APPENDIX 1

RECLAMATION RESEARCH SUMMARY REPORTS

APPENDIX 1.1

2012 DSTF INTERIM RECLAMATION AND COVER SUMMARY REPORT

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Memorandum

To: Alexco Keno Hill Mining Corp.

From: Access Consulting Group

CC:

Date: March 20, 2013

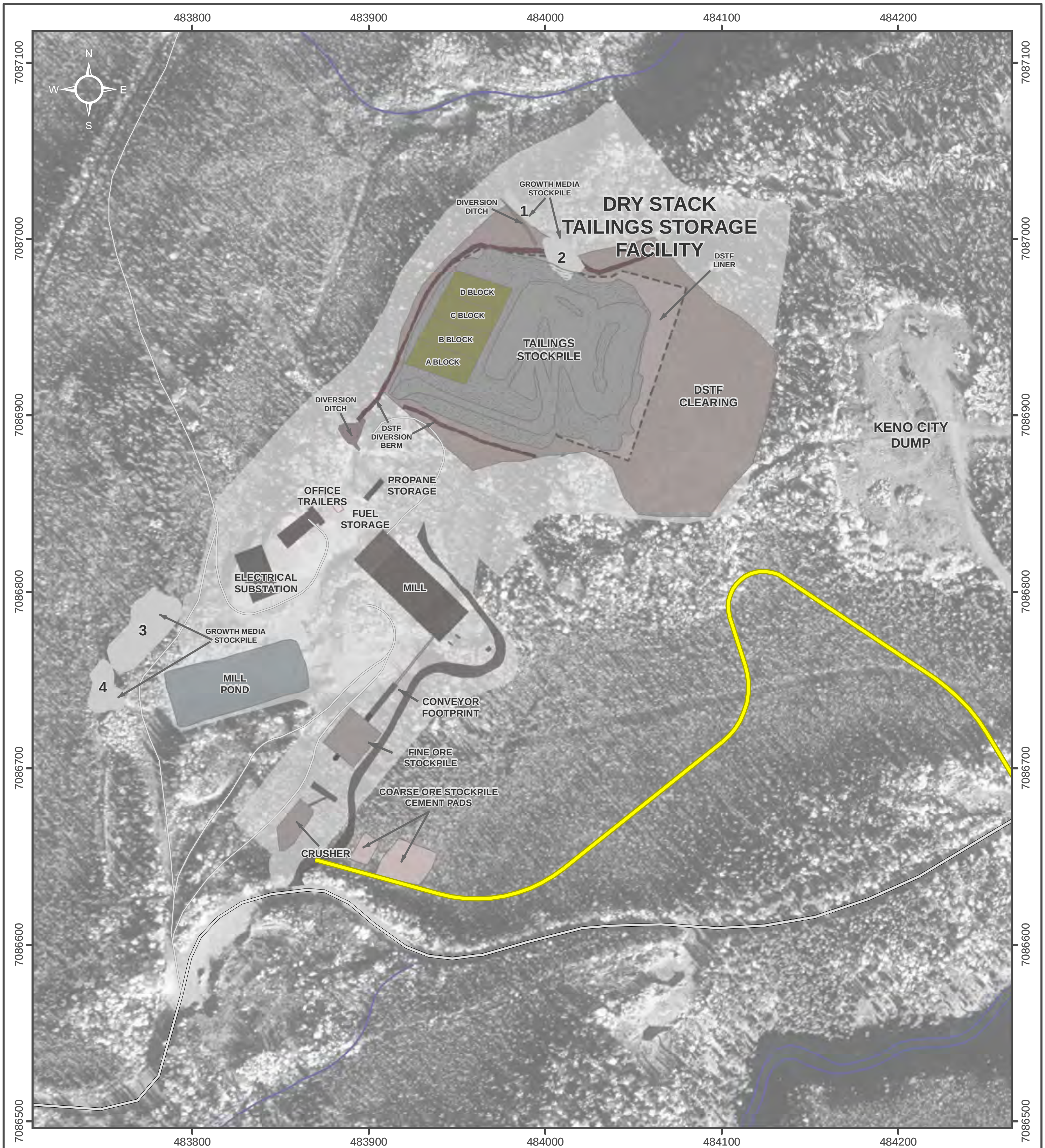
Re: 2012 Dry Stack Tailings Facility Cover Trial

Alexco Resource Corp. (Alexco) through its wholly owned subsidiary Alexco Keno Hill Mining Corp. owns and operates the Bellekeno Mine located in the Keno Hill Silver District. The Bellekeno Mine is licenced under Quartz Mining License QML-0009 and Water Use Licence QZ09-092.

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

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

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



DSTF Cover Trial

Duncan Creek Road

Mill Access

Haul Road

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

0 50 100 150 Meters

ALEXCO KENO HILL MINING CORP.

FIGURE 1
DSTF VEGETATION COVER TRIAL 2012

AKHM ACCESS

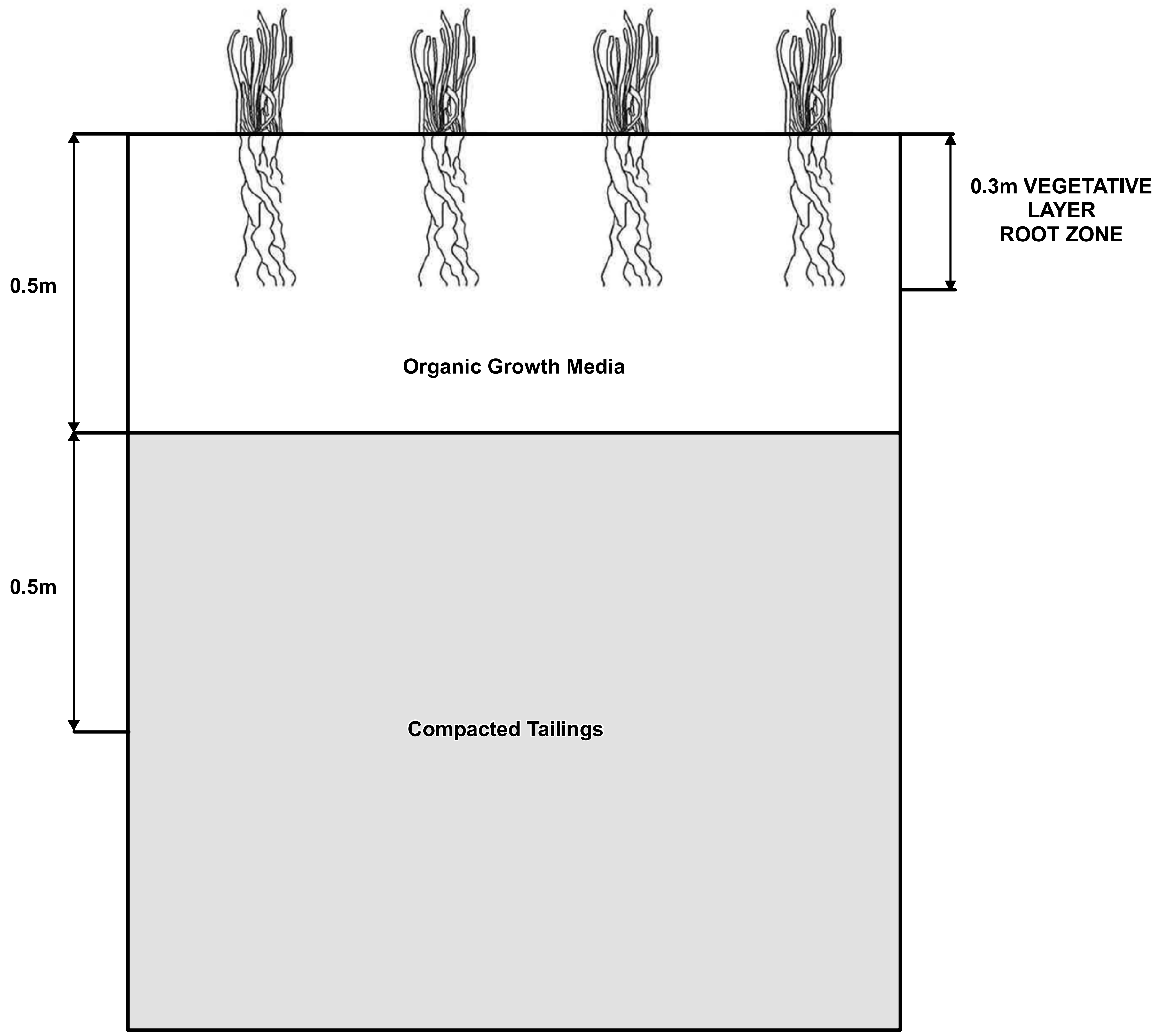
MARCH 2013

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

Datum: NAD 83; Projection: UTM Zone 8N

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

CONCEPTUAL SOIL COVER DESIGN



Conceptual drawing only. Drawing is not to scale.

AKHM

ACCESS

ALEXCO KENO HILL MINING CORP.
RECLAMATION AND CLOSURE PLAN

FIGURE 2

CONCEPTUAL SOIL COVER DESIGN

DRAWN BY JP	NOVEMBER 2011	VERIFIED BY BT

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

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

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

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

Table 1 Stockpiled Growth Media for Use as DSTF Cover

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

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

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

Table 2 Area by Section of DSTF Cover

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

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

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

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

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

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

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

REFERENCES

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

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

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

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

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

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

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

APPENDIX A

SOIL ANALYSIS

Maxxam

Success Through Science®

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

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

Report Date: 2012/05/28

CERTIFICATE OF ANALYSIS

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

Sample Matrix: Soil
Samples Received: 4

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

* Results relate only to the items tested.

(1) This test was performed by Maxxam Calgary Environmental

Encryption Key

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

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

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

Total cover pages: 1

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

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

Sampler Initials: LK

NPK (AVAILABLE)

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

RESULTS OF CHEMICAL ANALYSES OF SOIL

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

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

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

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

Sampler Initials: LK

MISCELLANEOUS (SOIL)

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

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

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

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

Sampler Initials: LK

CSR/CCME METALS IN SOIL (SOIL)

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

RDL = Reportable Detection Limit

Package 1	1.7°C

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

General Comments

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NPK (AVAILABLE) Comments

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

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

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

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

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

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

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

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

Sampler Initials: LK

QUALITY ASSURANCE REPORT

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

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

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

Sampler Initials: LK

QUALITY ASSURANCE REPORT

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

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

Maxxam Analytics Inc

8577 Commerce Court
Burnaby, BC V5A 4N5
www.maxxamanalytics.com

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

08351389

CHAIN-OF CUSTODY RECORD AND ANALYSIS REQUEST

PAGE 1 OF 1

LAB USE ONLY MAXXAM JOB #: B241340

ANALYSIS REQUEST

LAB USE ONLY COC #:

COMPANY NAME: Access Consulting Group

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

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

TEL.: 867-668-6463

E-MAIL:

FAX: 867-667-6680

SAMPLER NAME (PRINT): Lisa Knight

PROJECT MANAGER: Scott Davidson

LABORATORY CONTACT: Lanoy Luangkhamdeng

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

B241340

TAT (Turnaround Time)

LESS THAN 5 DAY TAT MUST HAVE PRIOR APPROVAL

* Some exceptions apply - please contact laboratory

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

OTHER BUSINESS DAYS ____

PO NUMBER OR QUOTE NUMBER:

SPECIAL DETECTION LIMITS / CONTAMINANT TYPE:

CCME / CSR / AB TIER 1 / OTHER

LAB USE ONLY

ARRIVAL TEMPERATURE °C: 1,2,2

DUE DATE:

LOG IN CHECK:

ACCOUNTING CONTACT:

SPECIAL REPORTING OR BILLING INSTRUCTIONS:

JARS USED:

RELINQUISHED BY SAMPLER: | DATE: DD/MM/YY | TIME: | RECEIVED BY:

RELINQUISHED BY: | DATE: DD/MM/YY 18/05/12 | TIME: 08:30 | RECEIVED BY: Nicole Lockyer

RELINQUISHED BY: Lisa Knight | DATE: DD/MM/YY | TIME: | RECEIVED BY LABORATORY:

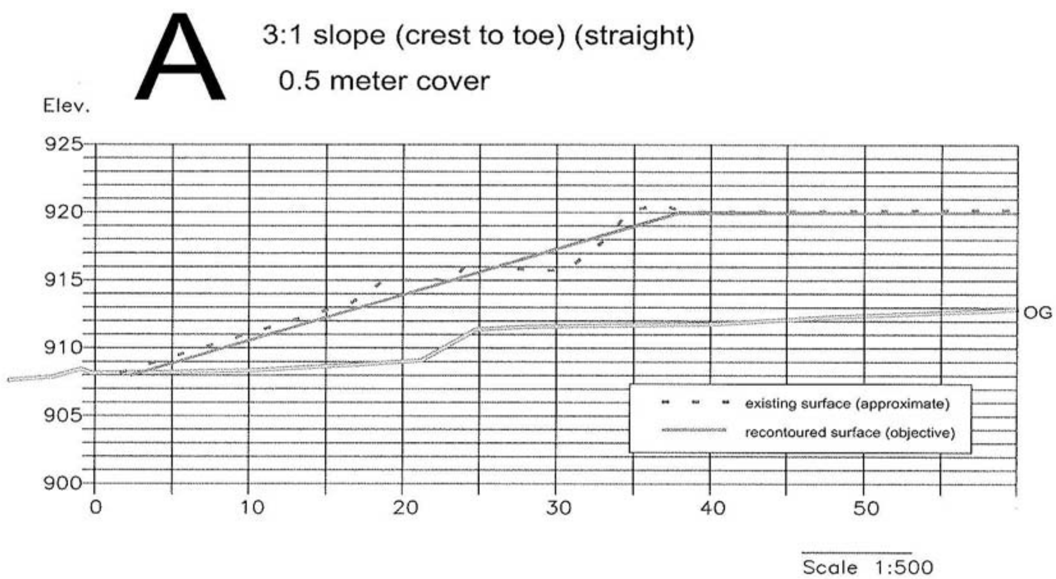
CUSTODY RECORD

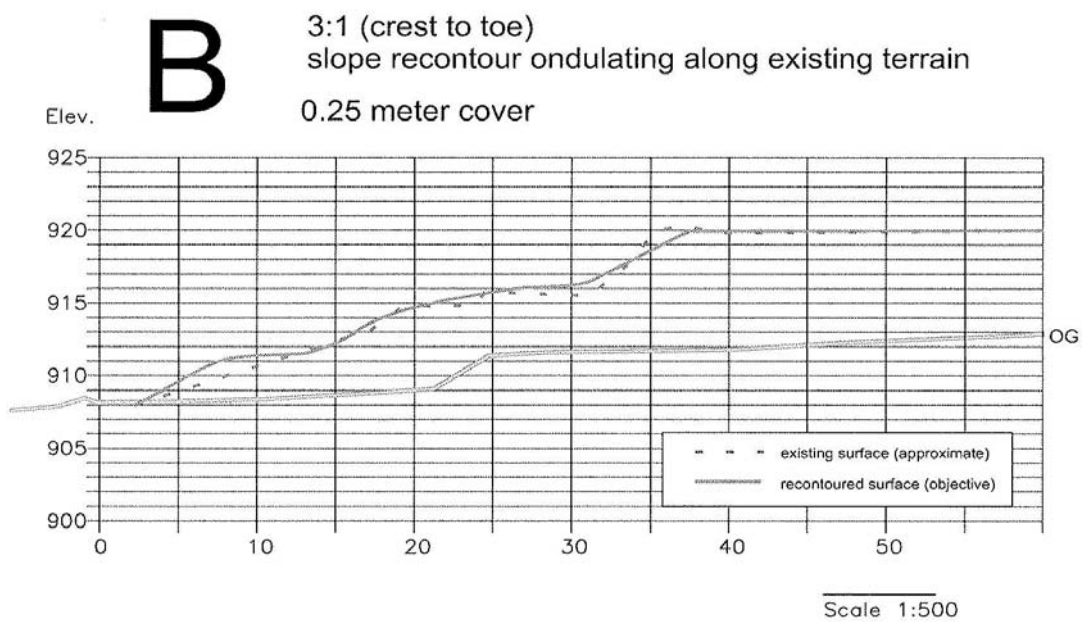
COCFORM - BC - 20070822

APPENDIX B

BLOCK PROFILES

DSTF Phase I Reclamation - Slope Profiles



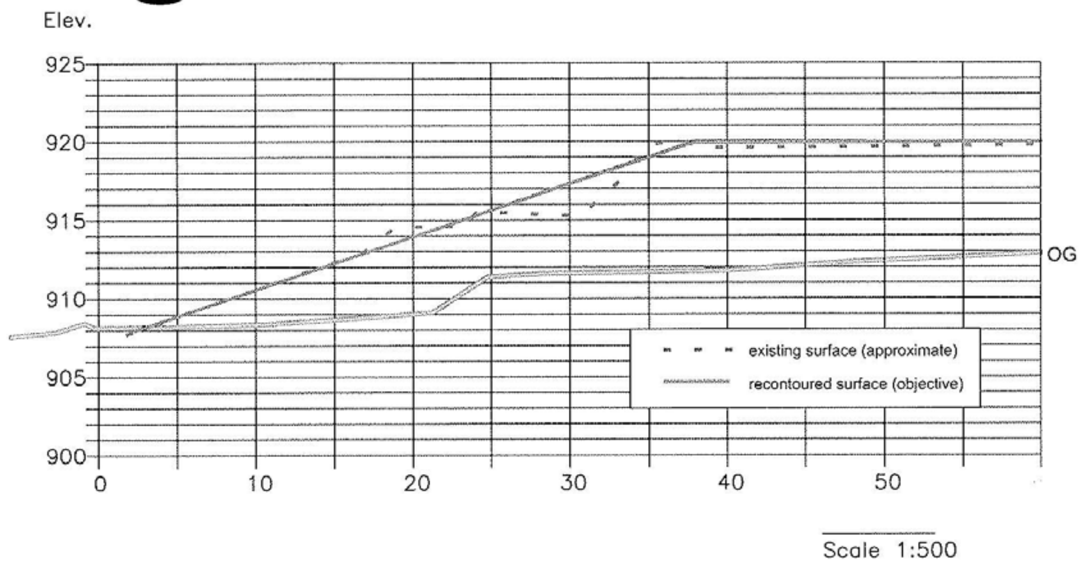


I

C

3:1 slope (straight)

0.25 meter cover

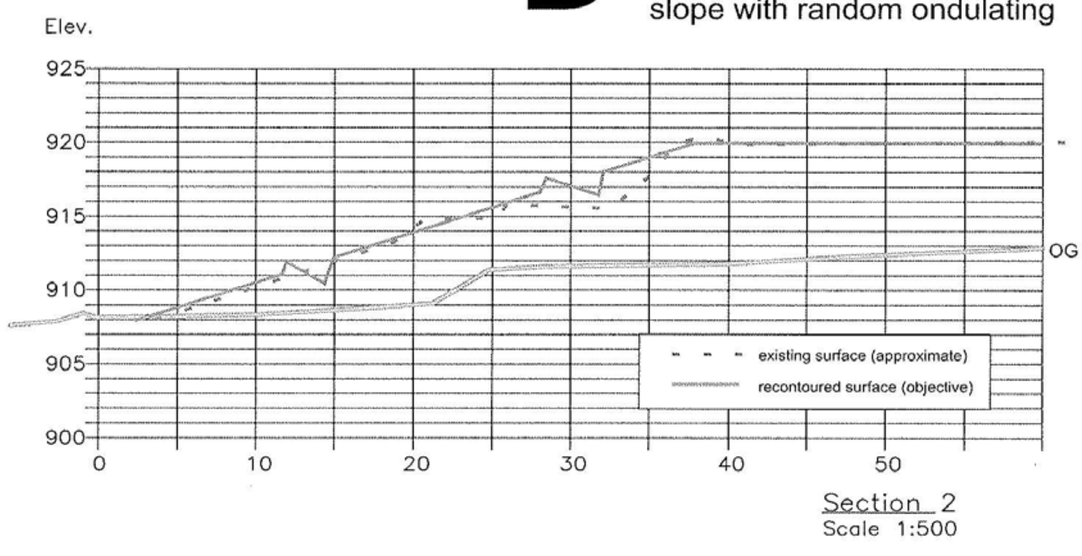


D

0.25 meter cover

3:1 (crest to toe)

slope with random ondulating



APPENDIX C

PHOTO LOG

Photo 1: Growth Media Pile 1

Photo 2: Growth Media Pile 2

Photo 3: Growth Media Pile 2

Photo 4: Growth Media Pile 3

Photo 5: Growth Media Pile 4

Photo 6: Growth Media Pile 4

Photo 7: Covered DSTF toe looking north

Photo 8: Covered DSTF mid-slope looking south

Photo 9: Covered DSTF crest looking north

Photo 10: Covered DSTF crest looking south

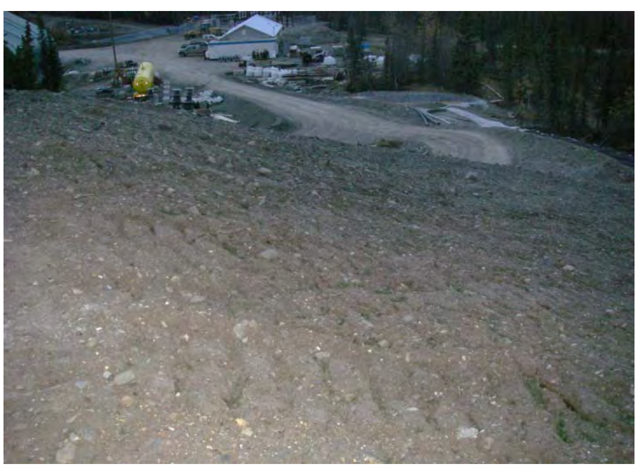


Photo 11: Grass sprouts DSTF looking south from crest

Photo 12: Grass sprouts DSTF looking west from crest

APPENDIX 1.2

SILVER KING IN SITU DEMONSTRATION TEST INTERIM REPORT

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

Memorandum

To: Elsa Reclamation and Development Company Ltd.

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

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

Date: October 24, 2016

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

Deliverable 2016-17-033-2_07

---

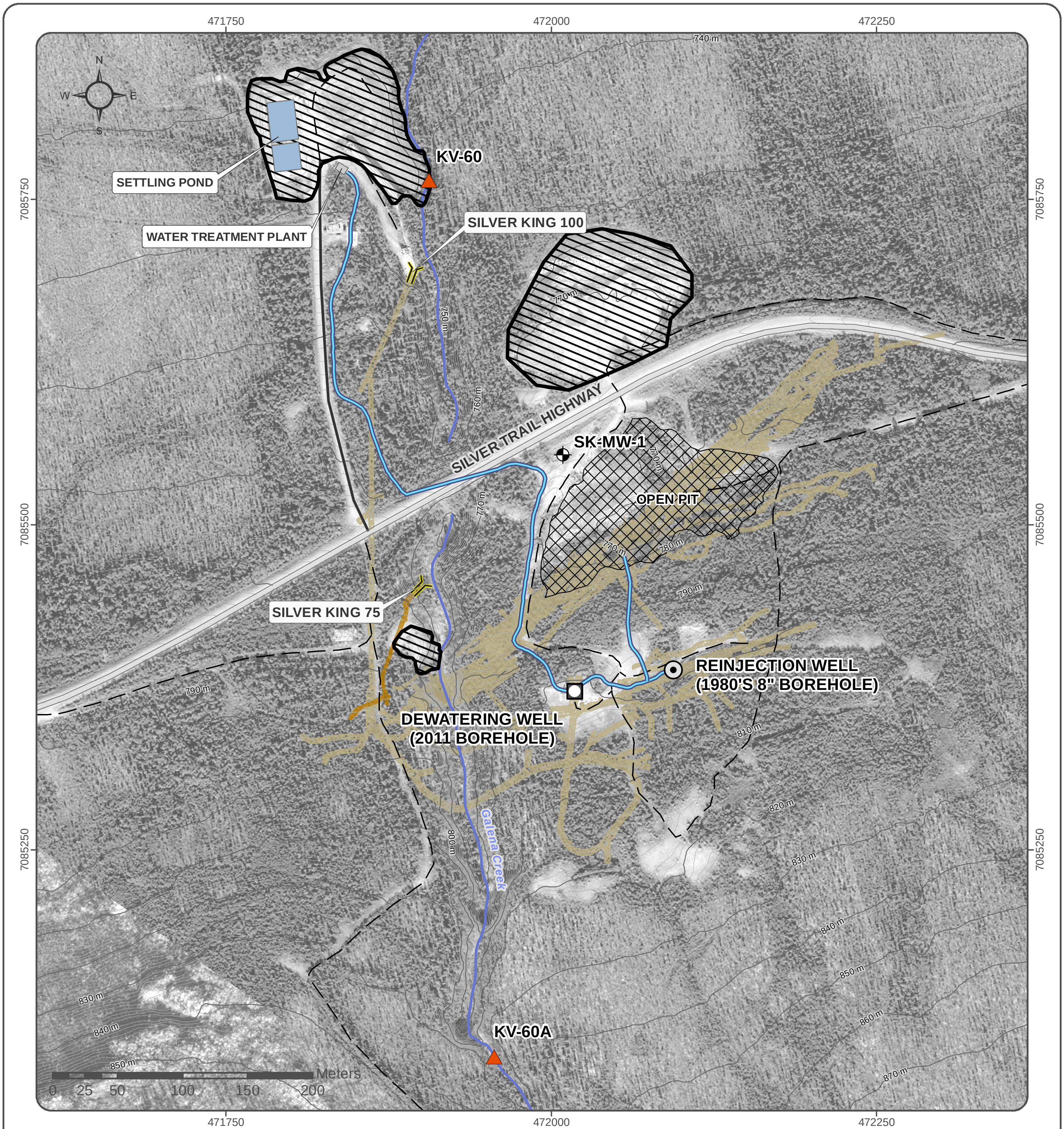
1 Introduction

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

2 Activity and Recent Data

2.1 Silver King Dewatering and Groundwater Level

An overview of the Silver King site is displayed in Figure 2-1. The groundwater level within the SK flooded workings is plotted in Figure 2-2 alongside flow rates of mine pool water pumped from the dewatering well to the SK water treatment plant (WTP) and water that is reinjected to create a recirculation loop within the flooded mine workings. The mine pool elevation varied between 728 and 738 masl for the majority of the March to August 2016 period. Overall, the dewatering rate ranged between 5 and 15 L/s, with approximately 3 L/s returned to the Silver King pit between March and the end of April, 2016. The reinjected water was amended with methanol to stimulate subsurface sulphate- and metal-reducing bacteria between January 22 and April 2, 2016.



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

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

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

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

ERDC

AEG

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

SILVER KING IN SITU TEST

FIGURE 2-1
SILVER KING LAYOUT

OCTOBER 2016

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

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

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

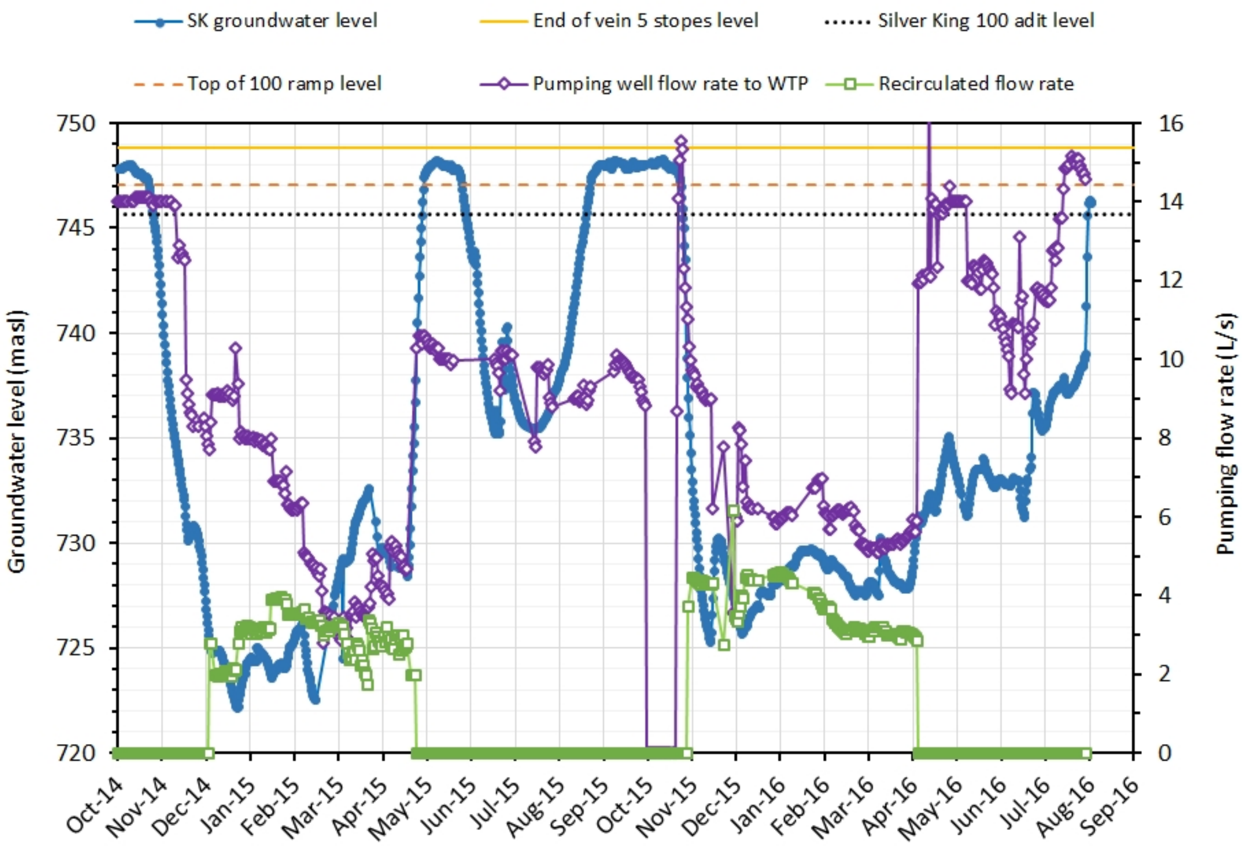


Figure 2-2: Response of groundwater level in SK mine pool during dewatering only and dewatering-recirculation phases of testing at different pumping flow rates. The level of the end of the Vein 5 stopes, top of the 100 ramp and SK100 adit are shown for reference.

2.2 SILVER KING MINE POOL GEOCHEMISTRY

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

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

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

- A rise in alkalinity (200 – 240 mg/L over April – June 2016 versus 146 – 160 mg/L prior to April 2016) since metal and sulphate reduction coupled to the oxidation of organic matter produces alkalinity;
- A rise in sulphide concentrations (0.02 – 0.06 mg/L versus non-detect (<0.02 mg/L) in the previous two months) and concomitant decline in sulphate levels (300 – 320 mg/L versus >390 mg/L for duration of test prior to April 2016) consistent with the transformation of dissolved sulphate to sulphide by sulphate-reducing microorganisms; and
- A fall in the total and dissolved concentrations of zinc, cadmium and thallium to their lowest concentrations observed to date as these chalcophile metals reach with the biogenic sulphide to form insoluble metal sulphide phases which precipitate out of the water column.

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

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

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

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

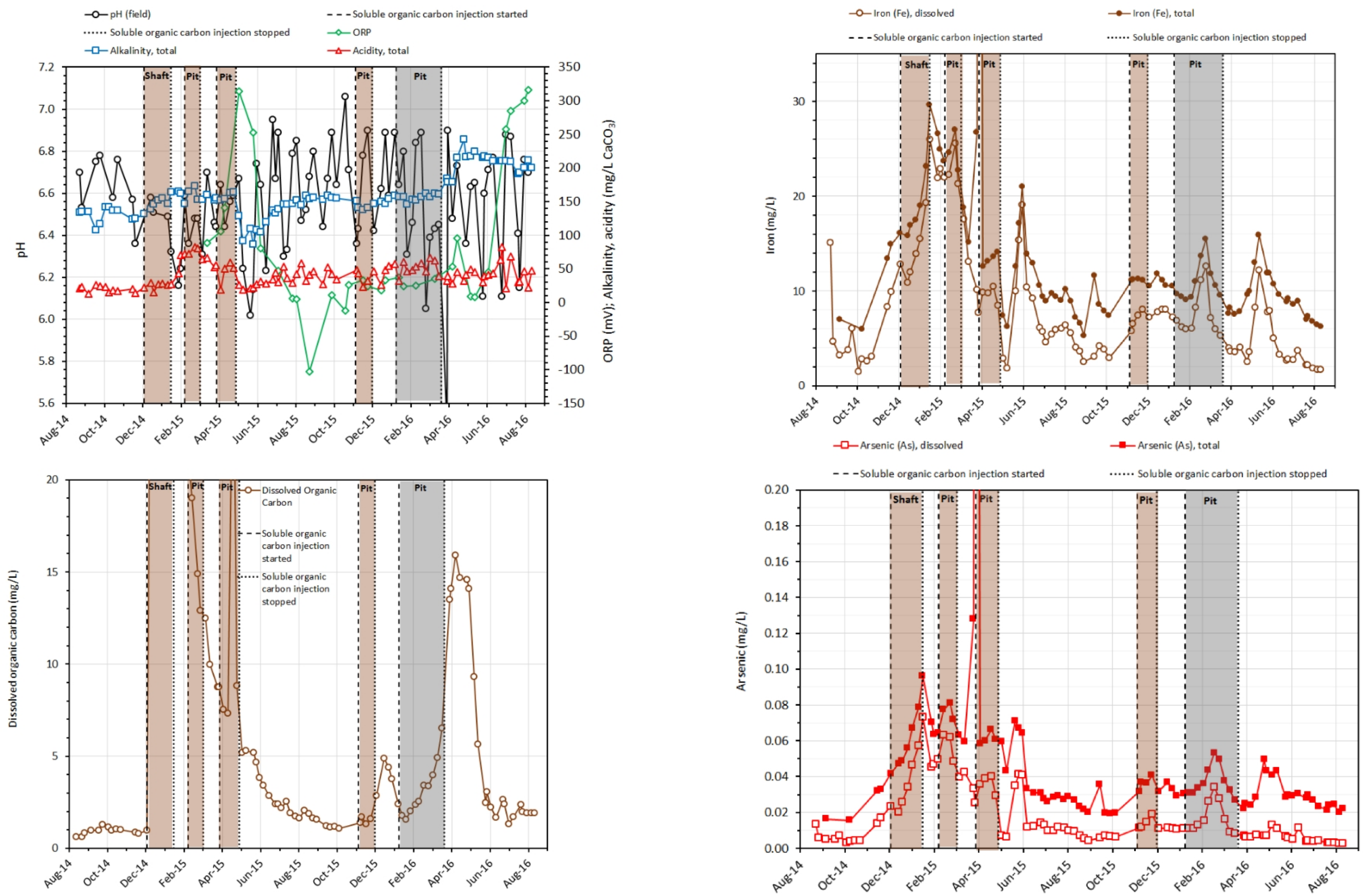


Figure 2-3: Change in selected constituents in SK mine pool water (collected via the dewatering borehole) during the dewatering and molasses amendment phases of the in situ mine pool treatment testing. The shaded areas indicate when continuous injection of molasses (brown) or methanol (grey) was ongoing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

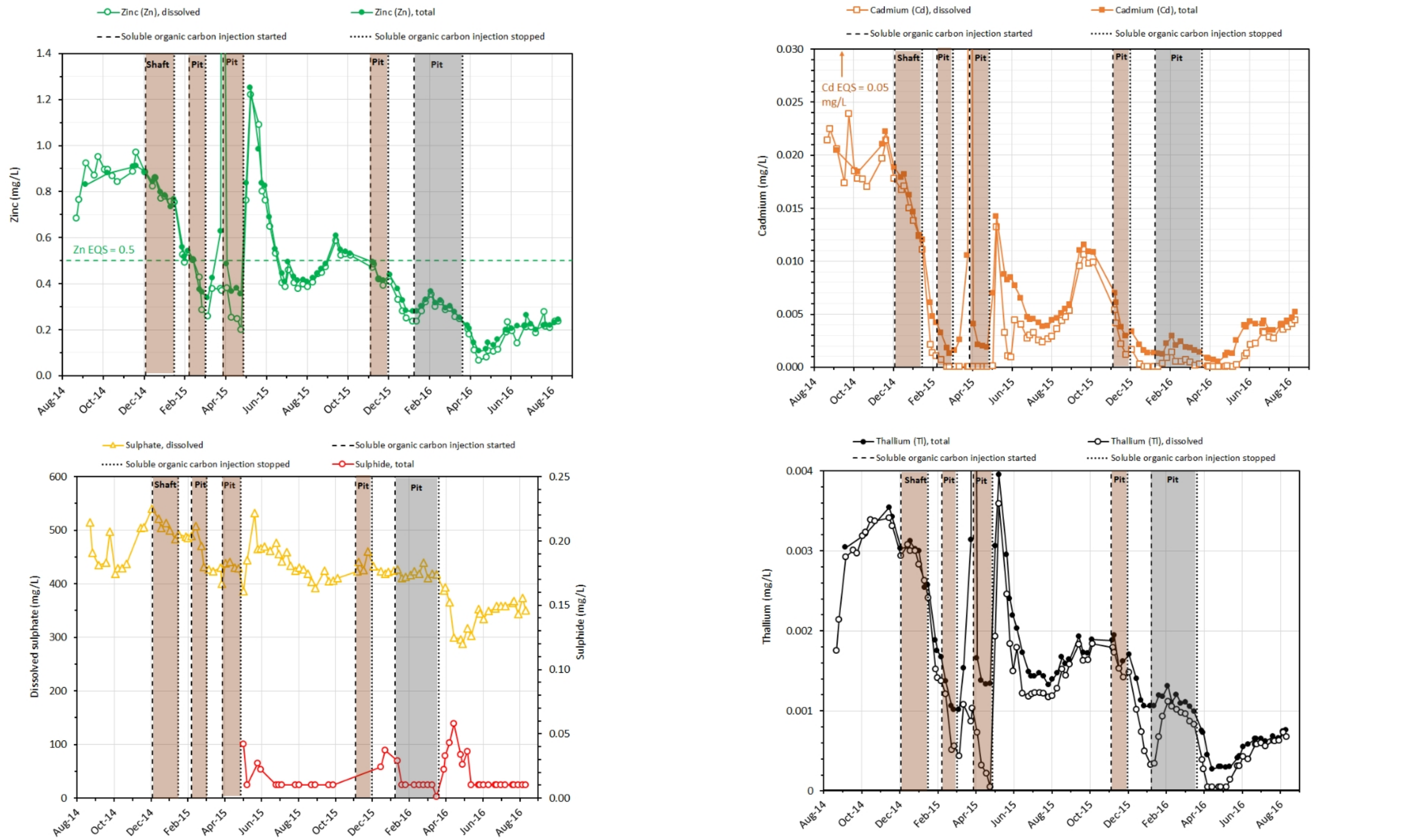


Figure 2-4: Change in zinc, cadmium, sulphur species, and thallium concentrations in SK mine pool water (collected via the 2011 dewatering borehole) during the dewatering and molasses amendment phases of the in situ mine pool treatment testing. The shaded areas indicate when continuous injection of molasses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

2.3 SILVER KING MINE POOL MICROBIOLOGY

Dewatering well samples were collected for microbial community profiling in April 2016. These were submitted to Contango Strategies (Saskatoon, SK) for genomic analysis. Further details regarding this analysis are reported in AEG (2016). In brief, DNA was extracted from the water samples and portions of the 16S rRNA gene, which can be used for taxonomic classification, were sequenced and matched against known microorganisms. Similar sequences (97% similarity or higher) were grouped together into operational taxonomic units (OTUs) and compared against a microbial database for classification at the genus level. Following classification, the matched genera were grouped into the following categories according to their ability to mediate redox transformations of sulphur and/or iron:

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

Many microorganisms are capable of both sulphide production and iron reduction; such genera were grouped together. The November 2015 and January 2016 data are also presented in order to provide some context for the April 2016 data (Figure 2-5 to Figure 2-7).

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

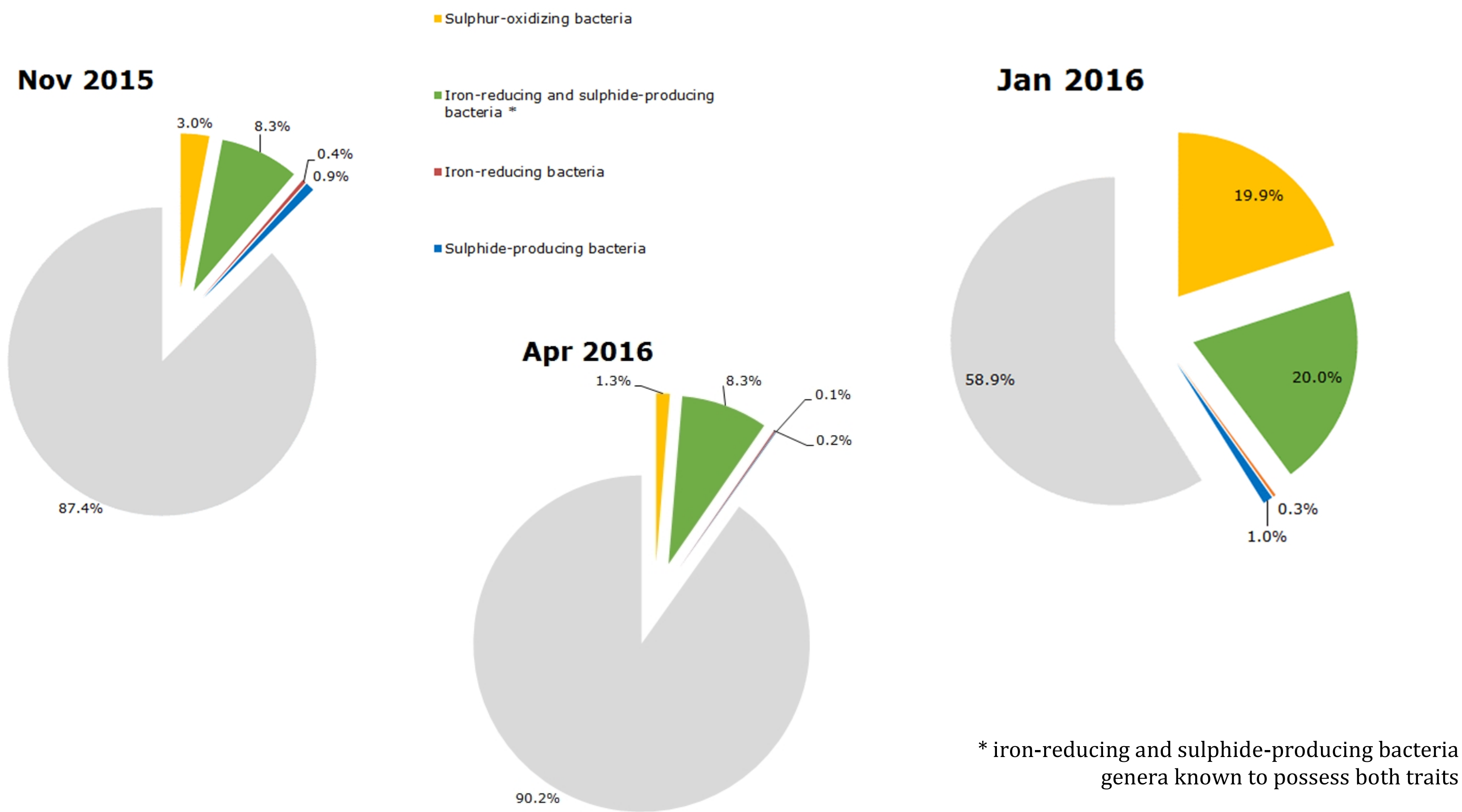


Figure 2-5: Percentage of OTUs assigned as FeRB, SPB and SOB in SK mine pool water samples.

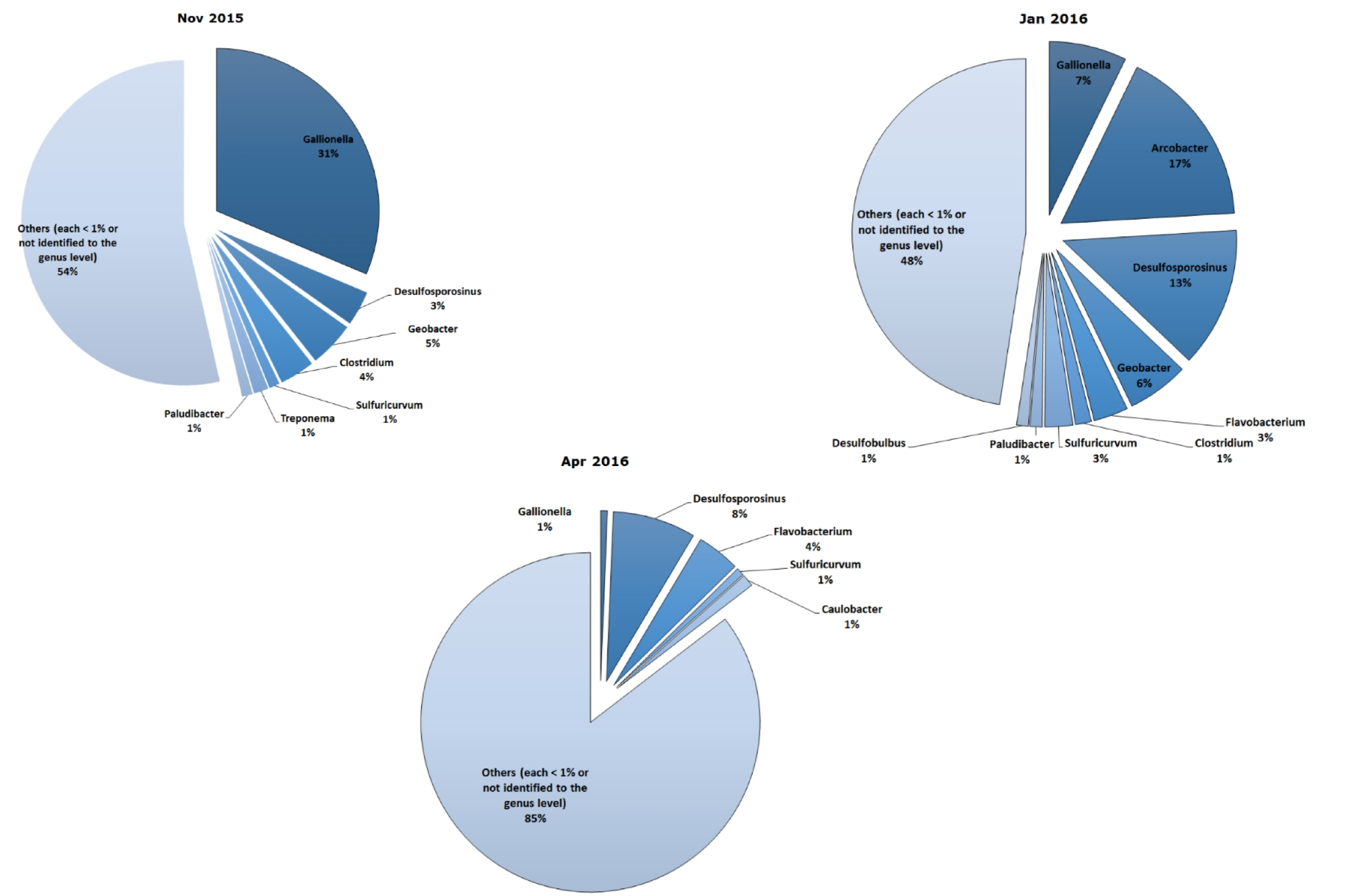


Figure 2-6: Highest percentage of organisms identified to genus level for November 2015, January 2016, and April 2016 sampling events

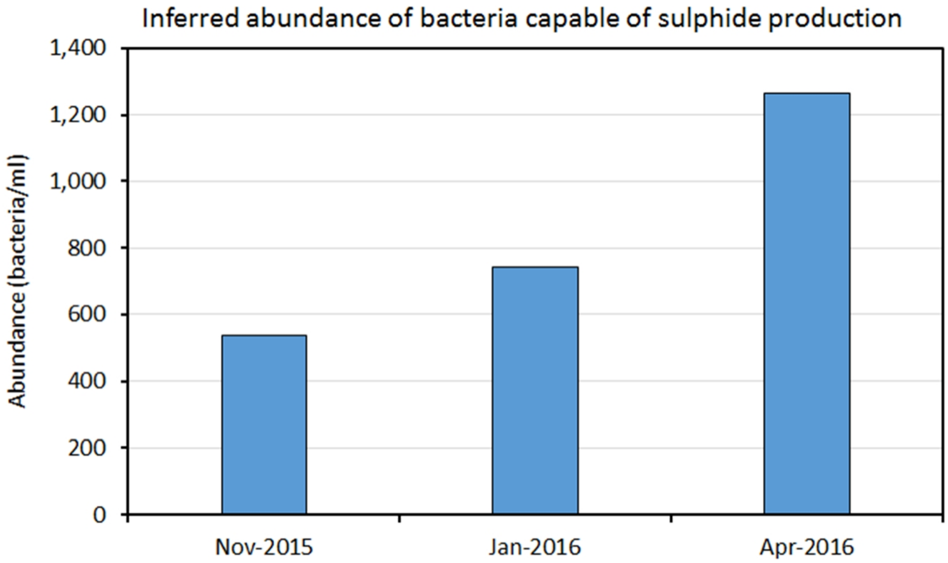


Figure 2-7: Inferred abundance of microorganisms with ability to produce sulphide determined for November 2015, January 2016, and April 2016 sampling events

2.3.1 ^{34}S-SO_4 Isotopic Analysis

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

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

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

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

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

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

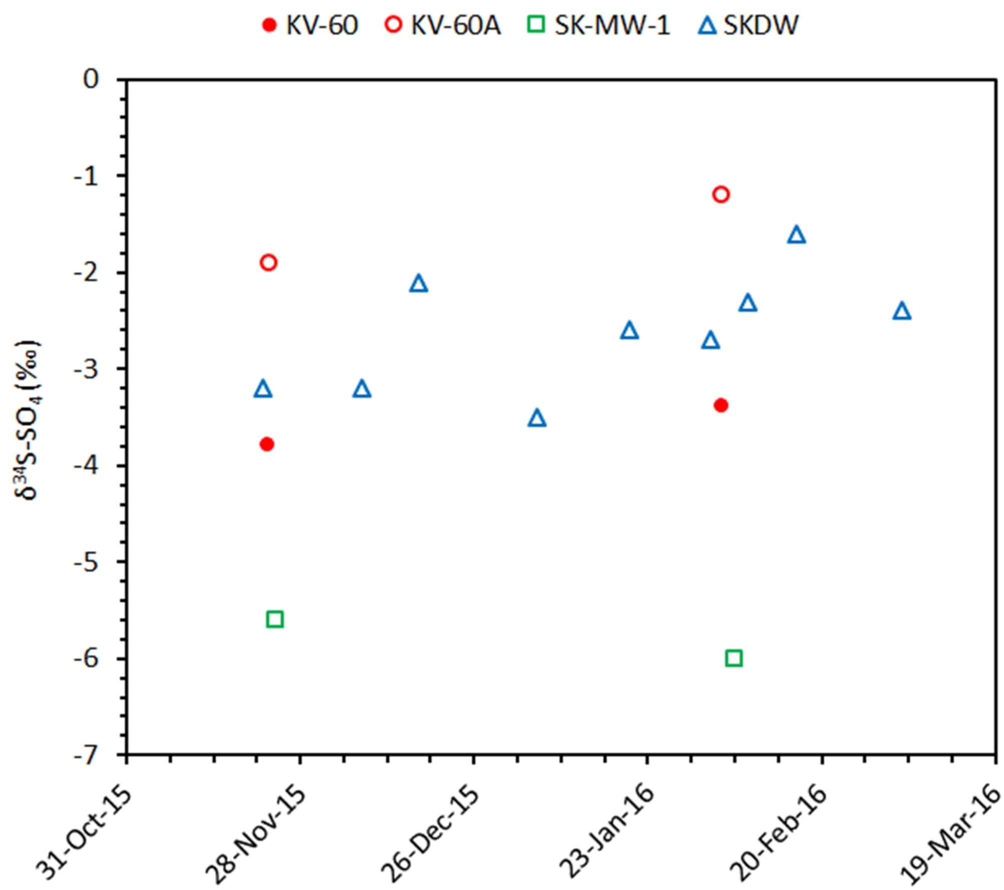


Figure 2-8: $\delta^{34}S\text{-}SO_4$ measurements from water samples collected from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

2.4 TRACER ANALYSIS

2.4.1 Dye

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

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

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

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

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

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

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

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

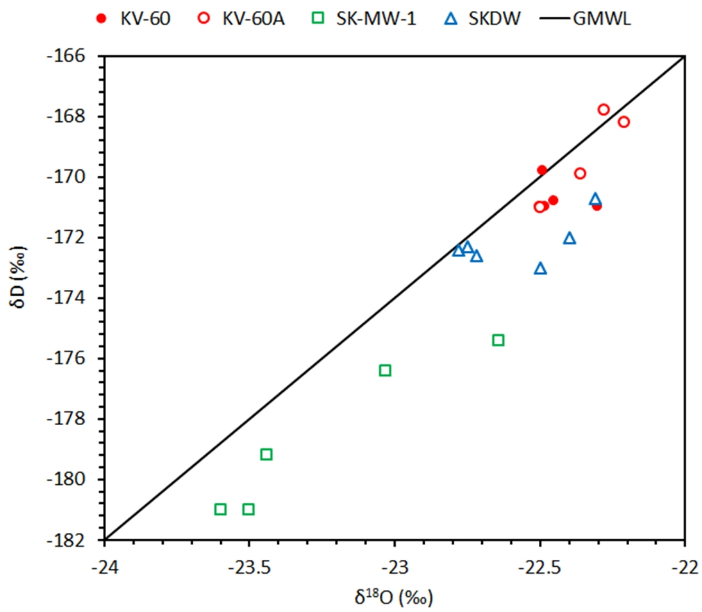


Figure 2-9: δD versus $\delta^{18}O$ plot of water samples from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

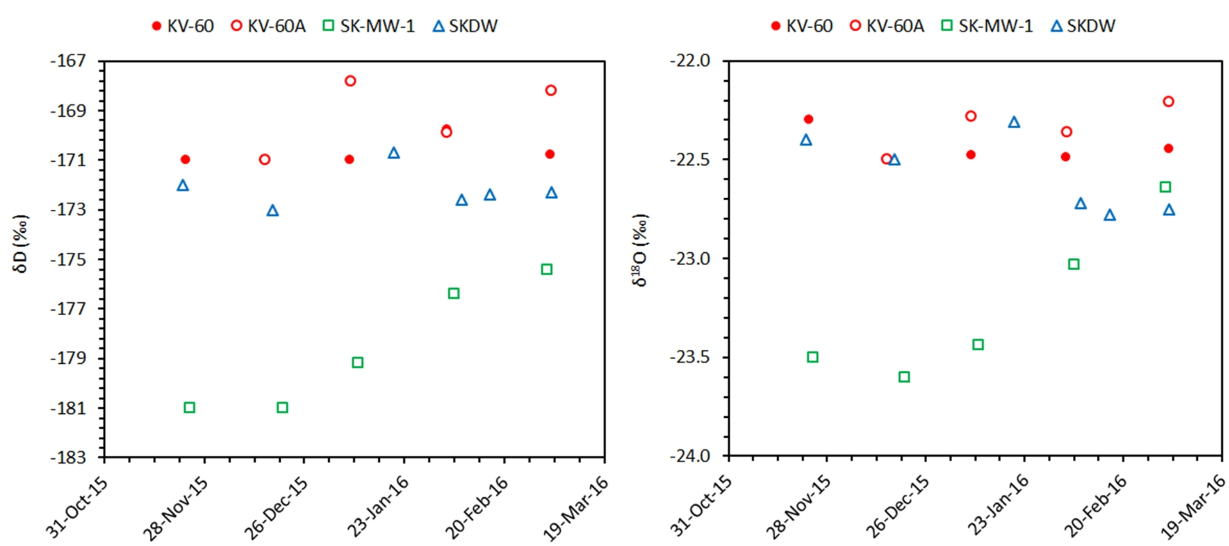


Figure 2-10: Temporal changes in hydrogen (left) and oxygen (right) isotope ratios measured in water samples collected from Galena Creek (KV-60 and KV-60A), the flooded SK mine workings (SKDW), and local groundwater (SK-MW-1).

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

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

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

The proportions of each endmember were varied such that:

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

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

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

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

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

3 SUMMARY

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

4 REFERENCES

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

APPENDIX 1.3
GALKENO 900 BIOREACTOR PERFORMANCE REPORT

GALKENO 900 SULPHATE-REDUCING BIOREACTOR 2008-2011 OPERATIONS

FINAL REPORT

March 2012

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT CORP.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 EXECUTIVE SUMMARY

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

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

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

2 BACKGROUND

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

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

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

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

Several adit discharge locations are being considered in the Closure Option assessment process for treatment in a bioreactor (Alexco Environmental Group, 2011). At this time, Silver King 100, Bermingham 200, Ruby 400, No Cash 500, Galkeno 900, Onek 400, Sadie Ladue 600 and Keno 700 are all considered as possible locations where bioreactor technology could be employed. Galkeno 900 has water chemistry and flow characteristics that are typical of these other adits in the KHSD. This test was of sufficient scale and operated long enough to provide design information that allows for the design of either a large scale bioreactor or an in-situ reduction field at several other adit drainage locations in the KHSD. The test was operated in a lined bioreactor allowing for the performance of the technology to be assessed while still in containment, but the results of the tests (reaction rates and stoichiometry) can be extended in the design of either a lined or an unlined system. The operation of the reactor continued through the winter season to demonstrate durability of metals removal mechanisms. During the course of the bioreactor demonstration, the conventional lime treatment system was maintained to ensure water license discharge compliance criteria were met.

3 GALKENO 900 TREATMENT LAYOUT

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

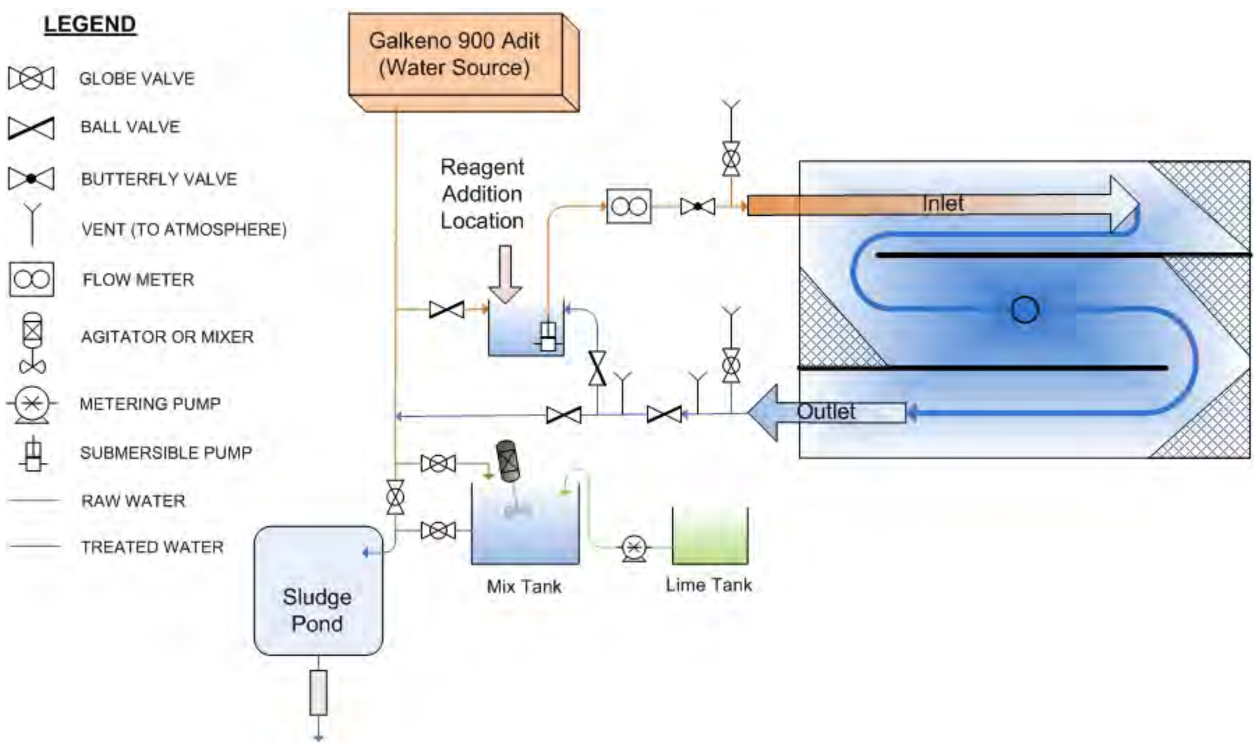


Figure 1 - Galkeno 900 Layout

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

Figure 2 - Inlet Valve

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

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

Figure 3 - Bioreactor Influent Sump

Within in the bioreactor inlet sump is a 1-horsepower submersible pump. The cable seen in Figure 3, stretching from lower left to upper right, attaches to a chain allowing the pump to be removed from the mix tank for servicing and/or replacement. The discharge from this pump is shown in Figure 4.

From the bottom of Figure 4 moving toward the top is a blue datalogger attached to the black Magnetic Flowmeter (Magmeter), a throttling globe valve, and finally a vertical anti-siphon standpipe. The datalogger records and stores the flow rates from the magmeter, allowing the system's operation rate to be tracked and analyzed. The globe valve is used to adjust the flow rate into the bioreactor. The vertical anti-siphon standpipe is exposed to the atmosphere. The system is designed so that in the event of pump failure, air will be pulled into the pipe and breaks the siphon. This series of instruments and valves is also located below grade in an insulated box and can be accessed through a cover.

Figure 4 - Bioreactor Inlet

The bioreactor is roughly 90 feet by 100 feet and has a liquid-filled portion that is 10 feet deep. It was dug partially into the native ground with an excavator, and the remaining depth was created by forming a berm around the excavated area. The bermed/excavated area was lined with 0.060 inch thick HDPE liner to form a pond, and then filled with waste rock recovered from a local placer mine. Figures 5 and 6 were taken during construction of the bioreactor and Figure 7 shows the overall design.

After the pond was filled with placer oversize rock, a geofabric was laid across the bioreactor, and soil from the excavated area and hillside was used to provide a 4 foot soil cover over the bioreactor. This soil cover layer acted as an insulating layer, minimizing the amount of ice formation in the top layer of the bioreactor. When the bioreactor solids were sampled in March 2011, the ice layer was approximately 18 inches to 2 feet thick.

Water enters the bioreactor through an inlet pipe that transports water to the far side of the bioreactor (see Figure 7 for an overall view of the layout). The last half of the pipe is perforated with ¾" holes, allowing water to fill the bioreactor and flow back and forth before final release.

Figure 5 - Bioreactor Construction

Figure 6 - Bioreactor Standpipe

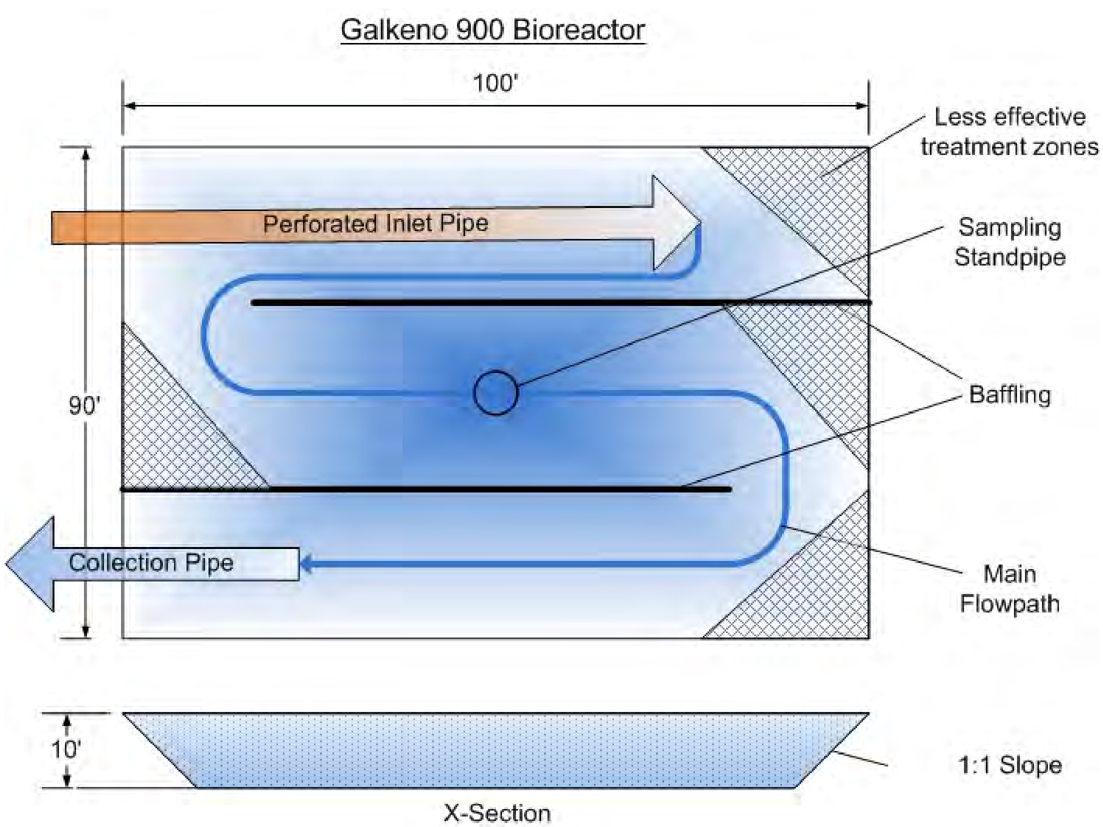


Figure 7 - Bioreactor Layout

Baffling was installed in two locations to create a torturous flow path and increase the contact time of the water with the media within the bioreactor,. This forces the water to travel a greater distance within the bioreactor before final release and to contact a greater fraction of the media. Also present at the center of the bioreactor is a sampling standpipe that can be seen in Figure 6. This allows samples to be collected and analyzed once water has passed midway through the bioreactor.

The discharge from the bioreactor is collected in a pipe and can then be either sent back to the bioreactor influent sump for recirculation or mixed with untreated adit water from the Galkeno 900 adit. This co-mingled water then passes through the lime treatment system mentioned earlier and is released into a sludge pond where heavy particulate settles and clean water is decanted and released. Figure 8 is the bioreactor discharge valve set-up. Water travels from the bioreactor on the right (not shown) and can either be sent up (as shown in the photo) to the bioreactor influent sump or to the left (as shown in the photo) to be co-mingled with adit water from the Galkeno adit. This setup is below surface grade and is accessible through a cover.

Figure 8 - Bioreactor Discharge Valves

Overall, the system was constructed to provide the operator with the maximum amount of flexibility to study the performance of a bioreactor without introducing the risk of releasing untreated water from the adit. Based on the positions of several valves, the system could be run in one of the following operation modes:

1) Bioreactor influent valve closed – collected adit water bypasses the bioreactor and is treated at the lime treatment facility.

2) Bioreactor influent valve and discharge valve closed – water pumped from the bioreactor influent sump fills the bioreactor and once filled, this mode allowed the water in the bioreactor to be continuously re-circulated. This was important to allow for the initial growth phase of the bioreactor, allowing the carbon source to be consumed in the bioreactor rather than being released from the discharge.

