

TITLE

BELLEKENO PROJECT (EP)

SIMPLIFIED FLOWSHEET
PROCESS FLOWSHEET No.1

Figure 5-5

FILENAME	PROJECT NUMBER	DRAWING NUMBER	REV.
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5.3 DRY STACK TAILINGS FACILITY

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

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



Figure 5-6 Compacted DSTF Lift

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

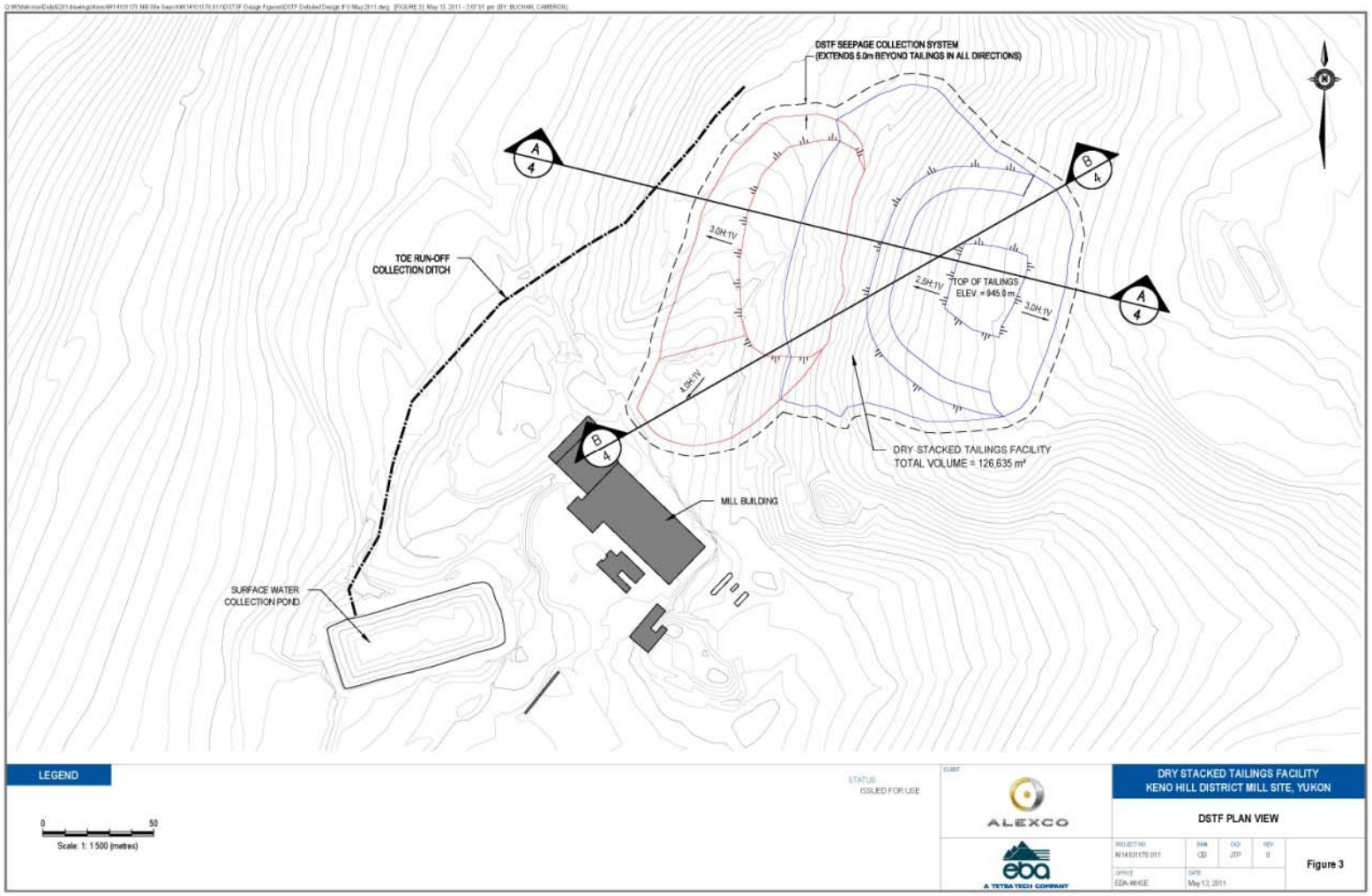


Figure 5-7 DSTF Phase I Plan View

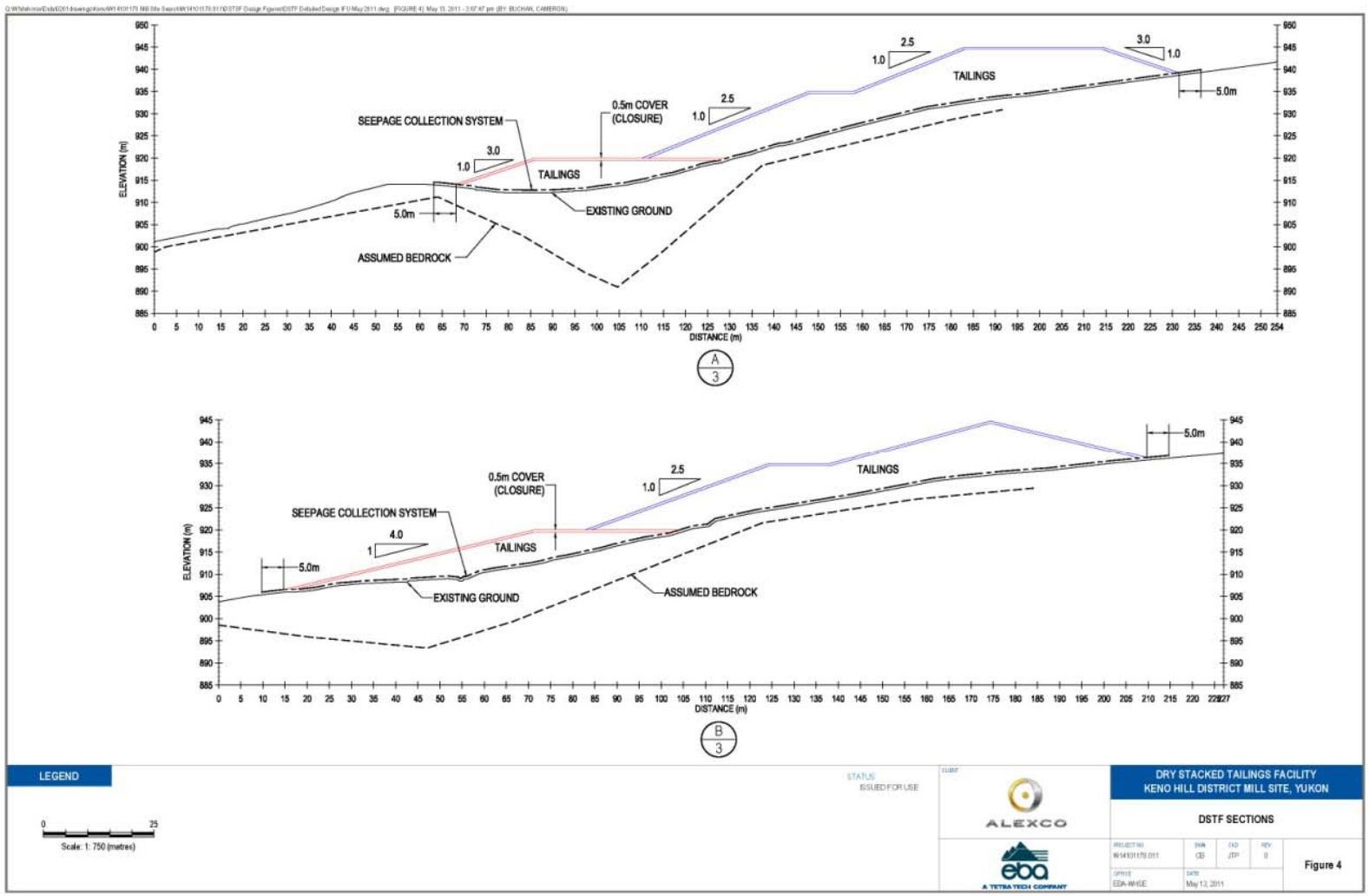
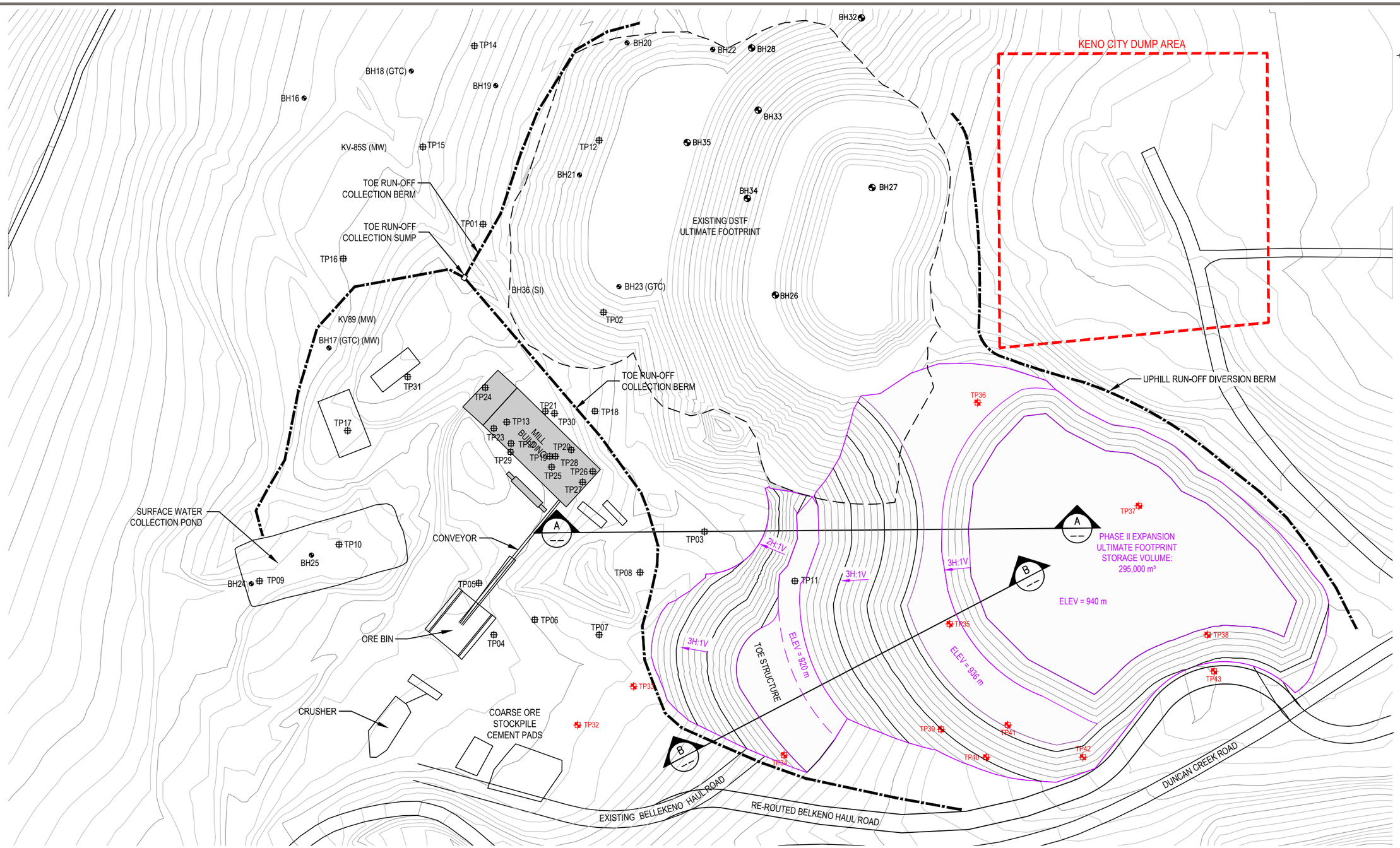


Figure 5-8 DSTF Phase II Sections



LEGEND:

- TESTPIT LOCATION (PREVIOUSLY ADVANCED)
- BOREHOLE LOCATION (PREVIOUSLY ADVANCED)
- TESTPIT LOCATION (PHASE II EXPANSION)

0 100

Scale: 1 : 1750 (metres)

CLIENT

ALEXCO

A TETRA TECH COMPANY

DRY-STACKED TAILINGS FACILITY EXPANSION - PHASE II
KENO HILL DISTRICT MILL SITE, YUKON

SITE PLAN SHOWING PROPOSED EXPANSION FOOTPRINT

PROJECT NO.	DWN	CKD	REV
W14103303-01	CB	JTP	0

OFFICE: EBA-WHSE

DATE: November 14, 2013

Figure 5-9

O:\Whitehorse\Data\0201drawings\Keno\W14103122-01 Keno DSTSF Re-design\DSTF Expansion Options\W14103122-01 DSTF Expansion Option 5.dwg [FIGURE 11] November 14, 2013 - 4:01:09 pm (BY: BUCHAN, CAMERON)

5.4 WATER MANAGEMENT

The water encountered during the development and operation of the Flame and Moth underground workings will either be utilized in the milling process as makeup water or discharged. Discharged water will meet the proposed effluent quality standards to achieve the water quality objectives presented within the application (Type A Water Use Licence QZ09-092 Renewal Application, October, 2014). Treated and released water for Flame and Moth will be managed using new water management facilities located within the current Mill footprint including a water treatment plant and storage/settling pond. Tailings produced will be deposited on the permitted and existing DSTF, as well as in an expanded area of the DSTF, which will be lined.

Given the close proximity of the Flame and Moth deposit and portal to the existing infrastructure at the Keno District Mill, a number of common facilities and infrastructure will be used which will improve the overall efficiency of the operation and reduce any potential environmental and socio-economic effects. A figure showing the project site can be found within the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014 (Figure 1-2 of that package).

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



Figure 5-10 Flame and Moth Portal Location

The Waste Rock Management Plan has been updated to incorporate waste rock generated from the Flame and Moth development (Appendix L, Type A Water Use Licence QZ09-092 Renewal

Application, October, 2014). An increase in the licenced total tonnage of waste rock stored on surface will not be required. Waste rock generated from the Flame and Moth Mine will be used for underground backfill, construction of laydown pads, access roads to the crusher, a toe abutment for the DSTF expansion, base layer for the DSTF expansion and for general construction purposes.

A comprehensive hydrogeological investigation was completed at the Flame and Moth deposit to assess the hydrological conditions associated with development of the deposit. The details of the program are included in Appendix D of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014. The hydrogeological investigation estimates that up to 35 lps of groundwater inflow could be expected and encountered during the operation of the Flame and Moth mine. Management of mine inflows at Flame and Moth is planned to be via underground sumps and pumps, similar to the water management program at the Bellekeno Mine. The water management plan outlines the water management strategy for managing the mine dewatering activities are outline in Table 5-5.

Table 5-5 Project Infrastructure Design and Performance Criteria

Component	Details
DSTF	Licenced and in use – details provided as part of Bellekeno Mine application. Expansion area details provided in Appendix G.
Lucky Queen	
Settling Pond	25m by 40m by 5.3 m/ 2985 m^3 with 291 m^3 of freeboard Located adjacent to Mill pond (Figure 1-2) 0.3 m free board for both ponds based on 24 hour maximum rain event of 37.7 mm Preliminary drawing provided in the preliminary design report (Appendix H) and in the Water Management Plan (Appendix I)
Water treatment plant	Treatment of up to 3,024m^3/day at proposed effluent quality standards. Additional details are provided (Appendix J).
P-AML WRSF	Technical memo specific to the Flame and Moth temporary P–AML WRSF is provided (Appendix K).
Water Pipelines	6” pipeline to Christal Creek to accommodate 23 L/s 5”pipeline to Lightning Creek to accomodate12L/s (Appendix I)

(Appendix references can be found within the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014).

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

Area sumps are planned as follows: two sumps at the lowest areas of Lightning and one at the lowest area of Christal. These sumps will be equipped with 45 kW dirty water submersible pumps to pump to the main sump at the 660 m elevation.

Table 5-6 presents details of the water management structures associated with the Flame and Moth Mine. Engineering design drawings are provided in Appendix I of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014.

Table 5-6 Water Management Structures

Component	Details
Settling/storage Pond	25 m by 40m by 5.3m/ 2,985m^3 Located adjacent to Mill Pond
Water treatment plant	See Appendix J

(Appendix references can be found within the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014)

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

Static and kinetic testing was conducted on Flame and Moth drill core samples, spanning all the major lithologies expected to encounter during excavation. The results and interpretation of this testing can be found within Appendix Q of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014. Briefly, ABA, ICP aqua regia digested metals, and shake flask extraction testing indicated that the samples are non-acid generating and the majority have low metal leaching capacity. Similar results were obtained from testing of waste rock from Bellekeno, Lucky Queen, and Onek deposits.

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

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

The preliminary AMP (as well as the approved AMP in place for the Keno Hill Silver District Mining Operations, from which the preliminary AMP has been adapted) includes an “event” for monitoring N-AML waste rock piles and their seepages, and stipulates adaptive management measures to be undertaken if an increasing trend in acid generation or metal leaching is detected. The AMP is included as Appendix R of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014.

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

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

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

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

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

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

Mass load model for Christal Creek and Lightning Creek were developed by Interralogic, Inc. using Goldsim simulation framework. The models were initially prepared for simulating metal loads in Christal Creek and Lightning Creek, and to evaluate the reclamation options (currently being developed) for the Keno Hill Silver District Type 2 Abandoned Mines. Interralogic's revised draft reports, Chemical Mass Load Model for Christal Creek: Description and results: 2013 update (Attachment A of Appendix S of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014) and Chemical Mass Load Model for Lightning Creek: Description and results: 2013 update (Attachment B of Appendix S of the Type A Water Use Licence QZ09-092 Renewal Application, October, 2014), dated November 12, 2013, provide a detailed description of the development of the models, including the loading sources, key assumptions, stochastic parameters and model calibration. The model has been recalibrated up to March 2014. The GoldSim model has also been updated to include potential loadings from the proposed Flame and Moth Mine including N-AML waste rock, expanded dry stack tailings facility, mine discharge and groundwater flow from the mine pool or bioreactor at closure for cadmium and zinc, the contaminants of concern, plus the additional parameters with effluent quality standards in Water Licence QZ12-053, which are ammonia (NH_3), arsenic (As), copper (Cu), lead, (Pb), nickel (Ni) and silver (Ag). Additional parameters for the model were not included as the N-AML waste rock humidity cell leaching rates and the deep ground water sampled from the three deep wells (FM-MW-1, FM-MW-2, FM-MW-3) did not identify any additional parameters of potential concern.

The load models calculated metal loadings for three phases of the project: pre-mining development, operations, and reclamation and post-closure. The load model calculates metal loading results for Christal Creek and Lightning Creek from 2008 to December 31, 2014 without any potential loading from the proposed mining activities from the Flame and Moth Mine. The models then accounts for

operating the Flame and Moth Mine from January 1 to March 31, 2021 at the maximum mining rate of 400 tonnes per day (tpd). The loading models incorporate potential loadings for the reclamation and post closure phase (2021 to 2031).

The largest proposed loading source, Flame and Moth Mine discharge, is only of short duration and will cease at the end of the mine life. The model results present the predicted concentrations for the Flame and Moth discharge at both the average anticipated concentrations and the proposed effluent quality standards for the complete life of mine. The comparison of the results using the EQS discharge for the complete life of the mine is overly conservative based on Alexco's track record for operating five water treatment plants in the Keno District and the scenario presented for average expected discharge concentrations is more representative of anticipated monthly concentrations. The modelling results also show that the long term concentrations in Christal Creek and Lightning Creek ameliorated by the District Closure Plan currently under development will not be impacted by the Flame and Moth project.

5.5 MONITORING

The Monitoring, Surveillance and Reporting Plan (Access, 2014) describes the framework used to manage mining operations in the KHSD. The plan includes monitoring and reporting of:

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

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

Prior to mine development in the KHSD, a number of monitoring programs and a surveillance networks were already in place as per care and maintenance activities (Water Licence QZ06-074), advanced exploration and preliminary development activities at the Bellekeno mine (Water Licence QZ07-078) as well as district-wide closure and new mine permitting studies. These programs include but are not limited to physical inspections, a water quality surveillance network, old mine workings monitoring, aquatic resources monitoring for benthic invertebrate and fisheries populations, sediment monitoring, waste rock and mine wall sampling and the Adaptive Management Plan. Monitoring, surveillance and reporting applicable to Bellekeno, Onek 990 and Lucky Queen Mines are presented in the Monitoring, Surveillance and Reporting Plan (Access, 2014). Additionally, this Plan has been updated to include the Flame and Moth Mine and the associated monitoring proposed as part of the project.

Alexco provides regular monitoring data, analysis and discussion of trends in our monthly and annual reports submitted as a condition of WUL 09-092 and QML-0009.

6 TEMPORARY CLOSURE

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

Table 6-1 provides a summary of the various project components and associated inspection and maintenance activities during any temporary cessation of mining activities. Alexco's ongoing care and maintenance activities in the District are currently scheduled to continue beyond the next 6 years which means that there would be minimal additional costs related to a temporary closure of the Keno Hill Mine Operations.

6.1 PHYSICAL STABILITY AND GEOCHEMICAL STABILITY

Stabilization of site works during any temporary closure will be addressed initially well in advance of any closure scenario through the Company's commitment to progressive reclamation and stabilization measures. Progressive reclamation will be implemented on an ongoing basis (Section 2.3) to fulfil the Company's commitment to maintaining site stability and reclaiming areas as soon as operationally possible, therefore reducing both financial and operational liability.

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

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

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

Table 6-1: Summary of Care and Maintenance Activities and Surveillance during Temporary Cessation of Mining Activities

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

6.2 SECURITY AND MONITORING

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

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

The care and maintenance crew will be responsible for:

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

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

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

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

6.3 REPORTING

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

7 FINAL RECLAMATION AND CLOSURE MEASURES

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

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

1. Underground Workings and Opening to Surface
    - Bellekeno Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
    - Onek Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
    - Lucky Queen Production Unit Area – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
    - Flame and Moth Deposit – including consideration of waste rock disposal areas/ storage facilities; water management; and surface facilities.
2. Dry Stack Tailings Facility – Phases I - II
3. Mill, Ancillary Facilities, Flat Creek Camp
4. Roads and Linear Disturbances

7.1 UNDERGROUND WORKINGS AND OPENINGS TO SURFACE

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

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

7.1.1 Closure Objectives

The objectives for closing the underground workings and openings to surface are to:

1. Ensure physical and geochemical stability of the site;
2. Achieve passive management and treatment of the mine pool;
3. Minimize safety risks to people and wildlife, and
4. Reclaim the site to an aesthetically acceptable level.

7.1.2 Bellekeno Mine Closure Measures

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). An as built of the Bellekeno Mine underground workings as of September 2013 when operations were suspended is shown in Figure 7-3. 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.

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; Backfill any remaining P-AML waste rock on surface to underground;
2. Remove/salvage underground assets and equipment;
3. Remove any hazardous materials;
4. Install mine pool treatment infrastructure
5. Install rock pile portal cover at Bellekeno East

The mine pool will be managed by transitioning from actively treating adit discharge to sealing the adit, implementing in situ mine pool treatment and installing a passive treatment system (bioreactor). Further discussion on the closure measures associated with long-term water management at Bellekeno is presented in Section 7.1.3.

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 7-7). 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.



Figure 7-1 Bellekeno East Portal and Site Facilities



Figure 7-2 Bellekeno East Portal

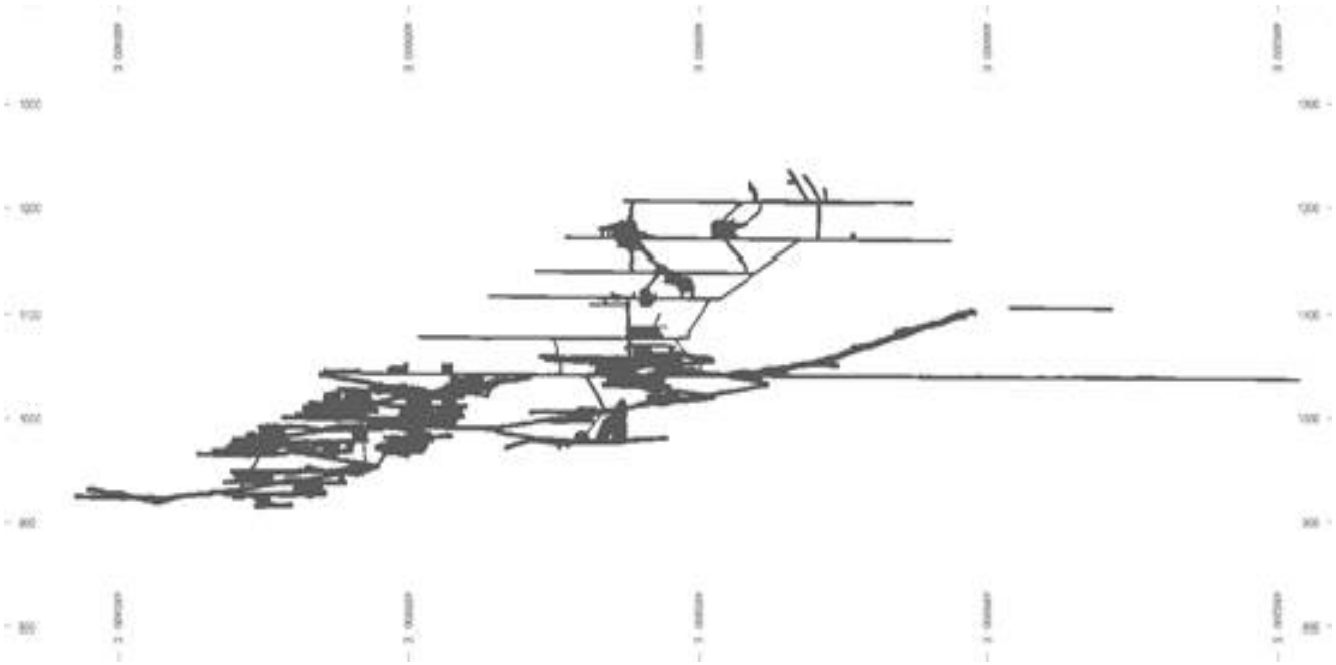


Figure 7-3 Bellekeno Mine As-Built September 2013

The shaded blocks in Figure 7-3 are the mined out stopes. An inventory of open versus backfilled stopes is maintained that will provide an accurate assessment of longterm fill rates for the underground workings.

7.1.3 Bellekeno 625 Adit

Without continued dewatering and pumping after closure, the static water elevation of the Bellekeno Mine will rise to and discharge from the Bellekeno 625 adit. A concrete adit bulkhead will be constructed to allow management of the mine pool long term. The bulkhead is not designed as a high head pressurized structure that will allow increased flooding above the 625 elevation, but rather as a water management tool and feature that will allow consistent flow to the secondary bioreactor treatment system. A conceptual design for the Bellekeno 625 adit bulkhead is shown in Figure 7-5. The size of the Bellekeno 625 adit opening is approximately 2.5 m x 2.5 m.

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

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

- A detailed hydrogeological study of the Bellekeno Mine is on-going during mine operations, and is required to determine the final flow and flooding rates to be expected from the Bellekeno mine. As noted above, based on the existing mine plan, the final elevation of the static water in the mine will be controlled by the Bellekeno 625 adit. This study will be based on information collected as part of the Bellekeno Hydrogeology Plan submitted in November 2010 as a requirement under Water Use Licence QZ09-092.

- Final detailed design engineering will be required to construct a bulkhead at Bellekeno 625. The bulkhead would be put in place as the mine pool is allowed to flood (estimated to take 12 - 18 months). Instrumentation installed in the mine and bulkhead in the form of a pressure gauge will be installed to assist with monitoring of the mine pool elevation.
- In situ mine pool treatment to reduce soluble metals (zinc) loads using a carbon source such as molasses will be implemented immediately upon commencing Bellekeno mine pool flooding. Alexco has implemented this technology at several minesites throughout North and South America and it has proven highly successful in reducing soluble metal loading. This technology is also undergoing a full scale demonstration at Silver King as part of the District Closure project. The mine pool would be accessed through the Bellekeno East decline which would not be blocked until Bellekeno 625 has been adequately decommissioned. *In situ* treatment of the mine pool for at least 12 months prior to the mine pool discharging at 625 is expected to produce acceptable water quality discharge criteria. Evidentiary information to support the expected success of the in mine pool treatment of Bellekeno 625 is included in Appendix 3.
- 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. Water from the flooding mine pool would be pumped to the bioreactor constructed at 625 and commissioning and optimization of the bioreactor would take place. Once the treated mine pool reaches the static elevation of the 625 adit and begins to gravity flow out of the adit, pumping to the bioreactor for commissioning would cease and passive flow and treatment through the bioreactor would continue. This approach allows construction and commissioning of the bioreactor to have already been completed by the time the Bellekeno 625 mine pool floods and reaches static water elevation and discharges out the 625 adit. A bioreactor was constructed and operated from 2009-2011 at Galkeno 900 as part of the District closure planning process. The results of the Galkeno 900 bioreactor performance is included in Appendix 4 as support for this approach in closure of the Bellekeno mine.
- The overall water management approach for Bellekeno is to have the bioreactor constructed and commissioned prior to when the mine pool is fully flooded and discharging out of the 625 adit. It is expected that the *in situ* mine pool treatment will obtain acceptable discharge water quality but in the event it does not then the bioreactor will already be fully commissioned by the time the mine pool reaches the elevation of the 625 level and can serve as a polishing step to the mine pool primary treatment.

A preliminary design of the bioreactor at 625 is shown in Figure 7-6. A water treatment and management schedule for Bellekeno 625 is included in Table 7-2.

7.1.3.1 Bellekeno 625 Water Treatment Facility

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

Sludge from the Bellekeno 625 WTF is currently disposed of into a cell on the surface of the Valley Tailings as per the current Sludge Management Plan and as authorized under QML-0009. Bellekeno water treatment sludge is also authorized for disposal in the DSTF. The sludge from Bellekeno 625 that is stored in the valley tailings cell is kept separate from the sludge generated at the other treatment facilities. The sludge containment cells are not lined in order to allow water to exfiltrate from the cells.



Figure 7-4 Bellekeno 625 Area Overview

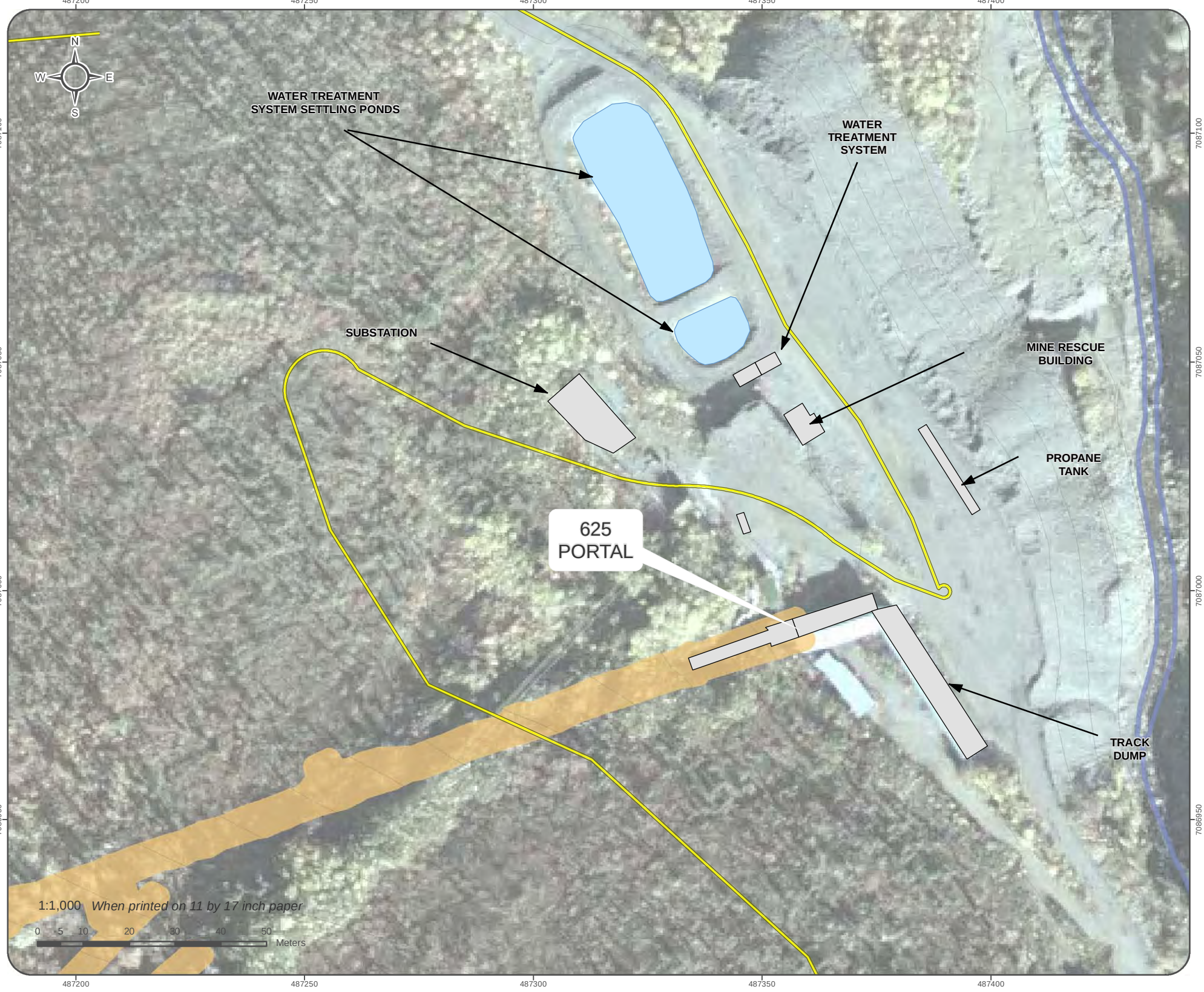
The discharge criteria currently authorized in WUL09-092 for the Bellekeno 625 water treatment plant is protective of the receiving environment. The proposed discharge criteria for the Bellekeno mine for closure and long-term is the same as the current effluent quality levels during operations and are summarized in Table 7-1 Bellekeno Mine Closure Effluent Quality Standards.

Table 7-1 Bellekeno Mine Closure Effluent Quality Standards

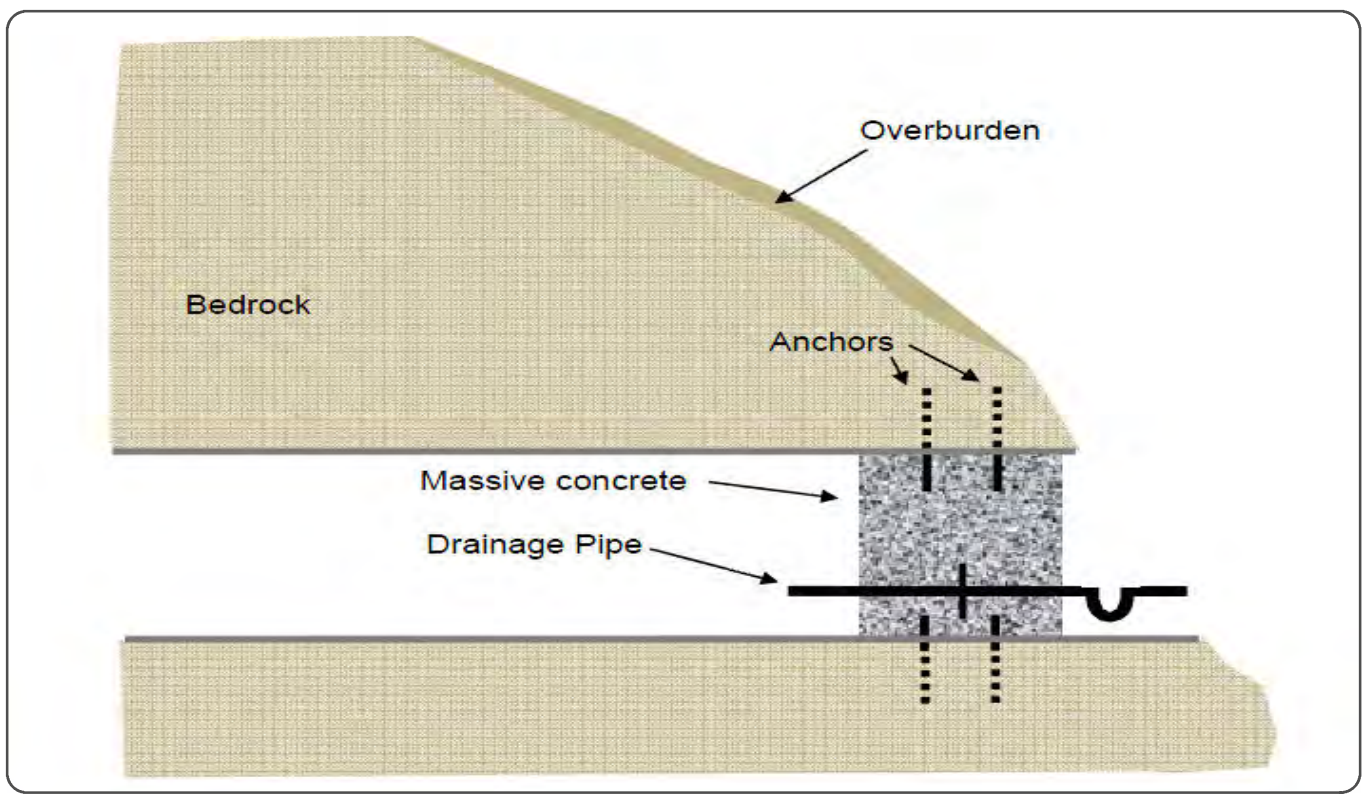
Parameter	Maximum Concentration in a Grab Sample
pH	6.5 to 9.5 pH Units
Total Suspended Solids	25 mg/L
Ammonia Nitrogen (as N)	5 mg/L
Arsenic (total)	0.1 mg/L
Cadmium (total)	0.01 mg/L
Copper (total)	0.1 mg/L
Lead (total)	0.2 mg/L
Nickel (total)	0.5 mg/L
Radium 226	0.37 BQ/L
Silver (total)	0.01 mg/L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

7.1.4 200 Level Vent Raise

The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 vent raise will be capped with an engineered concrete cap similar to what is used at mines elsewhere in Canada. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-8.



CONCEPTUAL 625 ADIT BULKHEAD DESIGN



Underground Workings

Building

Pond

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

Datum: NAD 83; Projection: UTM Zone 8N

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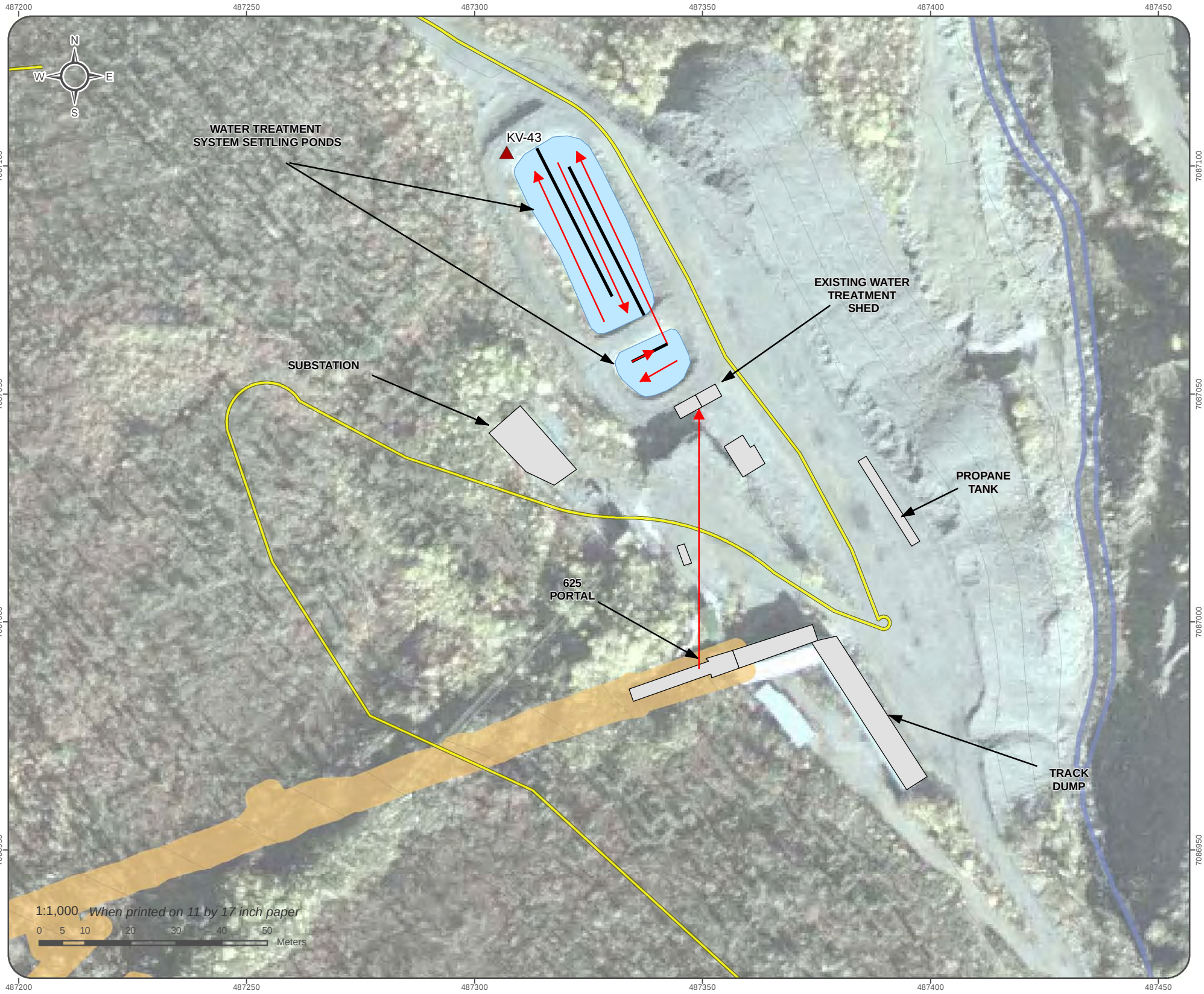
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KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-5
BELLEKENO MINE SITE LAYOUT
625 ADIT BULKHEAD

AUGUST 2012

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Conceptual Design Assumptions

Divide Pond 1 into 2 zones with a HDPE liner divider. 2 cells @ 6m x 15m

Divide Poind 2 into 3 zones with a HDPE liner divider, 3 cells @ 5.3m x 42m

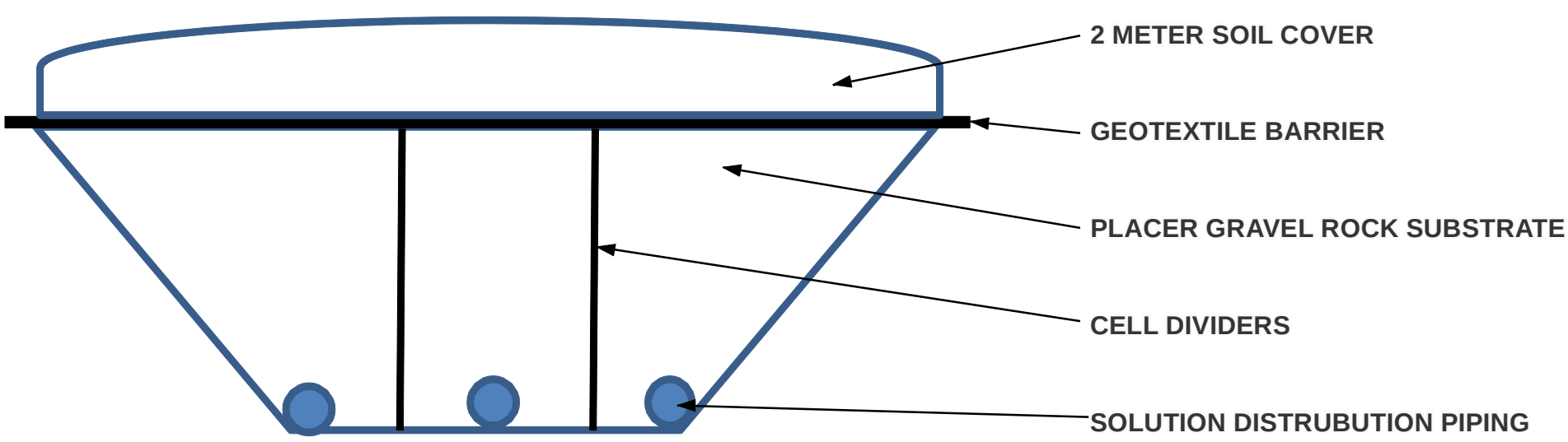
Total Volume = 2,700 m3

Porosity = 40%

Flowrate = 4 lps

Retention Time = (2700 m3 x 0.40)/4 lps = 3.1 days

TYPICAL BIROREACTOR - CROSS SECTIONAL VIEW



Building
Pond
Underground Workings
Flowpath of Adit Water
Cell Divider

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

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KENO DISTRICT MINE OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-6
BELLEKENO 625 BIOREACTOR
PRELIMINARY DESIGN

DRAWN BY JP	AUGUST 2012	VERIFIED BY TL

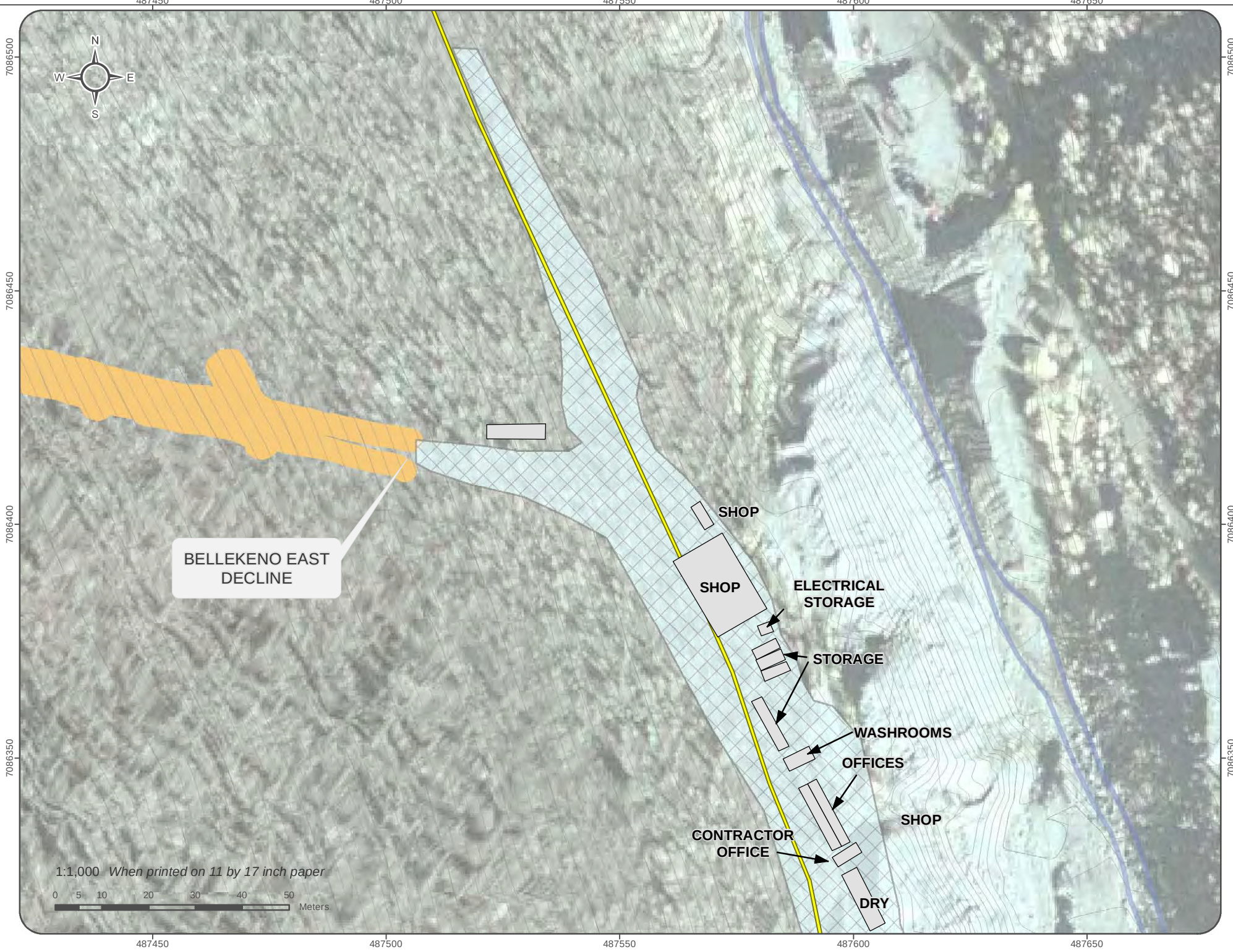
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Table 7-2: Underground Mines Water Management Schedule

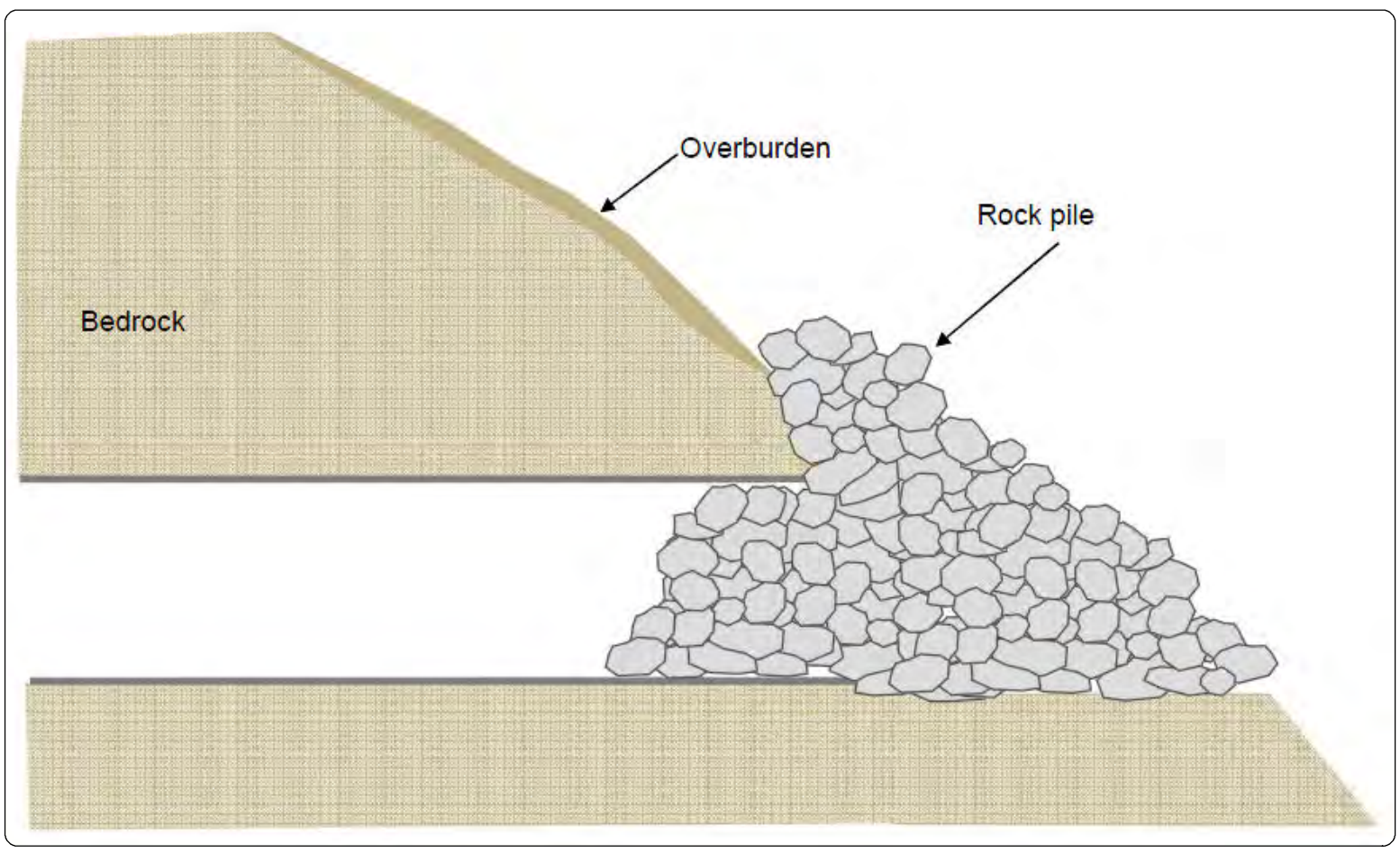
	Months following cessation of mining activities																
Bellekeno Water Management Task	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Pump shutdown and mine workings flooding																	
In Situ Mine Pool Treatment																	
Construct bioreactor																	
Commission bioreactor with mine pool water																	
Passive feed of bioreactor from mine pool																	

	Months following cessation of mining activities																
Lucky Queen Water Management Tasks	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6 +**
Cessation of mining																	
Construct bioreactor (if required)																	
Commission bioreactor with adit discharge (if required)																	
Passive feed of bioreactor from adit discharge																	

	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																	



CONCEPTUAL EAST PORTAL CLOSURE ROCK PILE



Building; Unknown
Bellekeno Haul Road
Underground Workings
Portal Area

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

Datum: NAD 83; Projection: UTM Zone 8N

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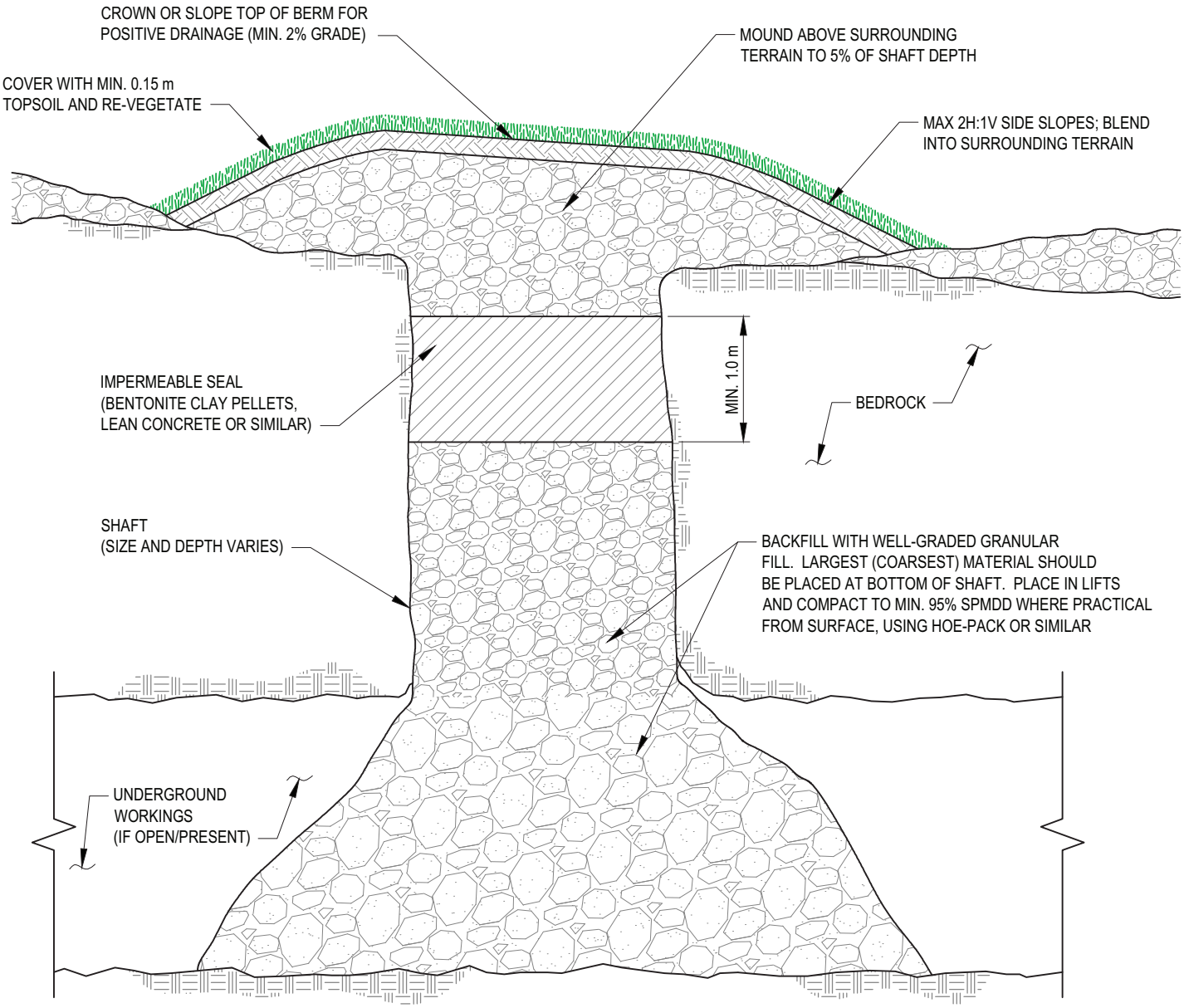
KENO DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN

FIGURE 7-7

BELLEKENO MINE SITE LAYOUT
EAST PORTAL CLOSURE ROCK PILE

AUGUST 2012

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NOTES:

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

CONCEPT DRAWING
NOT FOR CONSTRUCTION

STATUS
ISSUED FOR REVIEW

SCALE 1:50

500 0 500 1000 2000mm

CLIENT

KENO HILL SHAFT CLOSURES
KENO HILL, YT

CONCEPT A
DRY SEAL

A TETRA TECH COMPANY

PROJECT NO.	DWN	CKD	REV
V15101043	SF	JP	0

OFFICE	DATE
VANC	April 4, 2011

Figure7-7

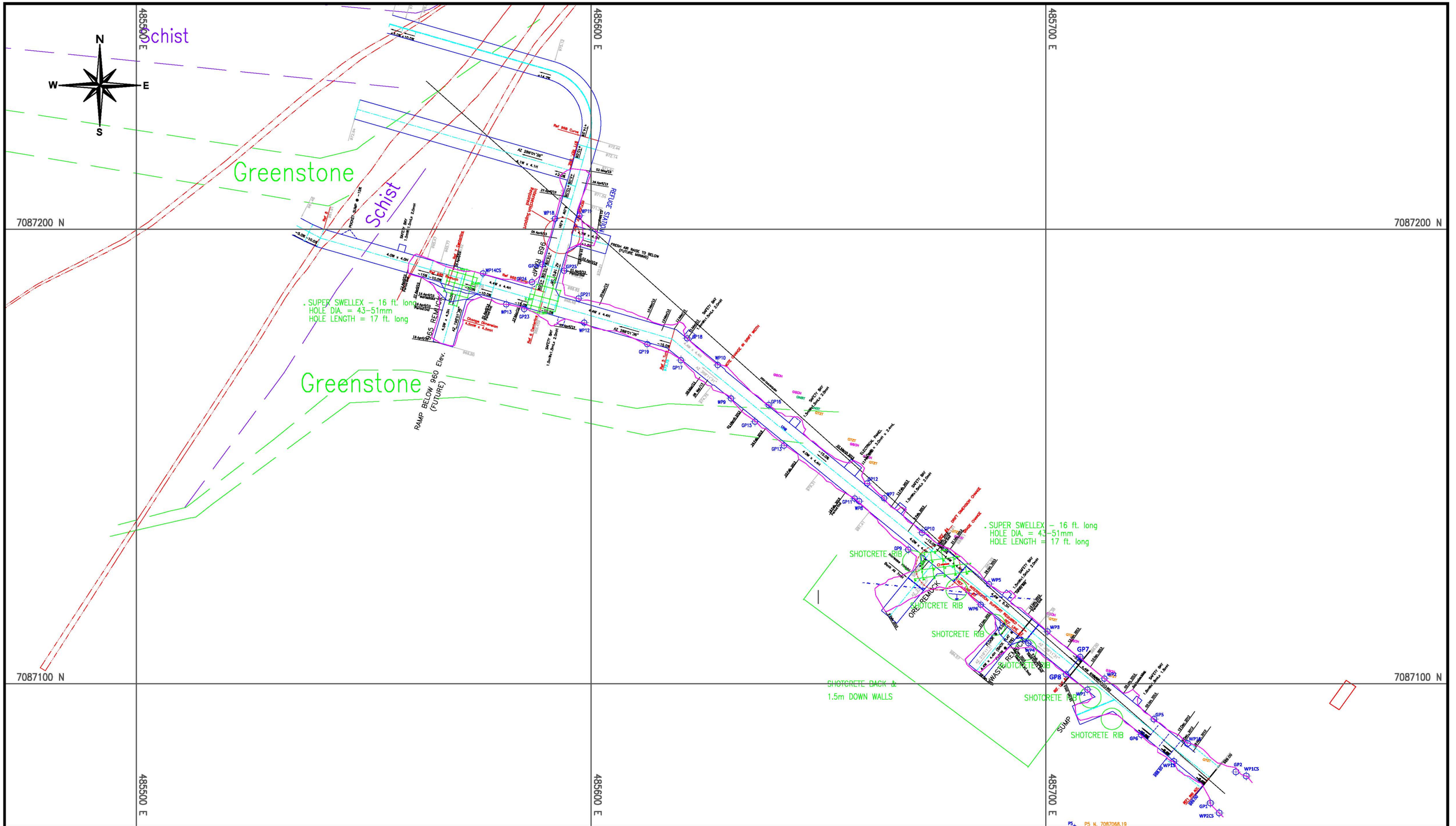
An overview of the Bellekeno 625 area and facilities is shown in Figure 7-4. All of the surface buildings at Bellekeno East are portable structures that will be removed and transported offsite for salvage at the end of the mine life. Water treatment measures for closure are addressed in Section 7.1.3.

7.1.5 Onek Mine Closure Measures

The Onek mine was developed in 2012 and currently consists of 220 meters of a primary decline and surface facilities (office building, storage containers, and ventilation fan). P-AML WRSFs, N-AML WRDAs, and the vent raise have not yet been constructed. The Onek mine is not currently included in the Keno Hill Mine Operations LOM plan and these additional facilities would not be constructed until Onek becomes part of the LOM plan. An overview of the Onek mine is also shown in Figure 7-9. The historic waste rock dumps associated with the new P-AML WRSFs and N-AML WRDAs are historic liabilities; however, they are included in the RCP because they are a component of the Onek Production Unit Area. An as built of the Onek mine underground workings is shown in Figure 7-10.



Figure 7-9 Onek Mine



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

TITLE: **ONEK**
ASBUILT 30 May 2013

Figure 7-10

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

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

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 any hazardous materials;
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. There are no water management features 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 (Figure 7-7) will be constructed to close the Onek 990 portal face and prevent inadvertent access from wildlife or people.

7.1.6 Lucky Queen Mine

The Lucky Queen mine adit was rehabilitated in 2011/2012 including installation of new ground support over the 1,200 metres of historic adit. This adit will provide primary ingress/egress to the Lucky Queen mine. The Lucky Queen mine will consist of the underground workings (rehabilitated historic 500 level adit and new workings), surface facilities and features at the Lucky Queen Portal Pad (portal, surface buildings and infrastructure), a new P-AML WRSF, a new N-AML WRDA, and the vent raise. The current status of the Lucky Queen mine includes the portal, a portable office trailer, shop maintenance building and a storage building. An unlined settling pond is in place to manage water flowing from the Lucky Queen mine. The historic waste rock dumps associated with the new P-AML WRSF and N-AML WRDA are historic liabilities; however, they are included in the RCP because they are a component of the Lucky Queen Production Unit Area. A P-AML WRSF has not been constructed yet for the Lucky Queen mine. An overview of the Lucky Queen mine surface area is shown in Figure 7-11. An as built of the Lucky Queen underground workings is shown in Figure 7-12.



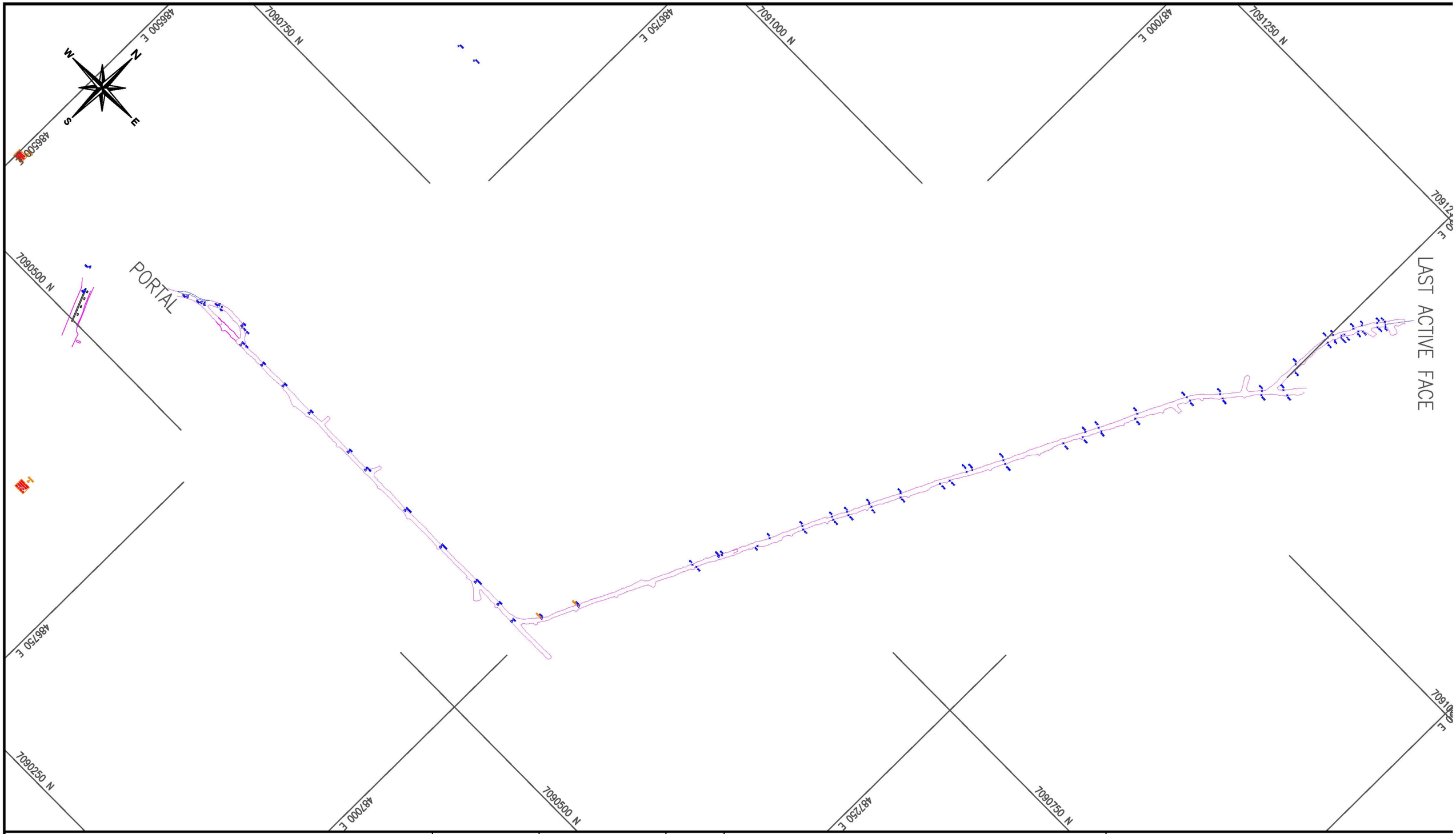
Figure 7-11 Lucky Queen Mine

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; Backfill any remaining P-AML waste rock on surface to underground;
2. Remove/salvage underground assets and equipment;
3. Remove any hazardous materials;

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

A concrete bulkhead will be constructed at Lucky Queen, similar to the design proposed for the Bellekeno 625 adit (Figure 7-5). The bulkhead is not designed for high pressure but will serve to collect water draining from the adit, prevent air movement and potential for ice formation inside the adit and prevent inadvertent access.



ALEXCO RESOURCE CORP BELLKENO MINE	DEPT.	APPROVED BY	DATE	COMMENTS	TITLE: LUCK QUEEN MINE Asbuilt March 8, 2013 Figure 7-12	
ALEXCO	SURVEY					
	ENGINEERING					
	GEOLOGY				Drawn by: DARIN BAKER	Scale: 1:2500
	ALEXCO MANAGER				Date: 03/08/2013	Approval: Date:
	PROCON SUPER				File: C:\Users\Darin Baker\Documents\Drawing1.dwg	

7.1.7 Flame and Moth Mine

The Flame and Moth deposit was outlined by surface exploration drilling in 2010 through 2013 with ongoing surface exploration. The Flame and Moth mine portal location is approximately 50 metres from the Keno District Mill and will utilize common infrastructure (offices, power, water, compressed air, etc) associated with the mill. The location of the Flame and Moth mine in relation to the mill is shown in Figure 7-13. The Flame and Moth underground workings design is shown in Figure 7-14.

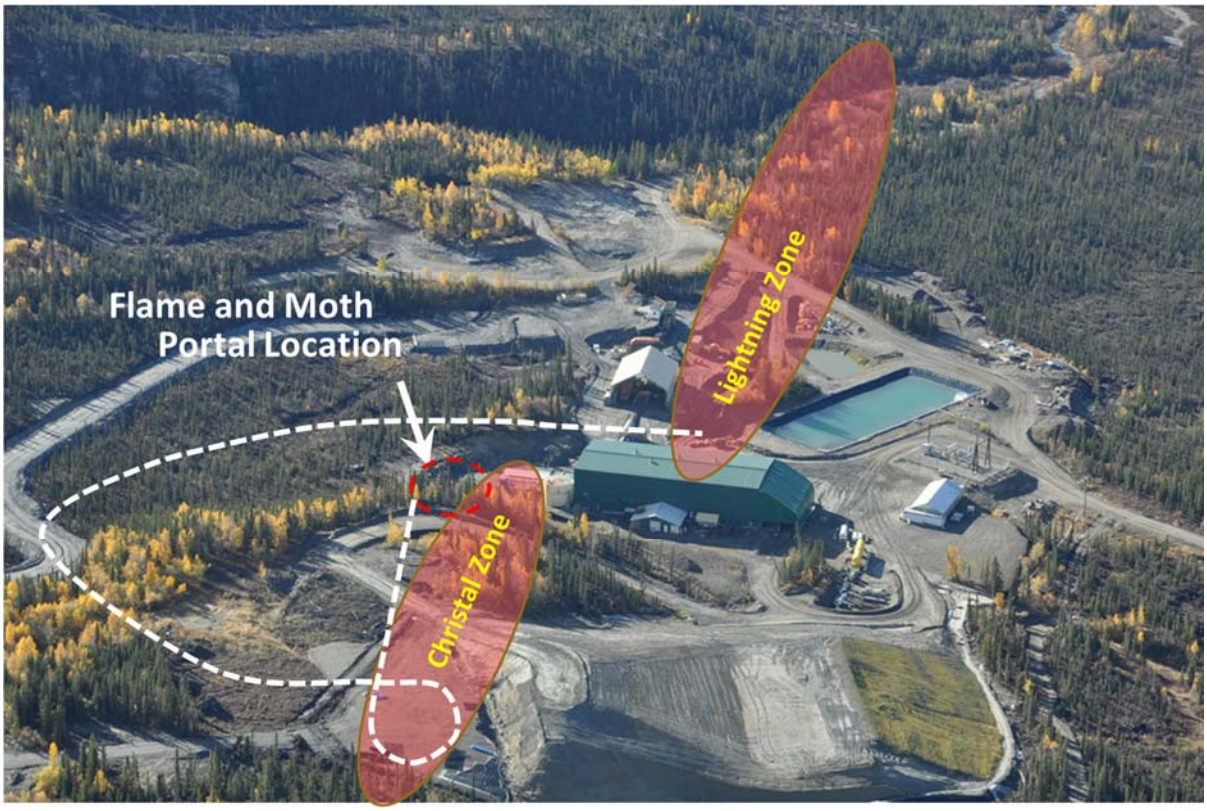


Figure 7-13 Flame and Moth Portal and Decline Layout

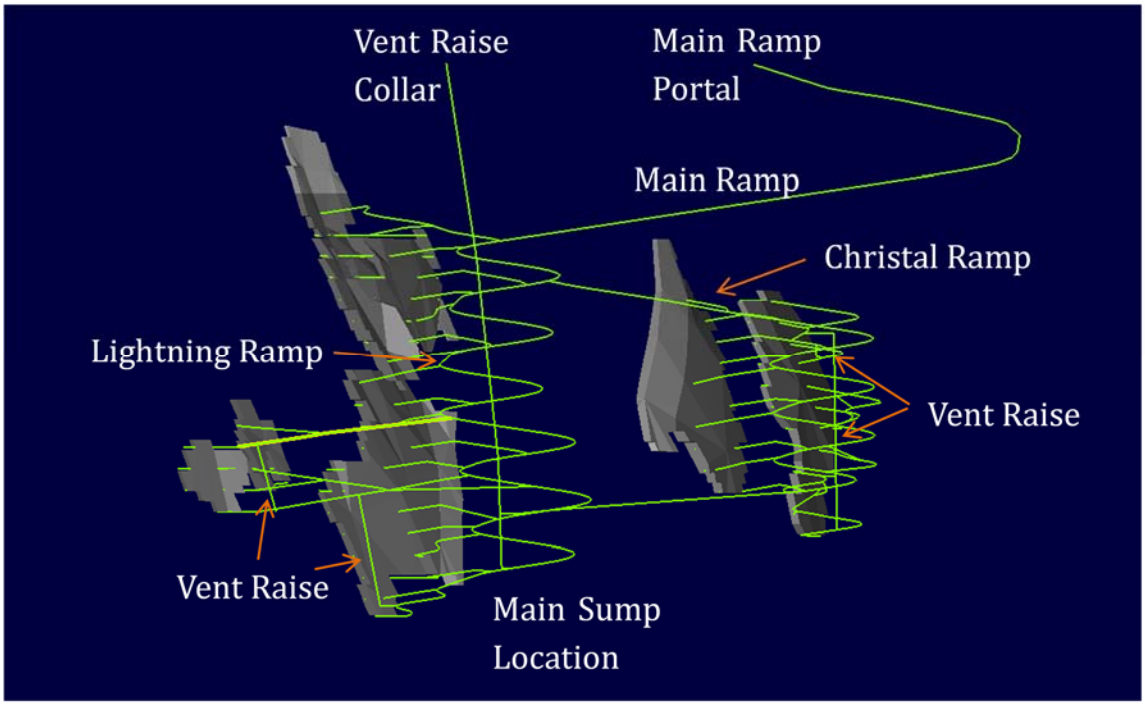


Figure 7-14 Flame and Moth Underground Workings Design

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

1. Stabilize or backfill any remaining stopes as necessary to ensure long-term geotechnical stability underground; Backfill any remaining P-AML waste rock on surface to underground;
2. Remove/salvage underground assets and equipment;
3. Remove any hazardous materials;
4. Install rock pile portal cover.

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

7.2 DRY STACK TAILINGS FACILITY

The dry stack tailings facility (DSTF) is located adjacent to the mill site and the most recent as-built of the facility is shown in Figure 7-16.

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 authorizes 322,000 tonnes of tailings can be placed on surface. As of June 2012, approximately 95,000 tonnes of tailings have been placed on the DSTF representing approximately 30% of the overall permitted capacity. The placement of tailings on surface is currently being conducted under an approved Phase 1 design and DSTF Operations and Monitoring Plan. Additional detailed designs will be required to ultimately expand the DSTF to the currently authorized 322,000 tonne volume. The DSTF will be progressively constructed and reclaimed over the life of the facility as tailings are generated by the mill. A portion of the DSTF will be built on an on-going basis each year. In the summer of each year or as the progression of the facility allows, progressive reclamation will occur through recontouring the side slopes to the final design slope angle (3:1) and placing granular/organic material as a cover.

7.2.1 DSTF Geochemical Performance

Geochemical characterization of the tailings is being conducted as part of the Bellekeno Mine Tailings Characterization Plan which was submitted in December 2010 as a requirement under Water Licence QZ09-092. A humidity cell test is in operations for a composite sample of Bellekeno tailings produced and stored on the DSTF. The results of the kinetic testing for tailings are presented in Appendix 5. The results of this program are also included in the Annual Reporting submitted for QZ09-092. Static geochemical characterization of the Onek and Lucky Queen tailings have been previously presented as part of the environmental assessment and water licence permitting stage for deposition of tailings from these deposits into the DSTF. Static and kinetic testing data from Flame and Moth waste rock and tailings are presented as part of Type A Water Use Licence QZ09-092 Renewal Application, October, 2014.

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 an approximately 0.25 - 0.5m thick evapotranspiration cover consisting of growth media and granular material that is locally stored in stockpiles. The cover will limit water migration through the stack. The first phase of reclamation has been completed on the western slope of the DSTF and includes recontouring to a 3:1 slope, placement of a 0.25 meter cover and seeding/fertilization. Figure 7-15 shows the reclamation underway on the DSTF during June 2012. A similar evapotranspiration cover has been constructed at the company's Brewery Creek Mine both on the heap leach pad (0.25 m cover) and a waste rock storage dump (0.5 m cover). The actual

performance results of the Brewery Creek covers indicate precipitation infiltration rates between 7% – 22% with the variation related to differences in cover thickness and topography. Given the performance of the Brewery Creek covers over a 7 year period, the similarities in soil properties and climate conditions and the highly compacted nature of the DSTF, the reclamation measures proposed for the DSTF are expected to result in <10% infiltration through the DSTF. The climate conditions at Brewery Creek are very similar to the Keno Hill Silver District and the actual performance results of the Brewery Creek cover are a supporting reference to the expected performance results on the DSTF.



Figure 7-15 DSTF Interim Reclamation, June 2012

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

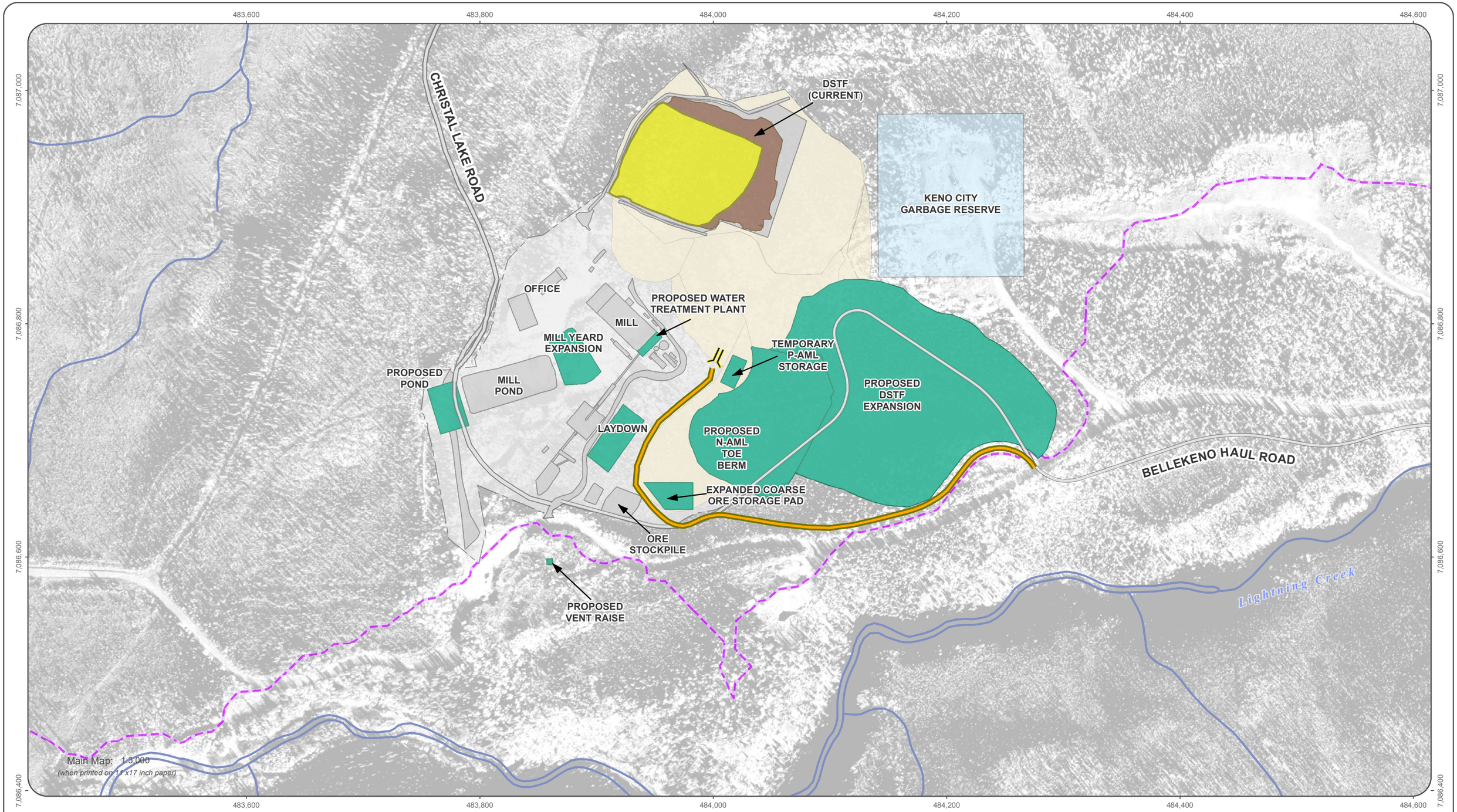
The soil cover design for the DSTF will include a hydrologic evaluation of the soil properties of both the tailings and the materials intended for use as cover so as to assess the hydraulic conductivity and indicate the level of expected infiltration to these facilities.

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

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

A conceptual evapotranspiration cover design is shown in Figure 7-17 and is based on the cover design constructed at Brewery Creek.

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



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

Datum: NAD 83; Projection: UTM Zone 8N

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- Proposed Road
- Road
- Watercourse
- Watershed Boundaries
- Land Disposition
- Mill Site Footprint
- Proposed Features
- DSTF Cover and Revegetation Phase I-II
- Building/Structures
- DSTF 322k Tonnes Design
- Current DSTF

AKHM
ACCESS

KENO HILL SILVER DISTRICT MINING OPERATIONS
RECLAMATION AND CLOSURE PLAN

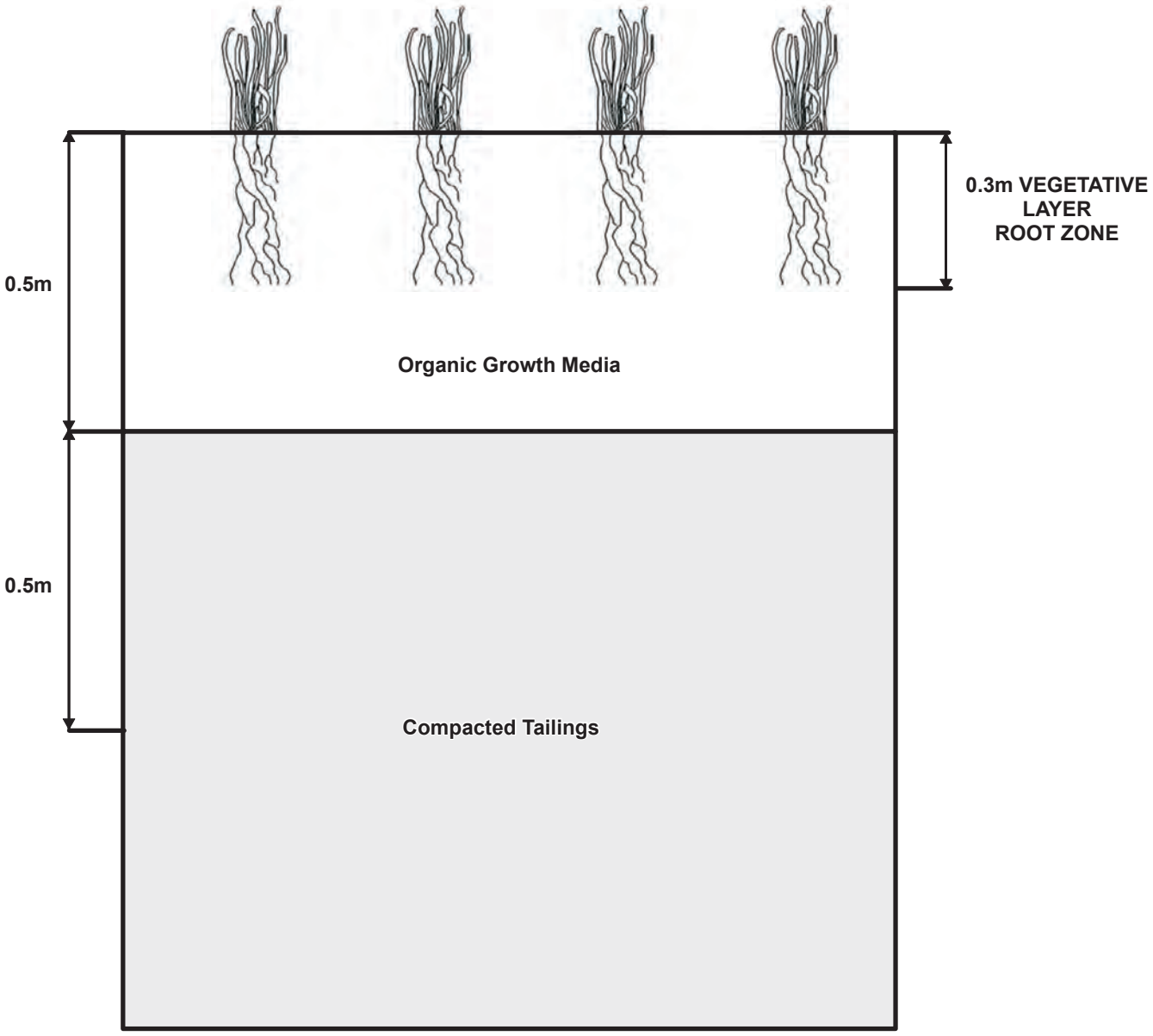
FIGURE 7-16

DRY STACK TAILINGS FACILITY AND MILLSITE LAYOUT

SEPTEMBER 2014

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(*Last edited by: amatlashevska;9/25/2014/09:54 AM*)

SOIL COVER DESIGN



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ACCESS

KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-17

DSTF SOIL COVER DESIGN

AUGUST 2012

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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 from the Bellekeno mine is currently being placed in a lined temporary Waste Rock Storage Facility (WRSF) located south of the Bellekeno East portal Figure 7-18 The facility was designed according to the approved generic design (EBA, 2008)[2]. At closure, P-AML waste rock stored in the temporary facility will be placed underground as mine backfill below the long-term static water level of the mine to limit oxygen contact with the P-AML waste rock. The temporary WRSF liner will be removed and the area recontoured and revegetated to be commensurate with the surrounding natural terrain. Revegetation will take place with appropriate growth media and seed mixes.

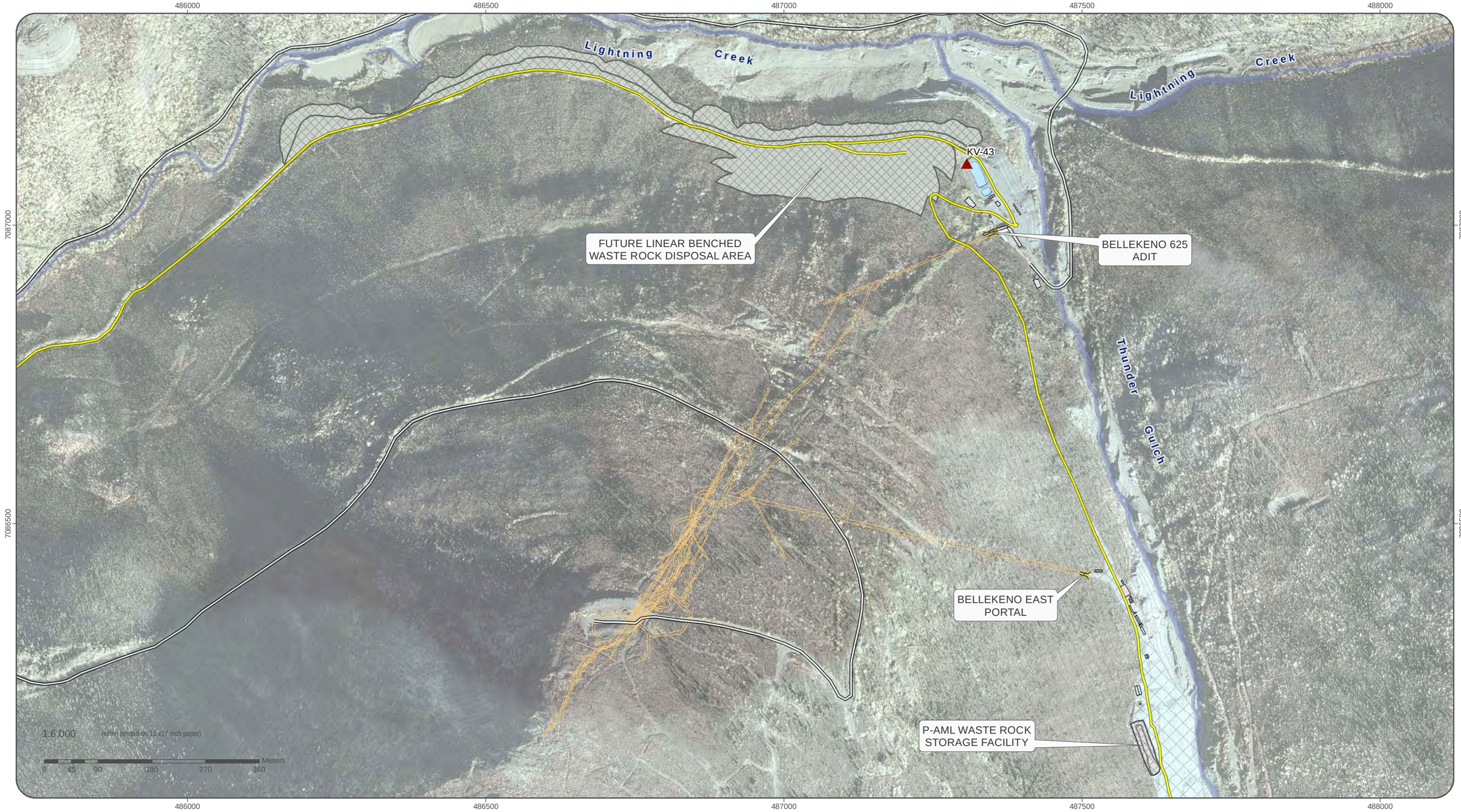
Additional permanent WRSFs for P-AML waste rock may be constructed at the Bellekeno site in accordance with the EBA approved generic facility design (Appendix 2). WRSFs will be recontoured by pulling the crests back with an excavator followed by scarification and revegetation of the flat surface of the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

7.3.1.2 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 (Figure 7-18). The

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

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.



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

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

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

AKHM ACCESS

KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-18

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

AUGUST 2012

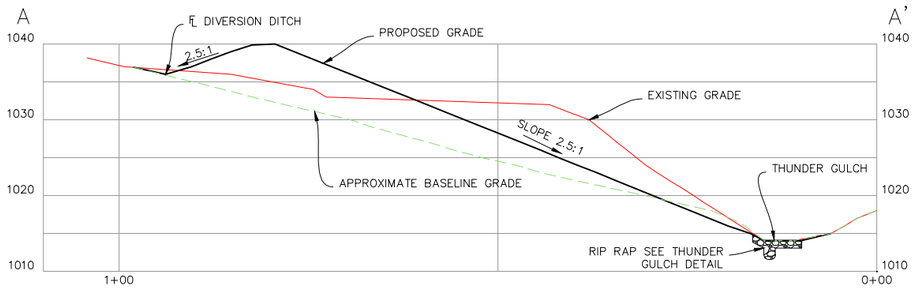
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(*Last edited by: mducharme;03/08/2012/12:23 PM*)

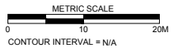
Preliminary engineering design by EBA of the proposed WRDA concluded that no additional contouring for stability is required upon closure. However, in order to further increase stability and improve aesthetics, Alexco will recontour the WRDA by pulling the crests back with an excavator followed by scarification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

7.3.1.3 Bellekeno Historic Waste Rock Dumps

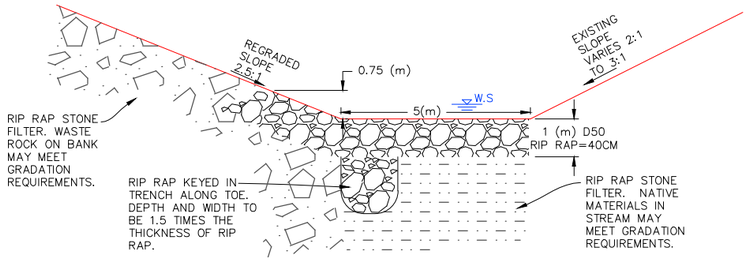
Preliminary design for recontouring the historic Bellekeno 625 waste dump is shown in

Figure 7-19 including re-sloping and construction of water diversion features. A toe buttress may be required along the alluvial terrace below the toe of the historic WRDA which was previously placer mined. This contingency may be necessary to improve the overall stability of the embankment in the event of an earthquake, or other seismic event. Adequate backfilling or re-contouring by the placer miner may alleviate this concern, but this should be re-examined at closure. A geotechnical inspection of the facility will be conducted to determine the need for a toe buttress.

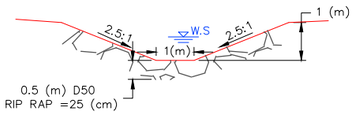




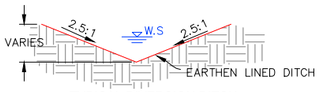
SECTION A-A'



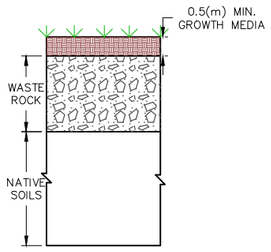
TYPICAL THUNDER GULCH SECTION
NTS



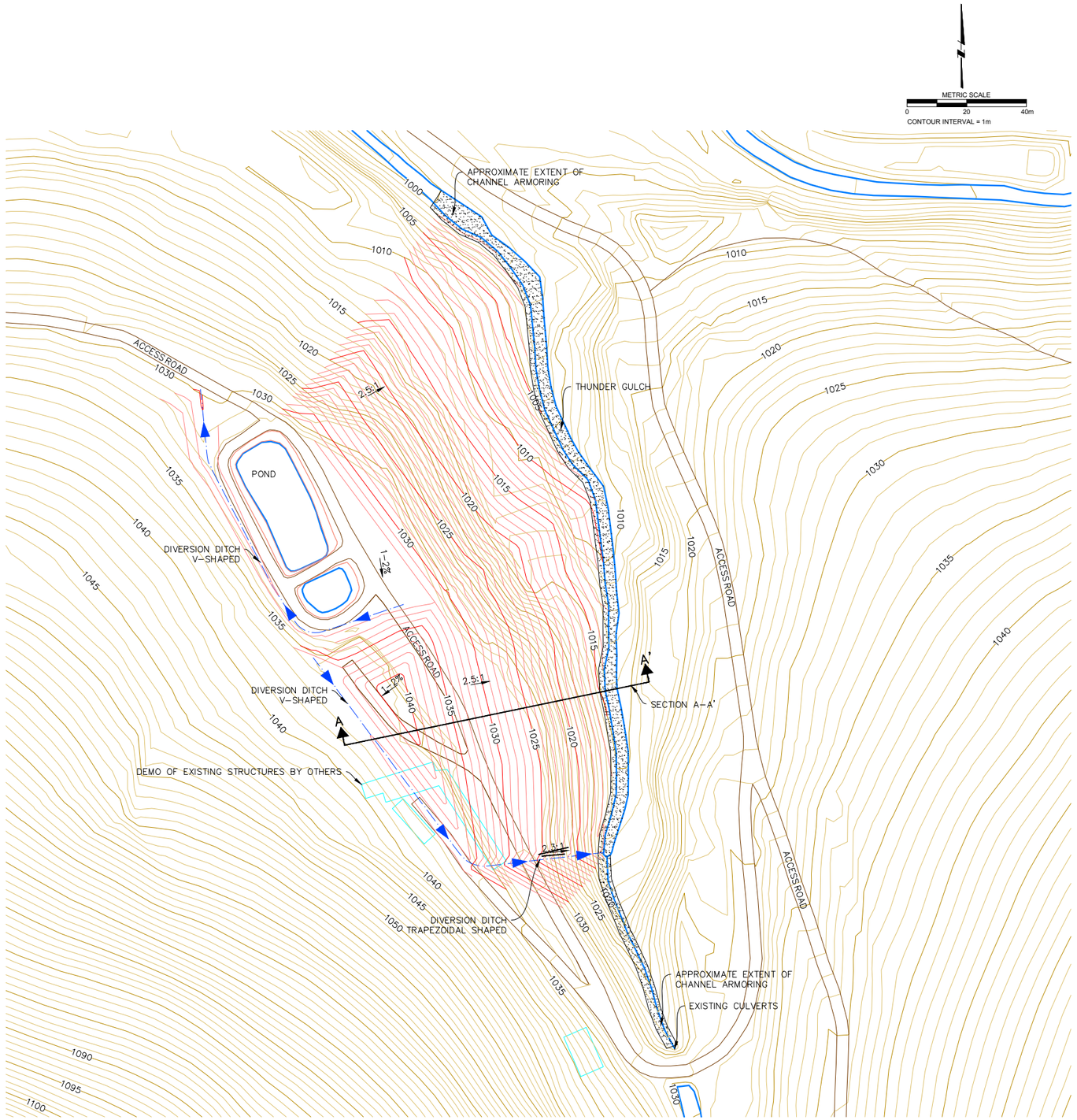
TYPICAL DIVERSION DITCH TRAPEZOIDAL SECTION
NTS



TYPICAL DIVERSION DITCH V-SHAPED SECTION
NTS



WASTE ROCK COVER DETAIL
NTS



NOTES:

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

ISSUE REV	DESCRIPTION	TECH	ENG	DATE
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DRAWING REFERENCE(S):
EXISTING TOPOGRAPHY PROVIDED BY _____, RECEIVED ____. 20__.