3) Bioreactor influent valve open and discharge valve open – untreated adit water was pumped into the bioreactor, sampled along several key locations, then discharged from the bioreactor and co-mingled with the untreated adit water where it was transferred to the lime treatment facility.

The water from the adit was a significant heat source for the bioreactor; therefore some amount of influent water from the adit was desired even during the initial growth phase of the bioreactor. In a full scale installation without the requirement of the downstream secondary treatment plant, these valving systems would not be required other than to provide a bypass from the adit if desired, and a temporary recirculation loop to allow discharged water to be sent back to the influent sump.

4 BIOREACTOR OPERATIONAL SUMMARY

Operational notes are included in this report to capture a few of the issues experienced during construction and operation of the bioreactor. The bioreactor construction began in the summer of 2008 with operation starting soon after. The following timeline outlines milestones, as well as issues, that were noted during operation:

- July-August 2008: Pond constructed and lined (see Figures 5 & 6).
- September 2008: Pond filled with oversize rock from a local placer mining operation (some small amounts of fines were present).
- October 4th, 2008: Start filling the bioreactor with untreated adit water.
- October 10th & 11th, 2008: Started recirculation of bioreactor water, added 182 kg sucrose to support microbial sulfate reduction.
- October 16th, 2008: 110 gal methanol and 1.8 kg dried milk solids added.
- October 2008: Bioreactor covered with geofabric and several feet of topsoil.
- October 2008 through May 2009: Occasional "top up" of untreated mine water to maintain full conditions in bioreactor. Make-up water averages ~ 1 m3/day or approximately 1 liter per minute average.
- January 23rd, 2009: 110 gal methanol added.
- January 2009: Determination of slow leakage rate from bioreactor ~ 1.09 m3/day.
- February 19th, 2009: Anti-siphon valve on the return recirculation line iced over, draining the bioreactor and flooding covers/box. Estimated ~135 m3 water was lost from the bioreactor through overflow of the tank.
- April 8th, 2009: Bioreactor standpipe blocked with ice – unable to sample.
- May 17th, 2009: Began adding methanol at the bioreactor influent sump at a rate of 1.0 litre per day.
- July 11th & 12th, 2009: Added 10 kg sucrose each day to jumpstart reduction, continued methanol addition at 1.0 litre per day.
- August 25th, 2009: Installed totalizer and flowmeter on the inlet to the bioreactor.

Once methanol was added at a constant rate, the bioreactor began through-flow operation. During that time, the following events occurred:

- October 8th, 2009: Initiated flow-through at a rate of 0.5 litre per second.
- December 18th, 2009: Initiated flow-through at a rate of 1.0 litre per second.
- January 7th-20th, 2010: Valve box flooded and frozen, thawed and repaired on January 20.
- February 15th, 2010: Power loss to submersible and metering pump.

- February 16th - 18th, 2010: Power loss while anti-siphon frozen which resulted in the loss of approximately half the bioreactor water volume through the sump; power restoration and line thawed; refilled bioreactor.
- August 6th, 2010: Reduced flow rate to 0.75 l/s to improve treatment.
- March 17th &18th, 2011: Return line frozen.
- May 11, 2011: cessation of active operations; bioreactor sampled for solids mineralogical analysis.

A review of the operator's log provides some important details that will guide future design. On February 19th 2009 and February 16th 2010, loss of power and a lack of continued pumping of water, which maintained heat in the bioreactor lines, resulted in ice formation in the anti-siphon valve. With the transfer pump stopped, the bioreactor siphoned water into the sump, which overflowed on the ground around the sump.

5 METALS REMOVAL MECHANISMS IN BIOREACTOR TREATMENT

The removal of metals from mine waters by bioreactors is done around the world, utilizing a variety of approaches. Doshi (2006) summarizes the many different types of bioreactors that are in operation, and discusses the relative advantages and disadvantages of these different bioreactor systems. The bioreactor utilized at Galkeno 900 is one type of reactor, where the only carbon source added to the bioreactor was added in a dissolved form semi-continuously during the operation of the bioreactor. Bioreactors are often constructed utilizing a mixture of substrates which either act as a carbon source for microbial reactions, or these substrates can act as sorptive surface for metals precipitation. However, bioreactors with solid phase carbon sources are often limited in their sulphate reduction rates by the availability of soluble organic carbon (Buccambuso et al, 2007) indicating that the constant supply of a carbon source as was done in Galkeno 900 bioreactor will tend to prevent microbial limitations on treatment.

For context of this discussion, the operation of the Galkeno 900 bioreactor can be divided into three distinct time periods. They are:

- **Recirculation Phase – Operation Mode 2 (October 2009 - July 2009):** During this period, the bioreactor was placed into service with water from the adit entering at an average rate of one litre per minute (1 lpm), which provided makeup water to replace slow leakage, and also to provide some heat from the adit water during the cold season. An initial carbon source addition consisting of (1.8 kg) milk powder and (182 kg) table sugar (sucrose) and (110 gal) methanol was added to provide an energy and nutrient source for an initial microbial growth phase. No source of microbes other than what was present on the placer rock and what is carried in the mine water was added to the bioreactor. However, researchers studying mine water and sediment at the Penn Mine Church et al (2007) showed that mine water even in an pH 4 mine drainage with high concentrations of heavy metals contained sulphate reducing bacteria and accounted for metals removal processes. The water in the bioreactor was re-circulated at a rate of one to two liters per second to mix and distribute water in the bioreactor. The water was periodically sampled to evaluate microbial growth and activity indirectly by evaluating water quality changes that could be inferred to be caused by microbial action. During this period there was incomplete formation of reducing conditions and the bioreactor likely had both aerobic and anaerobic zones. During the recirculation phase, metal concentrations were decreased over several months (discussed more below) and the removal mechanisms during this time may have included oxidative mechanisms (iron and manganese oxide formation) with metal co-precipitation on the iron and manganese oxides, carbonate mineral formation, and microbial sulphate reduction and metal sulphide precipitation.
- **Reduction Onset Phase – Operation Mode 2 (July 2009 – September 2009):** During this period, water within the bioreactor continued to be re-circulated while additional carbon sources were added at the bioreactor influent sump. This resulted in elevated carbon concentrations and the onset of more strongly sulphate-reducing conditions. During this time, the development of stronger reducing conditions were observed, characterized by greater sulphate reduction, the dissolution of manganese and iron from the reactor solid phase (likely manganese and iron oxides formed during initial bioreactor operations, as well

as structural iron and manganese minerals in the placer rocks), and greater metals removal as sulphides.

- **Operational Treatment Phase – Operation Mode 3 (October 2009 – May 2011):** An initial flow rate of 0.5 litre per second (lps) was established into the reactor, and after stable metal removal conditions were observed this flow rate was maintained for several consecutive bimonthly samples. Soon after, the flow rate was increased to one litre per second (lps) in December 2009. In August 2010, the flow rate of the bioreactor was reduced to 0.75 lps, or approximately 19% of the adit flow. This flow rate was then maintained for the remaining operation of the bioreactor.

The results displayed in this report focus primarily within the operational treatment phase. The other phases, while important, are reflective of treatment performance during the transition of the bioreactor from construction to operation.

5.1 LITERATURE REVIEW AND BACKGROUND DISCUSSION

The formation of metal precipitates in a bioreactor that has carbon sources added to or present in the solid phase of the bioreactor has been extensively studied for 30+ years. There are several different styles of bioreactors, both in terms of carbon sources and flow dynamics. Some very large bioreactors have been created to treat flows as large as 20 lps or greater, and some bioreactors are designed to treat very acidic or concentrated metal-containing mine drainage. Each bioreactor must be designed to reflect the environmental conditions, the water chemistry of the mine water being treated, and other relevant variables as discussed in this report.

To understand the processes that occur in bioreactors many studies have attempted to identify directly by examination of mineral formation or by inference from water chemistry signatures what primary mechanisms are responsible for metals removal. When complex carbon sources are added as a solid phase in the bioreactor construction (i.e., peat, straw, compost, wood chips, etc.), a broad range of mechanisms has been documented (Gusek, 2002; Doshi, 2007; Gusek et al, 2008), that include:

- Sorption of metals on organic matter.
- Precipitation of iron hydrous oxides including ferric and mixed valence minerals, which then provide mineral surfaces for sorptive removal of metals, or metals can also be co-precipitated within the iron mineral matrix.
- Precipitation of manganese oxides including manganese (IV) oxides and mixed valence (III/IV) oxides and manganese carbonates, which then provide mineral surfaces sorptive removal of metals, or metals can also be co-precipitated within the manganese mineral matrix.
- Precipitation of metal sulphides, including primary metal sulphides such as ZnS or CdS, as well as precipitation of iron sulphides such as amorphous FeS and co-precipitation of metals within the FeS matrix. Depending on the pH of the bioreactor and the availability of structural iron, a very large amount of FeS minerals can be formed by aqueous sulphide

formed by microbes reductively dissolving iron from the rock matrix, creating a "bank" of amorphous sulphide which has reactivity toward dissolved metals.

- Precipitation of some metals in their reduced forms, for example selenium reduction from a Se(VI or IV) anion to elemental selenium precipitates Se.
- Precipitation of metals as carbonate minerals. Some of the relevant metals have somewhat soluble carbonate minerals (e.g., zinc carbonate minerals including smithsonite, and hydrozincite) which are relatively more soluble than sulphides. When sulphide is not present, these minerals may provide a precipitation-removal mechanism.

Sorption of metals on organic matter is not a relevant metals removal mechanism by design in the Galkeno 900 bioreactor because only coarse rock was used as a solid substrate. The metal removal mechanisms in this reactor appear to initially relate to removal of iron and manganese during the recirculation phase, and then over time the removal mechanism transitioned to a metal sulphide removal mechanism (inferred because metals removal continued to occur when iron and manganese ceased being removed and actually increased in concentration during flow through the reactor). The precipitation and removal of metals in their reduced forms is not a significant potential mechanism for most of the metals present in Galkeno 900 adit water, with the potential exception of uranium which was only present in very low concentrations in the influent water. Consequently, the formation of sulphide from sulphate, which is a chemical reaction that is catalyzed by microbes and relies on the availability of organic carbon, is the primary performance variable that is relevant in the Galkeno 900 bioreactor performance evaluation. In typical evaluation of bioreactors where sulphate reduction/sulphide precipitation is a dominant mechanism, the Sulphate Reduction Rate (SRR) is determined as a primary design variable.

In a bioreactor with available sulphate and a soluble carbon source added, Dar et al (2007) showed that sulphate reducing bacteria (SRB) are the dominant microbe that accumulates in the bioreactor, and by inference the vast majority of the carbon consumption is performed by SRB. In their study, only a few different strains accounted for the majority of the cells present, indicating that microbes capable of utilizing the carbon source and reduce sulphate will become dominant in the bioreactor.

After the bioreactor entered stable operation, metals removal mechanisms appear to have shifted from the mixed reaction that were discussed in the prior report (Alexco Resource US Corp, 2009) to primarily a sulphide-based precipitation process. The stability of metals removed as sulphides are consequently an important consideration for the performance of the bioreactor. Jong and Perry (2004) studied the form of metals that were precipitated from solution as a result of the sulphate reduction process, and determined that arsenic, copper, iron, nickel, and zinc were primarily bound up in a sulphide phase that was also associated with residual organics, and that carbonate or hydroxide phases were relatively minor phases that held the metals removed from solution. The United States Environmental Protection Agency SITE program studied the stability of these sulphate-reducing bioreactor precipitates at the Leviathan Mine, in California. Using a series of different tests, the EPA determined that the metals in the bioreactor precipitates were below regulated total metals thresholds (California standards), the WET extraction test showed that the metals in the bioreactor did not leach above regulated soluble threshold standards, and that as defined by TCLP extraction testing the bioreactor solid materials were not hazardous.

The effectiveness of this sulphate reduction bioreactor process is sensitive to important variables including the hydraulic residence time in the bioreactor, the sulphate reduction rate, and the filtration capacity of the media.

Because the products of the sulphate reduction reaction include both sulphide and bicarbonate alkalinity, it is possible that carbonate precipitation is also an important mode of precipitation for some of the metals removed in the reactor. However, for most of the metals being removed in the bioreactor, including antimony, arsenic, cadmium, cobalt, iron, nickel, and zinc, a sulphide precipitation mechanism appears more likely because sulphide precipitates are less soluble than the carbonate precipitates of these elements. The mineralogical analysis discussed in Section 6.2.1.1 confirms that sulphide is the solid phase form of zinc precipitates formed in the bioreactor. Thus the sulphate reduction reaction is the primary reaction that we will focus on optimizing in the bioreactor operations.

5.2 DETERMINATION OF THE SULPHATE REDUCTION RATE

Microbial production of sulphide from sulphate is dependent on the presence of sufficient numbers of sulphate-reducing bacterial (SRB) cells, and the availability of organic carbon, according to the following reaction:

4 moles methanol + 3 moles sulphate → 3 moles sulphide + 4 moles bicarbonate

The rate of the reaction is nearly the same at temperatures in natural environments where the long-term temperature is around freezing (-2^{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.

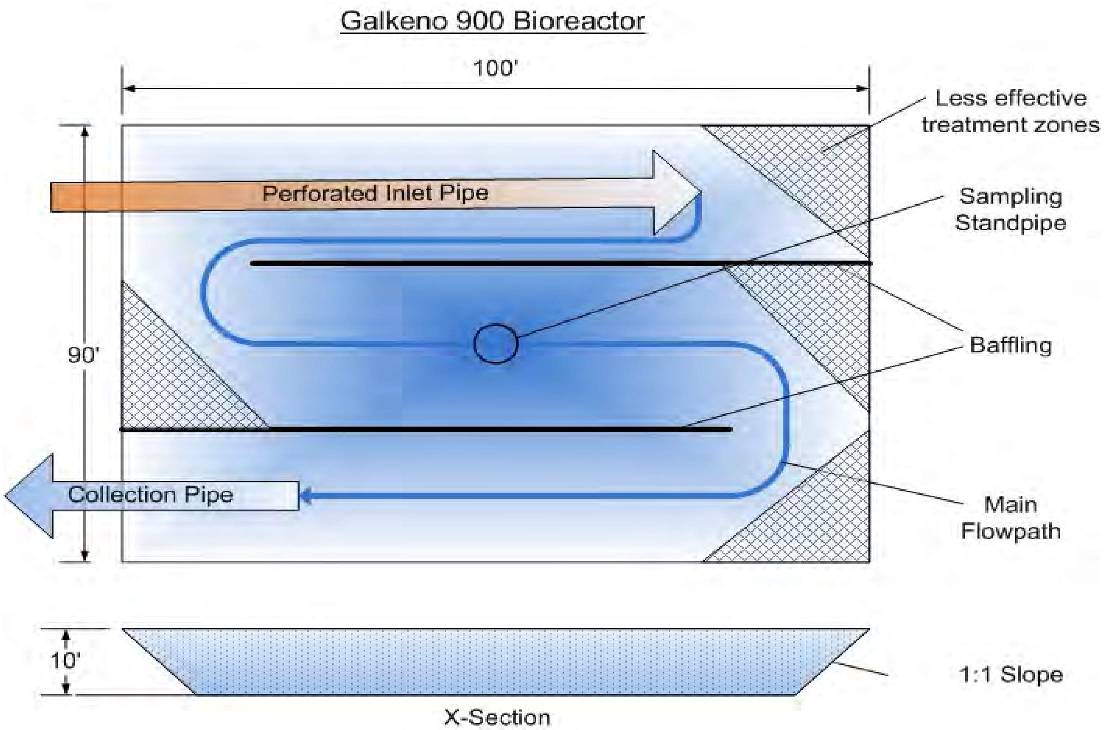


Figure 9 - Conceptualization of Flow Path in the Bioreactor

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.

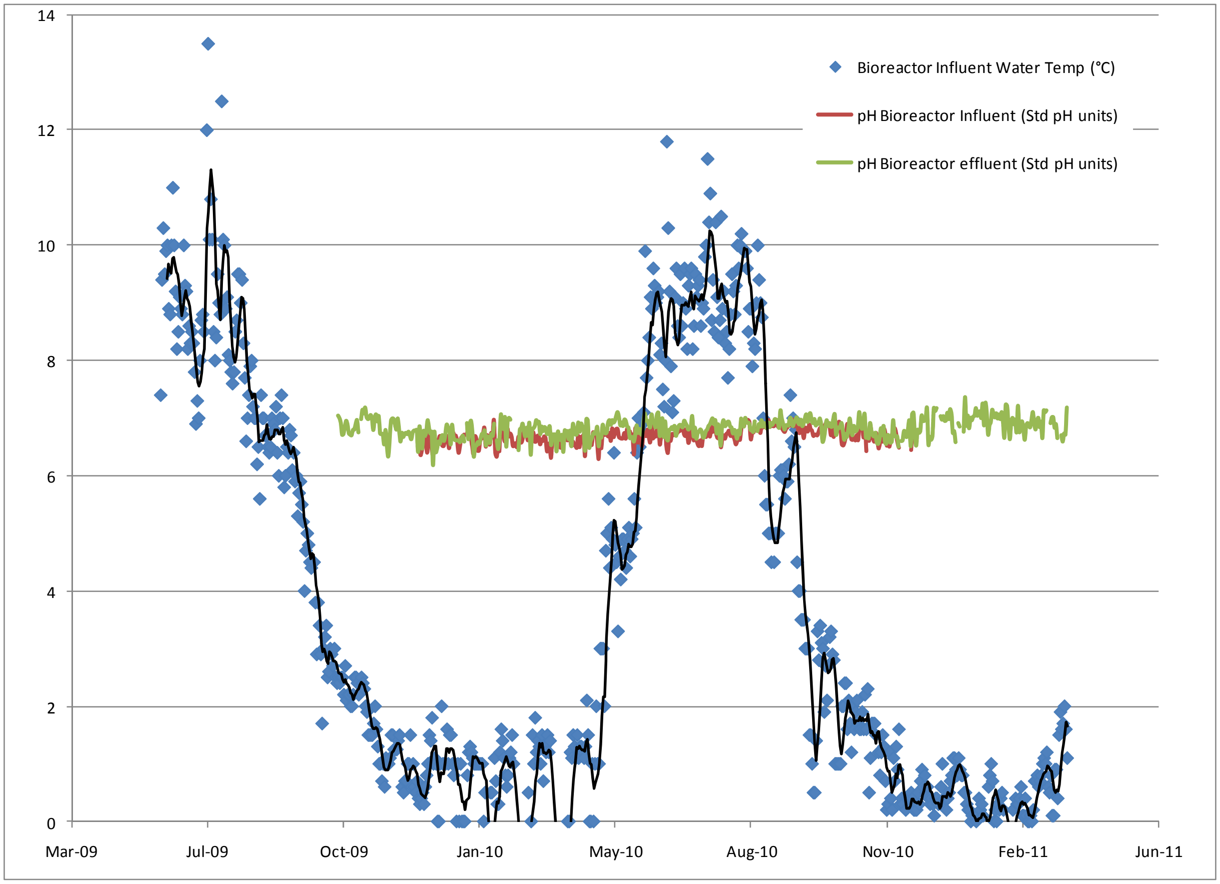


Figure 10 - Comparison of Galkeno 900 Adit pH and Bioreactor pH vs. Temp

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%

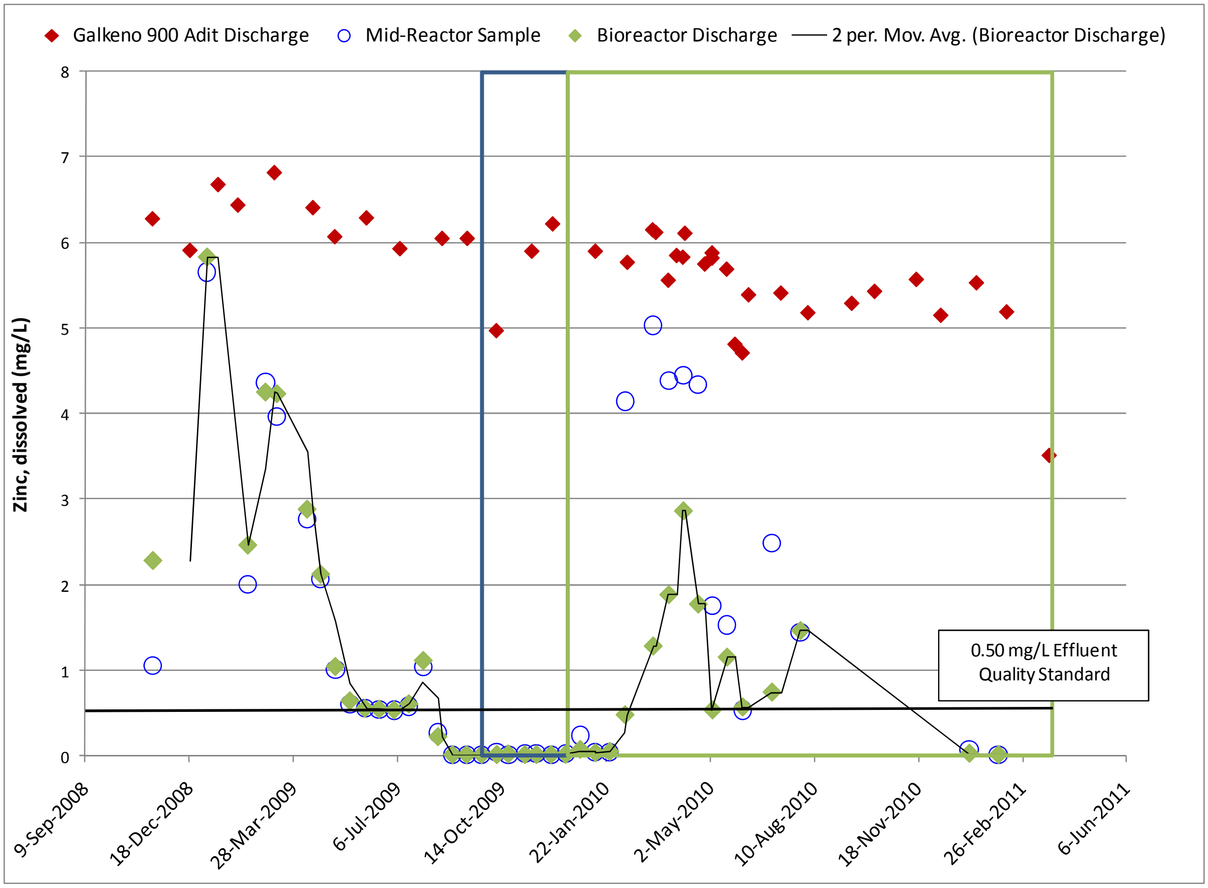


Figure 11 - Zinc removal by the Galkeno 900 Bioreactor

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.

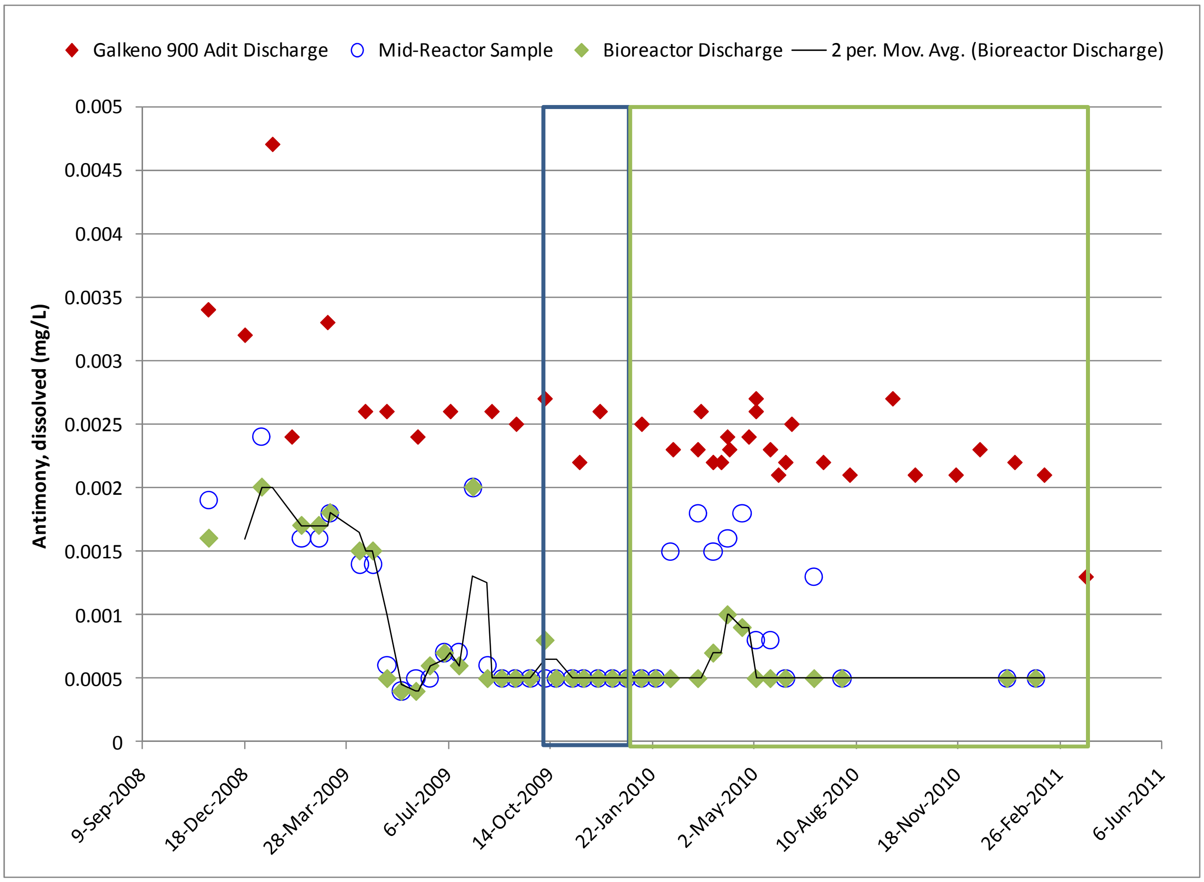


Figure 12 - Antimony Removal by the Galkeno 900 Bioreactor

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.

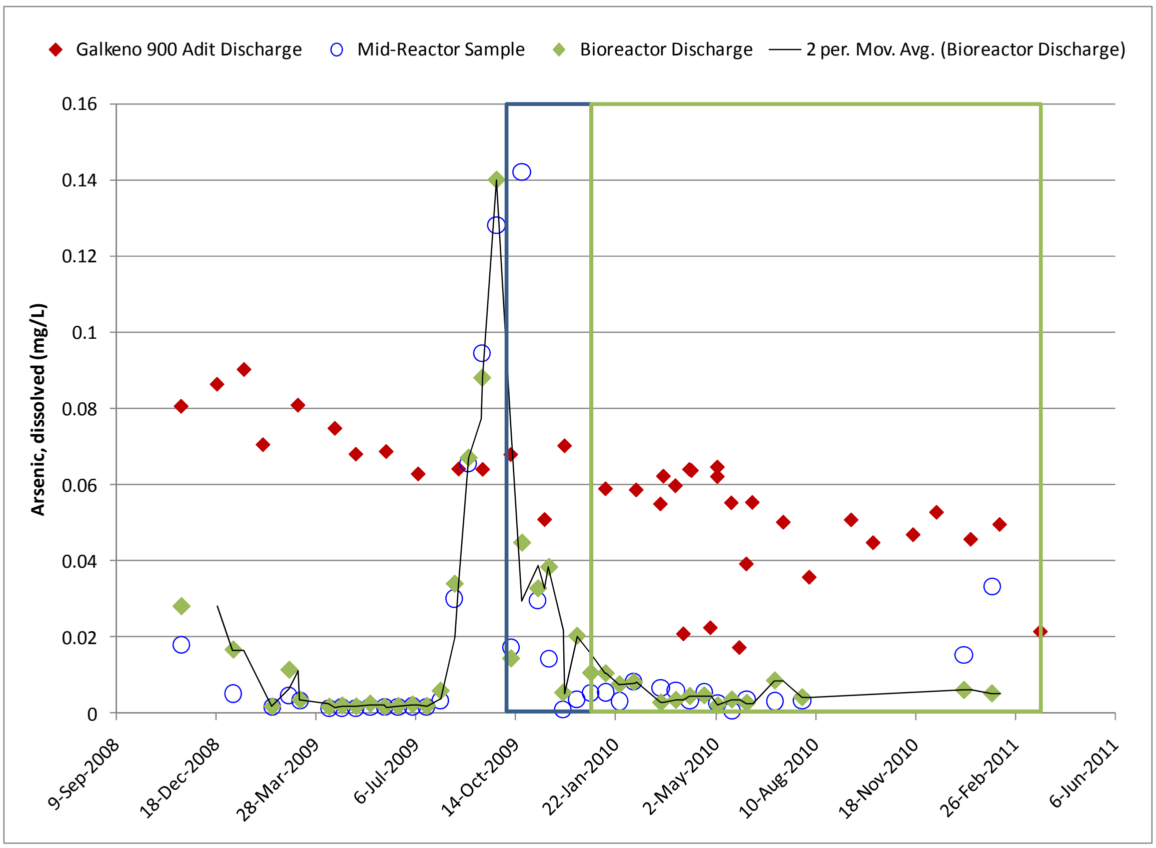


Figure 13 - Arsenic Removal by the Galkeno 900 Bioreactor

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.

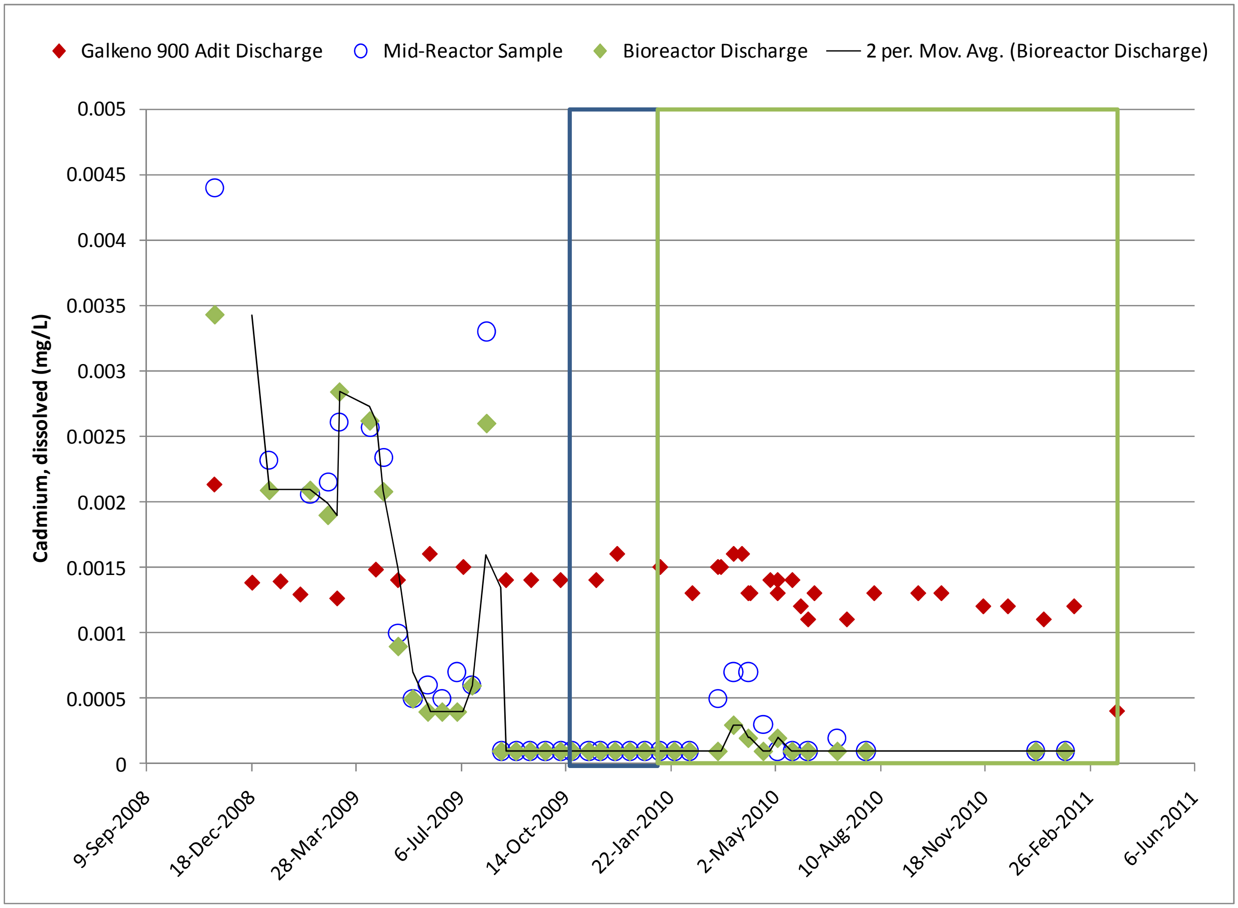


Figure 14 - Cadmium Removal by the Galkeno 900 Bioreactor

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.

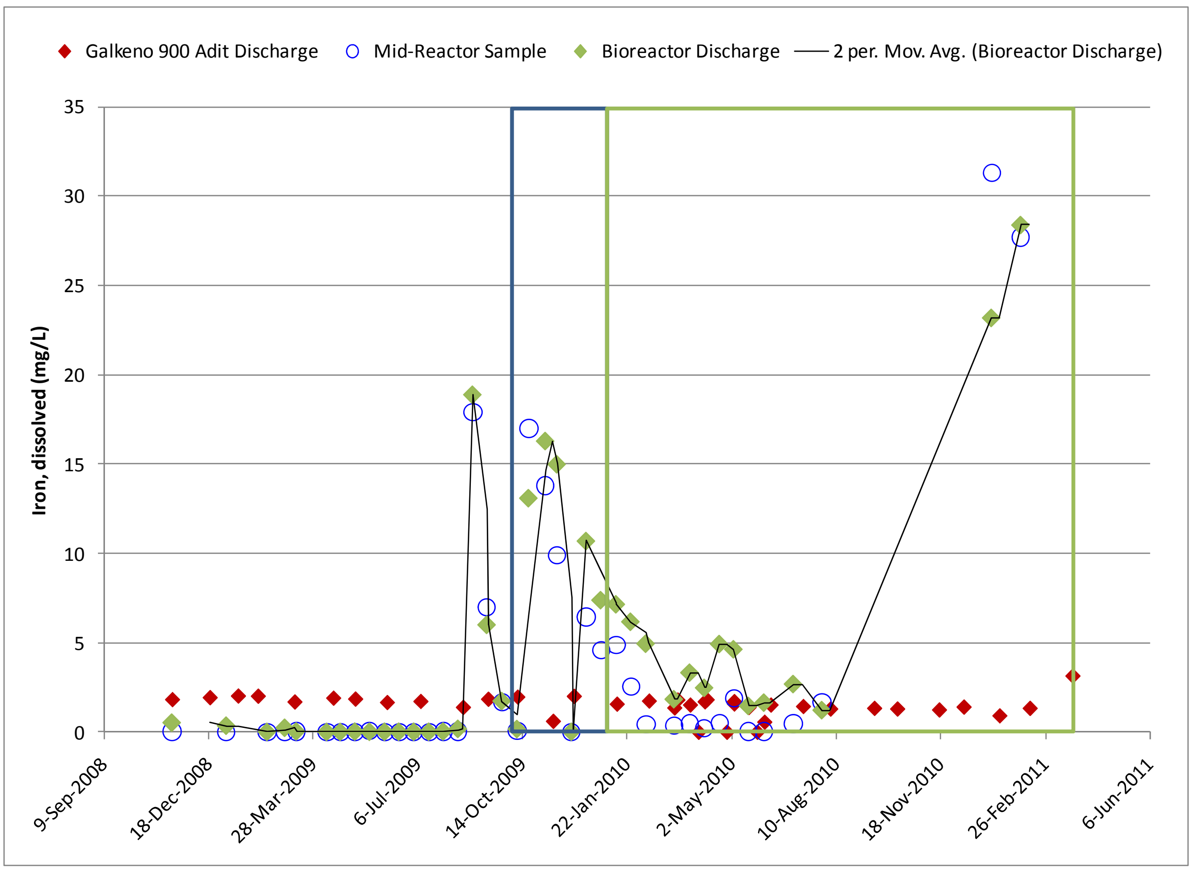


Figure 15 - Iron Removal by the Galkeno 900 Bioreactor

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.

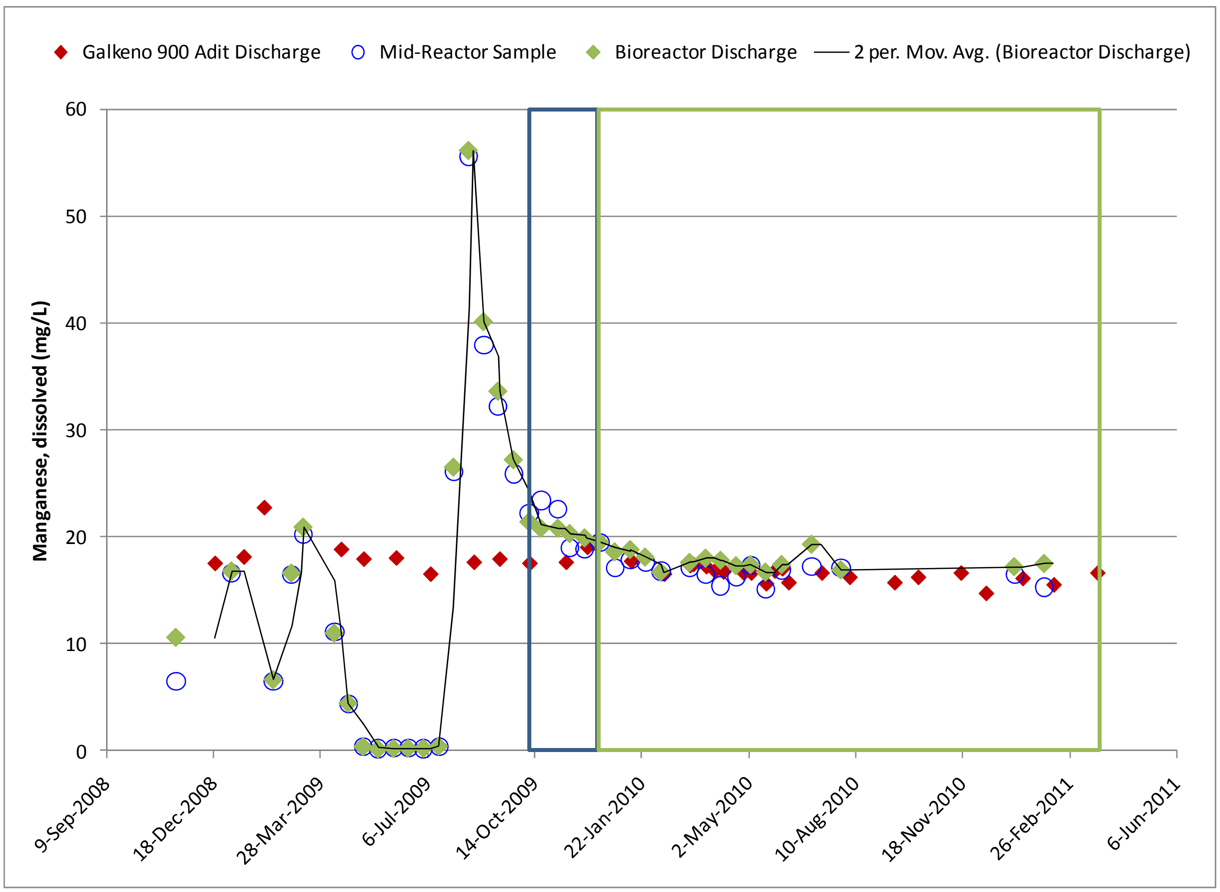


Figure 16 - Manganese Removal by the Galkeno 900 Bioreactor

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.

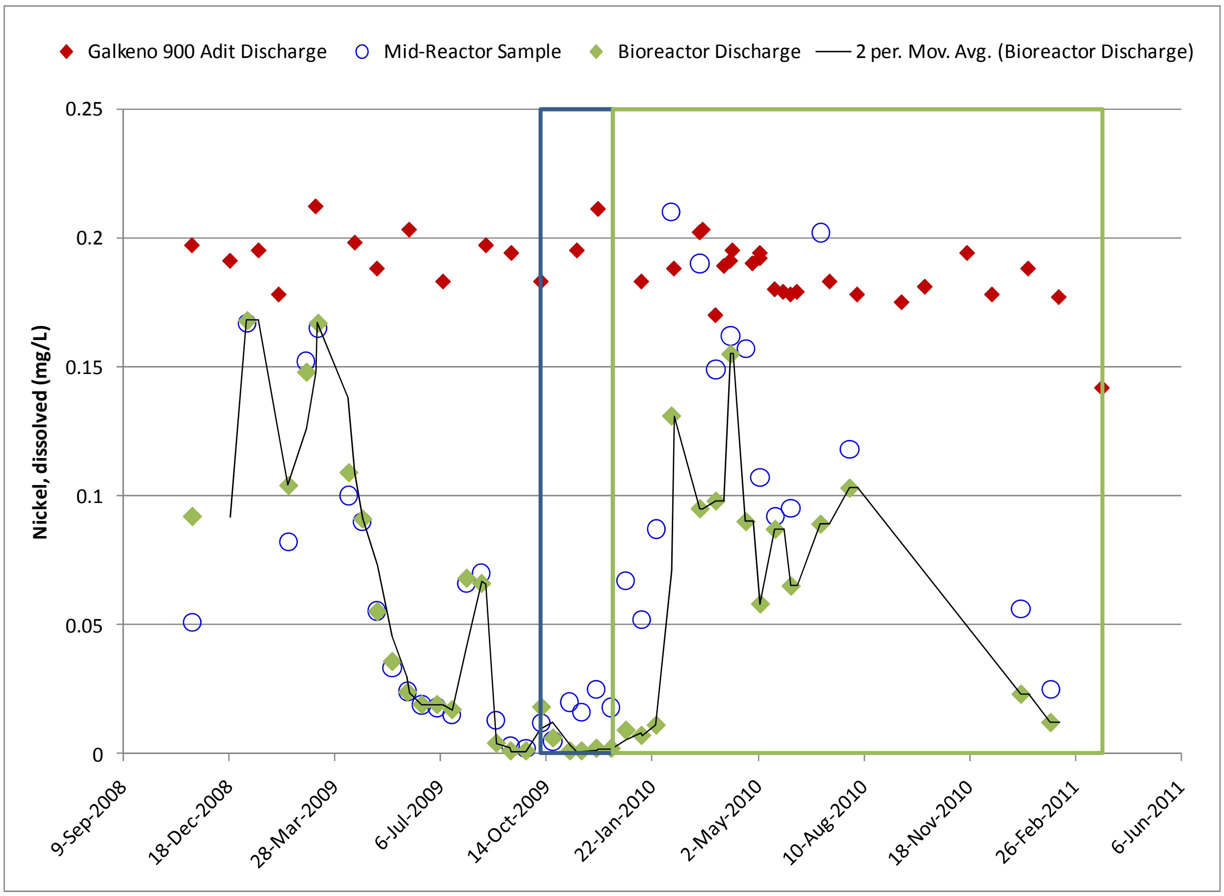


Figure 17 - Nickel Removal by the Galkeno 900 Bioreactor

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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Submitted, November 25, 2011

Table of Contents

List of Figures

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)

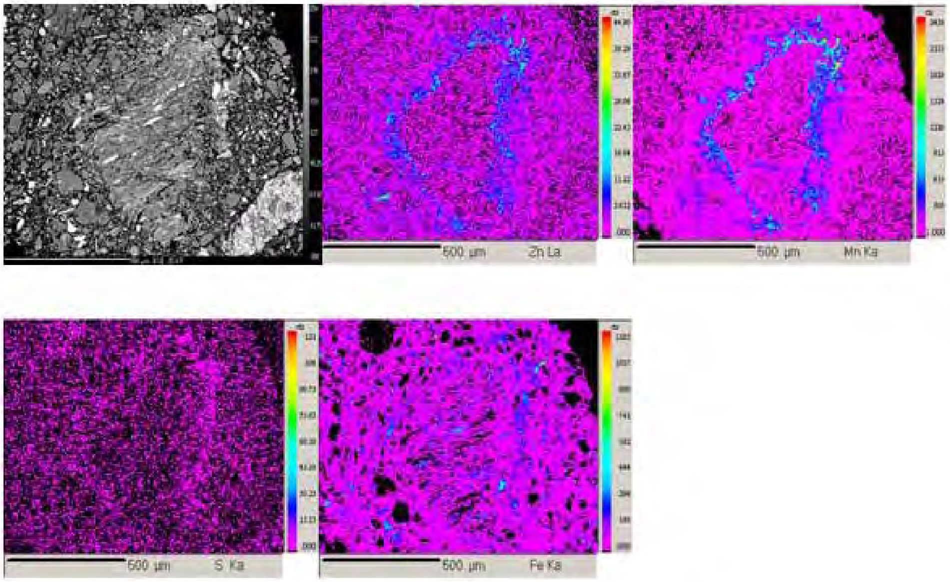

Figure 1: BSE images and element scans of Sample 8A FM Silt and Clay Bottom showing Mn and Zn rich coating around a lithic grain

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).

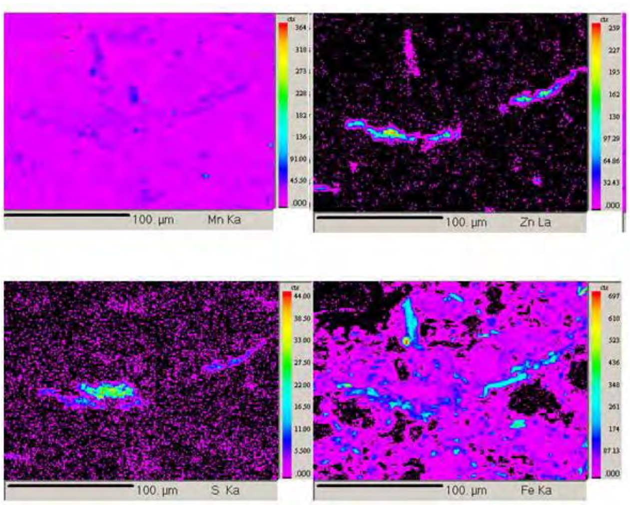

Figure 2: 1B G900 BIO BSE images and element maps

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).

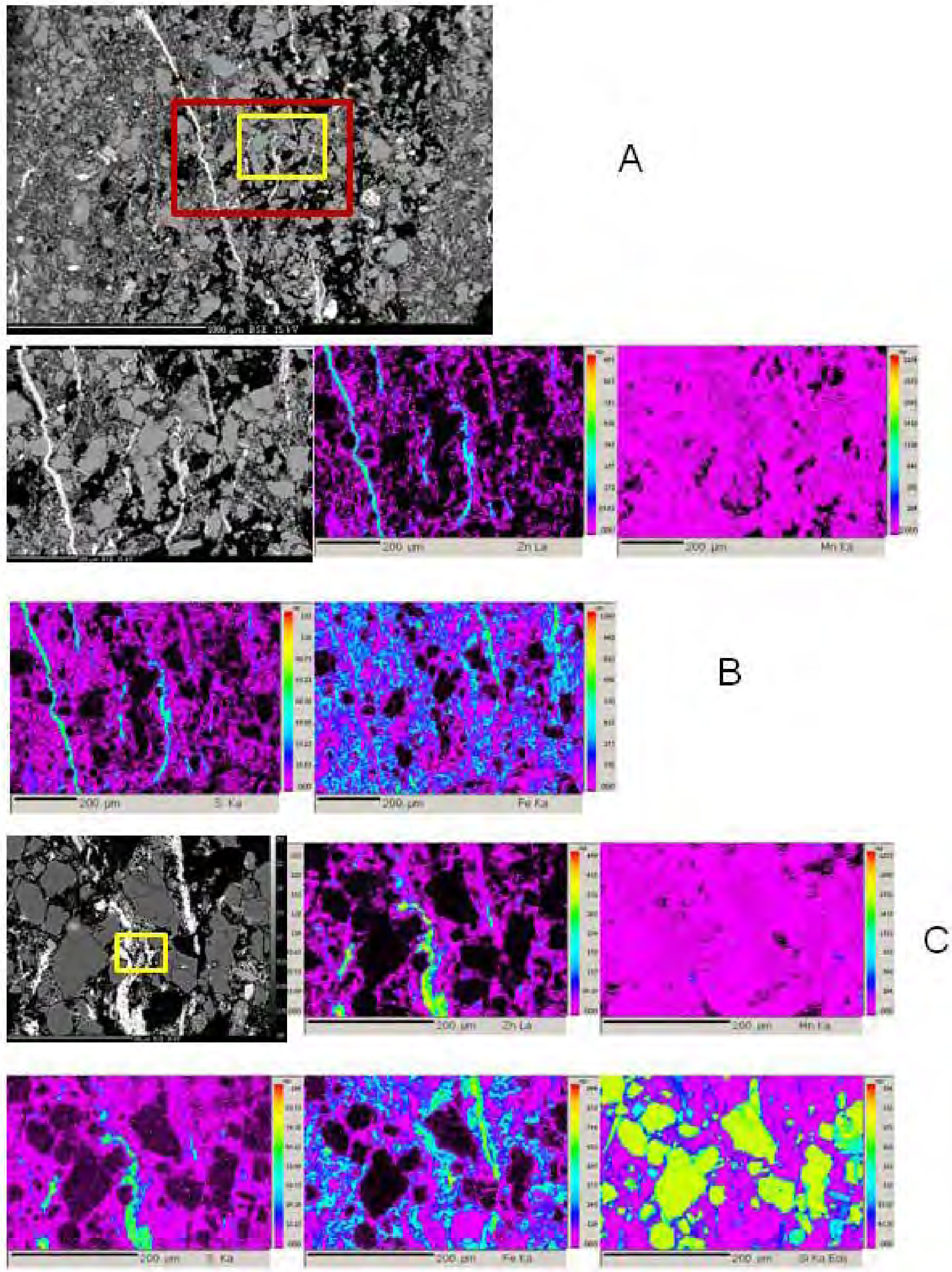

Figure 3 GK900 Bioreactor sample. (A) BSE image showing extensive bright bands of ZnS and Fe(B) BSE image and element scans of area in red box in (A) (C) BSE image and element scans of area yellow box in (A)

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.

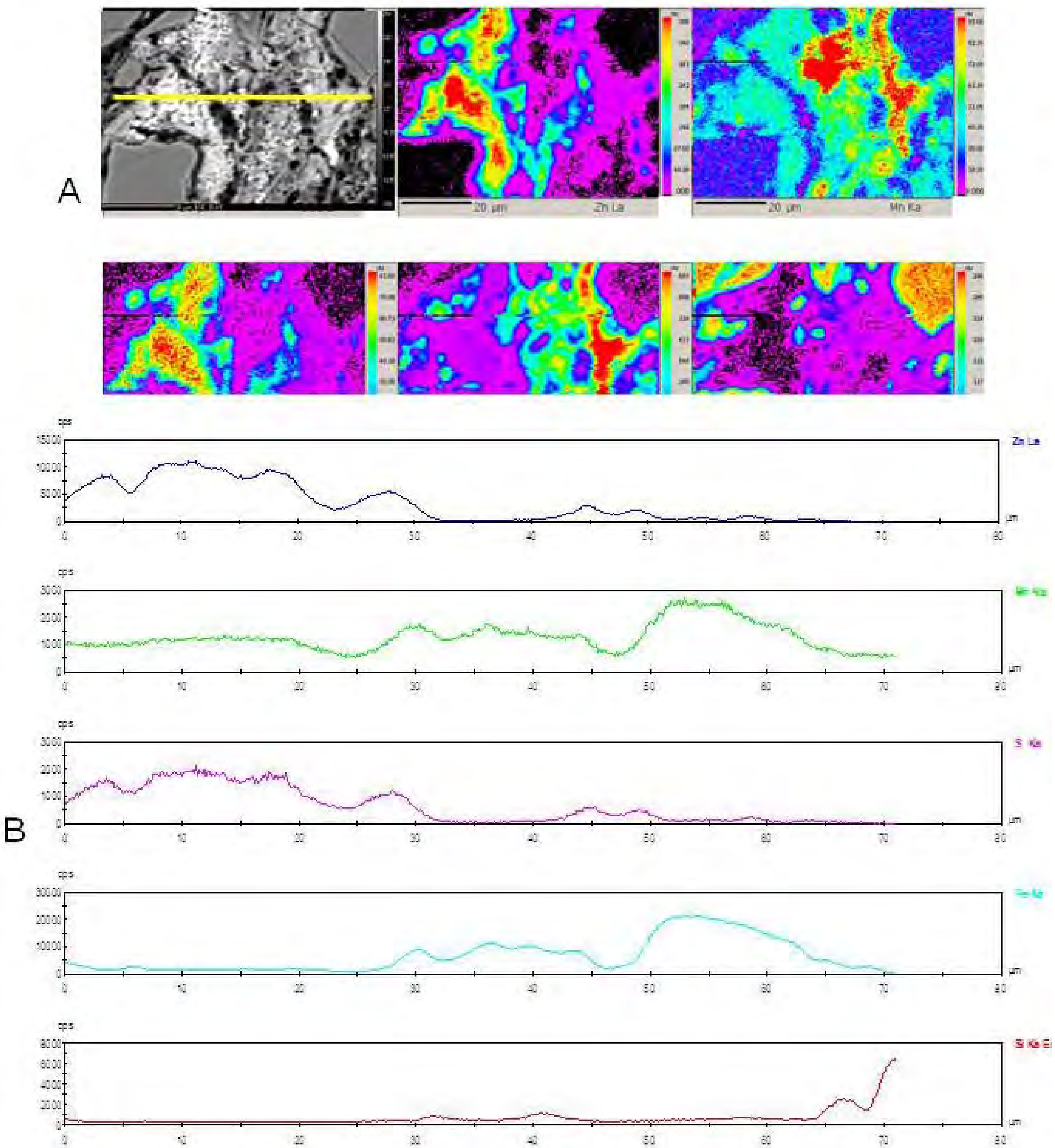

Figure 4: GK900. BSE image and element scans of area in yellow box in Figure 3 Element scans along the yellow line in BSE image (A)

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).

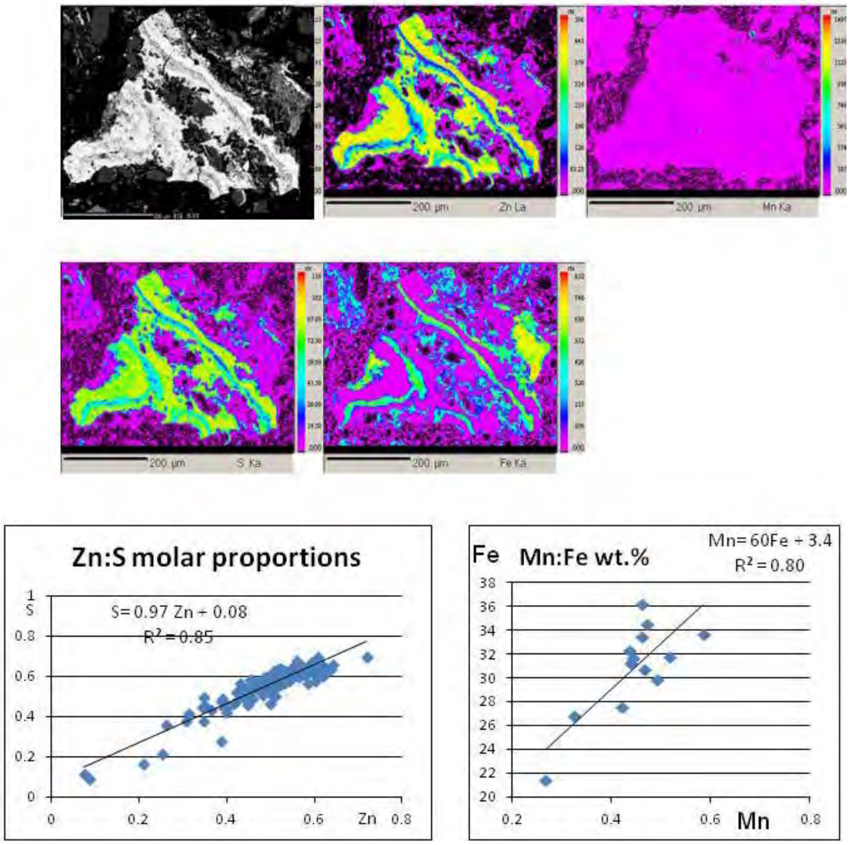

Figure 5: BioR sediment: BSE image and element maps showing the relation ship of Fe and Mn, Zn and S. Plots of molar Zn:S in the ZnS rich band and Mn:Fe wt % in the Fe rich band.

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.

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APPENDIX 1.4

PRELIMINARY ASSESSMENT OF PERFORMANCE FOR WRSA CLOSURE COVER SYSTEMS

March 30, 2015

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Ms. Fougere:

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

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

Project Context, Objectives, and Work Scope:

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

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

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

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

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

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

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

<u>Conceptual Model of Cover System Performance:</u>

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

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

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

$$MAP = 0.27 * Elev + 190$$

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

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

where:

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

Elev = elevation above sea level (masl).

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

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

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

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

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

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

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

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

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

<u>Preliminary Estimates of Cover System Performance:</u>

Cover Systems Modelled:

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

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

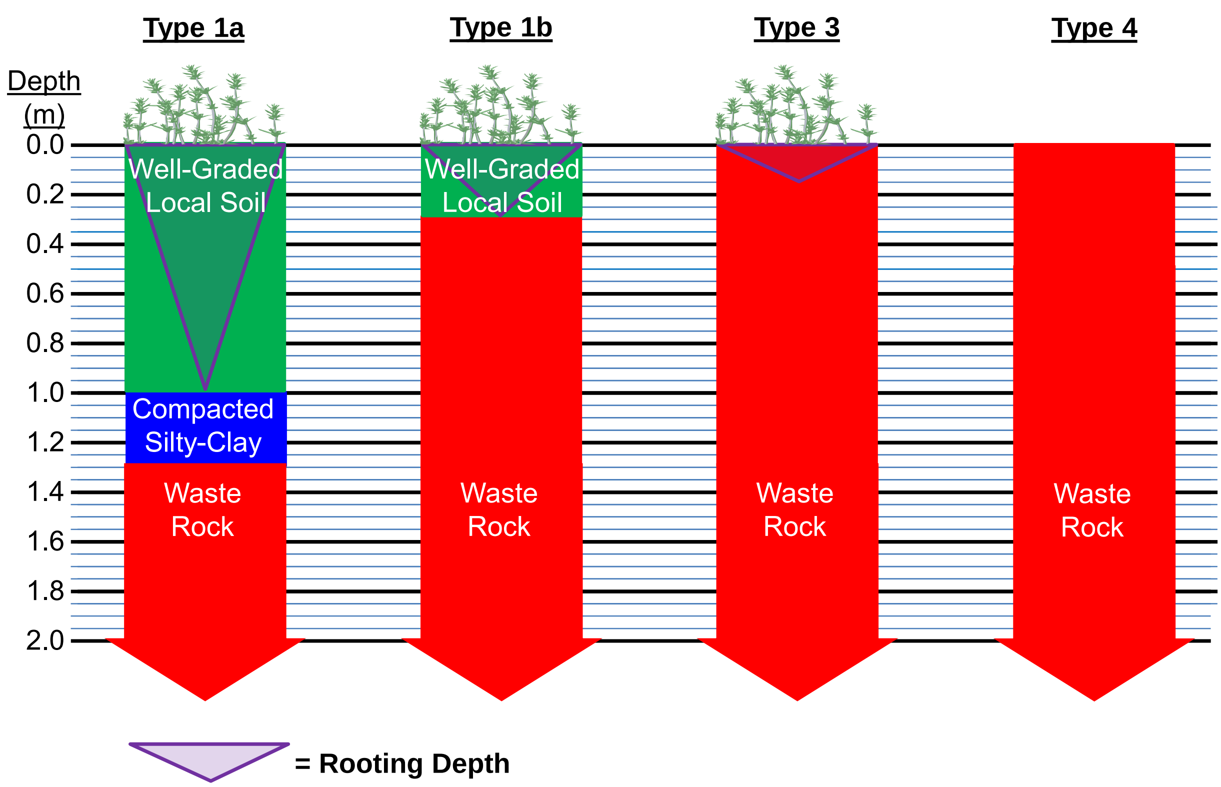

Figure 1 Schematic of four reclamation scenarios modelled for possible closure of WRSAs.

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

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

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

Key Inputs and Assumptions:

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

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

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

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

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

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

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

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

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

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

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

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

Key Modelling Results:

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

Practical Construction Issues for Consideration:

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

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

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

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

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

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

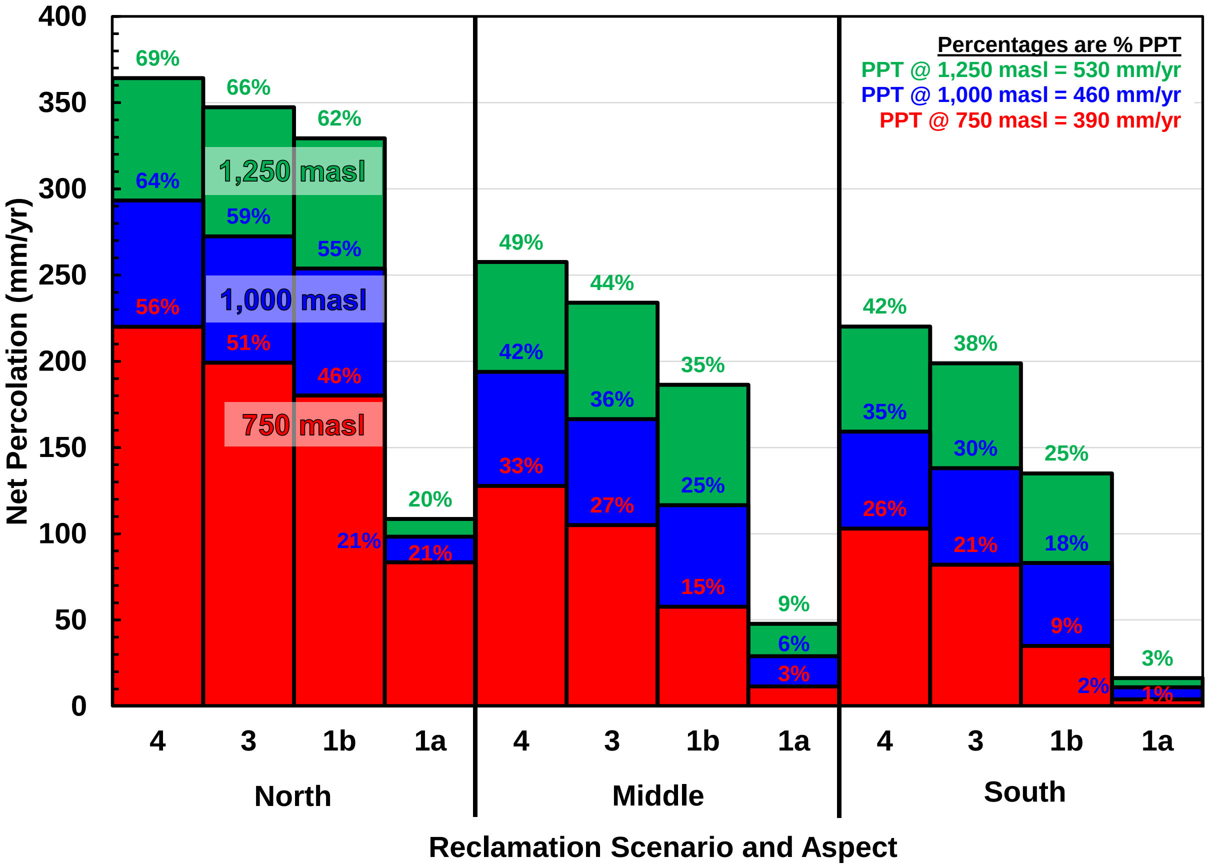

Figure 2 Annual average net percolation rates estimated for range of reclamation scenarios, elevations, and slope aspects.