DATUM: NAD83 | SCALE: 1"=100'

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

PROJECT LOCATION: KENO CITY, YUKON, CANADA
PROJECT: BELLEKENO MINE CLOSURE
TITLE: **FIGURE 7-19 WASTE ROCK DUMP REGRADING AND DETAILS**

INTERRA
1603 Oakridge Dr., Suite 202
Fort Collins, Co 80525
970.225.8222

DRAWING | REVISION
FILE NAME: Grading (11-16-2011)

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7.3.2 Onek Waste Rock Storage Facilities/Disposal Areas

7.3.2.1 P-AML Waste Rock Storage Facilities

P-AML waste rock will be stored either in the Onek P-AML WRSF to the north of the Onek historic open pit, which was previously licenced for Bellekeno advanced exploration and production, or in a new onsite P-AML WRSF. P-AML waste rock may also be placed underground as mine backfill. Additional WRSFs will be constructed as required as per EBA's generic facility design. To date, no P-AML rock has been brought to surface and stored from development of the Onek decline.

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

7.3.2.2 N-AML Waste Rock Disposal Area

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

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

7.3.2.3 Onek Historic Waste Rock Dumps

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

7.3.3 Lucky Queen Waste Rock Storage/Disposal Areas

7.3.3.1 P-AML Waste Rock Storage Facilities

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

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

7.3.3.2 N-AML Waste Rock Disposal Area

N-AML will be used for general construction and access road repairs and surface capping, or placed into the onsite N-AML WRDA (Figure 7-11). N-AML material may also be placed underground as mine backfill, as required.

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

7.3.3.3 Lucky Queen Historic Waste Rock Dumps

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

7.3.4 Flame and Moth Waste Rock Storage/Disposal Areas

7.3.4.1 Flame and Moth P-AML Waste Rock Storage Facilities

A lined temporary P-AML storage facility will be constructed as per EBA's generic facility design near the portal entrance. 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 to be moved back underground as backfill. All P-AML waste rock will be rehandled back underground prior to closure.

7.3.4.2 Flame and Moth N-AML Waste Rock Storage Facilities

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

7.4 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.

7.4.1 Bellekeno Surface Infrastructure

7.4.1.1 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:

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

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

Figure 7-20 shows the current state of the Bellekeno East decline. The decline collar is a multi-plate culvert 4 meters in diameter extending from the surface into the competent bedrock.

At closure, underground equipment will be removed from the underground mine through the Bellekeno East portal. The portal will remain temporarily accessible at closure for the rehandling of P-AML waste rock back into the underground. The Bellekeno East adit opening will then be blocked by inserting rock fill to limit access by humans and wildlife (Figure 7-7). 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.



Figure 7-20 Bellekeno East Surface Facilities

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

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

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

7.4.1.2 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 and propane tank
- Water treatment buildings
- Sea container storage units
- Electrical substation

7.4.2 Onek Surface Infrastructure

Various surface support buildings and facilities (Figure 7-9) are in place near the entrance to the Onek 990 portal and include:

- Sea container storage units
- Contractor offices
- Ventilation fan container

Additional facilities not constructed until Onek enters production include

- Ventilation raise at surface
- Maintenance shop
- Wash car
- Fuel storage

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

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

The new Onek vent raise will be capped with an engineered concrete cap. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-8.

7.4.3 Lucky Queen Surface Infrastructure

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

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

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

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

The new Lucky Queen vent raise will be capped with an engineered concrete cap. This cement plug will restrict physical entry and prevent air movement and possible ice plug formation at the adit. A preliminary design for a concrete cap is included in Figure 7-8.

7.4.4 Flame and Moth Surface Infrastructure

The Flame and Moth portal and mine surface facilities sit within the current mill area footprint and disturbance and will utilize as much existing infrastructure as possible. Figure 7-21 shows the location of the Flame and Moth portal in relation to the mill. Surface infrastructure that is new to Flame and Moth and not already included in the mill facilities and infrastructure includes:

- Sea container storage units
- Maintenance Shop
- Mine office

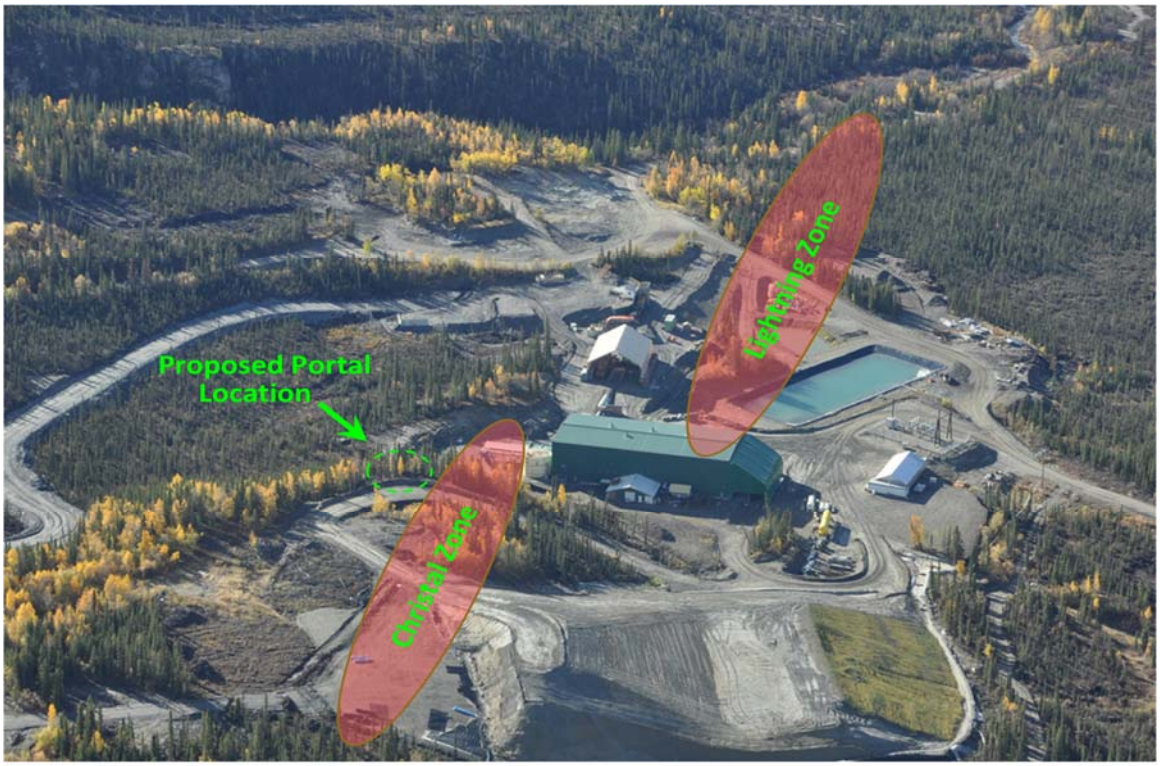
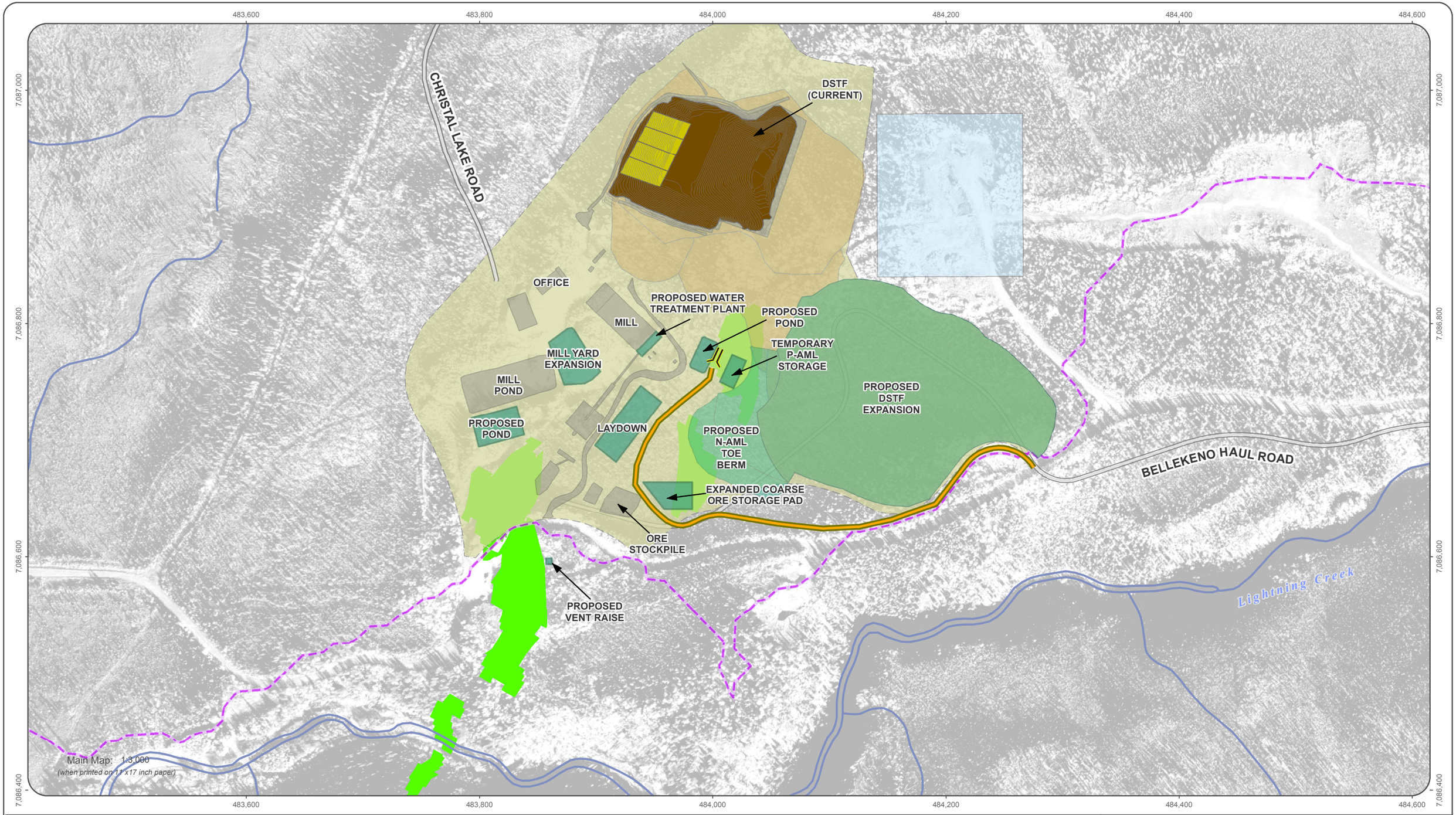


Figure 7-21 Flame and Moth Surface Facilities

An overview of the layout of the Flame and Moth mine surface infrastructure is shown in Figure 7-22. The water treatment plant (WTP) for the Flame and Moth mine will be constructed inside the mill building and closure measures associated with the WTP are included in the mill facilities. The ventilation fan for Flame and Moth will be installed inside the portal to reduce noise emissions.

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



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

Datum: NAD 83; Projection: UTM Zone 8N

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- Proposed Road
- Road
- Watercourse
- Proposed Features
- Watershed Boundaries
- District Mill Footprint
- DSTF 322,000 Tonnes Design
- Buildings/Structures
- As Built, DSTF, Sept 2013
- Land Disposition
- Flame and Moth Vein

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FIGURE 7-22

Flame and Moth Surface Facilities Layout

NOVEMBER 2013

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(Last edited by: jpan;2013-11-28/15:13 PM)

7.4.5 Mill Surface Infrastructure

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

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 7-23):

- Mill building
- Mill office and dry
- Electrical substation
- Mill process pond
- Crusher plant
- Crusher MCC
- Fine ore stockpile
- Mill feed conveyor
- Mill MCC
- Assay lab
- Process water tank
- Diesel storage tank
- Propane tank
- Lightning Creek bridge

7.4.5.1 Mill Buildings and Infrastructure

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

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

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

In the event that it is found at the time of decommissioning that any such unit(s) cannot be removed or sold for their salvage value, then the unit(s) will be inspected for hazardous materials, the hazardous

materials removed and units demolished on site. The materials with salvage value will be removed and sold for their respective value. Non-hazardous materials that have no salvage value will be disposed of in an approved landfill site on the mine site. Combustible wastes such as lumber-based building materials will be burned and the residue buried in the landfill site.

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

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



Figure 7-23 Arial View of Mill Site Infrastructure and Layout

7.4.5.2 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 7-24).

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 7-24 Mill Building

7.4.5.3 Mill Office and Dry

The mill office and dry facility is comprised of two skid mounted trailer units and one skid mounted wash car with a wooden truss constructed over the top of the 3 units. The two office units are 3.05 x 8.3 meters in dimension and the dry/shower facility is 3.35 x 11.58 meters (Figure 7-25).

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 7-25 Mill Office and Dry

7.4.5.4 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 7-26). 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 7-26 Electrical Substation

7.4.5.5 Mill Process Pond

The mill process pond is located downgradient from the mill building and contains and manages the process water balance required for the milling operation (Figure 7-27). Thickener overflow water from inside the mill building gravity flows via a 6" yellomine pipe into the mill process pond. Process makeup water is pumped from the pond to the process water tank for makeup and recycling in the milling process. The mill process pond is 32 x 79 meters in dimension with a total design capacity of 3,500 m^3.

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



Figure 7-27 Mill Process Pond

7.4.5.6 Crushing Plant

Coarse ore from the Bellekeno, Onek, Lucky Queen and Flame & Moth underground mines is transported to a crushing plant (Figure 7-28) where the coarse ore is crushed and reduced in size to nominally 3/8". The crushing plant is a portable two-stage closed circuit plant containing a jaw crusher, single deck screen and cone crusher. The crushers, screen deck and conveyors are all portable tire mounted units that can be easily removed from site. Once the material is crushed it is transported to the adjacent fine ore stockpile via a radial stacker conveyor.

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



Figure 7-28 Crushing Plant

7.4.5.7 Fine Ore Stockpile

Fine ore produced from the crushing plant is stored on a fine ore stockpile covered by a fabric membrane structure to isolate the ore from snow, rain and windy conditions (Figure 7-29). 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 7-29 Fine Ore Stockpile

7.4.5.8 Crusher MCC

A Motor Control Centre (MCC) for the crusher (Figure 7-30) 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 7-30 Crusher MCC

7.4.5.9 Assay Lab

The assay lab is located immediately adjacent to the mill building and consists of 3 skid mounted trailer units separated by a wooden deck and winter roof truss (Figure 7-31). 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 7-31 Assay Lab

7.4.5.10 Mill Motor Control Centre

A Motor Control Centre (MCC) for the mill building (Figure 7-32) 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.

7.4.5.11 Fresh Water Tank

A steel fresh water tank is located next to the mill building and sits on a compacted gravel pad. Fresh water is delivered to the fresh water tank via a water truck and the fresh water is used in eye wash stations located throughout the mill building, for reagent mixing and for pump gland water. The fresh water tank has a capacity of 50.26 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 7-32 Mill MCC

7.4.5.12 Diesel Storage Tanks

Two skid mounted double walled diesel storage tanks are located adjacent to the concentrate loadout area and are used for general fuelling of mobile equipment and vehicles. The tanks each have a storage capacity of 3.78 m^3.

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

7.4.5.13 Propane Tank

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

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

7.4.5.14 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.

7.4.6 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 4 staff houses that are located in Elsa (Figure 7-33). Additional personnel and camp accommodation requirements are on-going beyond Bellekeno, Onek, Lucky Queen and Flame & Moth deposits production operations including exploration, care and maintenance and district closure planning and implementation. Given these ongoing activities, removal and closure of the entire camp facility is not envisioned as part of the Bellekeno, Onek, Lucky Queen and Flame & Moth deposits production closure plan and requirement.

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



Figure 7-33 Flat Creek Camp

7.5 HAZARDOUS MATERIALS

7.5.1.1 Mill Wastes

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

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

7.6 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.

7.6.1 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 7-35):

- Bellekeno East portal to Upper Laydown (0.5 km L x 6 m W);
- Bellekeno 625 Access (0.3km L x 6 m W);
- Bellekeno East portal to BK 5 (3.0 km L x 9 m W);
- Keno City Bypass Road (1.2 km L x 9 m W) – includes Lightning Creek Bridge;
- Christal Lake Road from Silver Trail Highway to the Mill (1.9 km L x 6 m W);
- Onek Haul Road (2.1 km L x 9 m W);
- Keno City Bypass Road from Wernecke public road to Onek 990 (1.2 km L x 9 m W); and
- Flame and Moth Haul Road from portal to crusher (175 m 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 7-35). Re-

grading/contouring the roads will ensure that runoff sheds off the road surface. Localized seeding with native vegetation will take place where erosion control is necessary. Compacted areas will be scarified to promote revegetation. Figure 7-34 illustrates a typical section of the haul road between the mine and mill, and shows the bridge crossing at Lightning Creek.

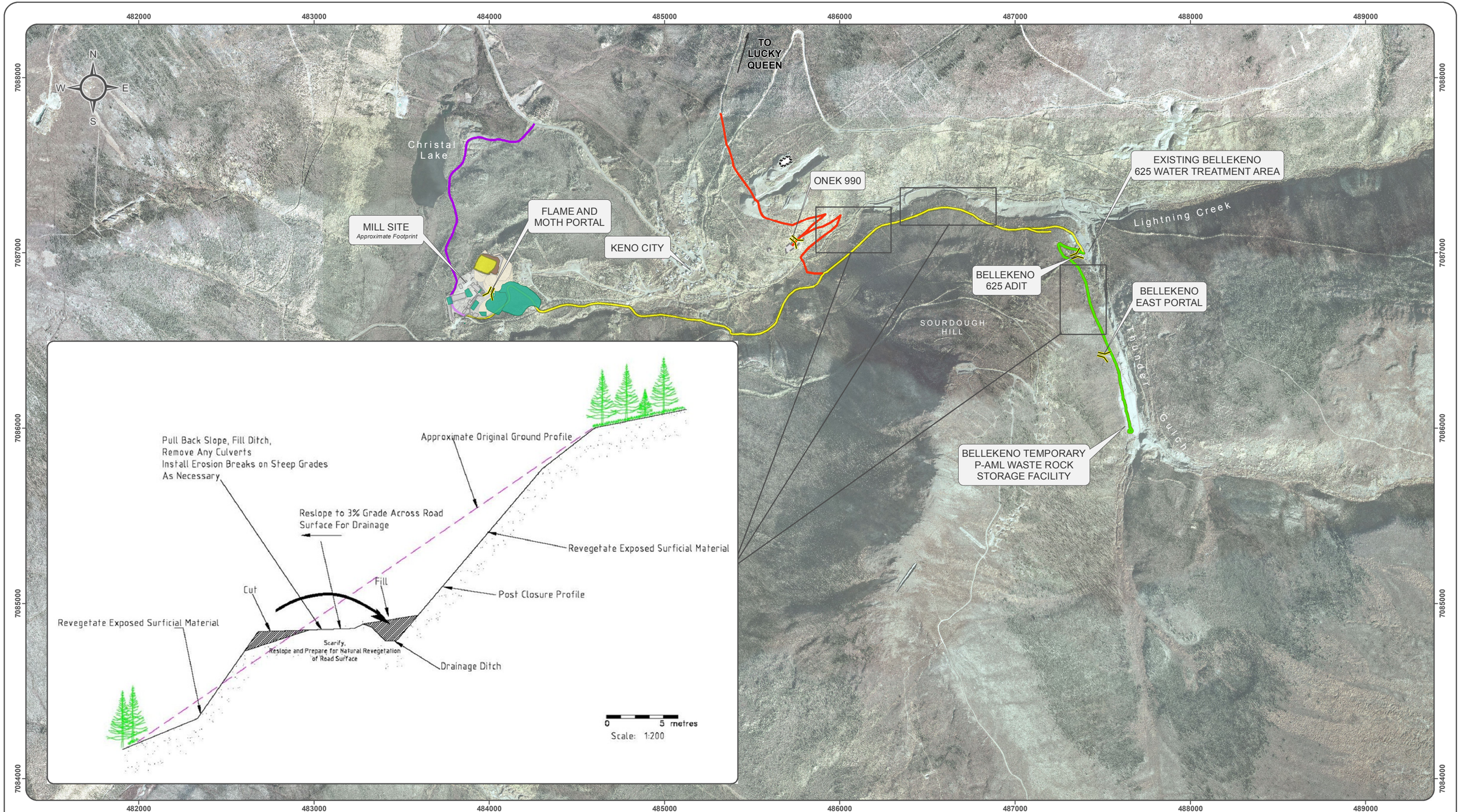
Alexco will consult EMR Client Services & Inspections and Highways & Public Works, Transportation Branch, to determine appropriate methods for limiting access to the sites. The Wernecke road from Keno City to Lucky Queen is not included in the RCP as this is a designated public road that provides access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

7.6.2 Transmission Lines

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



Figure 7-34 Lightning Creek Bridge and Typical Haul Road Section



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

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

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1:20,000 (when printed on 11 x17 inch paper)

Meters
0 125 250 500 750 1,000

- Adit
- Onek Connector Road
- Proposed Road
- Christal Lake Road
- Bellekeno 625 to Keno Temporary P-AML WRSF

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PRELIMINARY RECLAMATION AND CLOSURE PLAN

FIGURE 7 - 35

ROADS SUBJECT TO STANDARD DECOMMISSIONING AND RECLAMATION

SEPTEMBER 2014

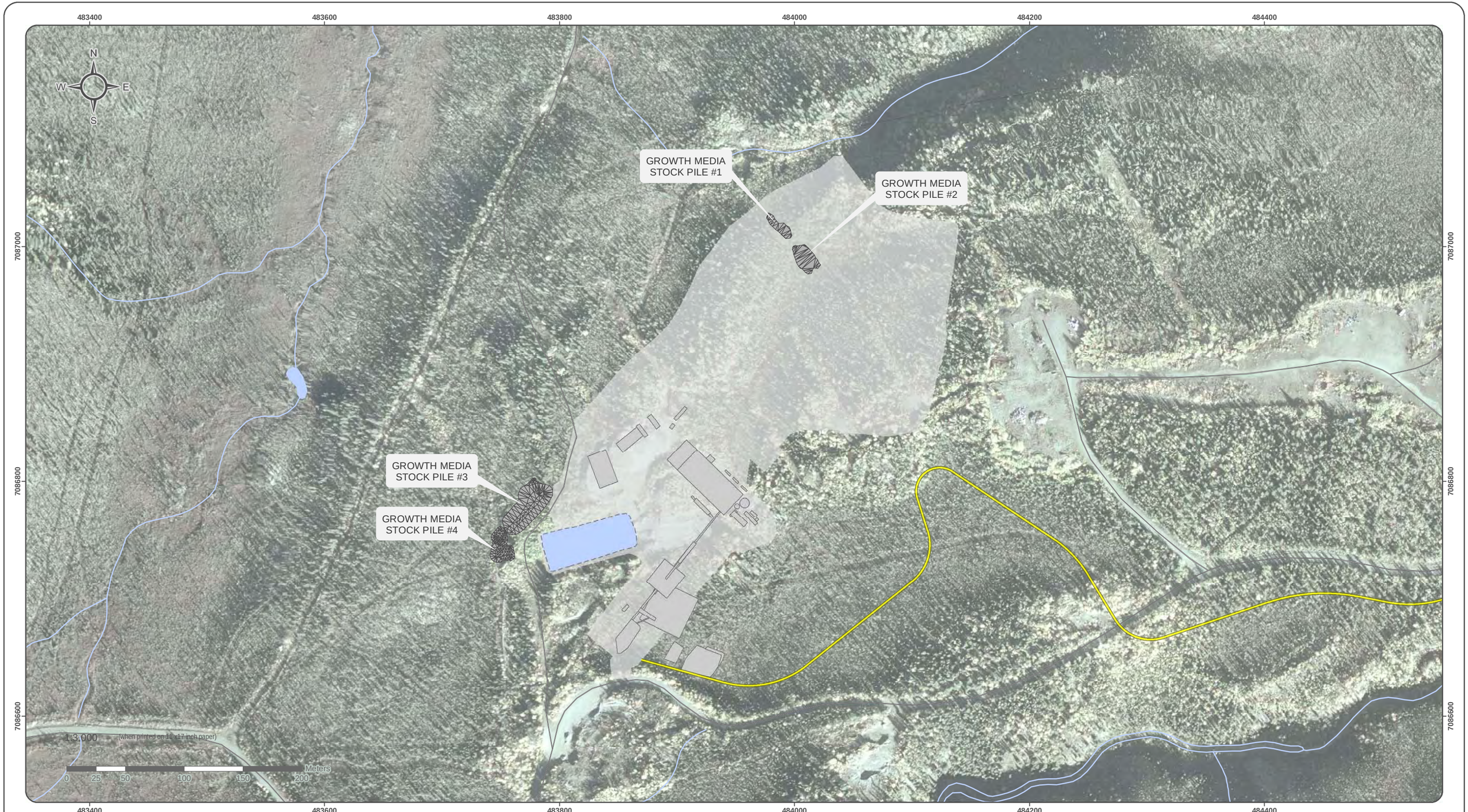
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7.7 BORROW MATERIALS PLANNING

7.7.1 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 7-36) 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 7-36 is approximately 4225 m^3.



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

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

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- Haul Road
- Highway
- Secondary Road
- Growth Media Stockpiles
- Building (As Built)
- Pond (As Built)
- Approximate Site Footprint

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KENO DISTRICT MINING OPERATIONS RECLAMATION AND CLOSURE PLAN

FIGURE 7-36

GROWTH MEDIA STOCKPILES

AUGUST 2012

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7.8 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 7-3)

b) Hydrological monitoring

c) Groundwater monitoring

d) Physical and engineered structures monitoring (geotechnical assessment)

e) Sediment, benthic and aquatic resources monitoring

f) Climate monitoring (as required for assessment of other resources)

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

Table 7-3 Keno Hill Mine Operations Reclamation and Closure Plan Surveillance Network Monitoring Schedule

Monitoring Stations QZ09-092	Stations duplicated in QZ06-074	Proposed closure monitoring station	Easting	Northing	Description	Total Metals	Dissolved Metals	Ammonia	Nitrite	Nitrate	Phosphorous	Sulphate	DOC	Hardness	Alkalinity	pH	Conductivity	TSS	Radium	LC50
KV-1	a		4742790	7092790	South McQuesten River u/s Christal Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-2	a		472076	7090036	South McQuesten River @ Pumphouse	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-6	a		483909	7088242	Christal Creek at Keno Highway	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-7	a		478657	7092413	Christal Creek at Hanson Road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-8	a		465836	7088410	Christal Creek @ Mouth	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-34	a	a	486562	7090614	Lucky Queen 500 Level Adit	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
KV-37	a		490315	7087776	Lightning Creek u/s Hope Gulch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-38*	a		488193	7087341	Lightning Creek u/s Thunder Gulch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-39	a		490252	7087783	Hope Gulch u/s Lightning Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-40	a		488982	7087503	Charity Gulch u/s Lightning Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-41	a		485429	7086764	Lightning Creek u/s bridge at Keno City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-42	a	a	487363	7087062	Bellekeno 625 Adit	W	W	W	W	W	W	W	W	W	W	W	W	W		
KV-43	a	a	487318	7087147	Bellekeno 625 Treatment Pond Decant	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
KV-44	a	a	487361	7087195	Bellekeno 625 Seep	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-45	a	a	485101	7087288	Onek 400 Adit	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-49	a		483582	7087009	Hinton Creek u/s Christal Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-50	a		483575	7086897	Christal Creek u/s Hinton Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-51*	a		483600	7087010	Christal Creek d/s Hinton Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-52	a	a	483756	7087869	Mackeno Creek	M	M	M	M	M	M	M	M	M	M	M	M	M	-	-
KV-65	a	a	487464	7086873	Thunder Gulch Upstream of Bellekeno	M	M	M	M	M	M	M	M	M	M	M	M	M	-	-
KV-72		a	482492	7104476	South McQuesten River at McQuesten Lake	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-76		a	487414	7087118	Thunder Gulch d/s of Bellekeno 625 adit	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-77		a	487742	7086013	Thunder Gulch upstream of Bellekeno East	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-78a		a	485690	7087474	Onek Waste Rock Storage Facility	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-78b		a	487126	7087052	Bellekeno Temporary Waste Rock Storage Facility	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-79		a	483796	7087919	Christal Creek d/s MacKeno Tailings	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-80		a	483790	7087869	Christal Lake u/s Mackeno Tailings	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-81		a	483548	7086423	Lightning Creek, South of Mill Site	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-83		a	483787	7086750	District Mill Pond Discharge	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-WD	W-WD
KV-84		a	484925	7087117	Keno City Well	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-85		a	483864	7086952	District Mill Site Groundwater Well #1 PH2	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-86		a	483836	7086707	District Mill Site Groundwater Well #2 PH5	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-87		a	484104	7086854	District Mill Site Groundwater Well #3 PH6	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-88d		a	483946	7087016	District Mill Site Groundwater Well #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-88s		a	483942	7087016	District Mill Site Groundwater Well #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-89d		a	483831	7086864	District Mill Site Groundwater Well #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-89s		a	483825	7086864	District Mill Site Groundwater Well #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-90		a	483828	7086845	District Mill Site Groundwater Well #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-91					Bellekeno Waste Rock Disposal Area Well #1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-92					Bellekeno Waste Rock Disposal Area Well #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-93					Bellekeno Waste Rock Disposal Area Well #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KV-94					Bellekeno Waste Rock Disposal Area Well #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ON-MW-01		a	7087277	485383	Onek Waste Rock Disposal Area Well #1	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
ON-MW-02		a	7087083	485244	Onek Waste Rock Disposal Area Well #2	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
LQ-MW-01		a	7090576	486426	Lucky Queen Waste Rock Disposal Area Well	-	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	-	-
KV-96		a			Onek 990 Portal Adit	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-WD	W-WD

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

Table 7-4 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 5 years after closure. The requirement for an annual geotechnical inspection will be reviewed 5 years after closure.

Table 7-4 Keno Hill Mine Operations LOM Plan Decommissioning and Reclamation Plan Closure Schedule

Phase / Activity	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
	Development/Operations							Closure	Post Closure Monitoring and Maintenance									
Progressive Reclamation																		
Closure and Reclamation Optimization/Research																		
Bellekeno Production Unit Area																		
- Underground Development/Operations																		
- Reclaim Bellekeno East Portal Site																		
- Reclaim Bellekeno 625 Adit Site																		
- Bulkhead 625 Bulkhead Installation																		
- Bellekeno Mine Flooding and Insitu Pool Treatment																		
- Bellekeno 625 Bioreactor and Commissioning																		
- 200 Level Vent Raise																		
Flame and Moth Production Unit Area																		
- Underground Development Operations																		
- Portal Closure																		
- Mine Flooding/In Situ Treatment																		
- Vent Raise																		
Lucky Queen Production Unit Area																		
- Underground Development Operations																		
- Reclaim Lucky Queen 500 Level Portal Site																		
- Vent Raise																		
Onek Production Unit Area																		
- Underground Development Operations																		
- Reclaim Onek 990 Portal Area																		
- Vent Raise																		
Waste Rock Storage																		
- Temporary P-AML WRSF - Bellekeno East																		
- Permanent P-AML WRSFs																		
- N-AML WRDAs																		
- Reclaim Borrow Areas																		
Roads																		
- Access Road Extension Bellekeno East to Bellekeno 625																		
- Bellekeno Haul Road																		
- Keno City Bypass																		
- Mill Site Access Including Christal Lake Road																		
- Lucky Queen Bypass Road																		
- Other Roads and Trails																		
Camp Downsize																		
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																		
- Progressive Reclamation																		
- Final Cover Reclamation																		
Closure Site Management (monitoring & maintenance)																		

Active Operations

Reclamation and Closure

Water Treatment/Management

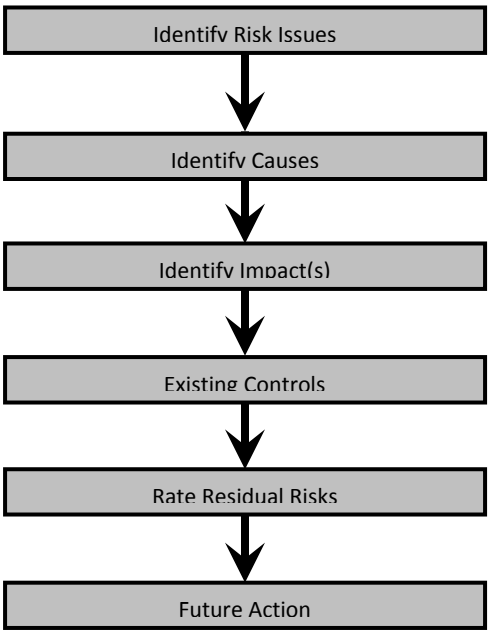
7.9 PERFORMANCE UNCERTAINTY AND RISK MANAGEMENT

7.9.1 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;
- Enhances employee and environmental safety

The risk assessment process can be summarized in the following steps:



Identify Risk Issue

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

Identify Causes

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

Identify Impacts

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

Identify Existing Controls

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

Rate Residual Risks

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

Future Actions

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

Risk Categories

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

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

Guidelines for Assessing Likelihood

The likelihood of a risk occurring must be estimated in order to determine the potential severity of the risk. The following table summarizes a guideline for determining the potential likelihood of a risk.

RISK LIKELIHOOD

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

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

Guidelines for Assessing Severity

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

RISK SEVERITY AND CONSEQUENCE TYPES

Risk Matrix

The likelihood and severity are combined to determine a risk rating for each of the particular risks. The risk rating matrix is shown in the following table.

RISK MATRIX

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

7.9.2 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 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.

7.9.3 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 90 of Water Use Licence QZ09-092, an Adaptive Management Plan (AMP) was developed specifically for the Bellekeno Mine. This Plan was based on the framework established by the District Wide AMP but was customized for the specific activities and developments of the Bellekeno Undertaking. The District Wide AMP was developed for the entire KHSD under QZ06-074 to address historic liabilities during the development and implementation of the District Closure Plan. An updated Adaptive Management Plan that includes the Bellekeno, Onek, Lucky Queen and Flame & Moth Production Unit Areas has been prepared and will be refined as necessary.

8 RECLAMATION AND CLOSURE SCHEDULE AND EXECUTION STRATEGY

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

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

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

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

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

8.1 RECLAMATION AND CLOSURE SCHEDULE

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

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

Mine decommissioning and reclamation including removal of equipment and infrastructure will mainly take place during the first year of mine closure. The Bellekeno 625 water treatment facilities will be transitioned from active to passive treatment. The schedule for implementation of water

management and treatment at Bellekeno and Lucky Queen is shown in Table 7-2, and Table 7-4 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 AANDC are in partnership to reclaim the abandoned former United Keno Hill Mine (UKHM) mines. The tenure of this project is on the order of decades, and as such there will be a site presence for many years to come. Decommissioning and reclamation of the Bellekeno, Onek, Lucky Queen and Flame & Moth Production Unit Areas will occur in tandem with closure of the UKHM sites and therefore can be orchestrated together with district monitoring programs over the long term.

9 RECLAMATION AND CLOSURE LIABILITY

Costing of the proposed decommissioning and reclamation measures is the basis for the provision of security held by Yukon Government (YG). YG currently holds a security bond (100% cash Letter of Credit) to cover the potential liabilities arising from the operation of the Keno Hill Mine Operations. 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 **$4,196,208**. Alexco also has estimated the reclamation and closure costs for the current operations at $3,359,719 and after two years of operations for the current mine plan at $3,792,296. The amount of security currently held by YG for reclamation and closure of the Keno Hill Mine Operations is **$4,172,850**. 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 ACG's and Alexco's operational and professional experience with other closure program costing estimates prepared for Yukon Government. Table 9-2 summarizes closure liability cost estimates for the current conditions (Year 0), after Year 2 of operations and at the end of mine life (EOM). Cost estimates for the separate reclamation components including site management are provided in the remaining tables.

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

Table 9.1

Summary Table of Estimated Closure Costs - Keno Hill Mine Operations

Description of Cost	Proposed Cost Year 0	Proposed Cost Year 2	Proposed Cost EOM
Closure Implementation			
General & Administration	$415,100	$415,100	$415,100
Waste Rock Dumps/Storage Facilities	$46,161	$50,726	$80,050
Underground Mines	$409,464	$734,213	$830,513
Water and Solutions Management	$374,282	$374,282	$374,282
DSTF	$21,293	$37,504	$136,030
Mill and Infrastructure/Facilities	$357,348	$357,348	$357,348
Haulage and Access Roads	$111,526	$118,246	$118,246
Supporting Studies	$47,000	$47,000	$47,000
Reclamation and Closure Research Program (Active Closure)	$30,000	$30,000	$90,000
Sub-total	$1,812,174	$2,164,418	$2,448,569
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$271,826	$324,663	$367,285
Cost Inflation [1]	$104,200	$124,454	$225,268
Total Closure Implementation Costs	**$2,188,200**	**$2,613,535**	**$3,041,122**
Post Closure Care, Maintenance, and Monitoring Costs			
Onsite Management	$0	$0	$0
Transport Costs	$46,000	$46,000	$46,000
Water Treatment Costs			
Active Treatment			
Capital Costs	$0	$0	$0
Capital Replacement Costs	$0	$0	$0
Operating Costs	$0	$0	$0
Passive Treatment			
Capital Costs	$65,000	$65,000	$65,000
Operation and Maintenance Costs	$55,000	$55,000	$55,000
Reclamation & Closure Research Plan (Post Closure)	$0	$0	$0
Monitoring & Reporting	$667,000	$667,000	$667,000
Sub-Total	$833,000	$833,000	$833,000
Sub-Total NPV (2.5% DROR)	$705,694	$671,690	$613,471
Indirect Costs (%)	15%	15%	15%
Indirect Costs	$105,854	$100,753	$92,021
Total (NPV)	$811,548	$772,443	$705,492
Total Financial Security (incl. Indirect Costs)	**$2,999,749**	**$3,385,978**	**$3,746,614**
Contingency Allowance	12%	12%	12%
Contingency Amount	$359,970	$406,317	$449,594
Total Financial Security (Plus Contingency)	**$3,359,719**	**$3,792,296**	**$4,196,208**

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

Table 9.2

Keno Hill Mine Operations Unit Rates

Equipment Rates		
Equipment	**Unit Rates**	**Per Unit**
D9H Dozer	$220	per hr
D8K Dozer	$220	per hr
Haul Truck D250E	$225	per hr
Tandem Haul Truck	$140	per hr
Cat 235 Excavator	$200	per hr
Cat 235 Excavator w hammer	$275	per hr
Cat 14H grader	$185	per hr
988B Loader	$150	per hr
Tractor Trailer (lowbed)	$160	per hr
30 ton Crane	$190	per hr
Hiab Flatdeck truck	$180	per hr
Cat 950 loader	$150	per hr
Vibratory Roller	$100	per hr
Pickup Truck	$2,500	per mo

Personnel Rates		
Personnel	**Unit Rates**	**Per Unit**
Blaster	$60	per hr
General Labourer	$45	per hr
Trades Labourer	$80	per hr
Site Supervisor	$95	per hr
Design Engineer	$140	per hr
Environmental Scientist	$130	per hr
Project Manager	$9,700	per mo
Camp Labourer	$4,000	per mo
Site Caretaker	$6,100	per mo
Environmental Monitor	$110	per hr

Revegetation Rates	**Unit Rates**	**Per Unit**
Revegetation Seed Mix	$13.00	per kg
Revegetation Seed Mix - 50kg/ha	$650	per ha
Fertilizer	$1.00	per kg
Fertilizer - 250kg/ha	$250	per ha
Tree Seedlings (1,000 seedlings per ha)	$1,750	per ha
Seed/Fertilizer Application	$1,500	per ha
Erosion Barrier		per sq.m
Revegetation cost per ha. Including application cost	**$2,400.00**	**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 Dec	$4.77	per cu.m
Compact and Contour Cover	$2.00	per cu.m
Excavation of Soil	$5.00	per cu.m
Supply and place Geotextile	$7.00	per cu.m
Load, haul and place soil cover	$8.00	per cu.m
Haul & Place rock cover	$8.00	per cu.m
Drill, Blast and Screen Rip Rap	$22.00	per cu.m
Load and Haul and Place Rip Rap	$13.00	per cu.m
HDPE Liner Install	$10.00	per sq. m
Erosion barriers	$3.00	per sq. m
Freight run to Whitehorse	$1,000	per load
Camp Cost (average cost based on 3 years of operations)	$58	per day per person
Power and Heat	$5,500	per month
Employee Transport Costs	$2,250	per month
		per month

Notes:

1) Custom Rates A through K developed specifically for Minto Mine, taking into account such factors as haul distance, grade, machinery req`d, time reqd, etc.

Table 9.3

General and Administration Costs

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
3.1	**Onsite Management**							
	Project Management and Engineering - Included in PME Costs in each Closure Component							
	Pickup truck (2 trucks, 7 months per year, 2 years)	Pickup Truck	monthly	10	$2,500	$25,000	$25,000	$25,000
	Sundry equipment maintenance	Unit Cost Basis	annually	2	$5,000	$10,000	$10,000	$10,000
	Power and heat (7 months per year, 2 years)	Power and Heat	monthly	14	$5,500	$77,000	$77,000	$77,000
	General Administrative expenses (7 months per year, 2 years)	Unit Cost Basis	monthly	14	$2,000	$28,000	$28,000	$28,000
	Camp Costs (2 year period)	Camp Cost	man-day	4,200	$58	$243,600	$243,600	$243,600
					Sub-Total	**$383,600**	**$383,600**	**$383,600**
3.2	**Transport Costs**							
	Employee transport costs (7 months per year, 2 years)	Employee Transport Costs	monthly	14	$2,250	$31,500	$31,500	$31,500
					Sub-Total		**$31,500**	**$31,500**
Total Estimated Cost for General & Administration During Closure							**$415,100**	**$415,100**

Note:

Table 9.4

Waste Rock Dumps, Quarries and Borrow Pits

Item No.	Work Item Description	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
4.1	**Bellekeno East Temporary P-AML WRSF**	**1.80**							
	Rehandle underground		Custom Rate B (Load, haul and dump mineralized rock stockpile in BK East Decline)	cu.m.	250	$5	$1,193	$1,193	$1,193
	Remove liner and haul to solid waste facility		Haul Truck D250E	hrs	2	$225	$450	$450	$450
			General Labourer	hrs.	8	$45	$360	$360	$360
	Site Recontouring		D8K Dozer	hrs.	12	$220	$2,640	$2,640	$2,640
	Revegetation	1.80	Revegetation cost per ha. Including application cost	ha	1.8	$2,400	$4,320	$4,320	$4,320
	Project Management & Engineering		7% of Total Cost	%		7.00%	$325	$325	$325
						Sub-Total	**$9,287**	**$9,287**	**$9,287**
4.2	**Bellekeno N-AML WRDA**								
	This has not been constructed and there is no plan for a Bellekeno WRDA in the LOM plan						$0	$0	$0
							$0	$0	$0
							$0	$0	$0
							$0	$0	$0
							$0	$0	$0
						Sub-Total	**$0**	**$0**	**$0**
4.3	**Onek P-AML WRSF**	**0.25**							
	Recontour P-AML rock inside lined WRSF (no rock placed)		D8K Dozer	hrs	12	$220	$528	$528	$2,640
	Place soil cover		Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	cu.m.	1,250	$4.64	$1,160	$1,160	$5,800
	Revegetation	0.25	Revegetation cost per ha. Including application cost	ha	0	$2,400	$125	$125	$624
	Project Management & Engineering		7% of Total Cost	%		7.00%	$127	$127	$634
						Sub-Total	**$1,940**	**$1,940**	**$9,698**
4.4	**Onek N-AML WRDA**								
	This has not been constructed and Onek is not in the current LOM plan and therefore no plan to construct an Onek N-AML WRDA			hrs			$0	$0	$0
				hrs			$0	$0	$0
				%			$0	$0	$0
						Sub-Total		**$0**	**$0**
4.5	**Lucky Queen P-AML WRSF**	**0.25**							
	Recontour P-AML rock inside lined WRSF		D8K Dozer	hrs	12	$220	$528	$528	$2,640
	Place soil cover		Custom Rate A (Load, haul and place overburden cover on P-AML Waste Rock)	cu.m.	1,250	$5	$1,160	$1,160	$5,800
	Revegetation	0.25	Revegetation cost per ha. Including application cost	ha	0.25	$2,400.00	$120.00	$120.00	$600
	Project Management & Engineering		7% of Total Cost	%		7.00%	$ 127	$ 127	$633
						Sub-Total	**$1,935**	**$1,935**	**$9,673**
4.6	**Lucky Queen N-AML WRDA (includes historic WRDA)**								
	Recontour crests		Cat 235 Excavator	hrs	20	$200	$500	$2,000	$4,000
	Scarify surface		D8K Dozer	hrs	6	$220	$165	$660	$1,320
	Revegetation		Revegetation cost per ha. Including application cost	ha	2	$2,400	$600	$2,400	$4,800
	Project Management & Engineering		7% of Total Cost	%		7.00%	$89	$354	$708
						Sub-Total	**$1,354**	**$5,414**	**$10,828**
4.7	**Flame and Moth Temporary P-AML WRSF**	**0.25**							
	Rehandle underground		Custom Rate B (Load, haul and dump P-AML rock to Flame underground)	hrs	1,500	$5	$2,500	$2,500	$7,500
	Remove liner and haul to solid waste facility		Haul Truck D250E	hrs	2	$225	$450	$450	$450
			General Labourer	hrs	8	$45	$360	$360	$360
	Site Recontouring		D8K Dozer	hrs	20	$220	$1,467	$1,467	$4,400
	Revegetation	0.25	Revegetation cost per ha. Including application cost	ha	0.25	$2,400	$200	$200	$600
	Project Management & Engineering		7% of Total Cost	%		7.00%	$348	$348	$932
						Sub-Total	**$5,325**	**$5,325**	**$14,242**
4.8	**Flame and Moth N-AML WRDA**								
	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			$0	$0	$0
				hrs			$0	$0	$0
				cu.m.			$0	$0	$0
				cu.m.			$0	$0	$0
			7% of Total Cost	%		7.00%	$0	$0	$0
						Sub-Total	**$0**	**$0**	**$0**
4.9	**Borrow Areas**	**2.00**							
	Stabilize slopes		Cat 235 Excavator	hrs	12	$200.00	$2,400	$2,400	$2,400
	Revegetation	2.00	Revegetation cost per ha. Including application cost	ha	2	$2,400.00	$4,800	$4,800	$4,800
	Project Management & Engineering		7% of Total Cost	%		7.00%		$504	$0
						Sub-Total	**$7,200**	**$7,704**	**$7,200**
4.9	**Coarse Ore Pad**	**2.00**							
	Concrete Demolition and Burial		Cat 235 Excavator w hammer	hrs	16	$275.00	$4,400	$4,400	$4,400
			D8K Dozer	hrs	16	$220.00	$3,520	$3,520	$3,520
	Dismantle Sprung Structure over fine ore stockpile		Misc.	l.s.	1	$5,000.00	$5,000	$5,000	$5,000
	Haul contaminated soils/materials to DSTF or underground		Cat 235 Excavator	hrs	6	$200.00	$1,200	$1,200	$1,200
			Haul Truck D250E	hrs	6	$225.00	$1,350	$1,350	$1,350
	Revegetation	1.00	Revegetation cost per ha. Including application cost	ha	1	$2,400.00	$2,400	$2,400	$2,400
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,251	$1,251	$1,251
						Sub-Total	**$19,121**	**$19,121**	**$19,121**
Total Estimated Cost in Reclaiming Overburden and Waste Rock Dumps							**$46,161**	**$50,726**	**$80,050**

Note:

Table 9.5

Mine Workings - Underground

Item No.	Work Item Description	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
5.1	**Bellekeno East Portal and Undergorund**	**0.4**							
	Remove underground equipment		6 yd LHD	hrs	60	$219	$13,140	$13,140	$13,140
			A30 Haul Truck	hrs	60	$250	$15,000	$15,000	$15,000
			Trades Labourer	hrs	120	$80	$9,600	$9,600	$9,600
			General Labourer	hrs	120	$45	$5,400	$5,400	$5,400
	Remove shop and other buildings (explosives and cap magazine)			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
	Labour for portal barrier		General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Characterize settling ponds sediments analytical costs			unit cost	1	$300	$300	$300	$300
	Remove settling ponds liners to landfill		A30 Haul Truck	hrs	2	$250	$500	$500	$500
			General Labourer	hrs	8	$45	$360	$360	$360
	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	$200	$1,200	$1,200	$1,200
			A30 Haul Truck	hrs	6	$250	$1,500	$1,500	$1,500
			General Labourer	hrs	16	$45	$720	$720	$720
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			A30 Haul Truck	hrs	20	$250	$5,000	$5,000	$5,000
			General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Test area soils for contamination		Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing			lump sum	1	$600	$600	$600	$600
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$3,200	$3,200	$3,200
			A30 Haul Truck	hrs	16	$250	$4,000	$4,000	$4,000
	Recontour and scarify area and slopes to establish drainage		D8K Dozer	hrs	24	$220	$5,280	$5,280	$5,280
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Install Signage		Misc.	lump sum	1	$500	$500	$500	$500
							$0		
	Project Management & Engineering		7% of Total Cost	%		7.00%	$7,251	$7,251	$7,251
						Sub-Total	**$110,831**	**$110,831**	**$110,831**
5.2	**Bellekeno 625 Adit Area**	**0.8**							
	Remove electrical substation		Misc.	lump sum	1	$15,000	$15,000	$15,000	$15,000
	Remove electrical transmission line (Keno City to BK 625)		Misc.	lump sum	1	$25,000	$25,000	$25,000	$25,000
	Remove shop/loadout facility, compressor station		Misc.	lump sum	1	$20,000	$20,000	$20,000	$20,000
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			A30 Haul Truck	hrs	20	$250	$5,000	$5,000	$5,000
			General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Test area soils for contamination		Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing			lump sum	1	$600	$600	$600	$600
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$3,200	$3,200	$3,200
			A30 Haul Truck	hrs	16	$250	$4,000	$4,000	$4,000
	Recontour and scarify area and slopes to establish drainage		D8K Dozer	hrs	24	$220	$5,280	$5,280	$5,280
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Install Signage		Misc.	lump sum	1	$500	$500	$500	$500
							$0		
	Project Management & Engineering		7% of Total Cost	%		7.00%	$6,227	$6,227	$6,227
						Sub-Total	**$95,187**	**$95,187**	**$95,187**
5.3	**Bellekeno 200 Level Vent Raise**								
	Engineering for Concrete Cap		Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
	Concrete Batch		Misc.	l.s.	1	$10,000	$10,000	$10,000	$10,000
			988B Loader	hrs	12	$150	$1,800	$1,800	$1,800
			Tractor Trailer (lowbed)	hrs	48	$160	$7,680	$7,680	$7,680
	Labour for cap		General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Project Management & Engineering		7% of Total Cost	%		7.00%	$2,190	$2,190	$2,190
						Sub-Total	**$33,470**	**$33,470**	**$33,470**
5.4	**Onek 990 Portal and Underground**								
	Remove underground equipment		6 yd LHD	hrs	10	$219	$2,190	$2,190	$2,190
			A30 Haul Truck	hrs	10	$250	$2,500	$2,500	$2,500
			Trades Labourer	hrs	20	$80	$1,600	$1,600	$1,600
			General Labourer	hrs	20	$45	$900	$900	$900
	Project Management & Engineering		7% of Total Cost	%		7.00%	$503	$503	$503
						Sub-Total	**$7,693**	**$7,693**	**$7,693**
5.5	**Onek 990 Portal Site and Infrastructure**								
	Remove shop and other buildings (explosives and cap magazine)		Misc.	hrs	1	$5,000	$2,500	$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	$45	$1,800	$1,800	$1,800
	Clean out fuel tank residue		Misc.	l.s.	1	$1,000	$0	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill		Cat 235 Excavator	hrs	6	$200	$0	$1,200	$1,200
			Haul Truck D250E	hrs	6	$225	$0	$1,350	$1,350
			General Labourer	hrs	16	$45	$0	$720	$720
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$2,000	$4,000	$4,000
			Haul Truck D250E	hrs	20	$225	$2,250	$4,500	$4,500
			General Labourer	hrs	40	$45	$900	$1,800	$1,800
	Sample and test area soils for contamination		Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing		Analytical Costs	Unit Cost	4	$300	$1,200	$1,200	$1,200
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$1,600	$3,200	$3,200
			Haul Truck D250E	hrs	16	$225	$1,800	$3,600	$3,600
	Recontour and scarify area and slopes to establish drainage		D8K Dozer	hrs	24	$220	$5,280	$5,280	$5,280
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Install Signage		Misc.	l.s.	1	$500	$500	$500	$500
	Remove electrical substation (not yet upgraded, not part of LOM Plan))		Misc.	l.s.	1	$0	$0	$0	$0
	Remove electrical transmission line (not yet constructed, not part of LOM Plan)		Misc.	l.s.	1	$0	$0	$0	$0
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			Haul Truck D250E	hrs	20	$225	$4,500	$4,500	$4,500
			General Labourer	hrs	24	$45	$1,080	$1,080	$1,080
			Haul Truck D250E	hrs	16	$225	$3,600	$3,600	$3,600
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Characterize settling pond sediments/sludge		Analytical Costs	Unit Cost	2	$300	$600	$600	$600
	Remove sludge from settling pond		Vacuum Truck	hrs	40	$140	$2,800	$5,600	$5,600
			General Labourer	hrs	40	$45	$900	$1,800	$1,800
	Remove settling ponds liners to landfill (not yet constructed)		Haul Truck D250E	hrs	4	$225	$900	$900	$900
	Site levelling		D9H Dozer	hrs	20	$220	$4,400	$4,400	$4,400
	Scrap hauled to solid waste facility		Cat 235 Excavator	hrs	8	$200	$1,600	$1,600	$1,600
			Haul Truck D250E	hrs	12	$225	$2,700	$2,700	$2,700
	Misc. Supplies & Tools		Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$6,182	$6,182	$6,182
						Sub-Total	**$75,472**	**$94,492**	**$94,492**
5.6	**Onek 990 Vent Raise**								
	Not Constructed and Not in the LOM Plan								
	Project Management & Engineering		7% of Total Cost	%		7.00%			
						Sub-Total	**$0**	**$0**	**$0**
5.5	**Lucky Queen Underground**								
	Remove shop and other buildings (explosives and cap magazine)		Misc.	hrs	1	$5,000	$2,500	$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	$45	$1,800	$1,800	$1,800
	Clean out fuel tank residue		Misc.	l.s.	1	$1,000	$0	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill		Cat 235 Excavator	hrs	6	$200	$0	$1,200	$1,200
			Haul Truck D250E	hrs	6	$225	$0	$1,350	$1,350
			General Labourer	hrs	16	$45	$0	$720	$720
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$2,000	$4,000	$4,000
			Haul Truck D250E	hrs	20	$225	$2,250	$4,500	$4,500
			General Labourer	hrs	40	$45	$900	$1,800	$1,800
	Sample and test area soils for contamination		Environmental Monitor	hrs	8	$110	$880	$880	$880
	Laboratory Analysis for soils testing		Analytical Costs	Unit Cost	4	$300	$1,200	$1,200	$1,200
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$3,200	$3,200	$3,200
			Haul Truck D250E	hrs	16	$225	$3,600	$3,600	$3,600
	Recontour and scarify area and slopes to establish drainage		D8K Dozer	hrs	12	$220	$2,640	$2,640	$2,640
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Remove electrical substation (not yet upgraded)		Misc.	l.s.	1	$15,000	$0	$0	$15,000
	Remove electrical transmission cable (not yet constructed)		Misc.	l.s.	1	$15,000	$0	$0	$15,000
	Remove shop/loadout facility		Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			Haul Truck D250E	hrs	20	$225	$4,500	$4,500	$4,500
			General Labourer	hrs	24	$45	$1,080	$1,080	$1,080
			Haul Truck D250E	hrs	16	$225	$3,600	$3,600	$3,600
			Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Install Signage		Misc.	l.s.	1	$500	$500	$500	$500
	Characterize settling pond sediments/sludge		Analytical Costs	Unit Cost	2	$300	$600	$600	$600
	Remove sludge from settling pond		Vacuum Truck	hrs	40	$140	$2,800	$5,600	$5,600
			General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Remove settling ponds liners to landfill (not yet constructed)		Haul Truck D250E	hrs	4	$225	$0	$900	$900
	Site levelling		D9H Dozer	hrs	20	$220	$4,400	$4,400	$4,400
	Scrap hauled to solid waste facility		Cat 235 Excavator	hrs	8	$200	$1,600	$1,600	$1,600
			Haul Truck D250E	hrs	12	$225	$2,700	$2,700	$2,700
	Misc. Supplies & Tools		Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
							$0		
	Project Management & Engineering		7% of Total Cost	%		7.00%	$6,347	$6,347	$8,447
						Sub-Total	**$81,397**	**$97,017**	**$129,117**
5.6	**Lucky Queen Vent Raise**								
	Engineering for Concrete Cap		Misc.	l.s.	1	$10,000		$10,000	$10,000
	Concrete Batch		Misc.	l.s.	1	$10,000		$10,000	$10,000
			988B Loader	hrs	12	$150		$1,800	$1,800
			Tractor Trailer (lowbed)	hrs	48	$160		$7,680	$7,680
	Labour for cap		General Labourer	hrs	40	$45		$1,800	$1,800
	Project Management & Engineering		7% of Total Cost	%		7.00%		218960.00%	$2,190
						Sub-Total	**$0**	**$194,034**	**$258,234**
5.5	**Flame and Moth Underground**								
	Remove shop and other buildings (explosives and cap magazine)		Misc.	hrs	1	$5,000	$0	$5,000	$5,000
	Supply rockfill for portal barrier		Load and Haul and Place Rip Rap	m3	700	$13	$0	$9,100	$9,100
	Labour for portal barrier		General Labourer	hrs	40	$45	$0	$1,800	$1,800
	Clean out fuel tank residue		Misc.	l.s.	1	$1,000	$0	$1,000	$1,000
	Haul fuel tank and liner for reuse or landfill		Cat 235 Excavator	hrs	6	$200	$0	$1,200	$1,200
			Haul Truck D250E	hrs	6	$225	$0	$1,350	$1,350
			General Labourer	hrs	16	$45	$0	$720	$720
	Area cleanup and haul debris to landfill		Cat 235 Excavator	hrs	10	$200	$0	$2,000	$2,000
			Haul Truck D250E	hrs	10	$225	$0	$2,250	$2,250
			General Labourer	hrs	40	$45	$0	$1,800	$1,800
	Sample and test area soils for contamination		Environmental Monitor	hrs	8	$110	$0	$880	$880
	Laboratory Analysis for soils testing		Analytical Costs	Unit Cost	4	$300	$0	$1,200	$1,200
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$0	$3,200	$3,200
			Haul Truck D250E	hrs	16	$225	$0	$3,600	$3,600
	Recontour and scarify area and slopes to establish drainage		D8K Dozer	hrs	12	$220	$1,320	$2,640	$2,640
			Cat 14H grader	hrs	16	$185	$1,480	$2,960	$2,960
	Remove electrical substation (included in mill facilities)		Misc.	l.s.	1	$0	$0	$0	$0
	Install Signage		Misc.	l.s.	1	$500	$500	$500	$500
	Characterize settling pond sediments/sludge		Analytical Costs	Unit Cost	2	$300	$0	$600	$600
	Remove sludge from settling pond		Vacuum Truck	hrs	30	$140	$0	$4,200	$4,200
			General Labourer	hrs	30	$45	$0	$1,350	$1,350
	Remove settling ponds liners to landfill		Haul Truck D250E	hrs	4	$225	$0	$900	$900
	Site levelling		D9H Dozer	hrs	16	$220	$1,760	$3,520	$3,520
	Scrap hauled to solid waste facility		Cat 235 Excavator	hrs	8	$200	$0	$1,600	$1,600
			Haul Truck D250E	hrs	12	$225	$0	$2,700	$2,700
	Misc. Supplies & Tools		Misc.	l.s.	1	$7,500	$0	$7,500	$7,500
							$0		
	Project Management & Engineering		7% of Total Cost	%		7.00%	$354	$4,450	$4,450
						Sub-Total	**$5,414**	**$68,020**	**$68,020**
5.6	**Flame and Moth Vent Raise**								
	Engineering for Concrete Cap		Misc.	l.s.	1	$10,000	$0	$10,000	$10,000
	Concrete Batch		Misc.	l.s.	1	$10,000	$0	$10,000	$10,000
			988B Loader	hrs	12	$150	$0	$1,800	$1,800
			Tractor Trailer (lowbed)	hrs	48	$160	$0	$7,680	$7,680
	Labour for cap		General Labourer	hrs	40	$45	$0	$1,800	$1,800
	Project Management & Engineering		7% of Total Cost	%		7%	$0	$2,190	$2,190
						Sub-Total	**$0**	**$33,470**	**$33,470**
Total Estimated Cost in Reclaiming Underground Mines							**$409,464**	**$734,213**	**$830,513**

Note:
Linear disturbances to be scarified / decompacted and allowed to naturally revegetate

Table 9.6

Water and Solutions Management

Item No.	Work Item Description	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
6.1	**Mill Runoff Collection Pond**								
	Pump down collected water		General Labourer	hrs	36	$45	$1,620	$1,620	$1,620
			Pump	hrs	16	$15	$240	$240	$240
	Misc. Supplies and Tools		Misc.	l.s.	1	$500	$500	$500	$500
	Characterize pond sediments/sludge		Analytical Costs	Unit Cost	1	$300	$300	$300	$300
	Remove pond sediments/sludge		Vacuum Truck	hrs	16	$140	$2,240	$2,240	$2,240
			General Labourer	hrs	16	$45	$720	$720	$720
	Breach dyke, relocate and contour materials		Excavation of soil	cu.m.	3,000	$5.00	$15,000	$15,000	$15,000
	Stabilize slopes with erosion barriers		Erosion barriers	cu.m.	3,000	$3.00	$9,000	$9,000	$9,000
	Remove discharge pipeline		Misc.	l.s.	1	$2,500	$2,500	$2,500	$2,500
	Project Management & Engineering		7% of Total Cost	%		7.00%	$2,083	$2,083	$2,083
						Sub-Total	**$34,203**	**$34,203**	**$34,203**
6.2	**Diversion Ditches**								
	Recontour Diversion Ditch to Mill Pond	525	D8K Dozer	hrs	20	$220	$4,400	$4,400	$4,400
			Cat 235 Excavator	hrs	10	$200	$2,000	$2,000	$2,000
	Recontour Diversion Ditch above Mill Area	285	D8K Dozer	hrs	10	$220	$2,200	$2,200	$2,200
			Cat 235 Excavator	cu.m.	5	$200	$1,000	$1,000	$1,000
	Revegetate	0.4	Revegetation cost per ha. Including application cost	cu.m.	0	$2,400	$960	$960	$960
	Project Management & Engineering		7% of Total Cost	%		7.00%	$291	$291	$291
						Sub-Total	**$10,851**	**$10,851**	**$10,851**
6.3	**Bellekeno 625 WTP - Mine Pool Treatment Transition**								
	625 Adit Bulkhead								
	Hydrogeologic study & engineering for concrete bulkhead		Misc.	lump sum	1	$35,000	$35,000	$35,000	$35,000
	Underground Rehab for bulkhead		Misc.	lump sum	1	$35,000	$35,000	$35,000	$35,000
	Construct concrete plug		General Labourer	hrs	120	$45	$5,400	$5,400	$5,400
			Trades Labourer	hrs	120	$80	$9,600	$9,600	$9,600
	Concrete Batch		Misc.	cu.m	31	$1,750	$54,880	$54,880	$54,880
			988B Loader	hrs	80	$150	$12,000	$12,000	$12,000
	Install Instrumentation (e.g pressure gauge)		Misc.	lump sum	1	$10,000	$10,000	$10,000	$10,000
	Remove salvageable equipment		Cat 235 Excavator	hrs	16	$200.00	$3,200	$3,200	$3,200
			Trades Labourer	hrs	16	$80	$1,280	$1,280	$1,280
	Load & return extra reagents/chemicals		General Labourer	hrs	8	$45	$360	$360	$360
			Misc.		1	$2,000	$2,000	$2,000	$2,000
							$0		
	In mine pool treatment implementation		Misc.	l.s.	1	$40,000	$40,000	$40,000	$40,000
							$0		
	Characterize settling ponds sediments/sludge		Analytical Costs	Unit Cost	2	$300	$600	$600	$600
	Remove sludge from settling ponds (to DSTF)		Vacuum Truck	hrs	40	$140	$5,600	$5,600	$5,600
			General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Remove settling ponds liners to landfill		Haul Truck D250E	hrs	4	$225	$900	$900	$900
			General Labourer	hrs	8	$45	$360	$360	$360
	Construct Bellekeno 625 bioreactor		Haul Truck D250E	hrs	80	$225	$18,000	$18,000	$18,000
			Cat 950 loader	hrs	60	$150	$9,000	$9,000	$9,000
			General Labourer	hrs	60	$45	$2,700	$2,700	$2,700
							$0		
	Operate Bellekeno 625 bioreactor (5 yrs)		Misc.	l.s.	5	$7,500	$37,500	$37,500	$37,500
							$0		
	Site levelling		D8K Dozer	hrs	25	$220	$5,500	$5,500	$5,500
	Scrap hauled to solid waste facility		Haul Truck D250E	hrs	8	$225	$1,800	$1,800	$1,800
			Cat 235 Excavator	hrs	12	$200	$2,400	$2,400	$2,400
	Misc. Supplies & Tools		Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$9,660	$9,660	$9,660
						Sub-Total	**$309,540**	**$309,540**	**$309,540**
6.4	**Mill Pond - Bioreactor Transition**								
	Discharge mill pond inventory (3,500 m3)		Analytical Costs	Unit Cost	2	$300	$600	$600	$600
			General Labourer	hrs	40	$45	$1,800	$1,800	$1,800
	Construct bioreactor in mill pond if necessary (DSTF runoff + Flame and Moth if necessary). Costs included in post closure care and maintenance								
	Operate mill bioreactor if necessary (5 years) costs included in Care and Maintenance								
	Construct outlet channel		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			D8K Dozer	hrs	20	$220	$4,400	$4,400	$4,400
			Place rip rap	cu.m.	5	$1,250	$6,250	$6,250	$6,250
			General Labourer	hrs	30	$45	$1,350	$1,350	$1,350
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,288	$1,288	$1,288
						Sub-Total	**$19,688**	**$19,688**	**$19,688**
6.4	**Flame and Moth Water Management**								
	In Mine Pool treatment implementation - costs included in post closure care and maintenance								
	Project Management & Engineering		7% of Total Cost	%		7.00%	$0	$0	$0
						Sub-Total	**$0**	**$0**	**$0**
Total Estimated Cost in Constructing Primary Drainage Ditches							**$374,282**	**$374,282**	**$374,282**

Note:

Table 9.7

Dry Stack Tailings Facility

Item No.	Work Item Description	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
7.1	**DSTF - Current**	**0.5**							
	Recontour slopes to final design and compact		D8K Dozer	hrs	20	$220.00	$4,400.00		
			Vibratory Roller	hrs	8	$100.00	$800.00		
	Place soil cover and spread		Haul Truck D250E	hrs	20	$225.00	$4,500.00		
			Cat 235 Excavator	hrs	20	$200.00	$4,000.00		
			D8K Dozer	hrs	20	$220.00	$4,400.00		
	Revegetation		Revegetation Seed Mix - 50kg/ha	ha	0.8	$650.00	$487.50		
			Fertilizer - 250kg/ha	ha	0.8	$250.00	$187.50		
			Seed/Fertilizer Application	ha	0.8	$1,500.00	$1,125.00		
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,393		
						Sub-Total	**$21,293**		
7.2	**DSTF - Year 2**	**1.5**							
	Recontour slopes to final design and compact		D8K Dozer	hrs	55	$220.00		$12,100	
			Vibratory Roller	hrs	10	$100.00		$1,000	
	Place soil cover and spread		Haul Truck D250E	hrs	30	$225.00		$6,750	
			Cat 235 Excavator	hrs	30	$200.00		$6,000	
			D8K Dozer	hrs	20	$220.00		$4,400	
	Revegetation		Revegetation Seed Mix - 50kg/ha	ha	2.0	$650.00		$1,300	
			Fertilizer - 250kg/ha	ha	2.0	$250.00		$500	
			Seed/Fertilizer Application	ha	2.0	$1,500.00		$3,000	
				hrs	-				
	Project Management & Engineering		7% of Total Cost	%		7.00%		$2,454	
						Sub-Total		**$37,504**	
7.3	**DSTF - EOM**	**6.0**							
	Recontour slopes to final design and compact		D8K Dozer	hrs	220	$220.00			$48,400
			Vibratory Roller	hrs	40	$100.00			$4,000
	Place soil cover and spread		Haul Truck D250E	hrs	120	$225.00			$27,000
			Cat 235 Excavator	hrs	120	$200.00			$24,000
			D8K Dozer	hrs	80	$220.00			$17,600
	Revegetation		Revegetation Seed Mix - 50kg/ha	ha	6.0	$650.00			$3,900
			Fertilizer - 250kg/ha	ha	6.0	$250.00			$1,500
			Seed/Fertilizer Application	ha	6.0	$1,500.00			$9,000
	Project Management & Engineering		7% of Total Cost			7.00%			$630
						Sub-Total			**$136,030**
Total Estimated Cost in Reclaiming Tailings Area							**$21,293**	**$37,504**	**$136,030**

Note:

Table 9.8

Mill & Ancillary Facilities

Item No.	Work Item Description	Area (ha) / Length (m)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
9.1	**Mill and Ancilliary Facilities**								
	Remove equipment (crusher, conveyors, mill equipment, trailer units, other ancillary facilities - fine ore bin)		General Labourer	hrs	600	$45	$27,000	$27,000	$27,000
			Trades Labourer	hrs	400	$80	$32,000	$32,000	$32,000
			Cat 950 loader	hrs	150	$150	$22,500	$22,500	$22,500
			Cat 235 Excavator	hrs	50	$200	$10,000	$10,000	$10,000
			Tractor Trailer (lowbed)	hrs	120	$160	$19,200	$19,200	$19,200
	Load and return extra chemicals/reagents		General Labourer	hrs	75	$45	$3,375	$3,375	$3,375
			Misc.	l.s.	1	$2,500	$2,500	$2,500	$2,500
	Dismantle Mill Building		Cat 950 loader	hrs	70	$150	$10,500	$10,500	$10,500
			Tractor Trailer (lowbed)	hrs	70	$160	$11,200	$11,200	$11,200
			Trades Labourer	hrs	300	$80	$24,000	$24,000	$24,000
			General Labourer	hrs	1000	$45	$45,000	$45,000	$45,000
	Concrete Demolition		Cat 235 Excavator w hammer	l.s.	1	$275	$275	$275	$275
			D9H Dozer	hrs	20	$220	$4,400	$4,400	$4,400
	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	$200	$10,000	$10,000	$10,000
			Haul Truck D250E	hrs	100	$225	$22,500	$22,500	$22,500
	Misc. Supplies and Tools		Misc.	l.s.	1	$2,000	$2,000	$2,000	$2,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$19,912	$19,912	$19,912
						Sub-Total	**$304,362**	**$304,362**	**$304,362**
9.2	**Mill Pad**	**2.8**							
	Test area soils for contamination		Environmental Monitor	hrs	16	$110	$1,760	$1,760	$1,760
	Laboratory Analysis for soils testing		Analytical Costs	Unit Cost	20	$300	$6,000	$6,000	$6,000
	Haul any contaminated soils to nearest Land Treatment Facility		Cat 235 Excavator	hrs	16	$200	$3,200	$3,200	$3,200
			Haul Truck D250E	hrs	16	$225	$3,600	$3,600	$3,600
	Regrade embankment shoulders		D8K Dozer	hrs	8	$220	$1,760	$1,760	$1,760
	Scarify pad area		Cat 14H grader	hrs	8	$185	$1,480	$1,480	$1,480
	Revegetate		Revegetation cost per ha. Including application cost	hrs	2.8	$2,400	$6,720	$6,720	$6,720
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,716	$1,716	$1,716
						Sub-Total	**$26,236**	**$26,236**	**$26,236**
9.3	**Camp Downsize**								
	Dismantle 5 trailer units and transport to Lot 960		Misc.	l.s.	1	$25,000	$25,000	$25,000	$25,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,750	$1,750	$1,750
						Sub-Total	**$26,750**	**$26,750**	**$26,750**
Total Estimated Cost in Reclaiming Mill and Ancillary Facilities							**$357,348**	**$357,348**	**$357,348**

Table 9.9

Haulage and Access Roads

Item No.	Work Item Description	Area (ha) / Length (km)	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
11.1	**Bellekeno East Portal to Upper Laydown (0.5 km)**								
	Culvert Excavation and install swales (2 ea)		Cat 235 Excavator	hrs	6	200	$1,200	$1,200	$1,200
			General Labourer	hrs	12	45	$540	$540	$540
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	16	200	$3,200	$3,200	$3,200
	Scarify road surface	0.5	Cat 14H grader	hrs	16	$185	$2,960	$2,960	$2,960
	Erosion barrier (50% of length)		Misc.	m2	500	$2	$1,000	$1,000	$1,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$623	$623	$623
						Sub-Total	**$9,523**	**$9,523**	**$9,523**
11.1	**Bellekeno 625 Access (0.25 km)**								
	Culvert Excavation and install swales (15 ea)		Cat 235 Excavator	hrs	6	$200	$1,200	$1,200	$1,200
			General Labourer	hrs	12	$45	$540	$540	$540
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	12	$200	$2,400	$2,400	$2,400
	Scarify road surface	0.3	Cat 14H grader	hrs	16	$185	$2,960	$2,960	$2,960
	Erosion barrier (50% of length)		Misc.	m2	250	$2	$500	$500	$500
	Project Management & Engineering		7% of Total Cost	%		7.00%	$410	$410	$410
						Sub-Total	**$8,010**	**$8,010**	**$8,010**
11.3.2	**Bellekeno East to BK 5 (3.0 km)**								
	Culvert Excavation and install swales (4 ea)		Cat 235 Excavator	hrs	40	$200	$8,000	$8,000	$8,000
			General Labourer	hrs	30	$45	$1,350	$1,350	$1,350
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	10	$200	$2,000	$2,000	$2,000
	Scarify road surface	3.0	Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Erosion barrier (50% of length)		Misc.	hrs	3,000	$2	$6,000	$6,000	$6,000
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,474	$1,474	$1,474
						Sub-Total	**$22,524**	**$22,524**	**$22,524**
11.3.3	**Keno City Bypass Road (BK 5 to Crusher - 1.2 km)**								
	Culvert Excavation and install swales (5 ea)		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			General Labourer		16	$45	$720	$720	$720
	Reslope banks/remove safety berms		Cat 235 Excavator		16	$200	$3,200	$3,200	$3,200
	Scarify road surface	1.2	Cat 14H grader	hrs	12	$185	$2,220	$2,220	$2,220
	Erosion barrier (50% of length)		Misc.	hrs	12	$2	$24	$24	$24
	Remove Lightning Creek Bridge		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			Tractor Trailer (lowbed)	hrs	12	$160	$1,920	$1,920	$1,920
			Misc.	l.s.	1,200	$2	$2,400	$2,400	$2,400
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,294	$1,294	$1,294
						Sub-Total	**$19,778**	**$19,778**	**$19,778**
11.3.4	**Keno District Mill Access (Christal Lake Road - 1.9 km)**								
	Culvert Excavation and install swales (5 ea)		Cat 235 Excavator	hrs	15	$200	$3,000	$3,000	$3,000
			General Labourer	hrs	30	$45	$1,350	$1,350	$1,350
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	12	$200	$2,400	$2,400	$2,400
	Scarify road surface	1.9	Cat 14H grader	hrs	12	$185	$2,220	$2,220	$2,220
	Erosion barrier (50% of length)		Misc.	l.s.	1,900	$2	$3,800	$3,800	$3,800
	Project Management & Engineering		7% of Total Cost	%		7.00%	$894	$894	$894
						Sub-Total	**$13,664**	**$13,664**	**$13,664**
11.3.4	**Flame and Moth Haul Road (Portal to Crusher - 175 m)**								
	Culvert Excavation and install swales (3 ea)		Cat 235 Excavator	hrs	10	$200	$0	$2,000	$2,000
			General Labourer	hrs	10	$45	$0	$450	$450
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	10	$200	$0	$2,000	$2,000
	Scarify road surface	0.175	Cat 14H grader	hrs	8	$185	$0	$1,480	$1,480
	Erosion barrier (50% of length)		Misc.	l.s.	175	$2	$0	$350	$350
	Project Management & Engineering		7% of Total Cost	%		7.00%	$0	$440	$440
						Sub-Total	**$0**	**$6,720**	**$6,720**
11.3.4	**Onek Haul Road (Onek 990 Portal to BK9 - 2.1 km)**								
	Culvert Excavation and install swales (5 ea)		Cat 235 Excavator	hrs	30	$200	$6,000	$6,000	$6,000
			General Labourer	hrs	20	$45	$900	$900	$900
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	10	$200	$2,000	$2,000	$2,000
	Scarify road surface	2.1	Cat 14H grader	hrs	12	$185	$2,220	$2,220	$2,220
	Erosion barrier (50% of length)		Misc.	l.s.	2,100	$2	$4,200	$4,200	$4,200
	Remove Lightning Creek Bridge		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			Tractor Trailer (lowbed)	hrs	12	$160	$1,920	$1,920	$1,920
	Project Management & Engineering		7% of Total Cost	%		7.00%	$1,487	$1,487	$1,487
						Sub-Total	**$22,727**	**$22,727**	**$22,727**
11.3.4	**Lucky Queen Haul and Access Road (Wernecke to Onek 990 - 1.2 km)**								
	Culvert Excavation and install swales (2 ea)		Cat 235 Excavator	hrs	20	$200	$4,000	$4,000	$4,000
			General Labourer	hrs	16	$45	$720	$720	$720
	Reslope banks/remove safety berms		Cat 235 Excavator	hrs	10	$200	$2,000	$2,000	$2,000
	Scarify road surface	1.2	Cat 14H grader	hrs	8	$185	$1,480	$1,480	$1,480
	Erosion barrier (50% of length)		Misc.	l.s.	1,200	$2	$2,400	$2,400	$2,400
	Project Management & Engineering		7% of Total Cost	%		7.00%	$742	$742	$742
						Sub-Total	**$11,342**	**$11,342**	**$11,342**
11.3.4	**Other Roads and Trails (3 km)**								
	Scarify road surface	3	Cat 14H grader	hrs	20	$185	$3,700	$3,700	$3,700
	Project Management & Engineering		7% of Total Cost	%		7.00%	$259	$259	$259
						Sub-Total	**$3,959**	**$3,959**	**$3,959**
Total Estimated Cost for Haulage and Access Road Closure							**$111,526**	**$118,246**	**$118,246**

Note:

Table 9.10

Supporting Studies

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Current Total	Year 2 Total	EOM Total
14.1	**Kinetic Tailings and Waste Rock Materials Testing**							
	Field bin ARD/metal leaching studies/tests	Misc.	l.s.	5	$2,500	$12,500	$12,500	$12,500
	Humidity cells	Misc.	l.s.	3	$3,500	$10,500	$10,500	$10,500
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
					Sub-Total	**$23,000**	**$23,000**	**$23,000**
14.2	**Other Adaptive Management Plans Required**							
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
		Misc.	l.s.	1				$0
					Sub-Total		**$0**	**$0**
14.3	**Contaminated Site Assessment Plan**							
	Develop Plan	Misc.	l.s.	1	$4,000	$4,000	$4,000	$4,000
	Site Reportng	Misc.	l.s.	1	$5,000	$5,000	$5,000	$5,000
					Sub-Total	**$9,000**	**$9,000**	**$9,000**
14.4	**Reclamation & Closure Research Plan**							
	Resesarch during active mine operations	Misc.	l.s.	1	$15,000	$30,000	$30,000	$90,000
		Misc.	l.s.	1				$0
					Sub-Total	**$30,000**	**$30,000**	**$90,000**
14.5	**Passive Treatment Design**							
	Design for BK 625 and mill pond bioreactors	Misc.	l.s.	1	$15,000	$15,000	$15,000	$15,000
					Sub-Total	**$15,000**	**$15,000**	**$15,000**
Total Estimated Cost for Supporting Studies						**$77,000**	**$77,000**	**$137,000**

Note:

Table 9.11

Post Closure Care, Maintenance, and Monitoring

Item No.	Work Item Description	Equipment / Labour	Units	Quantity	Unit Rates	Annual Cost	Full Cost	NPV Current	NPV	NPV Year 2
15.1	**Onsite Management**									
	Project Management and Engineering - Included in PME Costs in each Closure Component									
	Pickup truck (1 truck for Environmental Monitor)									
	Active Closure + Post Closure 10 Years	Light truck	annually	11		$7,200	$79,200			
	Sundry equipment maintenance									
	Active Closure + Post Closure 10 Years	Unit Cost Basis	annually	11		$2,500	$27,500			
	Power and heat (5 months per year)									
	Active Closure + Post Closure 10 Years	Unit Cost Basis	annually	11		$2,500	$27,500			
	General Administrative expenses									
	Active Closure + Post Closure 10 Years	Unit Cost Basis	annually	11		$4,500	$49,500			
	Camp Costs									
	Post Closure 10 Years	Unit Cost Basis	man-day	600	$58	$3,480	$34,800			
					Subtotal - Post Closure 10 Years	**$21,850**	**$218,500**	**$207,885**	**$197,868**	**$179,259**
15.2	**Transport Costs**									
	Employee transport costs									
	Post Closure 10 Years	Unit Cost Basis	monthly	120			$46,000			
					Subtotal - Post Closure 10 Years		**$46,000**	**$41,061**	**$39,082**	**$35,407**
15.3	**Water Treatment Costs**									
	Active Treatment									
	Capital Costs	Misc.	annually							
	Capital Replacement Costs	Misc.	annually							
	Operating Costs	Misc.	annually							
	Passive Treatment									
	Capital Costs	Misc.	annually				$65,000	$63,415	$60,359	$54,682
	Operation and Maintenance Costs	Misc.	annually	10		$5,500	$55,000	$48,851	$46,497	$42,124
					Subtotal - Post Closure 10 Years		**$120,000**	**$112,266**	**$106,856**	**$96,806**
15.4	**Reclamation & Closure Research Plan**									
	Reclamation & Closure Research Plan	Misc.	annually	-	$0	$0	$0			
					Subtotal - Post Closure 10 Years		**$0**		**$0**	**$0**
15.5	**Monitoring & Reporting**									
	Disbursements (non-labour/non-analytical)	Misc.	annually	10	$2,000	$2,000	$62,500	$55,332	$52,666	$52,666
	Water Quality Monitoring									
	Active Closure + Post Closure 10 Years	Misc.	each	60			$460,000	$410,609	$390,824	$354,067
	Biological Monitoring (Sediment and Benthos):									
	Active Closure + Post Closure 10 Years	Misc.	each	11	$4,000		$32,000	$28,440	$27,070	$24,524
	Geotechnical Inspections:									
	Years 1- 5 (Annual)	Misc.	annually	5			$30,000	$27,541	$26,214	$23,748
	Reclamation Inspections:									
	Years 1- 5 (Annual)	Misc.	annually	5			$17,500	$14,962	$14,241	$12,902
	Site Maintenance									
	Site Maintenance Years 1-5	Misc.	each	5	$3,000	$3,000	$32,000	$28,002	$26,652	$24,146
	Annual Inspection + report	Misc.	annually	10	$3,000	$3,000	$33,000	$28,543	$27,167	$24,612
						Sub-Total	**$667,000**	**$593,429**	**$564,834**	**$516,665**
Total Estimated Cost for Post Closure Site Management							**$787,000**	**$705,694**	**$671,690**	**$613,471**

Note:

10 REFERENCES

Access Consulting Group (2014) Monitoring, Surveillance and Reporting Plan – Revision 2.5 Keno Hill Silver District Mining Operations. Report prepared for Alexco Resource Corp., September 2014.

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

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

Interralogic (2013) Natural Attenuation Evaluation Summary Report. United Keno Hill Mines, Elsa, YT. Report prepared for Elsa Reclamation Development Company, Ltd., November 2013

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

Appendix 1 Suporting Environmental Data

ACCESS

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Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

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

CC: Tiffany Lunday, Access Consulting Group

Date: March 28, 2012

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

INTRODUCTION

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

OBSERVATIONS AND EQUIPMENT CONDITIONS 2011:

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

METHODS AND RESULTS:

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

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

CONCLUSIONS AND RECOMMENDATIONS:

- A pyranometer should be installed at the Flame and Moth meteorological station, to allow the incorporation to the datalogger program of an instruction calculating evapotranspiration. Additionally, an evaporation pan may also be considered to validate estimates of evaporation.

- A program revision has been written for the Campbell Scientific data logger which fixes the code for the relative humidity sensor and should be sent to the data logger at the next site visit.

- Hourly data for the period of recorded has been requested from Environment Canada for the MAYO A meteorological station and can be used to extend the record of rainfall and relative humidity at the Flame and Moth station.

REFERENCES:

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

Appendix I: Meteorological Station Components

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



Appendix II: Tables

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

	Monthly Avg. Temp (°C)	Monthly Avg. Max Temp (°C)	Monthly Extreme Max Temp (°C)	Monthly Avg. Min Temp (°C)	Monthly Extreme Min Temp (°C)	Monthly Total Rain (mm)	Monthly Avg. Wind Speed (m/s)	Monthly Max Wind Speed (m/s)
Jun-11[1]	11.96	18.59	24.72	6.3	-2.56		1.35	9.14
Jul-11	12.91	18.5	25.67	8	5.09		1.15	8.02
Aug-11	9.78	15.58	22.32	5.37	1.93		1.18	9.15
Sep-11	6.07	11.29	17.97	1.85	-2.47		1.43	11.36
Oct-11	-2.74	0.2	7.2	-5.41	-9.84	*2.602*	0.94	13.12
Nov-11	-19.54	-16.79	-4.23	-22.47	-34.99	0	0.58	12.05
Dec-11	-12.95	-9.37	-2.61	-16.47	-24.17	0	0.81	14.52

1. 29 complete days – station was commissioned on June 2
2. Partial month (16 complete days) - also some rainfall was recorded at temperatures below 0C and may be due to snowmelt

Table 2: Evapotranspiration estimates at Flame and Moth site

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

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

Legend:

Data from Galena Hill Met. Station
Date from MAYO A Met. Station

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

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Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

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

CC: Tiffany Lunday, Access Consulting Group

Date: March 28, 2012

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

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CONCLUSIONS AND RECOMMENDATIONS:

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Solar Panel	SX320J	T21008289B30EC8
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Battery	PS-12120 F2	06299-HC



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Nov-11	-19.54	-16.79	-4.23	-22.47	-34.99	0	0.58	12.05
Dec-11	-12.95	-9.37	-2.61	-16.47	-24.17	0	0.81	14.52

1. 29 complete days – station was commissioned on June 2
2. Partial month (16 complete days) - also some rainfall was recorded at temperatures below 0C and may be due to snowmelt

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Mar	0.62	0.07	0.4	9.7	-13.1	-18.1	2.3	-22.1	19.24	2.15	12.42
Apr	1.11	0.63	0.85	16.48	-4.4	-10.2	2.9	-11.2	33.41	18.91	25.38
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Jun	3.67	4.11	3.14	20.1	18.6	6.3	1.4	7.1	109.97	123.38	94.24
Jul	3.08	3.63	2.73	15.9	18.5	8	1.1	9.3	95.5	112.39	84.63
Aug	2.3	2.48	2	12.9	15.6	5.4	1.2	7.1	71.35	76.79	62.14
Sep	1.65	1.26	1.28	8.9	11.3	1.9	1.4	2.3	49.62	37.94	38.43
Oct	0.02	0.27	0.12	3.5	0.2	-5.4	0.9	-0.4	0.73	8.28	3.83
Nov	0	-0.01	-0.02	0.9	-16.8	-22.5	0.6	-19.1	-0.11	-0.28	-0.52
Dec	-0.17	0.01	-0.25	0.3	-9.4	-16.5	0.8	-12.7	-5.28	0.22	-7.86

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

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Data from Galena Hill Met. Station
Date from MAYO A Met. Station

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Rs	Solar Radiation (From Galena Hill Station)
Tx	Avergae Daily Maximum Temperature
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Memorandum

To: Vanessa Benwood, Alexco Keno Hill Mining Corp.

From: Anthony Bier, Access Consulting Group

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

Date: August 1, 2012

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

DRAFT

1 INTRODUCTION

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

2 METHODS

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

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

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

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

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

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

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

3 RESULTS

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

Table1: 2011 Snow survey results in cm of SWE

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

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

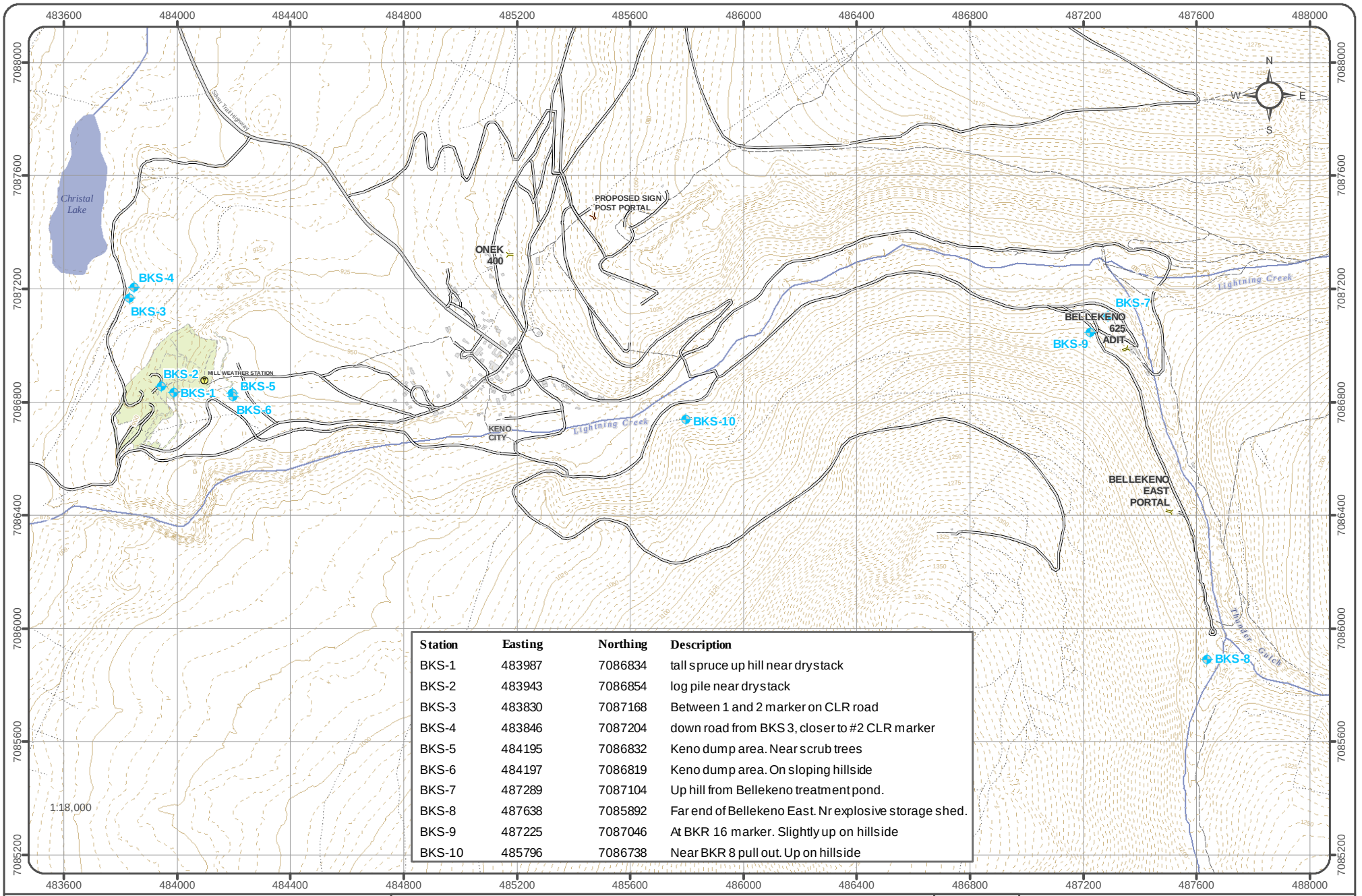
Table 2: 2012 Snow survey results in cm of SWE

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

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

REFERENCES

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



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

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

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

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

AKHM

ACCESS

WINTER 2011 & 2012
KENO SNOW SURVEY SUMMARY

FIGURE 1:
AKHM SNOW SURVEY SAMPLE LOCATIONS

AUGUST 2012

D:\Project\AllProjects\ALEX-05-01\Bellekeno\GIS\mxd\Overview_Maps\WQ_Stations\snowsurvey\SnowMonitoring_20120801.mxd
(Last edited by: jlindeman; 01/08/2012/15:15 PM)

Appendix 2 Typical Waste Containment Facility Design, EBA, 2008

Alexco Resource Canada Corp.

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

W14101142

July 2008

EBA Engineering Consultants Ltd.
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Calcite Business Centre • Unit 6, 151 Industrial Road • Whitehorse, Yukon Y1A 2V3 • CANADA

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Section 1008	Operation and Maintenance	2

APPENDICES

Appendix A Construction Drawings

Section 1001

DEFINITIONS

DEFINITIONS

1.0 General

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

2.0 Definitions

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

END OF SECTION

Section 1002

GENERAL

GENERAL

1.0 General

.1 Alexco Resource Canada Corp. intends to construct a containment facility to store waste rock from the Bellekeno advanced underground exploration and development program. As the company advances through the Keno Hill Silver District, it is anticipated further underground exploration and development programs will require similar containment facilities. Therefore, a typical design has been developed to account for the various potential site and construction material conditions.

.2 The Facility is to be located within previously disturbed areas, all of which will be incorporated within a district wide closure plan. This district wide closure plan is required under the water license QZ06-074.

.3 Site specific conditions and Facility location have not been provided or considered. Once Facility location and site specific conditions are known, they must be reviewed by the Engineer. Furthermore, the base of the Facility must be approved by the Engineer prior to fill placement.

.4 The Facility will be lined with a suitable geomembrane. Water in the Facility will flow towards the vertical culvert and pond within the voids of the waste material.

.5 Water in the Facility will be monitored and tested on a regular basis. Based on water quality analysis, the waste water will be extracted via pump truck and discharged to the environment or treated in a designated treatment facility.

.6 Once the Facility reaches its ultimate capacity, the Facility will be capped and reclaimed.

2.0 Scope of Work

.1 The scope of work for the construction of the Facility is as follows:

a. Construct the liner subgrade and berms with Zone B material at the specified grade. This could include cut/fill operations should the foundation material be satisfactory;
b. If required, install a geotextile layer to act as separator for Zone A and Zone B materials;
c. Construct the liner bedding with Zone A material;

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

END OF SECTION

Section 1003

FILL MATERIALS

FILL MATERIALS

1.0 General

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

2.0 Reference Standards

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

3.0 Material Sources

.1 No material of any type shall be borrowed or excavated without the Owner's prior approval.

.2 Pits and quarries shall be maintained and managed in accordance with the requirements set out in the Owner's Land Use and Quarry Permits.

.3 Zone A material shall be obtained from sources approved by the Owner, provided the final product meets the requirements specified herein. Processing may be required to achieve the specified gradation.

.4 Zone B material shall be obtained from sources approved by the Owner, provided the final product meets the requirements specified herein. Processing may be required to achieve the specified gradation.

.5 The parent rock from which all fill materials are derived shall consist of sound, hard, durable material free from soft, thin, elongated or laminated particles and shall contain no unsuitable substances. The potential quarry source shall be approved by the Engineer.

.6 The quarry source for the Facility fill materials shall be inspected by the Engineer throughout material processing to ensure the product meets the requirements stated herein.

4.0 Material Specifications

.1 Zone A Material

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

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

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

.2 Zone B Material

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

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

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

END OF SECTION

Section 1004

FILL PLACEMENT

FILL PLACEMENT

1.0 General

.1 The fill placement methods to be used during construction of the Waste Containment Facility are described in this Section.

.2 Construction shall be performed in accordance with the best modern practice and with equipment best adapted to the work being performed. Embankment materials shall be placed so that each zone is homogeneous; free of stratifications; ice chunks, lenses or pockets; and layers of material with different texture grading not conforming to the requirements stated herein.

.3 No fill material shall be placed on any part of the foundation until it has been prepared, as specified herein. Placement of fill material shall conform to the lines, grades and elevations shown on the Construction Drawings.

.4 Embankment construction shall not proceed when the work cannot be performed in accordance with the requirements of the Construction Specifications. Any part of the embankment that has been damaged by the action of rain, snow or any other cause shall be removed and replaced with the appropriate material conforming to the requirements stated herein.

.5 Stockpiling, loading, transporting, placing, and spreading of all materials shall be carried out in such a manner to avoid segregation. Segregated materials shall be removed and replaced with the materials meeting the requirements stated herein.

.6 The Contractor shall remove all debris, vegetation or any other material not conforming to the requirements stated herein. The Contractor shall dispose of these materials in an area approved by the Owner.

2.0 Zone B Material Placement

.1 The Zone B material shall be placed to the design elevation as specified in the Construction Drawings in lifts no greater than 500 mm in uncompacted thickness.

.2 The design elevation for the top of the Zone B berm material shall be no less than 0.5 m above original ground.

.3 Moisture condition and compact using the minimum number of passes established in accordance with section 1006.4.2.

3.0 Zone A Material Placement

.1 The Zone A material shall be placed as bedding for the liner system (minimum 300 mm thick) to the design grade specified in the Construction Drawings.

.2 Subsequent to the liner installation, the Zone A material shall be placed as liner system cover material. The liner system cover material shall be placed to the minimum thickness specified in Table 1004.1 dependent on the type of liner selected.

TABLE 1004.1: RECOMMENDED MINIMUM COVER THICKNESSES

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

.3 The Construction Drawings are based on the selection of Enviro Liner® 4040 with the installation of a geocomposite reinforcing material. Other design alternatives are detailed in Section 1007.

.4 Zone A material shall be placed in lifts not exceeding 300 mm in uncompacted thickness. Vehicle traffic is prohibited from maneuvering within the Facility until the cover material has reached the minimum thickness required as specified in Table 1004.1.

.5 Moisture condition and compact with using the minimum number of passes established in accordance with section 1006.4.1.

.6 Equipment with ground pressures higher than 380 kPa should not be permitted inside the Facility once the liner system has been placed. Care is required to provide the appropriate thickness of fill beneath a vehicle when placing material above the liner system to ensure it is not damaged. Traffic in the area should be restricted to low ground pressure equipment.