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

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

Closure:

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

Sincerely yours,

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

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

APPENDIX 1.5

NATURAL ATTENUATION EVALUATION SUMMARY REPORT

DRAFT REPORT

Natural Attenuation Evaluation Summary Report

United Keno Hill Mines
Elsa, YT

Prepared for:

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Project No: 102003

November 2013

TABLE OF CONTENTS

Section No. **Page No.**

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 REPORT OBJECTIVES

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

1.2 PROJECT OBJECTIVES

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

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

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

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

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

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

1.3 PROJECT OVERVIEW

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

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

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

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

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

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

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

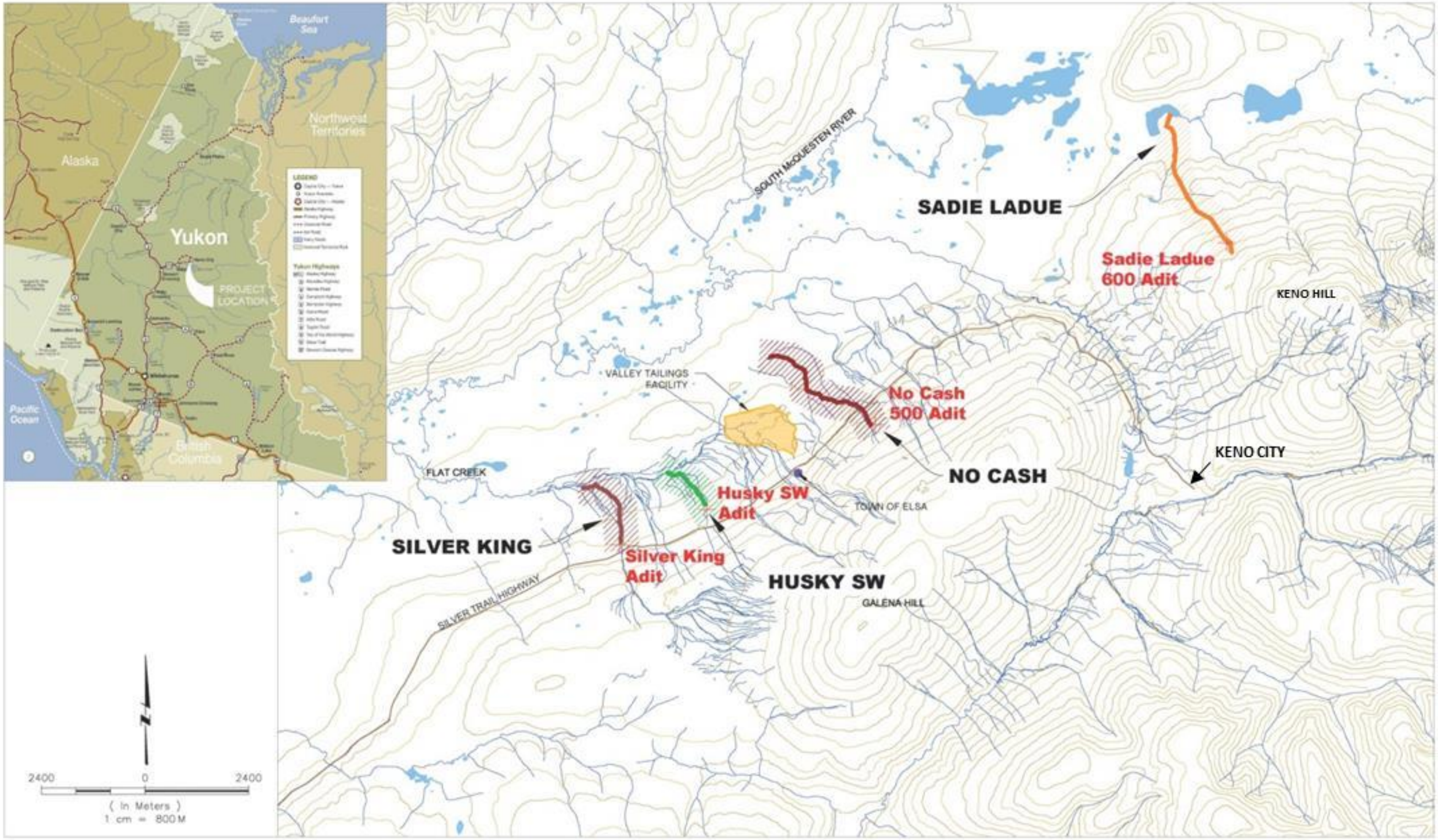
and Keno 700, are not suitable for natural attenuation as a closure option because of overly-elevated zinc/cadmium concentrations, unfavorable hydrologic flow characteristics, and/or the adit discharge does not flow through wetlands where attenuation processes are most effective. The Galkeno 300, Galkeno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

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

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

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

Figure 1 - Site Map and Attenuation Area Location



1.4 NATURAL ATTENUATION TARGET AREAS

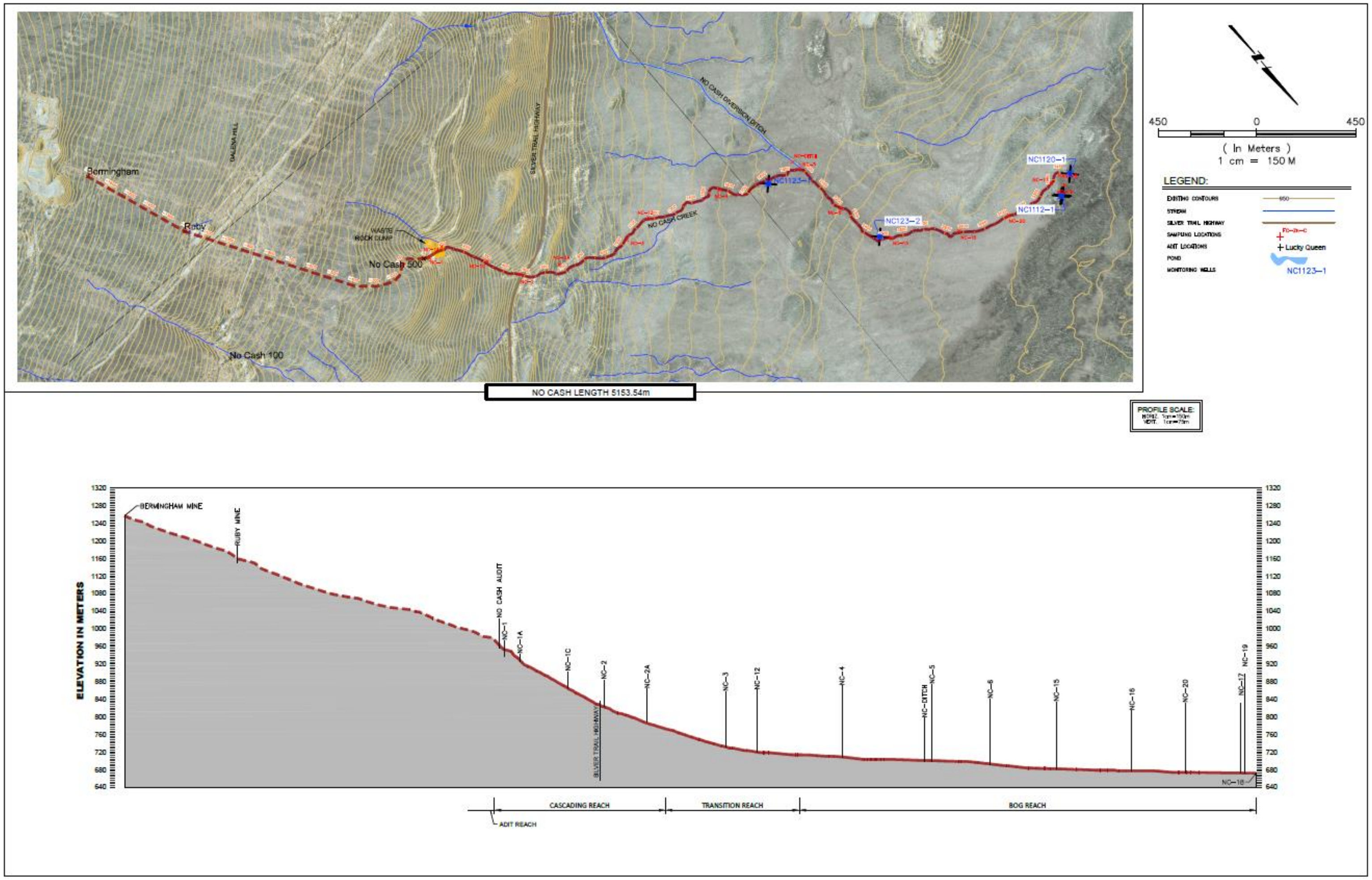
The areas originally targeted for evaluation for natural attenuation were NCC, Husky SW, Silver King, and Sadie Ladue. Each of these had low to moderate zinc mass loading, low to moderate flow, had a hillside (i.e., faster moving) reach where aeration could occur, and also flowed through peaty areas.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

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

1.4.1 NO CASH CREEK AREA

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

Figure 2 - No Cash Plan and Profile



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

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

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

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

Figure 4 - No Cash Creek Cascading Reach

Figure 5 - No Cash Bog

1.4.2 HUSKY SW AREA

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

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

Figure 6 - Husky SW Plan and Profile

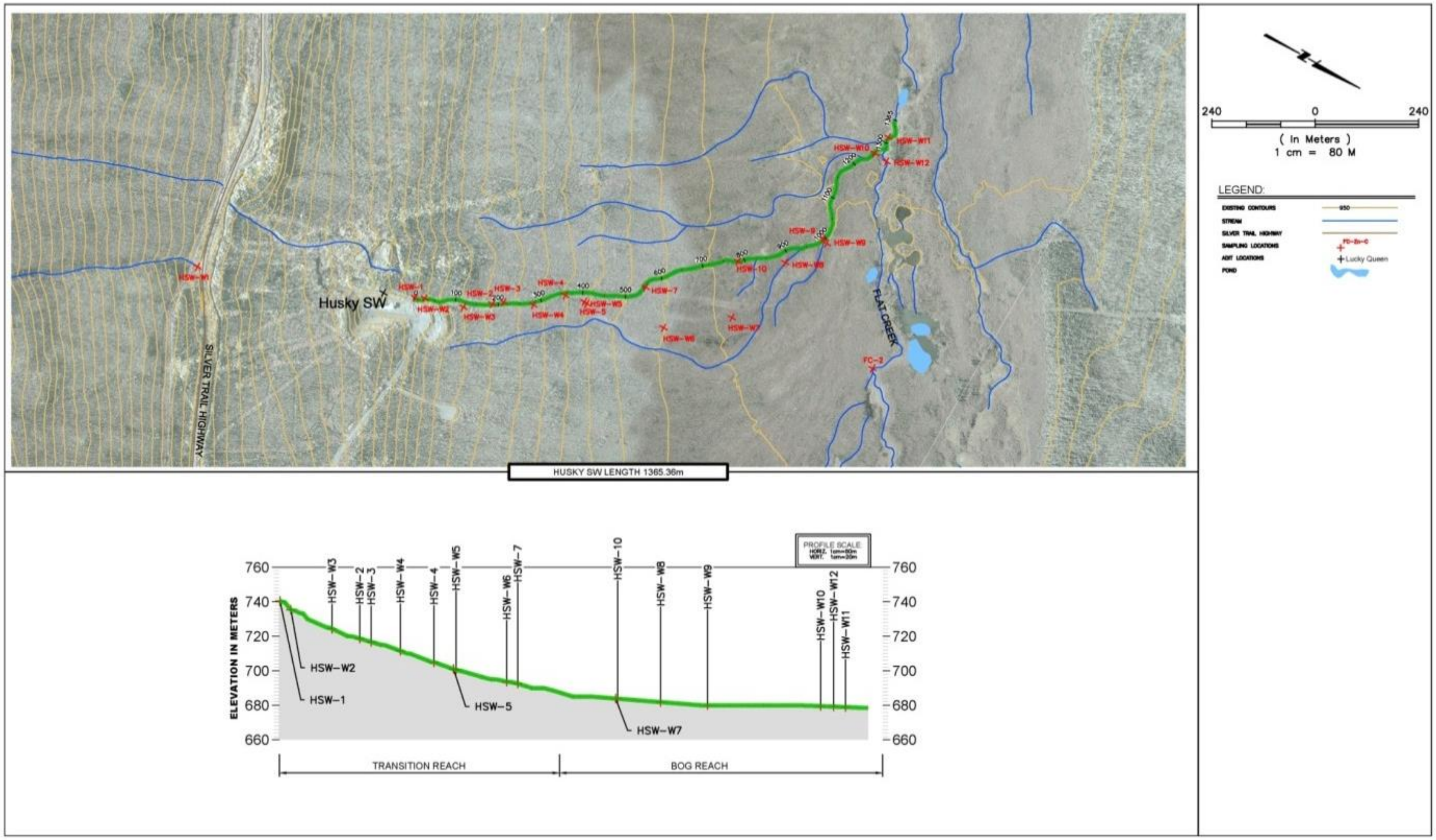


Figure 7 - Husky SW Crib Structure and Flow

Figure 8 - Sampling the Transition Reach of Husky SW

Figure 9 - Intersection of Husky SW and Flat Creek Drainages

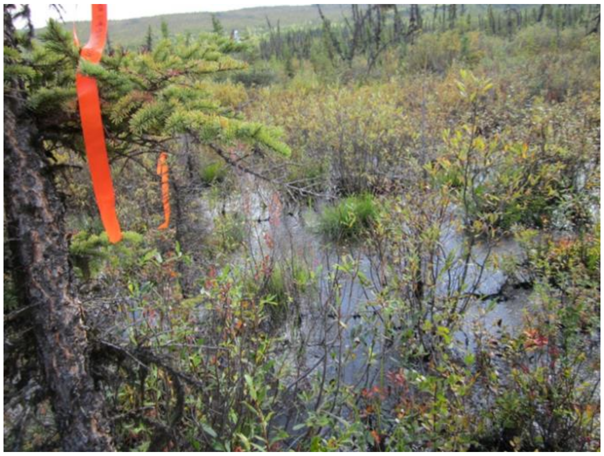


Figure 10 - Husky SW Bog Reach

1.4.3 SILVER KING AREA

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

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

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

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

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

Figure 11 - Silver King Plan and Profile

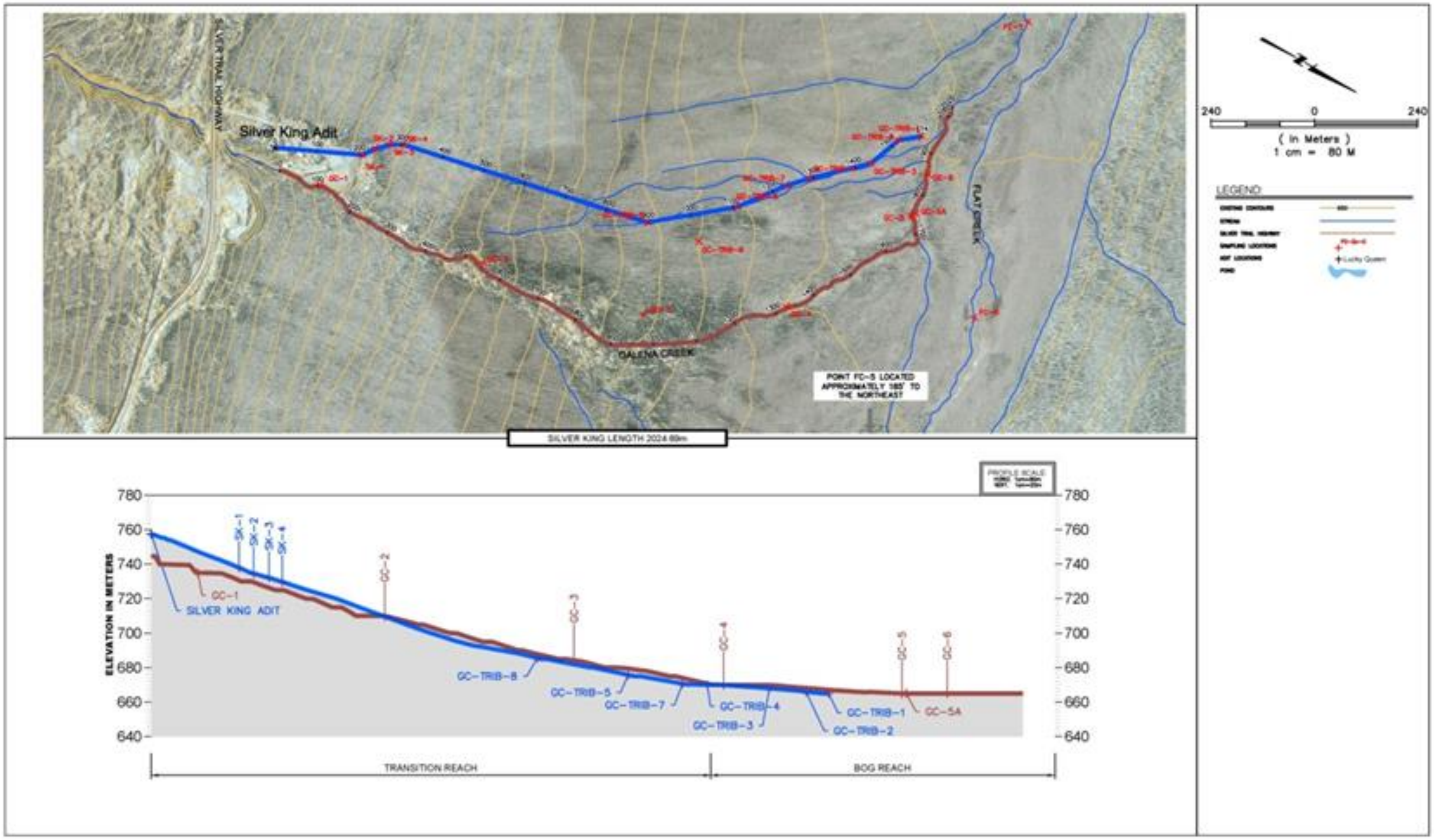


Figure 12 - Wooded Area North of Silver King 100

Figure 13 - Thermokarst Features in Silver King Drainage

Figure 14 - Silver King Bog Reach

2 STUDY METHODS

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

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

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

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

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

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

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

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

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

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

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

2.1 ANALYSIS OF ZINC AND CADMIUM GEOCHEMISTRY AND MINERALOGY

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

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

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

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

3 RESULTS

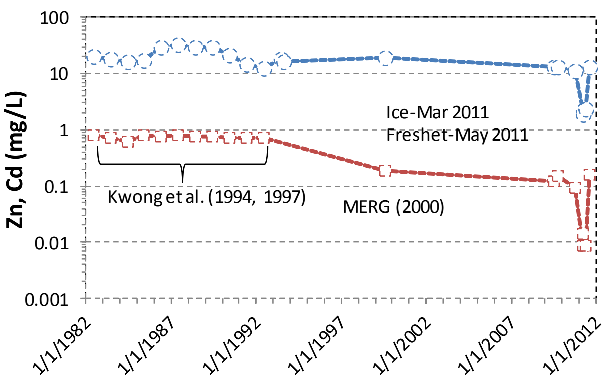
3.1 WATER CHEMISTRY

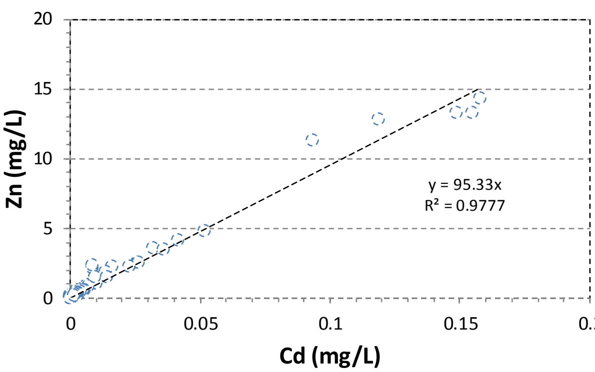
3.1.1 NO CASH CREEK

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

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

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





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

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

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

[a] Quartz mining water licence – effluent quality standard

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

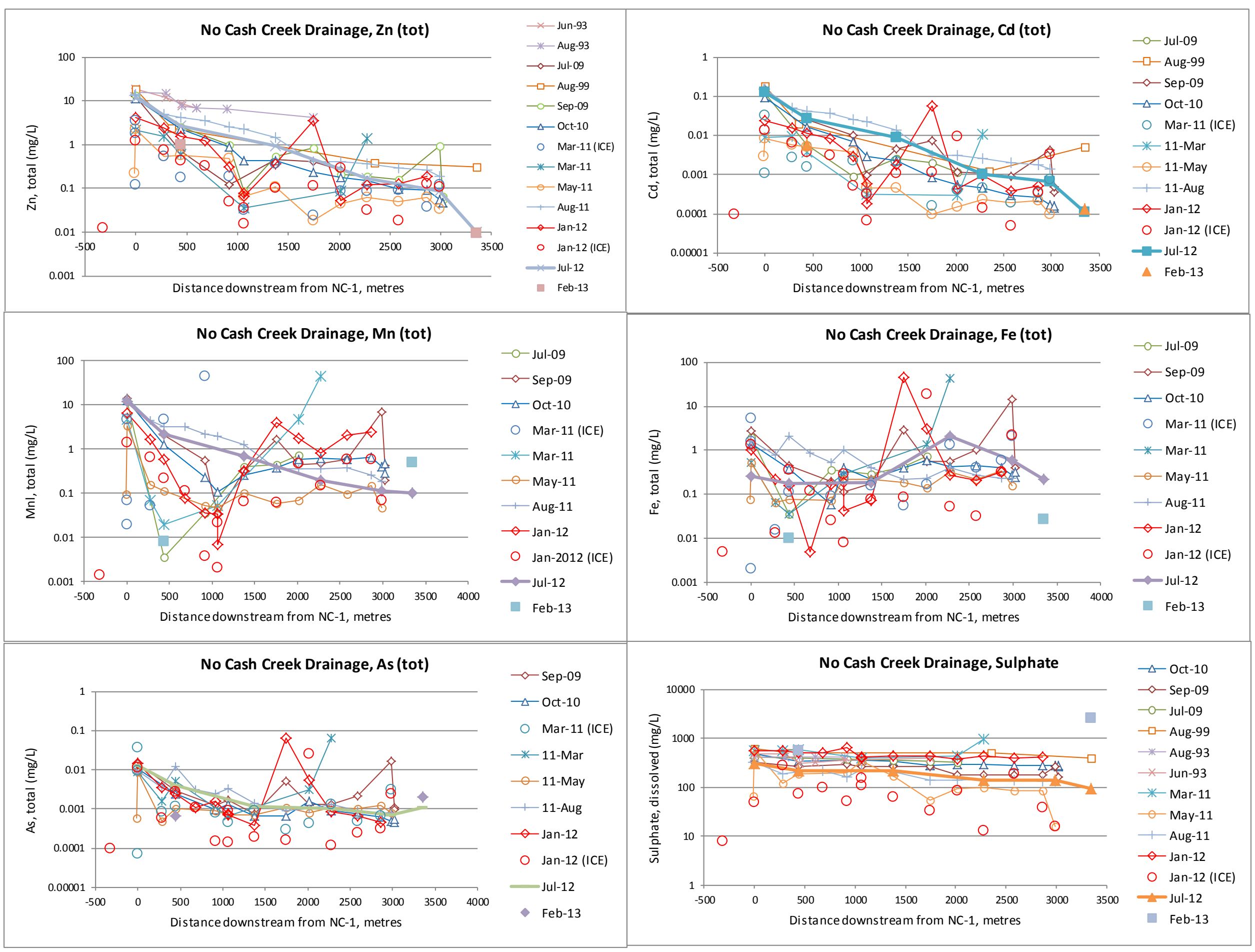
[c] Canadian Council of Ministers of the Environment – Protection of Aquatic Life

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

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

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

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



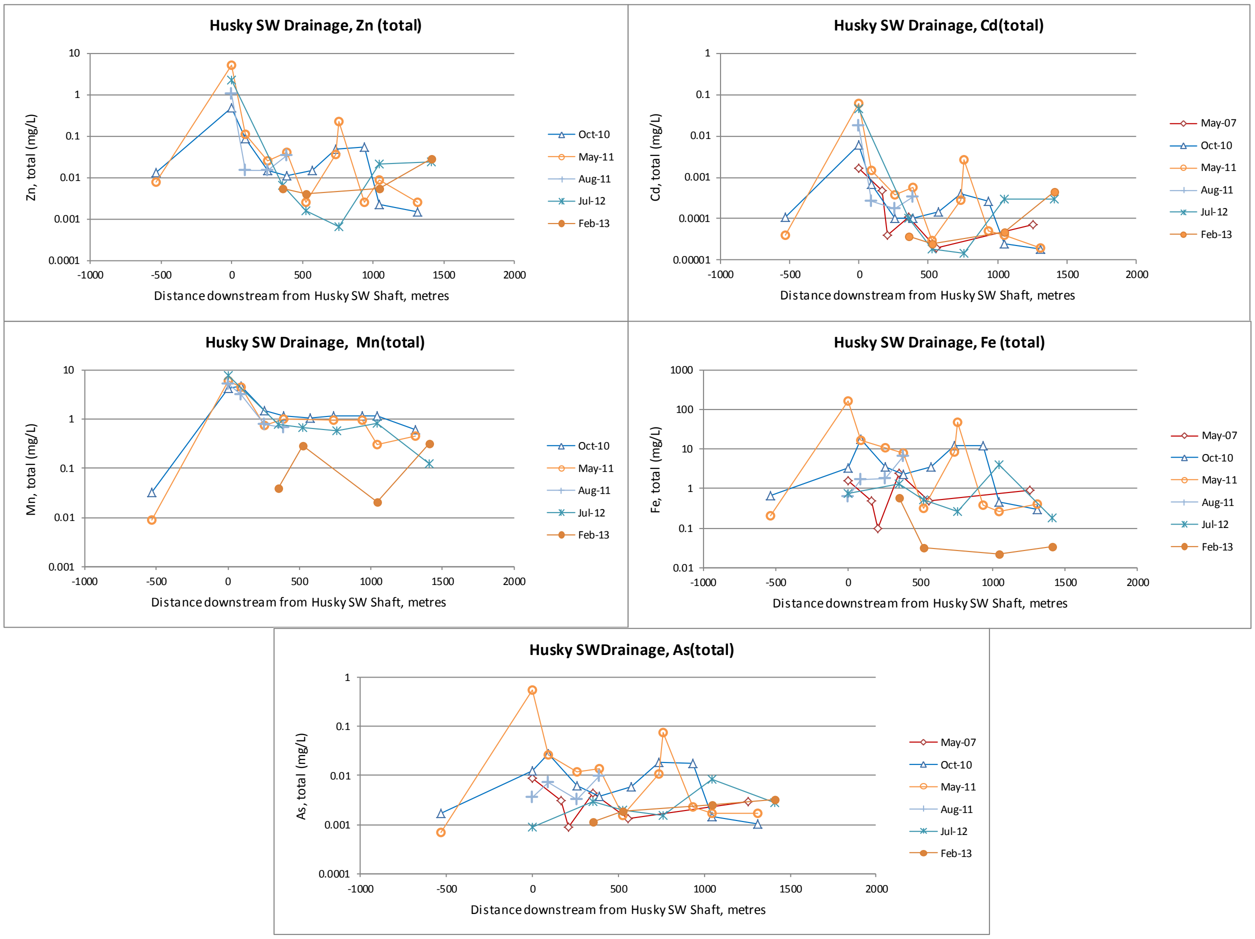
3.1.2 HUSKY SW

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

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

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

Figure 17 – Selected analyte trends along the Husky SW drainage



3.1.3 SILVER KING

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

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

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

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

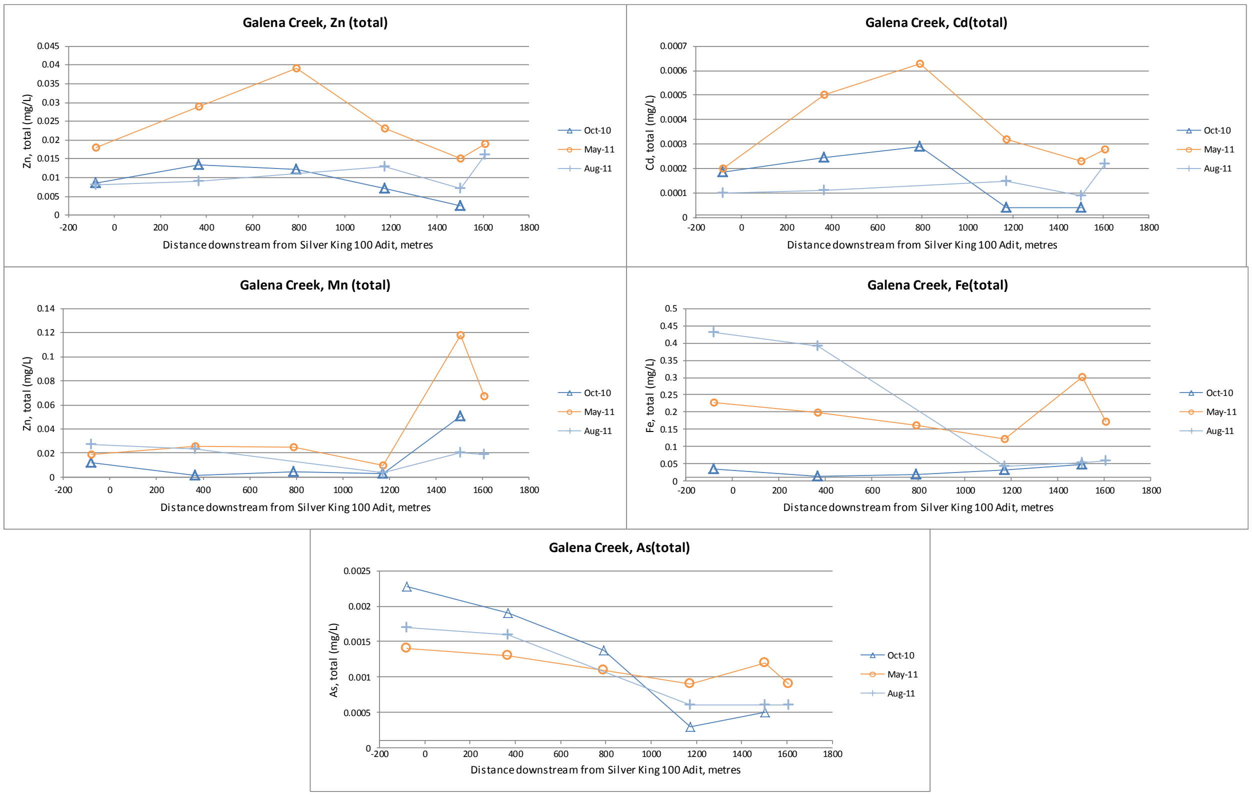
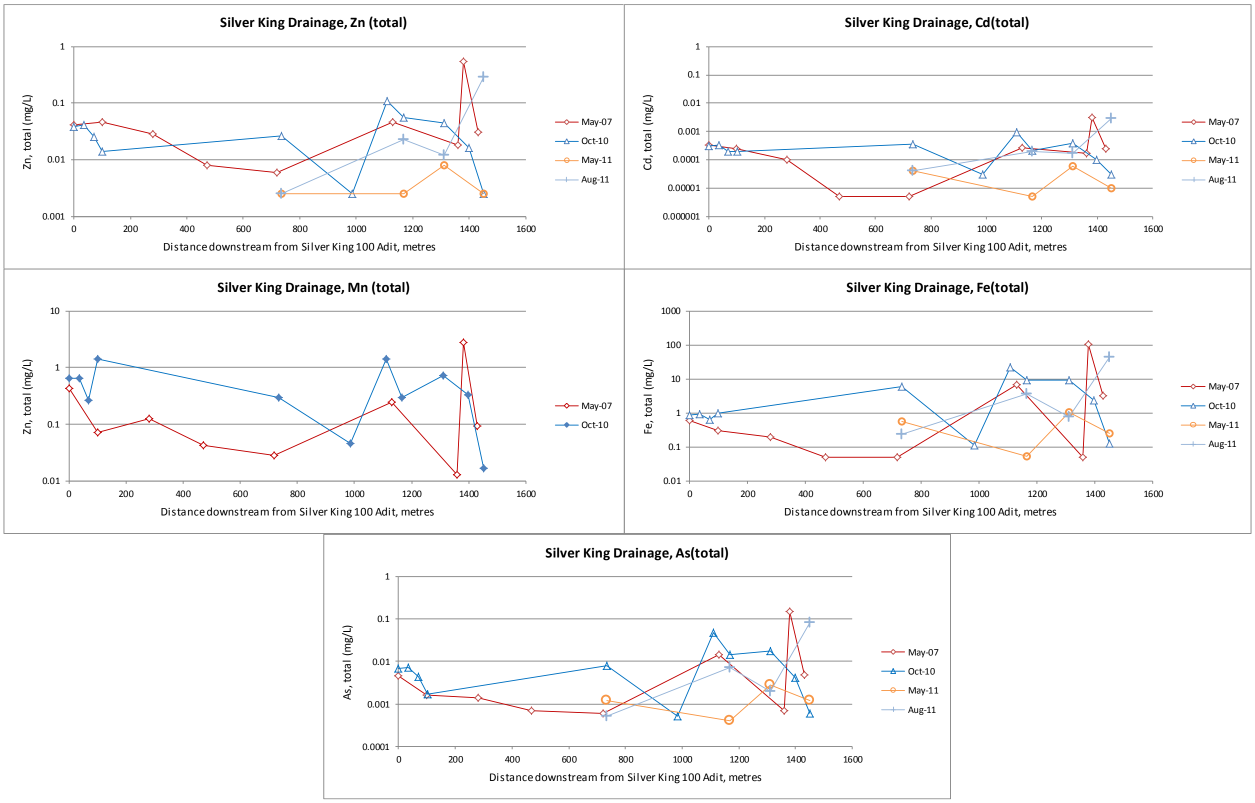


Figure 19 - Selected water chemistry trends along the Silver King decant drainage



3.2 SOLID PHASE GEOCHEMISTRY

3.2.1 NO CASH CREEK

3.2.1.1 GEOCHEMICAL AND MINERALOGICAL CONTROLS ON ZINC AND CADMIUM ATTENUATION

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

3.2.1.2 ZINC AND CADMIUM SEQUESTRATION IN UPPER "CASCADING" REACH

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

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

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

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

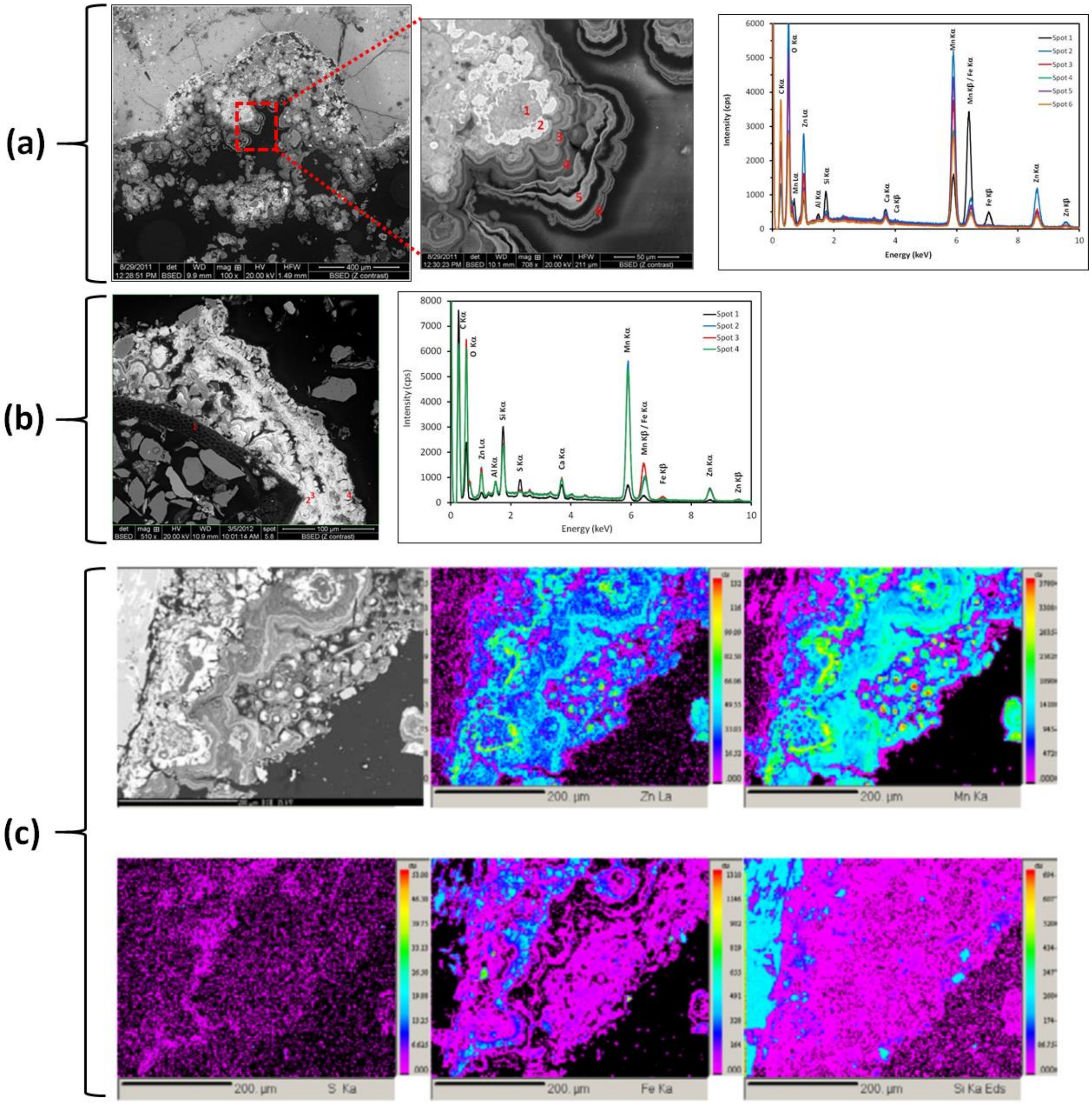


Figure 21 - (a) EMP and (b) LA-ICP-MS line scans across colloform particle coatings observed in No Cash Creek thin sections. Note the close correlation between manganese, zinc and cadmium. Little correspondence was observed between cadmium, zinc and iron, although arsenic concentrations appeared to follow those of iron.

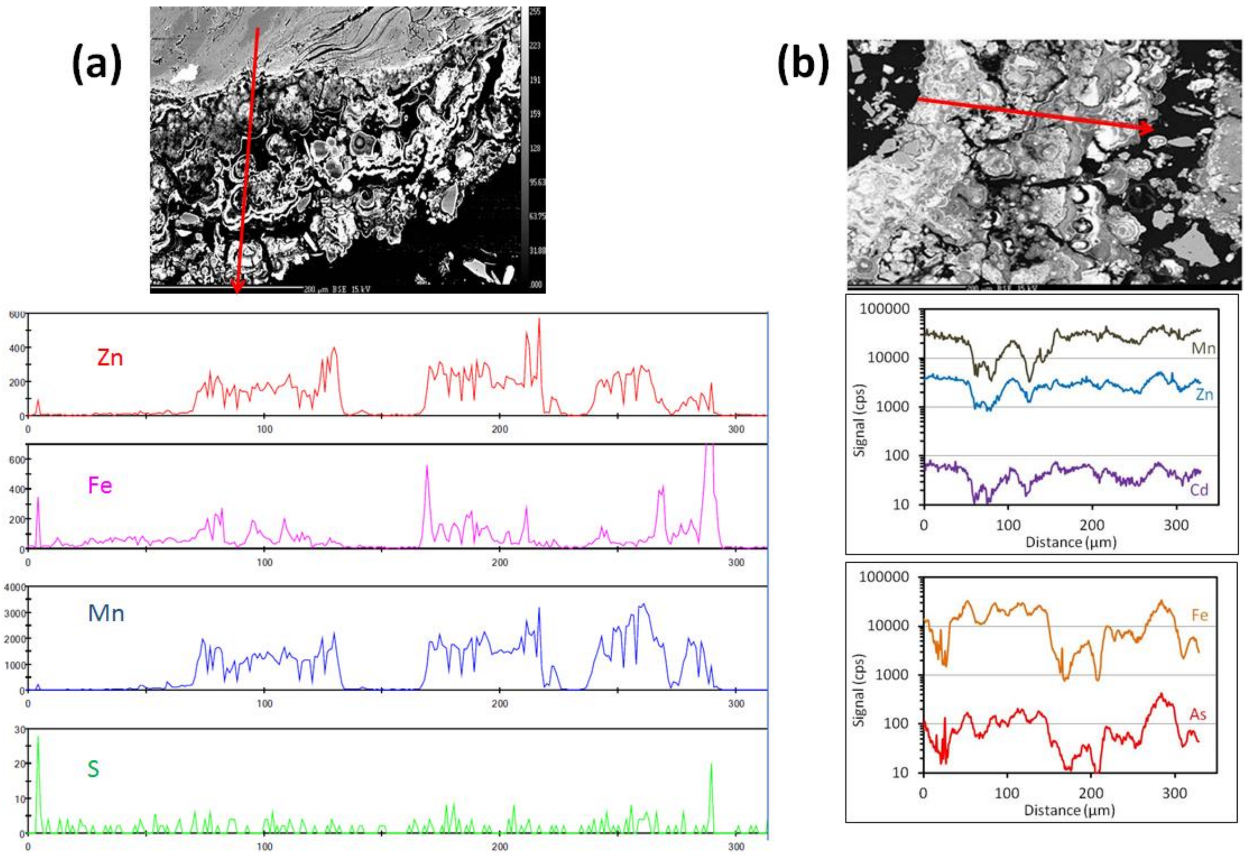


Figure 22 - (a) Backscattered electron and (b) associated synchrotron-based μ-XRF tricolor element map showing the distribution of iron (red), manganese (green) and zinc (blue) in a colloform rim on a lithic particle in a thin section sediment sample collected close to the No Cash Creek adit. Numbers denote points where (c) μ-XRD measurements were collected, which indicated that hydrohetaerolite ($Zn_2Mn_4O_8.H_2O$) was the primary nanocrystalline phase present in the manganese-zinc-rich coating.

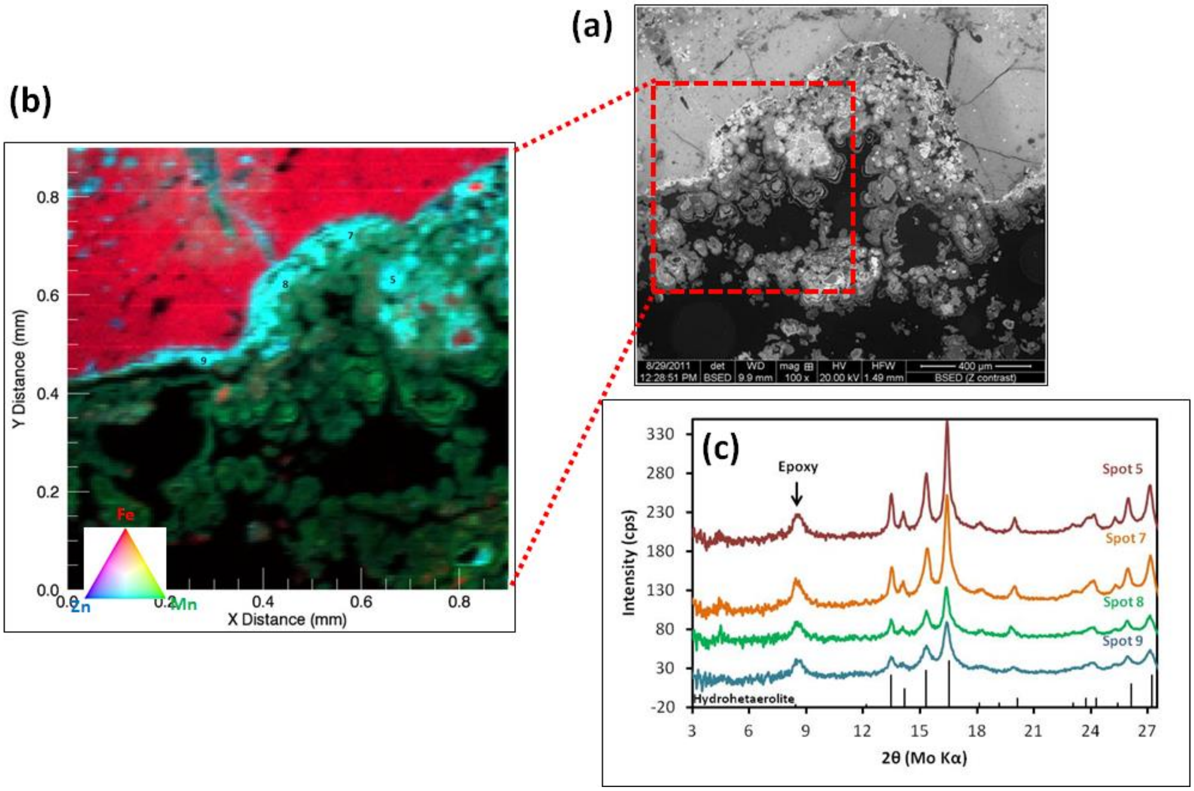
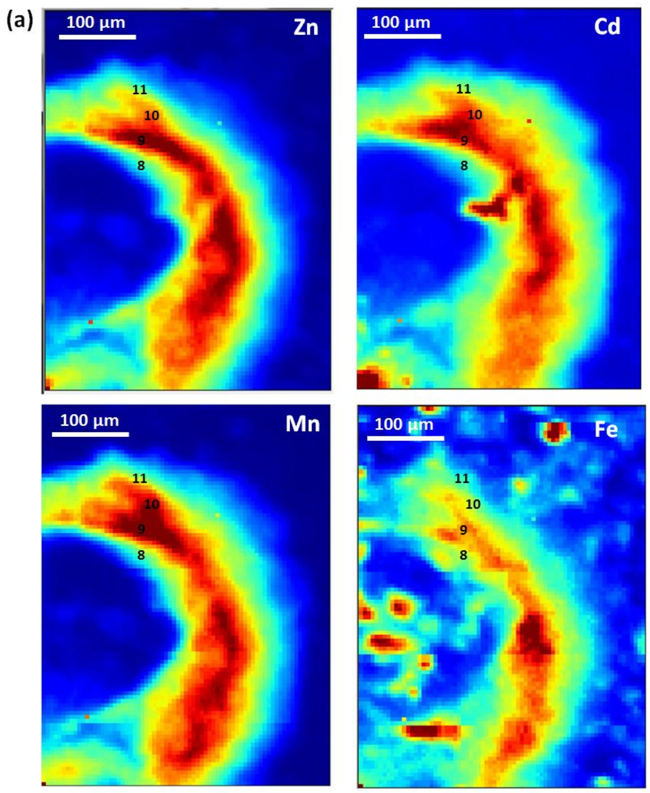
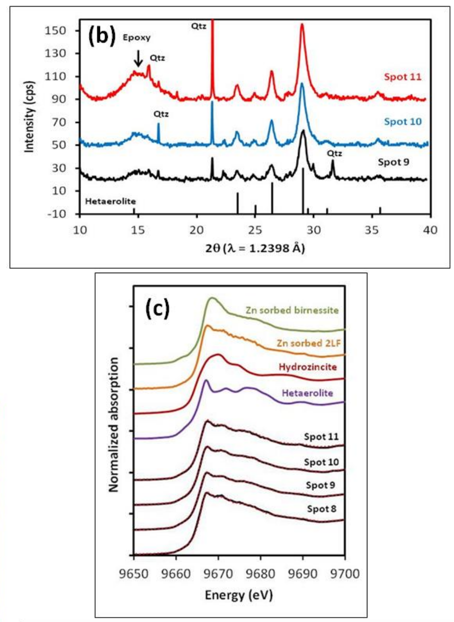


Figure 23 - (a) Synchrotron-based µ-XRF maps of zinc, cadmium, manganese and iron distribution in the colloform rim imaged by backscattered electrons in Figure 20 (b). Numbers denote spots where (b) µ-XRD and (c) zinc µ-XANES measurements were taken. Red dotted lines to sample µ-XANES data represent the best fit listed in (d)





(d)	Hetaerolite	Hydrozincite	Sorbed ferrihydrite	Sorbed birnessite
Spot 8	12%	-	83%	-
Spot 9	44%	32%	24%	-
Spot 10	40%	20%	32%	8%
Spot 11	33%	14%	44%	11%

While zinc and cadmium were predominantly associated with oxidized phases in the colloform coatings, sphalerite ((Zn,Fe)S) grains were also observed occasionally (Figure 24). These appeared to be primarily detrital based on particle morphology and the presence of weathering rims, however, small spheres (1 – 3 μm diameter) of putatively biogenic sphalerite were also observed in one sample collected at 8" depth (Gault et al., 2012, 2013; #38NC12). These were associated with organic structures, perhaps suggesting the presence of micro-niches of microbial sulphate reduction, which may offer added redundancy in zinc (and cadmium) sequestration should reducing conditions develop deeper in the sediment column and further downgradient into the No Cash wetland area.

Zinc and cadmium XANES analyses were also performed on the bulk sediments to evaluate the average speciation in the sediments. Only the adit sediment had a high enough cadmium concentration for cadmium K-edge XANES to be collected, and this was again indicative of a cadmium sorption complex. Zinc bulk XANES were obtained from sediments collected along the watercourse (Figure 25, Table 4). Close to the adit, the data were best fitted with zinc sorbed on ferric oxyhydroxides and birnessite with additional hetaerolite and hydrozincite contributions. Moving downstream zinc was still associated with ferric oxyhydroxides, while zinc-humate complexes became more prominent components as the creek moved into the more organic rich, boggy portion of its reach.

Figure 24 - (a) Backscattered electron image of small (1 – 3 µm diameter) electron dense particles within an apparent organic (cellulose?) matrix found in a No Cash Creek thin section. Red numbers denote spots where (b) energy dispersive spectra were collected, indicating the dominance of zinc and sulphur. (c) Corresponding synchrotron-based µ-XRF maps of zinc, cadmium, manganese and iron distribution and (d) zinc µ-XANES and (e) cadmium µ-XANES point analyses, which suggest the zinc and cadmium is present as sulphide phases.

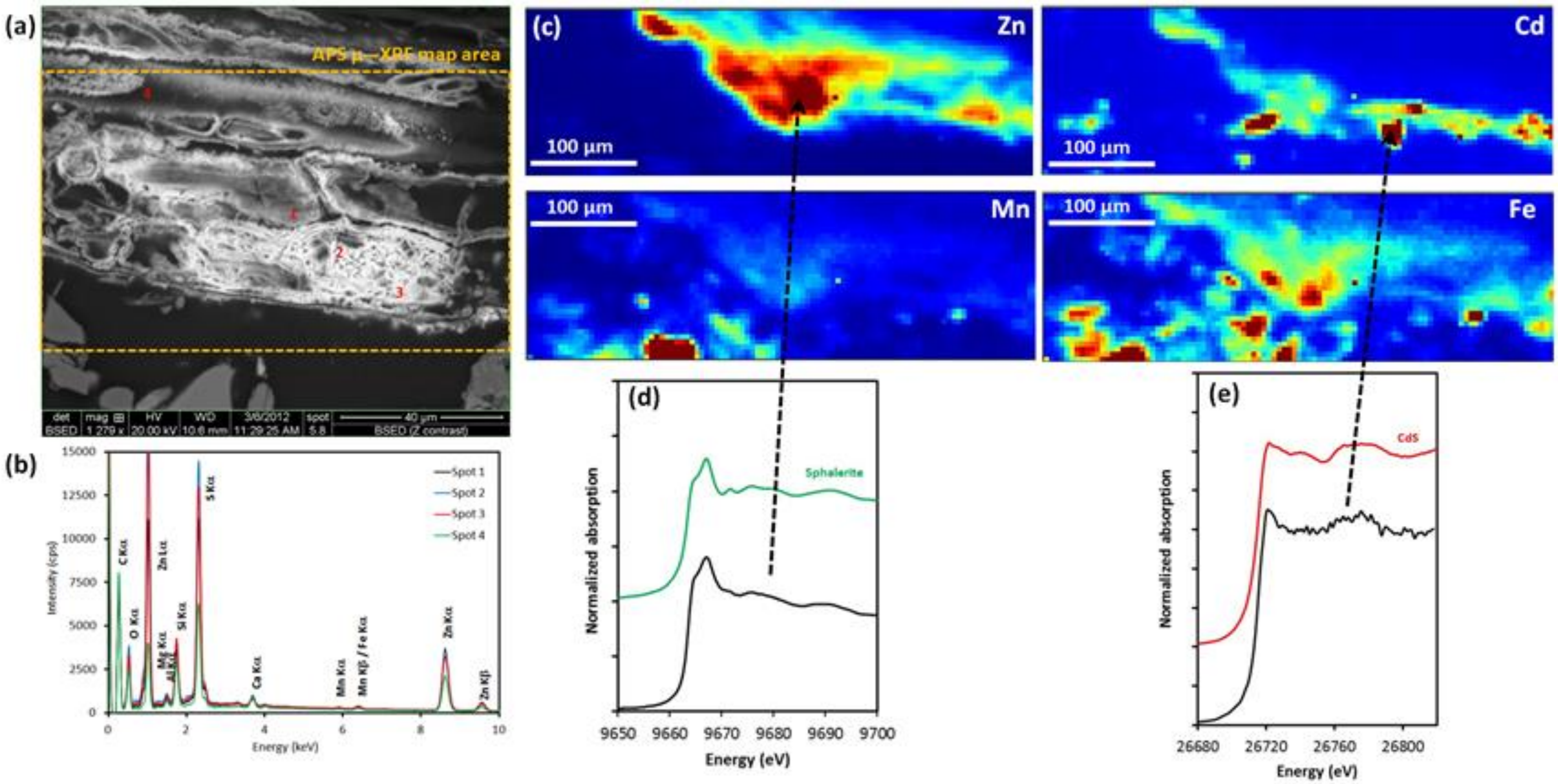


Figure 25 - (a) Zinc K-edge XANES spectra of model zinc-bearing phases used in fitting sample spectra. (b) Zinc K-edge XANES spectra collected for bulk No Cash Creek sediments. Black, solid lines represent sample data and red, dotted lines the best fit listed in Table 4.

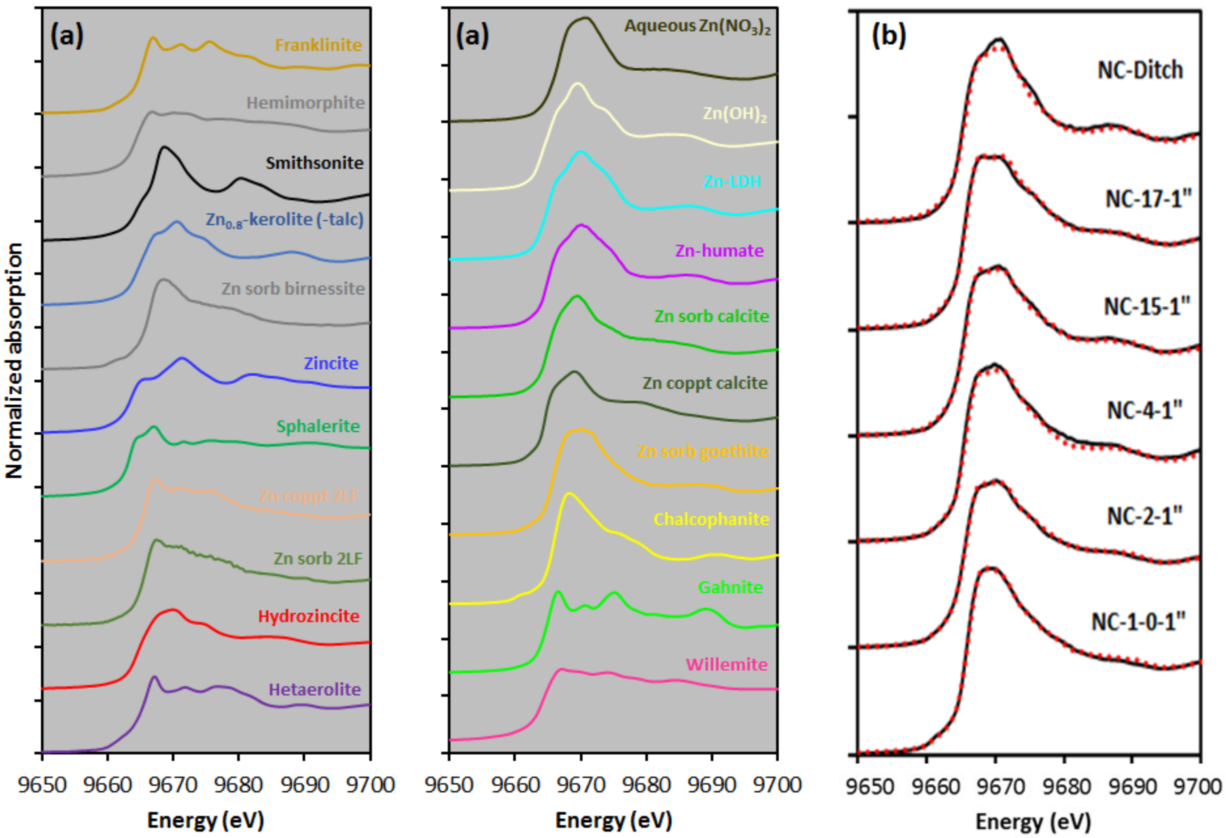


Table 4 - Best fits for bulk zinc K-edge XANES data collected for No Cash Creek bulk surficial sediment samples[a]

		Proportion of Zn present as:										
	Zn (mg/kg)	Coppt 2LF[b]	Sorbed 2LF	Sorbed goethite	Zn-humate	Sorbed birnessite	Hetaerolite	Chalcophanite	Sorbed calcite	Hydrozincite	Sphalerite	$Zn_{0.8}$-kerolite (-talc)
NC-1-0-1"	41,100	-	24	49	-	29	-	-	-	-	-	-
NC-2-1"	3,800	-	17	26	17	-	17	-	-	23	-	-
NC-4-1"	3,540	32	-	28	15	-	-	-	24	-	-	-
NC-15-1"	2,020	-	38	11	42	-	-	-	-	-	7	-
NC-17-1"	1,760	44	-	37	-	-	-	-	20	-	-	-
NC-ditch	186	11	-	-	71	-	-	11	-	-	-	6

[a] The components were not forced to sum to 100% during the fitting process (typically 97 – 103%)
[b] “2LF” denotes 2-line ferrihydrite; “coppt” indicates “co-precipitated with”

3.2.1.3 ZINC AND CADMIUM SEQUESTRATION IN LOWER “BOG” REACH

Approximately 1,000 m downstream of the adit, NCC transitions from its steep “cascading” reach into the much flatter “bog” reach as it travels through a peaty wetland. In the subsequent 2,500 m of the bog reach, aqueous zinc and cadmium concentrations decline further as this portion of the watercourse acts as a polishing step to the rapid zinc and cadmium removal observed upstream. It is hypothesized that the zinc and cadmium are removed via sorption on the peat, although co-precipitation with iron/manganese (oxyhydr)oxides and reductive precipitation as sulphide-bearing phases are also possible. Visual and smell-based observations of black sulphides in quiescent sediments along the saturated bog areas have also been noted throughout the No Cash wetland areas.

Column experiments using peat collected from the NCC wetland have been conducted to assess the role of peat in zinc and cadmium attenuation (Alexco Environmental Group, 2011). Two metre columns were packed with peat from the No Cash area and operated under (i) Column experiments using peat collected from the NCC wetland have been conducted to assess the role of peat in zinc zinc and cadmium attenuation (Alexco Environmental Group, 2011). Two metre columns were packed with peat from the No Cash area and operated under (i) saturated conditions, where water flowed upwards from the bottom, filling the column and was sampled at the top; and (ii) unsaturated conditions, where water was added to the top and allowed to percolate through the column before collection at the base. Water from the Galkeno 900 adit was passed through the columns, which contained initial zinc and cadmium concentrations of 5.76 and 0.0014 mg/L, respectively. Two pore volumes of water were passed through the columns per week and 54 pore volumes were run in total. Zinc and cadmium removal by the peat column was >99% and 94%, respectively, for both saturated and unsaturated experiments for the entirety of the experiment. Significant manganese removal (94%) was also observed for the unsaturated column, with minimal loss of sulphate (<2%), suggesting that aerobic processes such as co-precipitation with manganese (oxyhydr)oxides may have been the primary driver of zinc and cadmium removal, alongside sorption on organic matrices. In the saturated column, manganese removal was much less pronounced (16%), while 22% of the sulphate was removed, indicating that microbial sulphate reduction and the associated precipitation of zinc and cadmium as sulphide phases may be a prominent sequestration process in this column.

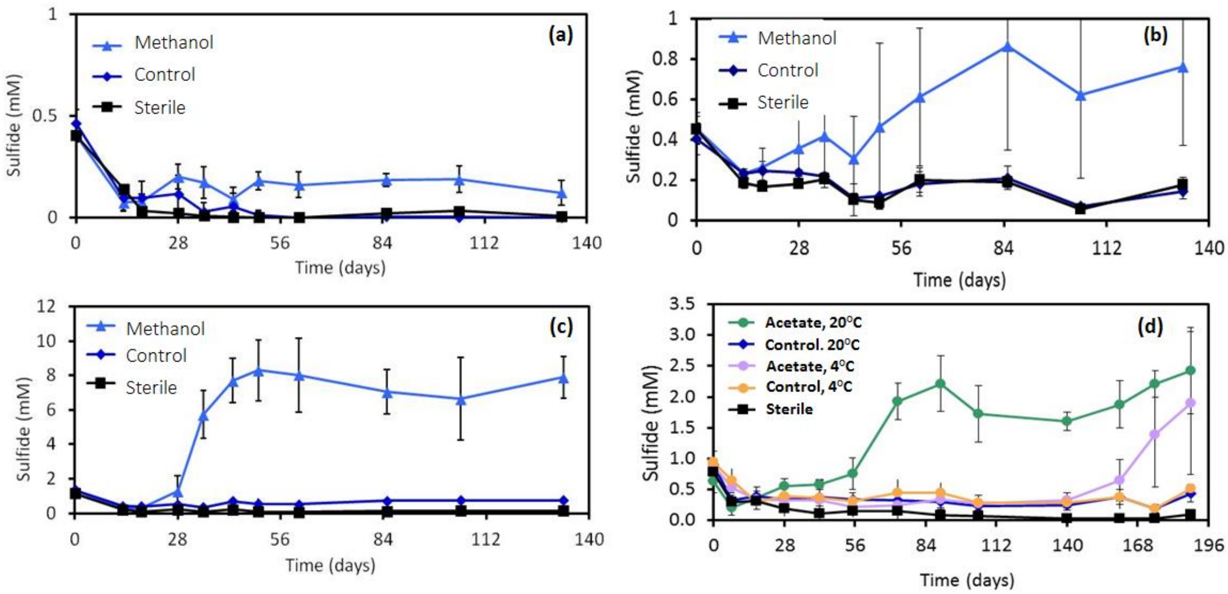
Similar attenuation of cadmium and zinc has been observed in twinned wells in the Valley Tailings Facility screened above and below the peat layer that underlies the tailings. Here, groundwater concentrations of zinc and cadmium are more than three orders of magnitude lower beneath the peat layer than in the tailings porewater (SRK, 2009). This was recorded in an area where tailings have been present for at least 50 years with zinc and cadmium tailings porewater concentration orders of magnitude higher than those in the lower reach of NCC, demonstrating the longevity of the natural metal attenuation offered by this peat layer. The penetration depth of metal contamination into the peat layer is typically <0.5 m (Interralogic, 2012b).

3.2.1.4 MICROBIOLOGY OF NO CASH CREEK SEDIMENTS

Sediments were collected near the No Cash 500 level adit and approximately 250 m downstream for microbiological examination. They were incubated under anoxic conditions in the presence of a variety of organic electron donors in order to assess the importance of such substrates to the onset of microbial sulphate reduction (Londry, 2013). Similar experiments were also conducted at 4 and 20°C to evaluate the role of temperature. Minimal microbial sulphate reduction was observed in both the adit and downstream sediments (Figure 26), ascribed to the high sedimentary metal concentrations which may hinder microbial activity. The addition of an electron donor such as methanol or acetate enhanced the extent of sulphate reduction, while colder temperatures delayed the onset of sulphate reduction by approximately 3 months (Figure 26d), but once established, the rates of sulphate reduction at both 4°C (1.8 mg/L/d) and 20°C (2.2 mg/L/d) were comparable (Londry, 2013). That organic electron donor amendment was required to initiate marked microbial sulphate reduction suggests that the sediments were deficient in the labile organic carbon required to drive this process, however, the work did show that a small community of sulphate-reducing bacteria was present in the NCC sediments. This was reflected in the 16S rRNA profiling work, which indicated that 0.4 – 0.8% of the 16S rRNA gene pyrotags were matched to the Deltaproteobacteria, known to host a wide range of sulphate-reducing bacteria. *Thiobacillus* (9%) species were prominent in the adit surface sediment, suggesting that metal oxidation is likely an important biogeochemical reaction occurring at this site. Psychrophilic *Polaromonas* (9%) species were also prominent in the adit sediment samples, and their presence is consistent with the culturing experiment results that demonstrated sulphate reduction at 4°C.

Given the low abundance of sulphate-reducing bacteria in these sediments, it is unlikely they play a significant role in zinc and cadmium sequestration in the aerobic, upper cascading reach of NCC, but microbial sulphate reduction is likely an active process and an important mechanisms of zinc and cadmium attenuation in the shallower, peaty bog portion of NCC.

Figure 26 - Sulfide production in cultures established from the No Cash Creek (a) adit surface sediment, (b) adit 18" depth sediment, and (c,d) sediment collected 250 m downstream of the adit



3.2.1.5 STABILITY TESTING OF NO CASH CREEK SEDIMENT

Although the streambed precipitates appear durable under the prevailing geochemical conditions (Interralogic, 2012a), future potential changes in temperature, pH or redox conditions along NCC could possibly change their stability. In this work, precipitate collected from close to the No Cash 500 adit was subjected to a variety of environmental stresses, ranging from changes in temperature and pH, to more aggressive (and less likely) tests such as strongly reducing conditions. Such information will help frame the geochemical window of stability for these precipitates, and aid future monitoring and adaptive management programs by identifying geochemical conditions under which metal remobilization might be expected.

Sediment was collected within a few metres of the No Cash 500 adit, mixed with water collected further downstream, and subjected to shake flask style experiments (Gault and Jamieson, 2013). The sediment-water slurry was mixed at 200 rpm on an orbital shaker at 4°C for 48 h, then a sample was taken to establish the baseline analyte conditions. An environmental variable (Table 5) was then changed, the sample shaken for a further 48 h, and a final sample collected to examine the impact of the environmental variable on the mobility of zinc and cadmium.

A temperature rise of 5°C resulted in the mobilization of some zinc and cadmium, whereas a rise of 10°C caused a reduction in soluble zinc concentrations and had negligible impact on cadmium (Figure 27). Such contrasting results are likely due to the competing effects of enhanced mineral dissolution rates and lowered metal carbonate solubility with increasing temperature. Threefold and twofold rises in zinc and cadmium concentrations, respectively, were noted at the end of a rapid freeze thaw experiment. This was attributed to enhanced CO_2 solubility during the cooling step of the experiment, which likely drove the 0.5 pH unit drop observed and promoted partial metal carbonate dissolution and desorption of zinc and cadmium from iron/manganese (oxyhydr)oxide surfaces.

Equilibrium pH increases of 0.5 and 1.2 pH units (from a starting point of pH ~7.2) caused marked drops in dissolved zinc and cadmium due to precipitation as/with metal hydroxide and carbonate phases (Figure 27). Lower pH systems were not examined directly since the NCC watercourse is well buffered and not expected to become acidic. Experiments were conducted that involved some removal of alkalinity (up to 56%), resulting in reductions in aqueous zinc and cadmium levels (Figure 27).

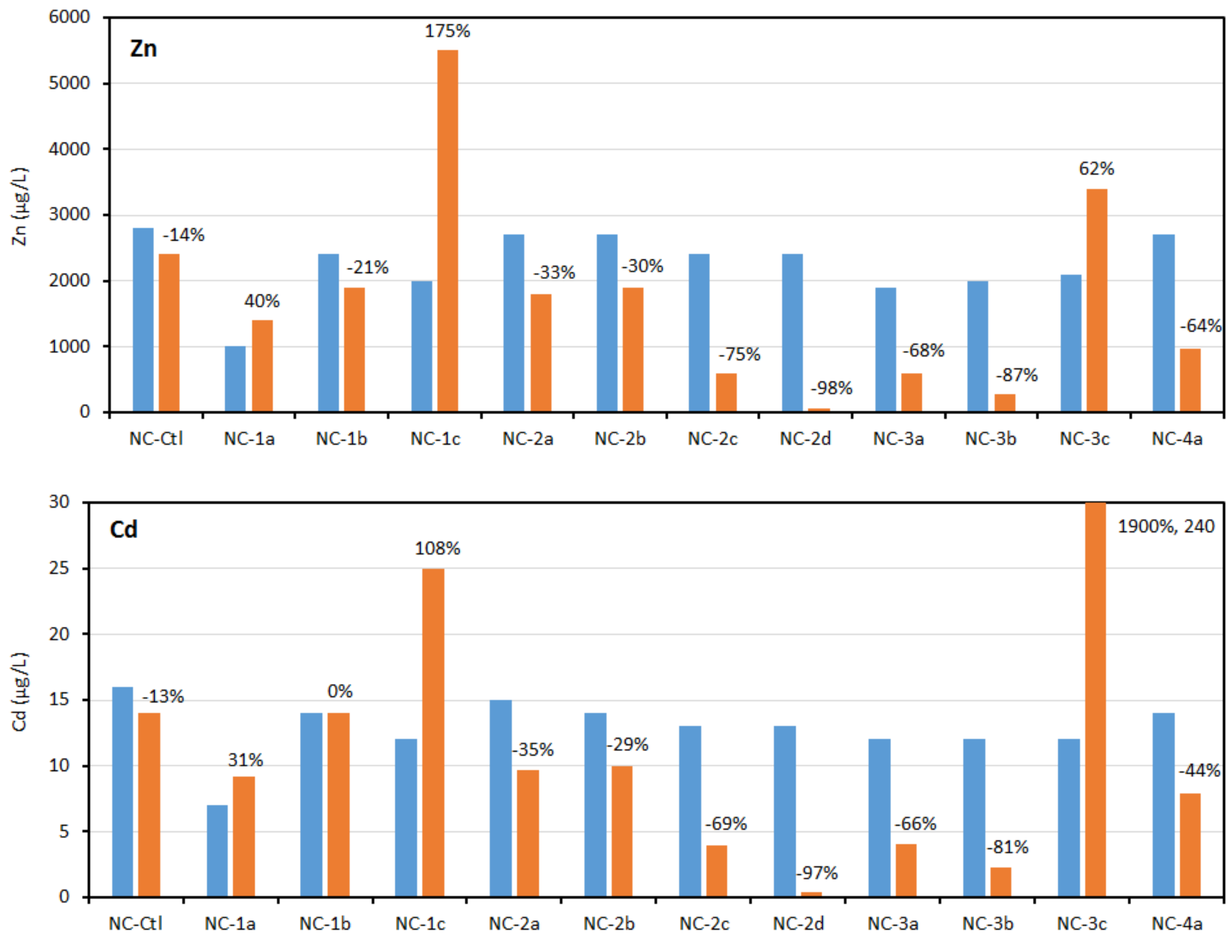
Table 5 - Stability test environmental variables.