END OF SECTION

Section 1005

LINER SYSTEM

LINER SYSTEM

1.0 General

.1 The product and installation specifications for the non-woven geotextile, liner systems and geocomposite materials to be used in the Waste Containment Facility are presented in this section.

.2 The liner system will be provided by the Owner and installed by the Contractor.

2.0 Reference Standards

.1 The most recent copy of the following American Society for Testing Materials standards:

a. ASTM D638 Standard Methods for Tensile Properties of Plastics.

b. ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

c. ASTM D1004 Standard Test Methods for Initial Tear Resistance of Plastic Film and Sheeting.

d. ASTM D1603 Standard Test Methods for Carbon Black in Olefin Plastics.

e. ASTM D1777 Standard Test Methods for Thickness of Textile Materials.

f. ASTM D4533 Standard Test Methods for Trapezoidal Tearing Strength of Geotextiles.

g. ASTM D4632 Standard Test Methods for Grab Breaking Load and Elongation of Geotextile.

h. ASTM D4751 Standard Test Methods for Determining Apparent Opening Size of a Geotextile.

i. ASTM D4833 Standard Test Methods for Index Puncture Resistance for Geotextile, Geomembranes, and Related Products.

j. ASTM D5199 Standard Test Methods for Measuring the Nominal Thickness of Geosynthetics.

k. ASTM D5261 Standard Test Methods for Measuring Mass per Unit Area of Geotextiles.

l. ASTM D5994 Standard Test Methods for Measuring Core Thickness of textured Geomembranes

.2 Federal Test Method

a. FTM Standard 101.

3.0 Materials

.1 Geotextile

a. The non-woven geotextile shall have a weight of 542 g/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

NOTES

1. CONTAINMENT FACILITY SIZED FOR 4900 m³ OF DEWATERED ASH. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIAL & 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						
MLM	DATE	DWN	CKD	APR	DESCRIPTION	

DRAWING STATUS				
NUM	DATE	APR	DESCRIPTION	
B	09/07/06	JPS	ISSUED FOR CONSTRUCTION	
A	03/26/06	JPS	ISSUED FOR REVIEW	

PERMIT

PROFESSIONAL SEAL

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Tribble, P.Eng. Seal: Jason Dobson, P.Eng.
Date: July 6, 2006 Date: July 6, 2006

The signed Professional Seal and Permit to Practice across from this statement apply only to the drawing which is part of the report prepared by EBA Engineering Consultants Ltd. and contained in EBA Report No. VA06-00142.

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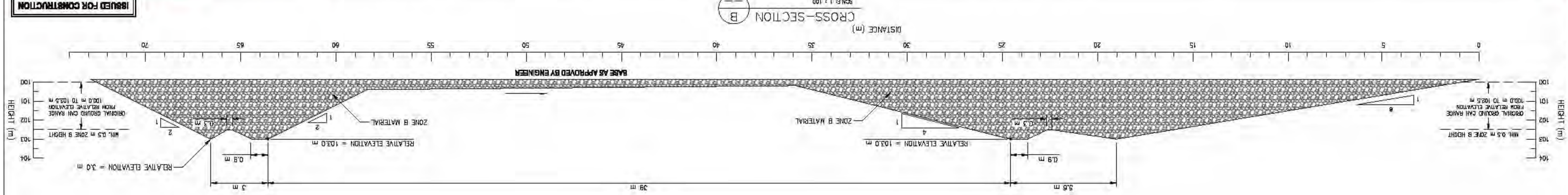
ALEXCO

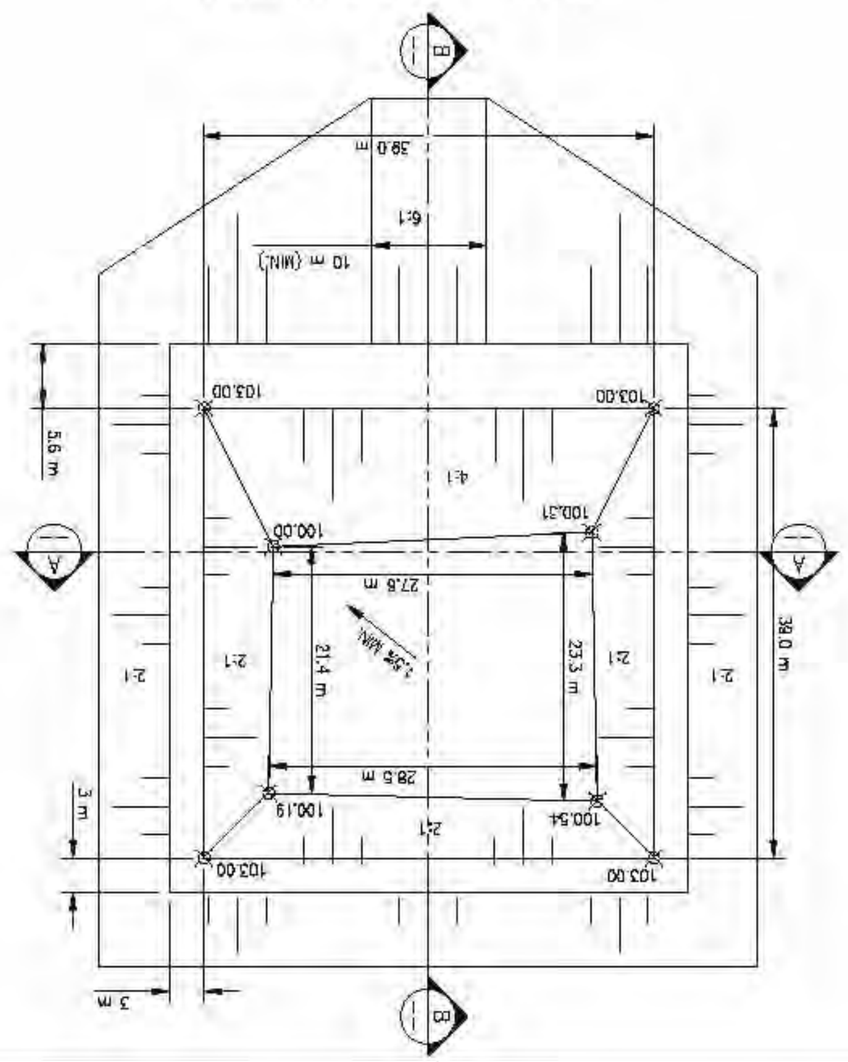
TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE B MATERIAL PLAN & CROSS SECTIONS

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VA10-142	CP/SE	DWB	JPS	0	WCF-1
DATE	SCALE AS NOTED	APP			
June 26, 2006	1 of 4	KLT	JRT	B	

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NOTES

1. CONTAINMENT FACILITY SIZED FOR 1800 m^3 OF GENERATED ASH. 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						
MLM	DATE	DWN	CKD	APR	DESCRIPTION	

DRAWING STATUS			
NUM	DATE	APR	DESCRIPTION
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A	09/26/06	JPS	ISSUED FOR REVIEW

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Date: July 6, 2006 Date: July 31, 2006

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EBA Engineering Consultants Ltd.

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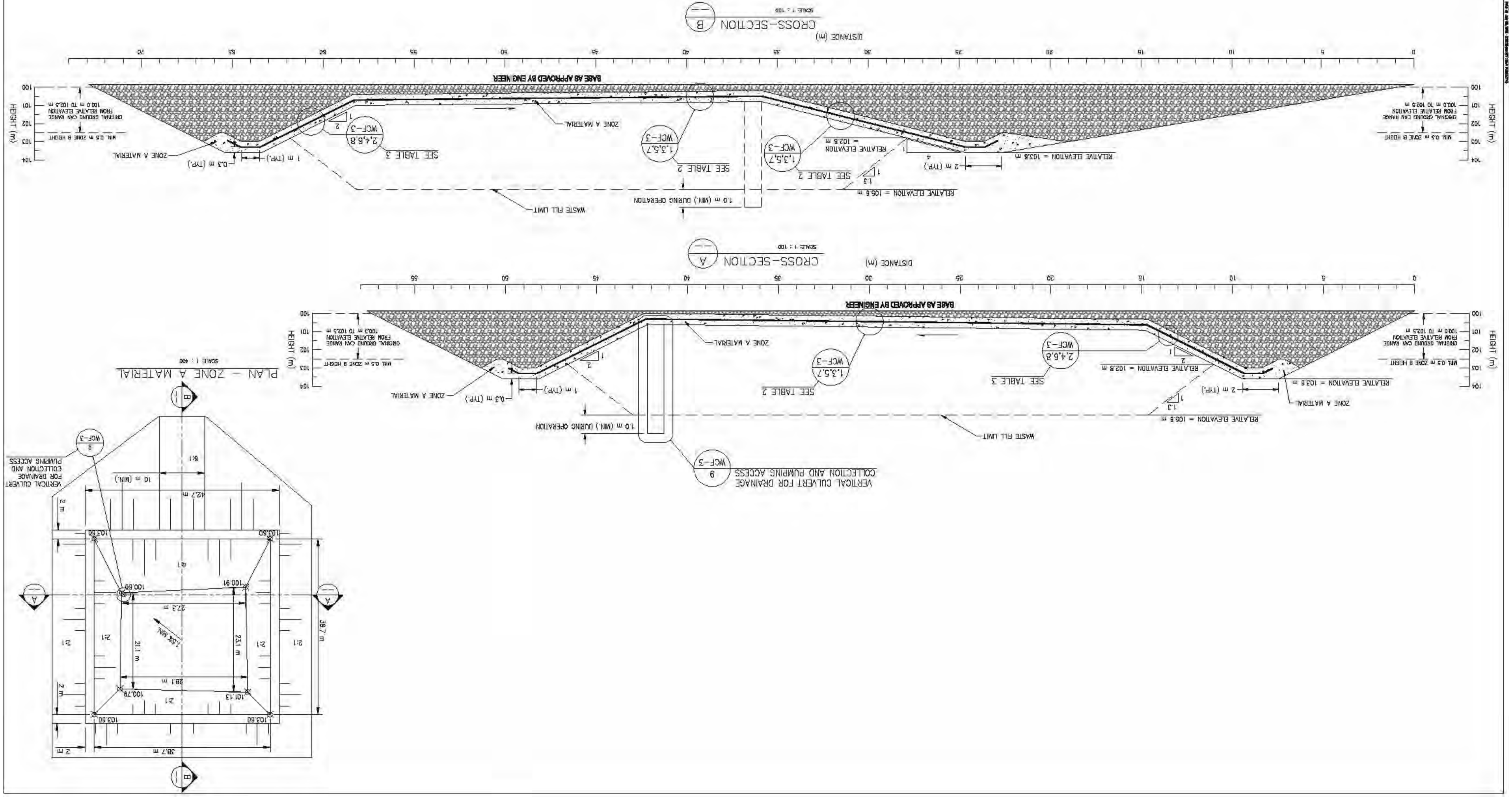
TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE A MATERIAL PLAN & CROSS SECTIONS

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VH10142	VH/BE	JTP	JPS
DATUM	SCALE/As	DWG	APP
UTM	2 of 4	KLT	JRT
June 26, 2006			

WCF-2

ISSUED FOR CONSTRUCTION



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NOTES

1. CONTAINMENT FACILITY SIZED FOR 4900 m³ OF GENERATED ASH. 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

MLM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
2	09/27/06	JPS	ISSUED FOR CONSTRUCTION
1	09/26/06	JPS	ISSUED FOR REVIEW

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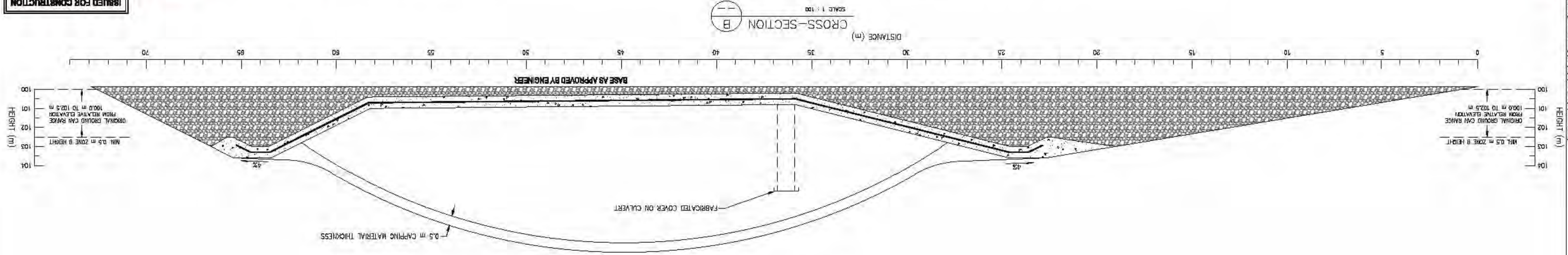
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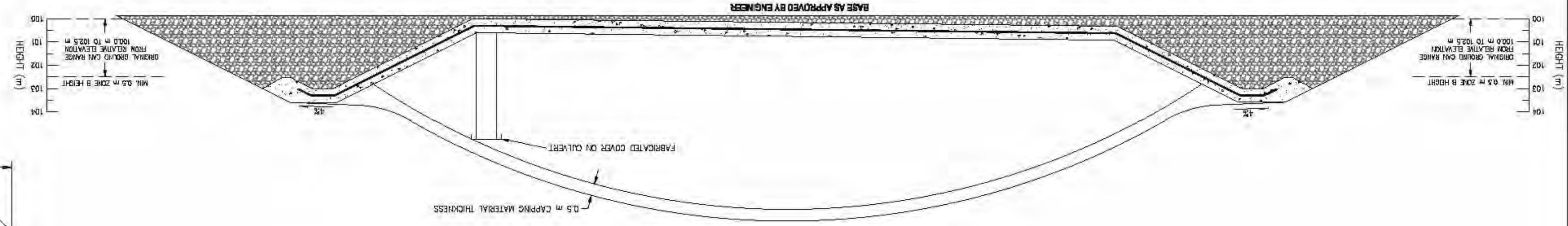
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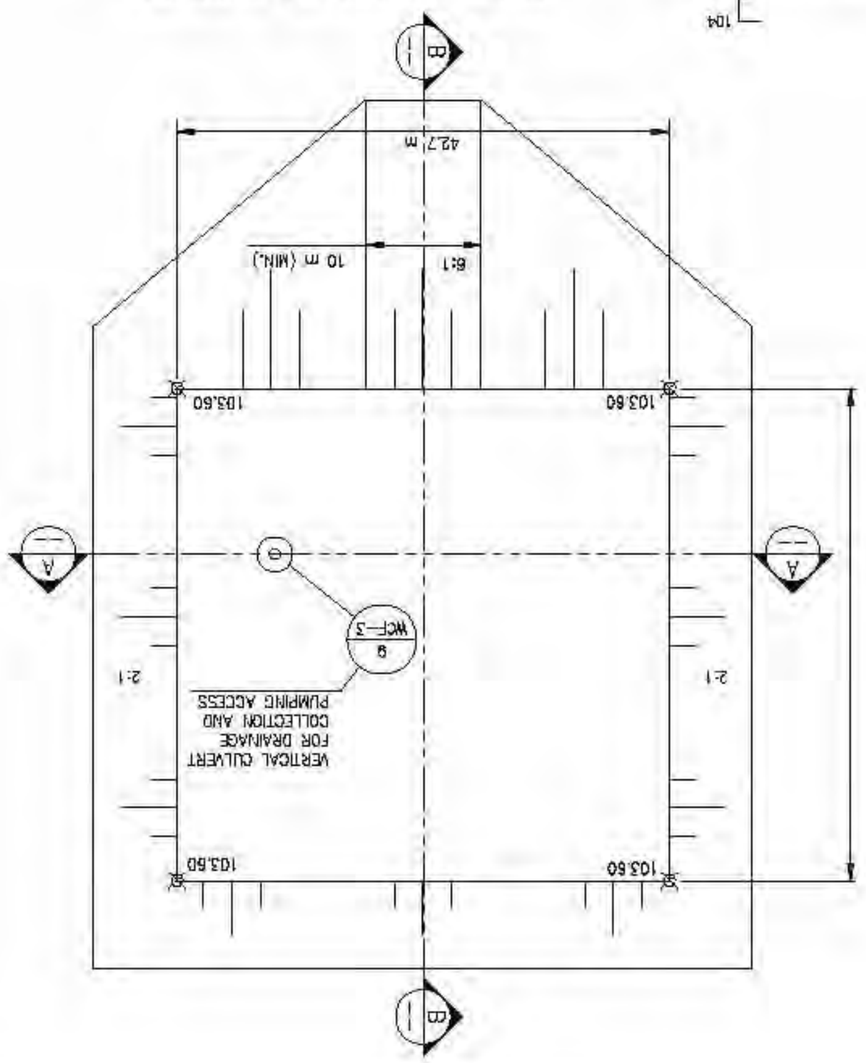
TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

FACILITY CLOSURE PLAN & CROSS SECTIONS

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Appendix 3 Platoro Project – Example Of In Mine Pool Treatment

Treatment Sludge Use in Mine Pools

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

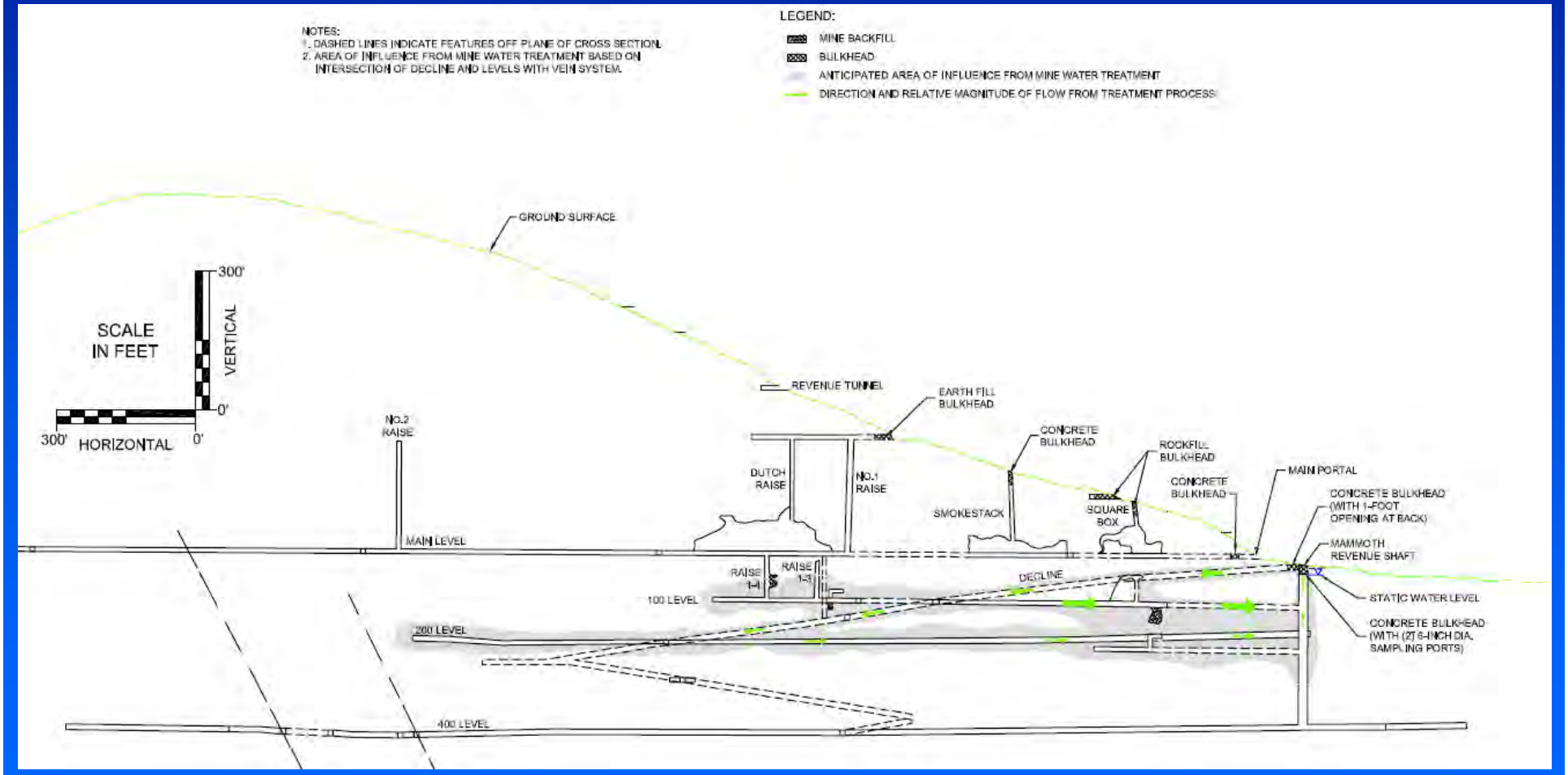
Site History

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

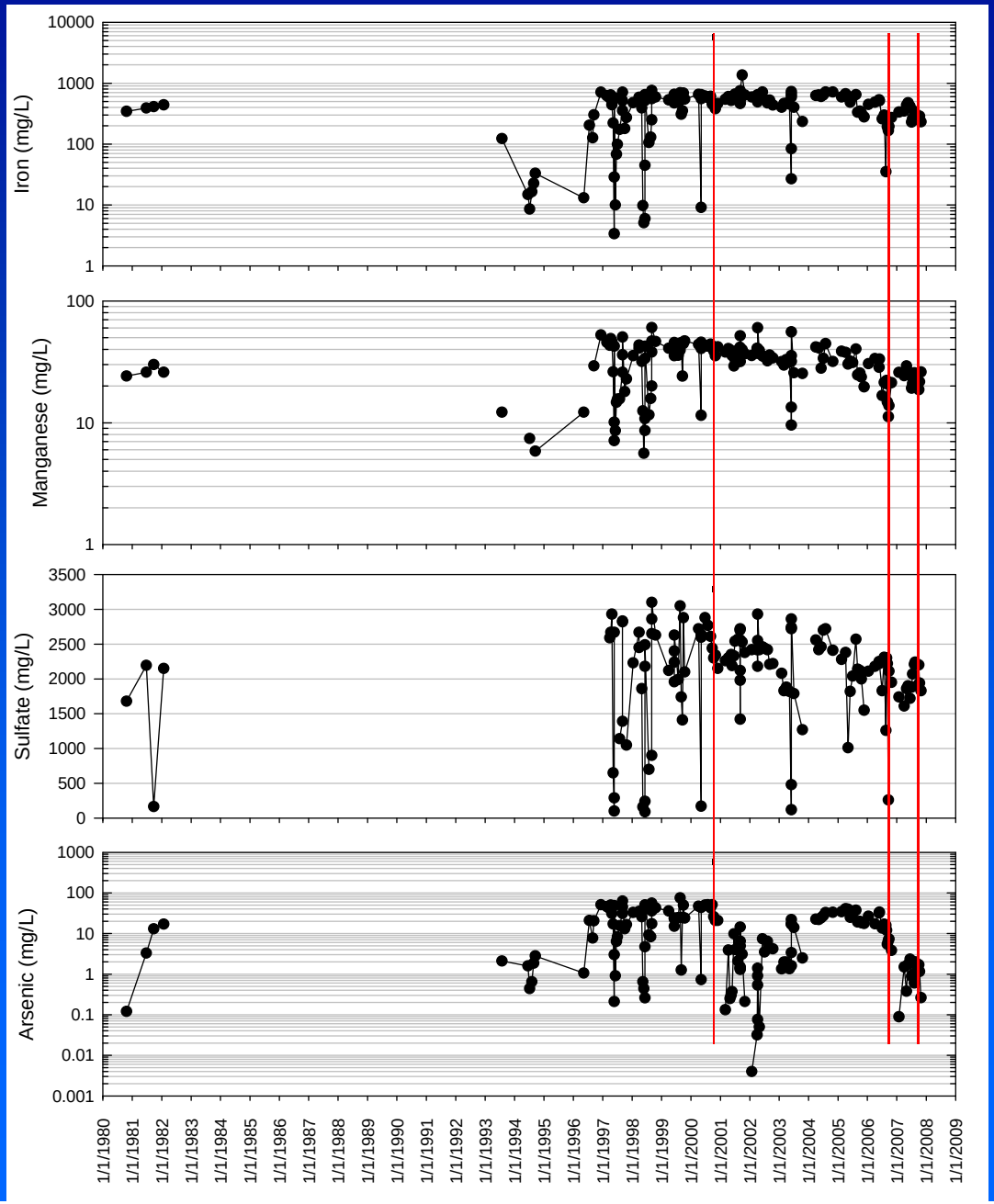
Aerial view of site



Mine Workings



Mine Water Chemistry



Treatment Solids Management

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

Benefits of sludge use in mine pool

- Site-wide reduction of toxicity, mobility and volume

- Iron from treatment plant sludge
  - improves geochemical stability of in pool treatment precipitates
  - improves treatment plant efficiency by enhancing iron | arsenic ratio

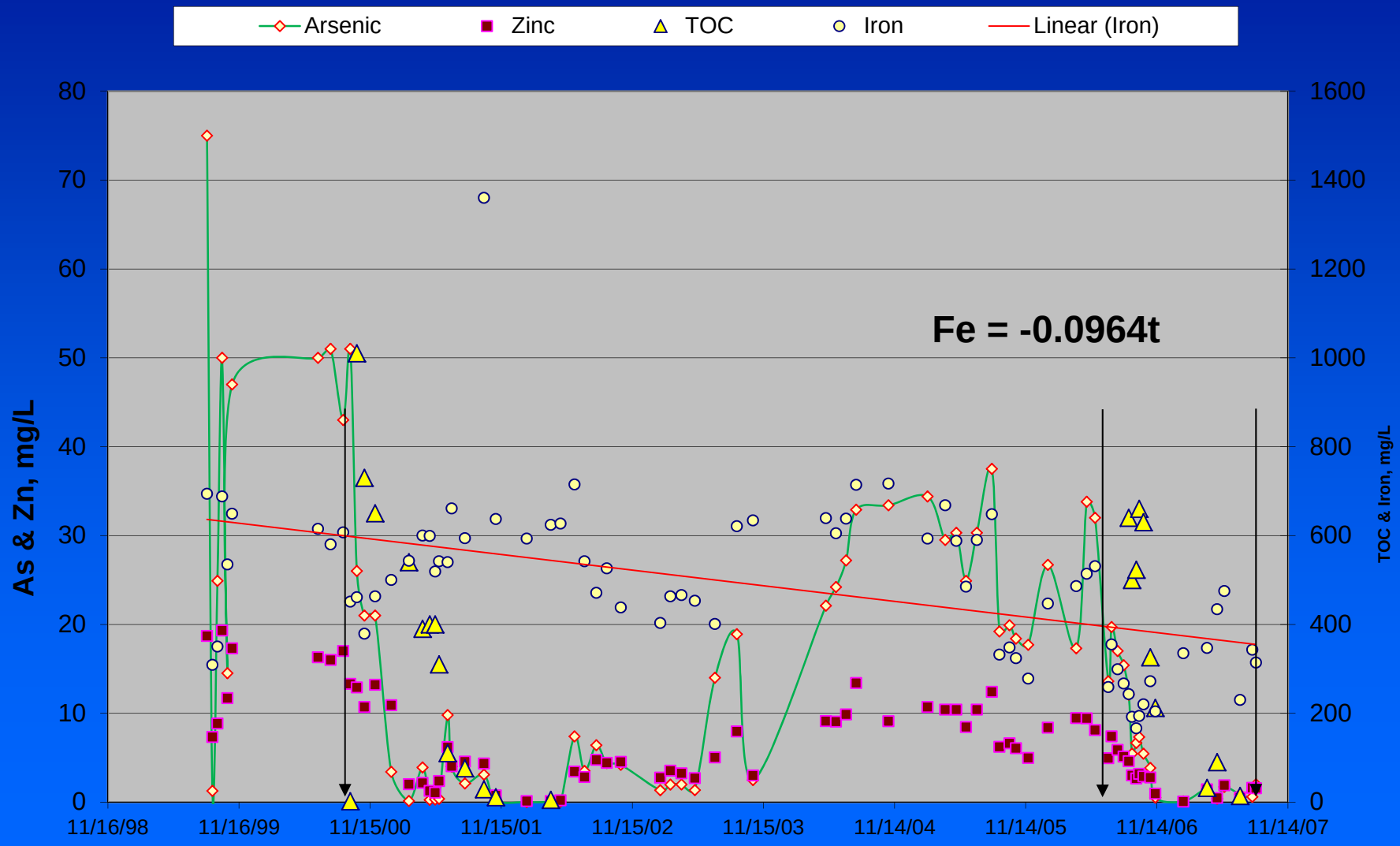
Platoro Mine Pool Treatments

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

Methanol injection into mine pool



Mine pool injection results



Carbon-Amended Sludge Use

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

Advantages of carbon-amended sludge use

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

Fate of contaminants	Ex-situ storage	In-Mine pool treatment
Arsenic	FeOOH|arsenate	As_2S_3:$FeAsS_2$
Zinc	$Zn(OH)_2$	ZnS
Al, Mn	Al/Mn oxides	Reduced gangue leaching of Al, Mn
Iron	Iron oxyhydroxides	Iron sulfide

Stoichiometry of reactive carbon amendments

$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H$

$5.3(Fe(OH)_3 + H_2SO_4) + 48H \rightarrow 5.3FeS + 37H_2O$

342 lbs sugar + 570 lbs Ferric hydroxide + 523 lbs sulfuric acid

→ 528 lbs CO_2 + 469 lbs **FeS** + 667 lbs water

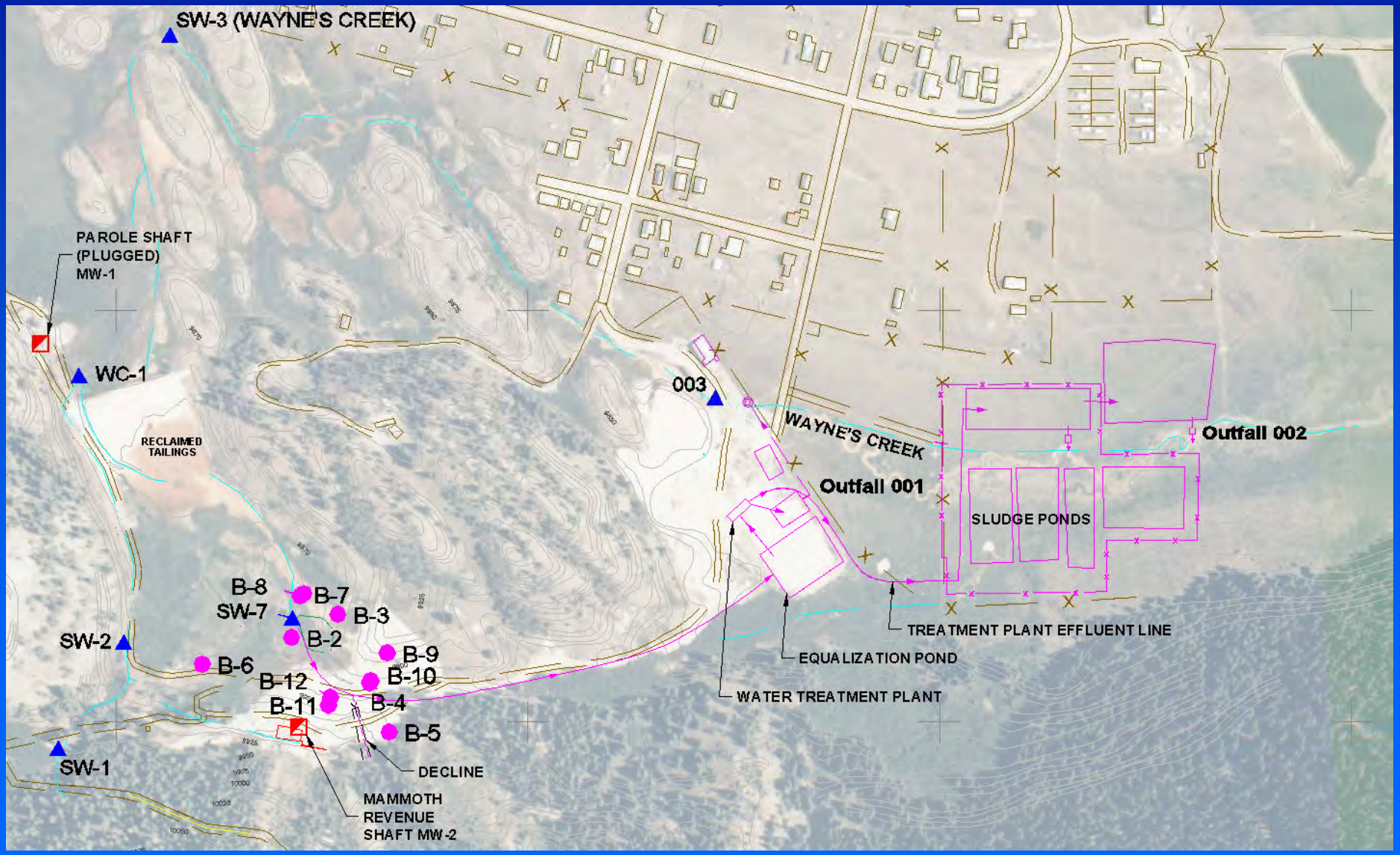
- 1 mole of table sugar reduces 5.3 moles each of iron hydroxide and sulfuric acid; forming iron monosulfide and water
- Net consumption of acidity and large reduction in contaminant volume; re-storing contaminants as insoluble and stable minerals
- Volume of iron hydroxide sludge is more than 17 x greater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

Sludge Stability Effects

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



Site Overview



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

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TELESTO

SOLUTIONS • INCORPORATED

February 2003

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1.0 INTRODUCTION

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

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

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

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

2.0 MINE AREA HYDROGEOLOGY

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

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

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

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

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

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

Table 2-1 Hydraulic Conductivity Of Geologic Materials In The Platoro Valley[1]

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

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

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

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

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

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

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

3.0 CHEMISTRY OF TREATMENT PLANT SOLID RESIDUALS

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

3.1 Chemical Characteristic of Solids

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

3.2 Alkalinity Potential of Solids

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

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

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

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

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

An additional potential alkalinity measurement of a filtered sample of fresh residual, to partition alkalinity attributable to soluble and solid phases, yielded a solution alkalinity concentration of 0.14 meq/L (28 mg/L as $CaCO_3$). The preceding calculations of total fresh residual alkalinity and soluble alkalinity measurement suggest that greater than 90 percent of fresh residual alkalinity is related to the solid content of the solution. Comparison of the solids content for the two residual types (42 times higher for the aged residual) and the respective observed rates of pH change, also suggest that alkalinity is primarily attributable to the solid content of the treatment residuals (both fresh and aged).

3.2.1 Distribution of Solids Alkalinity Potential

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

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

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

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

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

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

Alkalinity is presented as meq/dry gram of solid.

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

3.3 Solids Interaction and Steady-State Solution Chemistry

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.4 Long-Term Chemical Stability of Solid Residuals

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.0 CONCEPTUAL ENGINEERING DESIGN

4.1 Characterization of Solids

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

4.1.1 Solids Content

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

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

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

Solids contents are presented as percentages (by weight).

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

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

4.1.2 Volume

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

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

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

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

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

4.1.3 Physical Characteristics

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

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

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

4.2 Transfer System

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

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

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

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

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

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

4.3 Water and Solids Mass Balance

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

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

4.3.1 DSM Development

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

4.3.2 Flows

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

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

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

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

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

4.3.3 System Limitations

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

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

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

4.4 Transfer Period

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

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

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

In estimating the time for completing the solids transfer, and associated percentage of solids volume transferred, a start date of June1 and end date of October 31 are assumed. At an average 2 percent solids concentration, approximately 48 percent of the initial solids volume in Ponds 1 to 4 can be transferred in the first year of operation.

4.5 System Configuration

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

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

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

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

4.6 Monitoring and Contingency Plan

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

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

4.6.1 Transfer System Monitoring

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

4.6.2 Mine Workings Discharge System

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

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

4.6.3 Secondary Containment for the Transmission Line

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

4.6.4 Mine Workings Response Monitoring

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

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

PAROLE SHAFT
(PLUGGED)

TAILINGS

RECLAIMED
ORE PILE

MAMMOTH
REVENUE SHAFT

DECLINE

WATER TREATMENT
PLANT

HOLDING
POND

1 2 3 4 5
SOLIDS
COLLECTION
PONDS

TREATMENT PLANT
EFFLUENT LINE

LEGEND

MINE SHAFT

SURFACE WATER

SCALE IN FEET

300 0 600

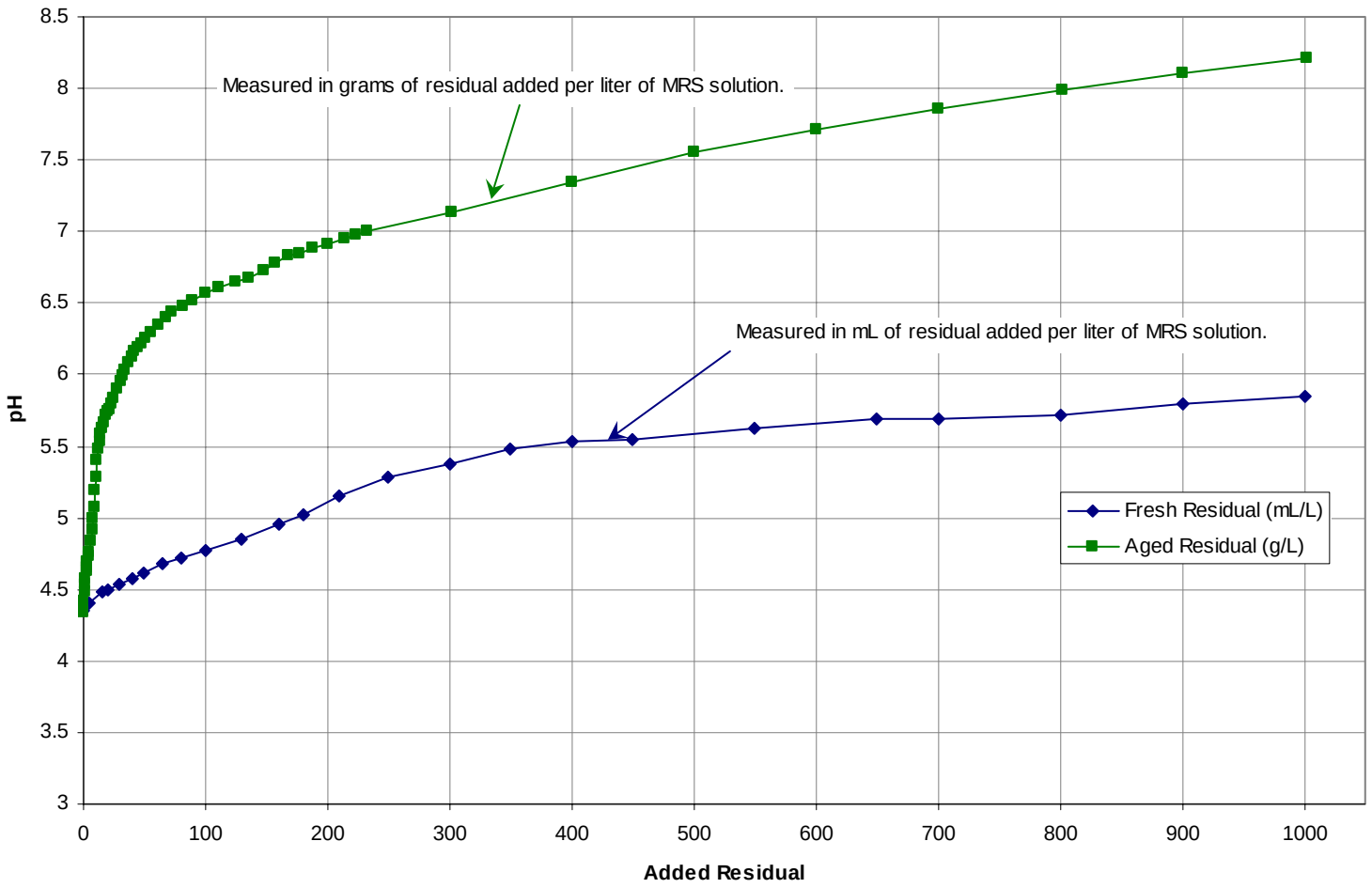
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FIGURE 1-1
SITE LOCATION

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Project:	216100T03
File:	216100T03 SITE LOCATION

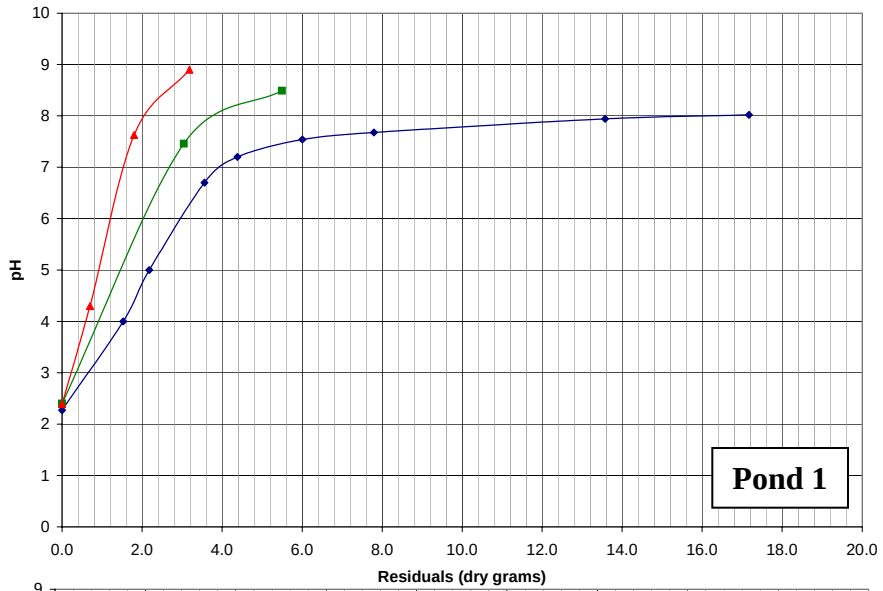
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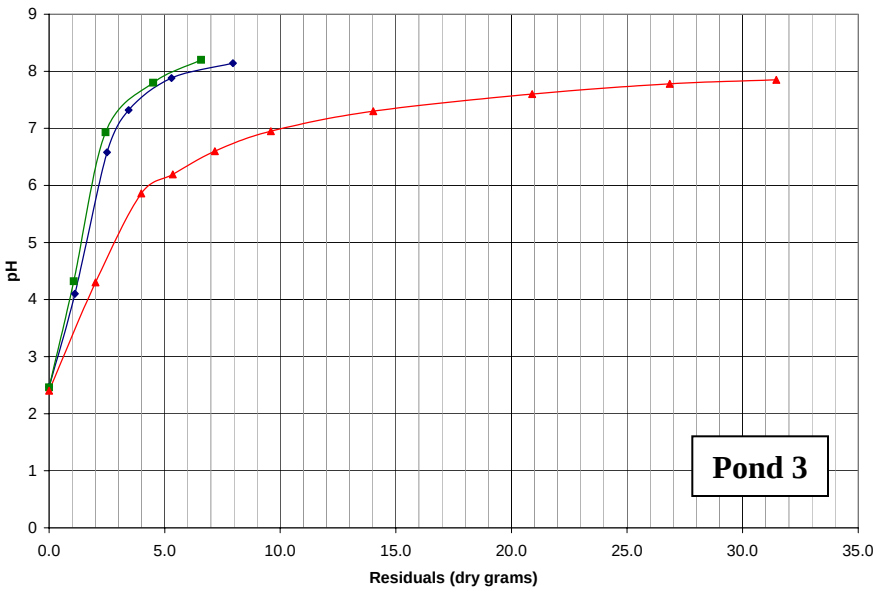


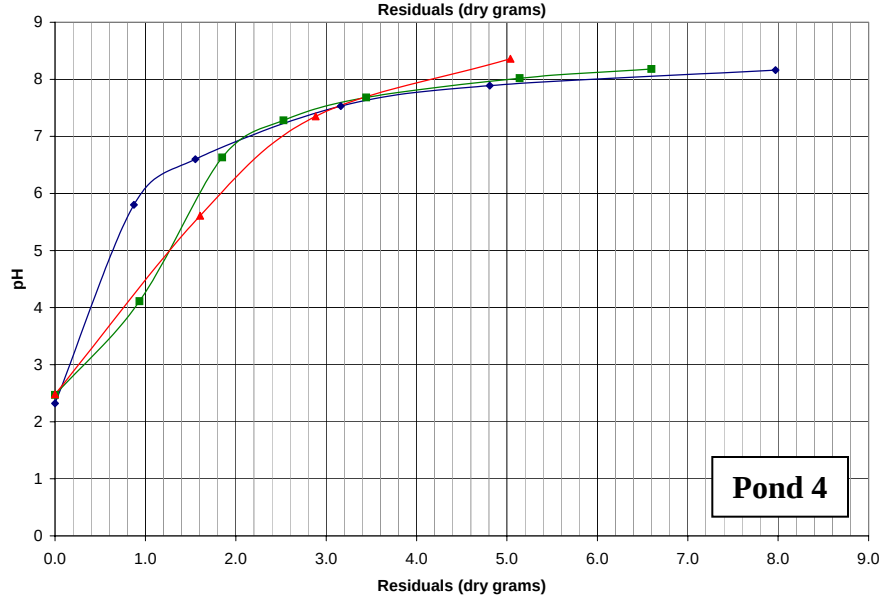
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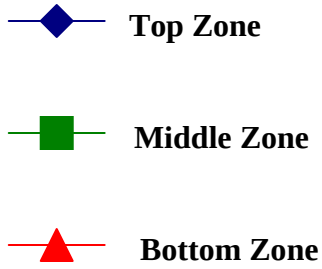
FIGURE 3-1
MRS SOLUTION PH RESPONSE
TO TREATMENT PLANT RESIDUAL ADDITIONS

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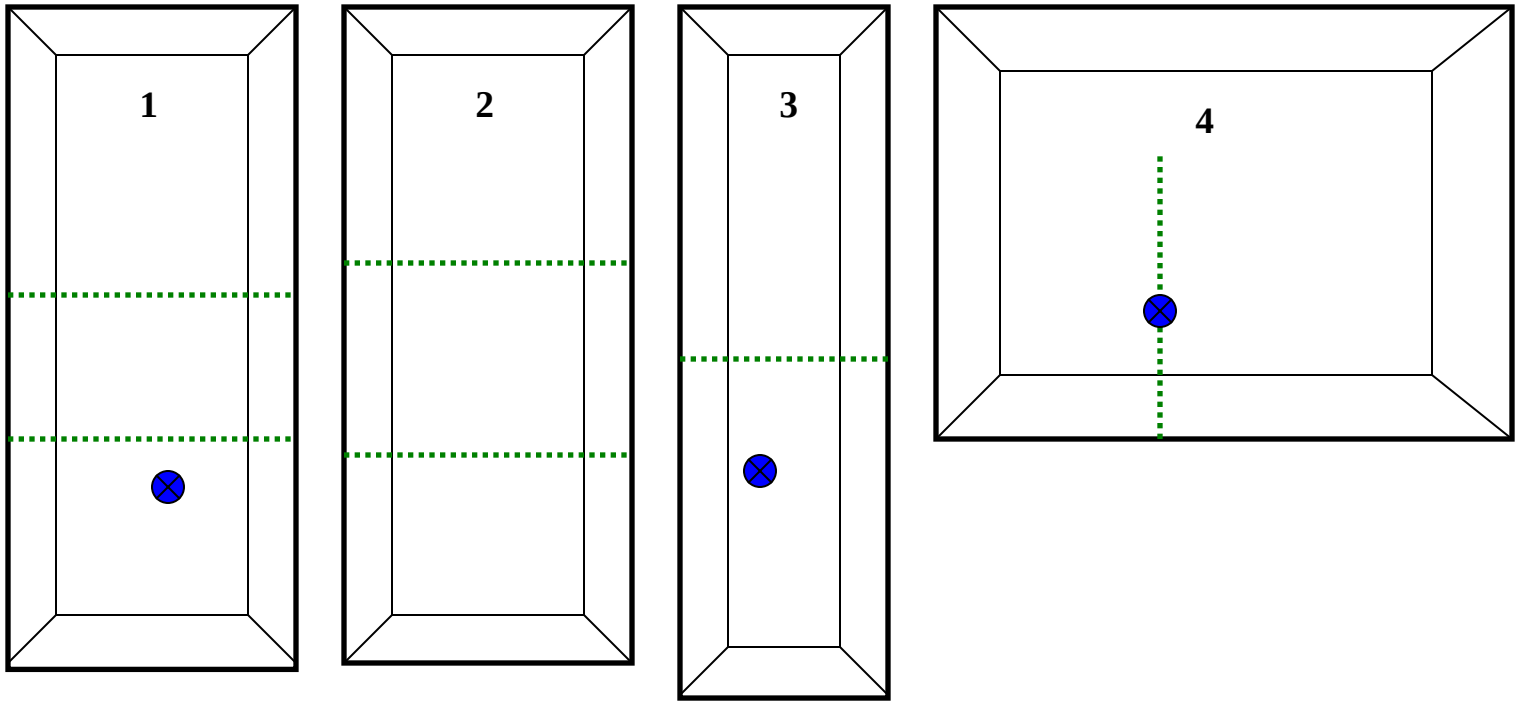




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FIGURE 3-2
ALKALINITY TITRATION CURVES
AT VARIOUS DEPTHS IN THE PLATORO SOLIDS COLLECTION PONDS

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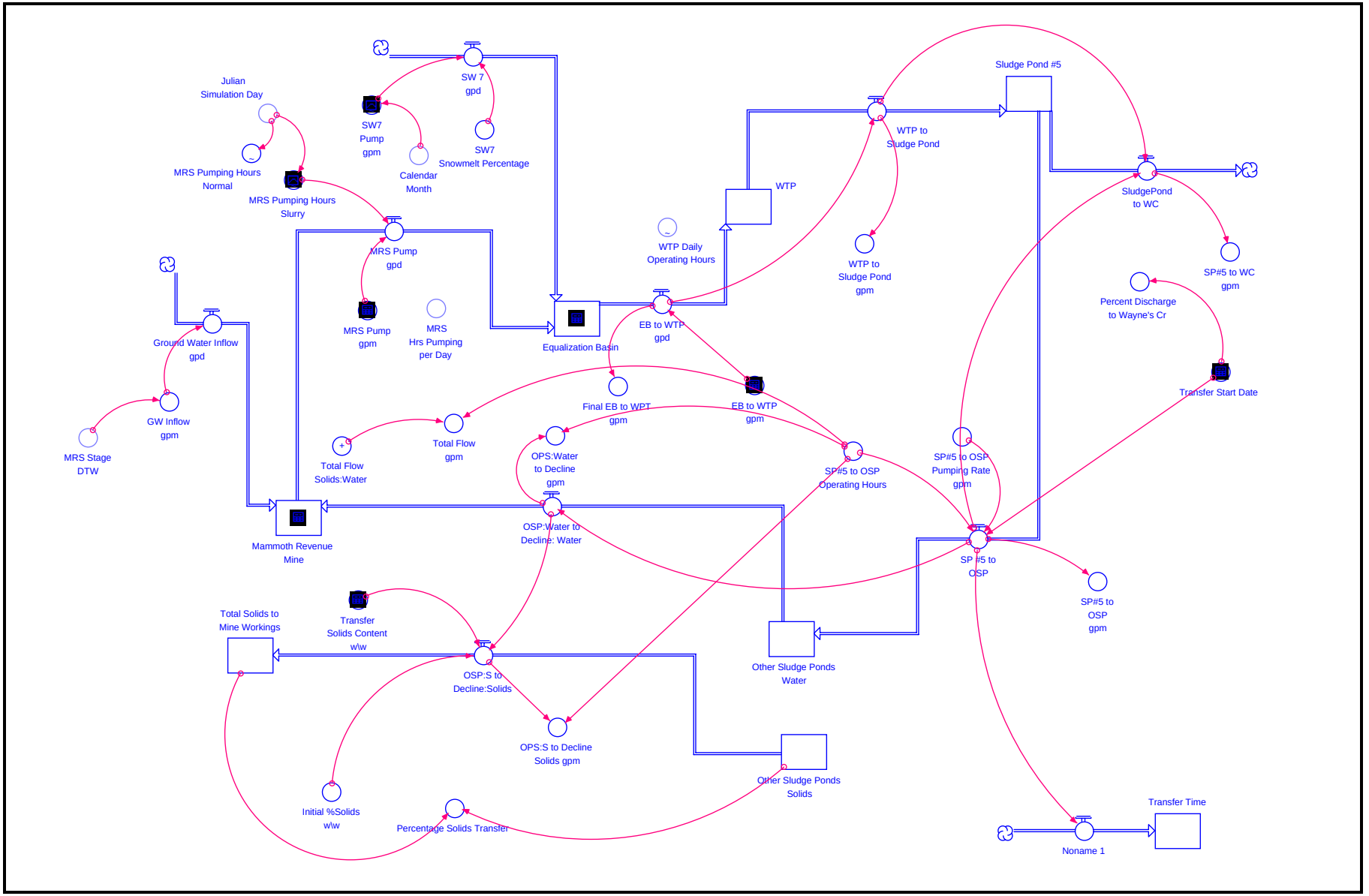


Scale is approximated.

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FIGURE 4-1
SOLIDS COLLECTION PONDS PROFILE SAMPLING LOCATIONS

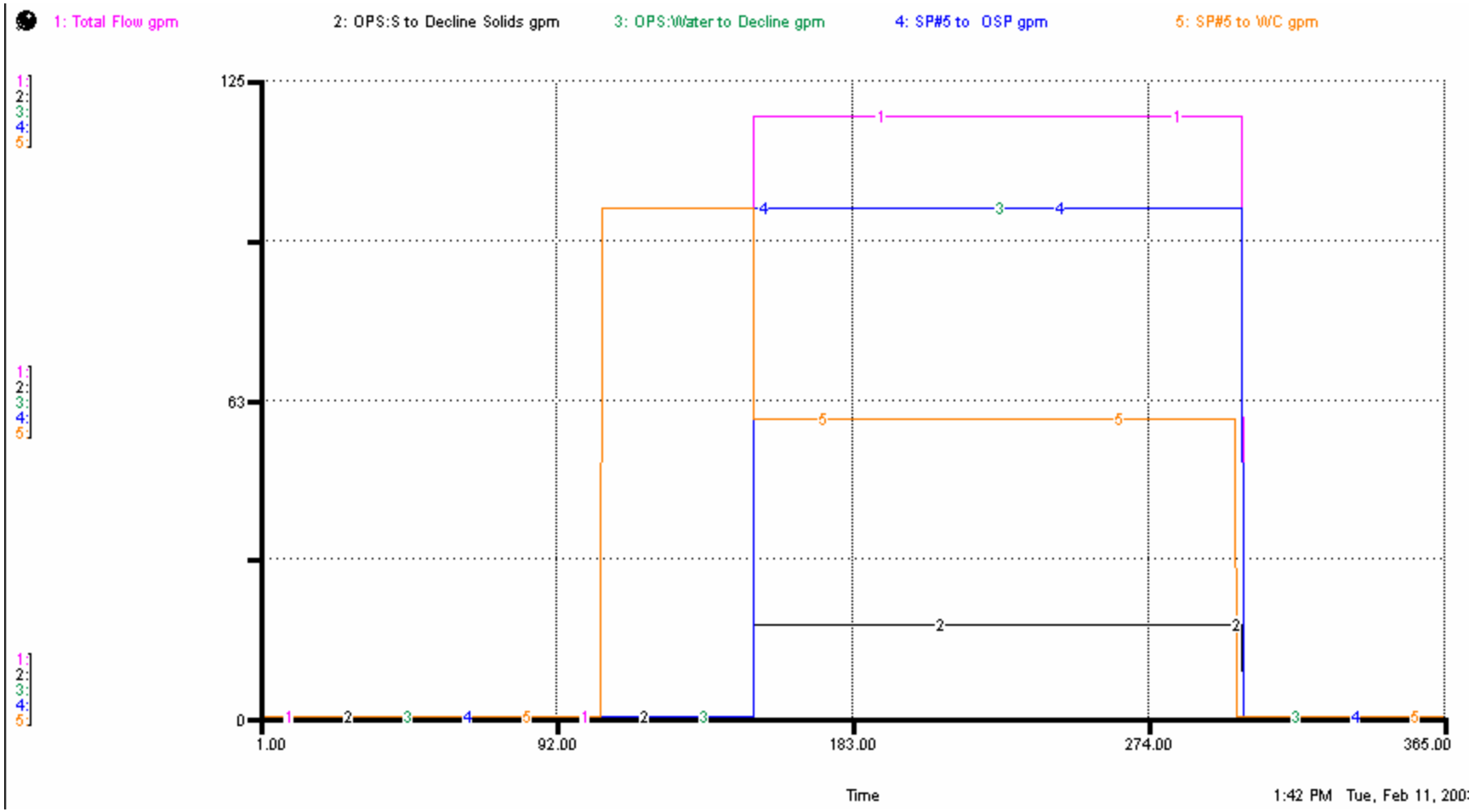
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FIGURE 4-3
DYNAMIC SYSTEMS MODEL OF SLURRY SYSTEM

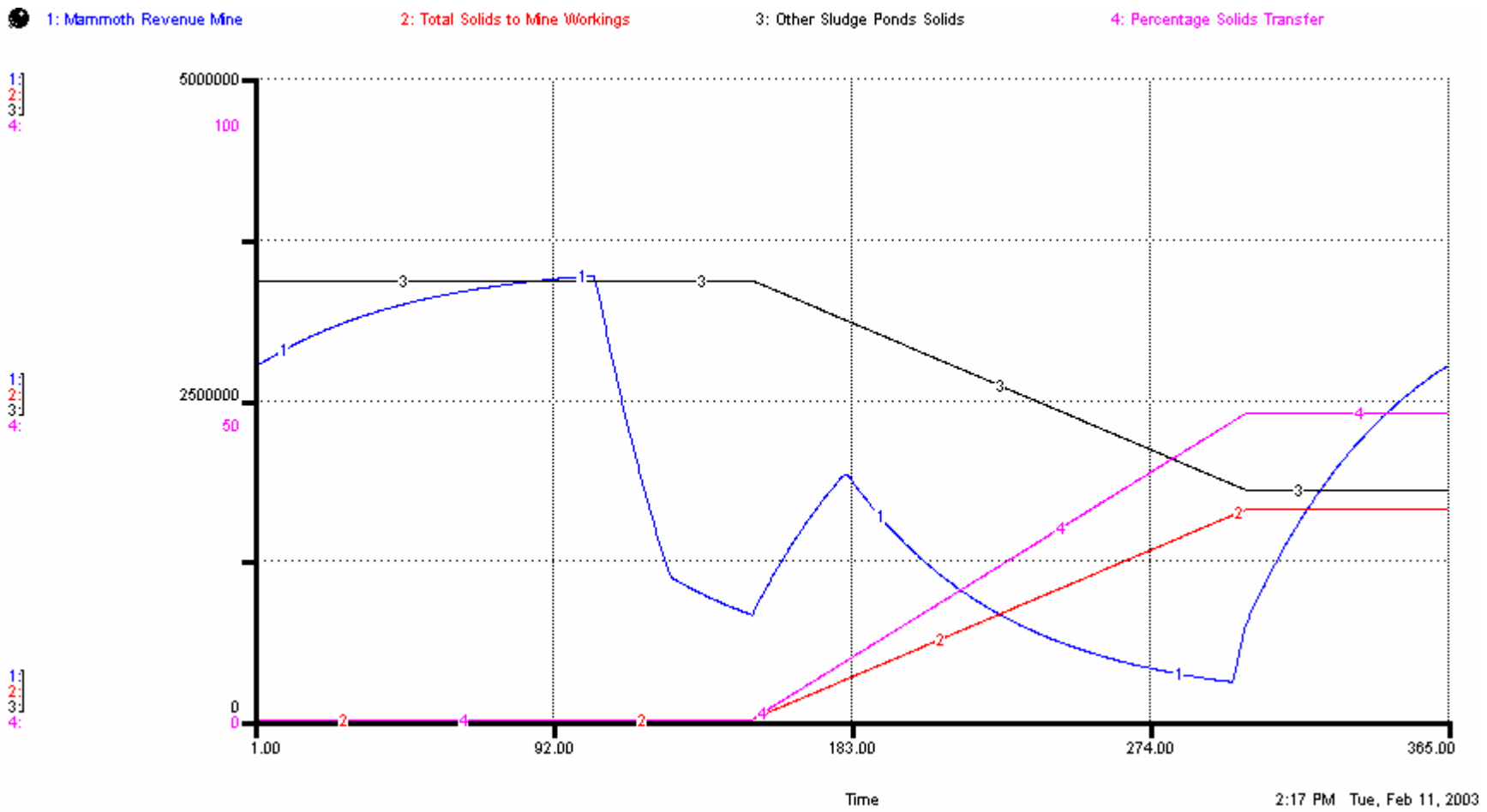
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FIGURE 4-4
SIMULATED FLOWS IN THE SLURRY TRANSFER SYSTEM

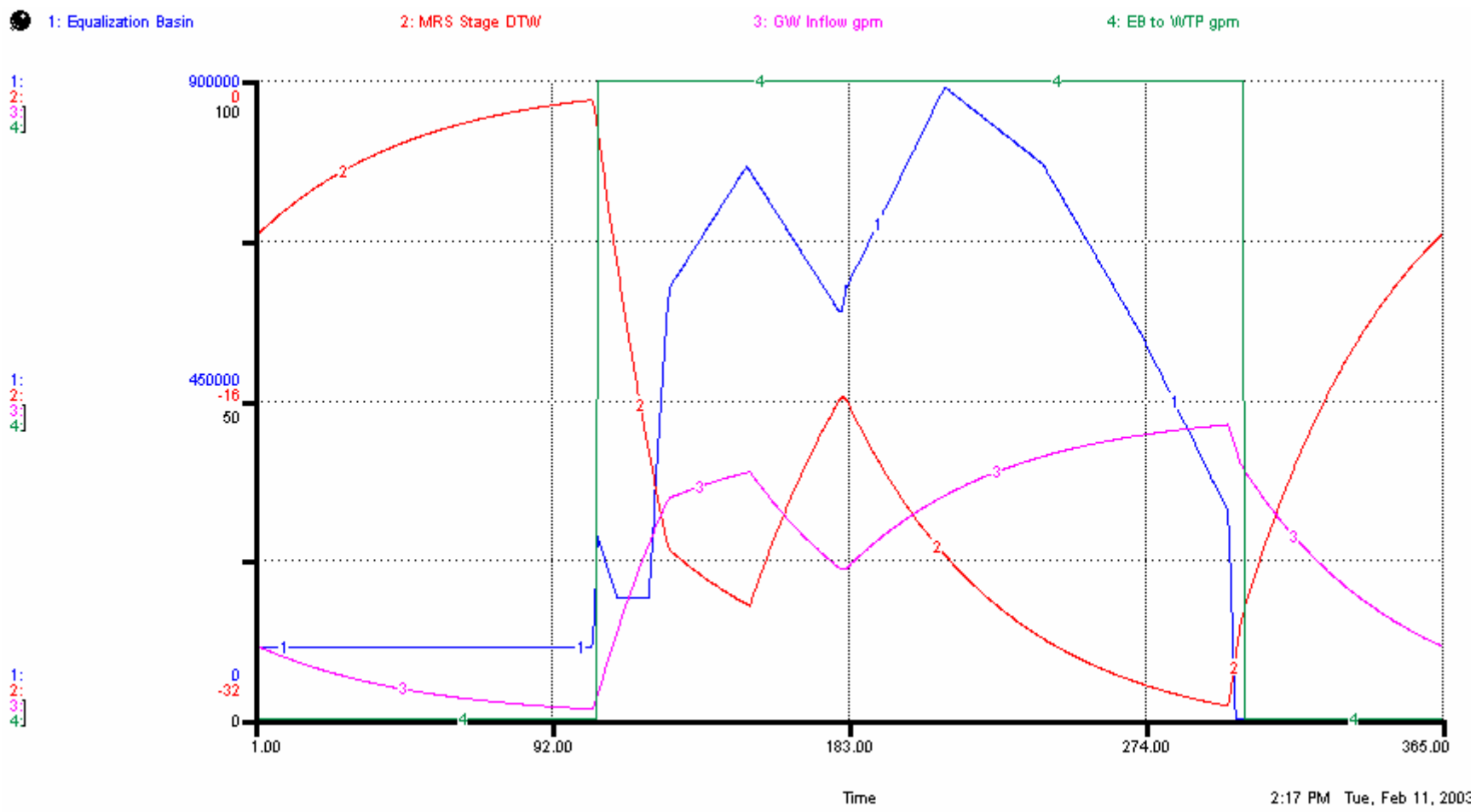
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FIGURE 4-5
SELECTED METRICS OF THE SLURRY TRANSFER SYSTEM

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TELESTO SOLUTIONS INCORPORATED	**FIGURE 4-6** **ADDITIONAL METRICS OF THE SLURRY TRANSFER SYSTEM**	**Date: FEBRUARY 2003** **Project: 216100** **File: SludgeTrans_figs.ppt**

ATTACHMENT 1

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

INTRODUCTION

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

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

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

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

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

Historical Bench-Scale Evaluation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Long-Term Chemical Stability of Solid Residuals

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

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

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

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

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

Table 2 Second Phase Batch Mixtures and Solution pH Measurements

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

Table 3 Metals Analyses in Select Second Phase Test Batch Mixtures

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

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

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

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

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

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

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

The following equation presents the net stoichiometric reaction from the addition of carbohydrate-based carbon (general formula of CH_2O) sources to sulfate-saturated iron hydroxide-rich water treatment solids:

$$9CH_2O + 4CaSO_4 \cdot 2H_2O(s) + 4Fe(OH)_3(s) \rightarrow 4CaCO_3(s) + 4FeS(s) + 5CO_2(g) + 23H_2O(l)$$

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

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

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

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

$$270\ g\ C_6H_{12}O_6 + 688\ g\ CaSO_4 \cdot 2H_2O(s) + 427\ g\ Fe(OH)_3(s) \rightarrow 400\ g\ CaCO_3(s) + 331\ g\ FeS(s) + 220\ g\ CO_2(g) + 270\ g\ H_2O(l)$$

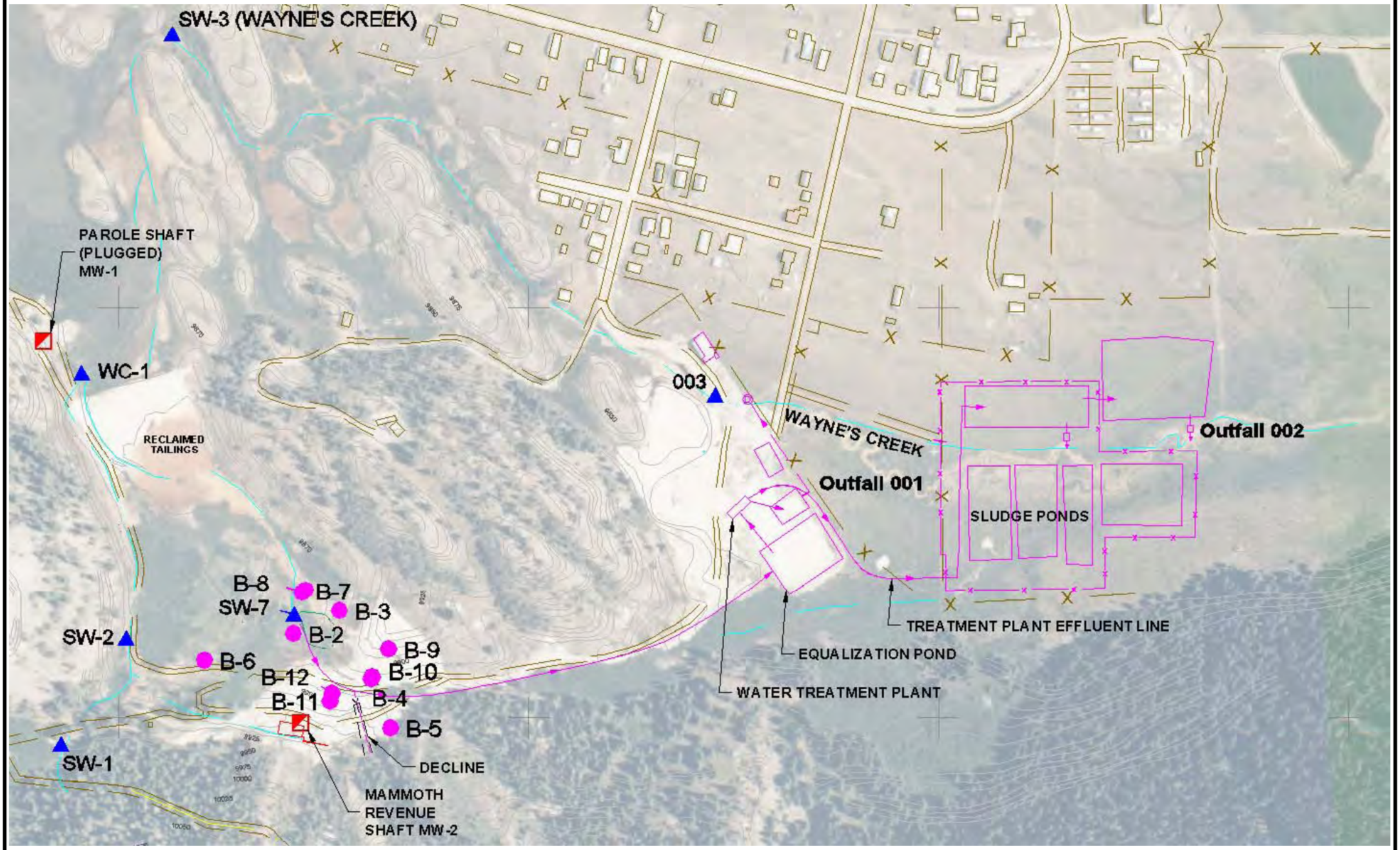
While chemically accurate, this equation does not fully present the associated physical changes (i.e., densification and volumetric reduction) that will occur during the process of converting hydroxides to sulfides in the mine workings. The approximate density of the water treatment pond solids is presently 1.07 grams per cubic centimeter (g/cm^3) with about 15% dry matter by weight. Solids conversion via the above listed chemical reaction with added carbon sources and in time will reduce the anticipated volume of the inputs of newly formed in-place minerals by approximately 96 percent with a solids density of 3.41 g/cm^3. The volume of solids formed in the mine after treatment and removal of the entire pond inventory of 17,500 CY will therefore be condensed and converted to around 640 CY.

CONCEPTUAL MINE WORKINGS CHEMICAL RESPONSE

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

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

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



PROJECT:	TASK
Platoro	*04*

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE 1 GENERAL SITE LAYOUT

PREPARED FOR: umicore

ATTACHMENT 2

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

MINE AREA HYDROGEOLOGY

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

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

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

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

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

Table 1 Hydraulic Conductivities of Geologic Materials in the Platoro Valley[1]

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

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

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

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

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

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

CONCLUSION

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

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

REFERENCES

Bohn, E.E. 1983. "Geology and precious metal deposits within the Platoro Caldera, Colorado: A high level epithermal system." in *89th Annual Northwest Mining Association Convention*, Spokane, WA.

Steffen, Robertson, and Kirsten. (SRK) 1981. *Site Selection Investigation for the Platoro Project*. Prepared for Union Gold, Inc.

ATTACHMENT 3

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

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

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

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

September 10th, 2008
Barite Hill Pit Lake and Mineral Springs Seep Updates

Water Quality Improvements for Barite Hill Pit Lake

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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The Problem

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

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

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

Evaluation of Potential Solutions

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

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

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

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

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

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

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

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

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

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

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Table 1 Summary of Barite Hill Pit Remedy Options and Costs

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

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

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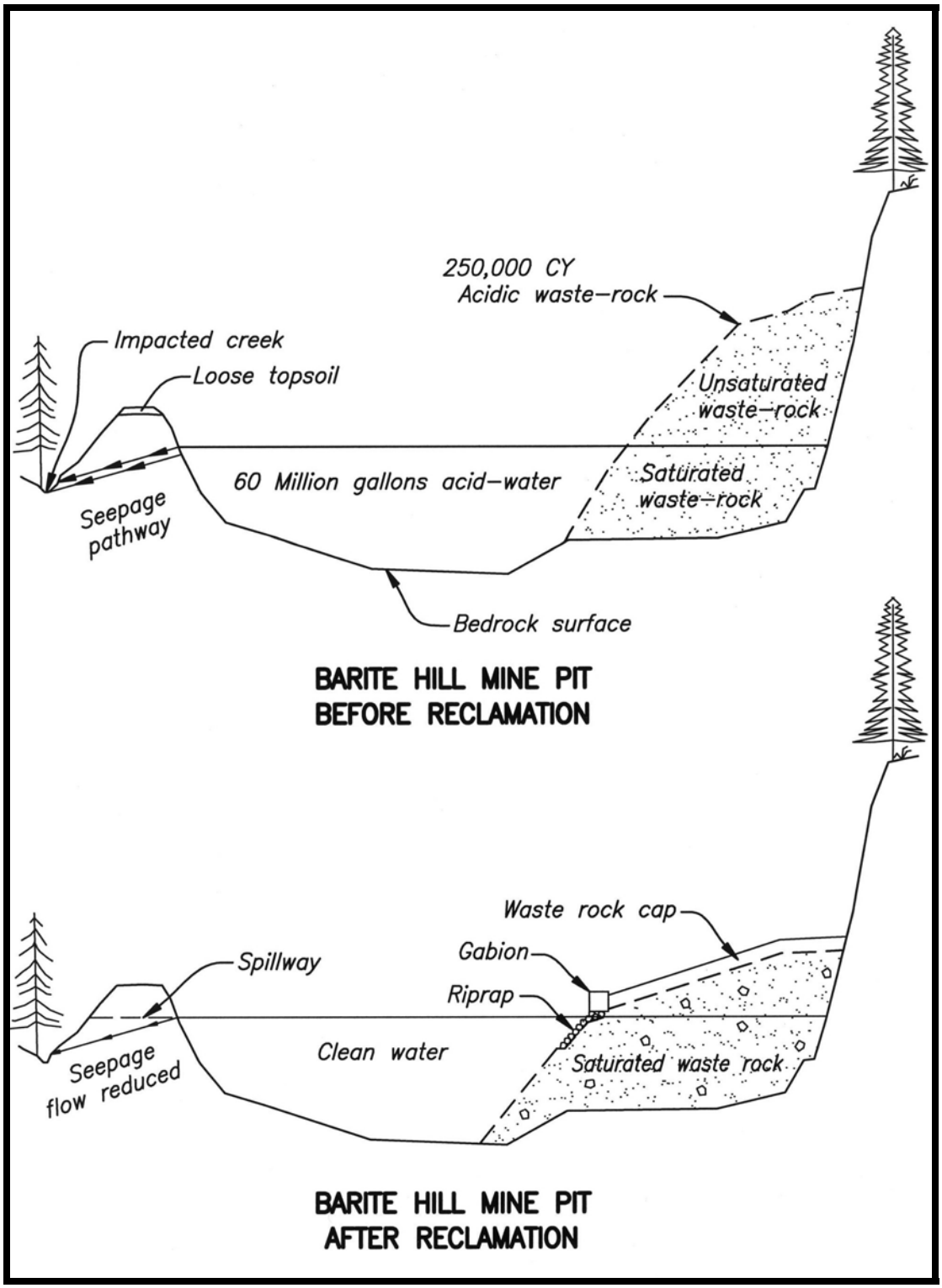


Figure 2 Cross section of the Barite Hill Mine Pit selected option.

Implementation of the Chosen Removal Action



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

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

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

manufacturing plants. Because the waste-rock gave off SO_2 fumes after rain events, a thin layer of lime was periodically spread onto the waste surface during grading operations to reduce the rate of acid generation. This action protected the workers and lowered the amount of additional stored acidity being released into the pit lake as the waste rock was submerged.

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

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

Periods of drought are more problematic to mitigate against decreases in the lake elevation. The upstream watershed was increased by excavating through the south pit wall to drain an adjacent area. Storm-water runoff into the pit would increase for a given storm event by enlarging the watershed. For drought, a ground water well and pump was installed to allow for water addition. Even this measure has limits, the bedrock at the site is tight and wells have a low yield. Finally, excess neutralization potential is provided by the pit treatment. A monitoring system will detect adverse changes in the pit lake, but it is expected that excellent water quality will be maintained for a long time. Stoichiometric calculations coupled with empirical analytical evidence support the expectation of sustainable, excellent water quality. Current water quality compared to October 2007 pretreatment can be seen in Table 2.

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

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

1. USEPA drinking water criteria
2. Priority Pollutant Criteria provided under Regulation 61-68 (adopted June 2004) and adjusted for a water hardness of 400 mg/L.
ND not detected at the reporting limit shown

<u>Acid loading potential from waste rock fills to the pit lake</u>

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

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$$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2H_2SO_4 + 590\ KJ/Mol\ heat$$

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

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

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

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

Fe^{3+}; $3x10^{-4}$ g/cc
d_{py} in cm; 100 micron or 0.01 cm
ρ_{py} is about 4.8 g/cc
Rpy [g/cc-day] =
6 x k1 x $(3x10^{-4})^p$ / (0.01 x 4.8); = 5.9 (18 yrs) or 7.6(14 yrs) $x10^{-7}$ g pyrite oxidized/cc-day.
$k_1 = (R_{py}\ d_{py}\ \rho_{py}) / (6[Fe^{3+}]^p)$; g/cm2-days $k_1 = 2.1 \times 10^{-8}$ for high ferric ion concentrations, calculated in centimeters, grams, days or cgd units.

At lowered concentrations, below 0.01 molar Fe3+, the reaction order approaches first order with respect to ferric ion (from 0.15), and the reaction rate equation becomes:

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

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



Figure 4 Grading of the South Waste Rock Pile

Using the previously derived values and assuming that Fe^{3+} concentrations in the lake would be kept below 5 mg/L, the rate of subaqueous oxidation would be reduced to $3.8x10^{-12}$ g pyrite oxidized/cc-day. Maintenance of sufficiently reducing conditions, such as through provision of excess organic carbon to maintain the SRB culture and assure reducing conditions (negative redox), will keep ferric ion below 5 mg/L and therefore ensure that the rate of subaqueous pyrite oxidation is reduced by as much as 200,000-times from the previously calculated oxidation rate of $5.9x10^{-7}$ g pyrite oxidized/cc-day that the wastes were subjected to prior to carbon loading and prior to placement under water. In effect, the submerged rock becomes a negligible source of acid loading.

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

Benefits of capping wastes surrounding the pit lake

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

grains, significantly slowing oxidation rates.

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

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

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

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

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

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

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

Benefits of vegetated oxygen consuming cover

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

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

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

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

High wall oxidation rate estimate

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

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

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

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

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

Pit Lake neutralization and carbon amendment process



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

Stoichiometry: Estimate of liquid and solid phase contaminants

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

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

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

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

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

Lime neutralization alone proceeds according to the following equation:

$6Ca(OH)_2 + 2Fe_2(SO_4)_3 \rightarrow 6CaSO_4 + 4Fe(OH)_3$

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

1332 tons hydrated lime + 2400 tons ferric sulfate → 2448 tons gypsum + 1284 tons iron hydroxide

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

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

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

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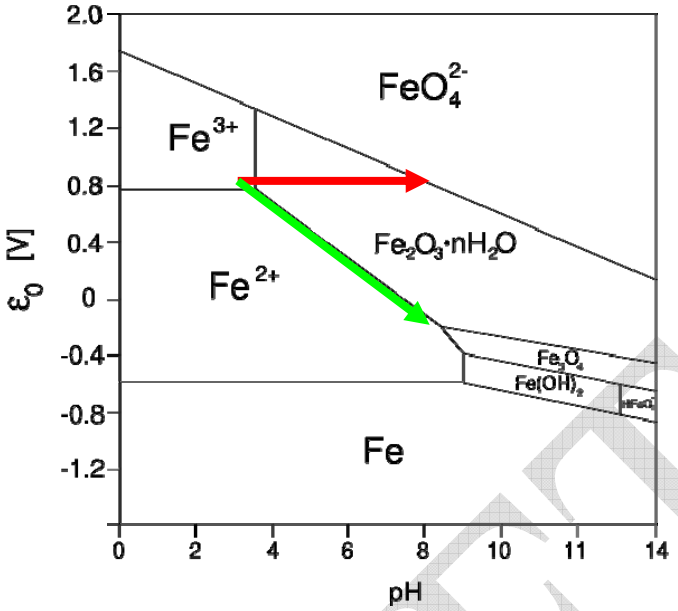


Figure 6 Pourbaix diagram of the thermodynamic conversion process for iron

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

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

$4CaSO_4 + 9CH_2O + 4Fe(OH)_3 \rightarrow 4FeS + 15H_2O + 4CaCO_3 + 5CO_2$

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

8,130 t sludge $\{573$ t $Fe(OH)_3 + 730$ t $CaSO_4\} + 363$ t $CH_2O \rightarrow 296$ t $CO_2 + 537$ t $CaCO_3 + 471$ t $FeS + 7189$ t H_2O

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

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

Geochemical end-states

The treatment provides several benefits including:

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

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

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

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Figure 7 Iron monosulfide sludges

Reduction in Environmental Impact and Off-site Contaminant Loading

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

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

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

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

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

Table 3 Chemistry of Pit Lake Seepage to the Stream

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

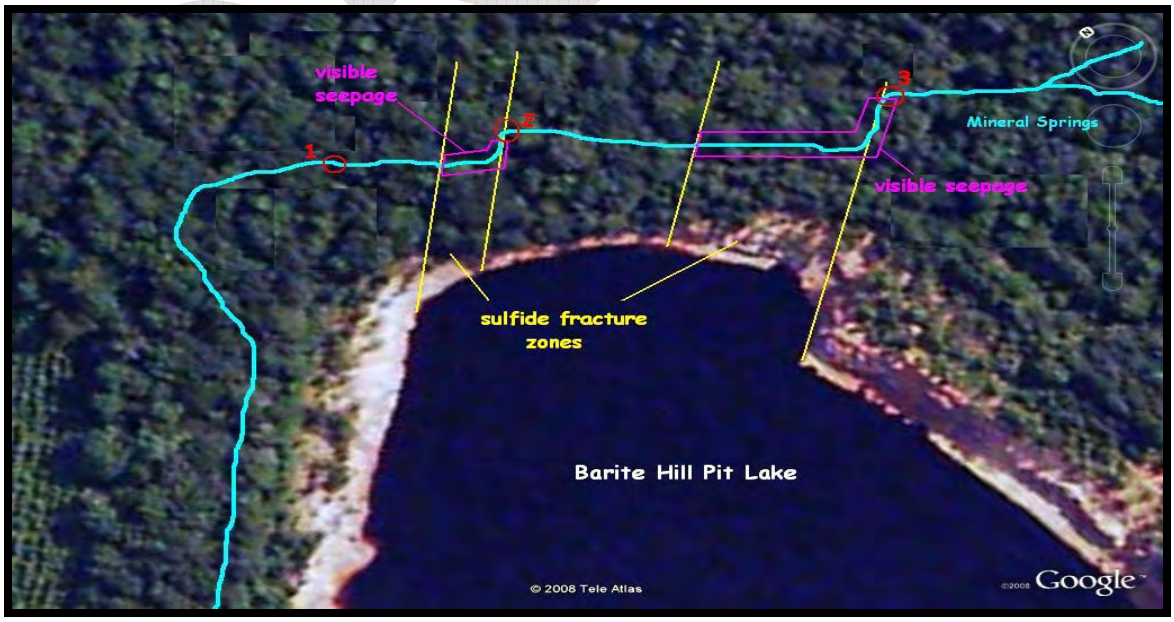


Figure 8 Aerial illustration of Pit Lake seeps and fracture zones

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

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

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

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

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

Conclusion

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

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

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Appendix 4 Galkeno 900 Bioreactor Performance

PRELIMINARY RECLAMATION AND CLOSURE PLAN

KENO DISTRICT MINE OPERATIONS

KENO HILL SILVER DISTRICT

REVISION 1

APPENDICES

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AUGUST 2012

Appendix 4 Galkeno 900 Bioreactor Performance



GALKENO 900 SULPHATE-REDUCING BIOREACTOR 2008-2011 OPERAITONS

FINAL REPORT

March 2012

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT CORP.

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

1 EXECUTIVE SUMMARY

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

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

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

2 BACKGROUND

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

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

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

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

Several adit discharge locations are being considered in the Closure Option assessment process for treatment in a bioreactor (Alexco Environmental Group, 2011). At this time, Silver King 100, 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.

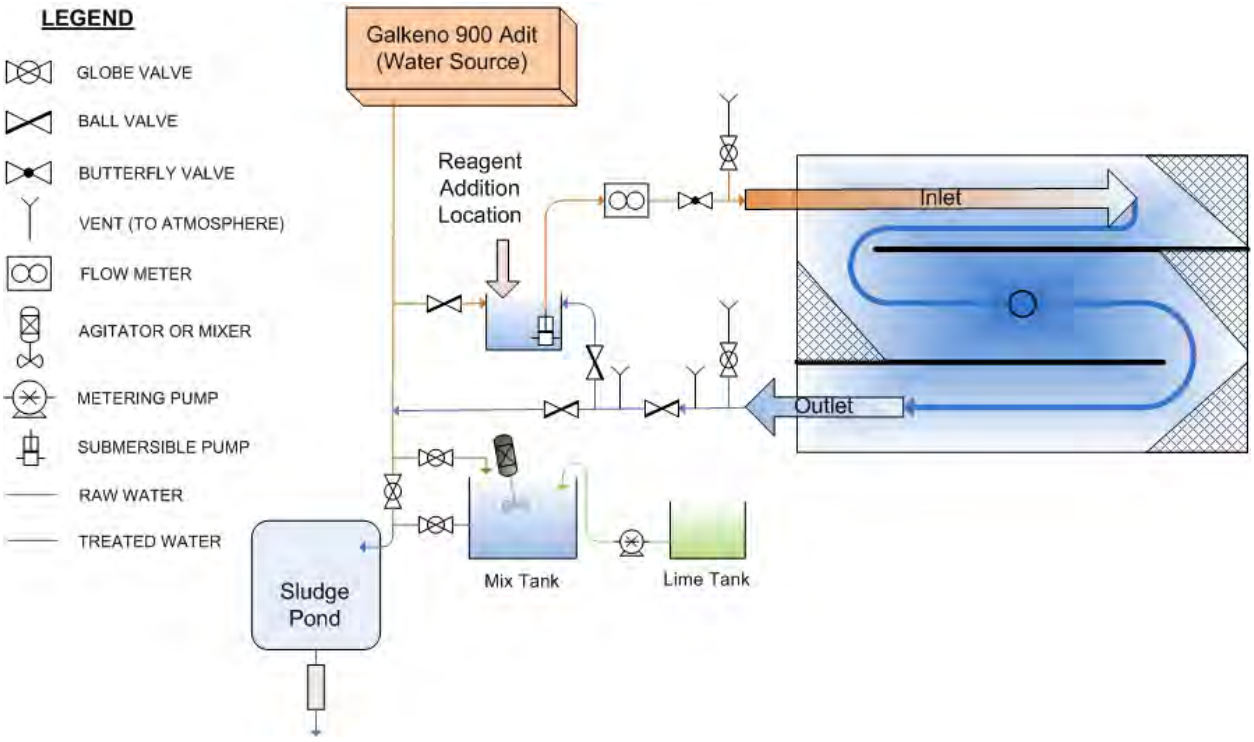


Figure 1 - Galkeno 900 Layout

Water drains from the Galkeno 900 adit at an average annual rate of 4 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.



Figure 4 - Bioreactor Inlet

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.

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

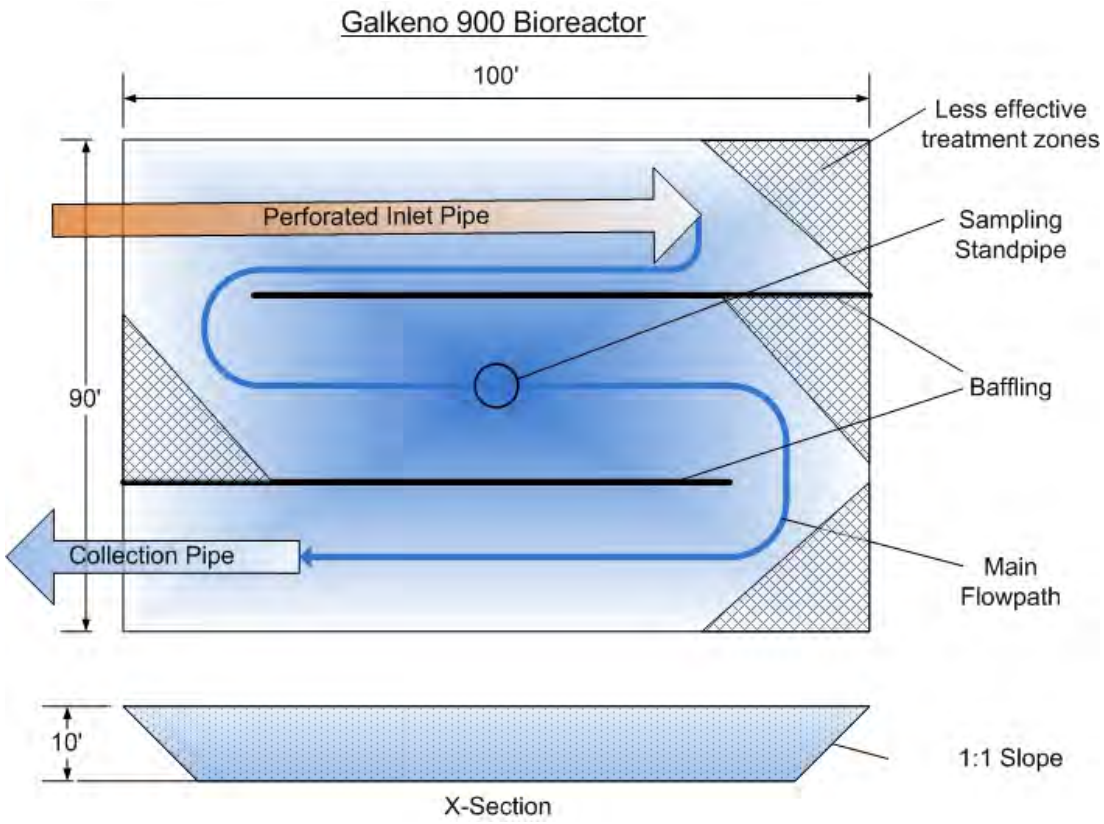


Figure 7 - Bioreactor Layout

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 lps was established into the reactor, and after stable metal removal conditions were observed this flow rate was maintained for several consecutive bimonthly samples. Soon after, the flow rate was increased to 1.0 lps in December 2009. In August 2010, the flow rate of the bioreactor was reduced to 0.75 lps, or approximately 19% of the adit flow. This flow rate was then maintained for the remaining operation of the bioreactor.

The results displayed in this report focus primarily within the operational treatment phase. The other phases, while important, are reflective of treatment performance during the transition of the bioreactor from construction to operation.

5.1 LITERATURE REVIEW AND BACKGROUND DISCUSSION

The formation of metal precipitates in a bioreactor that has carbon sources added to or present in the solid phase of the bioreactor has been extensively studied for 30+ years. There are several different styles of bioreactors, both in terms of carbon sources and flow dynamics. Some very large bioreactors have been created to treat flows as large as 20 lps or greater, and some bioreactors are designed to treat very acidic or concentrated metal-containing mine drainage. Each bioreactor must be designed to reflect the environmental conditions, the water chemistry of the mine water being treated, and other relevant variables as discussed in this report.

To understand the processes that occur in bioreactors many studies have attempted to identify directly by examination of mineral formation or by inference from water chemistry signatures what primary mechanisms are responsible for metals removal. When complex carbon sources are added as a solid phase in the bioreactor construction (i.e., peat, straw, compost, wood chips, etc.), a broad range of mechanisms has been documented (Gusek, 2002; Doshi, 2007; Gusek et al, 2008), that include:

- Sorption of metals on organic matter.
- Precipitation of iron hydrous oxides including ferric and mixed valence minerals, which then provide mineral surfaces for sorptive removal of metals, or metals can also be co-precipitated within the iron mineral matrix.
- Precipitation of manganese oxides including manganese (IV) oxides and mixed valence (III/IV) oxides and manganese carbonates, which then provide mineral surfaces sorptive removal of metals, or metals can also be co-precipitated within the manganese mineral matrix.
- Precipitation of metal sulphides, including primary metal sulphides such as ZnS or CdS, as well as precipitation of iron sulphides such as amorphous FeS and co-precipitation of metals within the FeS matrix. Depending on the pH of the bioreactor and the availability of structural iron, a very large amount of FeS minerals can be formed by aqueous sulphide formed by microbes reductively dissolving iron from the rock matrix, creating a “bank” of amorphous sulphide which has reactivity toward dissolved metals.

- Precipitation of some metals in their reduced forms, for example selenium reduction from a Se(VI or IV) anion to elemental selenium precipitates Se.
- Precipitation of metals as carbonate minerals. Some of the relevant metals have somewhat soluble carbonate minerals (e.g., zinc carbonate minerals including smithsonite, and hydrozincite) which are relatively more soluble than sulphides. When sulphide is not present, these minerals may provide a precipitation-removal mechanism.

Sorption of metals on organic matter is not a relevant metals removal mechanism by design in the Galkeno 900 bioreactor because only coarse rock was used as a solid substrate. The metal removal mechanisms in this reactor appear to initially relate to removal of iron and manganese during the recirculation phase, and then over time the removal mechanism transitioned to a metal sulphide removal mechanism (inferred because metals removal continued to occur when iron and manganese ceased being removed and actually increased in concentration during flow through the reactor). The precipitation and removal of metals in their reduced forms is not a significant potential mechanism for most of the metals present in Galkeno 900 adit water, with the potential exception of uranium which was only present in very low concentrations in the influent water. Consequently, the formation of sulphide from sulphate, which is a chemical reaction that is catalyzed by microbes and relies on the availability of organic carbon, is the primary performance variable that is relevant in the Galkeno 900 bioreactor performance evaluation. In typical evaluation of bioreactors where sulphate reduction/sulphide precipitation is a dominant mechanism, the Sulphate Reduction Rate (SRR) is determined as a primary design variable.

In a bioreactor with available sulphate and a soluble carbon source added, Dar et al (2007) showed that sulphate reducing bacteria (SRB) are the dominant microbe that accumulates in the bioreactor, and by inference the vast majority of the carbon consumption is performed by SRB. In their study, only a few different strains accounted for the majority of the cells present, indicating that microbes capable of utilizing the carbon source and reduce sulphate will become dominant in the bioreactor.

After the bioreactor entered stable operation, metals removal mechanisms appear to have shifted from the mixed reaction that were discussed in the prior report (Alexco Resource US Corp, 2009) to primarily a sulphide-based precipitation process. The stability of metals removed as sulphides are consequently an important consideration for the performance of the bioreactor. Jong and Perry (2004) studied the form of metals that were precipitated from solution as a result of the sulphate reduction process, and determined that arsenic, copper, iron, nickel, and zinc were primarily bound up in a sulphide phase that was also associated with residual organics, and that carbonate or hydroxide phases were relatively minor phases that held the metals removed from solution. The United States Environmental Protection Agency SITE program studied the stability of these sulphate-reducing bioreactor precipitates at the Leviathan Mine, in California. Using a series of different tests, the EPA determined that the metals in the bioreactor precipitates were below regulated total metals thresholds (California standards), the WET extraction test showed that the metals in the bioreactor did not leach above regulated soluble threshold standards, and that as defined by TCLP extraction testing the bioreactor solid materials were not hazardous.

The effectiveness of this sulphate reduction bioreactor process is sensitive to important variables including the hydraulic residence time in the bioreactor, the sulphate reduction rate, and the filtration capacity of the media.

Because the products of the sulphate reduction reaction include both sulphide and bicarbonate alkalinity, it is possible that carbonate precipitation is also an important mode of precipitation for some of the metals removed in the reactor. However, for most of the metals being removed in the bioreactor, including antimony, arsenic, cadmium, cobalt, iron, nickel, and zinc, a sulphide precipitation mechanism appears more likely because sulphide precipitates are less soluble than the carbonate precipitates of these elements. The mineralogical analysis discussed in Section 6.2.1.1 confirms that sulphide is the solid phase form of zinc precipitates formed in the bioreactor. Thus the sulphate reduction reaction is the primary reaction that we will focus on optimizing in the bioreactor operations.

5.2 DETERMINATION OF THE SULPHATE REDUCTION RATE

Microbial production of sulphide from sulphate is dependent on the presence of sufficient numbers of sulphate-reducing bacterial (SRB) cells, and the availability of organic carbon, according to the following reaction:

4 moles methanol + 3 moles sulphate → 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.

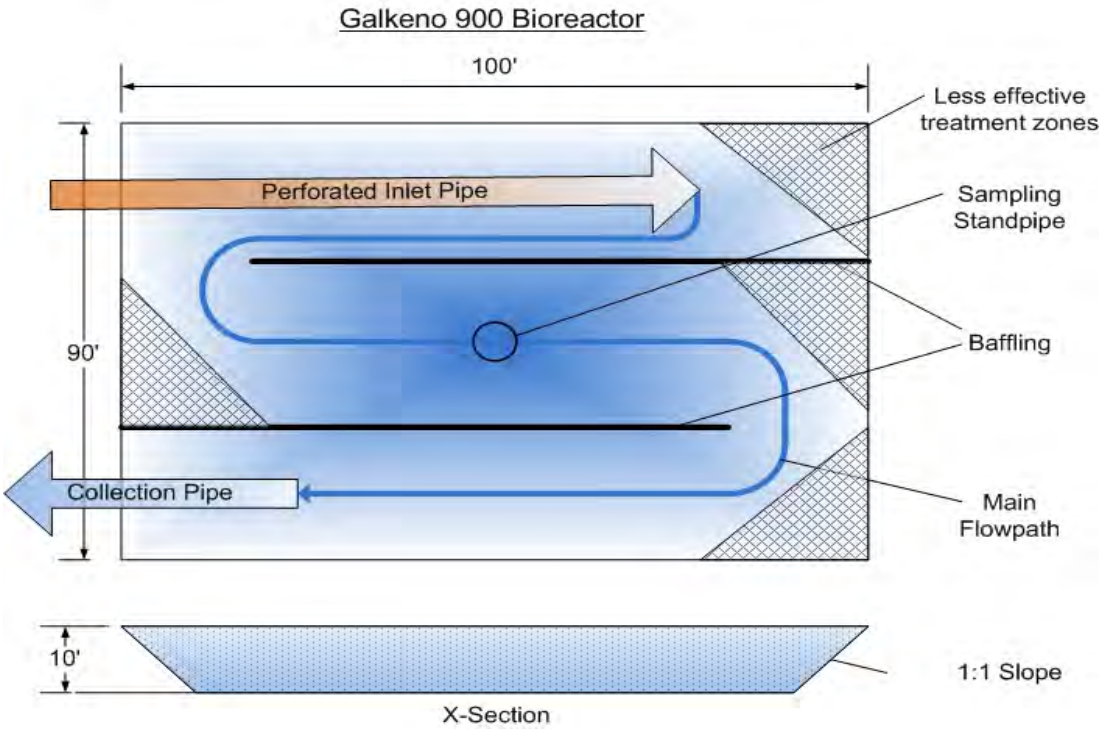


Figure 9 - Conceptualization of Flow Path in the Bioreactor

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.