Test ID	Variable	Description
NC-1a	Temperature	Increase temperature by 5° C
NC-1b	Temperature	Increase temperature by 10° C
NC-1c	Temperature	Freeze/thaw
NC-2a	pH/alkalinity	Titrate out 33% of alkalinity
NC-2b	pH/alkalinity	Titrate out 66% of alkalinity
NC-2c	pH/alkalinity	Raise pH by 1 standard unit
NC-2d	pH/alkalinity	Raise pH by 2 standard unit
NC-3a	Redox	Oxidation – bubble with air
NC-3b	Redox	Mild anoxia – lower dissolved O_2 concentration by bubbling with N_2
NC-3c	Redox	Reduction – add sodium dithionite to create reducing conditions
NC-4a	Biological activity	Inhibit biological activity

Bubbling with air or nitrogen, intended to simulate strongly aerobic and mildly anoxic conditions, respectively, caused diminutions in soluble zinc and cadmium concentrations (Figure 27), likely due to the removal of dissolved CO_2 which would have favoured the precipitation of metal carbonate phases. Amendment with 50 mM sodium dithionite, designed to stimulate reducing conditions, resulted in extensive mobilization of manganese (from <0.001 mg/L to 300 mg/L) and cadmium (from 0.012 mg/L to 0.24 mg/L), and more moderate solubilisation of zinc (from 2.1 mg/L to 3.4 mg/L). While the establishment of manganese-reducing conditions was clear from the dissolved manganese concentrations, the lack of soluble iron suggests that iron(III)-reducing conditions were not attained.

The maximum cadmium and zinc concentrations released to solution in these experiments was relatively minor, equivalent to 0.2% and <0.05% of the sedimentary cadmium and zinc content. The freeze-thaw experiment caused the largest release of zinc to solution, alongside a marked rise in cadmium, however, freeze-thawing in the field occurs over longer timescales and may not have been representatively simulated in this experiment. Observations from the field data indicate somewhat lower-than-average metals concentrations in liquid water sampled during winter events. Freshet waters generally have the lowest metals concentration and the late summer water have the highest overall concentrations of metals.

Figure 27 - Changes in selected analyte concentrations for stability experiments NC-Ctl (no environmental changes), NC-1a (+5°C temp rise), NC-1b (+10°C temp rise), NC-1c (freeze-thaw), NC-2a and NC-2b (alkalinity lowered), NC-2c and NC-2d (pH increased), NC-3a (bubbling with air), NC-3b (bubbling with nitrogen), NC-3c (dithionite reduction), and NC-4a (azide microbiocide). Blue and orange bars indicate analyte concentration after 48 h of baseline equilibration and a further 48 h after the environmental variable was changed, respectively. Data label above orange bars indicates percentage change; for NC-3c, additional number indicates analyte concentration, which was off-scale in this expt. Where no data are shown, the analyte was below the limit of detection



Most cadmium mobilization and a sizeable increase in dissolved zinc were observed when manganese-reducing conditions were imposed on the sediment. This is in line with zinc and cadmium XANES data which suggest that a sizeable portion of the solid phase zinc is sorbed on manganese oxyhydroxides, while cadmium is also present as a sorption complex (Gault et al., 2013). The limited zinc remobilization (<0.02% of the sedimentary zinc inventory) likely reflects re-sorption of the zinc onto other mineral phases such as ferric oxyhydroxides that appear not to have been targeted by the dithionite reagent. Thus, although a pulse of elevated zinc and cadmium concentrations might be expected during manganese- (and iron(III)-) reducing conditions, re-adsorption on secondary mineral assemblages, and precipitation as authigenic sulfide minerals under subsequent sulfate-reducing conditions would be expected to limit dissolved zinc and cadmium concentrations. Given the low organic carbon concentrations in the No Cash sediments (<0.5 wt. %; Interralogic, 2011b), it seems unlikely that such reducing conditions would develop, while a pulse of reducing water emanating from the mine is also thought implausible, making such a scenario a very extreme event. Any zinc and cadmium that is released under reducing conditions that diffuses up the sediment column towards the surface would also be expected to be scavenged by the manganese (and iron) oxyhydroxides that would re-precipitate upon meeting the oxidizing surface conditions.

3.2.2 HUSKY SW

3.2.2.1 GEOCHEMICAL AND MINERALOGICAL CONTROLS ON ZINC AND CADMIUM SEQUESTRATION

The majority of zinc-rich areas in the Husky SW thin sections were present as discrete particles or bands within particles (Gault et al., 2012; Sherriff 2012, 2013). Colloform coatings on grains were observed only occasionally, although a few of the discrete manganese-zinc-bearing particles had a colloform appearance, perhaps suggesting they had become detached from the particles around which they formed. Zinc and cadmium concentrations followed those of manganese most closely (Figure 28 - Figure 30), often in particles that appeared to show successive manganese- and iron-rich banding (e.g. Figure 28). Birnessite, goethite (FeO(OH)), and possibly manganite (MnO(OH)) were the most common nanocrystalline phases identified by μ-XRD, while zinc μ-XANES were generally best fitted with a mixture of zinc hosted in hetaerolite and co-precipitated with calcite ($CaCO_3$) and/or ferrihydrite (Figure 31; Gault et al., 2013). SEM-EDX, EMP and LA-ICP-MS spot analyses showed that the manganese/zinc ratios in the zinc-bearing particles were much higher for samples from Husky SW compared with NCC, in line with bulk sediment manganese/zinc ratios (Sherriff, 2012, 2013). The tentative identification of birnessite and other manganese oxide phases in the Husky SW samples is likely responsible for the higher manganese/zinc ratio observed for these samples, and might suggest that zinc sorption complexes are more prevalent for the Husky SW samples. Detrital sphalerite was also observed occasionally, but the small spherules of biogenic sphalerite were absent from the few Husky SW thin sections examined to date. Similar to NCC, multiple cadmium μ-XANES point analyses suggested cadmium was present as a sorption complex, but the similarity of the standard spectra precluded a more detailed examination of cadmium speciation.

Zinc and cadmium XANES spectroscopy were also performed on bulk sediments collected from Husky SW (Gault et al., 2013). The cadmium concentration was only high enough in the Husky SW adit sediment for cadmium XANES analysis, which again indicated that cadmium was likely present as a sorption complex. Relatively poor fits were obtained for the bulk zinc XANES, suggesting a model zinc phase was missing from our standard library, however, zinc sorbed on ferric oxyhydroxides comprised a sizeable fraction of the zinc inventory in most of the sediments analyzed. Chalcophanite ($(Zn,Fe,Mn)Mn_3O_7.3H_2O$) accounted for up to a third of the zinc speciation in the adit sediment, while moving downstream, zinc complexed with humic acid became more prominent, perhaps reflecting more organic-rich conditions.

Figure 28 - (a) EMP images of banded iron- and manganese-rich areas within particles in a Husky SW thin section sample collected close to the adit. The distribution of zinc, manganese, sulphur and iron are also mapped. The red arrow indicates where (b) the EMP linescan was conducted, showing a close correlation between manganese and zinc concentrations.

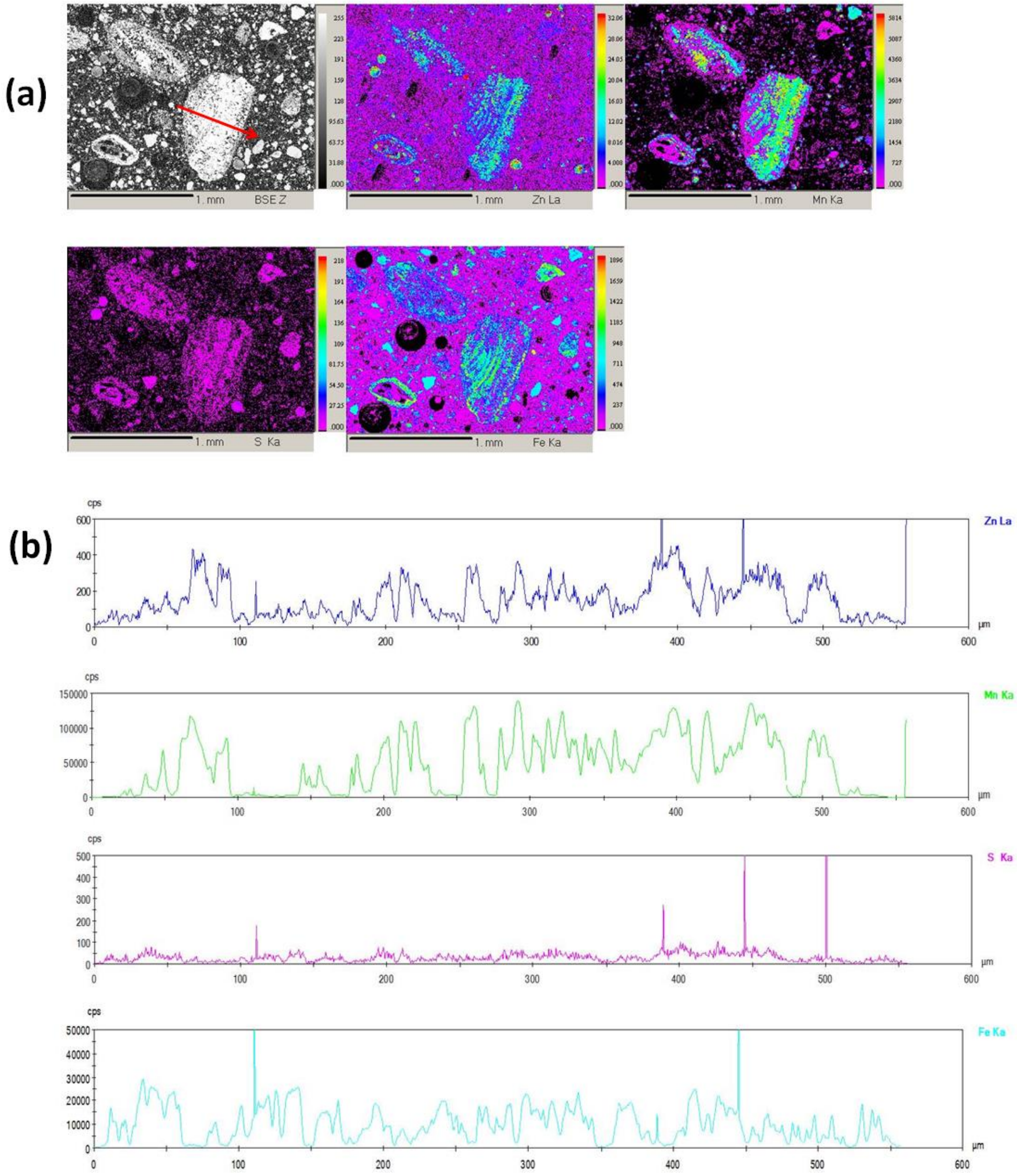


Figure 29 - (a) Backscattered electron image of a zinc-bearing particle in a Husky SW thin section sample collected close to the adit. (b) LA-ICP-MS raster line scan demonstrating the correlation between manganese, zinc and cadmium concentrations. Lead and arsenic concentrations also appear to follow those of iron.

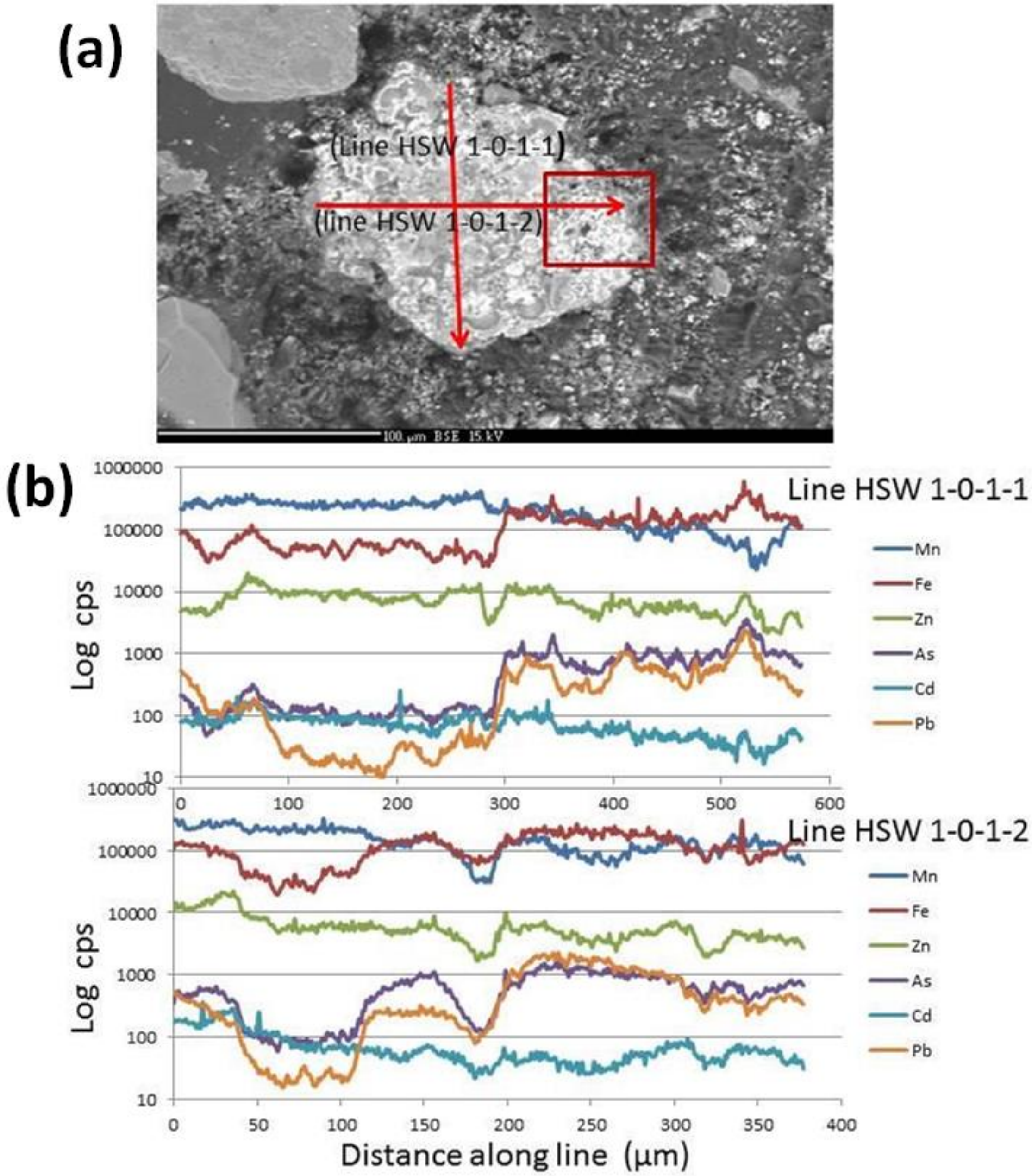


Figure 30 - Synchrotron-based µ-XRF imaging of the distribution of zinc, manganese and iron in a particle in a Husky SW thin section sample collected close to the adit.

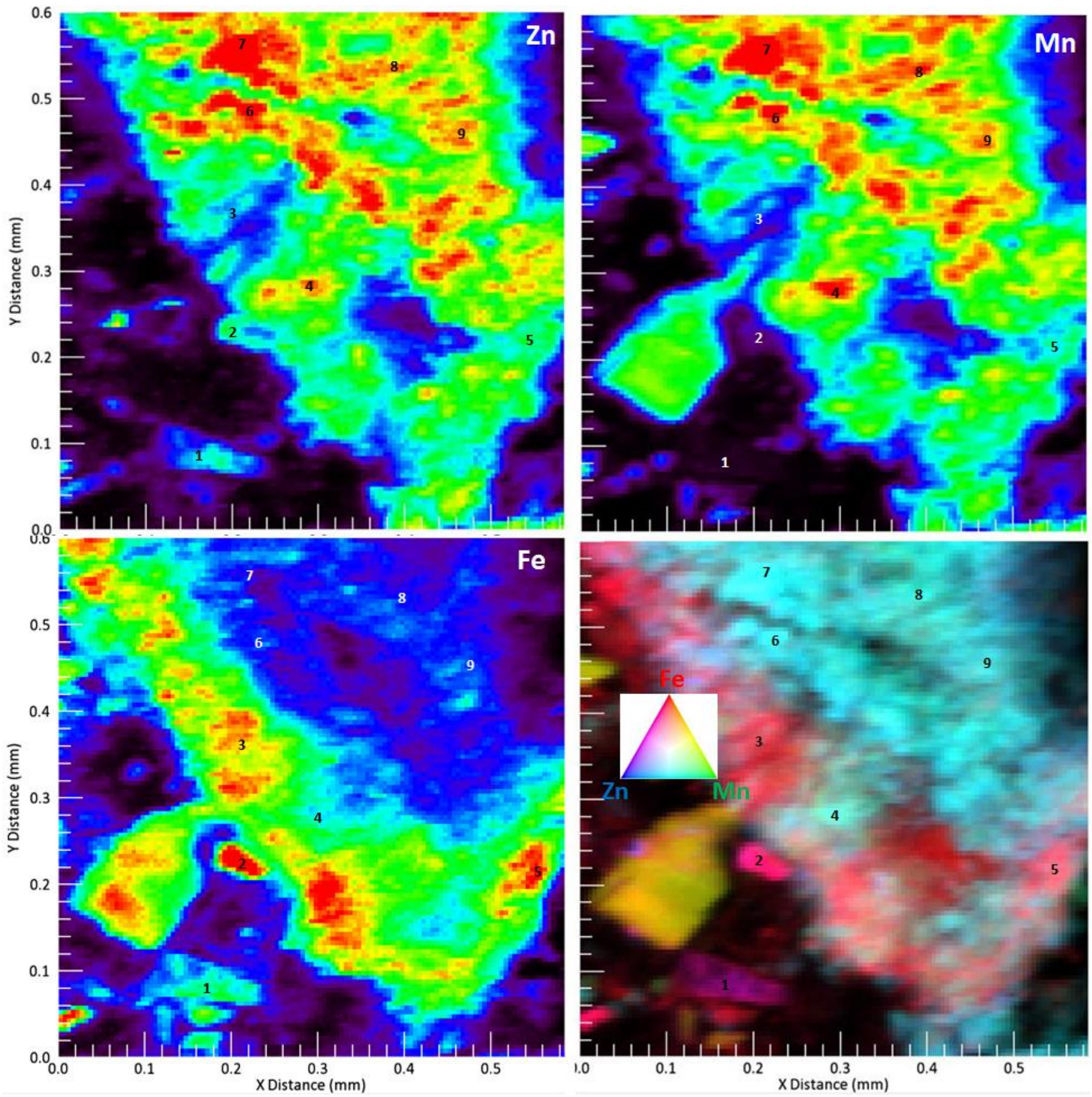
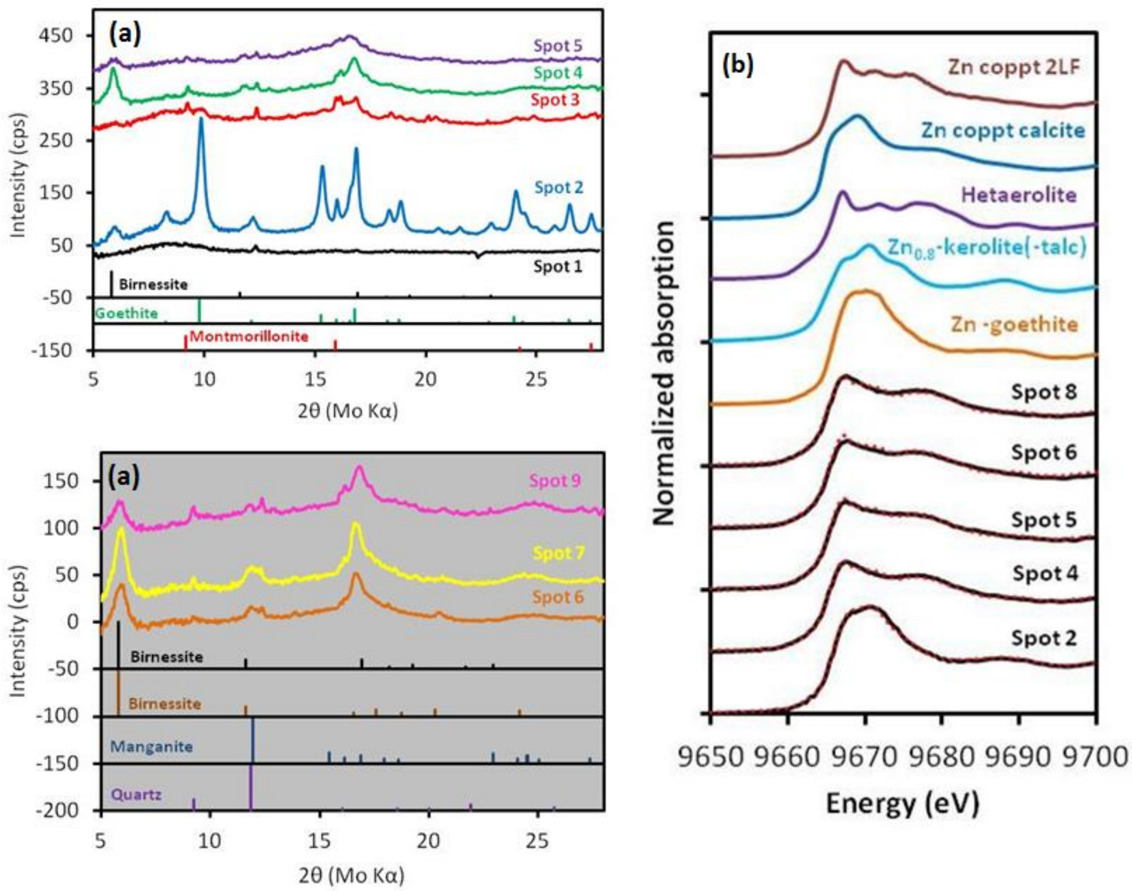


Figure 31 - Synchrotron based (a) μ-XRD and (b) zinc μ-XANES collected for the spots marked in Figure 30 for a Husky SW thin section sample collected close to the adit. The solid, black lines in (b) represent the sample data and dashed, red lines the best fit based on the combination listed in (c).



(c)	Proportion of Zn present as:				
	Hetaerolite	Coppt calcite	Coppt 2LF[b]	Sorbed goethite	$Zn_{0.8}$-kerolite (-talc)
HSW-1-0"					
Spot 2	-	-	-	72	26
Spot 4	49	32	19	-	-
Spot 5	40	25	34	-	-
Spot 6	56	29	16	-	-
Spot 8	62	38	-	-	-

3.3 VEGETATION METAL ACCUMULATION

A baseline study of metal concentrations in soil and vegetation samples collected in the KHSD was initiated in 2011, comprising two sampling seasons during the summers of 2011 and 2012 (Access, 2012, 2013). Alongside soil samples, leaves were collected from willow (*Salix* sp.) and Labrador Tea (*Ledum* sp.). These plant species were selected due to (1) their common occurrence across the KHSD; (2) their consumption by local wildlife that may in turn be consumed by humans (e.g. moose); (3) their use in traditional medicine; and (4) their ability to tolerate elevated metal concentrations in soils allowing them to grow along mine drainage impacted watercourses. Sampling sites included the natural attenuation study areas of No Cash Creek, Silver King and Husky SW, alongside off-claim control areas for use as background comparators. Only one bog blueberry (*Vaccinium uliginosum*) and one scrub birch (*Betula glandulosa*) leaf sample were collected near the NCC, Husky SW and Silver King watercourses, and no samples were collected at control sites, so these sparse data are not discussed further here.

3.3.1 NO CASH CREEK

Zinc concentrations in willow leaves collected along the reach of NCC (62 – 1820 mg/kg) were two to forty-nine fold higher than the average zinc concentration in willow leaves from the control sites (37 mg/kg). Cadmium concentrations in NCC willow leaves ranged from marginally above (1.1 mg/kg) to thirty-four times (34 mg/kg) the control site average concentration (1 mg/kg). Values for arsenic and lead followed similar trends. By contrast, metal concentrations in Labrador Tea leaves collected along NCC showed more limited extremes, ranging between two (17 mg/kg zinc) and eight (0.065 mg/kg cadmium) fold higher than the average metal concentrations of control site Labrador Tea leaves (8.9 mg/kg zinc; 0.008 mg/kg cadmium). This reflects the ability of willow species to hyperaccumulate cadmium and accumulate zinc.

3.3.2 HUSKY SW

Similar trends were observed in samples collected along the Husky SW watercourse. Willow leaf zinc (16 – 540 mg/kg) and cadmium (0.1 – 16 mg/kg) concentrations were up to fifteen and sixteen fold higher than the respective control site willow leaf average levels. However, the zinc and cadmium concentrations in Labrador Tea leaves collected in the Husky watershed were generally comparable to the control site average concentration.

3.3.3 SILVER KING

Zinc concentrations in willow leaves collected near the Silver King adit (59 – 210 mg/kg) exceeded the control site willow leaf average by two to six fold, while only one Silver King willow leaf sample (4.3 mg/kg) exceeded the cadmium control average. The highest willow leaf zinc and cadmium concentrations were found closest to the adit, and exceeded the associated soil metal concentrations, illustrating the (hyper)accumulator characteristics of willow species. The metal concentrations in Labrador Tea leaf samples collected near the Silver King adit were similar to those collected at the control sites. Willow leaves collected further downstream in Galena Creek also showed elevated zinc and cadmium concentrations that were up to five and seven times higher than the control sites, respectively. Willow leaves obtained from the tributary channels to Galene Creek generally contained similar metal concentrations to the control samples. Labrador Tea leaves exhibited background metal concentrations, regardless of their sample location within the Galena Creek watershed.

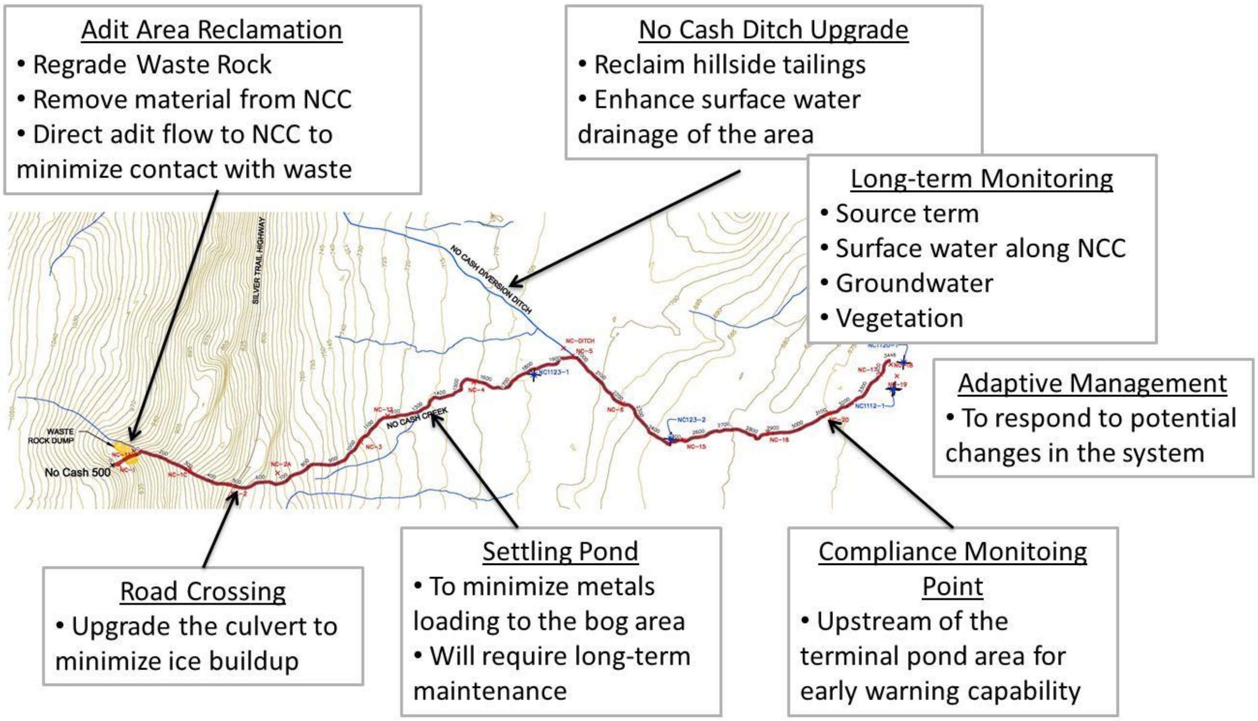
3.4 PRELIMINARY ENGINEERING SURVEY AND CLOSURE CONCEPTUAL MODEL

Figure 32 illustrates the closure conceptual model of the NCC natural attenuation area. This model summarizes the key closure concepts and considerations that could be incorporated into a designed natural attenuation treatment system. Some of the closure concepts are not exclusive to a natural attenuation closure scenario but were included below because they would be part of the natural-attenuation closure plan. The recommended engineering design should include:

1. Adit reclamation activities to effectively minimize mass load and control flow including:
   a. refurbishing the adit portal and discharge area to achieve safety goals. The refurbishment requirements for a natural attenuation scenario would include integration of a suitable flow capture structure (item “c” below).
   b. establish a flat discharge area near the adit to encourage local mineral precipitation reactions and to allow removal of precipitated solids
   c. design of an effective adit-flow capture and conveyance structure

    d. regrading of the waste rock dump and removing waste rock from the NCC channel to eliminate the waste rock as a potential direct source of additional metals mass.
2. Road crossing refurbishment to minimize ice-damming, scour, and road damage. Maintaining a consistent flow through potential bottlenecks will limit surges to the downstream natural attenuation areas.
3. No Cash Ditch refurbishment:
    a. Channel stabilization
    b. Reclamation of the catchment area to minimize metals loading to the ditch (and therefore to NCC)
4. Additional settling pond installation to capture particulate metals mass and minimize metals loading to the lower NCC. This could be a location for long term maintenance/sediment removal if desired or shown to be necessary by monitoring.
5. Long-term monitoring of the system at key locations along the flow path:
    a. Source term flow and chemistry at the adit
    b. Surface water chemistry along NCC at selected locations
    c. Groundwater chemistry in monitoring wells
    d. Vegetation (health and metals uptake)
6. Adaptive management to learn and react to the system as it is implemented and to potential changes in the future. Potential adaptive management activities include:
    a. Additional or reduced monitoring type and frequency
    b. Design adaptations to increase performance of engineered facilities such as settling ponds, conveyance structures, and water spreading areas. These would be considered on a case-by-case basis to considering cost-benefit and potential effects of additional disturbance due to access and construction.
    c. Short- or long-term active treatment with mobile units in response to upsets or long-term changes in the source term
    d. Alternative short or long-term passive treatment system (e.g. bioreactors)

Figure 32 - Natural Attenuation Closure Concepts for No Cash Creek



4 SUMMARY OF FINDINGS

4.1 NATURAL ATTENUATION PROCESSES

The primary hydrologic and (bio)geochemical processes responsible for metals attenuation are summarized in the following two sections. As the most intensively studied system, most attention is focused on NCC, however, the hydrological and (bio)geochemical processes that aid the natural attenuation of zinc and cadmium are similar at NCC and Husky SW. Since the adit water discharging from Silver King is already treated by a conventional lime water treatment plant, the processes responsible further attenuation of zinc and cadmium observed downstream are harder to discern, but are expected to be broadly similar.

4.1.1 HYDROLOGIC

Figure 33 illustrates the hydrologic mechanisms model of the NCC natural attenuation area. This model summarizes the key surface and groundwater processes related to metals attenuation and corresponding closure issues. These issues are described below and correspond to numbered points on the profile in Figure 33.

1. **Adit Reach (surface water)/Upper Hydrologic Area (groundwater) -** Water discharging from the adit spreads out on the waste rock bench and iron and manganese precipitates are formed as mats and sediment. The water cascades down the sides of the waste rock slopes and joins the NCC. Groundwater recharge occurs on Galena Hill, including from NCC where permafrost is not present. Minor increases in flow from the adit occur during freshet resulting in a slightly larger wet area on the waste rock bench. Winter conditions result in no surface flow from the adit portal, however, small flows were observed emanating from the waste rock lower on the slope.
2. **Cascading Reach (surface water)/Upper Hydrologic Area (groundwater) -** Cascading water results in highly aerated water and oxidized conditions, even during the winter months. Freshet flows are significantly higher yet still confined to the well-defined creek channel. Hydrologic conditions are very well suited to precipitation of metal oxyhydroxides. Depth to groundwater is generally shallower in the valley than on hillsides and mine workings.
3. **Transition and Bog Reaches (surface water)/Middle-Lower Hydrologic Area (groundwater) -** Braided and intermittent stream patterns dominate in these reaches Permafrost is ubiquitous in the bog reach. The resulting low-permeability permafrost horizon separates the shallow active zone and surface water flow from the deeper aquifer in the glacial sediments below. Freshet melt conditions result in the bog area becoming completely saturated and with larger areas of standing water in the lowlands. Winter conditions result in ice damming and complete blockage of the NCC channel in some areas, with flow being forced into shallow sediments beneath the ice. Bedrock groundwater discharges into the valley fill glacial sediments and generally flows toward the South McQuesten River.
4. **The surface expression of the Terminal Pond Area -** The NCC ends at the terminal pond, where the NCC water evaporates and infiltrates. Groundwater in this area is assumed to flow in a northerly direction toward the South McQuesten River. Groundwater monitoring wells completed in the terminal pond area show no chemical impacts from NCC infiltration; metals concentrations are low in the NCC terminal pond and groundwater is good quality.
5. **Terminal Pond to South McQuesten River -** Hummocky/thermokarst terrain between the terminal pond and the South McQuesten River has no developed surface drainage

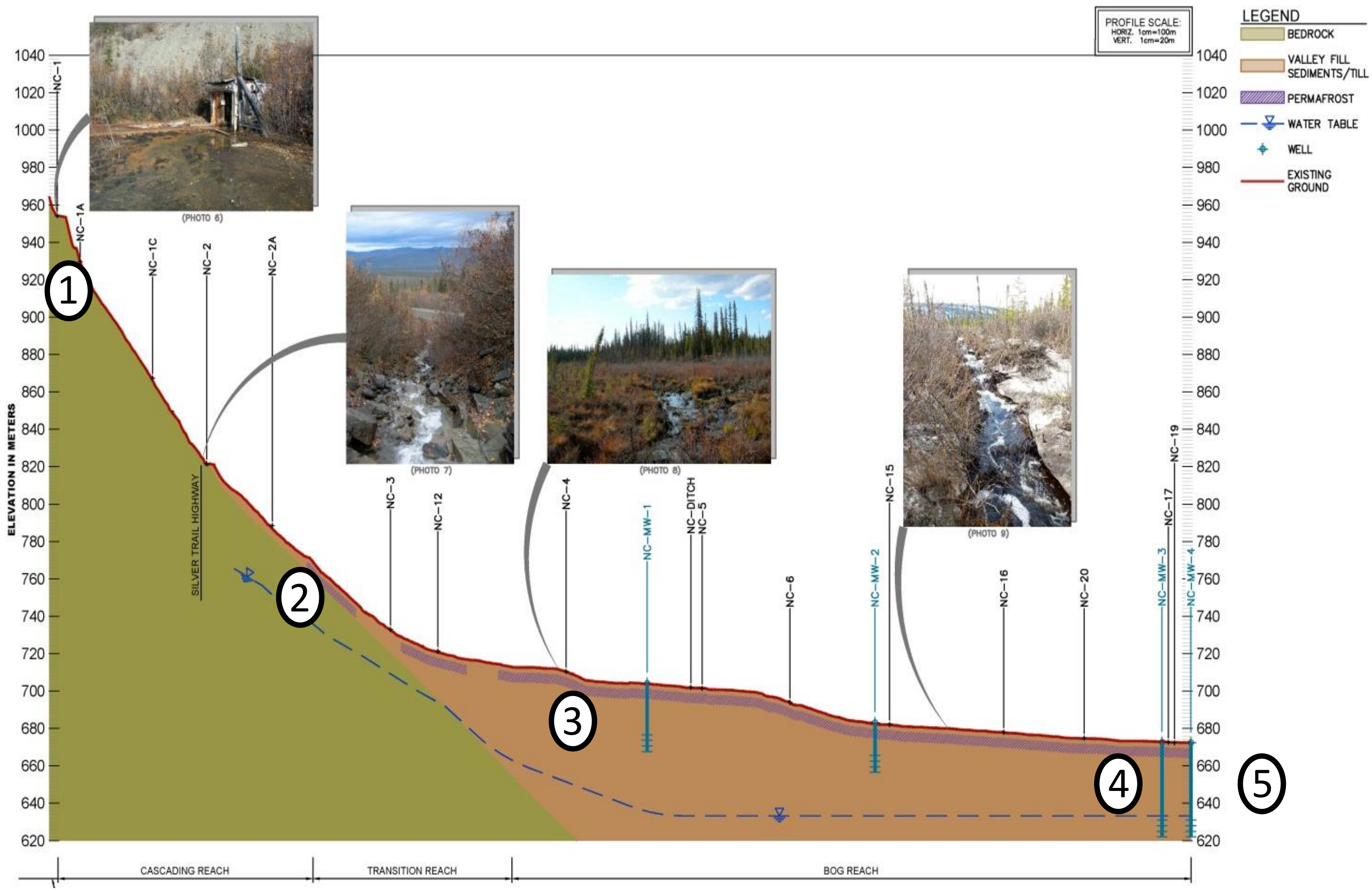
pattern and limited, if any significant runoff. The area is characterized by thick forest and well drained soils where infiltration of snowmelt recharges the glacial sediments below. The South McQuesten River serves as the discharge area for the basin for both groundwater and surface water.

4.1.2 (BIO)GEOCHEMICAL

The key geochemical mechanisms responsible for metals attenuation and relationship to potential closure issues are described below and correspond generally to numbered points on the profile in Figure 33.

1. Iron, manganese and zinc (oxyhydr)oxide minerals, notably ferrihydrite, birnessite and (hydro)hetaerolite, precipitate out of adit discharge water quickly resulting in significant dark orange/black sediment near the adit portal. These mineral reactions occur regardless of hydrologic or seasonal variability. Zinc is present as authigenic zinc-bearing mineral phases ((hydro)hetaerolite, hydrozincite), or co-precipitated/sorbed on iron and manganese oxyhydroxides. Cadmium is almost exclusively present as a sorption complex and although the sorbent could not be directly elucidated, the strong correlation between cadmium and zinc in the sediments suggests they have similar mineralogical hosts (likely iron and manganese oxyhydroxides). Surficial sediments, as well as buried sediments are of similar mineralogy and environmental stress testing of these sediments has indicated that elevated temperatures, pH and lowered alkalinity do not significantly impact the precipitate stability. A switch to reducing conditions in the stability testing did result in marked zinc and cadmium release to solution, however, the low organic carbon content of sediment in the adit reach/upper hydrologic area effectively restricts the development of such conditions within the sediment column. Furthermore, microbiological testing of these sediments indicated they had limited populations of metal- and sulphate-reducing bacteria.
2. Zinc and other metals continue to come out of solution along the cascading reach of the stream as oxyhydroxide phases. Geochemical mechanisms continue during hydrologic or seasonal variability. Suspended metals transport (as sediment and precipitated solids) occurs due to the high energy of NCC in this reach.

Figure 33 - No Cash Creek Hydrologic Profile



3. Similar geochemical reactions occur in the bog reach as in the upper, higher-energy reaches. However, the transition to a higher organic carbon content in stream sediment and surrounding soil horizons results in increased microbial activity and provides additional potential metals attenuation through sulphate reduction and metal-sulphide precipitation (e.g. sphalerite). Small (1 – 3 μm diameter) sphalerite granules have been identified in association with organic material in sediment thin sections and also in the peat itself. The increase in organic material (peat, wood, grasses, etc) also serve as important potential nucleation sites and micro-environments for supporting manganese and iron mineral precipitation reactions. Column experiments indicated that the NCC peat material is a highly effective sorbent, both in saturated and unsaturated conditions. It removed 99% of zinc and 94% of cadmium from 54 pore volumes of water pumped through peat-filled columns. As such, the peat bog may be viewed as a polishing step to the initial massive metals removal further upstream, adding redundancy to the natural attenuation process. Seasonal and hydrologic variability do not adversely affect the metals attenuation in this reach. Carbon accumulation in the bog is robust and consistent with observations from other comparable bogs, with carbon generation being more than sufficient for sustainable attenuation of all zinc generated from the No Cash Adit.
4. The terminal pond area shows very limited accumulation of metal precipitates as sediment. Total soluble zinc concentrations decline to a relatively constant low at about 0.1 mg/L approximately 1 km upstream of the terminal pond.
5. Elevated concentrations of total or dissolved metals are not observed in the monitoring wells adjacent to the terminal pond.

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APPENDIX 2

SUPPORTING ENVIRONMENTAL DATA

KENO HILL SILVER DISTRICT STREAM DISCHARGE MONITORING

AND AUTOMATED STREAM DISCHARGE MONITORING 2016 REPORT

Revision 0

Deliverable Number 2016-17-009-7/8_01

31 January 2017

Prepared for:

ELSA RECLAMATION AND DEVELOPMENT COMPANY LTD.

ALEXCO ENVIRONMENTAL GROUP SIGNATURES

Report prepared by: January 31, 2017

Anthony Bier — Date
Hydrologist

Report reviewed by: January 31, 2017

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EXECUTIVE SUMMARY

This report meets the requirements for deliverables as specified in the workplans for tasks ERDC 009-7 and ERDC 009-8 through the provision of the hydrometric monitoring results from the 2016 field season. In accordance with the work plans eight hydrometric monitoring stations were maintained through semi-annual visits including winterizing and surveys. Monthly monitoring was carried out by Alexco Environmental Group Inc. (AEG) Whitehorse personnel with assistance from Na-Cho Nyak Dun First Nation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 INTRODUCTION

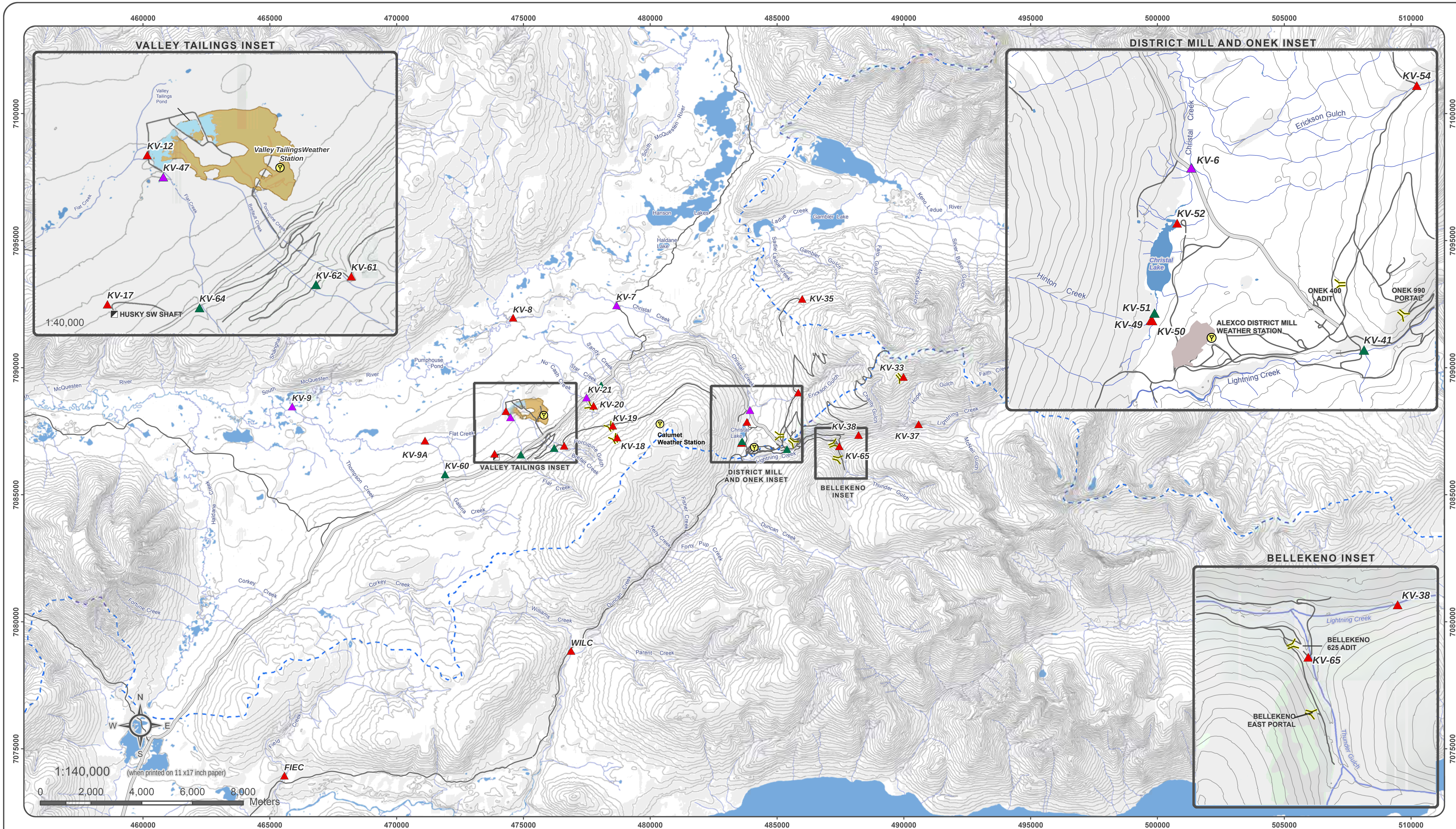
This report presents the surface water discharge data collected in the Keno Hill Silver District (KHSD) during 2016 as part of a site wide hydrometric and water quality program. Table 1 lists the discharge site names and their descriptions as well as the monitoring type and sampling schedule. Most sites require discharge to be measured whenever possible during monthly water quality sampling events, though conditions may occassionally not permit discharge measurements during the ice covered season.

There are eight hydrometric monitoring stations with stilling wells and staff gauges. Formerly there were ten sations, but two stations, KV-62 and KV-47, were not providing reliable data due to unfavourable stream conditions and were decommissioned in 2016. At the eight operational stations, automated water level recorders are deployed in stilling wells to provide a continuous water level record during the ice-free season with interpolated winter data. Alexco Environmental Group Inc. (AEG) personnel from Whitehorse conducted sampling of these sites, with assistance from Nacho Nyak Dun First Nation (NNDFN) environmental monitors. Historic data are included in this report for completeness.

The following is a brief overview of the field program followed by results sections describing the continuously monitored hydrometric stations in more detail. There are four appendices to present that data including: Appendix A, 2016 discrete measurements; Appendix B, Historic discrete measurements; Appendix C, Hydrographs; and Appendix D, Photographs. Figure 1 provides an overview of the hydrometric sampling network.

Table 1 – Surface water sites sampling schedule and type.

Site	Description	Sampling Schedule	Continuous (Y/N)
KV-6	Christal Creek at Silver Trail Highway	monthly	**Y**
KV-7	Christal Creek at Hanson Road	monthly	Y
KV-8	Christal Creek at mouth	monthly	N
KV-9	Flat Creek upstream of South McQuesten River	monthly	Y
KV-9A	Flat Creek between Valley Tailings & KV-9	monthly	N
KV-12	Valley Tailings Pond #3 Decant	monthly	N
KV-17	Husky Southwest Adit	monthly	N
KV-18	Bermingham Adit	monthly	N
KV-19	Ruby Adit	monthly	N
KV-20	No Cash 500 Adit	monthly	N
KV-21	No Cash Creek at Silver Trail Highway	monthly	Y
KV-33	Keno 700 Adit	monthly	N
KV-35	Sadie Ladue Adit	monthly	N
KV-37	Lightning Creek upstream of Hope Gulch	monthly	N
KV-38	Lightning Creek upstream of Thunder Gulch	quarterly	N
KV-41	Lightning Creek upstream of bridge at Keno City	monthly	Y
KV-47	Porcupine Diversion Ditch downstream of Upper Flat Creek	quarterly	N
KV-49	Hinton Creek upstream of Christal Creek	monthly	N
KV-50	Christal Creek upstream of Hinton Creek	monthly	N
KV-51	Christal Creek downstream of Hinton Creek	monthly	Y
KV-52	Natural Spring to Christal Lake at Old Mackeno Pump house	monthly	N
KV-53	UN Adit	quarterly	N
KV-55	Sandy Creek at Silver Trail Highway	quartrly + winter months	N
KV-56	Star Creek at Silver Trail Highway	quarterly + winter months	N
KV-60	Galena Creek upstream of Silver King Adit	monthly	Y
KV-61	Porcupine Gulch at Calumet Road Crossing	monthly	N
KV-62	Brefault Creek upstream of Porcupine diversion ditch	quarterly	N
KV-64	Flat Creek at Silver Trail Highway	monthly	Y
KV-65	Thunder Gulch upstream of Bellekeno 625	monthly	N
KV-66	Klondike Keno Adit	quarterly	N
KV-72	South McQuesten River at McQuesten Lake	monthly	N
WILC	Williams Creek downstream of Duncan Creek Road	monthly	N
FIEC	Field Creek upstream of Duncan Creek Road	monthly	N



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

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- Hydrometric Monitoring Station
- Automatic Hydrometric Monitoring Station with Barologger
- Automatic Hydrometric Monitoring Stations
- Weather Station
- Shaft
- Adit
- Watercourse
- Contour (100 feet)
- Watershed Divide
- Keno District Mill Site
- Valley Tailings
- Valley Tailings Ponds

ERDC

KENO HILL MINING DISTRICT

FIGURE 1

KENO HILL SILVER DISTRICT DISCHARGE MONITORING LOCATIONS

DECEMBER 2015

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2 METHODS

2.1 DATA COLLECTION OVERVIEW

Discharge measurements and staff gauge observations, if applicable, are taken during scheduled visits to the stations identified in Table 1. The velocity-area method is used for discharge measurements and taken with an electromagnetic current meter where and when suitable. Salt slug dilution gauging is used where a current meter is not suitable. These data are used to develop rating curves for computation of continuous water level data into derived continuous discharge records for the open water season. Discrete measurements during the winter allow the estimation of continuous winter low flows by drawing a recession curve through the observations. Continuous water levels are recorded at thirty minute or one hour intervals using Solinst Levelogger water level recorders in conjunction with Solinst Barologgers.

A typical hydrometric station installation consists of a cribbing structure (wood or metal) at least one graduated staff gauge, a stilling well (ABS or PVC), a pressure transducer (Solinst Levelogger), and bench marks (large spikes in tree bases or 6+ foot angle iron driven into the ground). Solinst Barologgers are used to compensate the Leveloggers and are shared between multiple stations. An example installation is shown in Figure 2.

Since 2012, all continuous hydrometric data have been processed using Aquatic Informatics' Aquarius time-series software; previous time-series and rating curve development was done in Microsoft Excel and, prior to 2011, by Clearwater Consultants Ltd.

More detailed methodology can be found in the AEG's *Standard Operating Protocol – Surface Water Hydrology – Data Collection and Management.*

Figure 2 – KV-64 hydrometric monitoring station, installed in September 2015, below the Silver Trail Highway

2.2 FIELD ACTIVITIES SUMMARY

AEG and NNDFN monitors conducted monthly site visits in 2016. Data are recorded manually in field books and transcribed into Excel templates for discharge calculation. AEG Whitehorse personnel provide data management and QA/QC for all data collected.

Hydrometric stations were de-winterized in May 2016 and winterized in September 2016. Continuous data are provided to late September 2016 as loggers are not routinely downloaded in winter due to weather conditions and complications with electronic equipment. The hydrometric stations are also surveyed during the two bi-annual maintenance trips. All stations remain in good condition. Data loggers were removed from stations KV-47 and KV-62 and these stations are now monitored quarterly during routine water quality data collection.

There was a greater emphasis in 2016 on gathering discharge from some historic adits which have few measurements and on gathering winter low flow discharge measurements on Sandy and Star creeks to better understand winter baseflow and groundwater. However, it became apparent that these sites lack measurements because they go dry or flows are so low measurement is not possible (i.e. less than 1-2 L/s). Visits to all sites in 2016 are recorded in Appendix A.

3 RESULTS

3.1 DISCRETE MEASUREMENTS

Appendix A lists discrete discharge measurements taken in 2016 for all sites listed in Table 1. Appendix B includes all discrete discharge observations to date at those same sites. Site visits in 2016 where no measurement was taken have also been included in Appendix B when relevant comments on hydrological conditions are included. Climatic conditions in the region present an exceptional challenge to gathering discharge measurements year around which can result in no observations during winter months.

3.2 HYDROMETRIC STATIONS AND CONTINUOUS MONITORING

There were eight hydrometric stations active during the 2016 monitoring season including: KV-6, KV-7, KV-9, KV-21, KV-41, KV-51, KV-60, and KV-64. KV-51 and KV-64 have fewer rating measurements than other longer term sites and therefore there is greater uncertainty in the rating curves and derived discharge records at these sites.

All stations remain stable and did not require maintenance beyond surveys and stilling well de-silting. KV-21 requires removal of built up sediment on a monthly basis to ensure the weir pond does not fill up. KV-60, Galena Creek above Silver King, was relocated in 2014 and though the gradient of the stream lends some uncertainty to the rating curve it continues to provide a continuous derived discharge record. KV-7 and and KV-41 are both older stations with wooden cribbing structures. These stations should be replaced with metal cribbing and new stilling wells and staff gauges in the next 2-3 years to bring them up to the standard of quality of the other stations and ensure continued stability.

All hydrometric stations now yield year round continuous data; although the winter is estimated based on monthly discrete measurements. In 2016 continuous discharge data are available for all eight hydrometric stations.

3.2.1 KV-6 CHRISTAL CREEK ABOVE SILVER TRAIL HIGHWAY

The hydrometric station on Christal Creek at KV-6 is above the Silver Trail highway and several hundred metres downstream of Christal Lake. The catchment area is ~6.1 km^2 with a median elevation of ~1002 metres above sea level (masl). Instantaneous discharge measurements have been collected since June 2008 on a monthly basis where possible.

A Solinst water level recorder was deployed at KV-6 in a stilling well on July 20th 2011 and retrieved on October 23rd 2011. There was one discharge measurement taken during the continuous water level record but no staff gauge was installed.

The 2012 Solinst Levelogger record begins May 1st and extends till mid-October. Ice begins to affect the pressure readings on October 10th making water levels and derived discharge following that unreliable (Figure C1, Appendix C). A staff gauge was installed along with the Levelogger on May 1st with a corresponding BaroLogger (barometric pressure data logger). After mid-July the record becomes unreliable due to a ponding effect (Figure C1, Appendix C).

In 2013, the KV-6 station was moved upstream due to the ponding encountered from the road culvert in 2012, but due to infrequent measurements a continuous record could not be produced. Furthermore, the station was moved again in September 2013 to a more stable reach with a better control section more favourable to measuring flow. The current location remains relatively stable and free of backwater effects.

Reliable stage records began at the new location in late May 2014 (Figure C2, Appendix C) and a derived discharge record has been produced continuously since that time. Winter records are approximated by drawing a line through discrete measurements as appropriate or manipulation of the record relative to the discrete measurements, taking into consideration higer winter measurement uncertainty. The peak annual discharge in 2015 at KV-6 was 0.353 m^3/s on May 11th, 2015 (Figure C3, Appendix C). Figure C4 (Appendix C) shows the 2016 hydrograph including the peak, 0.280 m^3/s, on April 27th, 2016.

Table 2 shows instantaneous discharge measurements taken since 2008 at KV-6, while Table 3 shows all monthly means where continuous data are available. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 2 - Instantaneous discharge measurements at KV-6, Christal Creek below Christal Lake (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2008						0.064	0.130	0.119	0.080	0.161		
2009						0.124	0.101	0.114	0.103	0.033		
2010					0.071		0.094	0.061	0.141	0.094		
2011					0.136	0.080	0.091		0.127	0.088	0.075	0.107
2012		0.077		0.062	0.126	0.089	0.095	0.091	0.089	0.076		
2013						0.123	0.082	0.079	0.091	0.093	0.080	
2014			0.050	0.052	0.143	0.059	0.100	0.063	0.110	0.102	0.080	
2015	0.104		0.07	0.056	0.324	0.106	0.100	0.125	0.137	0.092	0.147	0.142
2016	0.130	0.067	0.086	0.071	0.170	0.104	0.098	0.180	0.122	0.094	0.087	
Mean	0.058	0.077	0.060	0.057	0.160	0.092	0.099	0.093	0.110	0.092	0.096	0.068
95% Confidence limit	0.025	0.010	0.020	0.008	0.069	0.017	0.009	0.027	0.014	0.021	0.026	0.034

Table 3 – Mean Monthly Discharge at KV-6, Christal Creek below Christal Lake, for months where continuous data are available (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2012					0.123	0.089	0.102					
2013												
2014					0.063	0.096	0.073	0.117	0.115	0.107	0.081	0.077
2015	0.092	0.078	0.066	0.084	0.185	0.110	0.119	0.123	0.128	0.116	0.115	0.107
2016	0.101	0.09	0.072	0.115	0.127	0.110	0.136	0.154	0.127			
Mean	0.097	0.084	0.069	0.100	0.125	0.101	0.108	0.131	0.123	0.112	0.098	0.092
95% Confidence limit	0.009	0.012	0.006	0.030	0.049	0.010	0.026	0.022	0.008	0.009	0.033	0.029

3.2.2 KV-7 CHRISTAL CREEK AT HANSON-MCQUESTEN LAKES ROAD BRIDGE

Christal Creek at KV-7 drains an area of ~35.8 km^2 with a median elevation of ~970 masl and includes KV-6, KV-51 and Christal Lake. There are a number of old workings within the watershed including Galkeno 300, Galkeno 900, Brewis Red Lake, Lucky Queen, Klondike Keno and, at least partially, Onek 400. Additionally, the Alexco District Mill, the Silver Trail Highway and parts of Keno City including the Keno City dump are at least partially within the watershed. It includes both a major east facing slope of Galena hill and west facing aspects of Sourdough hill.

Clearwater Consultants Ltd. (CCL) processed and summarized the data for 2004 - 2009 (CCL 2008; 2010). Data for 2010 and 2011 were processed by AEG following the same methodology as CCL. AEG has utilized Aquarius time series software since 2012 to manage the hydrometric data at KV-7. Mean monthly discharge is shown since 2003 at KV-7 in Table 4. Figure C55 to Figure C1011 (Appendix C) show the hydrographs for 2010, 2011, 2012, 2013, 2014, 2015, and 2016, respectively. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

The 2016 hydrograph shows a substantial peak in late April associated with freshet as well as a several peaks throughout the summer and fall associated with storm events. The peak annual discharge was 2.026 m^3/s captured on July 26th, 2016 as a result of summer rain storms (Figure C10, Appendix C). KV-6 did not show the same peak, which is assumed to be as a result of the dampening effect of the lake.

Table 4 – Mean Monthly Discharge at KV-7, Christal Creek at Hanson-McQuesten Road Bridge (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2003								0.42	0.51			
2004			0.15	0.166	1.153	0.314	0.119	0.112	0.163	0.135	0.103	0.101
2005		0.122	0.112	0.391	1.54	0.264	0.294	0.398	0.335	0.259	0.189	0.150
2006	0.166	0.138	0.117	0.124	1.089	0.519	0.397	0.278	0.415	0.368	0.203	0.142
2007	0.151	0.12			0.757	0.327	0.54	0.218	0.335	0.154		
2008								0.43	0.333	0.352		0.134
2009	0.079	0.068	0.048	0.074	1.123	0.338	0.102	0.183	0.368			
2010					0.309	0.24	0.359	0.23	0.232	0.186		
2011					1.26	0.142	0.503	0.419	0.268	0.173	0.126	
2012	0.154	0.078			0.730	0.258	0.400	0.217	0.267	0.200		
2013	0.075	0.066				0.285	0.126	0.08	0.332	0.227	0.140	0.110
2014	0.097	0.103	0.086	0.077	0.740	0.430	0.195	0.573	0.351	0.220	0.176	0.140
2015	0.089	0.072	0.059	0.165	1.091	0.192	0.368	0.517	0.614	0.271	0.165	0.137
2016	0.125	0.125	0.081	0.268	0.580	0.266	0.560	0.692	0.541			
Mean	0.117	0.099	0.093	0.181	0.943	0.298	0.330	0.341	0.362	0.231	0.157	0.131
95% Confidence limit	0.025	0.018	0.026	0.084	0.207	0.057	0.093	0.095	0.065	0.045	0.027	0.013

Note: Grey numbers are discrete discharge measurements (included in means Oct-Apr).

3.2.3 KV-9 FLAT CREEK NEAR THE MOUTH

The Flat Creek headwaters originate on the Northwest face of Galena Hill above the former Elsa town site. Flat Creek at KV-9 also includes Thompson, Galena, Porcupine and Brefault Creeks. Flowing adits and shafts within the Flat creek watershed include, but are not limited to, Silver King and Husky Southwest. The former Elsa town site and the Valley Tailings Facility are also situated within the Flat Creek watershed making it one of the more heavily anthropogenically modified watersheds in the district. The total drainage area of Flat Creek is ~56.5 km^2 with a median elevation of ~830 masl. Station KV-9 is located just above the confluence of Flat Creek with the South McQuesten River approximately 10 km east of Elsa. In recent years, Flat Creek at KV-9 has remained open all winter allowing for accurate low flow measurements with a velocity meter and applicable stage observations. This is an extremely valuable site because of this feature.

Mean monthly discharge values from derived continuous discharge records for KV-9 are presented in Table 5 with some spot flows included as estimates where noted. Figure C122 to Figure C178 (Appendix C) show the discharge time series for 2010, 2011, 2012, 2013, 2014, 2015, and 2016, respectively. The 2016 hydrograph captured the freshet flow with a maximum observed flow of 2.370 m^3/s on May 4th, 2016 (Figure C168, Appendix C). Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 5 – Mean Monthly Discharge at KV-9, Flat Creek near the Mouth (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004								0.116	0.099	0.11	0.046	0.034
2005	0.03	0.028	0.126	0.273	2.077	1.017	0.282	0.34	0.33	0.28		
2008								0.545	0.375	0.448	0.129	0.09
2009	0.053	0.029	0.02	0.01	2.155	0.51	0.088	0.092	0.364			
2010						0.133	0.171	0.086	0.118	0.099		
2011					1.97	0.349	0.927	0.756	0.364	0.299		
2012				0.014	1.574	0.430		0.208	0.361	0.276		
2013					2.825	0.636	0.159	0.084	0.102	0.411	0.081	
2014					1.856	0.520	0.204	0.786	0.535	0.559	0.06	0.015
2015	0.009	0.007	0.01	0.102	1.927	0.178	0.31	0.511	0.873	0.423	0.131	0.057
2016	0.021	0.009	0.001	0.538	1.011	0.202	0.402	0.758				
Mean	0.028	0.018	0.039	0.187	1.924	0.442	0.318	0.389	0.352	0.312	0.092	0.049
95% Confidence limit	0.018	0.012	0.057	0.196	0.356	0.180	0.184	0.172	0.144	0.111	0.044	0.032

Note: Grey numbers are discrete discharge measurements (included in means Oct-Apr).

3.2.4 KV-21 NO CASH CREEK AT THE SILVER TRAIL HIGHWAY

No Cash Creek flows just northeast of Elsa and has a catchment area of ~1.4 km^2 at the Silver Trail Highway (KV-21). The median elevation is ~1212 masl and includes the No Cash 500 adit (KV-20), which is free draining. Calumet Drive (Galkeno 300 Road) bisects the catchment and two culverts convey water at different locations. The physical area of the catchment is a product of the road cut and associated culverts. It is possible that freshet flows may be reduced as a result of water bypassing frozen culverts and being directed into Porcupine Creek.

However, direct observations during this period are absent, but frozen culverts during freshet have been observed at other sites in and around Elsa (e.g. Porcupine diversion along Calumet Drive). Table 6 shows the discrete measurements gathered to date at KV-21.

Previous attempts at continuous gauging at KV-21 have not been successful due to heavy icing and a steep dynamic channel near the Silver Trail Highway. High water velocities, ice and machinery have all contributed to damage to the stilling wells and general channel instability. In September 2013, AEG and AKHM personnel installed a new station approximately 150 m below the Silver Trail Highway where the channel has a lower gradient. An artificial control was installed to create a step pool and provide a convenient place to measure water level. However, flows were so low in 2014 that stage changes were insufficient to establish a reliable rating curve. In June of 2015, AEG Whitehorse personnel installed a V-notch weir to garner reliable continuous data (Figure 3). The weir has provided a high confidence rating curve and continuous discharge has been successfully derived since installation. The highest discharge measured with the logger was 0.081 m^3/s on August 11th as the weir was not installed until after freshet. Figure C19 (Appendix C) shows the 2015 hydrograph but the freshet peak was not captured; however, a discrete measurement of 0.244 m^3/s was measured on May 14th, 2016 during freshet. Freshet was not as large in 2016 but peaked at 0.164 m^3/s on May 2nd, 2016 (Figure C20, Appendix C). Discrete measurements are also included in Appendix A (2016) and Appendix B (all years).

Table 6 – Discrete Discharge measurements at KV-21, No Cash Creek at the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2007							0.015					
2008								0.007				
2009							0.003			0.006		
2010					0.010	0.008	0.007			0.008		
2011					0.020		0.005	0.011				
2012		0.002					0.012					
2013									0.016	0.017	0.004	
2014					0.058	0.005	0.005	0.011	0.026	0.013	0.007	
2015	0.003			0.002	0.244	0.011			0.035	0.017	0.002	0.010
2016	0.005	0.004	0.006	0.003	0.049	0.016	0.022	0.045	0.025	0.010	0.006	0.006
Mean	0.004	0.003	0.006	0.002	0.076	0.010	0.010	0.019	0.026	0.012	0.005	0.008
95% Confidence limit	0.002	0.002	N/A	0.001	0.084	0.005	0.005	0.018	0.008	0.004	0.002	0.004

Figure 3 – Weir at KV-21, June 2015

Table 7 – Mean Monthly Discharge at KV-21, No Cash Creek at the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015						0.010	0.017	0.020	0.027	0.016	0.004	0.008
2016	0.005	0.004	0.005	0.01	0.044	0.017	0.019	0.019	0.019			
Mean	0.005	0.004	0.005	0.010	0.044	0.014	0.018	0.020	0.023	0.016	0.004	0.008

3.2.5 KV-41 LIGHTNING CREEK AT KENO CITY BRIDGE

Lightning Creek at KV-41 has a catchment area of ~59 km² and a median catchment elevation of approximately ~1400 masl. Lightning Creek originates east of Keno City and drains the southern aspect of Keno Hill and the northern aspect of Mount Hinton. Lightning Creek flows to the south of Galena Hill into Duncan Creek. Within the Lightening Creek watershed are multiple adits including Keno 200 and 700, multiple old surface workings, Bellekeno workings and active placer mining on Thunder Gulch.

Hydrometric station KV-41 is located above the Keno City Bridge, and downstream of the Bellekeno Mine and local placer mining activity. Figure C2121 through Figure C256 (Appendix C) show the discharge time series for 2010, 2011, 2012, 2014, 2015, and 2016, respectively. Due to a logger failure in 2013 no continuous discharge was available.

Figure C256 (Appendix C) shows the 2016 hydrograph at KV-41 which includes the peak annual discharge 6.334 m^3/s captured June 7th, 2016. As with previous years the peak occurred later on Lightening Creek, presumably due to a lag in snowmelt associated with the higher median elevation of the Lightening Creek Catchment.

Table 8 presents mean monthly data gathered since continuous data collection began and includes discrete discharge measurements in grey in lieu of monthly means where data are unavailable. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 8 – Mean Monthly Discharge at KV-41, Lightening Creek above Keno City Bridge (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004								0.433	0.315	0.24	0.153	0.125
2005	0.098	0.067	0.056	0.13	1.802	1.418	0.989	1.111	0.958	0.637	0.452	0.299
2006	0.219	0.192	0.194	0.272	0.793	1.994	1.326	0.921	1.083	0.889	0.554	0.447
2007					1.231	1.926	1.193					
2008								1.136	0.77	1.03		
2009		0.11	0.128	0.069	1.595	1.628						
2010					1.172	1.383	1.007	0.76	0.57	0.457		
2011						1.206	1.826	1.542	0.926			0.268
2012	0.251	0.159	0.182			2.096	1.404	0.707	0.869	0.566		
2013						1.901	0.71	0.437	0.774	0.766	0.421	0.174
2014	0.149	0.126	0.096		1.25	1.746	0.703	1.264	0.851	0.614	0.336	0.212
2015	0.198	0.198	0.197	0.195	2.487	1.178	1.035	1.377	1.544	0.735	0.388	0.217
2016	0.201	0.211	0.21	0.217	1.27	1.862	0.924	1.246	0.785			
Mean	0.183	0.142	0.142	0.167	1.513	1.619	1.185	1.028	0.876	0.659	0.384	0.249
95% Confidence limit	0.044	0.039	0.044	0.069	0.356	0.192	0.211	0.220	0.181	0.152	0.108	0.077

Note: Grey numbers are discrete discharge measurements (Included in means Oct-Apr).

3.2.6 KV-51 CHRISTAL CREEK DOWNSTREAM OF HINTON CREEK

In 2015, a new hydrometric station was commissioned above Christal Lake to better quantify the water balance of Christal Lake. Provisional data were provided in 2015 and the rating curve was updated for 2016. The 2015 hydrograph begins in early June when the station was established and shows similar event peaks to lower Christal Creek sites, but unfortunately did not capture freshet. However, a discrete measurement of 0.116 m^3/s was taken May 12th during the freshet period (Figure C27, Appendix C). As at KV-7 freshet did not produce the peak annual flow at KV-51; peak discharge occurred on July 25th, 2016 at 0.136 m^3/s (Figure C28, Appendix C). Table 9 summarizes the continuous data collected to date as mean monthly discharge while discrete measurements are included in Appendix A (2016) and B (historic).

Table 9 – Mean Monthly Discharge at KV-51, Christal Creek downstream of Hinton Creek (m³/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015						0.024	0.029	0.034	0.045	0.038	0.035	0.034
2016	0.033	0.031	0.031	0.036	0.053	0.043	0.052	0.067	0.053			
Mean	0.033	0.031	0.031	0.036	0.053	0.034	0.041	0.051	0.049	0.038	0.035	0.034

3.2.7 KV-60 GALENA CREEK ABOVE SILVER KING ADIT

Galena Creek is southwest of Elsa and the upper reaches of the watershed boarder those of Flat Creek with northwest aspect. KV-60 is located below the Silver Trail Highway and adjacent to the Silver King 100 Adit. Treatment water from Silver King does not influence KV-60. The catchment at KV-60 is ~9.4 km² with a median elevation of ~997 masl. The channel is deeply incised and flows through a rocky canyon just above the Silver Trail Highway and is characterized by large boulders and step pools, not dissimilar to Flat Creek. The historic Silver King 75 adit is located in the canyon above the highway.

Continuous hydrometric monitoring at KV-60 has been challenging due to the high gradient and flow velocity of the site. Large gravel and cobbles are frequently transported at this. The stream morphology can change each season during freshet compounding data collection challenges. KV-60 was re-established and resurveyed in September 2013 in conjunction with some channel modifications in an attempt to establish a stable control using large rocks in the channel. In September 2014 the channel was modified in an effort to minimize deposition of gravel around the staff gauge, once again altering the stage-discharge relationship. In June 2015 is was found that these efforts had ultimately failed to create favourable conditions for the reach and a decision was made in the field to establish a new staff gauge in the pool just above without any modifications to the natural arrangement of the channel as it was observed that this pool seemed to be stable over the preceding years.

Hydrographs for 2012, 2013, 2014, 2015 and 2016 are included in Appendix C; Figure C29 to Figure C33 respectively. The 2015 hydrograph peaks on May 13th at 4.40 m³/s which is the highest reliable data point measured to date (Figure C32, Appendix C). Freshet peaked much lower in 2016 at 0.725 m³/s on April 2nd, 2016 (Figure C33, Appendix C). One discrete measurement in August of 2016 appears to disagree with the derived record, but the measurement showed high uncertainty (45%) so can be disregarded. Table 10 presents the mean monthly discharge since continuous data gathering began in 2012. Discrete measurements are included in Appendix A (2016) and Appendix B (all years).

Table 10 - Monthly Discharge at KV-60, Galena Creek above Silver King Adit (m³/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2012	0.007	0.004			0.386	0.039	0.095	0.046	0.065	0.025		
2013				0.994	0.891	0.315	0.018		0.045	0.078		
2014					0.039	0.144	0.017	0.234	0.104	0.112	0.026	0.016
2015	0.010	0.006	0.037	0.149	0.354	0.055	0.143	0.206	0.185	0.084	0.035	0.017

2016	0.013	0.009	0.012	0.117	0.268	0.058	0.094	0.116	0.113			
Mean	0.009	0.005	0.037	0.572	0.388	0.122	0.073	0.151	0.102	0.075	0.031	0.017
95% Confidence limit	0.003	0.003	0.024	0.563	0.274	0.101	0.048	0.084	0.047	0.036	0.009	0.001

Note: Grey numbers are discrete discharge measurements (Included in means Oct-Apr).

3.2.8 KV-64 FLAT CREEK AT SILVER TRAIL HIGHWAY

Flat Creek at the Silver Trail Highway is steep, rocky, and unstable. Water Quality measurements are gathered above the highway, but there is no suitable location for continuous gauging above the highway. Attenuation of peak flows occurs at the highway were significant deposition has covered older culverts and it is clear that water levels rise above the top of the culvert during freshet. Perhaps due to this effect or due to lessened anthropogenic influence the reaches below appear more stable and ultimately a station was established below the highway in September 2015 (Figure 2). The deposition above the highway was excavated and repairs were made to the culverts in 2016 to mitigate ponding above the highway during freshet. Continuous discharge was derived for 2016 and shows a peak on 0.334 m^3/s on May 9th, 2016 (Figure C34, Appendix C). However, due to the lower number of rating measurements there is still greater uncertainty at this site compared to other long term stations in the district. Table 11 presents the mean monthly discharge from the period of the derived discharge record. Discrete measurements are included in Appendix A (2016) and Appendix B (all available)

Table 11 – Mean Monthly Discharge at KV-64, Flat Creek below the Silver Trail Highway (m^3/s)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2015									0.077	0.037	0.043	0.017
2016	0.007	0.004	0.003	0.029	0.115	0.037	0.047	0.065	0.048			

4 REFERENCES

Clearwater Consultants Ltd. 2008. Memorandum CCL-UKHM-1 United Keno Hill Mines – Hydrological Update and Assessment.

Clearwater Consultants Ltd. 2010. Memorandum CCL-UKHM-3 United Keno Hill Mines – Hydrological Update and Assessment.

APPENDIX A

DISCRETE DISCHARGE MEASUREMENTS 2016

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-6	Christal Creek u/s Silver Trail Highway	06/01/2016	14:45	129.6	0.1	
		02/02/2016	12:40	66.5	38.1	
		05/03/2016	15:13	86.1	2.6	
		06/04/2016	12:22	71.3	0.2	
		03/05/2016	5:18	169.5	4.4	0.265
		15/06/2016	10:37	103.5	7.1	0.215
		14/07/2016	14:20	98.1	4.4	0.226
		07/08/2016	9:21	180.3	1.1	0.294
		23/09/2016	10:00	112	2.6	0.248
		22/10/2016	14:50	93.7	5.1	0.314
		09/11/2016	17:45	86.7	4.1	
		03/12/2016	Entire staff gauge is under ice, overflow backed up from highway, could not find second location with flowing			
KV-7	Christal Creek at Hanson Road	09/01/2016	12:09	163.3	14.5	
		01/02/2016	12:10	144.9	1.6	
		03/03/2016	12:18	110.7	3.1	
		06/04/2016	11:01	100.1	9.6	
		03/05/2016	14:05	1006.1	0.3	0.695
		15/06/2016	9:03	256.5	3.8	0.425
		14/07/2016	12:56	518.7	1.2	0.54
		06/08/2016	16:07	574.8	16.7	0.602
		22/09/2016	12:32	473.4	0.5	0.549
		22/10/2016	13:41	207.2	3.9	
		09/11/2016	13:45	188.7	0.7	
		03/12/2016	10:54	236.5	0.9	
KV-8	Christal Creek at mouth	09/01/2016	10:58			
		01/02/2016	10:48			
		03/03/2016	11:09	166.1		
		06/04/2016	9:59	106.8		
		03/05/2016	12:36	1009.4		
		13/06/2016	15:34	330	10.2	
KV-8	Christal Creek at mouth	14/07/2016	11:39	501.7		
		06/08/2016	13:57	748.6		
		22/09/2016	10:05	465.7		
		22/10/2016	12:09	310.3		
		09/11/2016	11:28	141.6		

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-9	Flat Creek upstream of South McQuesten River	08/01/2016	11:13	47.4	17.7	
		02/02/2016	14:26	19.9	7.5	0.296
		04/03/2016				
		07/04/2016	9:35	20	19.2	0.282
		02/05/2016	13:37	1740.1	3.2	0.85
		13/06/2016	11:50	269.2	2.2	0.459
		13/07/2016	13:45	263	1.6	0.451
		05/08/2016	12:18	543.6	4.6	0.554
		22/09/2016	3:10	551.6	1.6	0.584
		21/10/2016	13:46	93	0.8	0.46
		08/11/2016	13:08	73.5	4.8	
		02/12/2016	9:35	30.7	4.5	0.299
KV-9A	Flat Creek u/s Galena Creek	08/01/2016				
		04/02/2016				
		04/03/2016				
		07/04/2016				
		05/05/2016	10:01	296.8		
		14/06/2016	9:55	148	7.6	
		15/07/2016	9:58	146.2		
		05/08/2016	14:34	204.6		
		24/09/2016	9:21	162.3		
		23/10/2016				
		08/11/2016	15:12	78.3		
		02/12/2016				
KV-12	Valley Tailings Pond #3 Decant	21/06/2016		21.80		
		19/07/2016		16.86		
		16/08/2016		7.87		
		25/09/2016		13.37		
		20/10/2016		12.55		
		31/10/2016		11.92		
KV-17	Husky South West Shaft	05/01/2016				
		03/02/2016		0		
		04/03/2016				
		02/05/2016		0		
		14/07/2016				
		21/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-18	Bermingham 200 Adit	05/01/2016	14:38	2		
		03/02/2016	10:04	2.4		
		05/03/2016	14:01	1.3		
		07/04/2016	15:54	1.1		
		05/05/2016	16:09	1.3		
		15/06/2016	14:10	2.8	6.3	
		14/07/2016	16:18	2.9		
		08/08/2016	13:18	9.9		
		24/09/2016	15:30	3.8		
		20/10/2016	13:12	2.7		
		11/11/2016	9:30	1.8		
		03/12/2016	13:42	6.9		
KV-19	Ruby 400 Adit	05/01/2016	15:26	4		
		03/02/2016	10:53	2.8		
		05/03/2016	13:25	2.7		
		07/04/2016	15:06	2.1		
		04/05/2016				
		05/05/2016	17:19	2.8		
KV-19	Ruby 400 Adit	15/06/2016	13:24	1.3	0.9	
		15/07/2016	9:24	2.3		
		08/08/2016	12:33	2.8		
		24/09/2016	14:12	3.1		
		20/10/2016	12:35	2.9		
		11/11/2016	8:54	2.9		
		01/12/2016	15:02	9.2		
KV-20	No Cash 500 Adit	09/01/2016	15:27	10.3		
		03/02/2016	13:02	4.9		
		05/03/2016	12:44	4.1		
		07/04/2016	14:12	3		
		05/05/2016	14:00	4.4		
		14/06/2016	14:56	10	10.3	
		17/07/2016	9:02	10.7		
		05/08/2016	16:13	13.5		
		23/09/2016	13:35	11.5		
		23/10/2016	14:27	8.8		
		11/11/2016	11:15	5.5		
		03/12/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-21	No Cash Creek u/s Silver Trail Highway	09/01/2016	14:12	5.4	5.1	
		01/02/2016	13:24	3.6	9.2	
		06/03/2016	11:01	5.8		
		05/04/2016	16:26	2.7	6.7	
		04/05/2016	12:50	48.9	10.4	0.546
		16/06/2016	11:30	16.2	1.5	
		15/07/2016	13:55	21.6	2.8	0.458
		06/08/2016	17:18	45.2	9.1	0.503
		23/09/2016	11:59	25.1	13.7	0.45
		23/10/2016	11:30	10.2	3.7	
		10/11/2016	17:40	5.8	0	
		01/12/2016	12:24	6.2	3.5	
KV-33	Keno 700 Adit	07/01/2016	12:30	3.2		
		03/02/2016	15:25	0.42		
		05/03/2016		2.3		
		08/04/2016		2.3		
		19/05/2016	9:30	8.9		
		16/06/2016	10:47	5.8	9.4	0.156
		17/07/2016	11:02	6	5.6	
		08/08/2016	15:11	7.2	15.7	
		21/09/2016	19:49	6.6	3.3	
		20/10/2016	9:27	3.9	17.3	
		11/11/2016	13:22	4.3	4.2	
		04/12/2016	11:17	2.5	25	
KV-35	Sadie Ladue 600 Adit	07/01/2016	14:09	3.3		
		30/01/2016	10:51	3.9	0.5	
		05/03/2016	10:29	2.8		
		08/04/2016	9:54	2.8		
		18/05/2016	17:36	29.2	18.07	
		14/06/2016	17:39	15.8	2.5	
		17/07/2016	15:19	22.7	3.1	
		18/08/2016	16:23	47.3	0.4	
		24/09/2016	15:38	29.7	3	
		19/10/2016	17:36	13.9	3.1	
		09/11/2016	15:56	13	5.2	
		04/12/2016	12:37	11.1	1.6	

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-37	Lightning Creek u/s Hope Gulch	06/01/2016				
		08/02/2016	11:18	112.2	3.5	
		02/03/2016	10:24	102.5		
		08/04/2016	11:46	78		
		01/05/2016	13:20	92.8		
		16/06/2016	12:31	1180.2	0.5	
KV-37	Lightning Creek u/s Hope Gulch	12/07/2016	12:27	440.5		
		07/08/2016	Large beaver dam immediately above site, and small dam below, flooding banks and making poor conditions for measuring discharge, good spot for Q just d/s of sign			
		22/09/2016	14:01	489.6		
		20/10/2016	12:42	211.8		
		11/11/2016	14:31	187.8		
		04/12/2016	15:15	186.6		
KV-38	Lightning Creek u/s Thunder Gulch	08/02/2016	9:28	93.9		
		01/05/2016	11:32	156.4		
		12/07/2016	10:35	688.6		
		22/09/2016	13:09	702.3		
		20/10/2016	10:59	342.3		
KV-41	Lightning Creek u/s Keno City bridge	05/01/2016	12:03	200.3	2.6	
		02/02/2016	11:45	213		
		02/03/2016	9:38	228.8	4	
		06/04/2016	14:46	175.7	1	
		01/05/2016	10:19	236	0.9	0.065
		16/06/2016	9:33	1801.7	1.1	
		12/07/2016	9:45	884.1	5.7	0.144
		07/08/2016	12:58	1365.8	0.8	0.193
		22/09/2016	11:15	1049.5	4.6	0.159
		20/10/2016	10:10	521.5	2.2	
		08/11/2016	18:23	282.2	6.1	
		04/12/2016	14:36	320.7	2.2	
KV-47	Porcupine Diversion Ditch d/s Upper Flat Creek	04/02/2016				
		05/05/2016				0.208
		16/07/2016				0.282
		21/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-49	Hinton Creek upstream Christal Creek	03/02/2016		0		
		04/05/2016				
		15/07/2016				
		23/10/2016				
KV-50	Christal Creek upstream Hinton Creek	03/02/2016	13:48	24.7	1.7	
		04/05/2016	11:30	28.5	4.6	
		15/07/2016	14:38	33.1	20.3	
		23/10/2016	9:47	43.3		
KV-51	Christal Creek d/s Hinton Creek	06/01/2016	15:30	37		
		03/02/2016	13:17	25.3	2.3	
		02/03/2016	16:13	25.8	9.6	
		06/04/2016	16:11	19.2	16.6	
		04/05/2016	10:55	47	6	0.451
		15/06/2016	15:48	46.7	2.5	0.406
		15/07/2016	13:52	41.4	10.9	0.461
		07/08/2016	10:36	78.9	3.2	0.513
		23/09/2016	14:48	53.2	1.7	0.428
		23/10/2016	9:12	41.5	4.7	
		11/11/2016	16:59	29.7		
		05/12/2016	10:01	37.1	1.5	
KV-52	Natural spring to Christal Lake at old pumphouse	07/01/2016	15:09	70.7		
		03/02/2016	11:06	47	0.1	
		05/03/2016	15:53	41.4		
		06/04/2016	13:08	34.5		
		04/05/2016	9:02	29.4		
		15/06/2016	12:40	36.9		
		14/07/2016	15:37	40.4		
		07/08/2016	10:01	33		
		23/09/2016	15:19	41.9		
		22/10/2016	16:04	39.4		
KV-52	Natural spring to Christal Lake	10/11/2016	18:33	41.2		
		03/12/2016	16:33	53.3		
KV-53	UN Adit	05/01/2016				
		05/02/2016				
		02/03/2016				
		01/05/2016		0		
		15/07/2016				
		20/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-55	Sandy Creek at Silver Trail Highway	01/02/2016	Conditions not suitable for salt slug, could only find what appears to be overflow water, large ice jam present at			
		02/03/2016				
		03/05/2016				
		13/07/2016	15:47	5.3		
		23/10/2016				
KV-56	Star Creek at Silver Trail Highway	01/02/2016	Creek appears to be frozen to the ground, moved up from culvert but could find water, only stagnant pools near			
		03/05/2016	16:28	95.3		
		13/07/2016	16:26	20.6		
		23/10/2016				
KV-60	Galena Creek upstream of Silver King 100 adit	08/01/2016	15:19	13.9	2.4	
		04/02/2016	12:06	10.1	2.2	
		04/03/2016	12:44	10.6		
		07/04/2016	12:07	5	1.6	
		05/05/2016	11:13	418.6	11.4	0.359
		14/06/2016	11:58	58.4	2.6	0.253
		15/07/2016	11:10	49.3	0.2	0.248
		06/08/2016	9:15	279.6		0.3065
		24/09/2016	11:06	82.9	0.9	0.26
		23/10/2016	11:56	21.2	0.3	
KV-60	Galena Creek upstream of	10/11/2016	10:10	17.2	1.4	
		02/12/2016	12:31	12.6	7.2	
KV-61	Porcupine Gulch at Calumet Road Crossing	03/02/2016	11:41	5.4		
		04/05/2016	15:41	26.8	8.4	
		15/07/2016	10:11	10.4		
		20/10/2016	11:05	14		
KV-62	Brefalt Creek upstream of Porcupine Diversion	07/02/2016				
		06/05/2016	12:54	65.7	2.7	
		16/06/2016	12:23	1.9		
		15/07/2016	12:51	1.7	3.0	0.259
		20/10/2016				

Station ID	Description	Sample Date	Measurement Time	Discharge (L/s)	Discharge RPD (%)	Stage (m)
KV-64	Flat Creek at Silver Trail Highway	09/01/2016	16:28	8.8	8.9	
		01/02/2016	10:12	4.2	37.6	
		03/03/2016	15:56	3.4	2.3	
		08/04/2016	11:22	2.7	21.8	
		06/05/2016	10:06	142.9	4.7	0.29
		16/06/2016	15:07	44.5	0.2	0.425
		15/07/2016	11:30	38.6	26.1	0.412
		08/08/2016	10:26	130.8	3.6	0.485
		23/09/2016	13:29	64.3	9.4	0.474
		23/10/2016	14:38	21.9	5.5	
		10/11/2016	16:25	15	0.2	
		02/12/2016	14:57	11.4	1.4	
KV-65	Thunder Gulch upstream of Bellekeno	06/01/2016	13:06	62.5		
		08/02/2016	13:34	47.6	2.9	
		06/03/2016	13:10	45.7		
		07/04/2016	16:30	35.9		
		01/05/2016	14:53	44.8		
		16/06/2016	14:35	223.3	0.2	
KV-65	Thunder Gulch upstream of Bellekeno	12/07/2016	13:48	75.4		
		09/08/2016	8:49	136.6		
		22/09/2016	14:58	97.8		
		20/10/2016	14:01	134		
		24/10/2016				
		11/11/2016	15:17	90.9		
		05/12/2016	8:54	75.6		
KV-66	Klondike Keno Adit	01/02/2016				
		05/05/2016	11:03	2	3.1	
		16/07/2016	16:11	1.2		
		21/10/2016	14:11	1.6		
KV-72	South McQuesten River at McQuesten	07/02/2016				
		03/05/2016	9:51	527.1		
		14/07/2016	9:42	724.4		
		22/10/2016	9:49	357.4		
FIEC	Field Creek upstream of Duncan Creek Road	10/01/2016	10:55	34.3		
		09/02/2016				
		06/03/2016				
		08/04/2016				
		06/05/2016	8:36	931		
		16/06/2016	13:41	126.5		
		16/07/2016	11:46	467.9		
		08/08/2016	8:23	1077.2		
		25/09/2016	14:16	222.2		
		23/10/2016	13:12	84.6		
		12/11/2016	9:13	53		
		04/12/2016	9:29	43.1		

APPENDIX B

DISCRETE DISCHARGE MEASUREMENTS HISTORIC

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
01/01/1994								
27/01/1994						0.1	3	2
01/02/1994								
24/02/1994						0.1	3	2
01/03/1994								
28/03/1994						0.1	3	0.5
23/04/1994						1.5	3	1
10/05/1994							2	
13/05/1994						2		
31/05/1994								12
01/06/1994							2	12
27/06/1994						0.8	2.8	1.5
28/06/1994								
27/07/1994							2	
28/07/1994								
29/07/1994							2	0.4
17/08/1994						0.1	2	0.4
07/09/1994		116						
29/09/1994						0.1	2	0.4
27/10/1994								
31/10/1994						0.1	2	0.5
29/11/1994						0.1	2	0.5
05/01/1995						0.1	2	0.5
06/02/1995							2	0.5
01/03/1995								
29/03/1995							2	0.2
27/04/1995						0.1	1.5	0.5
03/05/1995		298.6					1.3	1.5
06/06/1995								0.7
06/07/1995	18	220				2	2	0.7
11/07/1995								0.5
05/08/1995		236						
11/08/1995						0.1	2.5	2
04/09/1995						0.1	25.3	0.2
05/09/1995								
11/10/1995						0.1	14.5	0.6
05/11/1995						0.7	3	1
12/12/1995						0.1		
01/01/1996						0.1		
09/02/1996						0.1		
05/03/1996						0.1		
07/04/1996						0.1		
28/04/1996								
24/06/1996						9		
18/07/1996						18		

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
02/08/1996						4.9		
16/09/1996						0.1		
03/10/1996						0.1		
30/10/1996						0.1		
30/11/1996						0.1		
28/01/1997						0.1		
26/02/1997						0.1		
27/03/1997								2
12/05/1997						30		
25/06/1997							0.8	6.7
30/06/1997						2.8	1	2.5
31/07/1997						27		
20/08/1997						15		
13/09/1997						10.5		
10/10/1997		92		40		6	3	2.5
21/12/1997						0.33		
15/01/1998				30			1.5	1
13/03/1998				20				1
25/04/1998						0.08		
11/05/1998								
14/05/1998								1
23/05/1998						10.3		
30/05/1998						5.6		
06/06/2000						17		
07/11/2000						5.3		
10/07/2001						32	1.0	7.0
11/07/2001		872						
02/08/2003		165.7		109.2		1.4	0.1	0.5
24/01/2004		127	302	28				
19/02/2004		180						
23/03/2004		150						
24/04/2004		150						
15/06/2004		247	268					
20/07/2004		108						
29/07/2004	85							
30/07/2004		323	347	293				
25/08/2004		121						
21/09/2004		149						
21/10/2004		104						
29/11/2004		102						
17/12/2004		259						
25/01/2005		351.685439	383	24.6				
26/02/2005				28				
27/02/2005		233.065736	302					
22/03/2005		290						

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
21/04/2005		62.099477	357					
22/04/2005	48							
27/05/2005		657.269274						
30/06/2005	73.7	136	268			1.26		
19/07/2005				282				
20/07/2005	93	204						
22/08/2005				245				
23/08/2005		237						
22/09/2005		149						
25/10/2005	73	186	282					
25/01/2006		188	336	117				
22/02/2006		117						
14/03/2006				23				
15/03/2006		159.453969	332					
27/04/2006			313					
28/06/2006	130	858	221			8.4	0.4	
31/08/2006	108.987092	251.196066	263.1					
21/09/2006	112	374						
25/10/2006							0.5	2
15/06/2007						>20		
11/07/2007						>20		3.5
12/07/2007							0.3	
13/07/2007				1092.9				
15/07/2007								
16/07/2007								
17/07/2007								
18/08/2007						7.5		
31/08/2007			159.145					
05/09/2007	60.63	189.2	200.28					
06/09/2007				166.2				
08/09/2007								
10/09/2007							1.6	1.5
11/09/2007						2.6		
13/09/2007								
28/10/2007						3.2		
13/03/2008								2
16/05/2008				1137.0				
18/05/2008 11:45								
03/07/2008		159.4	210	152.2				
05/07/2008								
06/07/2008	129.6							
13/08/2008		437.6	488.35	1020.195				
14/08/2008	119.385					15		
15/09/2008	80.18							
18/09/2008		518.43	412.38	320.64				

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
02/10/2008		419.66						
03/10/2008	160.71		724.44					
04/10/2008				538.36				
05/10/2008						3.15		
26/05/2009 17:15				1940.275			0.16	2
27/05/2009 14:15			1421.154			20		
28/05/2009 12:00								
05/06/2009 17:00	124.365	441.74	356.11	474.39				
06/06/2009						20		
04/07/2009 13:45				173.93			0.25	0.25
05/07/2009 14:35								
06/07/2009 14:10		124.245	94.06					
07/07/2009 09:30	101.233					6.487		
08/09/2009		269.23	220.16	253.095				
09/09/2009	102.54							
11/09/2009						10		
06/10/2009		228.95						
07/10/2009	33.155							1
08/10/2009							0.5	
09/10/2009				201.83				
03/05/2010								
04/05/2010		612.41						
05/05/2010	71.19						0.2	
26/05/2010								5
27/05/2010								
28/05/2010				429.36				
08/06/2010		357.17						
05/07/2010								2
06/07/2010							0.1	
07/07/2010		287.520533	340.0533					
08/07/2010	94.01815							
09/07/2010						12		
04/08/2010	61.129433	231.0865	230.559					
14/09/2010	141.375	186.5	137.65	136.3				
15/09/2010						10		
05/10/2010	94.041	184.638	130.976					1
06/10/2010				109.313			0.2	
07/10/2010								
09/02/2011 12:00								1
12/05/2011 15:30				1179.0934				
13/05/2011 08:50		357.0665						
25/05/2011 15:20	135.975							12
26/05/2011 11:55								
27/05/2011 14:00							0	
21/06/2011 12:00								0.5

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
22/06/2011 15:20	79.95	104.985	106.99					
12/07/2011 13:20							0	2.5
13/07/2011 13:15	90.96							
14/07/2011 15:15				540.63				
19/07/2011 12:20						15		
16/08/2011 14:50								
17/08/2011 10:45	127							9
18/08/2011 16:00		258.7				30		
17/09/2011 08:25								
22/09/2011 15:05								
23/09/2011 09:30		286.48						
24/09/2011 14:40	127.0575		290.185					
25/09/2011 12:55						0		
23/10/2011				155				
24/10/2011		173	188					
25/10/2011								
26/10/2011 16:20								
27/10/2011								
29/10/2011 16:00	88							
30/10/2011 14:30								
31/10/2011 12:30								
20/11/2011 14:25						0		2.6
21/11/2011 11:00	74.8							
22/11/2011 10:00								
24/11/2011 15:00			137.5					
26/11/2011 09:00		125.7						
13/12/2011 14:15						0		
14/12/2011 16:25	107.2							
15/12/2011 12:20			134					
16/12/2011 15:10								
17/12/2011 09:30								2.1
18/12/2011 12:25								
20/12/2011 13:30								
21/12/2011 15:20								
12/01/2012 15:30								1.3
13/01/2012 12:00		153.7	162.2					
14/01/2012 14:40						0		
17/01/2012 13:00								
18/01/2012 09:40								
24/01/2012 15:45								
09/02/2012 15:25								
11/02/2012 15:30						0		
12/02/2012 10:35								
13/02/2012 13:30	77.2							
14/02/2012 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
16/02/2012 13:00					0			
09/03/2012 10:50								
10/03/2012 12:50			90.4					
11/03/2012 10:00	77.3							
12/03/2012 08:45								
14/03/2012 13:30					0			
15/03/2012 12:00						0		
07/04/2012 14:10								
08/04/2012 09:25	61.7			11.7				
09/04/2012 13:50						0		
01/05/2012 11:30	147.0	540.4						
03/05/2012 14:07								
04/05/2012 11:30				1574.2				
05/05/2012 10:17			677.0					
06/05/2012 13:28								
07/05/2012 09:00	104.7	600.0						
08/05/2012 10:35						15.66		
09/05/2012 08:45								
31/05/2012								
01/06/2012		368.9875	388.94					
03/06/2012	88.65							
04/06/2012					221.895			15.636
05/06/2012						12.12		
06/06/2012 14:00								
07/06/2012 09:05				429.68				
01/07/2012 10:00								
02/07/2012 14:47								
03/07/2012 12:05								
04/07/2012 13:40	85.35							
05/07/2012 09:50								
07/07/2012 12:00				243.5	118.2			
08/07/2012 14:55								
09/07/2012 08:50								
10/07/2012 10:30						13.3		
16/07/2012 15:30	104.69	205.67						
01/08/2012 10:25	91							
02/08/2012 12:30		258	192					
03/08/2012 10:00				239	115			
05/08/2012 13:05								3
07/08/2012 08:10						5		
02/09/2012 08:50								1.6
03/09/2012 13:15								
20/09/2012 15:10								
21/09/2012 14:00		270.1	97.1					
22/09/2012 10:33				245.2				

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
23/09/2012 08:15	89.1				109.2			
25/09/2012 09:29						8.7		
10/10/2012 16:40								
11/10/2012 14:00			84.31					
12/10/2012 10:30				136.8563				
14/10/2012 13:30					73.291			
15/10/2012 10:45								
16/10/2012 12:50	76.18							
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30		74.75						
15/01/2013 09:30								
16/01/2013 14:00								1.18
08/02/2013 15:30		65.91						
09/02/2013 10:30								
10/02/2013 12:10								
12/02/2013 11:10								
07/03/2013 15:30								
08/03/2013 14:00		109.69						
12/03/2013 14:00								
14/03/2013 12:00								
04/04/2013 11:45								
06/04/2013 09:15								
09/04/2013 12:40							0	
10/04/2013 11:15								
02/05/2013 15:25								
03/05/2013 09:45								
04/05/2013 09:35								
07/05/2013 11:50								
01/06/2013 12:00								
02/06/2013 16:00								16.2425
03/06/2013 08:45								
04/06/2013 11:50					199.39			
05/06/2013 11:00				765.66				
07/06/2013 14:50		852						
08/06/2013 09:40	122.62							
09/06/2013 08:45								
01/07/2013 13:45				290.41				
02/07/2013 13:50			207.927					
03/07/2013 12:00								
04/07/2013 15:00		223.8						
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45					31.968			

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
12/07/2013 13:45	81.948							
06/08/2013 15:15						12.19		
10/08/2013 16:35			128.34					
11/08/2013 09:30		101.93						
12/08/2013 09:50	107.92							
01/09/2013 14:20								
02/09/2013 12:30		140.115	147.6					
03/09/2013 14:05	87.213							
04/09/2013 13:40				526.40				
05/09/2013 11:00								
07/09/2013 14:30								
08/09/2013 10:14								
09/09/2013 13:00						11.5		
11/09/2013 17:30	91.5							
12/09/2013 13:18		434.72		151.6				
13/09/2013 14:45								
14/09/2013 11:31								
01/10/2013 16:15						9.13		
03/10/2013 15:55								
04/10/2013 10:30				411.02				
05/10/2013 12:25		266.14	284.02					
06/10/2013 15:00								
07/10/2013 10:25								
09/10/2013 14:35								
10/10/2013 08:30	92.7							
04/11/2013 14:30								
06/11/2013 10:05				81.17				
07/11/2013 10:10								
08/11/2013 14:45								
09/11/2013 13:30								
11/11/2013 11:00	80.2							
02/12/2013 13:00								
03/12/2013 08:30								
04/12/2013 14:40								
06/12/2013 13:25		116.82						
02/01/2014 16:05								
03/01/2014 14:05		106.7						
25/01/2014 14:05								
02/02/2014 09:55								
03/02/2014 10:30		85.7						
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50								
12/02/2014 12:20								
18/02/2014 10:00					0			

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
01/03/2014 11:15	49.5							
02/03/2014 13:10								
04/03/2014 14:40					0		0	
04/04/2014 16:00	51.56							
05/04/2014 13:15		97.64						
06/04/2014 12:30							0	
07/04/2014 12:00					0			
03/05/2014 15:35								
04/05/2014 09:35								
05/05/2014 13:00								
06/05/2014 14:50								
07/05/2014 11:50								
08/05/2014 13:15		1760	1490					
10/05/2014 11:25	290							
11/05/2014 11:20							0	
13/05/2014 10:45				1856.458				
14/05/2014 12:00						0		
03/06/2014 15:00							0	
04/06/2014 11:40								
05/06/2014 11:45			120.1					
06/06/2014 10:43					80			
07/06/2014 12:50								
08/06/2014 12:25	58.8	115.6						2.8
09/06/2014 10:45				117.4				
10/06/2014 11:00								
01/07/2014 11:35								
02/07/2014 12:30								
03/07/2014 15:35	99.67	203.09						
04/07/2014 10:15			193.6					2.5
05/07/2014 13:25				253.82				
06/07/2014 09:00					113			
07/07/2014 10:00							0	
01/08/2014 09:50								
02/08/2014 12:00		199.85	201.2					
03/08/2014 09:00	63.01							
04/08/2014 09:30				141.7	110.6			
05/08/2014 16:00								
22/08/2014 15:30							0	
24/08/2014 11:00								5.5
25/08/2014 09:45				913.555				
02/09/2014 14:15								
16/09/2014 13:10						17.22		
18/09/2014 12:20								
19/09/2014 12:00	110.1515	270.11	330					
20/09/2014 10:00								3.163

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
21/09/2014 11:15						11.482		
22/09/2014 12:45					228			
27/09/2014 09:40				493.48				
16/10/2014 10:00								
17/10/2014 11:00								
18/10/2014 14:25			156.1					
19/10/2014 09:00	102.2	282.6						
20/10/2014 13:20				309.6				
21/10/2014 14:30					125.2			
22/10/2014 11:10						0		
23/10/2014 09:40								
24/10/2014 14:55								3
25/10/2014 11:00								
26/10/2014 09:00								
13/11/2014 13:30								
14/11/2014 12:30								
15/11/2014 14:20	80.1	150.2						
16/11/2014 14:45					31.9			
17/11/2014 14:15							0	
18/11/2014 10:00								
19/11/2014 14:05								2.4
20/11/2014 09:59								
21/11/2014 14:00								
22/11/2014 14:31						0		
12/12/2014 13:20								
13/12/2014 13:20								
14/12/2014 11:30								
15/12/2014 13:00		137.1	107.1					
16/12/2014 09:50								
18/12/2014 14:23							0	1.8
19/12/2014 15:40						0		
11/01/2015 13:16								
12/01/2015 11:57								
13/01/2015 13:12		162.7	182.3					
14/01/2015 10:13	104.3							
17/01/2015 13:00								
19/01/2015 15:05							0	
22/01/2015 13:24						0		
28/01/2015 10:00								
05/02/2015 13:07								
06/02/2015 11:50								
07/02/2015 14:00								
12/02/2015 13:07								
14/02/2015 14:47				7.8				
15/02/2015 11:30								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
16/02/2015 15:20						0		
17/02/2015 12:50								0.9
18/02/2015 08:00							0	
06/03/2015 13:30								
07/03/2015 13:00								
09/03/2015 10:30	69.8	87.7						
10/03/2015 12:05						0		0.9
11/03/2015 14:30							0	
13/03/2015 13:00				13				
03/04/2015 11:10								
06/04/2015 09:40								
07/04/2015 13:20		72.5	98.7					
08/04/2015 11:30	55.8							
09/04/2015 13:25						0		0.9
10/04/2015 12:00				16.7				
12/04/2015 10:40								
12/05/2015 10:15	324	2540				0		
13/05/2015 13:01								
14/05/2015 11:30				3682.3				
23/05/2015 14:20			738.9					
24/05/2015 16:14					266.4			
26/05/2015 07:30								
27/05/2015 12:34								
28/05/2015 12:42								
02/06/2015 13:16								
03/06/2015 14:30	105.9	233.6						
04/06/2015 10:30				242.5	122.4			
09/06/2015 13:23								
11/06/2015 10:24								
12/06/2015 11:48								
16/06/2015 08:48								1.7
17/06/2015 08:50			173.9					
18/06/2015 10:41								
19/06/2015 09:30								
23/06/2015 15:05						13.84		
09/07/2015 14:56								
13/07/2015 12:30								
15/07/2015 13:10								
16/07/2015 12:15								
18/07/2015 14:10		1038.5						
19/07/2015 12:20								
26/07/2015 09:22								
28/07/2015 12:00				218.1	120.8			
29/07/2015 10:30	100.0		300.6			19.37		
30/07/2015 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
06/08/2015 11:05		342.1	332.3					
12/08/2015 13:25								2.2
17/08/2015 10:35								
19/08/2015 14:30	125.1							
20/08/2015 14:20								
21/08/2015 11:50				514.8	111.7			
22/08/2015 13:00								
23/08/2015 14:25								
26/08/2015 12:10						11.12		
01/09/2015 11:30	138.2							
03/09/2015 10:56				1049				
04/09/2015 09:15		611.6						
10/09/2015 11:59								
11/09/2015 15:05								5.6
12/09/2015 13:31								
13/09/2015 15:25			640.1		261.2			
15/09/2015 14:46								
16/09/2015				964.3				
17/09/2015 12:07								1.4
18/09/2015	134.5	635.3						
19/09/2015								2.5
10/10/2015 15:07								
11/10/2015 12:07		329.1						
14/10/2015 15:04								
16/10/2015 13:45	91.8							
17/10/2015 15:30								
18/10/2015 10:05			263.9				0	2.8
19/10/2015 12:19				357.1				
20/10/2015 13:16					169.1			
14/11/2015 14:48								
15/11/2015 13:42								
16/11/2015 10:57								
17/11/2015 14:10								1.8
18/11/2015 10:08				77.0				
19/11/2015 10:55	147.3							
20/11/2015 15:38								
22/11/2015 15:30		178.9						
23/11/2015 12:09								
24/11/2015 12:50								
15/12/2015 11:50								
16/12/2015 11:20								
17/12/2015 12:00		179.9						
18/12/2015 12:15	142.2							2.1
19/12/2015 11:44				47				
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
05/01/2016 11:56								2
06/01/2016 13:00	129.6							
07/01/2016 15:00								
08/01/2016 10:41				47.4				
09/01/2016 11:50		163.3						
10/01/2016 10:30								
30/01/2016 10:40								
01/02/2016 11:30		144.9						
02/02/2016 14:00	66.5			19.9				
03/02/2016 11:20							0	2.4
04/02/2016 11:45								
08/02/2016 13:19								
02/03/2016 15:54								
03/03/2016 10:45		110.7	166.1					
04/03/2016 12:15								
05/03/2016 14:55	86.1							1.3
06/03/2016 12:45								
05/04/2016 16:00								
06/04/2016 09:30	71.3	100.1	106.8					
07/04/2016 09:10				20				1.1
08/04/2016 12:50								
01/05/2016 14:35								
02/05/2016 13:00				1740.1			0	
03/05/2016 12:25	169.5	1006.1	1009.4					
04/05/2016 15:28								
05/05/2016 10:20					296.8			1.3
06/05/2016 10:10								
18/05/2016 17:15								
19/05/2016 09:42								
13/06/2016 11:05			330	269.2				
14/06/2016 11:18					148			
15/06/2016 08:37	103.5	256.5						2.8
16/06/2016 14:30								
21/06/2016 14:50						21.80		
12/07/2016 13:30								
13/07/2016 13:20				263				
14/07/2016 11:15	98.1	518.7	501.7					2.9
15/07/2016 10:45					146.2			
16/07/2016 15:51								
17/07/2016 15:00								
19/07/2016 12:15						16.86		
05/08/2016 11:56				543.6	204.6			
06/08/2016 13:43		574.8	748.6					
07/08/2016 08:59	180.3							
08/08/2016 10:02								9.9

Discharge (Flow) (L/s)

Sample Date	KV-6	KV-7	KV-8	KV-9	KV-9A	KV-12	KV-17	KV-18
09/08/2016 08:24								
16/08/2016 13:25						7.87		
18/08/2016 15:54								
21/09/2016 17:45								
22/09/2016 14:18		473.4	465.7	551.6				
23/09/2016 14:20	112							
24/09/2016 10:13					162.3			3.8
25/09/2016 09:35						13.37		
19/10/2016 17:33								
20/10/2016 13:46						12.55		2.7
21/10/2016 13:17				93				
22/10/2016 12:10	93.7	207.2	310.3					
23/10/2016 14:21								
31/10/2016 10:10						11.92		
08/11/2016 12:45				73.5	78.3			
09/11/2016 10:31	86.7	188.7	141.6					
10/11/2016 15:50								
11/11/2016 15:06								1.8
12/11/2016 08:56								
01/12/2016 12:05								
02/12/2016 09:00				30.7				
03/12/2016 10:20		236.5						6.9
04/12/2016 14:15								
05/12/2016 08:40								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
01/01/1994					14			
27/01/1994	1.5	5						
01/02/1994					14			
24/02/1994	1.5	5			14			
01/03/1994					10			
28/03/1994	1.5	5						
23/04/1994	2	5			12			
10/05/1994								
13/05/1994								
31/05/1994	2	6			16			
01/06/1994	2	6			16			
27/06/1994	2	6.5						
28/06/1994					20			
27/07/1994	1	4.2						
28/07/1994					12.9			
29/07/1994	1	4.2						
17/08/1994	1	5			18			
07/09/1994								
29/09/1994	1.3	4			18			
27/10/1994		3.9						
31/10/1994	1.3	4			12			
29/11/1994	1.3	4			12			
05/01/1995	1	3			10			
06/02/1995	1	3			10			
01/03/1995	1.5							
29/03/1995	1	3			10			
27/04/1995	1.5	2.5			3			
03/05/1995	1.5	3			12			
06/06/1995	2							
06/07/1995	2	4						
11/07/1995	2.5	5						
05/08/1995								
11/08/1995	2	5			13			
04/09/1995	1	3.5			13			
05/09/1995		5						
11/10/1995	0.8	3.8			6.5			
05/11/1995	0.5	4			4.7			
12/12/1995								
01/01/1996								
09/02/1996								
05/03/1996								
07/04/1996								
28/04/1996		7.3						
24/06/1996								
18/07/1996								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
02/08/1996								
16/09/1996								
03/10/1996								
30/10/1996	0.1							
30/11/1996	0.1							
28/01/1997								
26/02/1997								
27/03/1997								
12/05/1997								
25/06/1997		5.7		4.0	16.0			
30/06/1997				7	17			
31/07/1997								
20/08/1997								
13/09/1997								
10/10/1997	5			4.5	13			
21/12/1997								
15/01/1998				3	9			
13/03/1998		3			10			
25/04/1998								
11/05/1998		4			11			
14/05/1998								
23/05/1998								
30/05/1998								
06/06/2000								
07/11/2000					9.7			
10/07/2001	2.2	8.5			14.0			
11/07/2001				5.0				
02/08/2003	0.7			1.6		423.7	651.4	641.4
24/01/2004								63
19/02/2004								
23/03/2004								
24/04/2004								
15/06/2004								
20/07/2004								
29/07/2004								961
30/07/2004						589	836	
25/08/2004								
21/09/2004								
21/10/2004								
29/11/2004								
17/12/2004								
25/01/2005								
26/02/2005								
27/02/2005								63
22/03/2005								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
21/04/2005								
22/04/2005								
27/05/2005								
30/06/2005								1526
19/07/2005								1362
20/07/2005								
22/08/2005								963
23/08/2005								
22/09/2005								
25/10/2005								
25/01/2006								192
22/02/2006								
14/03/2006								192
15/03/2006								
27/04/2006								
28/06/2006								
31/08/2006								
21/09/2006								
25/10/2006								
15/06/2007								
11/07/2007	1							
12/07/2007		7.8		5.5				
13/07/2007								
15/07/2007			15					
16/07/2007								
17/07/2007								
18/08/2007								
31/08/2007								
05/09/2007								
06/09/2007								
08/09/2007				1.3				
10/09/2007	1.5	6.7						
11/09/2007								
13/09/2007					6.75			
28/10/2007								
13/03/2008								
16/05/2008								
18/05/2008 11:45						225.3	595.72	
03/07/2008								
05/07/2008						301.1	482.8	664
06/07/2008								
13/08/2008			6.5					
14/08/2008								1492.925
15/09/2008								713.355
18/09/2008								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
02/10/2008					4.5	474.275	842.38	1190.65
03/10/2008								
04/10/2008								
05/10/2008								
26/05/2009 17:15	0.25	2.5						
27/05/2009 14:15								
28/05/2009 12:00				4	7			
05/06/2009 17:00								3589.96
06/06/2009								
04/07/2009 13:45	0.25	3						
05/07/2009 14:35				3	6	421.55	625.68	718.62
06/07/2009 14:10								
07/07/2009 09:30			3					
08/09/2009								1035.19
09/09/2009								
11/09/2009								
06/10/2009			6					645.7
07/10/2009	0.5			3	7	443.8		
08/10/2009		4						
09/10/2009								
03/05/2010								440.68
04/05/2010								
05/05/2010			10					
26/05/2010	0.75	8						
27/05/2010				3	10	900.9395		
28/05/2010								
08/06/2010			8					1675.405
05/07/2010	3							
06/07/2010		4		4				967.45467
07/07/2010								
08/07/2010			7		12	594.67633		
09/07/2010								
04/08/2010								818.157667
14/09/2010								483.2
15/09/2010								
05/10/2010								415.336
06/10/2010	0.5				15	241.745		
07/10/2010		8	8					
09/02/2011 12:00								
12/05/2011 15:30								
13/05/2011 08:50								
25/05/2011 15:20	3							
26/05/2011 11:55				10				
27/05/2011 14:00		15	20					
21/06/2011 12:00	0.2			7				1054.925

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
22/06/2011 15:20		4						
12/07/2011 13:20	0.5	4	5	10				
13/07/2011 13:15					8			1075.31
14/07/2011 15:15						1020.97		
19/07/2011 12:20								
16/08/2011 14:50								
17/08/2011 10:45		1						1713.42
18/08/2011 16:00	2		11					
17/09/2011 08:25						347.615		973.035
22/09/2011 15:05				8				
23/09/2011 09:30								766.75
24/09/2011 14:40								
25/09/2011 12:55								
23/10/2011								
24/10/2011								
25/10/2011								
26/10/2011 16:20								
27/10/2011					1.69			
29/10/2011 16:00			0.181818					
30/10/2011 14:30						206	330.5	404
31/10/2011 12:30								
20/11/2011 14:25								
21/11/2011 11:00								
22/11/2011 10:00						162		
24/11/2011 15:00					10			
26/11/2011 09:00								
13/12/2011 14:15								
14/12/2011 16:25								
15/12/2011 12:20								
16/12/2011 15:10								
17/12/2011 09:30								
18/12/2011 12:25						92.1	205.3	267.6
20/12/2011 13:30								
21/12/2011 15:20								
12/01/2012 15:30								
13/01/2012 12:00								
14/01/2012 14:40								
17/01/2012 13:00								251.2
18/01/2012 09:40						119.7	100.3	
24/01/2012 15:45								
09/02/2012 15:25						135.3	168.7	
11/02/2012 15:30								
12/02/2012 10:35								
13/02/2012 13:30								
14/02/2012 13:40			2.2					

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
16/02/2012 13:00								
09/03/2012 10:50							134.1	182
10/03/2012 12:50								
11/03/2012 10:00								
12/03/2012 08:45								
14/03/2012 13:30								
15/03/2012 12:00								
07/04/2012 14:10						68.74	107.3	
08/04/2012 09:25								
09/04/2012 13:50								
01/05/2012 11:30								202.2
03/05/2012 14:07								
04/05/2012 11:30								
05/05/2012 10:17								
06/05/2012 13:28						62.1	127.8	
07/05/2012 09:00								
08/05/2012 10:35								
09/05/2012 08:45								
31/05/2012								1655.8
01/06/2012						781.25	997.6025	
03/06/2012								
04/06/2012								
05/06/2012								
06/06/2012 14:00								
07/06/2012 09:05								
01/07/2012 10:00						691.05		
02/07/2012 14:47							1544.98	1957.63
03/07/2012 12:05								
04/07/2012 13:40								
05/07/2012 09:50								
07/07/2012 12:00								
08/07/2012 14:55								
09/07/2012 08:50			11.8					
10/07/2012 10:30								
16/07/2012 15:30								
01/08/2012 10:25				7		62	668	884
02/08/2012 12:30								
03/08/2012 10:00								
05/08/2012 13:05								
07/08/2012 08:10								
02/09/2012 08:50								
03/09/2012 13:15								
20/09/2012 15:10						387.1	647	
21/09/2012 14:00								795.1
22/09/2012 10:33								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
23/09/2012 08:15								
25/09/2012 09:29								
10/10/2012 16:40						261.7388		
11/10/2012 14:00								
12/10/2012 10:30								
14/10/2012 13:30								
15/10/2012 10:45								
16/10/2012 12:50							485.33	565.65
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30								
15/01/2013 09:30								
16/01/2013 14:00								
08/02/2013 15:30								
09/02/2013 10:30						94.59	127.78	562.38
10/02/2013 12:10								
12/02/2013 11:10								
07/03/2013 15:30							219.42	
08/03/2013 14:00								
12/03/2013 14:00						134.48		
14/03/2013 12:00								2741.2
04/04/2013 11:45								1018.64
06/04/2013 09:15		0						
09/04/2013 12:40						85.132		
10/04/2013 11:15								
02/05/2013 15:25						70.55	107.05	
03/05/2013 09:45								112.26
04/05/2013 09:35								
07/05/2013 11:50								
01/06/2013 12:00						2210.99		
02/06/2013 16:00								
03/06/2013 08:45								
04/06/2013 11:50								
05/06/2013 11:00								
07/06/2013 14:50								
08/06/2013 09:40								1900.65
09/06/2013 08:45								
01/07/2013 13:45								
02/07/2013 13:50								
03/07/2013 12:00								
04/07/2013 15:00				2.9		495.451	575.523	709.583
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
12/07/2013 13:45								
06/08/2013 15:15								
10/08/2013 16:35								
11/08/2013 09:30						231.37	315.99	437.14
12/08/2013 09:50								
01/09/2013 14:20				4		305.3	427.3	546.22
02/09/2013 12:30								
03/09/2013 14:05								
04/09/2013 13:40								
05/09/2013 11:00								
07/09/2013 14:30								
08/09/2013 10:14			9.7					
09/09/2013 13:00								
11/09/2013 17:30								1002.36
12/09/2013 13:18								
13/09/2013 14:45			22.45					
14/09/2013 11:31								
01/10/2013 16:15								
03/10/2013 15:55								
04/10/2013 10:30								
05/10/2013 12:25								
06/10/2013 15:00						361.17	486.49	765.9
07/10/2013 10:25								
09/10/2013 14:35			17.36					
10/10/2013 08:30								
04/11/2013 14:30								420.7
06/11/2013 10:05								
07/11/2013 10:10								
08/11/2013 14:45						204.3	258	
09/11/2013 13:30			4.2					
11/11/2013 11:00								
02/12/2013 13:00								
03/12/2013 08:30								173.65
04/12/2013 14:40						174.1	271.97	
06/12/2013 13:25								
02/01/2014 16:05								148.8
03/01/2014 14:05								
25/01/2014 14:05						95.6	105.8	
02/02/2014 09:55								
03/02/2014 10:30								125.7
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50								
12/02/2014 12:20						88.15	73.02	
18/02/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
01/03/2014 11:15								95.8
02/03/2014 13:10						56.7	80.8	
04/03/2014 14:40								
04/04/2014 16:00						60.75	77.9	519.4
05/04/2014 13:15								
06/04/2014 12:30								
07/04/2014 12:00								
03/05/2014 15:35								
04/05/2014 09:35								
05/05/2014 13:00								719.5
06/05/2014 14:50						162.9	327.3	
07/05/2014 11:50								
08/05/2014 13:15								
10/05/2014 11:25			57.6					
11/05/2014 11:20								
13/05/2014 10:45								
14/05/2014 12:00								
03/06/2014 15:00								
04/06/2014 11:40						427.5	608	908
05/06/2014 11:45								
06/06/2014 10:43								1471
07/06/2014 12:50								
08/06/2014 12:25			4.5					
09/06/2014 10:45								
10/06/2014 11:00					13.4			
01/07/2014 11:35				4.37		778.34	820	1092.473
02/07/2014 12:30					12.9			
03/07/2014 15:35								
04/07/2014 10:15			4.74					
05/07/2014 13:25								
06/07/2014 09:00								
07/07/2014 10:00								
01/08/2014 09:50				4.695			392.3	429.079
02/08/2014 12:00								
03/08/2014 09:00			10.744					
04/08/2014 09:30								
05/08/2014 16:00								
22/08/2014 15:30								
24/08/2014 11:00								
25/08/2014 09:45						685.51		
02/09/2014 14:15				8.7719		702.21	468.00	705.20
16/09/2014 13:10								
18/09/2014 12:20								
19/09/2014 12:00								
20/09/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
21/09/2014 11:15								
22/09/2014 12:45		11.864	25.646		29.424			
27/09/2014 09:40								
16/10/2014 10:00						348.5	457.2	650.4
17/10/2014 11:00					26.1			
18/10/2014 14:25								
19/10/2014 09:00								
20/10/2014 13:20								
21/10/2014 14:30								
22/10/2014 11:10								
23/10/2014 09:40					16.1			
24/10/2014 14:55								
25/10/2014 11:00		10.5	12.5					
26/10/2014 09:00				3.508				
13/11/2014 13:30							259.2	
14/11/2014 12:30				2.79				
15/11/2014 14:20								
16/11/2014 14:45								
17/11/2014 14:15								
18/11/2014 10:00			6.7					
19/11/2014 14:05								
20/11/2014 09:59		6.4			13.3			
21/11/2014 14:00								
22/11/2014 14:31								
12/12/2014 13:20					10			
13/12/2014 13:20							180.3	186.8
14/12/2014 11:30				2.3		138.2		
15/12/2014 13:00								
16/12/2014 09:50								
18/12/2014 14:23		4.3						
19/12/2014 15:40								
11/01/2015 13:16						104.5	164.4	203.4
12/01/2015 11:57				2.5	6.8			
13/01/2015 13:12								
14/01/2015 10:13		7	3.3					
17/01/2015 13:00								
19/01/2015 15:05								
22/01/2015 13:24								
28/01/2015 10:00					2.7			
05/02/2015 13:07						91.7	112.8	
06/02/2015 11:50								
07/02/2015 14:00					5.6			
12/02/2015 13:07								
14/02/2015 14:47								
15/02/2015 11:30		0.6						

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
16/02/2015 15:20								
17/02/2015 12:50								
18/02/2015 08:00								
06/03/2015 13:30						89.7	122.6	199.6
07/03/2015 13:00					4.2			
09/03/2015 10:30								
10/03/2015 12:05		3.5						
11/03/2015 14:30								
13/03/2015 13:00								
03/04/2015 11:10			2.4					
06/04/2015 09:40					5.3	76	118.7	122.1
07/04/2015 13:20								
08/04/2015 11:30								
09/04/2015 13:25		3.2						
10/04/2015 12:00								
12/04/2015 10:40								
12/05/2015 10:15								
13/05/2015 13:01								1225.3
14/05/2015 11:30			243.5					
23/05/2015 14:20								
24/05/2015 16:14								
26/05/2015 07:30		5.5						
27/05/2015 12:34								
28/05/2015 12:42					44.2			
02/06/2015 13:16								1349.8
03/06/2015 14:30								
04/06/2015 10:30								
09/06/2015 13:23								
11/06/2015 10:24			10.8					
12/06/2015 11:48								
16/06/2015 08:48		5.6						
17/06/2015 08:50				4.3	7.2			
18/06/2015 10:41								
19/06/2015 09:30								
23/06/2015 15:05								
09/07/2015 14:56								
13/07/2015 12:30								
15/07/2015 13:10				6.67				
16/07/2015 12:15							718.4	
18/07/2015 14:10								
19/07/2015 12:20								
26/07/2015 09:22		4.8						
28/07/2015 12:00								
29/07/2015 10:30								
30/07/2015 13:40			0.152		21.8			

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
06/08/2015 11:05								
12/08/2015 13:25								
17/08/2015 10:35								
19/08/2015 14:30								
20/08/2015 14:20					35.6			
21/08/2015 11:50								
22/08/2015 13:00								
23/08/2015 14:25								1319.6
26/08/2015 12:10								
01/09/2015 11:30								2057.8
03/09/2015 10:56								
04/09/2015 09:15								
10/09/2015 11:59								
11/09/2015 15:05								
12/09/2015 13:31								
13/09/2015 15:25		16.3						
15/09/2015 14:46					40.1			
16/09/2015								
17/09/2015 12:07			34.9					
18/09/2015								1790.4
19/09/2015								
10/10/2015 15:07								
11/10/2015 12:07								
14/10/2015 15:04				8				
16/10/2015 13:45							523.6	735.9
17/10/2015 15:30					19.4			
18/10/2015 10:05	1.5	5.8						
19/10/2015 12:19								
20/10/2015 13:16			16.9					
14/11/2015 14:48					9.1			
15/11/2015 13:42								408.7
16/11/2015 10:57				7.8				
17/11/2015 14:10	1.8							
18/11/2015 10:08								
19/11/2015 10:55								
20/11/2015 15:38		4.1	2.3					
22/11/2015 15:30								
23/11/2015 12:09								
24/11/2015 12:50								
15/12/2015 11:50								
16/12/2015 11:20				3.4	6.5			
17/12/2015 12:00								
18/12/2015 12:15		9.5	10.4					162.1
19/12/2015 11:44								
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
05/01/2016 11:56	4							200.3
06/01/2016 13:00								
07/01/2016 15:00				3.2	3.3			
08/01/2016 10:41								
09/01/2016 11:50		10.3	5.4					
10/01/2016 10:30								
30/01/2016 10:40					3.9			
01/02/2016 11:30			3.6					
02/02/2016 14:00								213
03/02/2016 11:20	2.8	4.9		0.42				
04/02/2016 11:45								
08/02/2016 13:19						112.2	93.9	
02/03/2016 15:54						102.5		228.8
03/03/2016 10:45								
04/03/2016 12:15								
05/03/2016 14:55	2.7	4.1		2.3	2.8			
06/03/2016 12:45			5.8					
05/04/2016 16:00			2.7					
06/04/2016 09:30								175.7
07/04/2016 09:10	2.1	3						
08/04/2016 12:50				2.3	2.8	78		
01/05/2016 14:35						92.8	156.4	236
02/05/2016 13:00								
03/05/2016 12:25								
04/05/2016 15:28			48.9					
05/05/2016 10:20	2.8	4.4						
06/05/2016 10:10								
18/05/2016 17:15					29.2			
19/05/2016 09:42				8.9				
13/06/2016 11:05								
14/06/2016 11:18		10			15.8			
15/06/2016 08:37	1.3							
16/06/2016 14:30			16.2	5.8		1180.2		1801.7
21/06/2016 14:50								
12/07/2016 13:30						440.5	688.6	884.1
13/07/2016 13:20								
14/07/2016 11:15								
15/07/2016 10:45	2.3		21.6					
16/07/2016 15:51								
17/07/2016 15:00		10.7		6	22.7			
19/07/2016 12:15								
05/08/2016 11:56		13.5						
06/08/2016 13:43			45.2					
07/08/2016 08:59								1365.8
08/08/2016 10:02	2.8			7.2				

Discharge (Flow) (L/s)

Sample Date	KV-19	KV-20	KV-21	KV-33	KV-35	KV-37	KV-38	KV-41
09/08/2016 08:24								
16/08/2016 13:25								
18/08/2016 15:54					47.3			
21/09/2016 17:45				6.6				
22/09/2016 14:18						489.6	702.3	1049.5
23/09/2016 14:20		11.5	25.1					
24/09/2016 10:13	3.1				29.7			
25/09/2016 09:35								
19/10/2016 17:33					13.9			
20/10/2016 13:46	2.9			3.9		211.8	342.3	521.5
21/10/2016 13:17								
22/10/2016 12:10								
23/10/2016 14:21		8.8	10.2					
31/10/2016 10:10								
08/11/2016 12:45								282.2
09/11/2016 10:31					13			
10/11/2016 15:50			5.8					
11/11/2016 15:06	2.9	5.5		4.3		187.8		
12/11/2016 08:56								
01/12/2016 12:05	9.2		6.2					
02/12/2016 09:00								
03/12/2016 10:20								
04/12/2016 14:15				2.5	11.1	186.6		320.7
05/12/2016 08:40								

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
01/01/1994									
27/01/1994									
01/02/1994									
24/02/1994									
01/03/1994									
28/03/1994									
23/04/1994									
10/05/1994									
13/05/1994									
31/05/1994									
01/06/1994						0.2			
27/06/1994						0.2			
28/06/1994									
27/07/1994									
28/07/1994									
29/07/1994						0.2			
17/08/1994						0.2			
07/09/1994									
29/09/1994						0.2			
27/10/1994									
31/10/1994									
29/11/1994									
05/01/1995									
06/02/1995									
01/03/1995									
29/03/1995									
27/04/1995									
03/05/1995									
06/06/1995									
06/07/1995						0.1			
11/07/1995									
05/08/1995									
11/08/1995						0.3			
04/09/1995						0.8			
05/09/1995									
11/10/1995						0.4			
05/11/1995									
12/12/1995									
01/01/1996									
09/02/1996									
05/03/1996									
07/04/1996									
28/04/1996									
24/06/1996									
18/07/1996									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
02/08/1996									
16/09/1996									
03/10/1996									
30/10/1996	0.1								
30/11/1996	0.1								
28/01/1997									
26/02/1997									
27/03/1997									
12/05/1997									
25/06/1997									
30/06/1997									
31/07/1997									
20/08/1997									
13/09/1997									
10/10/1997									
21/12/1997									
15/01/1998									
13/03/1998									
25/04/1998									
11/05/1998									
14/05/1998									
23/05/1998									
30/05/1998									
06/06/2000									
07/11/2000									
10/07/2001									
11/07/2001									
02/08/2003	31								0.8
24/01/2004									
19/02/2004									
23/03/2004									
24/04/2004									
15/06/2004									
20/07/2004									
29/07/2004									
30/07/2004									
25/08/2004									
21/09/2004									
21/10/2004									
29/11/2004									
17/12/2004									
25/01/2005									
26/02/2005									
27/02/2005									
22/03/2005									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
21/04/2005									
22/04/2005									
27/05/2005									
30/06/2005									
19/07/2005									
20/07/2005									
22/08/2005									
23/08/2005									
22/09/2005									
25/10/2005									
25/01/2006									
22/02/2006									
14/03/2006									
15/03/2006									
27/04/2006									
28/06/2006									
31/08/2006									
21/09/2006									
25/10/2006									
15/06/2007									
11/07/2007						0.75			
12/07/2007									
13/07/2007									
15/07/2007								5	
16/07/2007					42.22				
17/07/2007		3	2.5	5.6					
18/08/2007									
31/08/2007									
05/09/2007									
06/09/2007									
08/09/2007									
10/09/2007									
11/09/2007	113.49								
13/09/2007									
28/10/2007									
13/03/2008									
16/05/2008									181.5
18/05/2008 11:45									
03/07/2008									
05/07/2008									
06/07/2008									188
13/08/2008									
14/08/2008									
15/09/2008									
18/09/2008									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
02/10/2008									
03/10/2008									
04/10/2008									
05/10/2008									
26/05/2009 17:15									
27/05/2009 14:15									
28/05/2009 12:00					3.5				
05/06/2009 17:00									
06/06/2009									
04/07/2009 13:45									
05/07/2009 14:35									
06/07/2009 14:10									
07/07/2009 09:30							2.5	1.5	
08/09/2009									
09/09/2009									
11/09/2009									
06/10/2009							8	5	
07/10/2009									
08/10/2009									
09/10/2009									
03/05/2010									
04/05/2010									
05/05/2010							10	60	
26/05/2010						0.25			
27/05/2010									
28/05/2010									
08/06/2010									
05/07/2010						0.25			
06/07/2010									
07/07/2010									
08/07/2010							13	9	
09/07/2010									
04/08/2010									
14/09/2010					33.6				
15/09/2010									
05/10/2010					55.918				
06/10/2010									
07/10/2010			10	10					
09/02/2011 12:00									
12/05/2011 15:30									
13/05/2011 08:50									
25/05/2011 15:20									
26/05/2011 11:55									
27/05/2011 14:00							30	20	
21/06/2011 12:00									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
22/06/2011 15:20									
12/07/2011 13:20						0.4			
13/07/2011 13:15							9	7	
14/07/2011 15:15									
19/07/2011 12:20									
16/08/2011 14:50		0							
17/08/2011 10:45			2			0.5			
18/08/2011 16:00									
17/09/2011 08:25									
22/09/2011 15:05			31.4265		48.638				
23/09/2011 09:30									
24/09/2011 14:40									
25/09/2011 12:55									
23/10/2011									
24/10/2011									
25/10/2011									
26/10/2011 16:20									
27/10/2011									28
29/10/2011 16:00	0							20	
30/10/2011 14:30									
31/10/2011 12:30		0	34	35.26	41				
20/11/2011 14:25									22.2
21/11/2011 11:00									
22/11/2011 10:00									
24/11/2011 15:00									
26/11/2011 09:00		0	34.6		49.1				
13/12/2011 14:15									
14/12/2011 16:25									
15/12/2011 12:20									
16/12/2011 15:10									15.2
17/12/2011 09:30									
18/12/2011 12:25									
20/12/2011 13:30		0							
21/12/2011 15:20									
12/01/2012 15:30		0	28.3		46.2				
13/01/2012 12:00									
14/01/2012 14:40									
17/01/2012 13:00									
18/01/2012 09:40									
24/01/2012 15:45									7.2
09/02/2012 15:25									
11/02/2012 15:30						0			
12/02/2012 10:35		0		23.1	40.8				
13/02/2012 13:30							0		
14/02/2012 13:40								0	