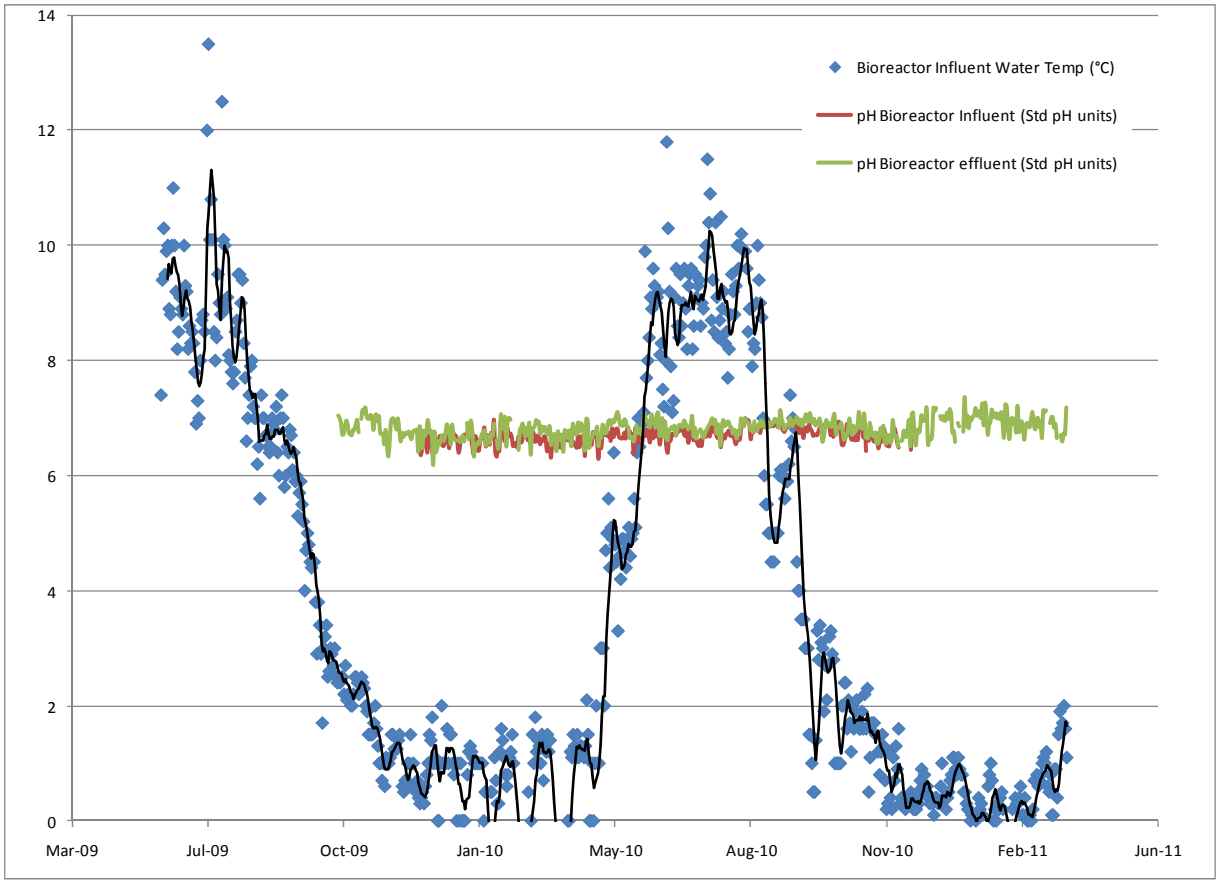


Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp

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%

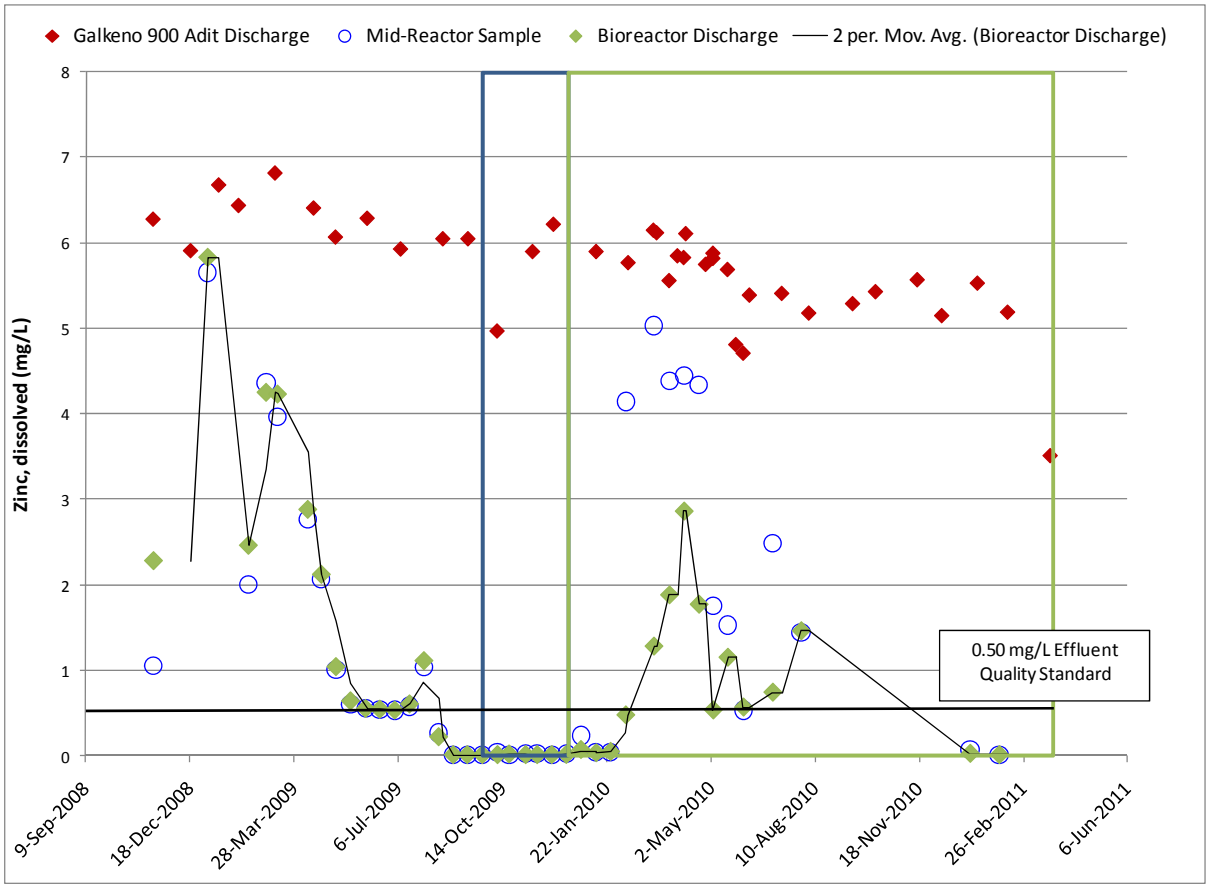


Figure 11 - Zinc removal by the Galkeno 900 Bioreactor

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.

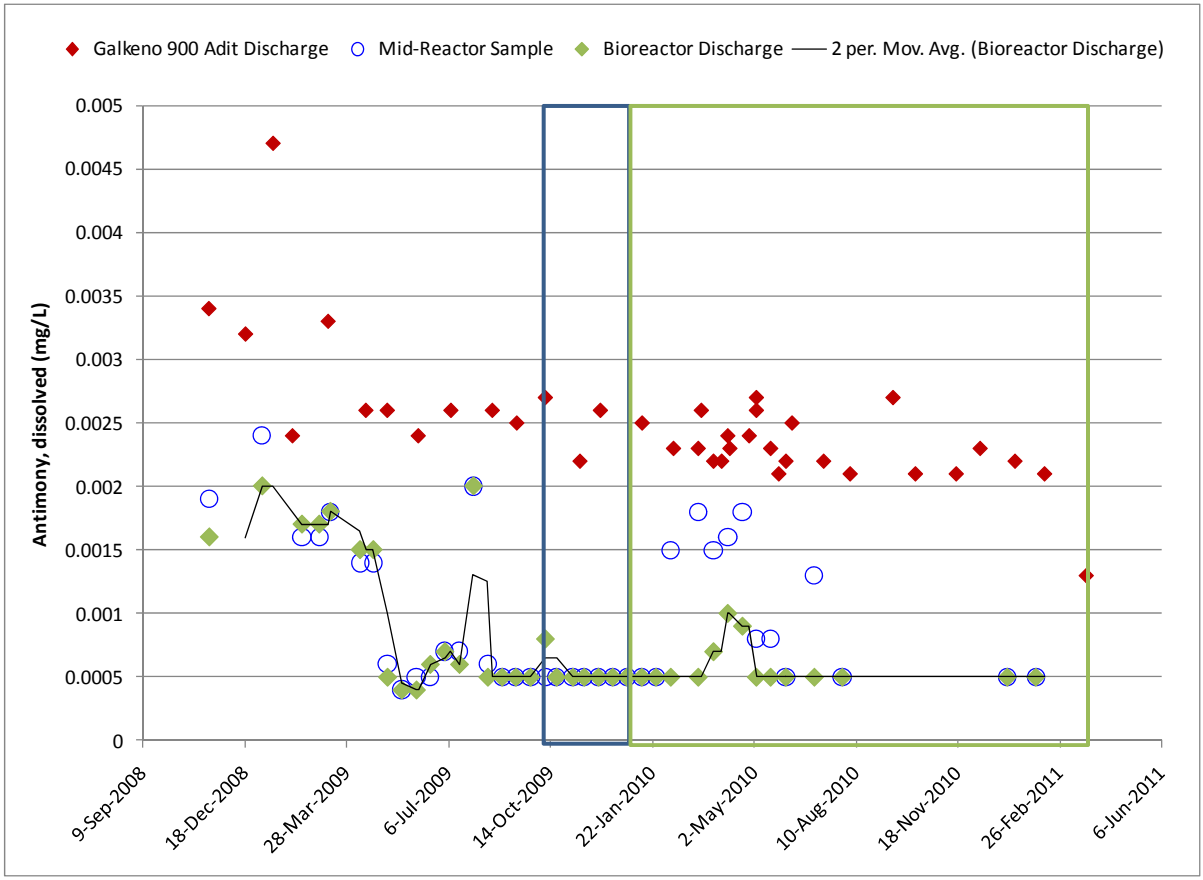


Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor

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.

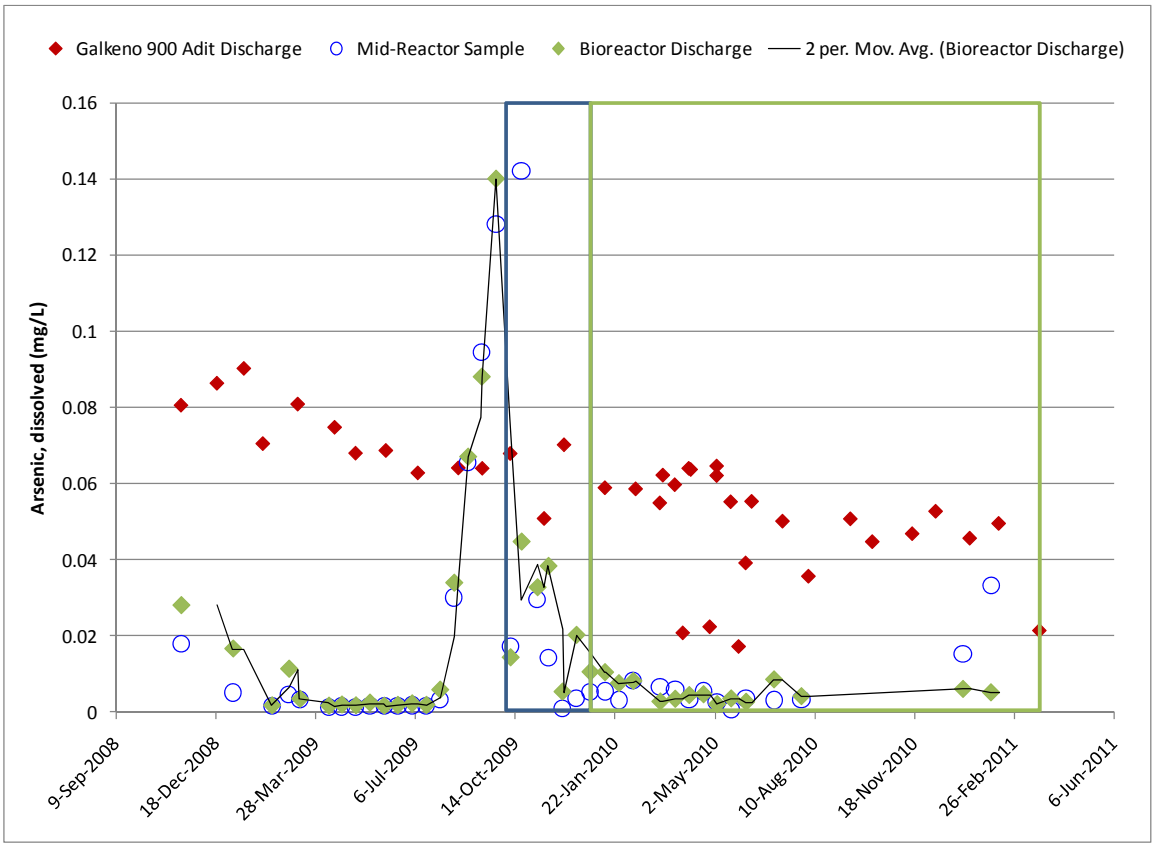


Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor

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.

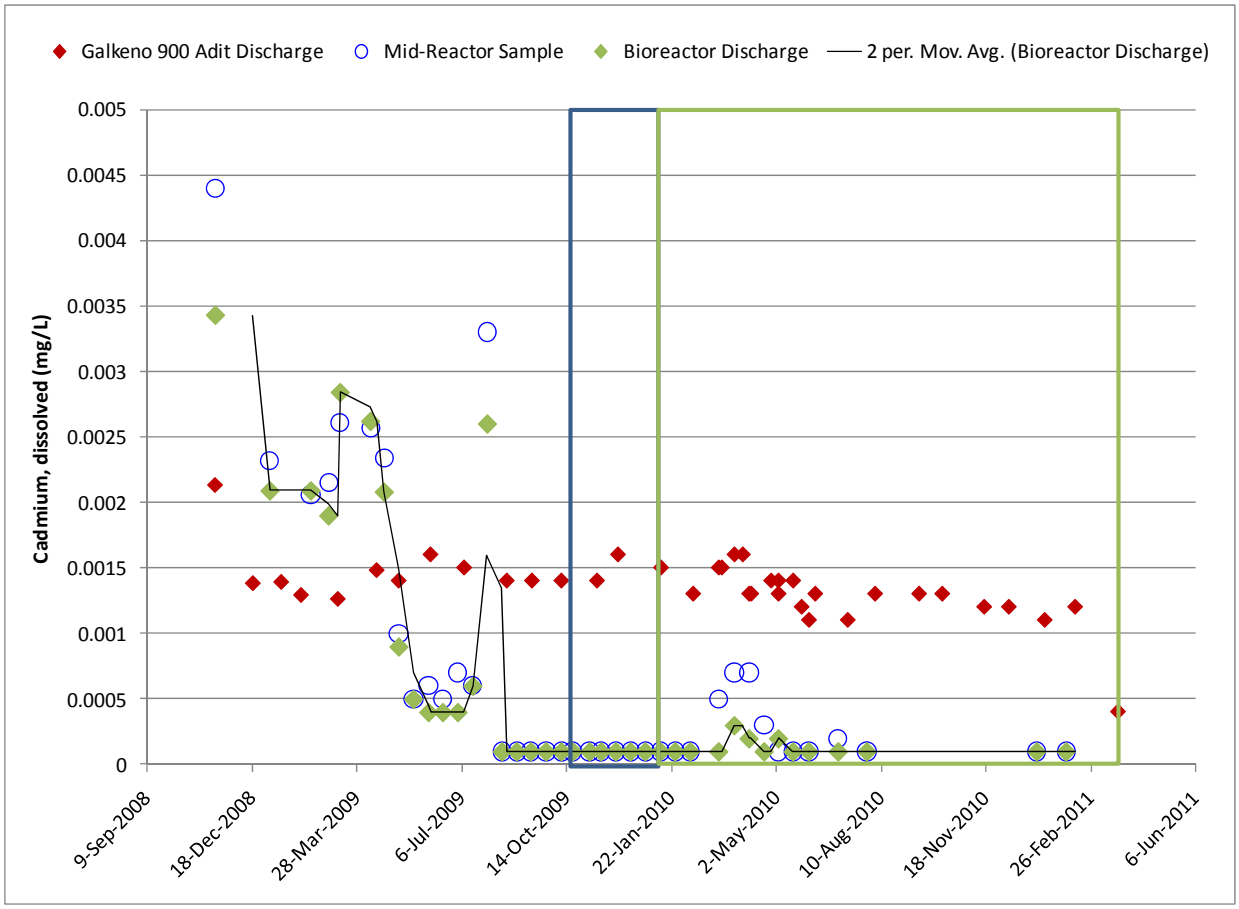


Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor

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.

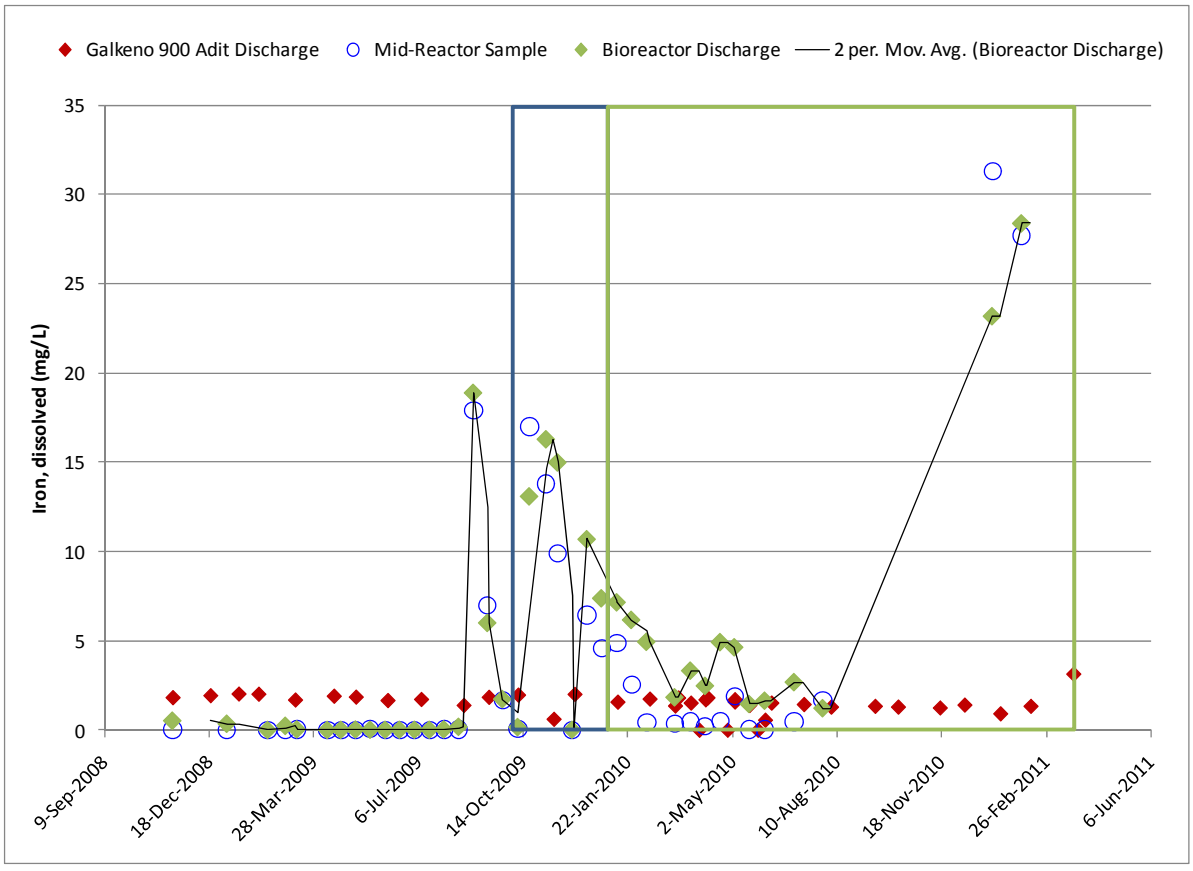


Figure 15 - Iron Removal by the Galkeno 900 Bioreactor

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.

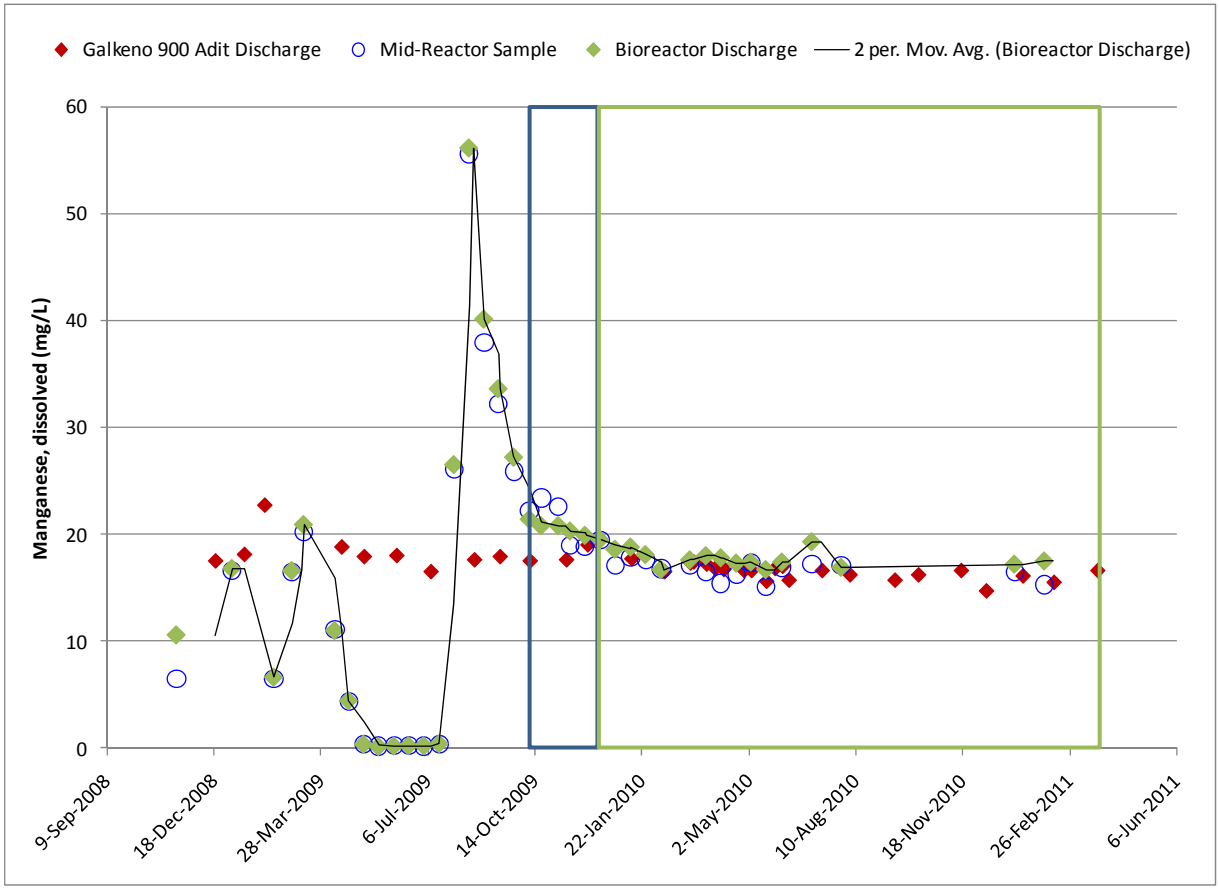


Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor

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.

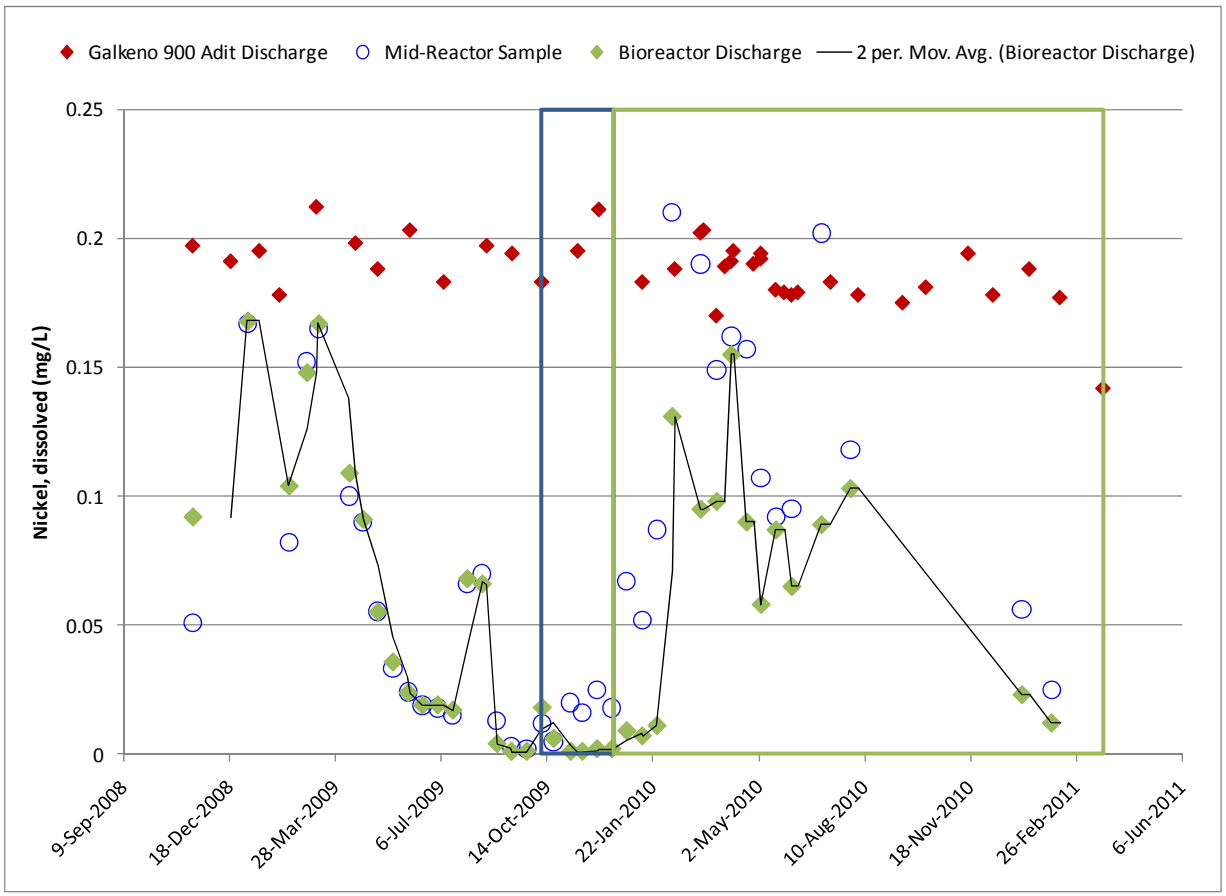


Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor

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

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APPENDIX A

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

Summary Report on optical and electron microprobe analysis of Galkeno 900 Bioreactor at Keno Hills

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Executive Summary

Samples of sediment from the Galkeno Bioreactor and also from a column experiment were analyzed using optical microscopy and an electron microprobe at the University of Manitoba. The first samples from the column experiment and from the Galkeno Bioreactor were oven dried in an aerobic environment prior to making polished thin sections. The second set of Galkeno Bioreactor sediments were kept in a wet anaerobic state before being sealed in epoxy resin.

Column samples contained Mn and Zn coatings on lithic grain.

The results showed that micron sized grains of ZnS were precipitated with a molar ratio of 1:1 indicating bacteriological sphalerite was being formed. The samples preserved anaerobically contained significantly more sphalerite than the first set of samples. The sphalerite formed bands indicative of biofilm deposition. Some if the ZnS layers were immediately adjacent to or surrounding layers of Fe and Mn oxide or hydroxide. This result fits with the water data from the Bioreactor. During the initiation the reactor was in an aerobic state and Mn and Fe oxides and hydroxides were deposited sequestering some Zn. When the Bioreactor became anaerobic the Mn and later Fe was mobilized but the Zn was now bacterially sequestered as ZnS. Some of this was formed on the remaining FeOOH biofilm layers.

1. Introduction

This study was initiated to investigate the form of Zn that was attenuated in column tests and in the Galkeno 900 Bioreactor. The initial set of samples had been oven dried prior to making the polished thin sections. This set consisted of duplicate thin sections (A and B) from 6 samples from the upper, middle, and lower section of four column tests (samples #3-8) and of two other samples from the bioreactor sediments (Sherriff 2011a) .

A second set of samples were obtained during the decommissioning of the Bioreactor (BioR Sed., and GK900 Sed.) These samples were sent to Vancouver Petrographics in jars as slurries. They were air dried and immediately sealed in eposxy resin to preserve minerals that might be unstable in an oxidizing environment. Two thin sections were made of sample BioR (A and B) (Sherriff 2011b).

2. Methodology

Polished thin sections were made by Vancouver Petrographics. The thin sections were examined optically to determine overall composition and delineate areas of interest. Selected areas were imaged on the electron microprobe (EMP) at the University of Manitoba using back scattered electrons (BSE) and mapped for Mn, Fe, S, and Zn. Points of further interest were the quantitatively analyzed.

The microprobe was operated at an acceleration potential of 15 kV and a beam current of 3 nA measured on the Faraday cup, with a 1 μm diameter beam. The standards for the quantitative analysis were albite (Na), olivine (Mg), andalusite (Al), diopside (Si, Ca), pyrite (S , Fe), orthopyroxene (K), sphene (Ti), spessartine (Mn), pentlandite(Ni), chalcopyrite (Cu), Gahnite (Zn), cobaltite (As), barite (Ba), chromite (Cr), and galena (Pb). The results of quantitative point analyses are given in wt. % elements with oxygen added to the Mn coating analyses to balance the cations.

3. Results

3.1 FM Column Tests

Only samples #5A FM Peat Bottom and #8A FM Silt and Clay Bottom were analyzed using the electron microprobe. Under optical microscopy thin section #5A FM Peat Bottom showed just plant fragments in a red mud whereas thin sections 8A FM Silt and Clay Bottom had lithic grains in fine grained matrix. The results from the column samples were rather ambiguous. Small areas (~1μm) in sample 5A had high Zn and S with Zn:S molar ratio of about 1:1 indicating possible precipitation of sphalerite. Sample 8A had a thin black coating of Mn and Zn around lithic grains with an average concentration is 8.1 wt. % Mn and 1.2 wt. % Zn giving an average Mn:Zn molar ratio of 3.4 (Figure 1)

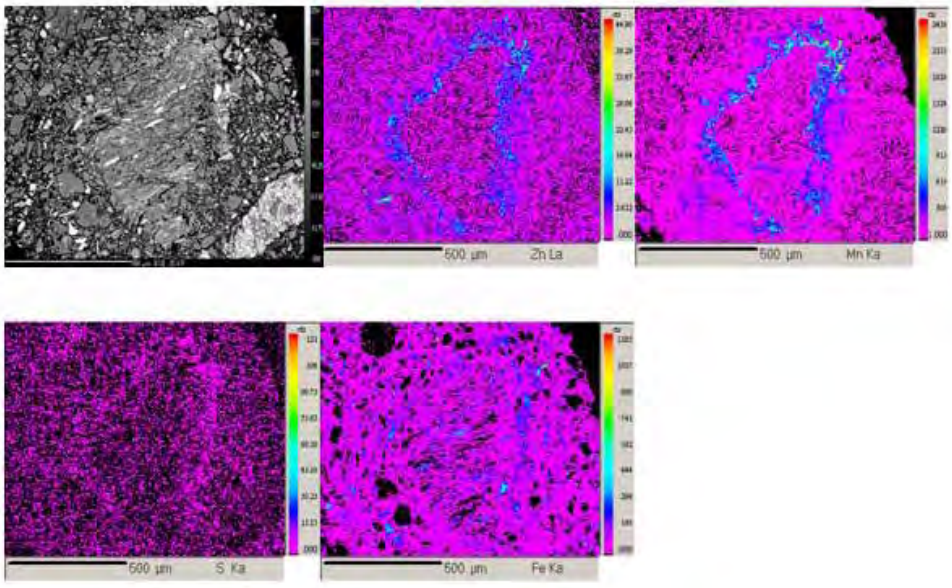


Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain

3.2 Galkeno Bioreactor

The first set of Galkeno Bioreactor samples showed a few small areas that contained micron sized areas of Zn and S in a ratio of about 1:1indicating the presence of ZnS (Figure 2).

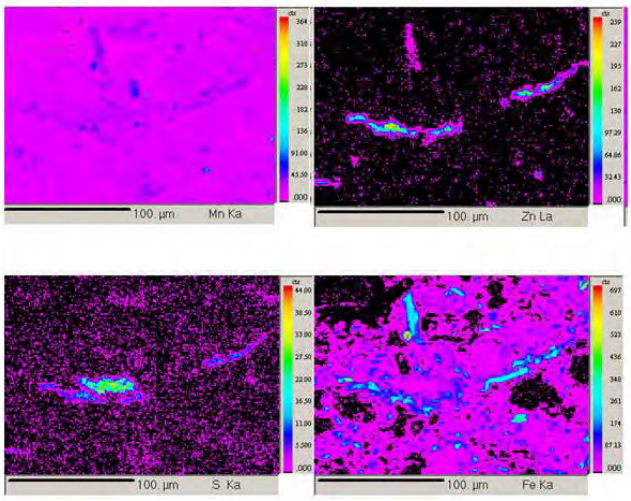


Figure 2: 1B G900 BIO BSE images and element maps

The second set of Galkena 900 samples (BioR Sediment and GK900 sediment) were kept under water and hence in an anaerobic environment until analyzed. These have a much higher concentration of micron sized ZnS grains, many of which formed bands indicating bacterial precipitation of sphalerite within a biofilm layer (Figure 3).

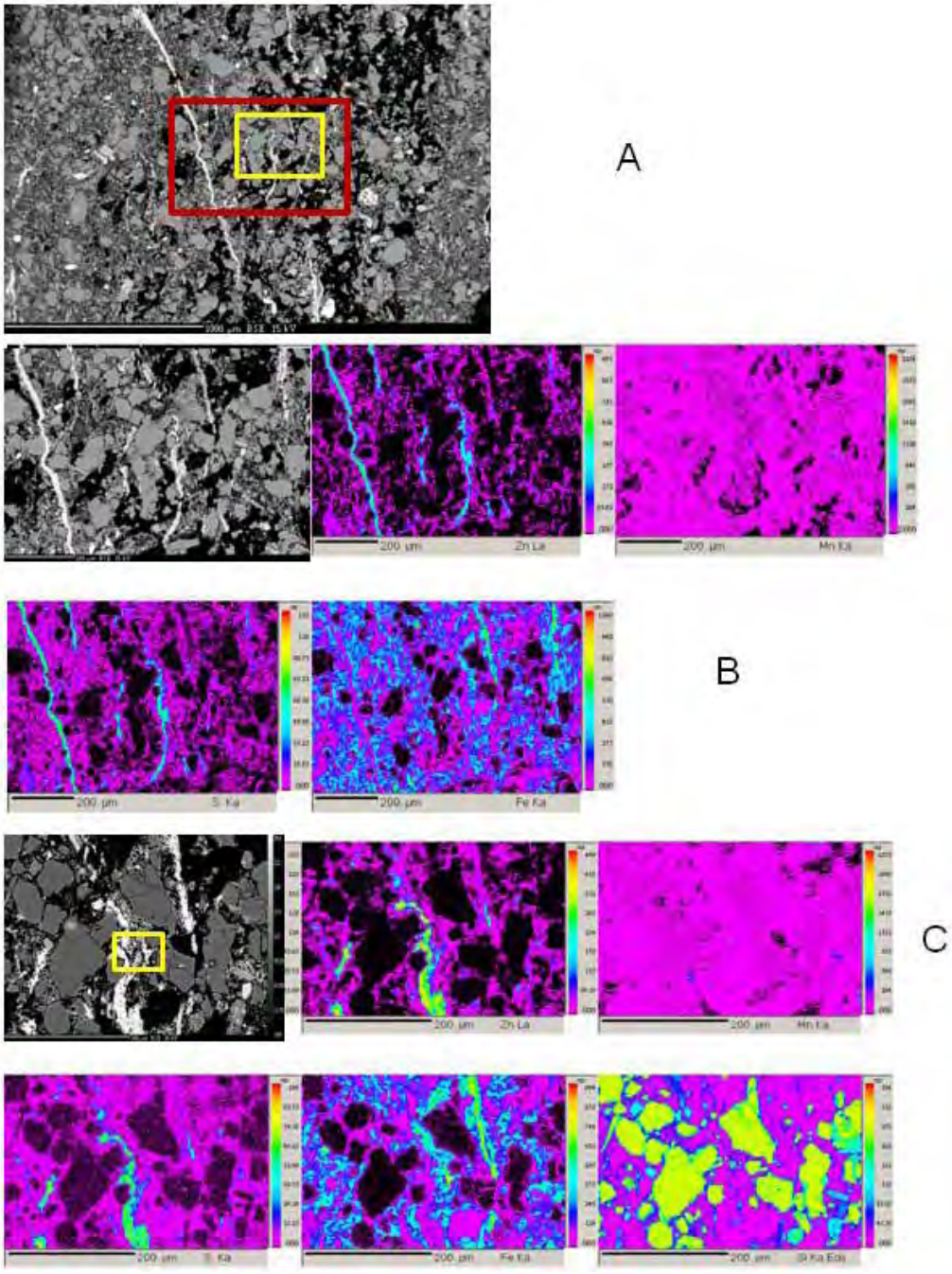


Figure 3 GK900 Bioreactor sample. (A) BSE image showing extensive bright bands of ZnS and Fe(B) BSE image and element scans of area in red box in (A) (C) BSE image and element scans of area yellow box in (A)

There were also areas containing Fe and Mn but not Zn or S (Figure 4). An elemental line scan across this area indicates regions rich in Zn and S adjacent to areas rich in Fe and Mn. Scatter plots of the quantitative analyses along the same line show that firstly Zn and S are related in atomic proportions of 1:1 (R^2 0.98) verifying the presence of sphalerite (ZnS) and secondly that Fe and Mn are precipitated together in a separate band (R^2 0.83). The concentrations of Mn are very low and there is no correlation between Fe and Zn or between Mn and Zn.

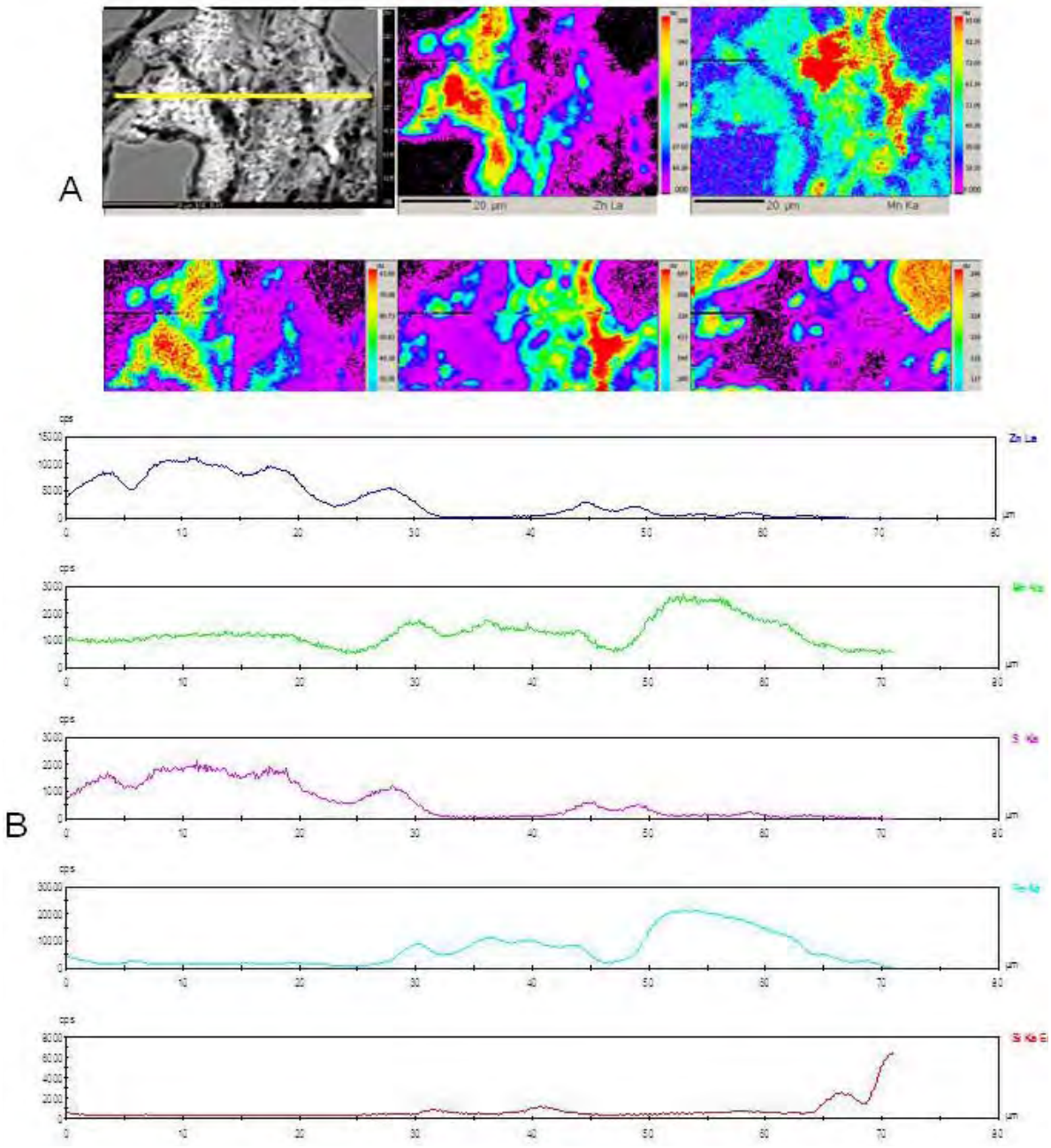


Figure 4: GK900. BSE image and element scans of area in yellow box in Figure 3 Element scans along the yellow line in BSE image (A)

In thin section BioR sediment A, a number of areas were imaged and mapped. A total of 160 points were selected within areas rich in Zn and S for quantitative analysis. In one area, two ZnS regions in the image have a thin band of Fe through the centre (Figure 5). The ZnS and Fe-rich bands were analyzed separately. A scatter plot of the concentrations of the ZnS band gives a 1:1 molar ratio of Zn to S indicating the presence of sphalerite. The Fe-rich bands have much lower concentrations of Zn and S and higher Fe and Mn. A plot of molar proportions of Zn and S indicates that there are still some grains of sphalerite in this region (Figure 5). In the Fe-rich band, there is a weak positive trend between the values of wt. % Fe and Mn (Figure 5).

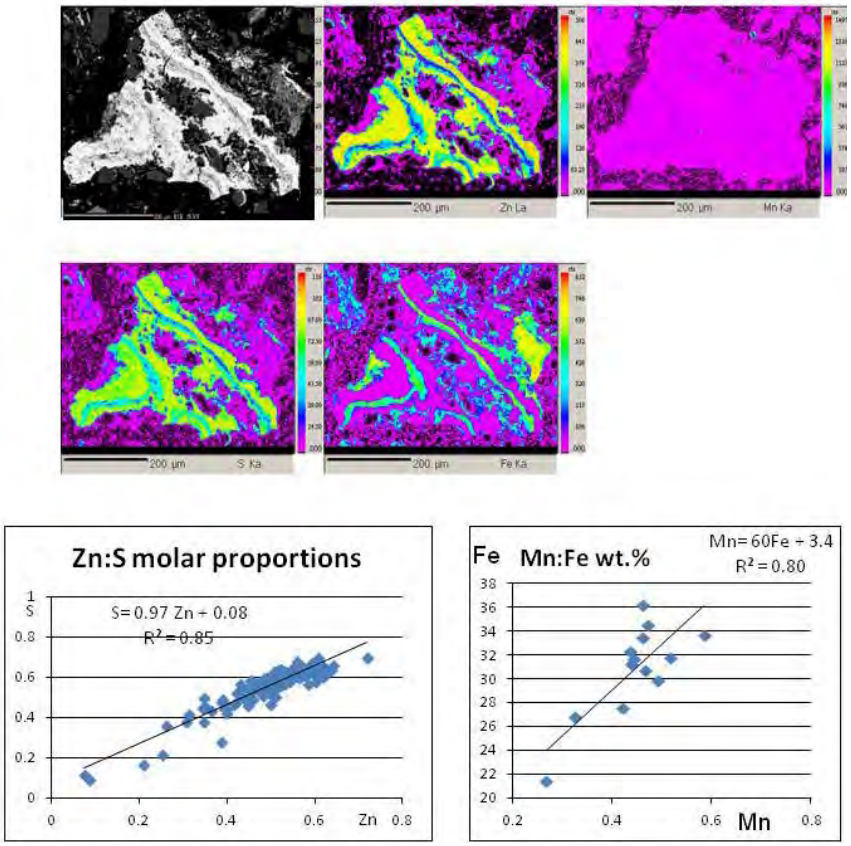


Figure 5: BioR sediment: BSE image and element maps showing the relation ship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.

4. Discussion

The chemical analytical data from the samples GK900 and BioR Sediment can be interpreted in light of the composition of water exiting the Bioreactor (Alexco Resource US Corp. 2011). When the reactor was initially established, from September 2008 to October 2009, the environment was aerobic, Mn, Zn and Fe were removed from the adit water probably as Zn absorbed on Mn oxide and FeOOH. In October 2009 the reactor became anaerobic and there was an immediate increase in the Mn concentration in the water. This would have been due to the dissolution of the Mn oxide. For the rest of the operation of the bioreactor, Mn was not removed from the mine water. Zn was then precipitated as ZnS by sulphate reducing bacteria with residual FeOOH acting as a template for the formation of a ZnS biofilm.