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
16/02/2012 13:00									
09/03/2012 10:50									
10/03/2012 12:50									
11/03/2012 10:00		0	21.2		35				
12/03/2012 08:45						0			3.6
14/03/2012 13:30									
15/03/2012 12:00									
07/04/2012 14:10						0			
08/04/2012 09:25		0	19.5		30.5				
09/04/2012 13:50									
01/05/2012 11:30									
03/05/2012 14:07			38.9	41.2	40.5				
04/05/2012 11:30						0.0			
05/05/2012 10:17									
06/05/2012 13:28									
07/05/2012 09:00									
08/05/2012 10:35	105.6								
09/05/2012 08:45									387.0
31/05/2012									
01/06/2012									
03/06/2012		6.741	28.525		40.524				
04/06/2012						0.2			
05/06/2012									
06/06/2012 14:00									75.53
07/06/2012 09:05									
01/07/2012 10:00									
02/07/2012 14:47					37.41				
03/07/2012 12:05			32.23	31.60					
04/07/2012 13:40									
05/07/2012 09:50									
07/07/2012 12:00									
08/07/2012 14:55	26.8								
09/07/2012 08:50							13.5		40.9
10/07/2012 10:30									
16/07/2012 15:30									
01/08/2012 10:25			38.24		36				
02/08/2012 12:30									
03/08/2012 10:00									56
05/08/2012 13:05						0.5			
07/08/2012 08:10									
02/09/2012 08:50						0.6			100.9
03/09/2012 13:15			28.8		38.7				
20/09/2012 15:10									
21/09/2012 14:00									
22/09/2012 10:33									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
23/09/2012 08:15									
25/09/2012 09:29									
10/10/2012 16:40									
11/10/2012 14:00									
12/10/2012 10:30									
14/10/2012 13:30			27.8387	35.13	33.48				
15/10/2012 10:45									24.91
16/10/2012 12:50									
17/10/2012 10:34	36.17								
19/11/2012 13:40		0							
10/12/2012 15:10		0							
12/01/2013 13:30									
15/01/2013 09:30					41.11				
16/01/2013 14:00									
08/02/2013 15:30									
09/02/2013 10:30									
10/02/2013 12:10						0	0	0	
12/02/2013 11:10		0	19.82	24.91	37.25				
07/03/2013 15:30					50.98				
08/03/2013 14:00									
12/03/2013 14:00									
14/03/2013 12:00									
04/04/2013 11:45						0			
06/04/2013 09:15									
09/04/2013 12:40					31.58				
10/04/2013 11:15									
02/05/2013 15:25									
03/05/2013 09:45		0			23.57				
04/05/2013 09:35									
07/05/2013 11:50							0	0	
01/06/2013 12:00									
02/06/2013 16:00									
03/06/2013 08:45						0.24			
04/06/2013 11:50					24.64				
05/06/2013 11:00									
07/06/2013 14:50									
08/06/2013 09:40									
09/06/2013 08:45									93.025
01/07/2013 13:45									
02/07/2013 13:50									
03/07/2013 12:00									17.627
04/07/2013 15:00									
05/07/2013 10:40	8.897								
06/07/2013 09:30			28.238	40.7	21.341				
07/07/2013 09:45									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
12/07/2013 13:45									
06/08/2013 15:15									
10/08/2013 16:35									
11/08/2013 09:30									
12/08/2013 09:50									
01/09/2013 14:20									
02/09/2013 12:30									
03/09/2013 14:05					43.68				
04/09/2013 13:40									
05/09/2013 11:00									4.99
07/09/2013 14:30									
08/09/2013 10:14									
09/09/2013 13:00									
11/09/2013 17:30									
12/09/2013 13:18									
13/09/2013 14:45									
14/09/2013 11:31	20.23								84.93
01/10/2013 16:15									
03/10/2013 15:55									
04/10/2013 10:30									
05/10/2013 12:25									
06/10/2013 15:00									
07/10/2013 10:25	24.165								78.37
09/10/2013 14:35							14.48	6.02	
10/10/2013 08:30			30.43	27.36	41.55				
04/11/2013 14:30									
06/11/2013 10:05									
07/11/2013 10:10									
08/11/2013 14:45									
09/11/2013 13:30									
11/11/2013 11:00					53.9				
02/12/2013 13:00									
03/12/2013 08:30									
04/12/2013 14:40					88.69				
06/12/2013 13:25									
02/01/2014 16:05									
03/01/2014 14:05									
25/01/2014 14:05					46.1				
02/02/2014 09:55							0	0	
03/02/2014 10:30									
08/02/2014 12:30	0								
10/02/2014 11:30		0		7.1	29.1				
11/02/2014 12:50									
12/02/2014 12:20									
18/02/2014 10:00									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
01/03/2014 11:15									
02/03/2014 13:10					26.8				
04/03/2014 14:40									
04/04/2014 16:00					30.80				
05/04/2014 13:15									
06/04/2014 12:30									
07/04/2014 12:00									
03/05/2014 15:35									
04/05/2014 09:35									
05/05/2014 13:00									
06/05/2014 14:50			21.9	49.4					
07/05/2014 11:50									
08/05/2014 13:15									
10/05/2014 11:25							44.4	62.8	770
11/05/2014 11:20	367.42				40				
13/05/2014 10:45									
14/05/2014 12:00									
03/06/2014 15:00									
04/06/2014 11:40									
05/06/2014 11:45									
06/06/2014 10:43									
07/06/2014 12:50					27.5				
08/06/2014 12:25									
09/06/2014 10:45	23.3								
10/06/2014 11:00									23
01/07/2014 11:35									
02/07/2014 12:30							7.0		
03/07/2014 15:35			27.6	30.62	34.94				
04/07/2014 10:15									
05/07/2014 13:25									
06/07/2014 09:00									18.0
07/07/2014 10:00	26.81								
01/08/2014 09:50									
02/08/2014 12:00									
03/08/2014 09:00					31.99				
04/08/2014 09:30									19.73
05/08/2014 16:00	19.419								
22/08/2014 15:30									
24/08/2014 11:00									
25/08/2014 09:45									
02/09/2014 14:15									
16/09/2014 13:10									
18/09/2014 12:20									
19/09/2014 12:00					53				
20/09/2014 10:00						0.67114			

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
21/09/2014 11:15									
22/09/2014 12:45									137.74
27/09/2014 09:40									
16/10/2014 10:00									
17/10/2014 11:00									
18/10/2014 14:25									
19/10/2014 09:00		0	35.2	32.9	48.2				
20/10/2014 13:20									
21/10/2014 14:30									57.9
22/10/2014 11:10									
23/10/2014 09:40									
24/10/2014 14:55									
25/10/2014 11:00							8.1		
26/10/2014 09:00									
13/11/2014 13:30									
14/11/2014 12:30									
15/11/2014 14:20									
16/11/2014 14:45									
17/11/2014 14:15									
18/11/2014 10:00					47.7				
19/11/2014 14:05									
20/11/2014 09:59									
21/11/2014 14:00									22
22/11/2014 14:31									
12/12/2014 13:20									
13/12/2014 13:20									
14/12/2014 11:30									
15/12/2014 13:00									
16/12/2014 09:50					56.9				
18/12/2014 14:23									
19/12/2014 15:40									
11/01/2015 13:16									
12/01/2015 11:57									
13/01/2015 13:12									
14/01/2015 10:13					44.8				
17/01/2015 13:00									9.3
19/01/2015 15:05									
22/01/2015 13:24									
28/01/2015 10:00									
05/02/2015 13:07									
06/02/2015 11:50						0		0	
07/02/2015 14:00									
12/02/2015 13:07		0	21	16.4	39.6				
14/02/2015 14:47									
15/02/2015 11:30									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
16/02/2015 15:20									
17/02/2015 12:50									6.3
18/02/2015 08:00									
06/03/2015 13:30									
07/03/2015 13:00									
09/03/2015 10:30					35.1				
10/03/2015 12:05									
11/03/2015 14:30									
13/03/2015 13:00									
03/04/2015 11:10									
06/04/2015 09:40									
07/04/2015 13:20									
08/04/2015 11:30					31.7				
09/04/2015 13:25									
10/04/2015 12:00									
12/04/2015 10:40									
12/05/2015 10:15			37.2	115.5	95.1				
13/05/2015 13:01									1050
14/05/2015 11:30									
23/05/2015 14:20							39.6		
24/05/2015 16:14								28.9	
26/05/2015 07:30									
27/05/2015 12:34									
28/05/2015 12:42									
02/06/2015 13:16				35					
03/06/2015 14:30									
04/06/2015 10:30									
09/06/2015 13:23									71.5
11/06/2015 10:24									
12/06/2015 11:48	62								
16/06/2015 08:48	71.2								17.7
17/06/2015 08:50									
18/06/2015 10:41					34.1				
19/06/2015 09:30									
23/06/2015 15:05									
09/07/2015 14:56									
13/07/2015 12:30									
15/07/2015 13:10									
16/07/2015 12:15									
18/07/2015 14:10									
19/07/2015 12:20					45.7				275.4
26/07/2015 09:22									
28/07/2015 12:00			28.6	26.1					
29/07/2015 10:30									
30/07/2015 13:40								12	

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
06/08/2015 11:05									
12/08/2015 13:25									
17/08/2015 10:35					38.8				
19/08/2015 14:30									
20/08/2015 14:20									
21/08/2015 11:50									
22/08/2015 13:00									93.5
23/08/2015 14:25									
26/08/2015 12:10									
01/09/2015 11:30									
03/09/2015 10:56									
04/09/2015 09:15									
10/09/2015 11:59									
11/09/2015 15:05									
12/09/2015 13:31					42.3				
13/09/2015 15:25									
15/09/2015 14:46									
16/09/2015									172.1
17/09/2015 12:07									
18/09/2015				45.7					
19/09/2015									
10/10/2015 15:07					38.2				
11/10/2015 12:07									
14/10/2015 15:04									
16/10/2015 13:45									
17/10/2015 15:30			36.3	37.5					
18/10/2015 10:05						0			
19/10/2015 12:19									
20/10/2015 13:16							12.1	6.2	75.6
14/11/2015 14:48									
15/11/2015 13:42									
16/11/2015 10:57									
17/11/2015 14:10									
18/11/2015 10:08									
19/11/2015 10:55					70.8				
20/11/2015 15:38									
22/11/2015 15:30									
23/11/2015 12:09									23.3
24/11/2015 12:50									
15/12/2015 11:50									17.4
16/12/2015 11:20									
17/12/2015 12:00									
18/12/2015 12:15					86.7				
19/12/2015 11:44									
20/12/2015 09:37				34.5					

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
05/01/2016 11:56									
06/01/2016 13:00				37					
07/01/2016 15:00					70.7				
08/01/2016 10:41									13.9
09/01/2016 11:50									
10/01/2016 10:30									
30/01/2016 10:40									
01/02/2016 11:30									
02/02/2016 14:00									
03/02/2016 11:20		0	24.7	25.3	47				
04/02/2016 11:45									10.1
08/02/2016 13:19									
02/03/2016 15:54				25.8					
03/03/2016 10:45									
04/03/2016 12:15									10.6
05/03/2016 14:55					41.4				
06/03/2016 12:45									
05/04/2016 16:00									
06/04/2016 09:30				19.2	34.5				
07/04/2016 09:10									5
08/04/2016 12:50									
01/05/2016 14:35						0			
02/05/2016 13:00									
03/05/2016 12:25								95.3	
04/05/2016 15:28			28.5	47	29.4				
05/05/2016 10:20									418.6
06/05/2016 10:10									
18/05/2016 17:15									
19/05/2016 09:42									
13/06/2016 11:05									
14/06/2016 11:18									58.4
15/06/2016 08:37				46.7	36.9				
16/06/2016 14:30									
21/06/2016 14:50									
12/07/2016 13:30									
13/07/2016 13:20							5.3	20.6	
14/07/2016 11:15					40.4				
15/07/2016 10:45			33.1	41.4					49.3
16/07/2016 15:51									
17/07/2016 15:00									
19/07/2016 12:15									
05/08/2016 11:56									
06/08/2016 13:43									279.6
07/08/2016 08:59				78.9	33				
08/08/2016 10:02									

Discharge (Flow) (L/s)

Sample Date	KV-47	KV-49	KV-50	KV-51	KV-52	KV-53	KV-55	KV-56	KV-60
09/08/2016 08:24									
16/08/2016 13:25									
18/08/2016 15:54									
21/09/2016 17:45									
22/09/2016 14:18									
23/09/2016 14:20				53.2	41.9				
24/09/2016 10:13									82.9
25/09/2016 09:35									
19/10/2016 17:33									
20/10/2016 13:46									
21/10/2016 13:17									
22/10/2016 12:10					39.4				
23/10/2016 14:21			43.3	41.5					21.2
31/10/2016 10:10									
08/11/2016 12:45									
09/11/2016 10:31									
10/11/2016 15:50					41.2				17.2
11/11/2016 15:06				29.7					
12/11/2016 08:56									
01/12/2016 12:05									
02/12/2016 09:00									12.6
03/12/2016 10:20					53.3				
04/12/2016 14:15									
05/12/2016 08:40				37.1					

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
01/01/1994								
27/01/1994								
01/02/1994								
24/02/1994								
01/03/1994								
28/03/1994								
23/04/1994								
10/05/1994								
13/05/1994								
31/05/1994								
01/06/1994								
27/06/1994								
28/06/1994								
27/07/1994								
28/07/1994								
29/07/1994								
17/08/1994								
07/09/1994								
29/09/1994								
27/10/1994								
31/10/1994								
29/11/1994								
05/01/1995								
06/02/1995								
01/03/1995								
29/03/1995								
27/04/1995								
03/05/1995								
06/06/1995								
06/07/1995								
11/07/1995								
05/08/1995								
11/08/1995								
04/09/1995								
05/09/1995								
11/10/1995								
05/11/1995								
12/12/1995								
01/01/1996								
09/02/1996								
05/03/1996								
07/04/1996								
28/04/1996								
24/06/1996								
18/07/1996								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
02/08/1996								
16/09/1996								
03/10/1996								
30/10/1996								
30/11/1996								
28/01/1997								
26/02/1997								
27/03/1997								
12/05/1997								
25/06/1997								
30/06/1997								
31/07/1997								
20/08/1997								
13/09/1997								
10/10/1997								
21/12/1997								
15/01/1998								
13/03/1998								
25/04/1998								
11/05/1998								
14/05/1998								
23/05/1998								
30/05/1998								
06/06/2000								
07/11/2000								
10/07/2001								
11/07/2001								
02/08/2003								
24/01/2004								
19/02/2004								
23/03/2004								
24/04/2004								
15/06/2004								
20/07/2004								
29/07/2004								
30/07/2004								
25/08/2004								
21/09/2004								
21/10/2004								
29/11/2004								
17/12/2004								
25/01/2005								
26/02/2005								
27/02/2005								
22/03/2005								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
21/04/2005								
22/04/2005								
27/05/2005								
30/06/2005								
19/07/2005								
20/07/2005								
22/08/2005								
23/08/2005								
22/09/2005								
25/10/2005								
25/01/2006								
22/02/2006								
14/03/2006								
15/03/2006								
27/04/2006								
28/06/2006								
31/08/2006								
21/09/2006								
25/10/2006								
15/06/2007								
11/07/2007								
12/07/2007								
13/07/2007								
15/07/2007								
16/07/2007		2						
17/07/2007								
18/08/2007								
31/08/2007								
05/09/2007								
06/09/2007								
08/09/2007								
10/09/2007								
11/09/2007								
13/09/2007								
28/10/2007								
13/03/2008								
16/05/2008								
18/05/2008 11:45								
03/07/2008								
05/07/2008								
06/07/2008								
13/08/2008								
14/08/2008								
15/09/2008								
18/09/2008								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
02/10/2008								
03/10/2008								
04/10/2008								
05/10/2008								
26/05/2009 17:15								
27/05/2009 14:15								
28/05/2009 12:00								
05/06/2009 17:00				1300.56				
06/06/2009								
04/07/2009 13:45								
05/07/2009 14:35				177.475				
06/07/2009 14:10								
07/07/2009 09:30			3.5					
08/09/2009				266.785				
09/09/2009								
11/09/2009								
06/10/2009				188.85				
07/10/2009								
08/10/2009								
09/10/2009								
03/05/2010								
04/05/2010								
05/05/2010	25		142.48					
26/05/2010				527.0095				
27/05/2010								
28/05/2010								
08/06/2010								
05/07/2010	12		150					
06/07/2010				221.428067				
07/07/2010								
08/07/2010								
09/07/2010								
04/08/2010								
14/09/2010								
15/09/2010								
05/10/2010				597.44				
06/10/2010								
07/10/2010								
09/02/2011 12:00								
12/05/2011 15:30								
13/05/2011 08:50								
25/05/2011 15:20								
26/05/2011 11:55					0			
27/05/2011 14:00								
21/06/2011 12:00				246.37				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
22/06/2011 15:20								
12/07/2011 13:20	20							
13/07/2011 13:15					0			
14/07/2011 15:15								
19/07/2011 12:20								
16/08/2011 14:50								
17/08/2011 10:45								
18/08/2011 16:00				271.9				
17/09/2011 08:25								
22/09/2011 15:05								
23/09/2011 09:30								
24/09/2011 14:40								
25/09/2011 12:55				227.9375				
23/10/2011								
24/10/2011						2455		
25/10/2011				115				
26/10/2011 16:20					0			
27/10/2011								
29/10/2011 16:00								
30/10/2011 14:30								
31/10/2011 12:30								
20/11/2011 14:25								
21/11/2011 11:00			8.3					
22/11/2011 10:00							21.3	34
24/11/2011 15:00								
26/11/2011 09:00								
13/12/2011 14:15								
14/12/2011 16:25								
15/12/2011 12:20								
16/12/2011 15:10								
17/12/2011 09:30								
18/12/2011 12:25				52.6				
20/12/2011 13:30								
21/12/2011 15:20							20.2	25.9
12/01/2012 15:30								
13/01/2012 12:00								
14/01/2012 14:40								
17/01/2012 13:00				45.7				
18/01/2012 09:40								
24/01/2012 15:45								
09/02/2012 15:25					0			
11/02/2012 15:30								
12/02/2012 10:35								
13/02/2012 13:30				26.5				
14/02/2012 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
16/02/2012 13:00			4.8					
09/03/2012 10:50								
10/03/2012 12:50								
11/03/2012 10:00								
12/03/2012 08:45				33.7				
14/03/2012 13:30								12.2
15/03/2012 12:00								
07/04/2012 14:10								
08/04/2012 09:25								
09/04/2012 13:50								
01/05/2012 11:30								
03/05/2012 14:07			6.7					
04/05/2012 11:30								
05/05/2012 10:17								
06/05/2012 13:28						3489.7		
07/05/2012 09:00								
08/05/2012 10:35				83.3				
09/05/2012 08:45								
31/05/2012								
01/06/2012						6461		
03/06/2012							263.76	346.12
04/06/2012	324.91			735.36				
05/06/2012								
06/06/2012 14:00			147.77					
07/06/2012 09:05								
01/07/2012 10:00					0			
02/07/2012 14:47								
03/07/2012 12:05							220.55	399.04
04/07/2012 13:40				283.14				
05/07/2012 09:50						5334.22		
07/07/2012 12:00								
08/07/2012 14:55								
09/07/2012 08:50								
10/07/2012 10:30								
16/07/2012 15:30								
01/08/2012 10:25				283				
02/08/2012 12:30						4923		
03/08/2012 10:00								
05/08/2012 13:05	10.1		40				98	13.8
07/08/2012 08:10								
02/09/2012 08:50	8.2		29.6	224.3				
03/09/2012 13:15							117.1	169.8
20/09/2012 15:10								
21/09/2012 14:00						2199.4		
22/09/2012 10:33								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
23/09/2012 08:15								
25/09/2012 09:29								
10/10/2012 16:40								
11/10/2012 14:00						1991.792		
12/10/2012 10:30								
14/10/2012 13:30								
15/10/2012 10:45			22.823					
16/10/2012 12:50				163.7675				
17/10/2012 10:34								
19/11/2012 13:40								
10/12/2012 15:10								
12/01/2013 13:30								
15/01/2013 09:30				44.94				
16/01/2013 14:00								
08/02/2013 15:30								
09/02/2013 10:30				39.1				
10/02/2013 12:10								
12/02/2013 11:10					0			
07/03/2013 15:30								
08/03/2013 14:00								
12/03/2013 14:00								
14/03/2013 12:00				71.54				
04/04/2013 11:45				30.3				
06/04/2013 09:15								
09/04/2013 12:40								
10/04/2013 11:15				41.23				
02/05/2013 15:25				26.38				
03/05/2013 09:45								
04/05/2013 09:35					0			
07/05/2013 11:50								
01/06/2013 12:00								
02/06/2013 16:00								
03/06/2013 08:45								
04/06/2013 11:50							313.61	329.448
05/06/2013 11:00								
07/06/2013 14:50								
08/06/2013 09:40			67.45	575.46				
09/06/2013 08:45								
01/07/2013 13:45								
02/07/2013 13:50						5511.28		
03/07/2013 12:00					0			
04/07/2013 15:00								
05/07/2013 10:40								
06/07/2013 09:30								
07/07/2013 09:45							44.77	58.916

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
12/07/2013 13:45								
06/08/2013 15:15								
10/08/2013 16:35								
11/08/2013 09:30						2305.59		
12/08/2013 09:50								
01/09/2013 14:20								
02/09/2013 12:30						1936.8		
03/09/2013 14:05								
04/09/2013 13:40								
05/09/2013 11:00								
07/09/2013 14:30							20.74	32.49
08/09/2013 10:14		3.1						
09/09/2013 13:00								
11/09/2013 17:30								
12/09/2013 13:18								
13/09/2013 14:45		2.09						
14/09/2013 11:31								
01/10/2013 16:15								
03/10/2013 15:55		1.83	30.05					
04/10/2013 10:30								
05/10/2013 12:25						4417.87		
06/10/2013 15:00								
07/10/2013 10:25								
09/10/2013 14:35								
10/10/2013 08:30							139.11	175.14
04/11/2013 14:30								
06/11/2013 10:05								
07/11/2013 10:10						2146		
08/11/2013 14:45								
09/11/2013 13:30								33.2
11/11/2013 11:00								
02/12/2013 13:00							0	
03/12/2013 08:30								
04/12/2013 14:40								
06/12/2013 13:25								
02/01/2014 16:05								
03/01/2014 14:05								
25/01/2014 14:05								
02/02/2014 09:55								
03/02/2014 10:30								
08/02/2014 12:30								
10/02/2014 11:30								
11/02/2014 12:50					0			
12/02/2014 12:20								
18/02/2014 10:00								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
01/03/2014 11:15								
02/03/2014 13:10								
04/03/2014 14:40								
04/04/2014 16:00								
05/04/2014 13:15								
06/04/2014 12:30								
07/04/2014 12:00								
03/05/2014 15:35					0			
04/05/2014 09:35							209.2	492
05/05/2014 13:00								
06/05/2014 14:50								
07/05/2014 11:50				800.13				
08/05/2014 13:15								
10/05/2014 11:25	150		540					
11/05/2014 11:20								
13/05/2014 10:45								
14/05/2014 12:00								
03/06/2014 15:00			336.5					
04/06/2014 11:40								
05/06/2014 11:45								
06/06/2014 10:43							44.9	64.2
07/06/2014 12:50				356.1				
08/06/2014 12:25		2.4						
09/06/2014 10:45								
10/06/2014 11:00								
01/07/2014 11:35								
02/07/2014 12:30				239.4	0			
03/07/2014 15:35								
04/07/2014 10:15	14.3							
05/07/2014 13:25								
06/07/2014 09:00		1.64					73.4	137
07/07/2014 10:00			33.0					
01/08/2014 09:50								
02/08/2014 12:00								
03/08/2014 09:00							51.51	48
04/08/2014 09:30								
05/08/2014 16:00								
22/08/2014 15:30								
24/08/2014 11:00		5.465	102.8					
25/08/2014 09:45				662.4				
02/09/2014 14:15								
16/09/2014 13:10								
18/09/2014 12:20							142.7	115
19/09/2014 12:00						3999		
20/09/2014 10:00	17.7	0.9935		119.9				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
21/09/2014 11:15			42.7					
22/09/2014 12:45								
27/09/2014 09:40								
16/10/2014 10:00								
17/10/2014 11:00					0			
18/10/2014 14:25						3812.2		
19/10/2014 09:00								
20/10/2014 13:20								
21/10/2014 14:30			51.4					
22/10/2014 11:10								
23/10/2014 09:40								
24/10/2014 14:55							129.9	124.7
25/10/2014 11:00	18	3						
26/10/2014 09:00				197.3				
13/11/2014 13:30								
14/11/2014 12:30								
15/11/2014 14:20								
16/11/2014 14:45								
17/11/2014 14:15								
18/11/2014 10:00	10.2		16.1	107.9				
19/11/2014 14:05								
20/11/2014 09:59								
21/11/2014 14:00							48	42.8
22/11/2014 14:31								
12/12/2014 13:20								
13/12/2014 13:20								
14/12/2014 11:30				30.7				
15/12/2014 13:00								
16/12/2014 09:50								
18/12/2014 14:23								
19/12/2014 15:40								35.9
11/01/2015 13:16				50.3				
12/01/2015 11:57								
13/01/2015 13:12								
14/01/2015 10:13								
17/01/2015 13:00								
19/01/2015 15:05								
22/01/2015 13:24		2.7						
28/01/2015 10:00								
05/02/2015 13:07								
06/02/2015 11:50								
07/02/2015 14:00					0			
12/02/2015 13:07								
14/02/2015 14:47								
15/02/2015 11:30				46.1				

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
16/02/2015 15:20								
17/02/2015 12:50								
18/02/2015 08:00								
06/03/2015 13:30				47				
07/03/2015 13:00								
09/03/2015 10:30								
10/03/2015 12:05								
11/03/2015 14:30								
13/03/2015 13:00								
03/04/2015 11:10			4.2					
06/04/2015 09:40								
07/04/2015 13:20								
08/04/2015 11:30								
09/04/2015 13:25								
10/04/2015 12:00								
12/04/2015 10:40				29.4				
12/05/2015 10:15								
13/05/2015 13:01		16.4						
14/05/2015 11:30								
23/05/2015 14:20								
24/05/2015 16:14								
26/05/2015 07:30			79.7					
27/05/2015 12:34				846.3				
28/05/2015 12:42							154.3	177.8
02/06/2015 13:16								
03/06/2015 14:30								
04/06/2015 10:30			31.8					
09/06/2015 13:23								
11/06/2015 10:24		3.6						
12/06/2015 11:48								
16/06/2015 08:48								
17/06/2015 08:50				145.7				
18/06/2015 10:41								
19/06/2015 09:30							46.3	73.7
23/06/2015 15:05								
09/07/2015 14:56			18.9					
13/07/2015 12:30	22.5							218
15/07/2015 13:10								
16/07/2015 12:15								
18/07/2015 14:10								
19/07/2015 12:20								
26/07/2015 09:22								
28/07/2015 12:00								
29/07/2015 10:30								
30/07/2015 13:40								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
06/08/2015 11:05								
12/08/2015 13:25								
17/08/2015 10:35								
19/08/2015 14:30								
20/08/2015 14:20								270.7
21/08/2015 11:50								
22/08/2015 13:00								
23/08/2015 14:25			59.4	176.9				
26/08/2015 12:10								
01/09/2015 11:30								
03/09/2015 10:56								
04/09/2015 09:15								
10/09/2015 11:59								817.2
11/09/2015 15:05								
12/09/2015 13:31				324.3				
13/09/2015 15:25								
15/09/2015 14:46								
16/09/2015								
17/09/2015 12:07		4.3	119.6					
18/09/2015								
19/09/2015								
10/10/2015 15:07								
11/10/2015 12:07								
14/10/2015 15:04								
16/10/2015 13:45				193.7				
17/10/2015 15:30								
18/10/2015 10:05	15.4				3.1			
19/10/2015 12:19		2.2	34.9					
20/10/2015 13:16							157.3	204.9
14/11/2015 14:48								
15/11/2015 13:42								
16/11/2015 10:57								
17/11/2015 14:10								
18/11/2015 10:08		1.9	102.7					
19/11/2015 10:55				12.6				
20/11/2015 15:38								
22/11/2015 15:30								
23/11/2015 12:09								
24/11/2015 12:50								72.4
15/12/2015 11:50								
16/12/2015 11:20								
17/12/2015 12:00				73.9				
18/12/2015 12:15			8					
19/12/2015 11:44								50.5
20/12/2015 09:37								

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
05/01/2016 11:56								
06/01/2016 13:00				62.5				
07/01/2016 15:00								
08/01/2016 10:41								
09/01/2016 11:50			8.8					
10/01/2016 10:30								34.3
30/01/2016 10:40								
01/02/2016 11:30			4.2					
02/02/2016 14:00								
03/02/2016 11:20	5.4							
04/02/2016 11:45								
08/02/2016 13:19				47.6				
02/03/2016 15:54								
03/03/2016 10:45			3.4					
04/03/2016 12:15								
05/03/2016 14:55								
06/03/2016 12:45				45.7				
05/04/2016 16:00								
06/04/2016 09:30								
07/04/2016 09:10				35.9				
08/04/2016 12:50			2.7					
01/05/2016 14:35				44.8				
02/05/2016 13:00								
03/05/2016 12:25						527.1		
04/05/2016 15:28	26.8							
05/05/2016 10:20					2			
06/05/2016 10:10		65.7	142.9					931
18/05/2016 17:15								
19/05/2016 09:42								
13/06/2016 11:05								
14/06/2016 11:18								
15/06/2016 08:37								
16/06/2016 14:30		1.9	44.5	223.3				126.5
21/06/2016 14:50								
12/07/2016 13:30				75.4				
13/07/2016 13:20								
14/07/2016 11:15						724.4		
15/07/2016 10:45	10.4	1.7	38.6					
16/07/2016 15:51					1.2			467.9
17/07/2016 15:00								
19/07/2016 12:15								
05/08/2016 11:56								
06/08/2016 13:43								
07/08/2016 08:59								
08/08/2016 10:02			130.8					1077.2

Discharge (Flow) (L/s)

Sample Date	KV-61	KV-62	KV-64	KV-65	KV-66	KV-72	WILC	FIEC
09/08/2016 08:24				136.6				
16/08/2016 13:25								
18/08/2016 15:54								
21/09/2016 17:45								
22/09/2016 14:18				97.8				
23/09/2016 14:20			64.3					
24/09/2016 10:13								
25/09/2016 09:35								222.2
19/10/2016 17:33								
20/10/2016 13:46	14			134				
21/10/2016 13:17					1.6			
22/10/2016 12:10						357.4		
23/10/2016 14:21			21.9					84.6
31/10/2016 10:10								
08/11/2016 12:45								
09/11/2016 10:31								
10/11/2016 15:50			15					
11/11/2016 15:06				90.9				
12/11/2016 08:56								53
01/12/2016 12:05								
02/12/2016 09:00			11.4					
03/12/2016 10:20								
04/12/2016 14:15								43.1
05/12/2016 08:40				75.6				

APPENDIX C

HYDROGRAPHS

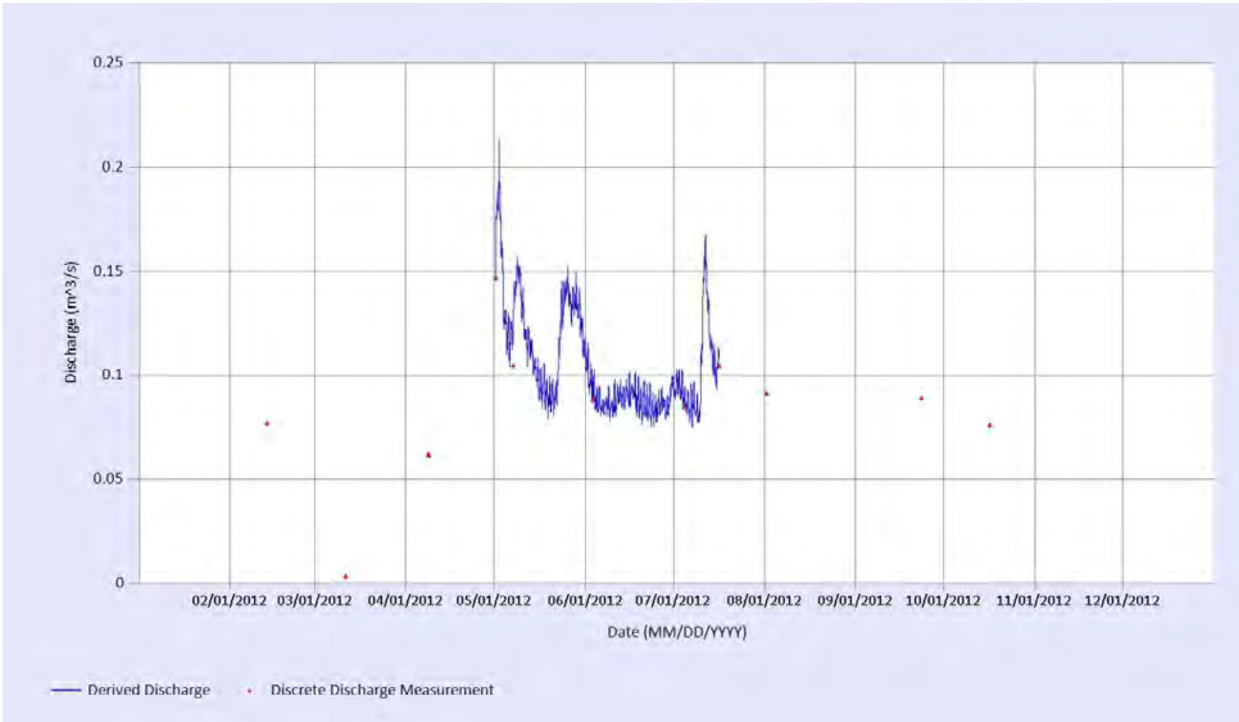


Figure C1 – Discharge at KV-6, Christal Creek below Christal Lake, 2012 open water season

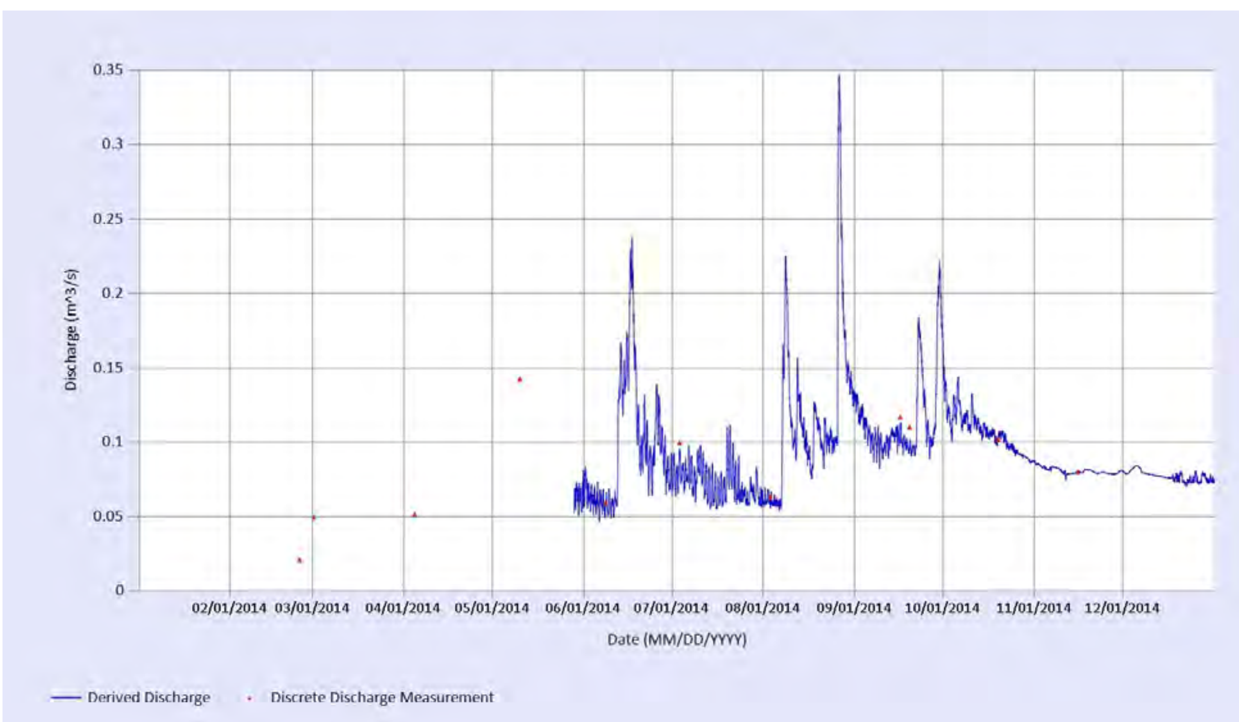


Figure C2 – Discharge at KV-6, Christal Creek below Christal Lake, 2014

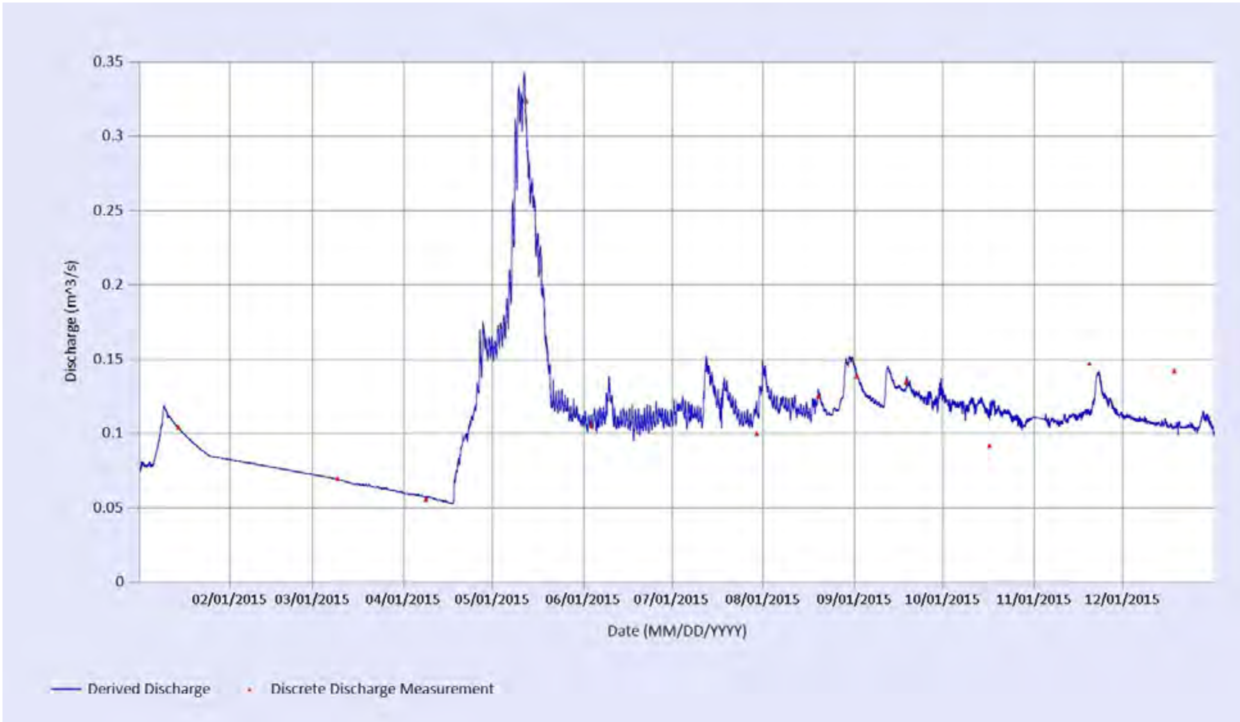


Figure C3 – Discharge at KV-6, Christal Creek below Christal Lake, 2015

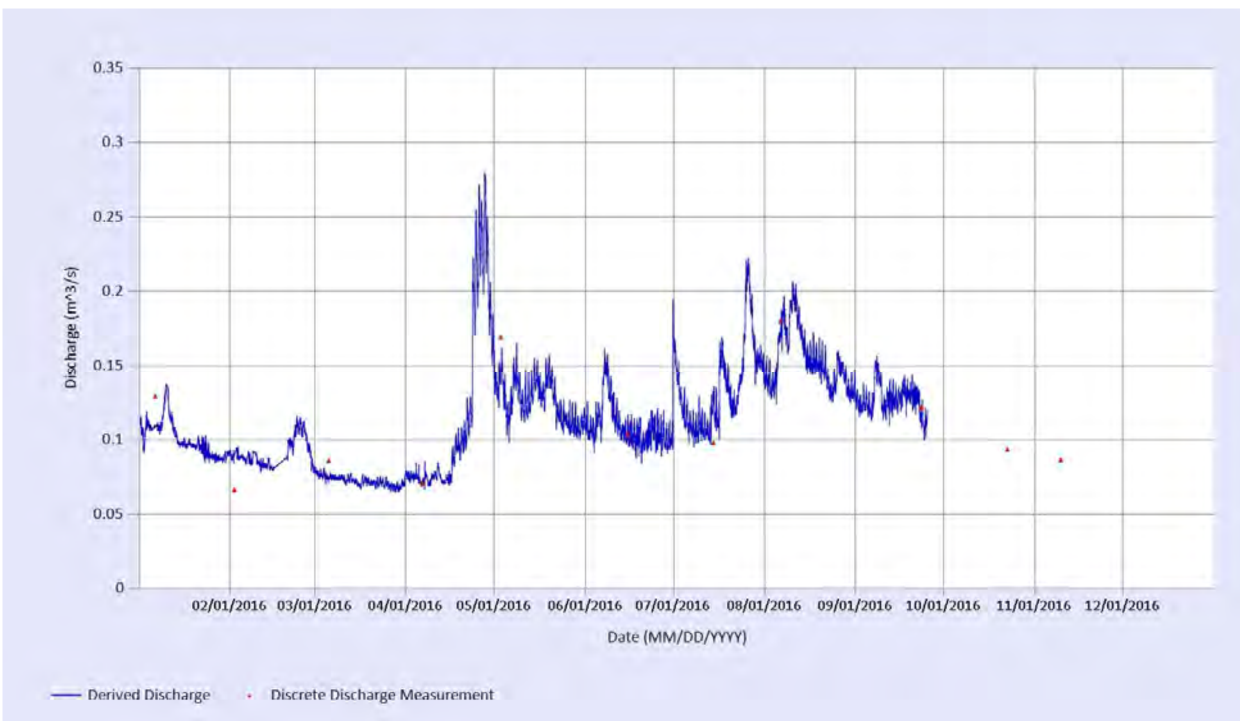


Figure C4 – Discharge at KV-6, Christal Creek below Christal Lake, 2016

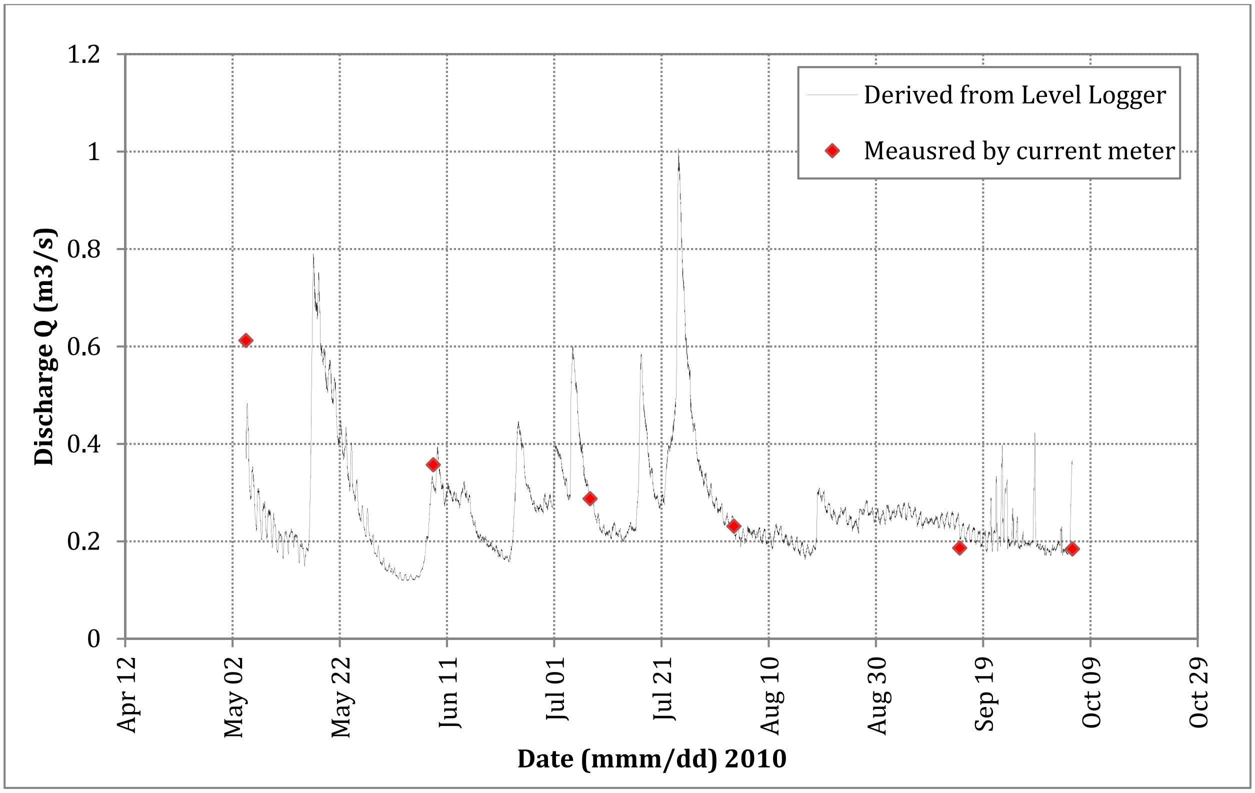


Figure C5 - Discharge at KV-7, Christal Creek at Hansen Road 2010

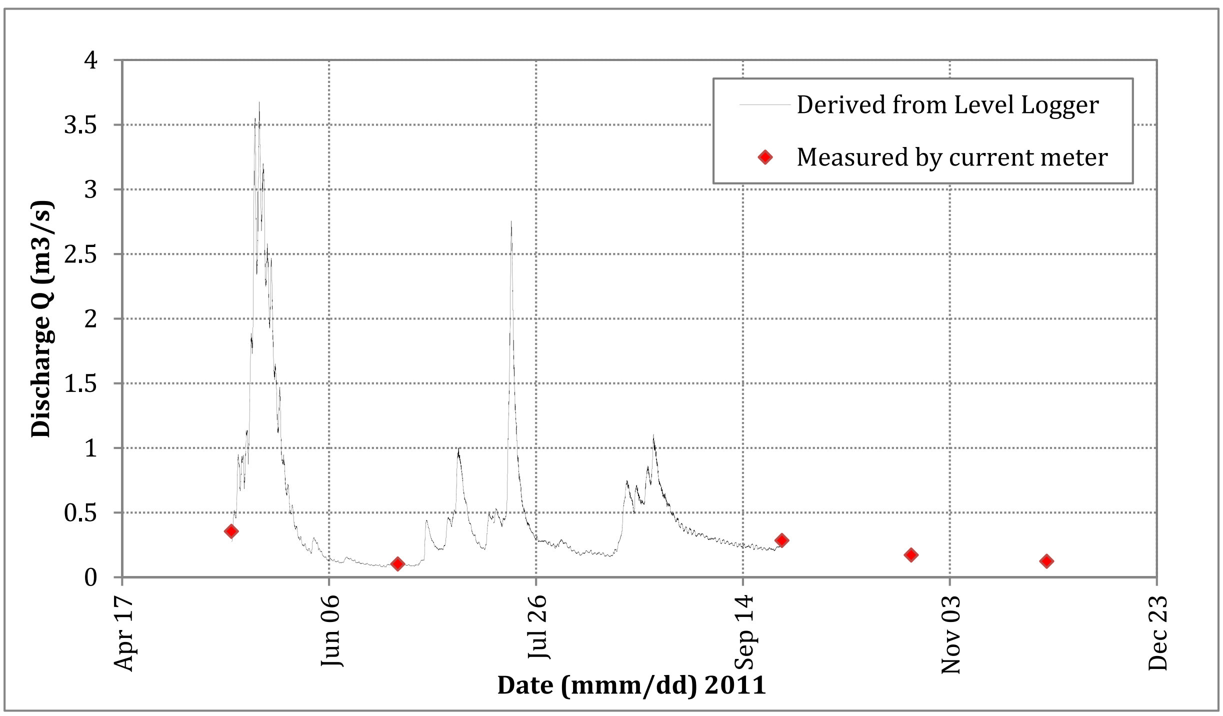


Figure C6 - Discharge at KV-7, Christal Creek at Hansen Road 2011

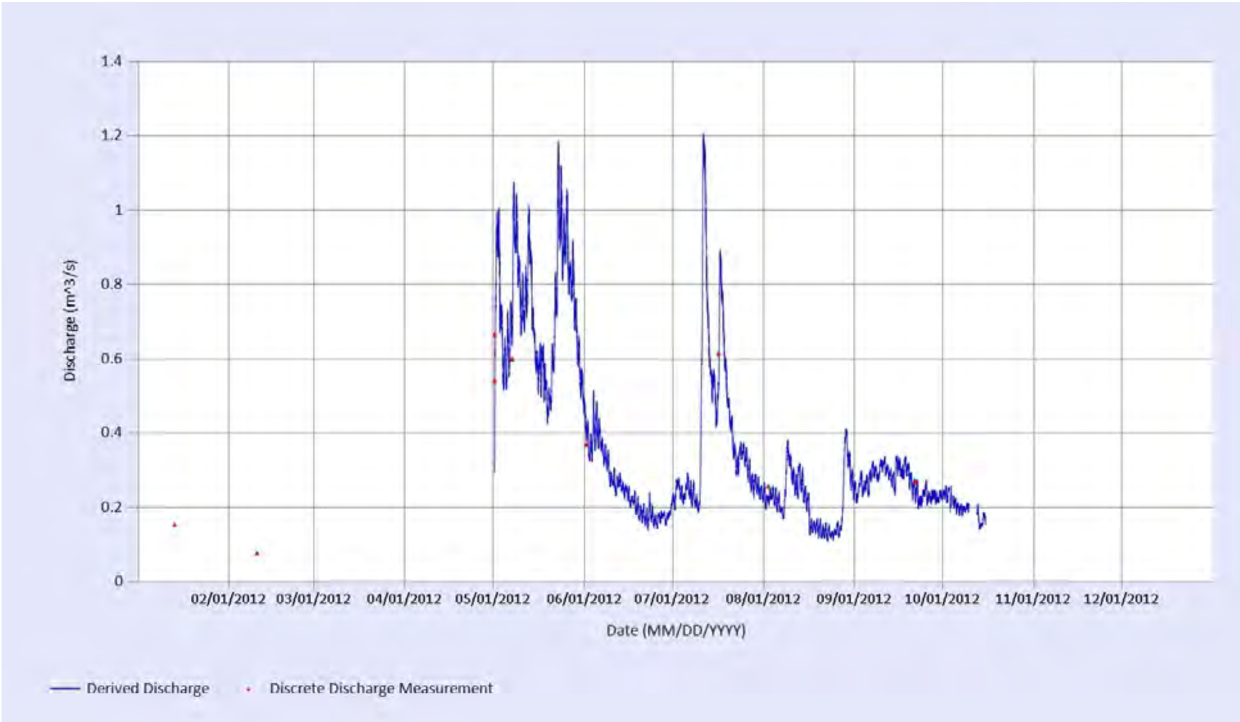


Figure C7 – Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2012

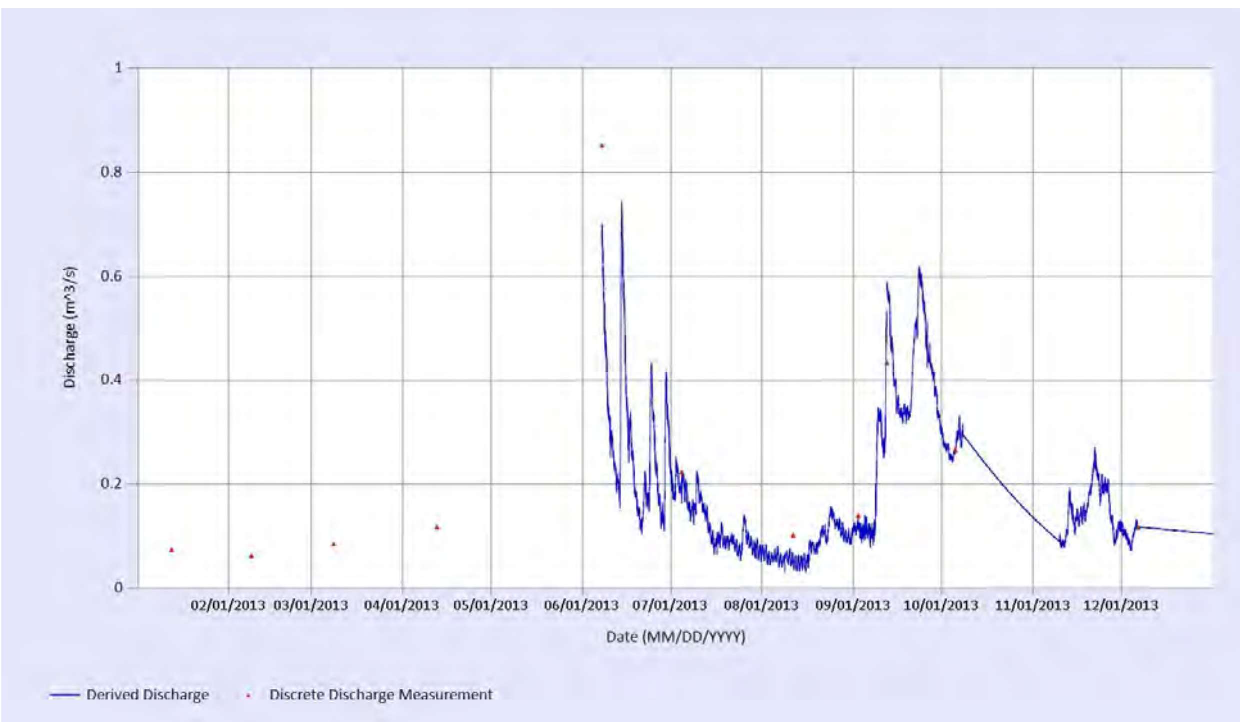


Figure C8 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2013

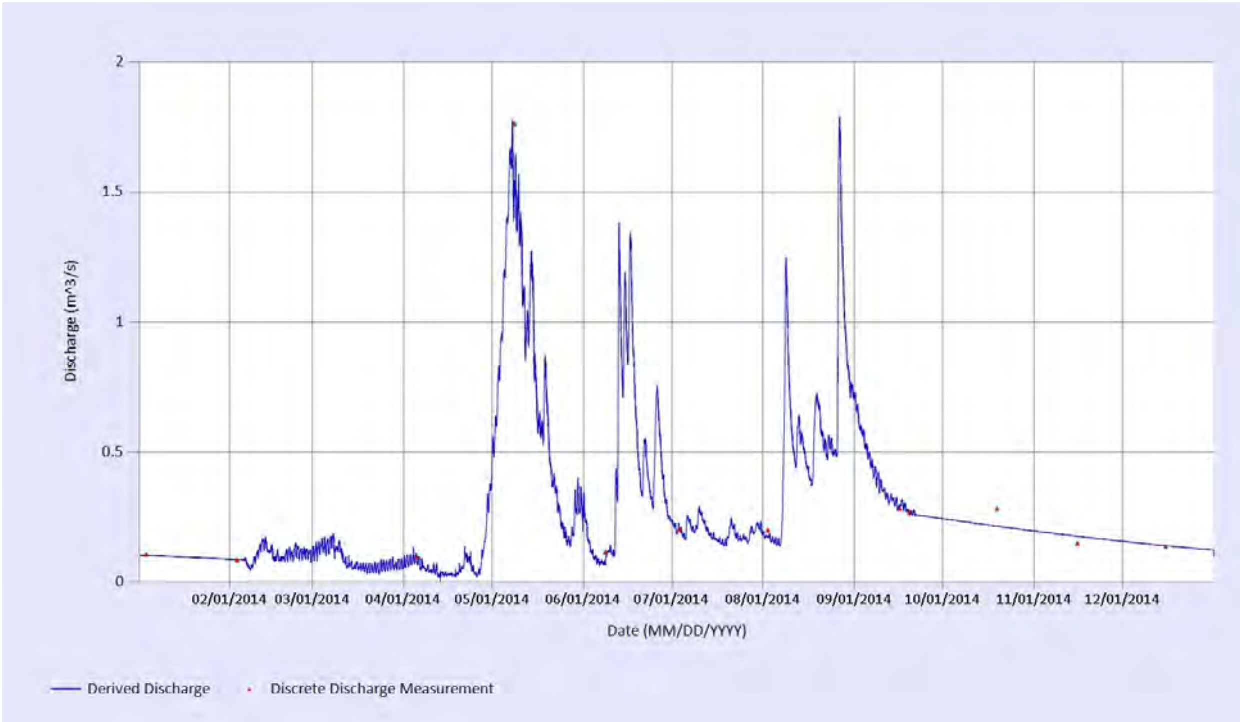


Figure C9 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2014

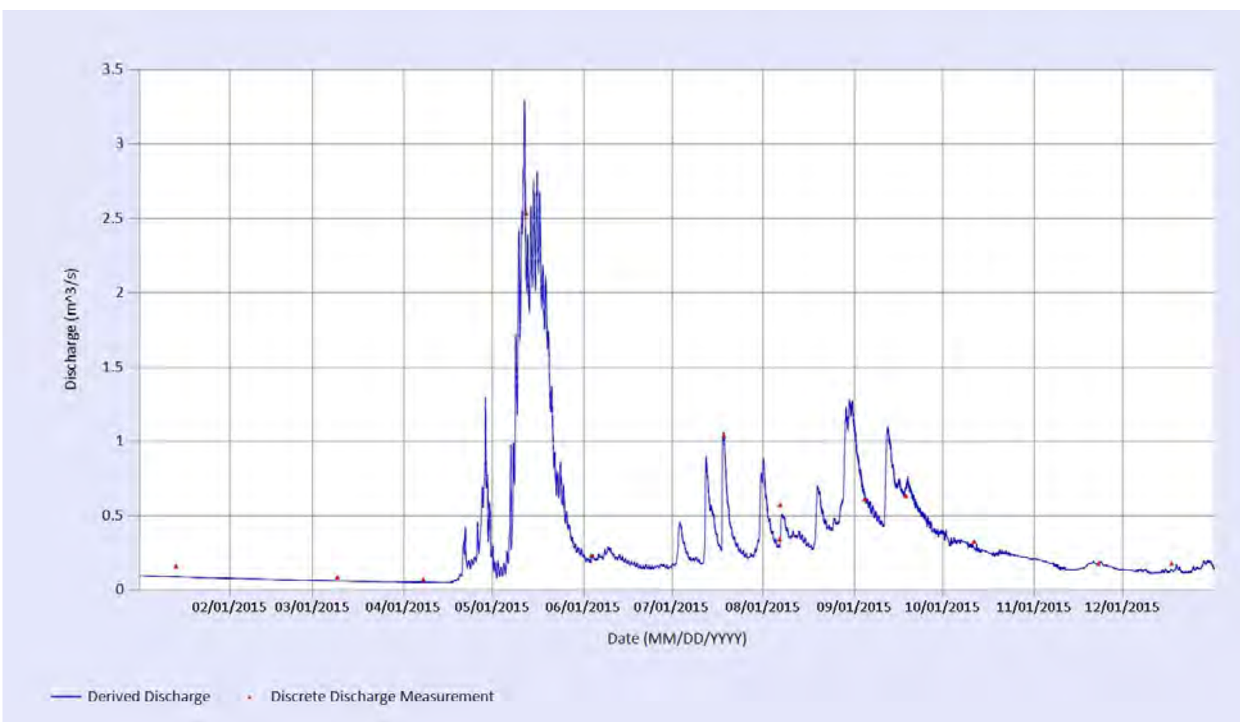


Figure C10 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2015

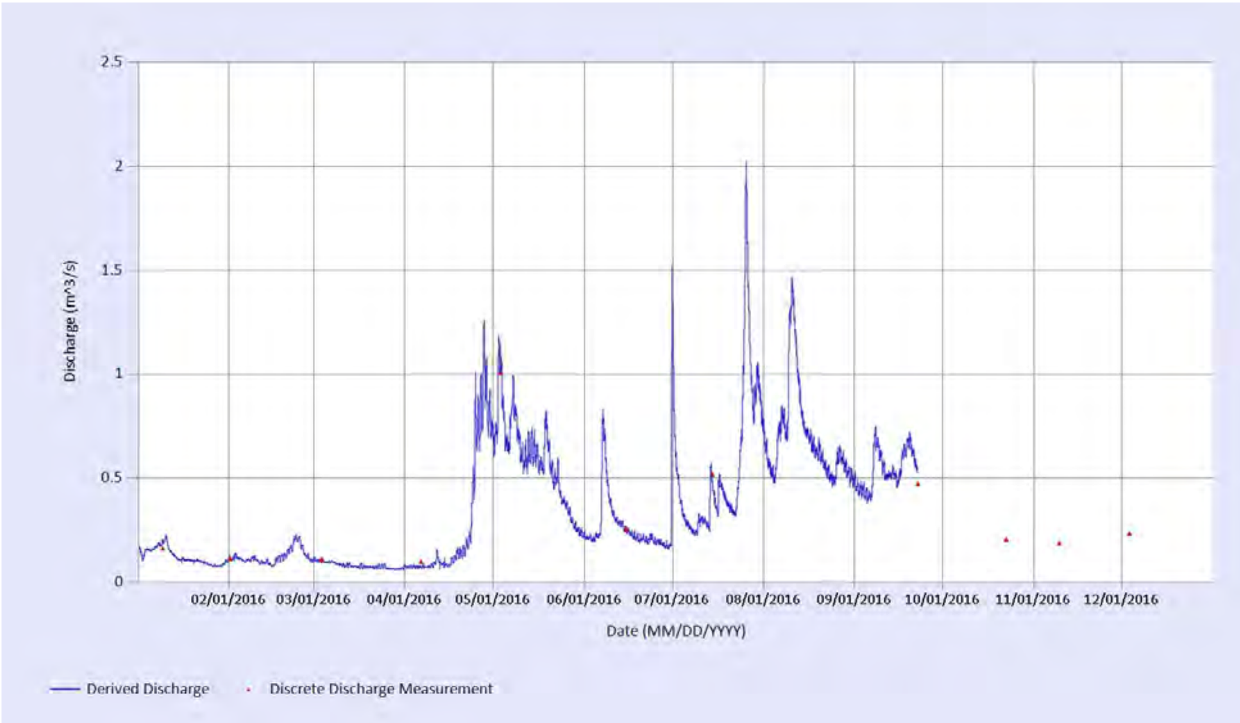


Figure C11 - Discharge at KV-7, Christal Creek at Hanson-McQuesten Lakes Road Bridge, 2016