5 References

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Sherriff, B.L. (2011a) Interim Report on optical and electron microprobe analysis of Keno Hills samples set 3

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

Appendix 5 Kinetic Testing Results for Bellekeno Tailings

Leach Cycle	0	1	2	3	4	5

Table 4-4. Bellekeno Humidity Cell Results up to Week 44

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-0	MILL TAILS COMPOSITE-JAN-JUN2011-1	MILL TAILS COMPOSITE-JAN-JUN2011-2	MILL TAILS COMPOSITE-JAN-JUN2011-3	MILL TAILS COMPOSITE-JAN-JUN2011-4	MILL TAILS COMPOSITE-JAN-JUN2011-5
Date Sampled	**17-AUG-11**	**24-AUG-11**	**31-AUG-11**	**07-SEP-11**	**14-SEP-11**	**21-SEP-11**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1045358-1**	**L1049390-1**	**L1051834-1**	**L1054437-1**	**L1057740-1**	**L1060984-1**
Matrix	**Water**	**Water**	**Water**	**Water**	**Water**	**Water**
Sample Preparation						
Total Volume In	750	500	500	500	500	500
Total Volume Out	550	460	460	450	450	475
Physical Tests						
Conductivity	1950	1050	1050	822	648	553
pH	7.89	7.7	7.86	7.81	7.91	7.81
Anions and Nutrients						
Acidity (as CaCO3)	**5**	**4.8**	**5.8**	**10.9**	**5**	**3.4**
Alkalinity, Total (as CaCO3)	43	45	68.3	64.5	49.6	62.7
Bromide (Br)	<0.050	<0.50	<0.5	<0.50	<0.050	<0.050
Chloride (Cl)	15.6	7.4	<5.0	<5.0	<0.50	<0.50
Fluoride (F)	0.354	0.37	0.34	0.34	0.288	0.27
Nitrate (as N)	10.1	3.36	<0.050	<0.050	0.0148	0.0065
Nitrite (as N)	0.0845	0.089	0.011	<0.010	0.0064	<0.0010
Sulfate (SO4)	1150	513	595	455	320	248
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.010	<0.010	<0.010	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	**0.023**	**0.0241**	**0.0222**	**0.0178**	**0.0159**	**0.0166**
Arsenic (As)-Dissolved	0.00081	0.00195	0.00248	0.0015	0.00139	0.00104
Barium (Ba)-Dissolved	0.0985	0.056	0.0372	0.0359	0.0387	0.0347
Beryllium (Be)-Dissolved	<0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.0010	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.166	0.157	0.185	0.117	0.075	0.076
Cadmium (Cd)-Dissolved	0.0264	0.0216	0.0339	0.0292	0.0228	0.0263
Calcium (Ca)-Dissolved	439	217	240	192	150	119
Chromium (Cr)-Dissolved	<0.0010	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00155	0.00089	0.00289	0.00318	0.00179	0.00198
Copper (Cu)-Dissolved	0.0049	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Iron (Fe)-Dissolved	**<0.030**	**<0.030**	**<0.030**	**<0.030**	**<0.030**	**<0.030**
Lead (Pb)-Dissolved	0.192	0.161	0.137	0.104	0.111	0.128
Lithium (Li)-Dissolved	0.0608	0.0495	0.0488	0.0269	0.0196	0.0162
Magnesium (Mg)-Dissolved	17.3	10.6	10.3	6.94	4.64	3.7
Manganese (Mn)-Dissolved	3.69	1.81	4.07	3.71	2.11	2.13
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00463	0.00467	0.00422	0.00327	0.00376	0.00393
Nickel (Ni)-Dissolved	0.0037	0.0015	0.0042	0.00415	0.00193	0.00223
Phosphorus (P)-Dissolved	0.61	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	27.1	13	8.75	4.78	3.74	2.88
Selenium (Se)-Dissolved	0.00176	0.00109	0.00076	0.00075	0.00054	0.00044
Silicon (Si)-Dissolved	**2.48**	**2.82**	**4.61**	**3.76**	**4.07**	**4.28**
Silver (Ag)-Dissolved	0.00801	0.000588	<0.000020	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	67.5	23.3	10.4	3.64	2.14	1.35
Strontium (Sr)-Dissolved	1.33	0.623	0.565	0.382	0.276	0.249
Sulfur (S)-Dissolved	459	249	198	147	111	86.1
Thallium (Tl)-Dissolved	0.000564	0.000455	0.000381	0.000248	0.000147	0.000189
Tin (Sn)-Dissolved	<0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	<0.010	<0.010	0.016	0.014
Uranium (U)-Dissolved	0.000725	0.000413	0.000698	0.000526	0.000315	0.000276
Vanadium (V)-Dissolved	<0.0020	<0.0020	<0.0020	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	0.478	0.587	1.97	2.16	1.16	1.77

Leach Cycle	6	7	8	9	10	11

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-6	MILL TAILS COMPOSITE-JAN-JUN2011-7	MILL TAILS COMPOSITE-JAN-JUN2011-8	MILL TAILS COMPOSITE-JAN-JUN2011-9	MILL TAILS COMPOSITE-JAN-JUN2011-10	MILL TAILS COMPOSITE-JAN-JUN2011-11
Date Sampled	**28-SEP-11**	**05-OCT-11**	**12-OCT-11**	**19-OCT-11**	**26-OCT-11**	**02-NOV-11**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1064228-1**	**L1067341-1**	**L1070094-1**	**L1073037-1**	**L1076479-1**	**L1079310-1**
Matrix	**Water**	**Water**	**Water**	**Water**	**Water**	**Water**
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	435	485	475	450	500	460
Physical Tests						
Conductivity	523	415	463	435	438	428
pH	7.91	7.86	7.84	7.79	7.91	7.83
Anions and Nutrients						
Acidity (as CaCO3)	**5.6**	**7.1**	**7.2**	**6.3**	**10.4**	**5.1**
Alkalinity, Total (as CaCO3)	68.4	78.3	73.7	73.9	72.1	75.6
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.254	0.208	0.183	0.164	0.161	0.179
Nitrate (as N)	0.0096	0.0052	<0.0050	<0.0050	0.007	0.0066
Nitrite (as N)	0.0036	0.0046	<0.0010	0.0016	0.0012	0.0043
Sulfate (SO4)	230	158	189	172	181	184
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	0.0219	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	**0.0159**	**0.016**	**0.0164**	**0.0154**	**0.0155**	**0.0152**
Arsenic (As)-Dissolved	0.00079	0.00091	0.0008	0.0008	0.00083	0.00078
Barium (Ba)-Dissolved	0.0371	0.0381	0.0395	0.0368	0.0389	0.0371
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.054	0.037	0.134	0.029	0.025	0.024
Cadmium (Cd)-Dissolved	0.0249	0.0205	0.0294	0.0292	0.0333	0.0328
Calcium (Ca)-Dissolved	121	90.3	101	94.3	100	94.2
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.002	0.0015	0.00223	0.002	0.00223	0.00219
Copper (Cu)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Iron (Fe)-Dissolved	**<0.030**	**<0.030**	**<0.030**	**<0.030**	**<0.030**	**<0.030**
Lead (Pb)-Dissolved	0.123	0.0971	0.0956	0.107	0.104	0.0985
Lithium (Li)-Dissolved	0.0113	0.00832	0.0074	0.00656	0.00592	0.00589
Magnesium (Mg)-Dissolved	2.89	1.89	2.05	1.71	1.67	1.46
Manganese (Mn)-Dissolved	2.08	1.53	1.81	1.59	1.72	1.6
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00387	0.00361	0.00333	0.00314	0.00299	0.00319
Nickel (Ni)-Dissolved	0.00209	0.00154	0.00264	0.00217	0.00238	0.00209
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	2.23	1.57	1.58	1.3	1.29	1.17
Selenium (Se)-Dissolved	0.00042	0.00028	0.00031	0.00029	0.00028	0.00026
Silicon (Si)-Dissolved	**4.42**	**4.11**	**3.97**	**3.98**	**4.07**	**4.17**
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.853	0.562	0.746	0.46	0.477	0.426
Strontium (Sr)-Dissolved	0.245	0.179	0.185	0.166	0.168	0.187
Sulfur (S)-Dissolved	78.8	53.1	63.5	58.5	60.9	57.7
Thallium (Tl)-Dissolved	0.000218	0.000232	0.000105	0.000097	0.000099	0.000263
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.000261	0.000179	0.000243	0.000193	0.000212	0.000188
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	1.82	1.56	2.34	2.23	2.71	2.87

Leach Cycle	12	13	14	15	16	17

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-12	MILL TAILS COMPOSITE-JAN-JUN2011-13	MILL TAILS COMPOSITE-JAN-JUN2011-14	MILL TAILS COMPOSITE-JAN-JUN2011-15	MILL TAILS COMPOSITE-JAN-JUN2011-16	MILL TAILS COMPOSITE-JAN-JUN2011-17
Date Sampled	**09-NOV-11**	**16-NOV-11**	**23-NOV-11**	**30-NOV-11**	**07-DEC-11**	**14-DEC-11**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1082246-1**	**L1084760-1**	**L1087901-1**	**L1090459-1**	**L1092275-1**	**L1095037-1**
Matrix	**Water**	**Water**	**Water**	**Water**	**Water**	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	460	480	450	475	470	450
Physical Tests						
Conductivity	359	408	362	374	362	341
pH	7.85	7.91	7.87	7.95	7.90	7.8
Anions and Nutrients						
Acidity (as CaCO3)	**6.2**	**7.5**	**5.8**	**7.7**	**4.8**	5.7
Alkalinity, Total (as CaCO3)	71.3	71.7	72.3	72.4	72.7	71.2
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.138	0.125	0.124	0.113	0.111	0.174
Nitrate (as N)	0.0064	0.0062	0.0141	0.0061	<0.0050	0.0101
Nitrite (as N)	0.0046	0.0052	0.0056	0.0046	0.004	0.0069
Sulfate (SO4)	128	159	129	138	130	119
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	**0.0141**	**0.0146**	**0.0145**	**0.0142**	**0.013**	0.0129
Arsenic (As)-Dissolved	0.00075	0.00087	0.00076	0.00084	0.00083	0.00082
Barium (Ba)-Dissolved	0.0397	0.0441	0.0397	0.0417	0.0415	0.04
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.019	0.018	0.015	0.017	0.015	0.012
Cadmium (Cd)-Dissolved	0.0272	0.0329	0.0318	0.0342	0.0351	0.0343
Calcium (Ca)-Dissolved	79.2	94.6	79.7	80.6	80.6	79.5
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00164	0.00213	0.00183	0.00194	0.00188	0.00173
Copper (Cu)-Dissolved	<0.00050	0.0005	0.00062	0.00074	0.00078	0.00056
Iron (Fe)-Dissolved	**<0.030**	**<0.030**	**<0.030**	**<0.030**	**<0.030**	<0.030
Lead (Pb)-Dissolved	0.0893	0.0894	0.0927	0.0918	0.0886	0.0852
Lithium (Li)-Dissolved	0.00417	0.00426	0.00365	0.00339	0.00291	0.00
Magnesium (Mg)-Dissolved	1.09	1.28	1.04	1.09	1	0.904
Manganese (Mn)-Dissolved	1.18	1.5	1.22	1.47	1.27	1.15
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00295	0.00277	0.00268	0.00265	0.00259	0.00248
Nickel (Ni)-Dissolved	0.00158	0.002	0.00161	0.00175	0.00163	0.0014
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	0.846	0.923	0.807	0.794	0.727	0.642
Selenium (Se)-Dissolved	0.0002	0.00022	0.00017	0.0002	0.00019	0.00017
Silicon (Si)-Dissolved	**3.67**	**3.71**	**3.73**	**3.51**	**3.62**	3.36
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.35	0.352	0.295	0.305	0.289	0.26
Strontium (Sr)-Dissolved	0.129	0.148	0.147	0.144	0.134	0.119
Sulfur (S)-Dissolved	43.4	54.1	44.3	46.7	43.5	40.5
Thallium (Tl)-Dissolved	0.000076	0.000079	0.000243	0.000267	0.000222	0.000176
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	0.01	0.011	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.000127	0.000184	0.000124	0.000147	0.00	0.0
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	2.14	2.69	2.55	2.71	2.76	2.64

Leach Cycle	18	19	20	21	22	23
Sample ID	**MILL TAILS COMPOSITE-JAN-JUN2011-18**	**MILL TAILS COMPOSITE-JAN-JUN2011-19**	**MILL TAILS COMPOSITE-JAN-JUN2011-20**	**MILL TAILS COMPOSITE-JAN-JUN2011-21**	**MILL TAILS COMPOSITE-JAN-JUN2011-22**	**MILL TAILS COMPOSITE-JAN-JUN2011-23**
Date Sampled	**21-DEC-11**	**28-DEC-11**	**04-JAN-12**	**11-JAN-12**	**18-JAN-12**	**25-JAN-12**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1097547-1**	**L1099484-1**	**L1100871-1**	**L1102685-1**	**L1104828-1**	**L1106888-1**
Matrix	Water	**Water**	**Water**	**Water**	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	460	410	445	425	420	490
Physical Tests						
Conductivity	397	512	525	505	472	435
pH	7.9	7.95	7.88	7.84	7.8	7.9
Anions and Nutrients						
Acidity (as CaCO3)	7.8	**6.2**	**7.1**	**6.2**	6.2	8.8
Alkalinity, Total (as CaCO3)	64.9	58.2	48.7	62.8	66.3	66.1
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.097	0.106	0.111	0.108	0.098	0.101
Nitrate (as N)	0.0137	<0.0050	0.0061	0.01	0.0096	0.0076
Nitrite (as N)	0.0054	0.0049	0.0026	0.0056	0.0045	0.0025
Sulfate (SO4)	129	194	206	193	175	148
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Antimony (Sb)-Dissolved	0.013	**0.0124**	**0.0107**	**0.0099**	0.00986	0.0103
Arsenic (As)-Dissolved	0.00089	0.00092	0.00076	0.00084	0.00098	0.00145
Barium (Ba)-Dissolved	0.04	0.0465	0.045	0.0431	0.04	0.05
Beryllium (Be)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Bismuth (Bi)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Boron (B)-Dissolved	0.014	0.013	0.011	0.01	0.011	<0.010
Cadmium (Cd)-Dissolved	0.0372	0.0391	0.0465	0.0485	0.0479	0.0528
Calcium (Ca)-Dissolved	76.7	102	103	104	97.4	85.3
Chromium (Cr)-Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Cobalt (Co)-Dissolved	0.00175	0.00184	0.00188	0.00201	0.00209	0.00241
Copper (Cu)-Dissolved	0.00073	<0.00050	<0.00050	0.00059	0.00099	0.00101
Iron (Fe)-Dissolved	<0.030	**<0.030**	**<0.030**	**<0.030**	<0.030	<0.030
Lead (Pb)-Dissolved	0.083	0.0794	0.0943	0.0898	0.0966	0.0898
Lithium (Li)-Dissolved	0.00	0.00297	0.00282	0.00284	0.00	0.00
Magnesium (Mg)-Dissolved	0.974	1.28	1.39	1.45	1.28	1.28
Manganese (Mn)-Dissolved	1.15	1.13	1.2	1.23	1.3	1.36
Mercury (Hg)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Dissolved	0.00226	0.00268	0.00266	0.00231	0.00233	0.00219
Nickel (Ni)-Dissolved	0.00148	0.00157	0.00125	0.00143	0.00141	0.0018
Phosphorus (P)-Dissolved	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Dissolved	0.652	0.715	0.702	0.618	0.583	0.627
Selenium (Se)-Dissolved	0.00018	0.00022	0.0002	0.00017	0.00017	0.00016
Silicon (Si)-Dissolved	3.21	**3.01**	**2.95**	**2.98**	2.94	3.25
Silver (Ag)-Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Sodium (Na)-Dissolved	0.29	0.338	0.322	0.315	0.28	0.31
Strontium (Sr)-Dissolved	0.111	0.147	0.174	0.146	0.143	0.12
Sulfur (S)-Dissolved	44.4	65.8	70.6	65.8	59.3	50.5
Thallium (Tl)-Dissolved	0.000074	0.000078	0.000238	0.000091	0.000287	0.000098
Tin (Sn)-Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Dissolved	<0.010	<0.010	0.011	<0.010	<0.010	<0.010
Uranium (U)-Dissolved	0.0	0.0002	0.000178	0.00	0.0	0.0
Vanadium (V)-Dissolved	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zinc (Zn)-Dissolved	2.72	2.18	2.69	2.98	2.91	3.47

Leach Cycle	24	25	26	27	28	29
Sample ID	**MILL TAILS COMPOSITE-JAN-JUN2011-24**	**MILL TAILS COMPOSITE-JAN-JUN2011-29**	**MILL TAILS COMPOSITE-JAN-JUN2011-30**	**MILL TAILS COMPOSITE-JAN-JUN2011-31**	**MILL TAILS COMPOSITE-JAN-JUN2011-32**	**MILL TAILS COMPOSITE-JAN-JUN2011-33**
Date Sampled	**01-FEB-12**	**07-MAR-12**	**14-MAR-12**	**21-MAR-12**	**28-MAR-12**	**04-APR-12**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1109203-1**	**L1121471-1**	**L1123018-1**	**L1125306-1**	**L1127559-1**	**L1130834-1**
Matrix	**Water**	**Water**	**Water**	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	425	460	475	500	470	425
Physical Tests						
Conductivity	409	382	344	351	369	383
pH	7.97	7.91	7.85	7.9	7.9	7.93
Anions and Nutrients						
Acidity (as CaCO3)	**4.1**	**5.4**	**7.4**	8.3	9	11.5
Alkalinity, Total (as CaCO3)	58.2	65.5	64.8	59.8	54.9	57.1
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.092	0.08	0.08	0.073	0.071	0.071
Nitrate (as N)	0.0104	0.0063	0.0074	0.0085	0.0095	0.0056
Nitrite (as N)	0.0052	0.0015	0.0019	0.0014	0.0017	0.0019
Sulfate (SO4)	141	124	109	112	122	131
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	**0.00943**		**0.00812**		0.00817	
Arsenic (As)-Dissolved	0.0011		0.00155		0.00129	
Barium (Ba)-Dissolved	0.0407		0.0393		0.04	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0433		0.0491		0.0486	0.0498
Calcium (Ca)-Dissolved	83.5		62.1		67	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.00195		0.00256		0.00268	
Copper (Cu)-Dissolved	0.00082		0.00192		0.0024	
Iron (Fe)-Dissolved	**<0.030**		**<0.030**		<0.030	
Lead (Pb)-Dissolved	0.0809		0.0779		0.0847	
Lithium (Li)-Dissolved	0.00238		0.00172		0.00	
Magnesium (Mg)-Dissolved	1.07		0.862		0.987	
Manganese (Mn)-Dissolved	1.04		1.09		0.958	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00223		0.00178		0.00175	
Nickel (Ni)-Dissolved	0.00145		0.00188		0.00189	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.497		0.385		0.374	
Selenium (Se)-Dissolved	0.00017		0.00014		0.00015	
Silicon (Si)-Dissolved	**2.87**		**2.72**		2.43	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.241		0.209		0.20	
Strontium (Sr)-Dissolved	0.119		0.104		0.112	
Sulfur (S)-Dissolved	50.7		36.7		39.4	
Thallium (Tl)-Dissolved	0.000058		0.000038		0.000059	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.000099		0.00		0.0	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	2.76	4.25	3.72	3.14	3.11	3.35

Leach Cycle	30	31	32	33	34	35

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-34	MILL TAILS COMPOSITE-JAN-JUN2011-35	MILL TAILS COMPOSITE-JAN-JUN2011-36	MILL TAILS COMPOSITE-JAN-JUN2011-37	MILL TAILS COMPOSITE-JAN-JUN2011-38	MILL TAILS COMPOSITE-JAN-JUN2011-39
Date Sampled	**11-APR-12**	**18-APR-12**	**25-APR-12**	**02-MAY-12**	**09-MAY-12**	**16-MAY-12**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1133140-1**	**L1135454-1**	**L1138358-1**	**L1141290-1**	**L1143994-1**	**L1147310-1**
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	480	455	475	475	500	455
Physical Tests						
Conductivity	322	341	332	309	294	330
pH	7.79	7.92	7.9	7.9	7.85	7.88
Anions and Nutrients						
Acidity (as CaCO3)	6.9	10.3	15	12.8	8	6.2
Alkalinity, Total (as CaCO3)	49	61.2	58.8	49.2	55.3	49.3
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.059	0.068	0.067	0.059	0.05	0.058
Nitrate (as N)	0.0057	<0.0050	0.0069	<0.0050	0.0194	0.0061
Nitrite (as N)	0.0018	0.001	0.0014	0.0012	<0.0010	<0.0010
Sulfate (SO4)	102	112	106	94.3	88.7	108
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	0.00804		0.00749		0.00858	
Arsenic (As)-Dissolved	0.00168		0.00145		0.00154	
Barium (Ba)-Dissolved	0.0388		0.04		0.0408	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0538	0.0604	0.0485	0.0564	0.0525	0.0505
Calcium (Ca)-Dissolved	58.2		67.9		55.3	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.00277		0.00299		0.00307	
Copper (Cu)-Dissolved	0.00225		0.00315		0.00261	
Iron (Fe)-Dissolved	<0.030		<0.030		<0.030	
Lead (Pb)-Dissolved	0.0834		0.085		0.0926	
Lithium (Li)-Dissolved	0.00099		0.00		0.00148	
Magnesium (Mg)-Dissolved	0.939		1.12		1.02	
Manganese (Mn)-Dissolved	1.03		0.978		1.01	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00158		0.00165		0.00162	
Nickel (Ni)-Dissolved	0.00204		0.00221		0.00234	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.331		0.349		0.317	
Selenium (Se)-Dissolved	0.00012		0.00014		0.00013	
Silicon (Si)-Dissolved	2.41		2.58		2.45	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.184		0.20		0.172	
Strontium (Sr)-Dissolved	0.101		0.103		0.103	
Sulfur (S)-Dissolved	34.7		36.7		29.6	
Thallium (Tl)-Dissolved	0.000039		0.000042		0.000041	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.000042		0.0		0.000037	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	3.48	4.28	3.01	3.87	3.29	2.6

Leach Cycle	36	37	38	39	40	41

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-40	MILL TAILS COMPOSITE-JAN-JUN2011-41	MILL TAILS COMPOSITE-JAN-JUN2011-42	MILL TAILS COMPOSITE-JAN-JUN2011-43	MILL TAILS COMPOSITE-JAN-JUN2011-44	MILL TAILS COMPOSITE-JAN-JUN2011-45
Date Sampled	**23-MAY-12**	**30-MAY-12**	**06-JUN-12**	**13-JUN-12**	**20-JUN-12**	**27-JUN-12**
Time Sampled	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**	**00:00**
ALS Sample ID	**L1150106-1**	**L1153466-1**	**L1156963-1**	**L1160875-1**	**L1164482-1**	**L1167961-1**
Matrix	Water	Water	Water	Water	Water	Water
Sample Preparation						
Total Volume In	500	500	500	500	500	500
Total Volume Out	485	495	490	475	475	475
Physical Tests						
Conductivity	299	299	292	281	277	274
pH	7.80	7.9	7.8	7.91	7.9	7.93
Anions and Nutrients						
Acidity (as CaCO3)	8.8	14.9	14.3	8.7	7.7	12.9
Alkalinity, Total (as CaCO3)	57.9	55.5	62.8	58.8	48.5	47.4
Bromide (Br)	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Fluoride (F)	0.052	0.05	0.048	0.044	0.041	0.037
Nitrate (as N)	0.0054	0.0067	<0.0050	<0.0050	<0.0050	<0.0050
Nitrite (as N)	<0.0010	<0.0010	0.0019	0.0018	<0.0010	0.0013
Sulfate (SO4)	92.9	90.9	87.4	81.8	82.7	82.3
Dissolved Metals						
Aluminum (Al)-Dissolved	<0.0050		<0.0050		<0.0050	
Antimony (Sb)-Dissolved	0.0077		0.008		0.00729	
Arsenic (As)-Dissolved	0.0016		0.00168		0.00137	
Barium (Ba)-Dissolved	0.0446		0.05		0.0468	
Beryllium (Be)-Dissolved	<0.00010		<0.00010		<0.00010	
Bismuth (Bi)-Dissolved	<0.00050		<0.00050		<0.00050	
Boron (B)-Dissolved	<0.010		<0.010		<0.010	
Cadmium (Cd)-Dissolved	0.0596	0.0614	0.0611	0.0614	0.0481	0.0493
Calcium (Ca)-Dissolved	53.9		56.6		52.8	
Chromium (Cr)-Dissolved	<0.00050		<0.00050		<0.00050	
Cobalt (Co)-Dissolved	0.0035		0.00402		0.0036	
Copper (Cu)-Dissolved	0.00241		0.00315		0.00261	
Iron (Fe)-Dissolved	<0.030		<0.030		<0.030	
Lead (Pb)-Dissolved	0.0831		0.0867		0.0875	
Lithium (Li)-Dissolved	0.00207		0.00		0.00165	
Magnesium (Mg)-Dissolved	1.32		1.43		1.46	
Manganese (Mn)-Dissolved	1.14		1.2		1.06	
Mercury (Hg)-Dissolved	<0.000010		<0.000010		<0.000010	
Molybdenum (Mo)-Dissolved	0.00139		0.00133		0.00138	
Nickel (Ni)-Dissolved	0.00278		0.00313		0.00282	
Phosphorus (P)-Dissolved	<0.30		<0.30		<0.30	
Potassium (K)-Dissolved	0.329		0.318		0.311	
Selenium (Se)-Dissolved	0.00015		0.00015		0.00015	
Silicon (Si)-Dissolved	2.57		2.62		2.48	
Silver (Ag)-Dissolved	<0.000010		<0.000010		<0.000010	
Sodium (Na)-Dissolved	0.183		0.18		0.159	
Strontium (Sr)-Dissolved	0.0966		0.0928		0.0919	
Sulfur (S)-Dissolved	31.1		29.3		27.4	
Thallium (Tl)-Dissolved	0.000039		0.000042		0.000037	
Tin (Sn)-Dissolved	<0.00010		<0.00010		<0.00010	
Titanium (Ti)-Dissolved	<0.010		<0.010		<0.010	
Uranium (U)-Dissolved	0.00		0.0		0.00003	
Vanadium (V)-Dissolved	<0.0010		<0.0010		<0.0010	
Zinc (Zn)-Dissolved	3.86	3.65	3.61	4.07	2.63	2.89

Leach Cycle	42	43

Sample ID	MILL TAILS COMPOSITE-JAN-JUN2011-46	MILL TAILS COMPOSITE-JAN-JUN2011-47
Date Sampled	**04-JUL-12**	**11-JUL-12**
Time Sampled	**00:00**	**00:00**
ALS Sample ID	**L1171477-1**	**L1174745-1**
Matrix	Water	Water
Sample Preparation		
Total Volume In	500	500
Total Volume Out	470	475
Physical Tests		
Conductivity	271	270
pH	7.9	7.9
Anions and Nutrients		
Acidity (as CaCO3)	5.3	6.8
Alkalinity, Total (as CaCO3)	49.1	56.2
Bromide (Br)	<0.050	<0.050
Chloride (Cl)	<0.50	<0.50
Fluoride (F)	0.038	0.04
Nitrate (as N)	<0.0050	0.015
Nitrite (as N)	0.0019	0.0012
Sulfate (SO4)	79.9	78
Dissolved Metals		
Aluminum (Al)-Dissolved	<0.0050	FIELD
Antimony (Sb)-Dissolved	0.00719	
Arsenic (As)-Dissolved	0.00141	
Barium (Ba)-Dissolved	0.05	
Beryllium (Be)-Dissolved	<0.00010	
Bismuth (Bi)-Dissolved	<0.00050	
Boron (B)-Dissolved	<0.010	
Cadmium (Cd)-Dissolved	0.0513	0.0596
Calcium (Ca)-Dissolved	51.2	
Chromium (Cr)-Dissolved	<0.00050	
Cobalt (Co)-Dissolved	0.00407	
Copper (Cu)-Dissolved	0.00311	
Iron (Fe)-Dissolved	<0.030	
Lead (Pb)-Dissolved	0.0901	
Lithium (Li)-Dissolved	0.00	
Magnesium (Mg)-Dissolved	1.54	
Manganese (Mn)-Dissolved	1.2	
Mercury (Hg)-Dissolved	<0.000010	
Molybdenum (Mo)-Dissolved	0.00131	
Nickel (Ni)-Dissolved	0.00332	
Phosphorus (P)-Dissolved	<0.30	
Potassium (K)-Dissolved	0.311	
Selenium (Se)-Dissolved	0.00013	
Silicon (Si)-Dissolved	2.49	
Silver (Ag)-Dissolved	<0.000010	
Sodium (Na)-Dissolved	0.16	
Strontium (Sr)-Dissolved	0.0854	
Sulfur (S)-Dissolved	27	
Thallium (Tl)-Dissolved	0.00004	
Tin (Sn)-Dissolved	<0.00010	
Titanium (Ti)-Dissolved	<0.010	
Uranium (U)-Dissolved	0.0	
Vanadium (V)-Dissolved	<0.0010	
Zinc (Zn)-Dissolved	2.96	3.96

Appendix 6 Waste Storage Facility Design, EBA 2014

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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61 Wasson Place
Whitehorse, YT Y1A 0H7 CANADA
Tel 867.668.3068 Fax 867.668.4349

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.

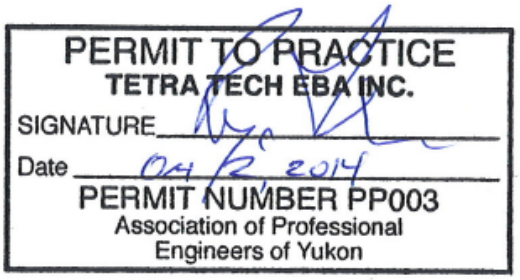
5.0 CLOSURE

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.



Justin Pigage, P.Eng.
Geotechnical Engineer, Arctic Region
Direct Line: 867.668.9213
Justin.Pigage@tetratech.com



REVISION I SUMMARY:

Added recommendations for alternate facility location (Location II).

REFERENCES

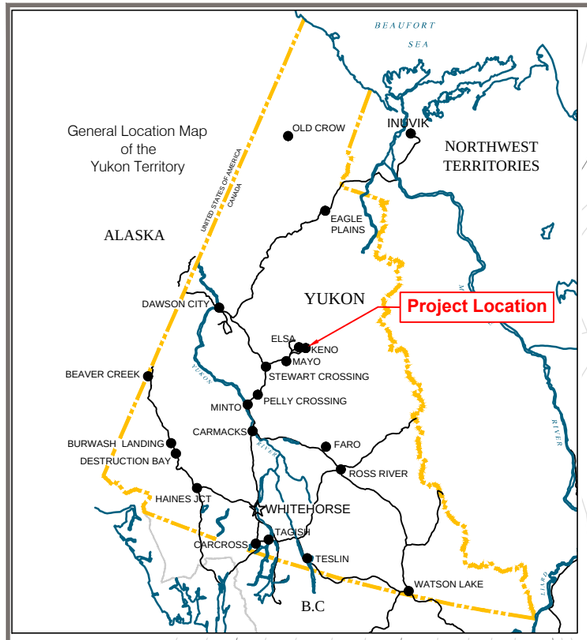
EBA, A Tetra Tech Company “Dry Stacked Tailings Facility – Risk Assessment Stability Model Update, Keno Hill District Mill Site, Yukon” February 2013.

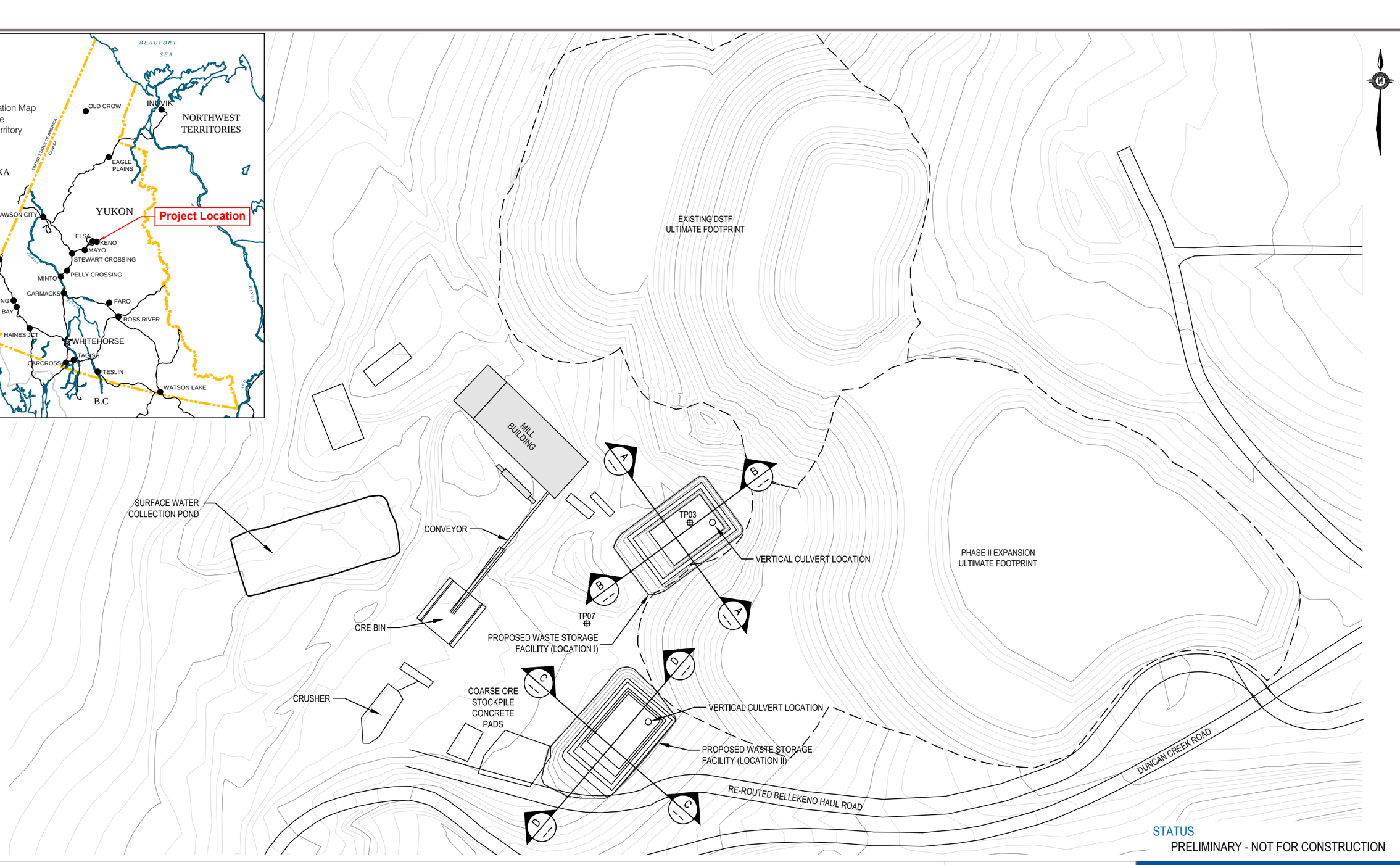
EBA Engineering Consultants Ltd. “Typical Waste Containment Facility Design, Keno Hill Silver District, YT – Construction Specifications” July 2008.

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

Figure 1 Site Plan
Figure 2 Location I Cross-Sections
Figure 3 Location II Cross Sections
Figure 3 Details and Notes





STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

LEGEND

⌗ - TESTPIT LOCATION (2009)

0 100 m

Scale: 1 : 1750 @ 11"x17"

CLIENT

ALEXCO

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

SITE PLAN

TETRA TECH EBA

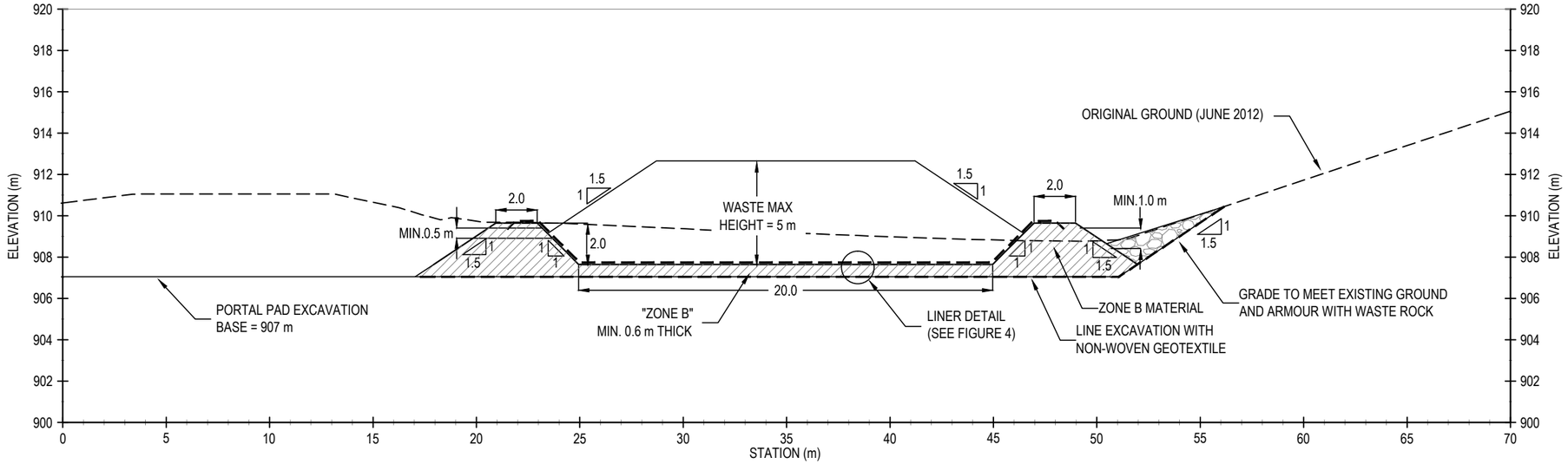
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0

OFFICE: EBA-WHSE

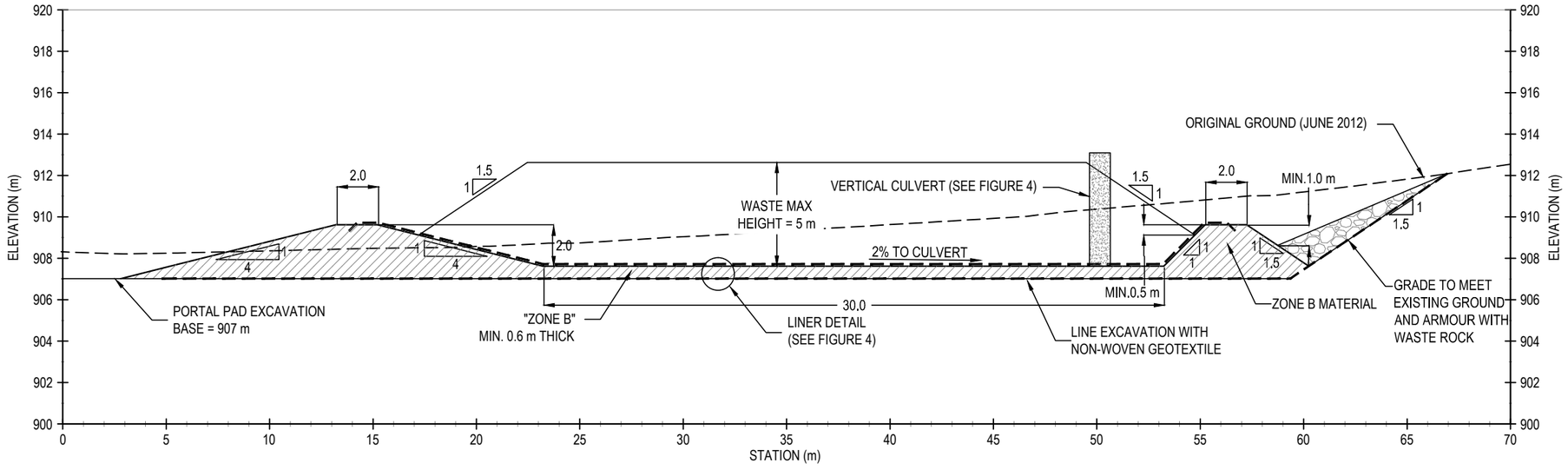
DATE: September 25, 2014

Figure 1

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame & Moth P-AML Design\W14103485-01 Figs 1-3_R0.dwg [FIGURE 1] October 01, 2014 - 2:19:36 pm (BY: BUCHAN, CAMERON)



SECTION A - A'



SECTION B - B'

STATUS
PRELIMINARY - NOT FOR CONSTRUCTION

0 10 m
Scale: 1:250 @ 11"x17"

CLIENT
ALEXCO

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

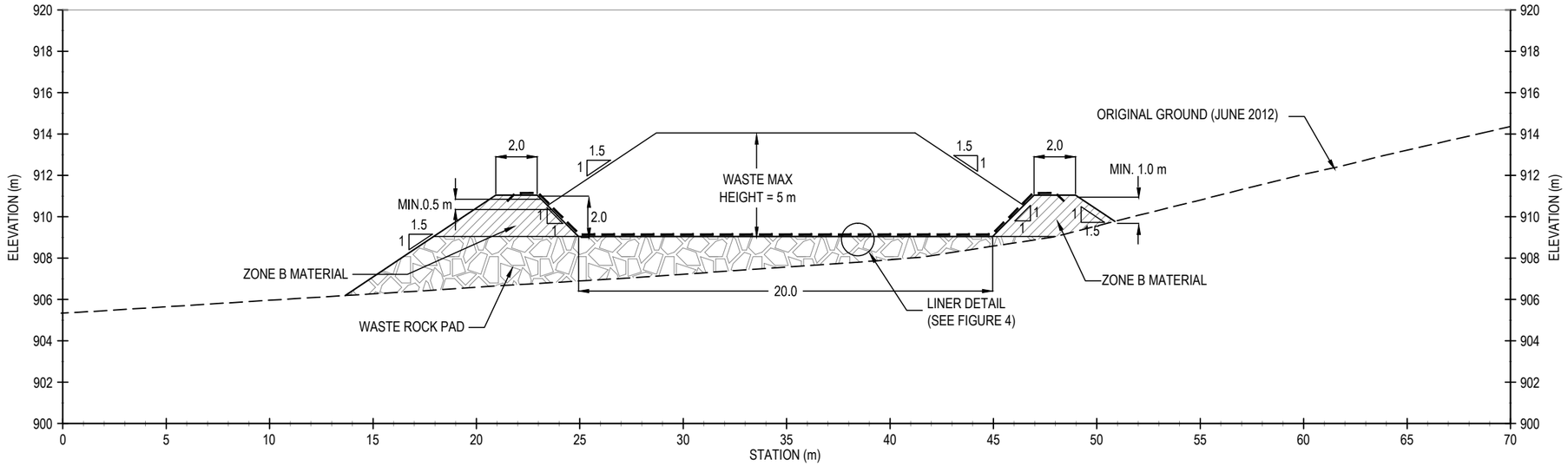
LOCATION I CROSS-SECTIONS

TETRA TECH EBA

PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE: EBA-WHSE	DATE: September 25, 2014		

Figure 2

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame & Moth P-AML Design\W14103485-01 Figs 1-3 R0.dwg [FIGURE 2] October 01, 2014 - 2:20:40 pm BY: BUCHAN, CAMERON



SECTION C - C'

SECTION D - D'

STATUS
PRELIMINARY - NOT FOR CONSTRUCTION

0 10 m
Scale: 1:250 @ 11"x17"

CLIENT
ALEXCO

TETRA TECH EBA

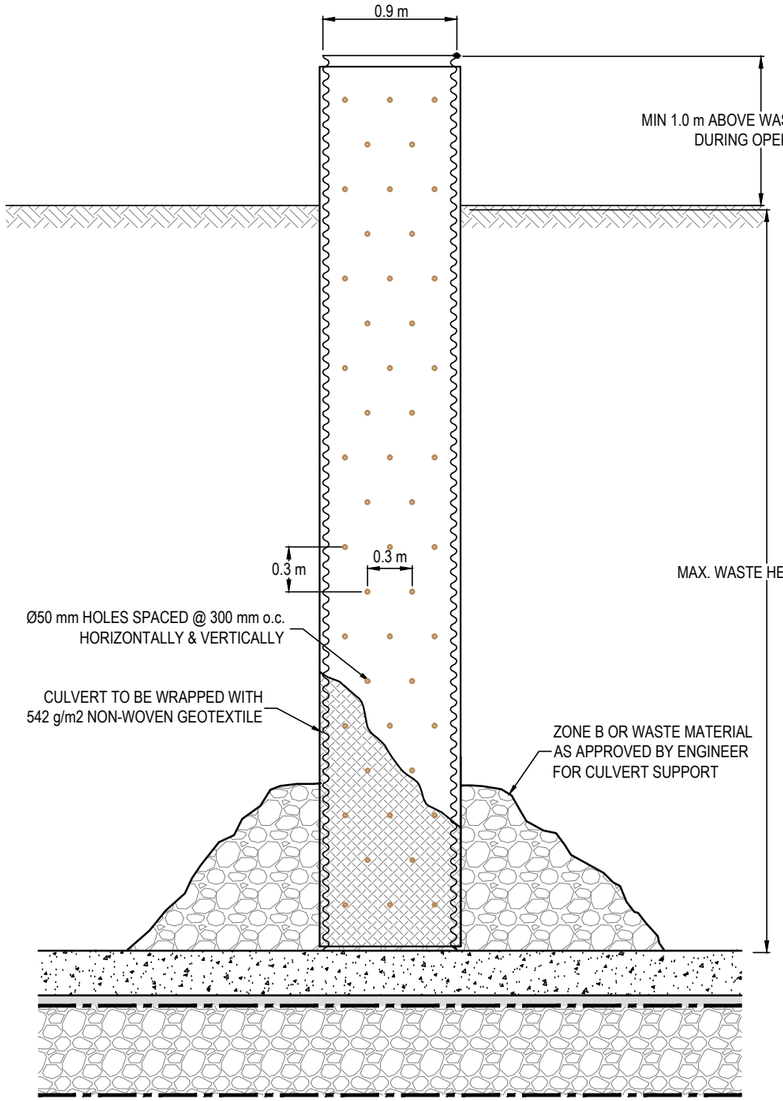
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

LOCATION II CROSS-SECTIONS

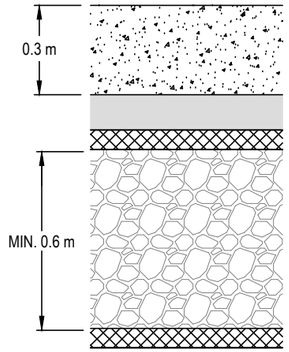
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE: EBA-WHSE	DATE: September 25, 2014		

Figure 3

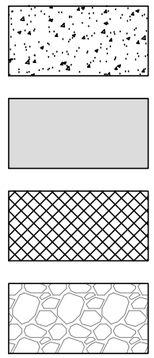
Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame & Moth P-AML Design\W14103485-01 Figs 1-3 R0.dwg [FIGURE 3] October 01, 2014 - 2:21:44 pm (BY: BUCHAN, CAMERON)



DETAIL 1 - VERTICAL SUMP CULVERT



DETAIL 2 - FACILITY FLOOR AND BERMS



LINER SYSTEM DETAIL KEY

NOTES :

These specifications, relevant to construction of the Flame & Moth Waste Storage Facility, have been extracted from the Typical Waste Containment Facility Design Construction Specifications, Keno Hill Silver District, YT (EBA July 2008).

The Flame & Moth Waste Storage Facility shall be constructed to the specifications below and the dimensions indicated on the Construction Drawings.

Water in the facility will flow towards and pond in the vertical culvert where it will be monitored and tested on a regular basis. Based on water quality analysis, the waste water will be extracted via pump truck and discharged to the environment or treated in a designated treatment facility.

The facility has been sized based on containment of approximately 4,500 m3 of waste, when the ultimate capacity is reached a 0.5 m soil cover will be placed over the entire facility.

The Zone A material shall consist of hard, durable particles, shall be free of roots, topsoil, and deleterious material and shall have a particle size distribution, as measured by ASTM C136, as presented in Table 1, or as approved by the Engineer.

The Zone B material shall consist of hard, durable particles, shall be free of roots, topsoil, and deleterious material and shall have a particle size distribution, as measured by ASTM C136, as presented in Table 1, or as approved by the Engineer.

The fill materials shall be placed in lifts not exceeding 0.5 m in uncompacted thickness and compacted to at least 95% of maximum dry density using standard effort as per ASTM D698.

The non-woven geotextile shall be 542 g/m2 Layfield LP16 or equivalent approved by the Engineer.

The HDPE geomembrane shall be 1.6 mm (60 mil) thick Layfield HDPE 60 or equivalent approved by the Engineer.

The HDPE geomembrane seems shall be welded by a suitably qualified contractor. Trial seems shall be conducted prior to start-up each day and at approximately 4-hour intervals during seaming operations. During the trial seam, the minimum strength criteria set by the manufacturer for the geomembrane should be met.

No construction equipment shall be allowed to travel on the liner prior to the placement of the protective Zone A cover material.

Table 1: Particle Size Distribution Limits

Zone B Material		Zone A Material	
Particle Size (mm)	% Passing by Mass	Particle Size (mm)	% Passing by Mass
200	100		
100	85 – 100		
50	65 – 100		
25	40 – 100	10	100
5	20 – 55	5	80 – 100
2	0 – 20	2	55 – 100
		0.63	25 – 65
		0.25	10 – 40
		0.08	2 – 15

STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

NOTE

- THIS PLAN IS NOT TO SCALE

CLIENT

ALEXCO

TETRA TECH EBA

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

DETAILS AND NOTES

PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0

OFFICE: EBA-WHSE

DATE: September 26, 2014

Figure 4

Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame & Moth P-AML Design\W14103485-01 Fig 3_R0.dwg [FIGURE 3] September 30, 2014 - 3:02:12 pm (BY: BUCHAN, CAMERON)

APPENDIX A

TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA’s Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA’s Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA’s instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA’s instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B
HISTORIC TESTPIT LOGS

Flame and Moth Mill & DSTF	CLIENT: Alexco	PROJECT NO. - TESTPIT NO.
Mill Pad	EXCAVATOR: Hitachi 270 LC	W14101178.002-TP03
near Keno City, YT	7086760N; 484004E; Zone 8	ELEVATION: 907.4m

SAMPLE TYPE: DISTURBED | NO RECOVERY | SPT | A-CASING | SHELBY TUBE | CORE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

Depth (m)	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NUMBER	TEMP (°C)	STANDARD PENETRATION (N) 20 40 60 80 / POCKET PEN. (kPa) 100 200 300 400 / PLASTIC M.C. LIQUID 20 40 60 80	GROUND ICE DESCRIPTION	Elevation (m)
0	PEAT - amorphous granular, roots, organics, black and brown, frozen					Frozen	907.0
1			SA01		354		906.0
			SA02		1158		
2							905.0
3	SILT - some sand, trace clay, soft (est.), low-plastic, massive, frozen, olive grey		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		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		SA01				
	SAND - gravelly, trace cobbles, trace silt,, compact (est.), medium grained, well graded, damp to moist, brown, sub-rounded						906.0
1			SA02				
						Unfrozen	905.0
	- seepage						
2						Frozen Nbn	
	SILT - sandy, some gravel, trace clay, stiff (est.), low plastic, massive, olive grey						904.0
3			SA03	-0.1	H	Vx, Vc (<5%)	
							903.0
						Unfrozen	
4							
			SA04	1.5	▲		902.0
5							
	EOH - refusal at probable bedrock (quarzite)						901.0
6							