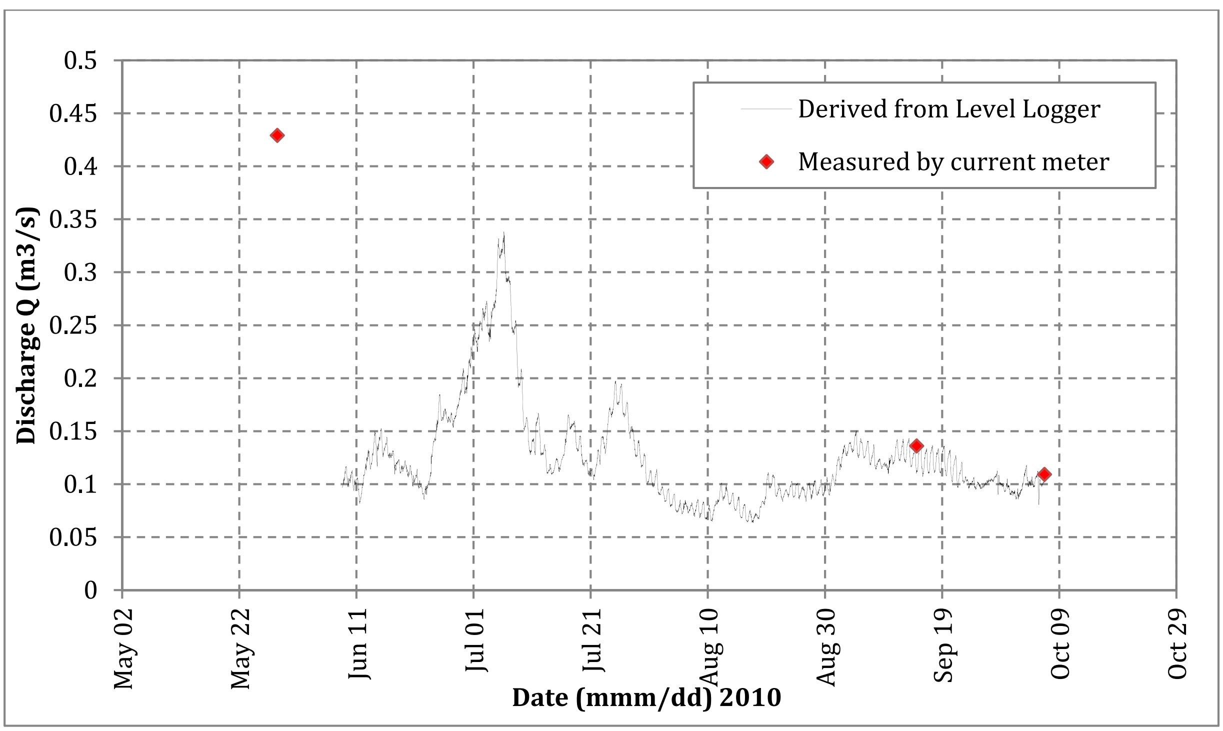


Figure C12 - Discharge at KV-9, Flat Creek 2010

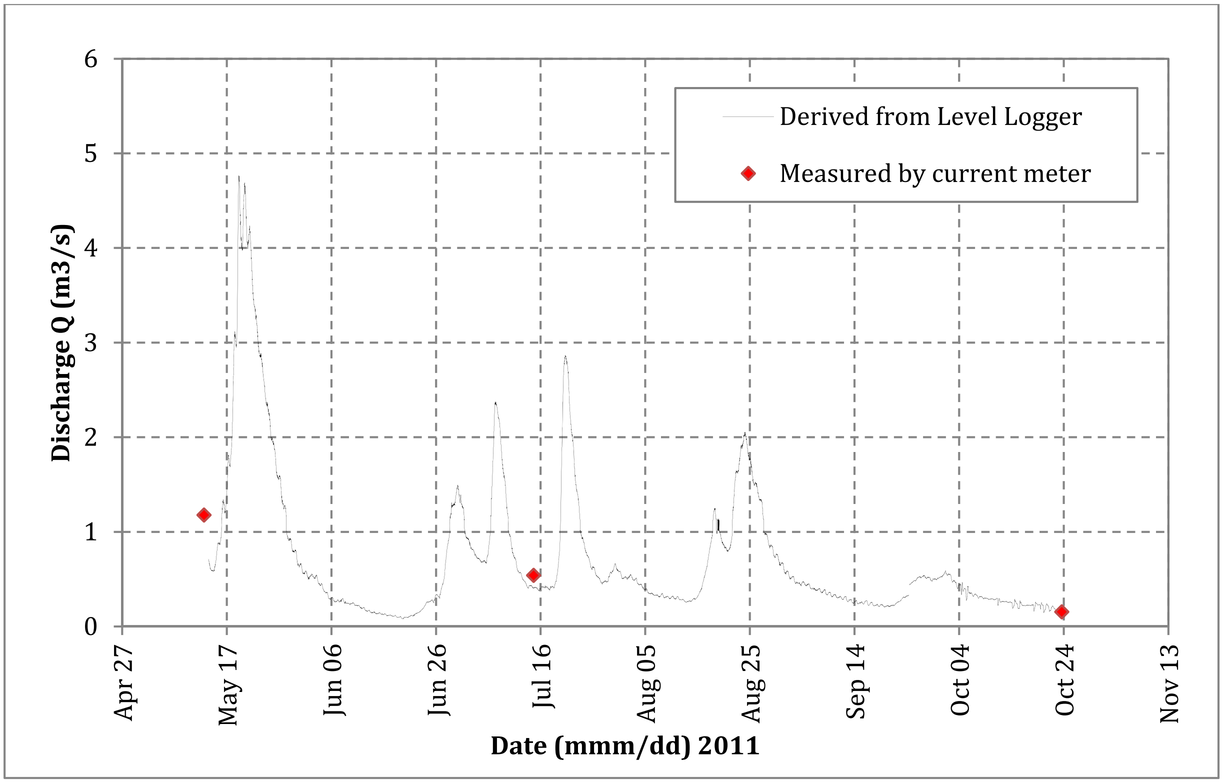


Figure C13 - Discharge at KV-9, Flat Creek 2011

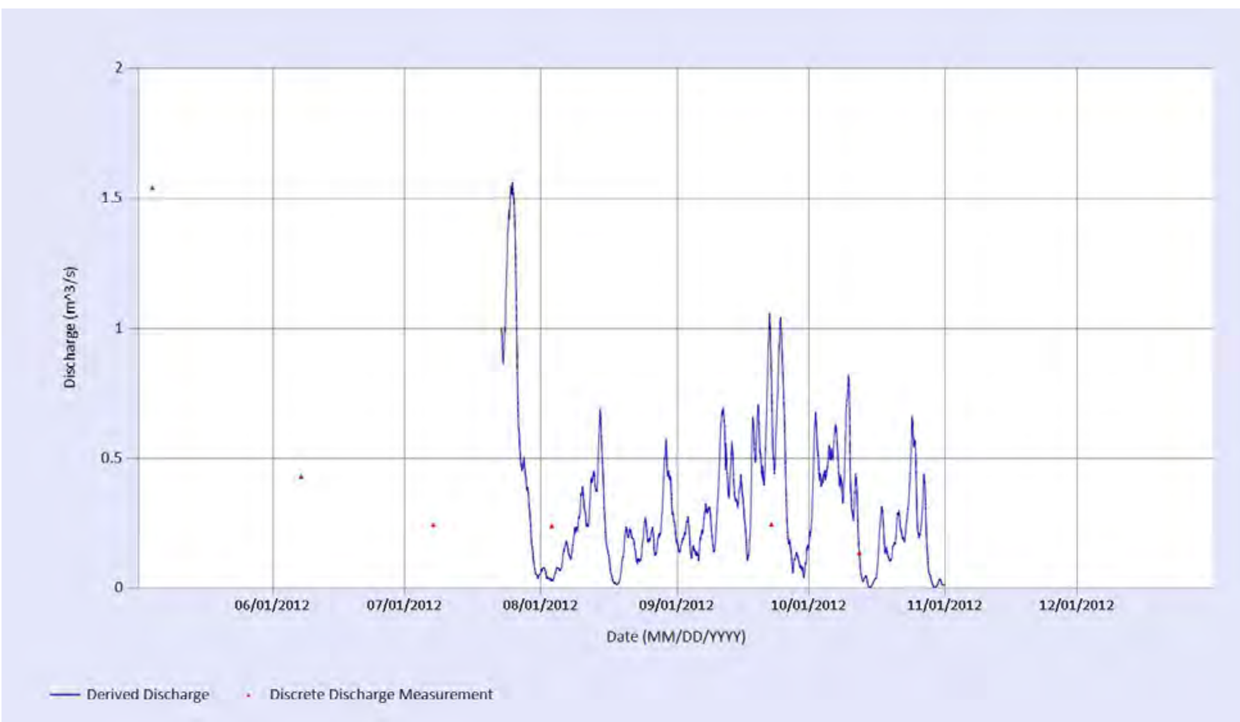


Figure C14 - Discharge at KV-9, Flat creek near the mouth, 2012

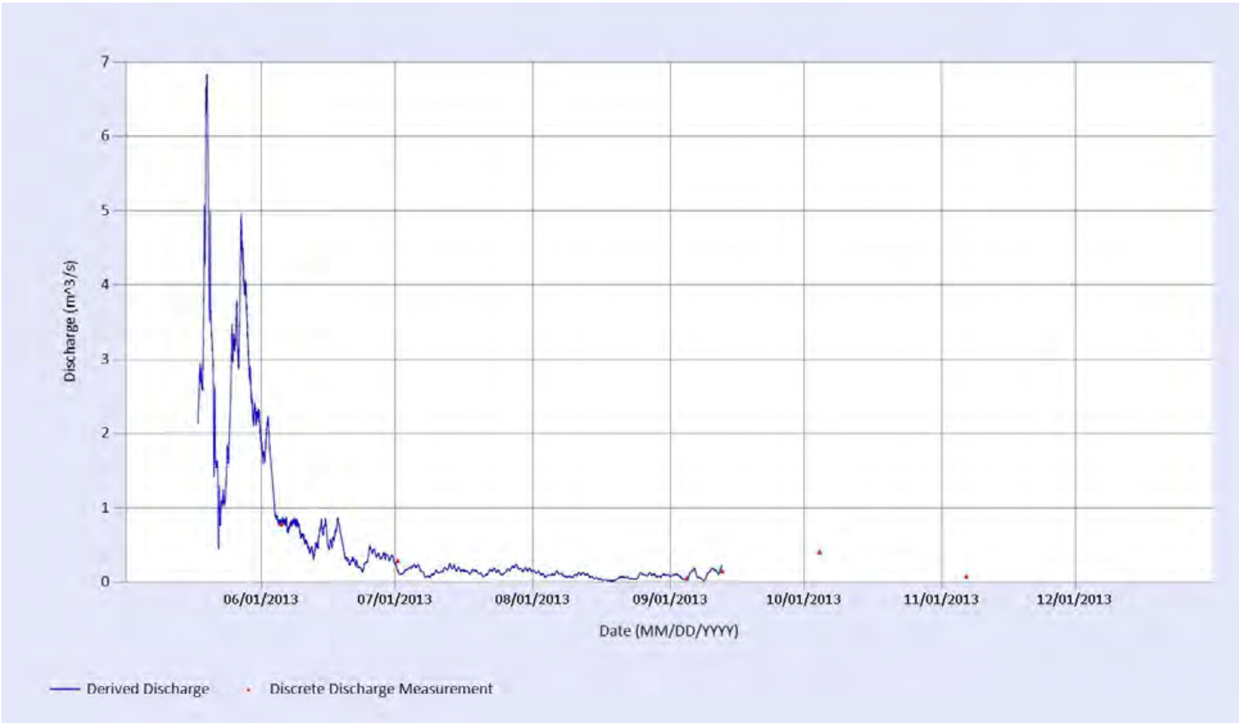


Figure C15 - Discharge at KV-9, Flat creek near the mouth, 2013

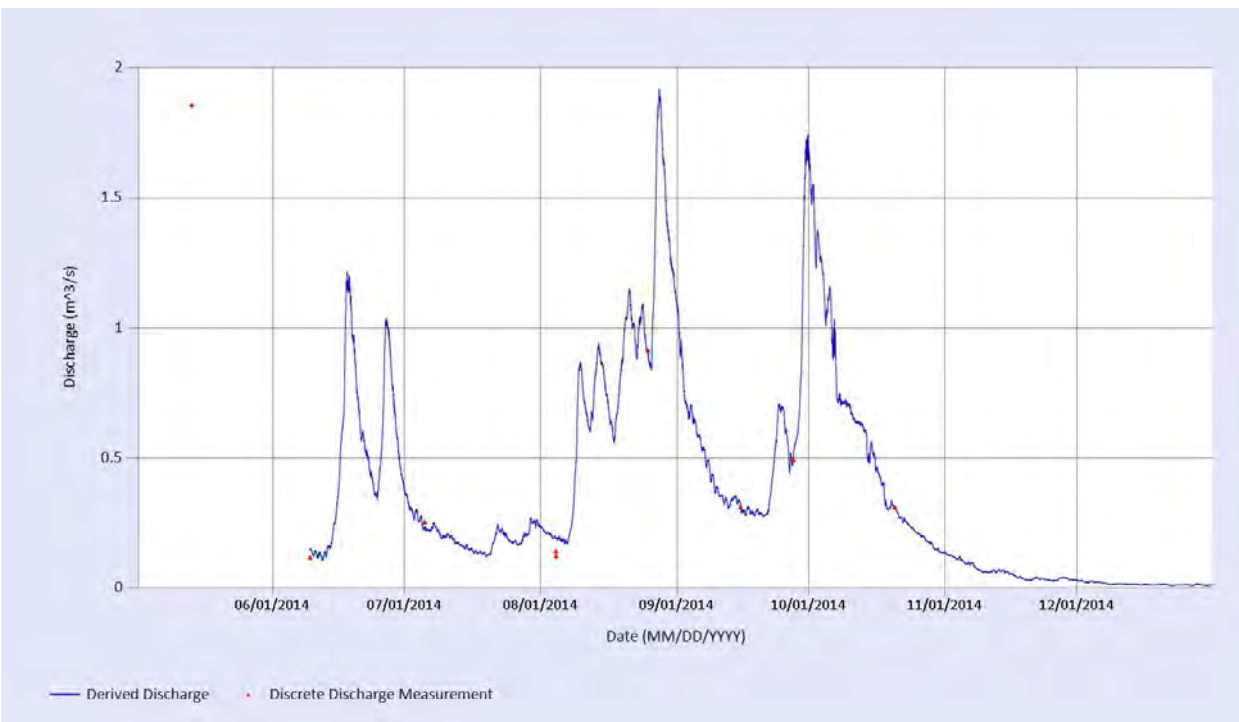


Figure C16 - Discharge at KV-9, Flat creek near the mouth, 2014

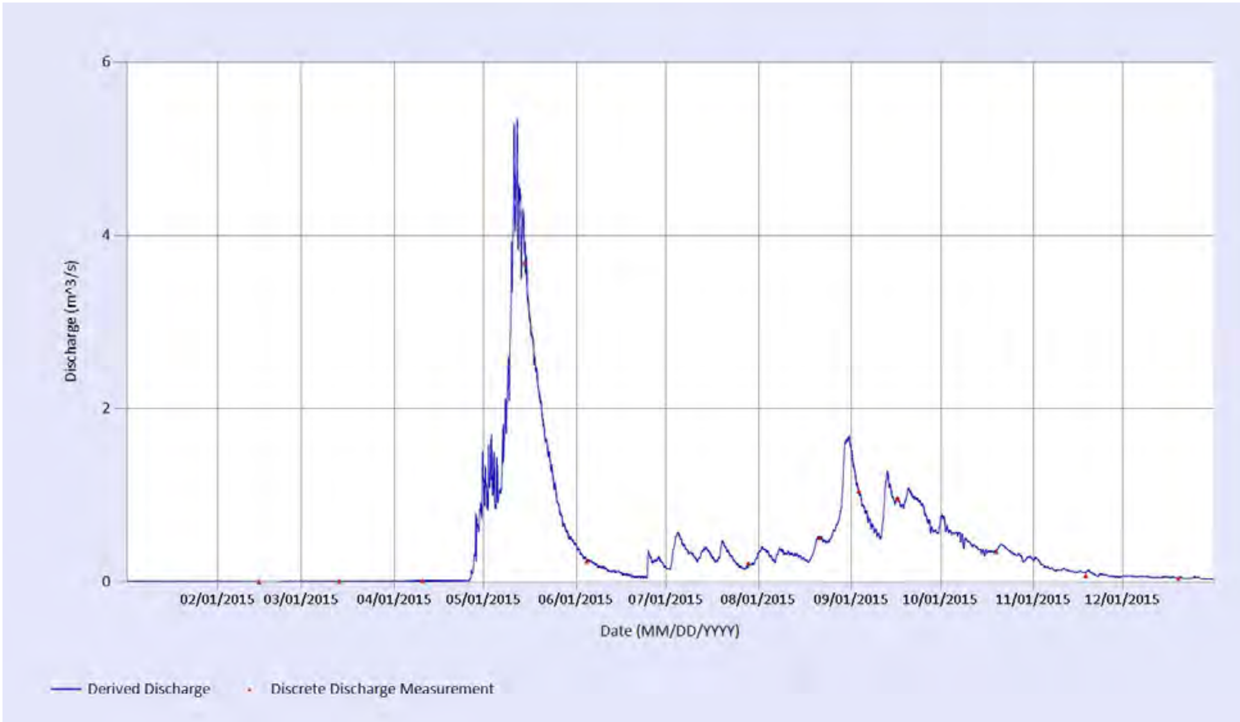


Figure C17 - Discharge at KV-9, Flat creek near the mouth, 2015

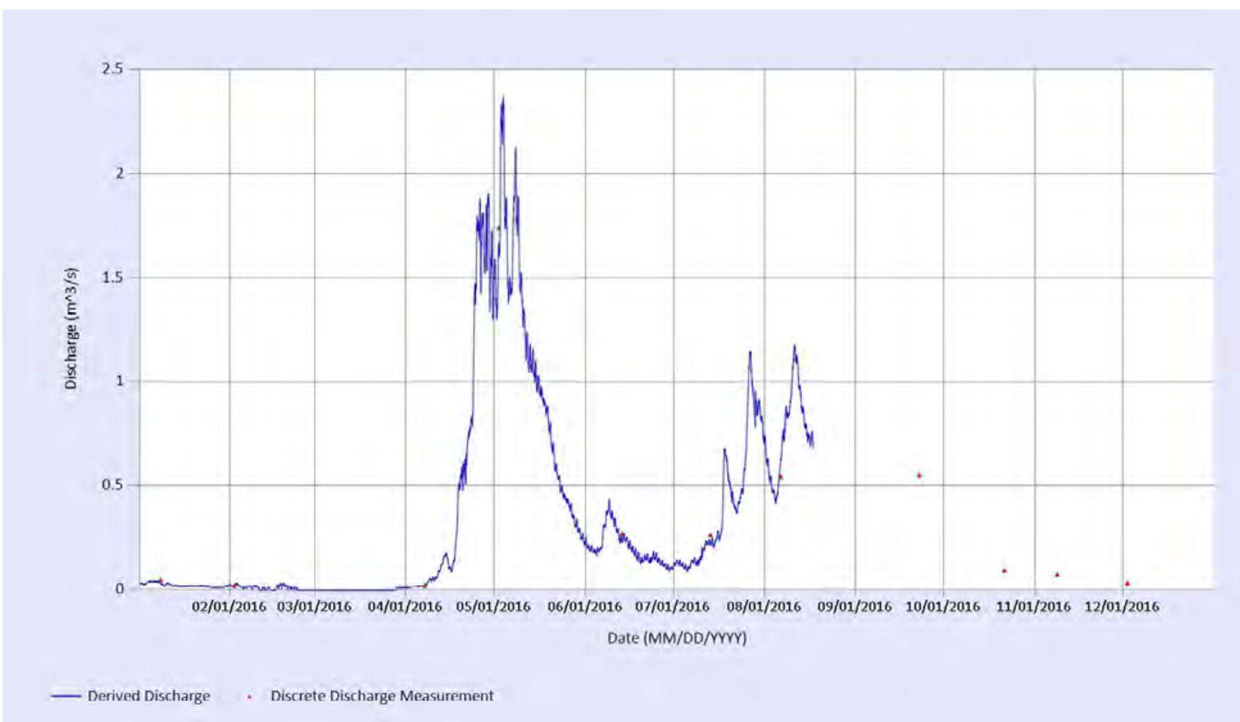


Figure C18 - Discharge at KV-9, Flat creek near the mouth, 2016

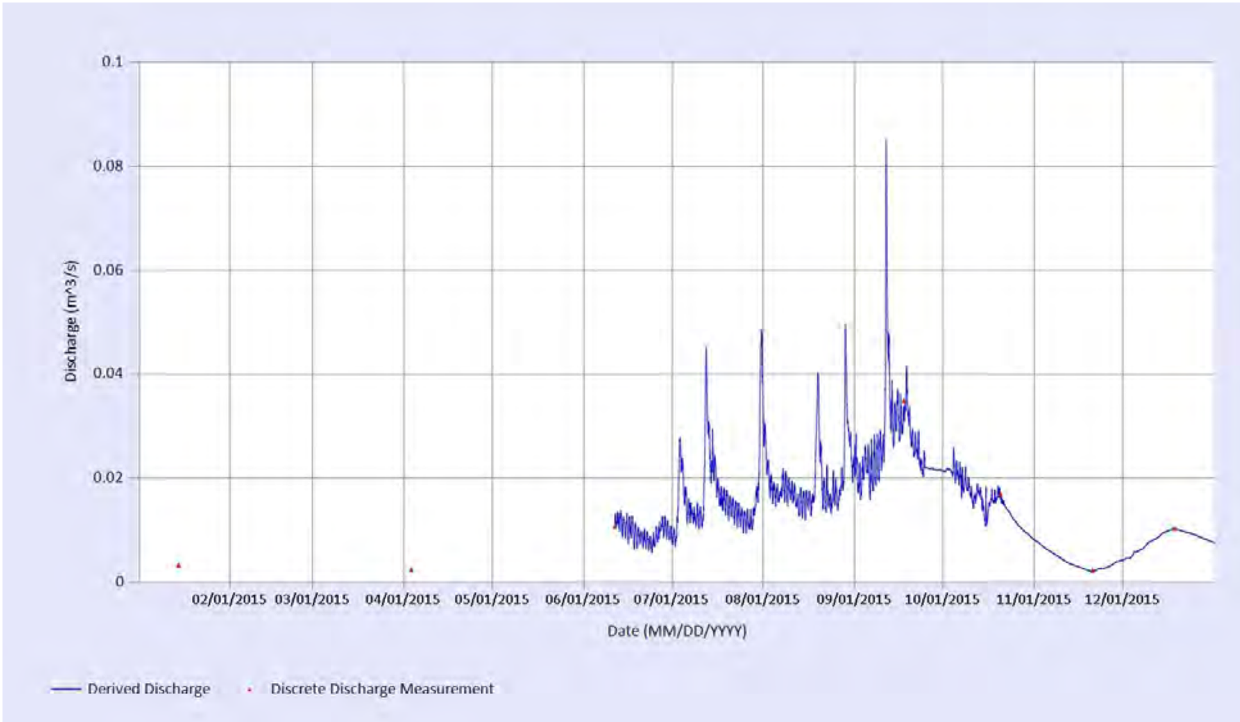


Figure C19 – Discharge at KV-21, No Cash Creek below Silver Trail Highway, 2015

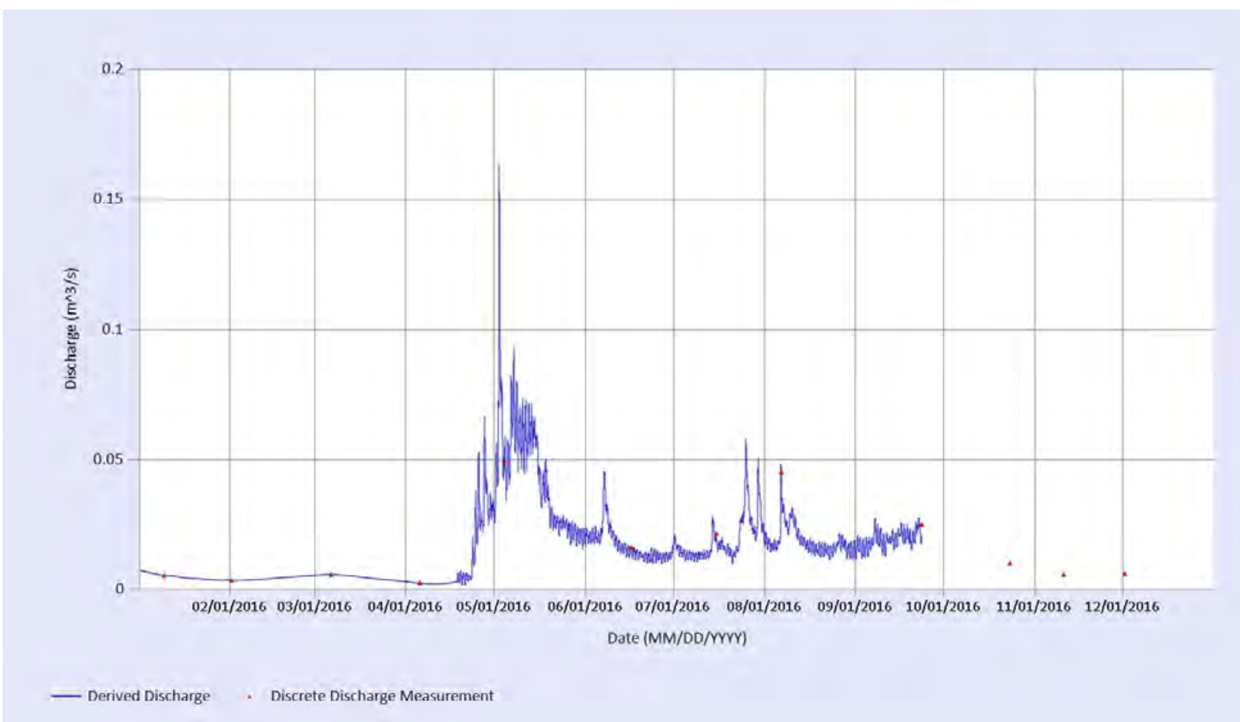


Figure C20 – Discharge at KV-21, No Cash Creek below Silver Trail Highway, 2016

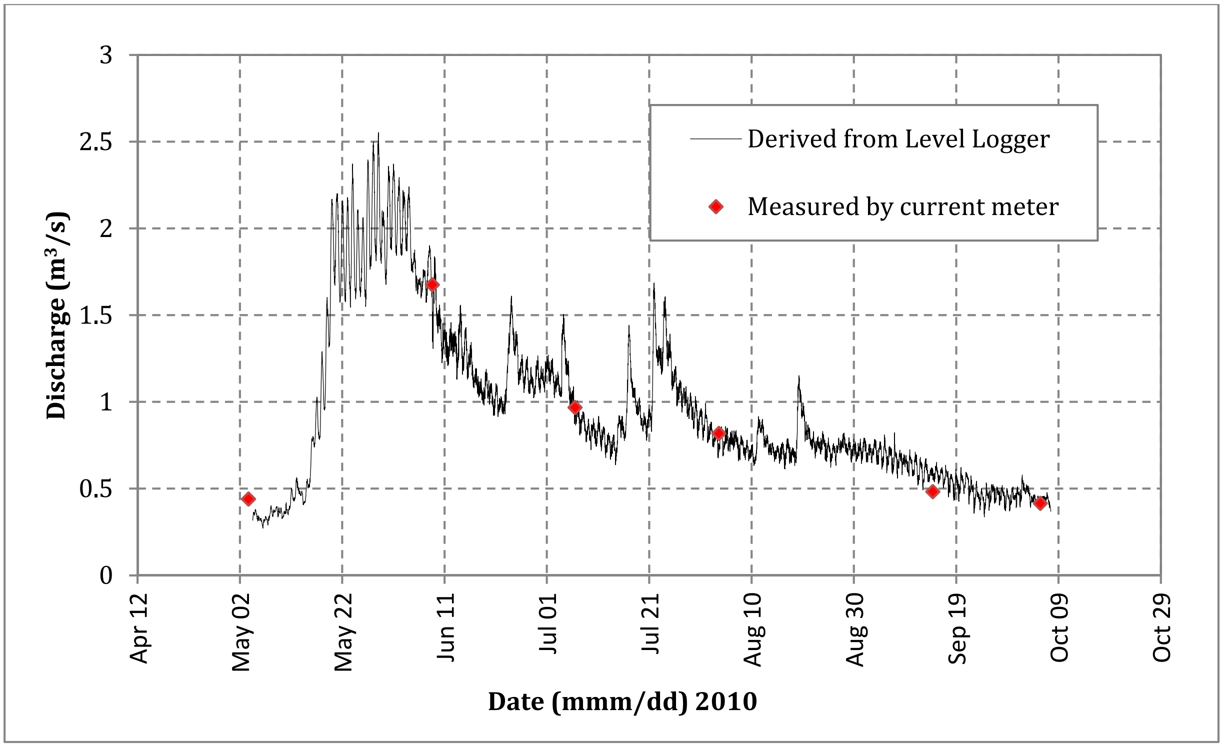


Figure C21 - Discharge at KV-41, Lightening Creek 2010

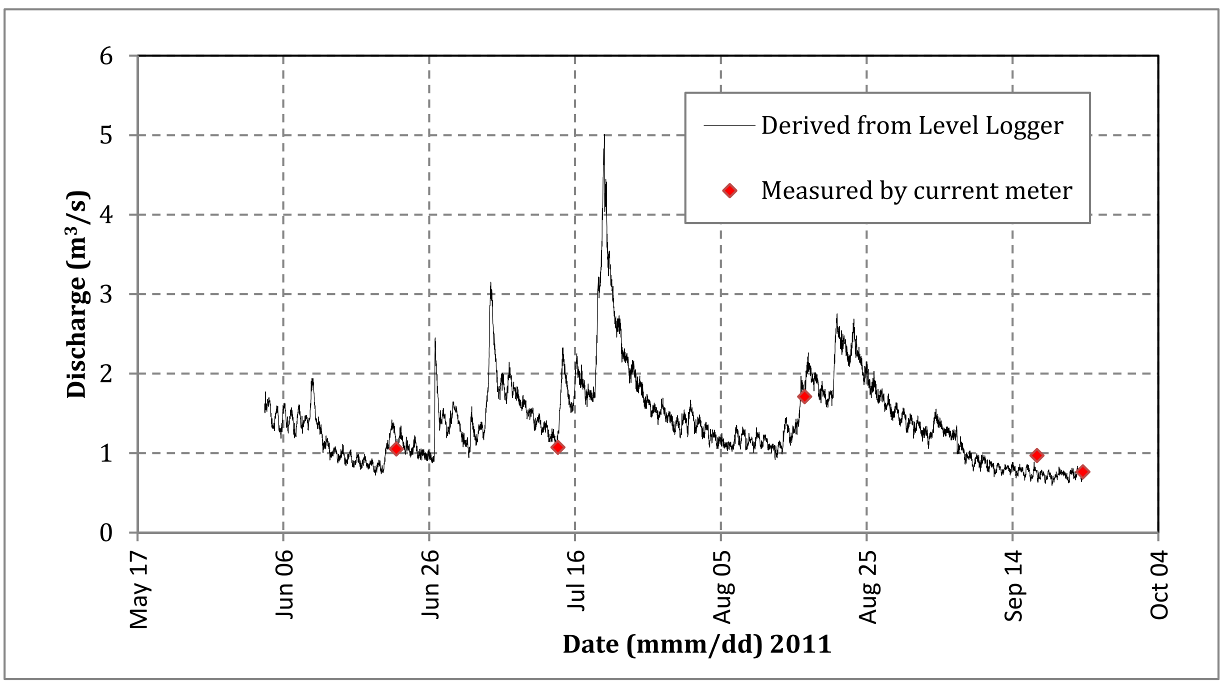


Figure C22 - Discharge at KV-41, Lightening Creek 2011

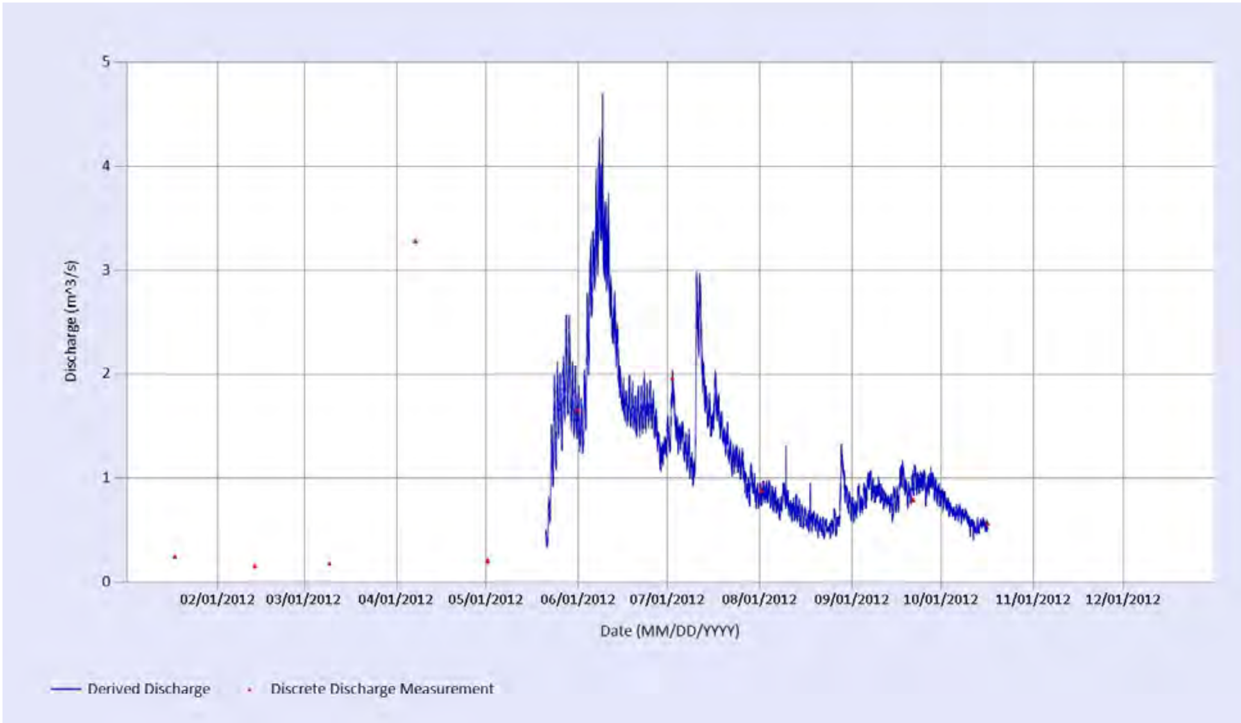


Figure C23 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2012

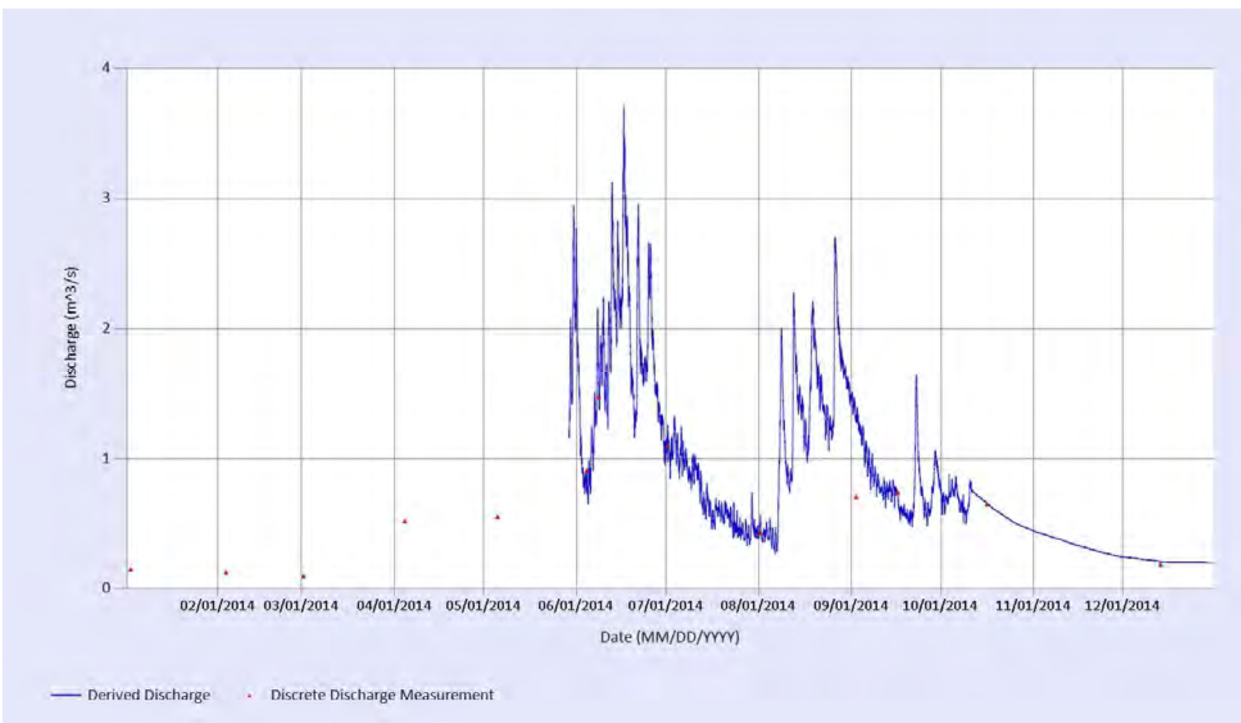


Figure C24 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2014 open water season

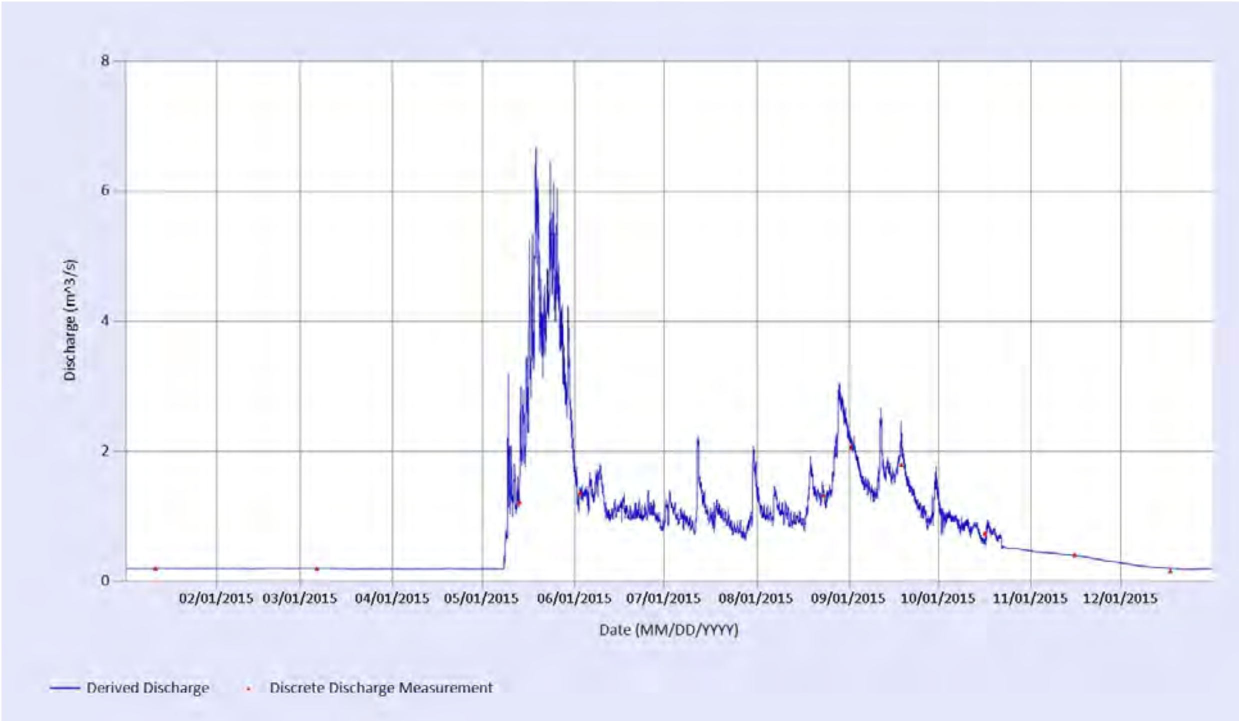


Figure C25 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2015

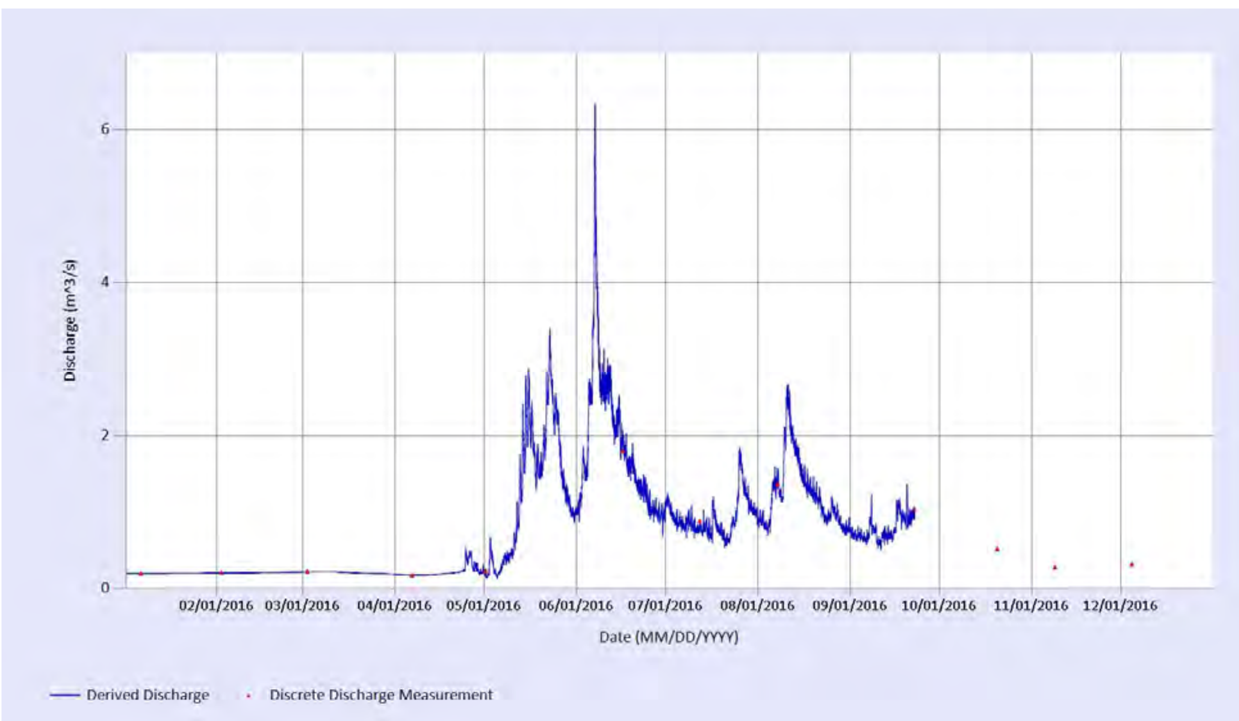


Figure C26 – Discharge at KV-41, Lightening Creek above Keno City Bridge, 2016

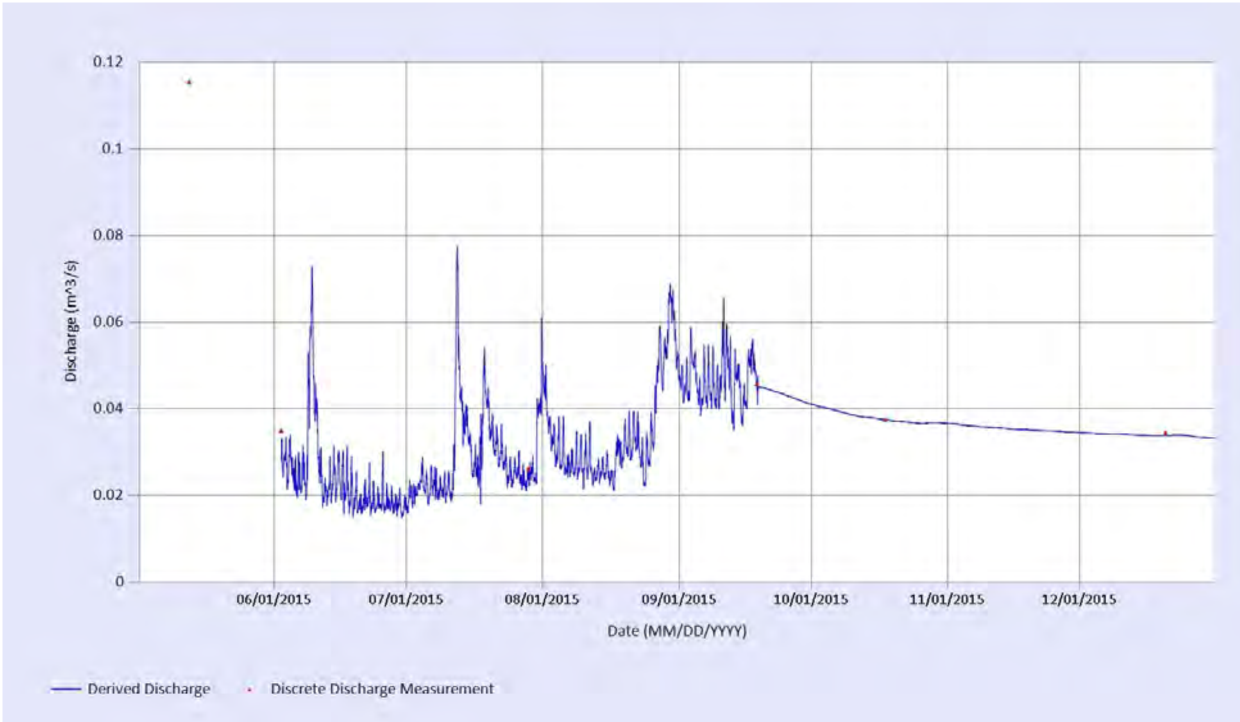


Figure C27 – Discharge at KV-51, Christal Creek downstream of Hinton Creek, 2015

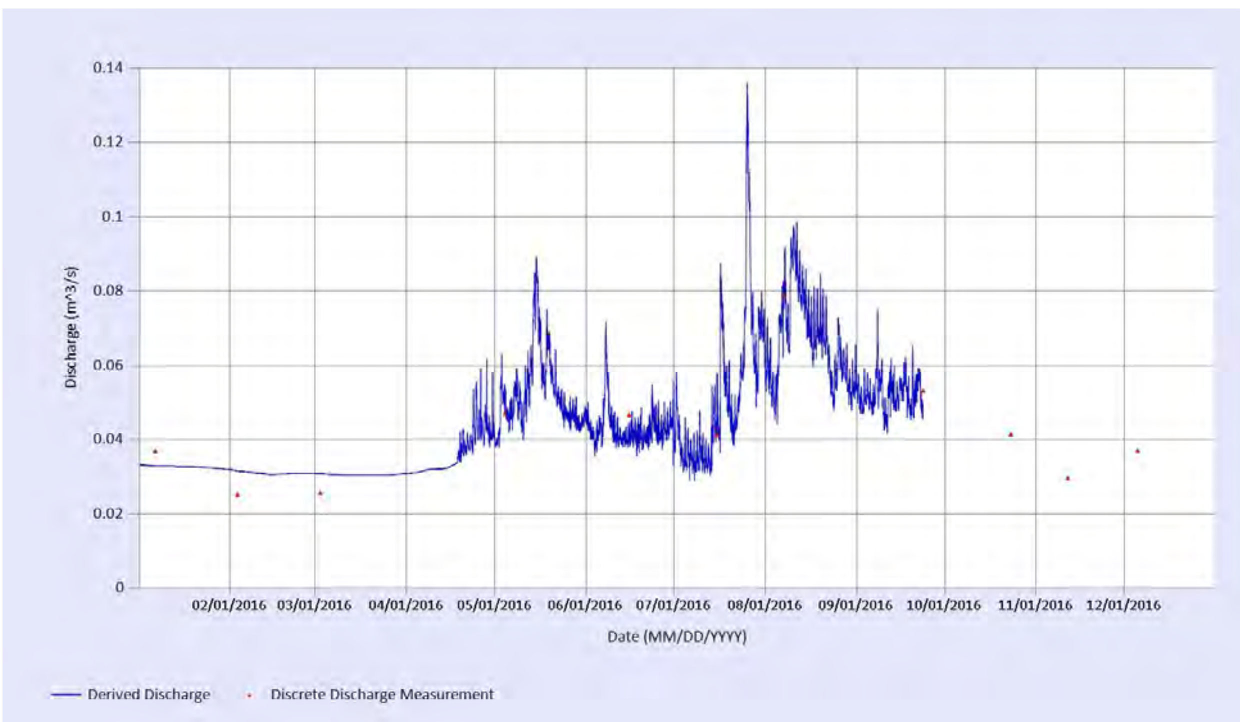


Figure C28 – Discharge at KV-51, Christal Creek downstream of Hinton Creek, 2016

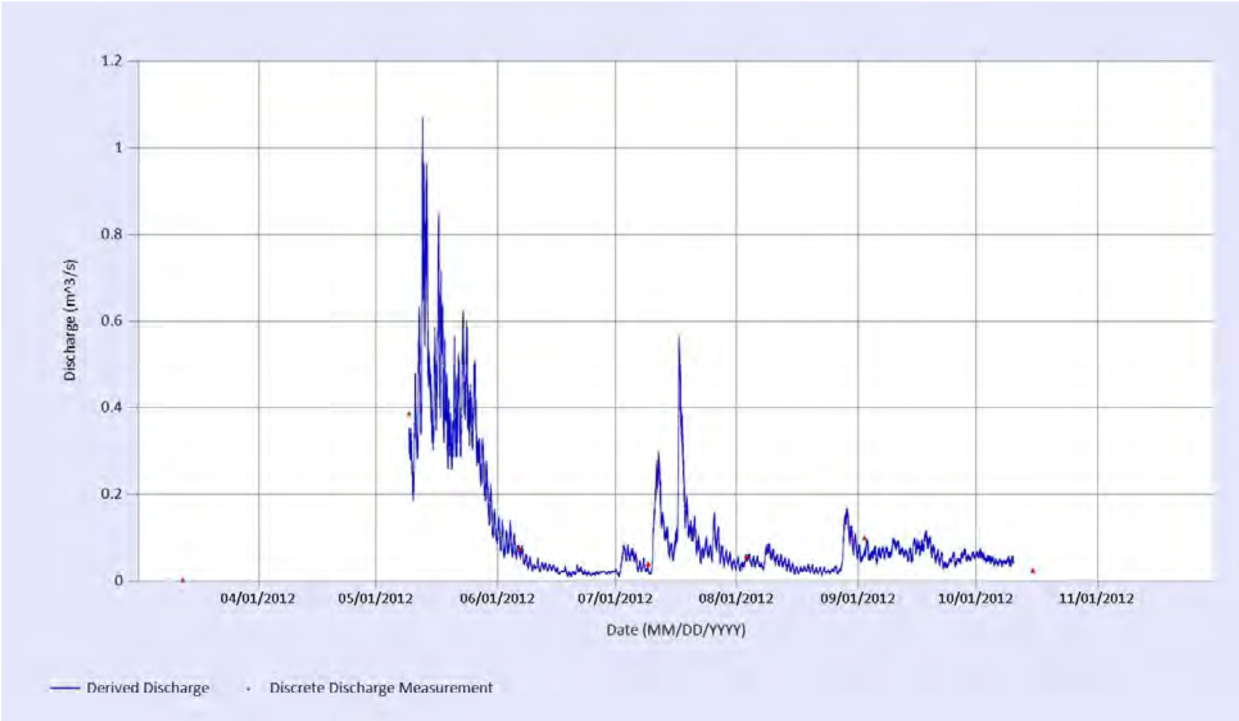


Figure C29 – Discharge at KV-60, Galena Creek above Silver King Adit, 2012 open water season

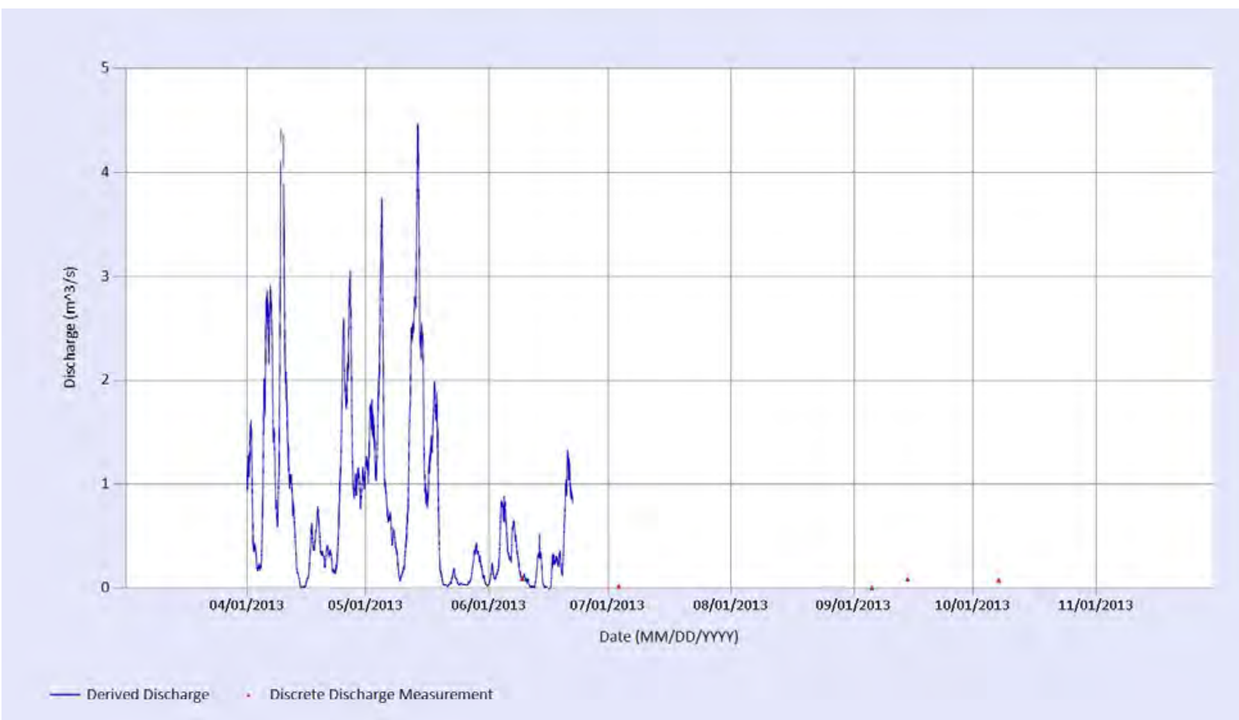


Figure C30 – Discharge at KV-60, Galena Creek above Silver King Adit, 2013 open water season

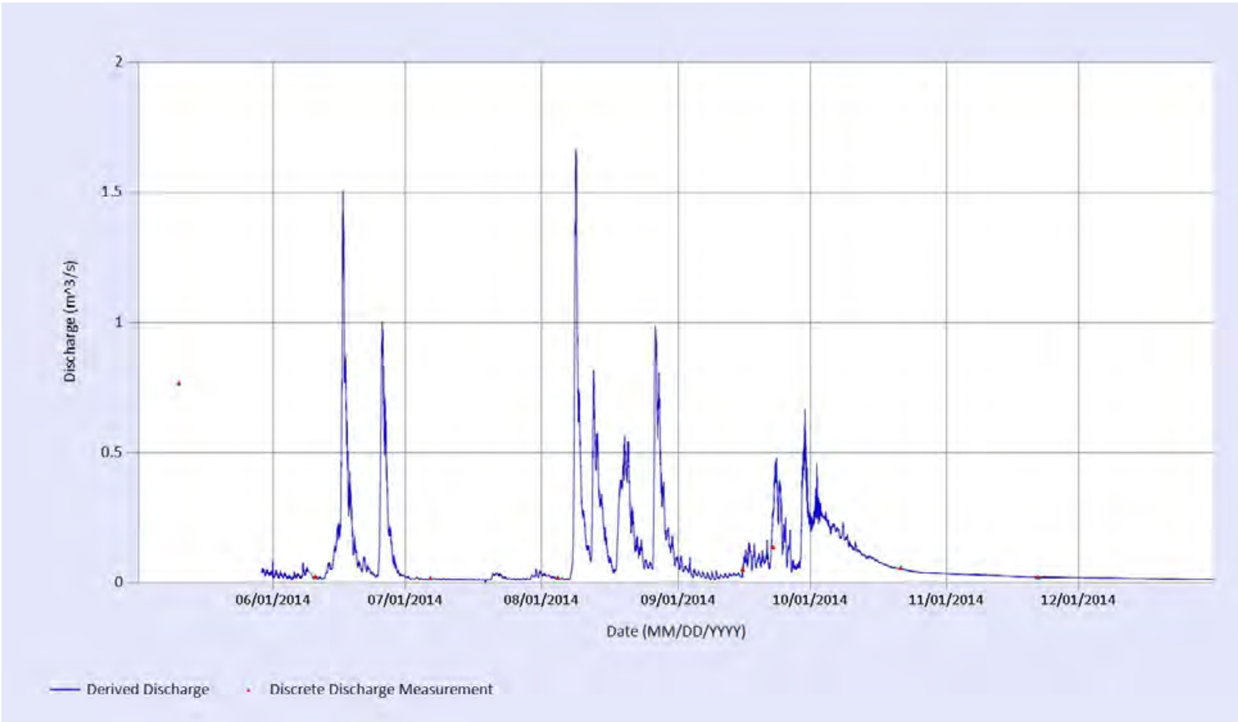


Figure C31 – Discharge at KV-60, Galena Creek above Silver King Adit, 2014 open water season

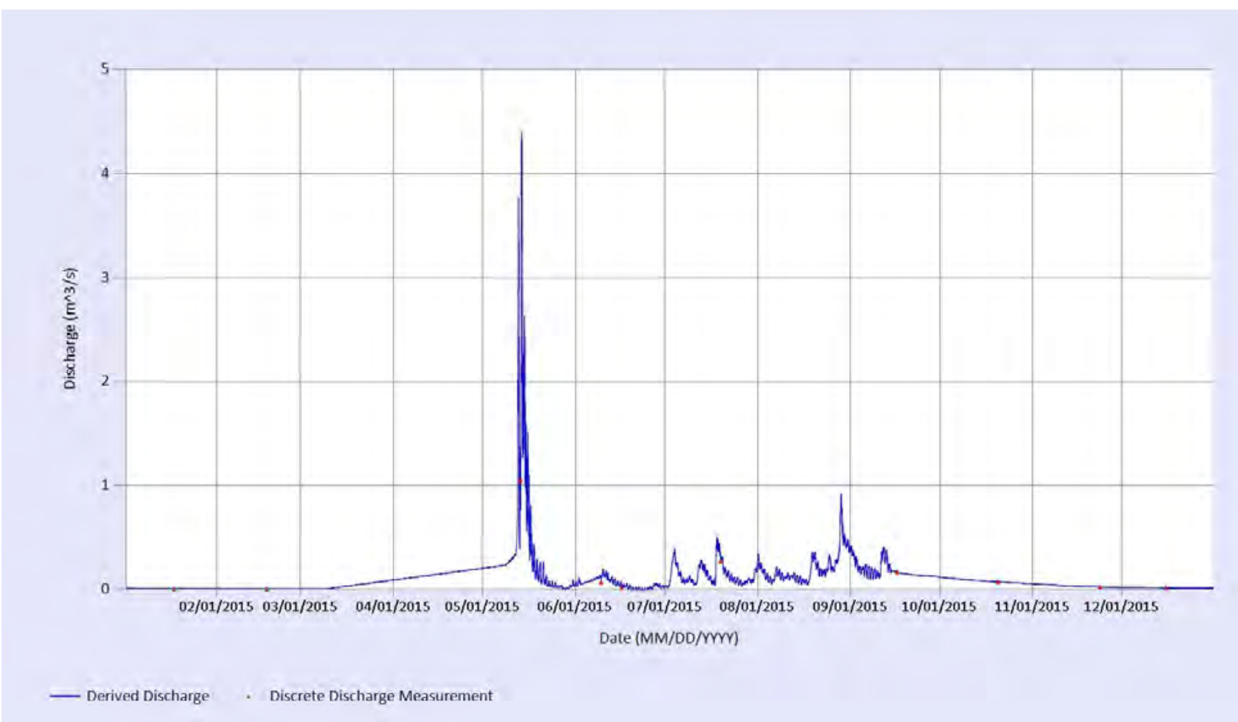


Figure C32 – Discharge at KV-60, Galena Creek above Silver King Adit, 2015

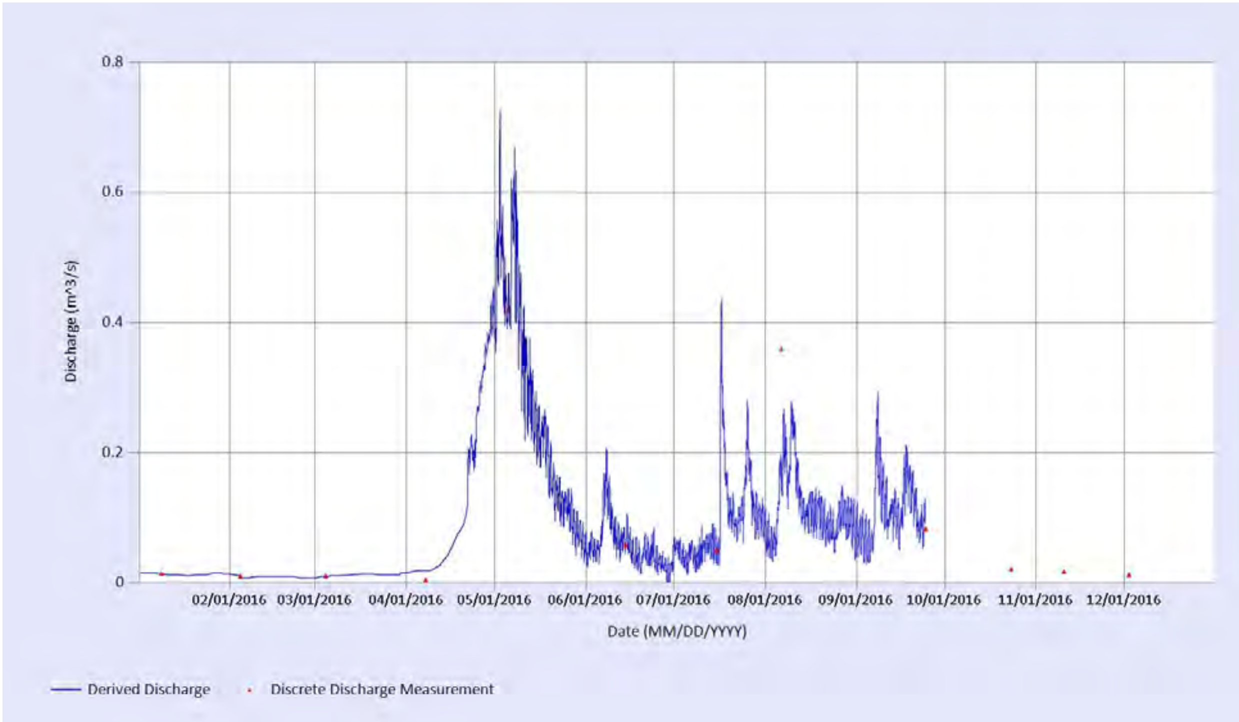


Figure C33 – Discharge at KV-60, Galena Creek above Silver King Adit, 2016

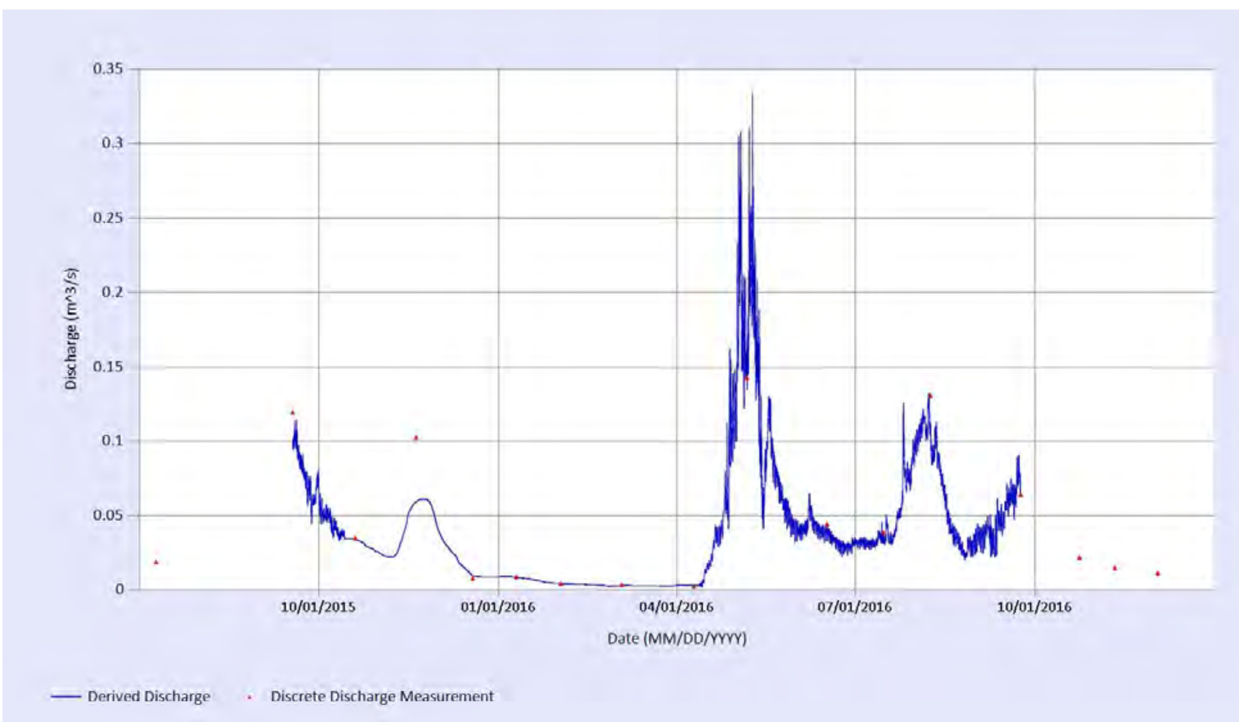


Figure C34 – Discharge at KV-64, Flat Creek below Silver Trail Highway, 2015-2016

APPENDIX D

PHOTOGRAPHS

Photo 1: KV-6, required periodic vegetation control, June 15th, 2016.

Photo 2: KV-7, old wooden cribbing, June 15th, 2016.

Photo 3: KV-9, looking downsteam, moderate-high stage, May 2nd, 2016.

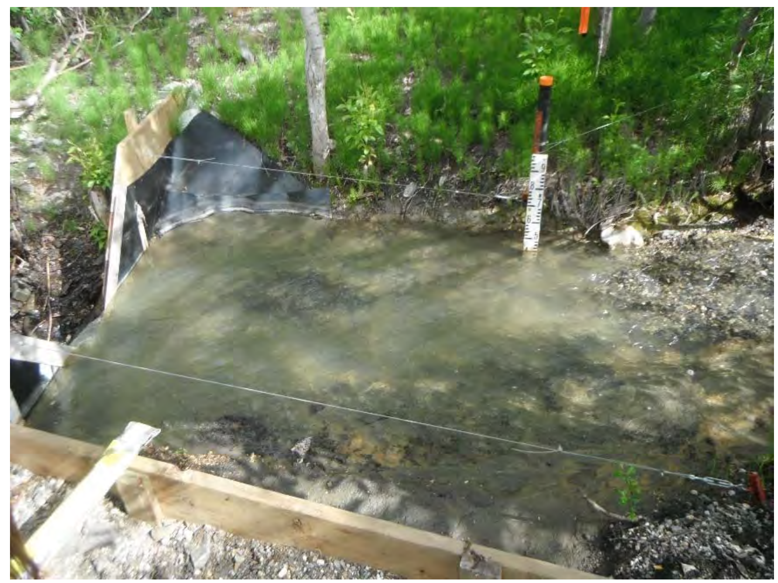


Photo 4: KV-21, weir pond showing significant sediment accumulation, June 16th, 2016.

Photo 5: KV-41, staff gauge and aging wooden cribbing structure, June 16th, 2016.

Photo 6: KV-51, looking upsteam, May 4th, 2016.

Photo 7: KV-60, looking upstream, July 15th, 2016.

Photo 8: KV-64, looking downstream May 5th, 2016.

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

Memorandum

To: Elsa Reclamation and Development Company Ltd.

From: Catherine Henry

CC: Kai Woloshyn

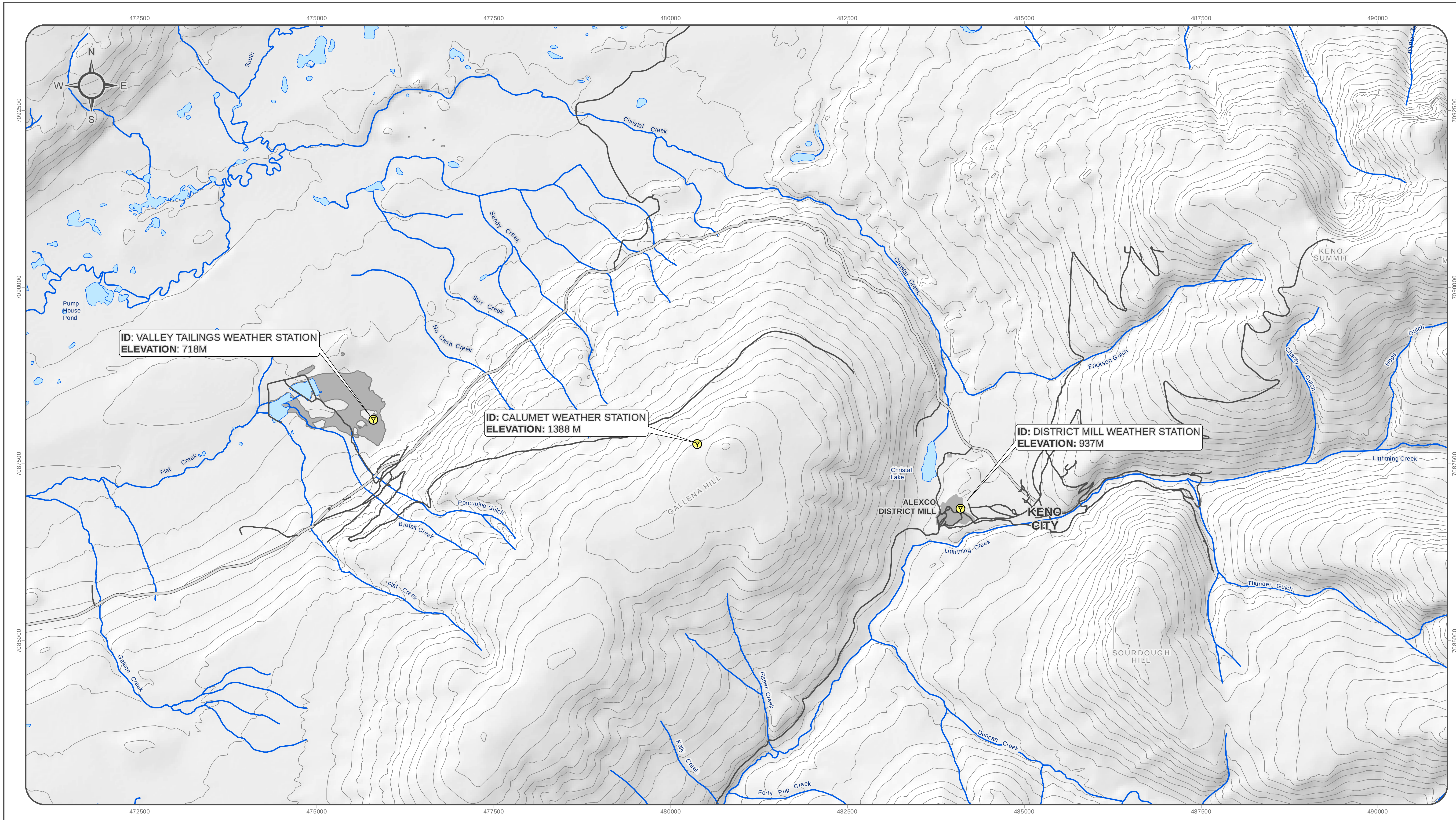
Date: February 11, 2017

Deliverable # 2016-009-9_14

Re: 2016 Meteorological Data Summary, Keno, YT

1. Introduction

This memo describes the meteorological data collected up to 2016 within the Keno Hill Silver Mining District at the Calumet weather station since 2007, at the District Mill meteorological station since 2011 (installed as part of Alexco's Bellekeno mining operations) and at the Valley Tailings meteorological station since 2012. The locations of the three weather stations are shown on Figure 1.



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

Quartz claim boundaries current as of February 24th, 2011. Ownership data current as of December 20th, 2010. Data source: http://geomaticsyukon.ca.

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

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

0 1 2 3 Kilometers

Weather Station

Highway

Road

Contours (100 ft)

Watercourse

Waterbody

ERDC

KENO HILL MINING DISTRICT

FIGURE 1

KENO METEOROLOGICAL STATIONS

JANUARY 2016

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\SpecifcTopics\Monitoring\Weather Stations\WeatherStations_20160106.mxd
(*Last edited by: mducharme; 1/6/2016/15:53 PM*)

2. CALUMET WEATHER STATION

An automated Onset HOBO meteorological station (Calumet Weather Station) was installed on Galena Hill above the Hector adit at 1,380 masl in June 2007 (UTM coordinates: 08 V 480377 7087790). See Attachment A for the list of components and a photo.

2.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The station was commissioned on June 15, 2007, and logs air temperature, relative humidity, barometric pressure, rainfall, wind speed and direction at a height of 3 meters, solar radiation, and soil temperature all at a 15-minute interval.

- The wind sensor experiences occasional icing during the winter months; as such, extended periods of zero wind speed were invalidated. Also note that winter wind speeds may occasionally be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- No total precipitation gauge or snowfall conversion adaptor is installed at this time, therefore only rainfall is measured. Note that instances of rainfall recorded at temperatures below zero are likely due to snowmelt.

- Datalogger connections for the soil temperature, rainfall and pressure sensors malfunctioned between June 23, 2016 and October 23, 2016, and these data are therefore missing for that period.

2.2. METHODS AND RESULTS

Monthly averages were calculated from 15-minute values recorded by the datalogger (averaged values from a 1 minute sampling interval). Average temperature and total rainfall are presented in Table 1 below.

Table 1 Monthly statistics for average temperature and total rainfall collected at Calumet Station

	Average Temperature (°C)										Total Rainfall (mm)									
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
January	-	-17.18	-18.84	-14.08	-16.78[3]	-18.71[4]	-16.90	[6]	-13.22	*-8.34*[12]	-	-	-	-	-	-	-	[6]	0.0	*0.0*[12]
February	-	-16.99	-16.95	-9.09	-15.88[3]	-9.94[4]	-10.81	-15.69	-13.42	-9.32	-	-	-	-	1.8[3]	[9]	-	-	0.2	0.3
March	-	-11.04	-16.39	-9.21	-12.92[3]	-12.92[4]	-14.45	-11.95	-10.69	-5.84	-	-	-	-	0.5[3]	[9]	0.6	-	2.8	2.8
April	-	-4.93	-4.75	-2.01	-3.77[3]	-1.88[4]	-12.32	-4.39	-3.33	-0.43	-	1	-	1.3[3]	2.8[3]	[9]	0.2	6.2	8.6	7.8
May	-	3.31	3.66	5.35	4.41[3]	1.61[4]	n/a	4.17	7.85	5.55	-	25.4	21.8	32.3[3]	15.5[3]	[9]	n/a	17.2	4.0	23.0
June	*11.25*[1]	8.70	9.58	8.68	8.82[3]	7.76[4]	11.59	*7.31*[11]	8.42	10.07	*55.2*[1]	44.6	*11.8*[7]	56.7[3]	121.8[3]	[9]	45.2	*69.8*[11]	45.2	43.0
July	11.80	8.17	12.45	10.50	3.80[3]	7.84[4]	11.11	[11]	9.67	10.60	108.8	108.4	*22.8*[8]	137.7[3]	135.9[3]	*27.8*[10]	39.2	[11]	135.5	[13]
August	9.63	5.54	7.47	9.61	[2]	8.33[5]	10.58	7.95	6.71	9.25	54.8	110.2	89.4	140.0[3]	[9]	45.0	35.6	112.0	97.0	[13]
September	1.12	2.27	3.58	2.40	[2]	3.39	3.33	1.86	*2.17*[12]	2.95	57.6	61.4	50.4	78.0[3]	[9]	17.4	64.6	43.8	*46.4*[12]	[13]
October	-6.53	-7.20	-4.73	-4.86	[2]	-8.16	-2.52	-5.02	[12]	-6.23	-	12.6	-	16.0[3]	[9]	1.6	14.6	15.2	[12]	*0.0*[13]
November	-9.41	-10.17	-11.94	-11.19	-17.39[4]	-18.44	-15.50	-9.87	[12]	-8.87	-	-	-	-	-	0.2	0.0	0.2	[12]	0.0
December	-16.19	-18.34	-11.16	-17.72	-11.78[4]	-18.83	*-14.55*[6]	-10.43	[12]	-15.27	-	-	-	-	-	0.0	*0.0*[6]	0.0	[12]	0.0

Notes:

Values in *grey italics* indicate a partial month

[1] *Station commissioned June 15, 2007*

[2] *Temperature probe malfunction – no proxy data available*

[3] *Calculated from MAYO A data*

[4] *Sensor occasionally offline but most data complete*

[5] *Sensor replaced August 7*

[6] *The station was down from December 12, 2013 to January 31, 2014.*

[7] *Rainfall gauge malfunction on June 11; total rainfall provided for June 1-11.*

[8] *Rainfall gauge back online; total rainfall provided for July 7-31.*

[9] *Tipping bucket malfunction – no proxy data available.*

[10] *Tipping bucket repaired July 4th; total rainfall provided for July 4-31.*

[11] *Station was down between June 26 and July 31, 2014.*

[12] *Data missing from September 17, 2015 to January 5, 2016.*

[13] *Rainfall data missing from June 23, 2016 to October 23, 2016.*

3. DISTRICT MILL WEATHER STATION

The District Mill Campbell Scientific automated meteorological station is located above the dry stack tailings facility and below the old Keno City dump near Keno, YT (UTM coordinates: 08 V 0484009 7086872, elevation: 936 masl). See Attachment A for the list of components and a photo.

3.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The Campbell Scientific Meteorological Station was commissioned on June 2, 2011 and includes sensors for the measurement of temperature, relative humidity, rainfall or total precipitation, wind speed and direction at a height of 10 meters, and solar radiation, all at a 1-hour interval.

- Relative humidity readings were invalidated from time of commissioning until May 7, 2012, at which time the problem was corrected by sending a revised program to the datalogger.

- A pyranometer (model SP Lite2) was installed on December 13, 2012, and the datalogger program was revised to incorporate hourly solar radiation readings and an evapotranspiration (ET) instruction. The ET instruction uses temperature, relative humidity, wind speed, solar radiation, latitude, longitude and altitude to calculate an evaporation rate for a short grass crop. This provides an approximation of actual evaporation, which varies locally depending on surface type and micro topography. Note that if one of the parameters listed above is invalid, the ET calculation is also invalidated.

- The wind sensor experiences occasional icing during the winter months and extended periods of zero wind speed were invalidated. Also note that winter wind speeds may occasionally be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- The total precipitation gauge or snowfall conversion adaptor was not installed in 2011 or 2012, therefore only rainfall was measured. Note that instances of rainfall recorded at temperatures below zero are likely due to snowmelt. A snowfall converter was installed on October 15, 2013 and now records total precipitation going forward. In 2016, the snowfall conversion adaptor was removed on May 19 and reinstalled on October 22.

- An alter screen was installed around the precipitation gauge on June 3, 2015, to reduce wind induced error in total precipitation measurement.

3.2. METHODS AND RESULTS

Monthly averages were calculated from hourly values recorded by the datalogger (averaged values from a 10 seconds sampling interval) for the following parameters: temperature, daily maximum temperature, daily minimum temperature, relative humidity, wind speed, maximum wind speed and solar radiation. Monthly extreme maximum temperature, extreme minimum temperature, maximum wind speed, total rainfall and total evapotranspiration are also shown in Table 2 below.

Wind data from time of commissioning to December 31, 2016 are also depicted in the wind rose presented in Figure 2, which was produced using WRPLOT View software. This period has a 92.1% data availability.

Table 2 Monthly statistics for meteorological parameters collected at District Mill Station

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)[8]
Jun -11[2]	24.72	18.59	11.96	6.30	-2.56	n/a	n/a	1.35	9.14	n/a	n/a
Jul-11	25.67	18.50	12.91	8.00	5.09	n/a	n/a	1.15	8.02	n/a	n/a
Aug-11	22.32	15.58	9.78	5.37	1.93	n/a	n/a	1.18	9.15	n/a	n/a
Sep-11	17.97	11.29	6.07	1.85	-2.47	n/a	n/a	1.43	11.36	n/a	n/a
Oct-11	7.20	0.20	-2.74	-5.41	-9.84	n/a	*2.60*[3]	0.94	13.12	n/a	n/a
Nov-11	-4.23	-16.79	-19.54	-22.47	-34.99	n/a	0.00	0.58	12.05	n/a	n/a
Jan-12	-0.96	-19.10	-23.13	-26.79	-37.32	n/a	0.00	*0.59*	*9.51*	n/a	n/a
Feb-12	2.77	-6.77	-10.00	-13.07	-26.78	n/a	0.10 [4]	*1.38*	*15.62*	n/a	n/a
Mar-12	5.33	-7.69	-13.37	-18.00	-27.80	n/a	0.00	*0.97*	*9.24*	n/a	n/a
Apr-12	9.69	6.13	0.96	-3.87	-15.92	n/a	0.60 [4]	1.37	10.27	n/a	n/a
May-12	17.78	10.73	6.31	1.91	-3.47	*51.81* [5]	18.30	1.78	10.60	n/a	n/a
Jun-12	27.62	18.41	13.46	8.29	4.42	56.35	21.70	1.44	10.26	n/a	n/a
Jul-12	25.14	18.07	12.75	7.73	1.64	69.26	85.80	1.36	12.99	n/a	n/a
Aug-12	21.72	16.31	11.25	6.56	-0.89	67.79	47.00	1.62	9.41	n/a	n/a
Sep-12	20.24	10.33	5.90	2.08	-5.22	69.51	36.40	1.84	14.27	n/a	n/a
Oct-12	7.60	-3.95	-7.35	-10.32	-20.62	79.54	7.60	1.13	10.37	n/a	n/a
Nov-12	-8.98	-19.55	-21.90	-24.32	-33.36	81.43	0.00	0.94	9.36	n/a	n/a
Dec-12	-3.36	-21.30	-23.44	-25.58	-36.32	81.34	0.00	*0.26*	*5.93*	*1.01* [6]	*0.05* [7]
Jan-13	-1.59	-17.06	-20.01	-23.08	-41.48	82.92	0.00	*0.76*	*14.48*	1.06	0.81
Feb-13	1.54	-9.10	-12.52	-15.46	-23.74	88.36	0.30 [4]	*0.85*	*12.25*	10.26	1.27
Mar-13	3.26	-7.52	-13.16	-17.99	-29.96	64.08	3.90	1.59	12.47	95.82	6.33
Apr-13	6.07	-2.76	-7.94	-13.69	-25.07	54.50	8.20	2.44	12.93	190.02	14.48

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m²)	Total Evapo-transpiration (mm)[8]
May-13	23.31	10.20	5.27	0.23	-9.46	61.83	39.60	1.77	11.76	215.44	21.70
Jun-13	30.51	19.97	14.27	8.30	1.84	58.72	57.30	1.82	12.87	234.69	29.79
Jul-13	24.93	19.40	14.01	8.60	2.25	62.67	46.90	1.75	16.14	211.00	27.10
Aug-13	27.34	18.54	12.98	8.01	-0.38	66.30	51.90	1.49	11.05	156.25	21.38
Sep-13	16.11	9.69	5.81	2.26	-3.74	77.52	59.70	1.54	10.99	79.69	10.88
Oct-13	8.25	1.61	-1.32	-4.21	-10.10	86.75	44.60	1.11	11.62	35.75	4.26
Nov-13	0.18	-13.41	-16.68	-20.08	-37.96	84.26	10.60	*1.02*	*10.96*	4.93	*1.08*
Dec-13	-1.73	-21.23	-23.91	-26.70	-35.29	78.77	4.90	*0.75*	*9.47*	0.57	*0.62*
Jan-14	3.74	-9.33	-12.16	-15.10	-32.22	89.44	24.9	*0.72*	*10.03*	2.42	*0.641*
Feb-14	-1.93	-15.25	-19.40	-23.02	-33.55	75.20	2.9	0.87	10.85	31.34	1.988
Mar-14	4.57	-5.31	-11.29	-16.16	-26.79	54.77	0.7	1.57	11.98	115.54	9.174
Apr-14	10.93	4.09	-0.96	-5.78	-17.33	57.54	5.1	1.64	12.05	171.28	15.77
May-14	21.30	12.70	7.64	2.03	-3.03	52.18	12.8	2.09	19.21	217.91	29.81
Jun-14	24.93	16.21	11.39	5.95	-0.13	56.14	40.4	1.78	10.43	217.90	28.58
Jul-14	23.44	18.49	13.68	8.73	-0.04	65.01	31.0	1.63	13.38	187.31	23.84
Aug-14	22.09	15.57	10.87	6.93	0.06	74.59	67.7	1.44	11.85	139.84	15.72
Sep-14	17.70	8.76	4.28	0.49	-6.74	70.54	36.4	1.37	11.32	93.38	11.56
Oct-14	7.47	-0.91	-3.79	-6.33	-15.42	88.21	15.7	1.24	12.80	24.83	3.39
Nov-14	-2.21	-12.15	-14.34	-16.59	-30.16	88.64	1.40	*0.59*	*6.27*	3.12	*0.60*
Dec-14	-0.09	-11.05	-13.67	-16.31	-26.66	89.06	1.40 [9]	*0.51*	*8.87*	0.33	*0.40*
Jan-15	-0.34	-13.74	-16.50	-19.13	-34.86	85.85	1.9	*0.49*	*5.488*	1.30	*0.431*
Feb-15	2.87	-12.95	-15.93	-18.78	-39.39	84.95	12.7	0.75	10.36	9.06	0.859
Mar-15	5.54	-4.76	-9.83	-14.37	-28.70	70.52	4.1	1.45	12.6	86.48	6.292

Month-Year (MMM-YY)	Extreme Maximum Temperature (°C)	Average Maximum Temperature (°C)	Average Temperature (°C)	Average Minimum Temperature (°C)	Extreme Minimum Temperature (°C)	Average Relative Humidity (%)	Total Precip (mm)	Average Wind Speed (m/s) [1]	Extreme Maximum Wind Speed (m/s) [1]	Average Solar Radiation (W/m^2)	Total Evapo-transpiration (mm)[8]
Apr-15	10.90	5.36	0.56	-3.89	-10.48	61.71	4.2	1.75	12.37	163.45	16.03
May-15	26.51	16.95	10.96	4.60	-7.00	45.35	1.4	1.89	10.64	246.80	34.67
Jun-15	23.18	16.65	11.37	5.81	0.52	61.05	26.3	1.85	12.62	219.18	26.46
Jul-15	25.43	17.54	12.54	7.72	4.73	68.63	72.4	1.48	12.62	190.74	19.98
Aug-15	24.63	14.03	9.35	5.08	-3.09	75.14	54.9	*1.47*	*9.86*	146.76	*13.87*
Sep-15	13.57	7.07	2.77	-0.72	-7.72	79.33	32.6	1.71	15.64	83.01	10.12
Oct-15	7.32	0.88	-1.78	-4.16	-13.22	89.14	19.4	*1.08*	*10.07*	32.52	*2.92*
Nov-15	0.83	-11.17	-13.75	-17.16	-31.38	89.09	22.8	*0.71*	*12.15*	4.03	*0.60*
Dec-15	0.18	-12.38	-14.60	-16.93	-31.06	89.01	4.0	*4.59*	*14.24*	0.63	*0.13*
Jan-16	1.17	-8.96	-11.14	-13.58	-21.91	88.06	24.9	*0.83*	*15.35*	1.67	*1.45*
Feb-16	2.04	-7.63	-10.94	-14.27	-26.68	82.96	2.3	0.86	9.55	22.80	2.32
Mar-16	12.35	-0.55	-4.96	-8.72	-16.96	73.13	7.1	1.26	8.11	82.81	7.12
Apr-16	13.50	7.12	2.28	-2.23	-12.45	63.20	3.8	1.64	10.66	159.95	15.86
May-16	22.80	13.61	8.44	3.04	-1.59	54.73	14.7	1.89	11.89	210.96	25.97
Jun-16	25.98	18.36	12.88	7.17	2.27	56.52	40.0	1.76	13.37	234.99	29.78
Jul-16	23.73	17.71	13.37	9.07	1.71	73.05	63.4	1.46	12.54	173.59	17.36
Aug-16	24.42	16.67	11.92	7.82	1.22	70.86	42.2	1.50	10.69	152.32	17.72
Sep-16	17.42	10.00	5.01	0.90	-6.18	71.05	28.9	1.50	10.81	100.94	14.02
Oct-16	2.43	-3.20	-7.07	-9.99	-17.15	79.60	11.4	1.12	8.29	50.66	4.15
Nov-16	4.05	-8.20	-10.89	-13.45	-25.46	86.45	7.6	*0.80*	*9.57*	5.70	*1.99*
Dec-16	-4.20	-17.39	-19.62	-21.89	-32.16	83.76	1.3	*0.62*	*8.45*	0.56	*0.51*

Notes: *Values in grey italics indicate a partial month*

[1]January 2012 has 25 days of complete wind data
February 2012 has 28 days of complete wind data
March 2012 has 30 days of complete wind data
December 2012 has 15 days of complete wind data
January 2013 has 21 days of complete wind data
February 2013 has 26 days of complete wind data
November 2013 has 24 days of complete wind data
December 2013 has 20 days of complete wind data
January 2014 has 9 days of complete wind data
November 2014 has 23 days of complete wind data
December 2014 has 6 days of complete wind data
January 2015 has 24 days of complete wind data
August 2015 has 28 days of complete wind data
October 2015 has 29 days of complete wind data
November 2015 has 9 days of complete wind data
December 2015 has 0 days of complete wind data
January 2016 has 16 days of complete wind data
November 2016 has 23 days of complete wind data
December 2016 has 22 days of complete wind data

[2] June 2011 has 29 days of complete data (station commissioned on June 2)
[3] 16 days of complete rain data
[4] Rainfall recorded at temperatures below zero may be due to snowmelt
[5] 25 days of complete RH data
[6] 18 days of complete solar radiation data
[7] 7 days of complete evapotranspiration data
[8] Evapotranspiration is invalid where wind is invalid
[9]Total precipitation likely underestimated due to partial freezing in snowfall conversion adaptor

WIND ROSE PLOT:

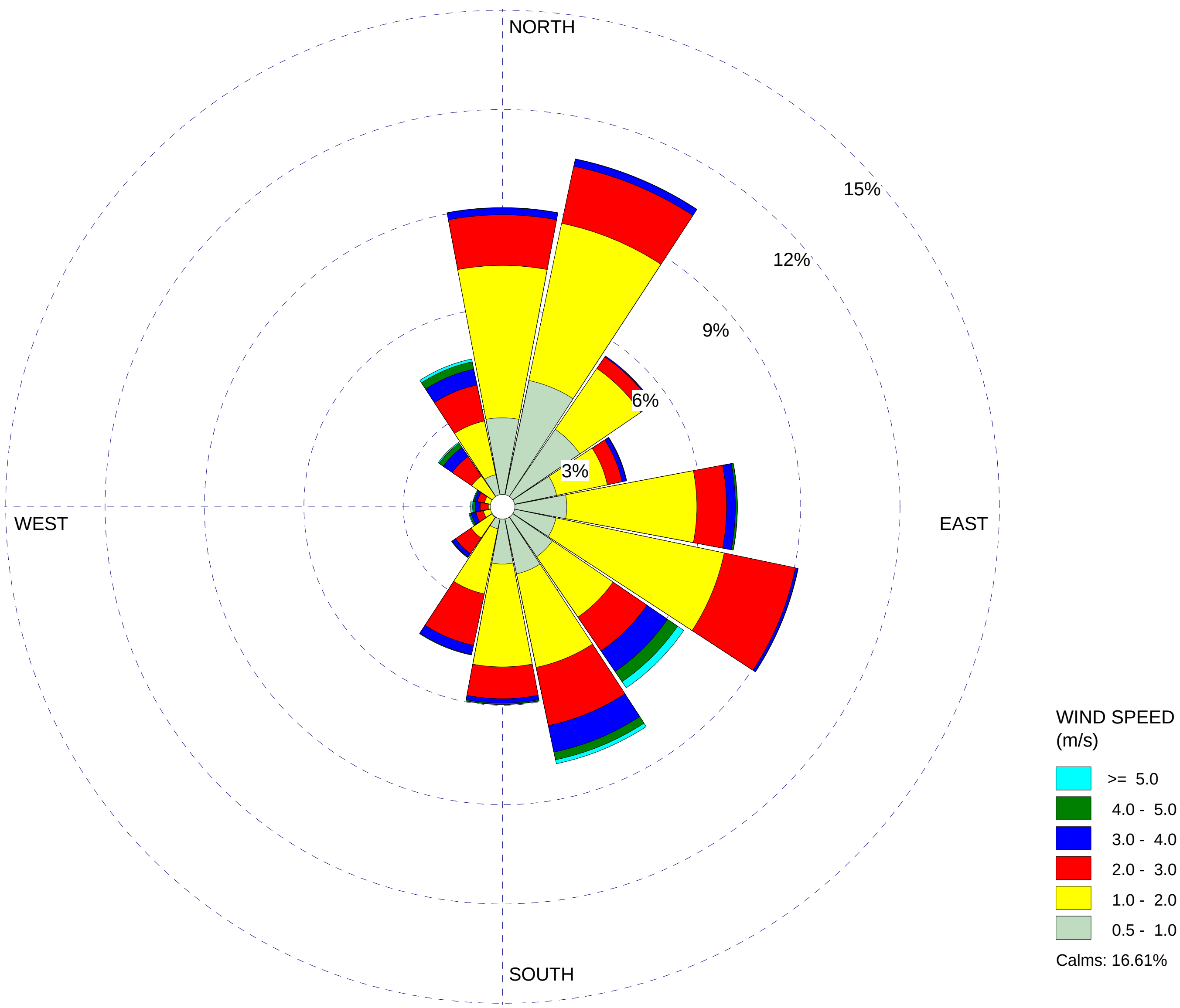
[illegible]

DISPLAY:

[illegible]

COMMENTS:

Excludes periods of ice affected or missing data.
Anemometer height: 10m



DATA PERIOD:

[illegible]

TOTAL COUNT:

[illegible]

CALM WINDS:

[illegible]

AVG. WIND SPEED:

[illegible]

COMPANY NAME:

MODELER:

DATE:

[illegible]

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Since the pyranometer was only installed in December 2012, no evapotranspiration data were calculated for 2011 or 2012. Estimates for evapotranspiration were developed previously from the 1996 data set using the computer program WREVAP developed by Environment Canada's National Hydrology Research Institute (Access, 1996). Since 2013, evapotranspiration is calculated in the datalogger program from local meteorological parameters, using the American Society of Civil Engineers (ASCE) standardized reference evapotranspiration equation (Penman-Monteith). Table 3 presents the comparison between the 2013, 2014, 2015, 2016 and the 1996 evapotranspiration data sets. It shows that the 1996 WREVAP evapotranspiration values may overestimate the local evapotranspiration, although more years of local evapotranspiration data will allow a more reliable comparison. It is interesting to note that results for 2013, 2014, 2015 and 2016 are very similar.

Table 3 Evapotranspiration Data Sets Comparison

Month	2013	2014	2015	2016	1996 WREVAP
January	*0.81*	*0.64*	*0.43*	*1.45*	0
February	*1.27*	1.99	0.86	2.32	0
March	6.33	9.17	6.29	7.12	0
April	14.48	15.77	16.03	15.86	10
May	21.70	29.81	34.67	25.97	42
June	29.79	28.58	26.46	29.78	43
July	27.10	23.84	19.98	17.36	44
August	21.38	15.72	13.87	17.72	20
September	10.88	11.56	10.12	14.02	20
October	4.26	3.39	*2.92*	4.15	0
November	*1.08*	*0.60*	*0.60*	*1.99*	0
December	*0.62*	*0.40*	*0.13*	*0.51*	0
Annual Total	**139.70**	**141.47**	**132.35**	**138.24**	**179**

** Values in grey italics indicate a partial month*

4. VALLEY TAILINGS WEATHER STATION

The Valley Tailings Onset HOBO automated meteorological station is located near the Valley Tailings at UTM coordinates: 08 V 0475799 7088130 and at an elevation of 718 masl. See Attachment A for the list of components and a photo.

4.1. OBSERVATIONS AND EQUIPMENT CONDITION

- The HOBO meteorological station was commissioned on October 19, 2012 and includes sensors for the measurement of temperature, relative humidity, rainfall, barometric pressure, soil water content, wind speed and direction at a height of 3 meters.

- The tipping bucket only records rainfall (not total precipitation). As the air temperature started to rise above 0°C in May 2013, it was noted that still no rain was being recorded. This observation triggered an inspection of the tipping bucket and the tipping mechanism was found to be obstructed. The obstruction was removed on May 16, 2013, and the tipping bucket is now functioning properly.

- The wind sensor experiences frequent icing during the winter months and extended periods of zero wind speed in combination with wind gusts of less than 1 m/s were invalidated. Similarly, extended periods with identical wind directions were also invalidated. Also, note that winter wind speeds may be underestimated due to the presence of ice on the sensor, but these occurrences cannot be detected in the data record.

- Starting on July 29, 2016, the wind direction data showed very little variability and it is suspected that results are invalid, due to a sensor or connection malfunction. The issue is currently being investigated.

- The logging interval was changed from 10 to 15 minutes on May 16, 2013, as this interval is sufficient for the purposes of this meteorological station and requires less datalogger memory.

4.2. METHODS AND RESULTS

Monthly averages from installation to December 2016 inclusively were calculated from instantaneous 10-minute or 15-minute values recorded by the datalogger for the following parameters: temperature, daily maximum temperature, daily minimum temperature, relative humidity, wind speed, gust speed, barometric pressure and solar radiation. Monthly extreme maximum temperature, extreme minimum temperature, maximum and minimum relative humidity, maximum gust speed and total rainfall are also shown in Table 4 below. Note that the barometric pressure has not been corrected for elevation and therefore represents the absolute pressure.

Table 4 Monthly Statistics for Meteorological Parameters Collected at the Valley Tailings Meteorological Station

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m²)	Soil Average Water Content (%)[4]
Oct-2012[1]	*-23.84*	*-20.12*	*-15.71*	*-9.71*	*-4.05*	*81.92*	*89.16*	*70.76*	n/a	*0.51*	*1.39*	*7.81*	*939.06*	*34.14*	n/a
Nov-2012	-40.71	-27.24	-23.77	-20.42	-8.07	82.04	90.97	69.24	n/a	*0.59*	*1.66*	*7.81*	932.15	7.72	n/a
Dec-2012	-44.20	-29.97	-26.29	-22.98	-3.99	82.75	97.20	71.67	n/a	*0.52*	*1.75*	*6.04*	926.06	1.48	n/a
Jan-2013	-45.56	-25.98	-21.58	-17.72	0.74	84.73	94.43	72.60	n/a	*0.94*	*2.10*	*14.61*	929.62	4.78	n/a
Feb-2013	-24.88	-16.72	-12.96	-8.80	2.40	90.08	96.67	81.42	n/a	*0.90*	*2.09*	*10.83*	919.93	23.70	n/a
Mar-2013	-33.45	-21.40	-13.93	-5.74	5.57	68.05	92.35	53.08	n/a	*0.84*	*2.00*	*13.85*	931.80	93.31	n/a
Apr-2013	-25.05	-14.66	-7.17	-0.87	8.37	53.23	81.57	39.58	n/a	*2.01*	*4.10*	*16.62*	930.07	171.18	n/a
May-2013	-8.36	0.10	6.08	11.66	23.35	62.90	95.00	40.13	*4.80*	*1.42*	*3.26*	*11.84*	928.76	186.87	12.3
Jun-2013	1.64	8.20	15.63	22.00	32.82	58.66	84.24	42.04	46.20	1.50	3.45	22.66	930.76	215.51	8.0
Jul-2013	1.59	8.95	15.68	21.90	29.32	60.65	87.50	38.38	25.40	1.39	3.22	16.12	931.69	194.18	6.9
Aug-2013	-1.90	6.94	13.85	20.49	29.49	68.65	95.18	44.98	43.00	*0.93*	*2.45*	*13.60*	926.92	144.34	9.6
Sep-2013	-2.45	2.00	6.39	10.85	18.06	80.70	98.19	60.89	64.80	*1.19*	*2.83*	*17.38*	921.41	71.21	14.4
Oct-2013	-11.22	-5.32	-1.54	2.56	9.11	91.89	99.04	68.02	49.40	*0.61*	*1.86*	*11.58*	927.19	32.16	12.2
Nov-2013	-42.69	-22.40	-18.25	-14.23	-0.59	88.31	99.71	75.50	0.00	*0.55*	*1.71*	*11.58*	931.23	8.07	n/a
Dec-2013	-40.38	-30.71	-27.25	-23.50	-2.48	83.73	95.83	72.42	0.00	*0.49*	*1.72*	*9.07*	936.80	1.69	n/a
Jan-2014	-37.92	-18.28	-14.50	-10.52	1.67	93.54	99.99	81.10	0.00	*0.17*	*1.96*	*6.30*	926.22	2.73	n/a
Feb-2014	-39.42	-27.88	-22.85	-14.48	-3.33	84.27	91.09	77.57	0.00	*0.34*	*1.43*	*8.31*	933.74	27.52	n/a
Mar-2014	-30.55	-20.48	-12.32	-3.50	5.85	63.32	80.35	46.47	7.00	*0.75*	*2.17*	*9.57*	928.51	103.16	n/a
Apr-2014	-20.69	-6.99	-0.45	6.19	11.52	59.76	87.11	43.10	5.00	*1.34*	*3.20*	*13.09*	923.72	152.86	n/a
May-2014	-3.24	1.34	8.66	14.54	21.94	53.49	74.94	35.74	11.40	*1.39*	*3.41*	*13.35*	931.01	201.57	17.3
Jun-2014	-0.85	6.35	12.79	18.09	28.17	56.74	87.94	38.68	56.80	1.39	3.45	15.61	926.57	206.09	14.0
Jul-2014[5]	*6.86*	*9.96*	*16.01*	*21.50*	*24.85*	*64.71*	*82.34*	*48.07*	*32.20*	*1.30*	*3.24*	*13.35*	*930.01*	*193.02*	*14.0*

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m^2)	Soil Average Water Content (%)[4]
Aug-2014 [5]									Station Down – No data						
Sep-2014 [5]															
Oct-2014 [5]	-17.47	-12.34	-7.87	-4.47	-1.47	93.68	95.52	90.51	0.00	0.69	1.93	7.05	923.44	16.88	n/a
Nov-2014	-35.71	-18.96	-15.69	-12.75	-2.25	89.63	99.47	80.36	0.00	0.75	2.09	8.06	932.50	8.54	n/a
Dec-2014	-29.59	-18.70	-15.22	-12.12	-1.73	92.55	98.58	85.41	0.00	0.59	1.93	10.32	924.68	1.53	n/a
Jan-2015	-41.27	-22.34	-19.15	-15.78	-0.14	90.13	99.54	78.03	0.00	0.32	1.68	9.07	932.43	2.93	n/a
Feb-2015	-41.50	-21.41	-17.51	-12.68	3.85	89.56	99.96	78.51	13.60	0.46	1.80	12.34	935.86	22.75	n/a
Mar-2015	-31.12	-16.89	-10.20	-3.39	6.84	75.01	91.08	58.48	3.20	1.00	2.33	13.35	927.14	84.81	n/a
Apr-2015	-11.15	-4.79	1.23	7.51	12.53	64.06	88.56	50.40	13.80	1.45	3.36	12.84	921.78	153.92	n/a
May-2015	-6.99	3.25	11.76	18.45	27.55	48.65	67.29	33.82	6.00	1.43	3.41	17.12	932.37	235.70	21.4
Jun-2015	1.24	5.77	12.99	19.00	25.82	59.92	81.85	34.81	27.20	1.48	3.49	16.62	929.55	213.66	13.1
Jul-2015	4.14	7.64	13.90	19.65	27.16	69.15	93.72	43.99	82.60	1.05	2.63	10.83	927.71	180.54	17.2
Aug-2015	-2.57	4.53	10.52	15.76	25.84	76.20	95.53	54.67	69.20	1.01	2.48	10.83	927.00	138.77	20.2
Sep-2015	-8.10	-0.86	3.67	8.66	16.03	81.30	93.24	61.31	42.60	1.29	2.97	21.40	923.36	80.01	20.7
Oct-2015	-12.79	-4.25	-1.37	1.63	7.70	91.95	99.99	65.89	14.00	0.75	2.01	8.56	924.77	33.28	8.6
Nov-2015	-36.15	-18.71	-14.44	-10.89	2.64	92.87	99.34	82.48	0.00	0.40	1.71	7.05	921.85	6.59	n/a
Dec-2015	-33.38	-18.58	-15.58	-12.85	3.01	92.73	97.50	83.71	0.00	0.46	2.12	11.84	919.23	1.26	n/a
Jan-2016	-26.91	-16.61	-13.08	-10.02	4.17	91.42	98.22	78.66	0.00	0.69	2.08	17.38	922.28	4.92	n/a
Feb-2016	-34.26	-17.54	-12.62	-7.02	2.96	89.23	97.60	79.77	2.00	0.49	1.71	9.82	924.51	26.62	n/a
Mar-2016	-15.91	-9.95	-4.83	0.67	13.83	76.08	94.59	62.59	4.80	1.34	2.86	9.82	922.88	80.42	n/a
Apr-2016	-10.97	-2.76	2.77	8.43	15.25	65.43	92.00	46.16	3.20	1.53	3.40	14.10	925.77	151.79	6.8
May-2016	-2.10	2.56	9.64	15.44	23.88	56.10	83.81	36.95	16.40	1.66	3.66	15.11	931.02	205.21	25.5
Jun-2016	3.01	7.16	14.43	20.48	27.53	55.89	88.06	36.60	40.40	1.63	3.64	15.11	927.96	233.69	21.6

Month	Extreme Minimum Temp.(°C)	Average Minimum Temp. (°C)	Average Temp. (°C)	Average Maximum Temp. (°C)	Extreme Maximum Temp. (°C)	Average Relative Humidity (%)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)	Total Rain (mm)[2]	Average Wind Speed (m/s)[3]	Average Maximum Wind Speed (m/s)[3]	Extreme Maximum Wind Speed (m/s)[3]	Average Barometric Pressure (mbar)	Average Solar Radiation (W/m^2)	Soil Average Water Content (%)[4]
Jul-2016	0.63	9.33	14.84	20.11	26.92	73.54	93.34	54.86	67.20	1.08	2.67	11.84	929.36	173.57	23.9
Aug-2016	-1.47	7.05	12.77	18.13	24.80	73.62	94.25	58.18	45.80	1.15	2.75	15.11	932.57	146.43	23.6
Sep-2016	-6.14	0.03	5.67	11.48	18.11	73.70	94.96	34.79	39.40	*0.96*	*2.56*	*14.86*	927.36	98.46	23.4
Oct-2016	-22.37	-11.82	-7.27	-1.85	5.00	84.13	97.87	63.33	0.60	*0.57*	*1.77*	*9.32*	929.65	47.00	5.2
Nov-2016	-32.83	-17.19	-13.41	-9.77	5.62	90.97	99.91	74.28	6.80	*0.49*	*1.84*	*10.83*	919.86	6.43	1.0
Dec-2016	-39.74	-25.23	-21.84	-18.83	-3.42	87.07	96.70	76.06	0.00	*0.43*	*1.68*	*6.55*	931.27	1.78	0.2

Notes: *Values in grey italics indicate a partial month*

[1] Station was commissioned on October 19 so October 2012 has 12 days of complete data

[2] May2013 has 14 days of compete rain data

[3] October 2012 has 2 days of complete and 11 days of partial wind data
November 2012 has 5 days of complete and 24 days of partial wind data
December 2012 has 2 days of complete and 16 days of partial wind data and
January 2013 has 5 days of complete and 16 days of partial wind data
February 2013 has 2 days of complete and 26 days of partial wind data
March 2013 has 4 days of complete and 27 days of partial wind data
April 2013 has 14 days of complete and 16 days of partial wind data
May 2013 has 15 days of complete and 16 days of partial wind data
June 2013 has 29 days of complete and 1 day of partial wind data
August 2013 has 29 days of complete and 2 days of partial wind data
September 2013 has 15 days of complete and 15 days of partial wind data
October 2013 has 6 days of complete and 25 days of partial wind data
November 2013 has 1 day of complete and 28 days of partial wind data
December 2013 has 2 days of complete and 23 days of partial wind data
January 2014 has 0 days of complete and 12 days of partial wind data
February 2014 has 0 days of complete and 13 days of partial wind data
March 2014 has 1 days of complete and 30 days of partial wind data
April 2014 has 10 days of complete and 20 days of partial wind data
May 2014 has 21 days of complete and 10 days of partial wind data
December 2014 has 3 days of complete and 12 days of partial wind data
January 2015 has 0 days of complete and 14 days of partial wind data

February 2015 has 1 day of complete and 17 days of partial wind data
March 2015 has 5 days of complete and 26 days of partial wind data
April 2015 has 12 days of complete and 18 days of partial wind data
May 2015 has 27 days of complete and 4 days of partial wind data
August 2015 has 29 days of complete and 2 days of partial wind data
September 2015 has 14 days of complete and 16 days of partial wind data
October 2015 has 12 days of complete and 19 days of partial wind data
November 2015 has 1 day of complete and 23 days of partial wind data
December 2015 has 0 day of complete and 9 days of partial wind data
January 2016 has 4 days of complete and 19 days of partial wind data
February 2016 has 2 days of complete and 17 days of partial wind data
March 2016 has 8 days of complete and 23 days of partial wind data
April 2016 has 22 days of complete and 4 days of partial wind data
May 2016 has 30 days of complete and 1 day of partial wind data
September 2016 has 22 days of complete and 8 days of partial wind data
October 2016 has 4 days of complete and 27 days of partial wind data
November 2016 has 3 days of complete and 11 days of partial wind data
December 2016 has 0 day of complete and 18 days of partial wind data
[4] *Negative values reported from Oct 2012 to April 2013, from Nov 2013 to Apr 2014, from Oct 2014 to Apr 2015 and from Nov 2015 to March 2016 were invalidated – soil assumed to be frozen*
[5] *Station was down between July 16 and October 26, 2014*

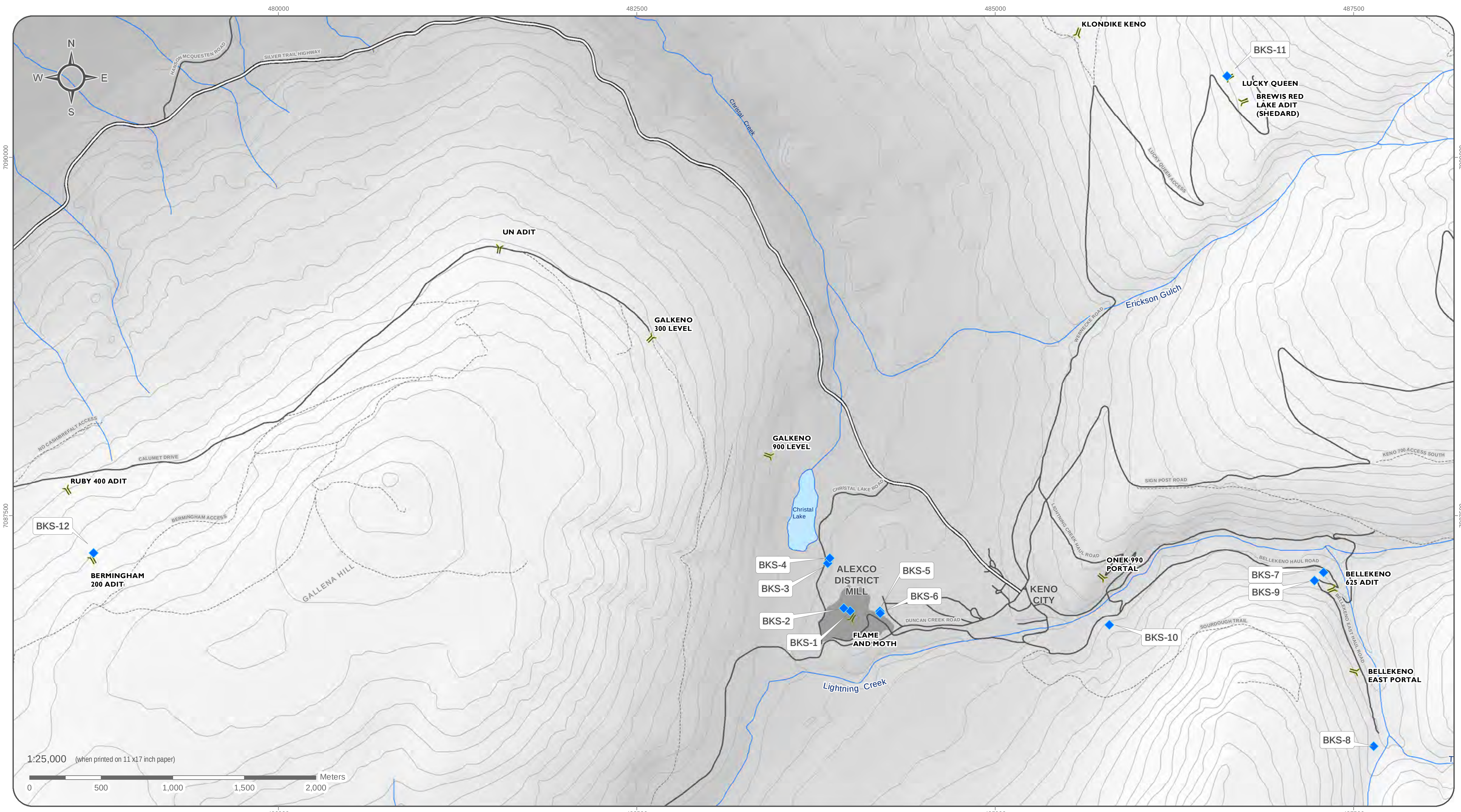
5. SNOW SURVEYS

Alexco has been conducting manual snow surveys since 2011 at ten monitoring stations in order to adequately represent the varying snow conditions as a function of aspect, elevation, etc. In 2016, surveys were conducted on January 30, March 2 and April 5. Snow water equivalent (SWE) results are presented in Table 5 below and the station locations are shown of Figure 3. Figure 4 presents the average snow water equivalent (SWE) across all stations.

Table 5 Snow Survey SWE Results (cm)

Station	Description	Jan 2011	Feb 2011	Mar 2011	Jan 2012	Feb 2012	Mar 2012	Apr 2012	Jan 2013	Feb 2013	Mar 2013	Apr 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	Feb 2015	Mar 2015	Apr 2015	Feb 2016	Mar 2016	April 2016
BKS-1	tall spruce up hill near dry stack	7.6	7.6	5.1	6.0	16.1	18.7	8.7	7.3	11.3	13.0	15.0	12.3	14.0	12.3	9.7	8.0	9.3	8.7	4.0	8.7	7.7
BKS-2	log pile near dry stack	7.6	7.6	7.6	12.2	13.6	9.3	20.8	9.3	10.7	11.7	13.8	10.3	10.7	10.0	7.7	9.0	10.3	9.0	8.0	11.0	10.3
BKS-3	Between 1 and 2 marker on CLR road	7.6	10.2	7.6	9.6	12.5	4.4	7.7	7.3	10.0	14.3	14.7	13.0	12.3	11.0	9.7	9.3	7.0	10.7	8.0	9.3	10.7
BKS-4	down road from BKS 3, closer to #2 CLR marker	7.6	7.6	7.6	8.5	17.6	12.3	8.8	9.3	11.7	18.3	14.3	12.7	12.0	11.7	7.3	3.7	8.7	7.3	10.0	8.7	12.3
BKS-5.0	Keno dump area. Near scrub trees	5.1	7.6	5.1	13.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BKS-5.1	Keno dump area. Near scrub trees	-	-	-	-	11.3	12.2	9.6	6.7	9.7	13.3	13.0	11.0	12.0	10.7	8.7	8.3	10.7	12.0	10.0	8.7	10.7
BKS-6	Keno dump area. On sloping hillside	2.5	2.5	0	11.2	12.6	14.8	19.8	6.7	9.2	12.0	11.3	10.7	10.3	8.7	8.3	7.3	8.7	9.0	8.0	8.0	8.3
BKS-7	Uphill from Bellekeno treatment pond	7.6	10.2	7.6	12.5	13.6	4.8	8.5	6.7	11.0	10.3	13.7	13.3	13.0	13.0	10.0	9.0	12.7	14.0	7.3	7.0	11.3
BKS-8	Far end of Bellekeno East. Nr explosive storage shed	7.6	7.6	5.1	9.9	13.8	17.6	19.5	8.0	10.0	18.5	19.7	9.3	12.7	12.7	10.7	6.7	17.0	12.3	7.3	9.3	-
BKS-9	At BKR 16 marker. Slightly up on hillside	7.6	10.2	10.2	12.4	13.3	17.1	0.00	7.3	10.0	15.0	14.0	12.3	11.7	11.3	9.0	7.7	10.7	8.3	7.3	7.0	0.0

Station	Description	Jan 2011	Feb 2011	Mar 2011	Jan 2012	Feb 2012	Mar 2012	Apr 2012	Jan 2013	Feb 2013	Mar 2013	Apr 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	Feb 2015	Mar 2015	Apr 2015	Feb 2016	Mar 2016	April 2016
BKS-10	Near BKR 8 pull out. Up on hillside	10.1	7.6	5.1	13.3	16.5	27.7	10.7	9.3	10.0	12.3	14.3	14.0	15.7	14.3	7.0	10.0	10.0	12.0	10.7	6.0	11.7
BKS-11	Lucky Queen, upslope of the pond	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.3	20.7	15.0
BKS-12	East of Bermingham 200 adit, Upslope of road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.3
Mean	-	7.1	7.9	6.1	10.9	14.1	13.9	11.4	7.8	10.4	13.9	14.4	11.9	12.4	11.6	8.8	7.9	10.5	10.3	8.1	8.4	9.8



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

Quartz claim boundaries current as of February 24th, 2011. Ownership data current as of December 20th, 2010. Data source: http://geomaticsyukon.ca.

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

Snow Monitoring Station	Silver Trail Highway	Contours (100 ft)
Adit	Other Road	Watercourse
	Limited-Use Road	Waterbody

ERDC

AEG

ENVIRONMENTAL CONDITION REPORT

FIGURE 3

SNOW SURVEY STATIONS LOCATION

JANUARY 2017

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\SpecifcTopics\Monitoring\Snow Monitoring\SnowMonitoring_20170126.mxd
(*Last edited by: mducharme; 1/26/2017/07:54 AM*)

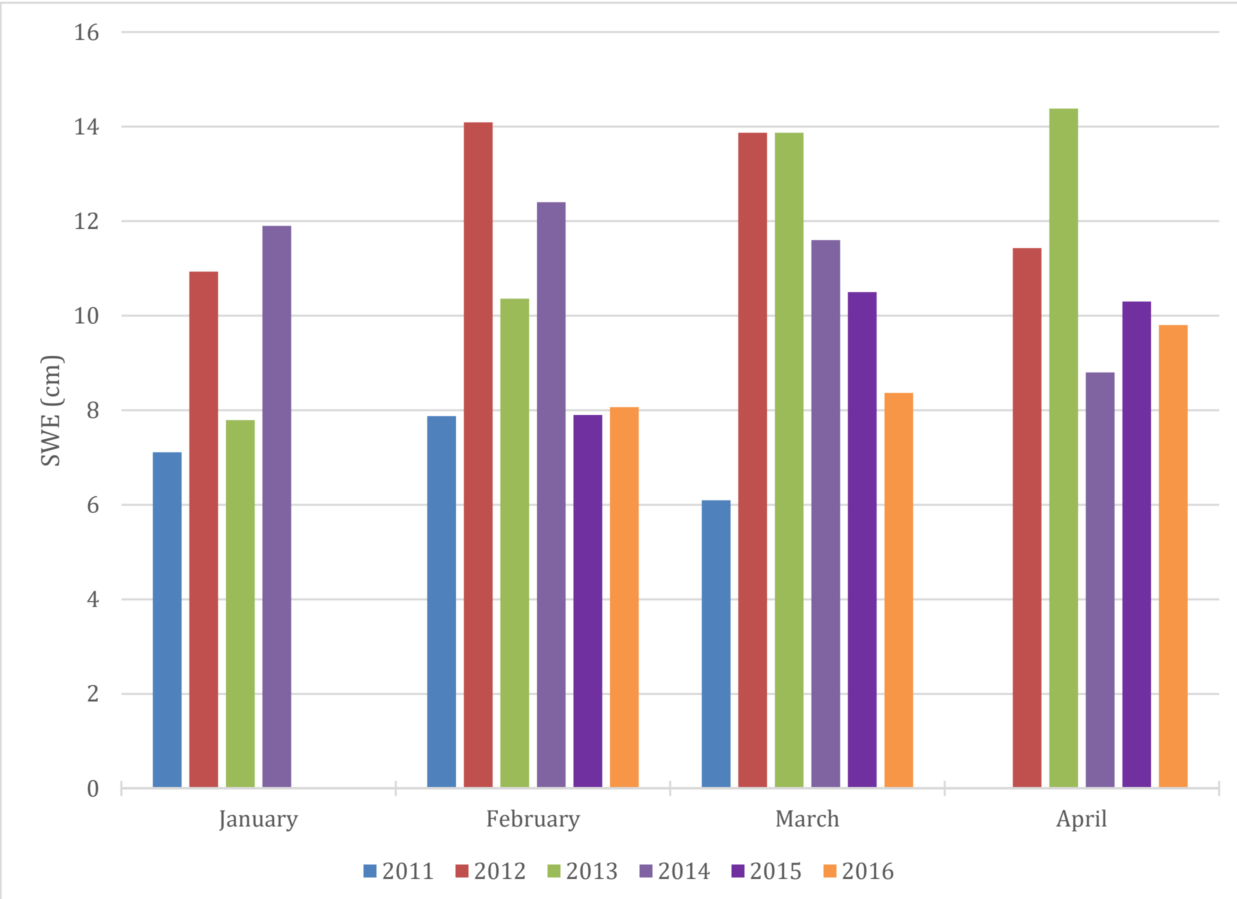


Figure 4 Average Snow Water Equivalent across all Snow Survey Stations

6. MEAN ANNUAL PRECIPITATION (MAP)

Mean annual precipitation (MAP) within a mountainous region typically increases with increasing elevation. The significant relief over which the Keno Hill area spans is well represented by two historical weather stations with Elsa at 814 masl and the Keno Hill weather station at 1472 masl. In 1996, Clearwater Consultants Ltd. used data from these two stations as well as from Environment Canada's station located at Mayo airport (504 masl.) to derive a relationship between MAP and elevation. Assuming a linear relationship, a line was fitted to the data of these stations (see Figure 5) (Access, 1996). The slope of this line indicates that MAP increases by an average of 27 mm for every 100 m of ascent, a value not too dissimilar from that observed in other regions of the Yukon interior.

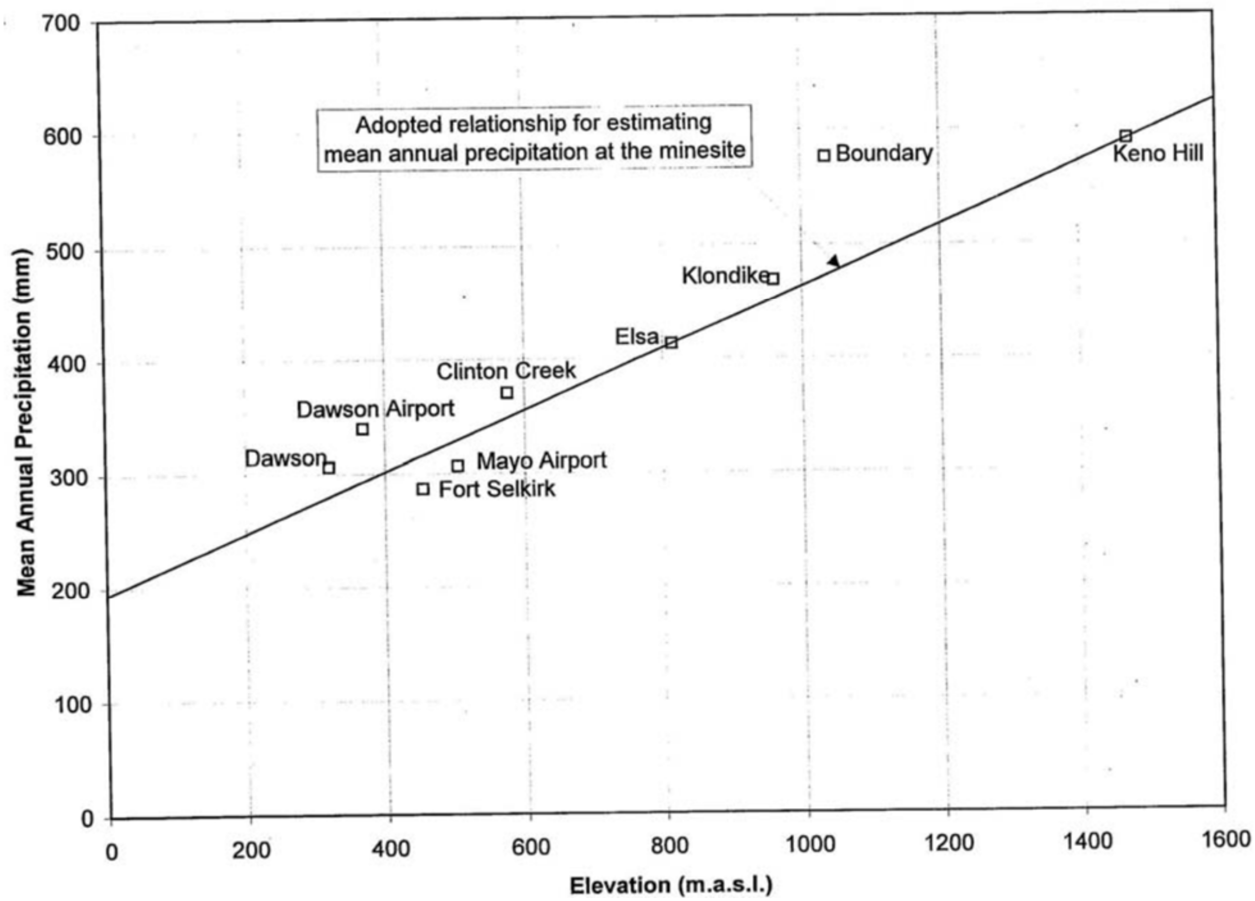


Figure 5 Mean Annual Precipitation as a Function of Elevation

As with MAP, the seasonal distribution is influenced by elevation. To demonstrate this influence, the seasonal distributions for Mayo Airport, Elsa, and Keno Hill have been plotted on Figure 6, as part of the same assessment conducted by Clearwater Consultants in 1996. The proportion of total precipitation which falls as rain decreases as elevation increases (60% of total precipitation at Mayo Airport, 53% at Elsa, and 41% at Keno Hill). Again, a simple linear relationship can be derived and the slope indicates that the proportion of total precipitation that falls as rain decreases by about 2% for every 100 m ascent.

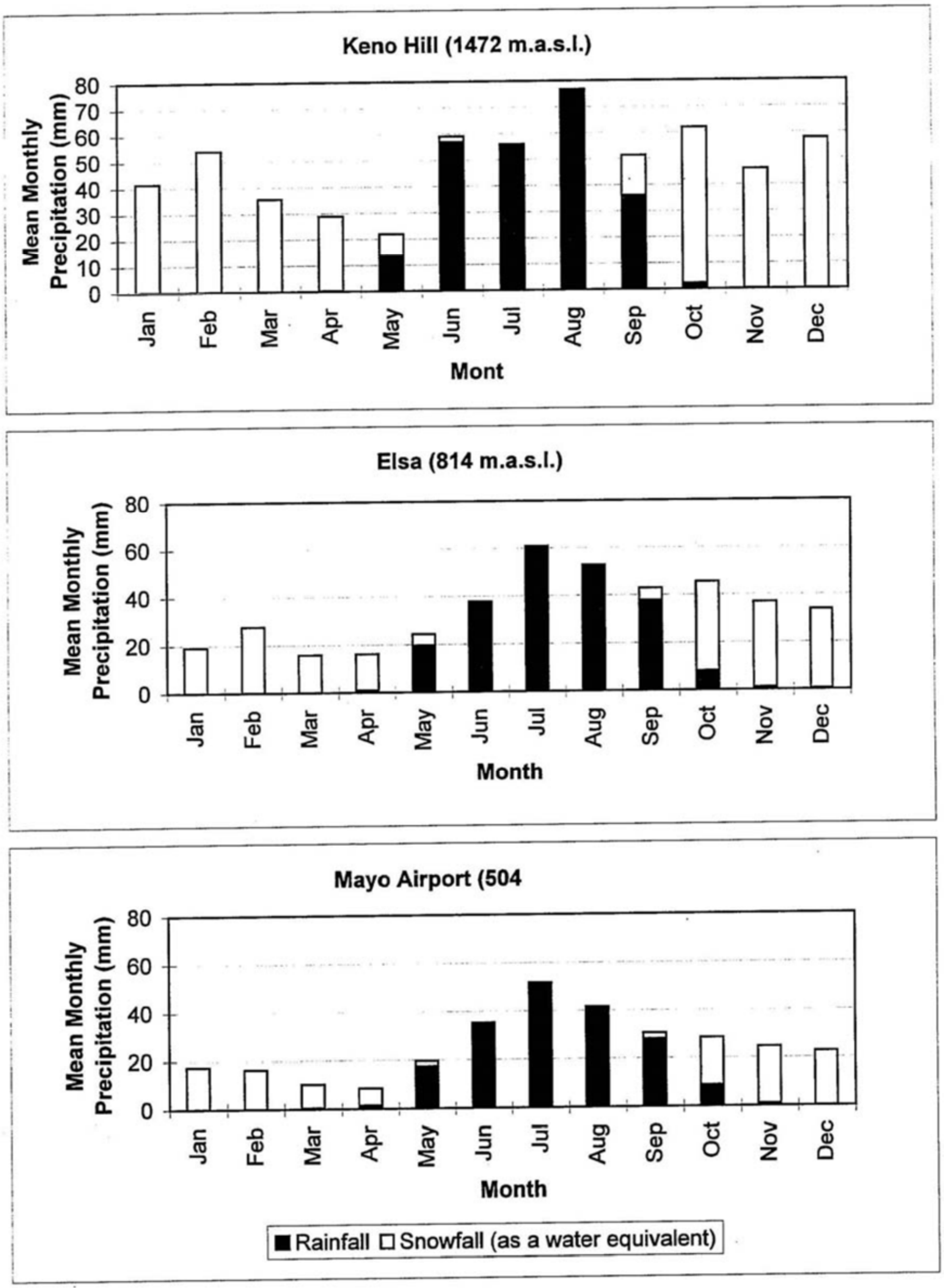


Figure 6 Mean Monthly Precipitation

Recent precipitation data from Mayo A, Calumet, District Mill and the Valley Tailings weather stations were used to verify the empirical relationships presented above. Validated precipitation data at Mayo A are available until the end of 2016, with the exception of the year 2013, which is missing, therefore, the common periods with Calumet station (2007-2016), with the District Mill station (2012-2016) and the valley Tailings (2014-2016) were used for this comparison. Mayo A reports both rain and total precipitation, while Galena Hill and the Valley Tailings weather stations record rainfall only. The District Mill weather station recorded rainfall only in 2012 and 2013 and total precipitation in 2014 and 2015. Table 6 presents the proportion of total precipitation that fell as rain for the 2007-2016 period at Mayo A.

Table 6 Annual Precipitation at Mayo A, 2007-2015

	Total Rain (mm)	Total Snow (cm)	Total Precipitation (mm)	% rain
2007	217.2	188.4	345.8	62.8
2008	309.3	157.8	429.3	72.0
2009	186.9	181.6	304.3	61.4
2010	198.1	129.8	293.7	67.4
2011	329.5	164.9	452.9	72.8
2012	171.7	158.4	276.1	62.2
2013	n/a			
2014	259.4	69.4	376.3	68.9
2015	133.9	123.5	393.4	34.0
2016	245.5	124.2	316	77.7
AVG	**227.9**	**144.2**	**354.2**	**64.4**

For this 9-year period, the average proportion of total precipitation that fell as rain was 64.4%, which is slightly higher than the original estimate of 60%. Since the value of 60% was estimated using data collected between 1974 and 1982, it is possible that the proportion of total precipitation falling as rain has increased with the warming temperature trend. Figure 7 shows the temperature trend at Mayo A since 1925; maximum, minimum and mean temperatures recorded over the 1925 to 2010 time period all show an increasing trend.

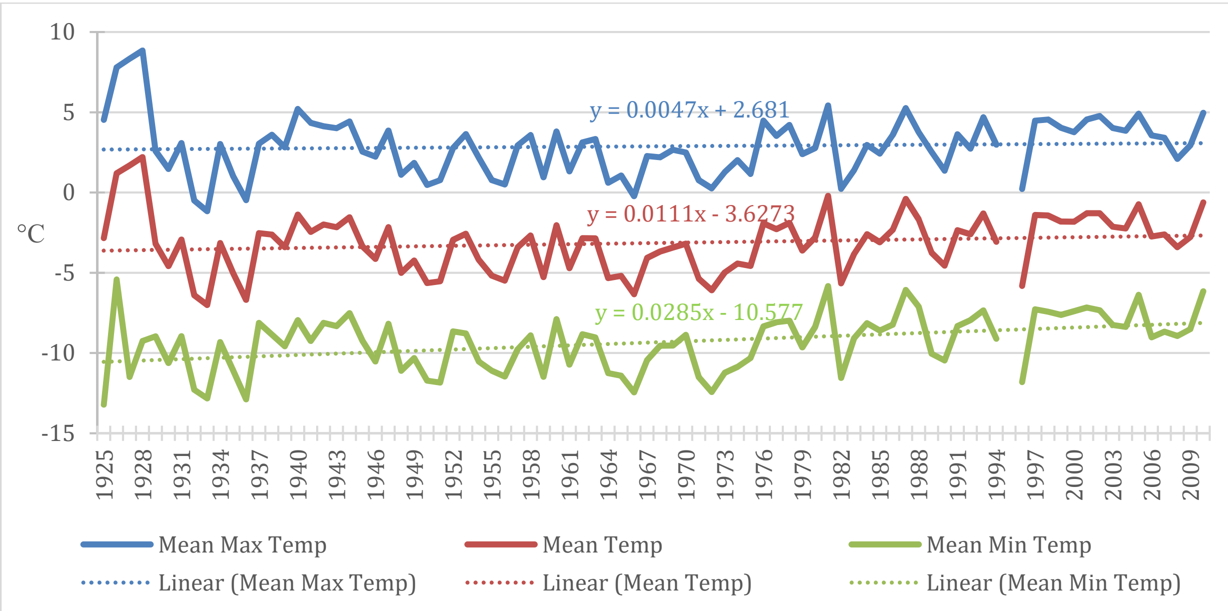


Figure 7 Mayo A Annual Temperatures, 1925-2010

Assuming the empirical linear relationship where the proportion of total precipitation that falls as rain decreases by about 2% for every 100 m ascent, it is expected that 45.2% of total precipitation falls as rain at Calumet, 54.1% at the District Mill and 58.4% at the Valley Tailings station. Since total precipitation was not measured at Galena Hill, Valley Tailings nor at the District Mill in 2012, this assumption was used to verify the linear relationship between MAP and elevation developed by Clearwater. Based on Mayo A annual total precipitation from 2007 to 2016 (Table 6), predicted total rainfall is compared to total rainfall measured at Galena Hill and the District Mill (Table 7). Note that Galena Hill observed rainfall data for 2016 are largely incomplete (see Table 1 for details) and that year was therefore not included in the comparison below.

Table 7 Predicted Versus Measured Total Rain (mm)

Year	Predicted Annual Total Precipitation (mm)	Predicted Total Rain (mm)	Measured Total Rain (mm)	Actual – Predicted (mm)	Difference (%)
Calumet (1380 masl)					
2007	582.3	263.1	*276.4*	13.3	4.8
2008	665.8	300.8	363.6	62.8	17.3
2009	540.8	244.3	*196.4*	-48.0	-24.4
2010	530.2	239.6	462.2	222.7	48.2
2011	689.4	311.5	*305.5*	-6.0	-2.0
2012	512.6	231.6	*137.0*	-94.6	-69.0
2013	n/a				
2014	612.8	276.9	264.4	-12.5	-4.7
2015	629.9	284.6	*339.7*	55.1	16.2
AVG	**595.5**	**269.0**	**293.1**	**24.1**	**-1.7**

Year	Predicted Annual Total Precipitation (mm)	Predicted Total Rain (mm)	Measured Total Rain (mm)	Actual – Predicted (mm)	Difference (%)
District Mill (936 masl)					
2012	419.5	226.8	217.5	-9.3	-4.3
2013	n/a				
2014	519.7	n/a	292.6**	-227.1	-77.6
2015	536.8	n/a	296.9**	-239.9	-80.8
2016	459.4	n/a	277.7**	-181.7	-65.4
AVG	**483.8**	**226.8**	**271.2**	**-164.5**	**-57.0**
Valley Tailings (718 masl)					
2014	460.8	269.2	*112.4*	-156.8	-139.5
2015	477.9	279.2	272.2	-7.0	-2.6
2016	400.5	234.0	226.6	-7.4	-3.3
AVG	**446.4**	**260.8**	**203.7**	**-57.1**	**-48.4**

**Values in grey italics indicate a partial total*
*** Measured total precipitation, corrected for winter undercatch and wind defelction*

Note that some years have incomplete rain data at Calumet (refer to Table 1 for specific details) and Valley Tailings, and this could explain the negative difference between actual and predicted rainfall in 2009 and 2012 at Calumet and 2014 at the Valley Tailings. In other cases however, the difference is positive even though the Calumet data set in incomplete (e.g. 2015). For the three years where the Calumet dataset is complete, the difference between actual and predicted total rainfall is positive for 2008 and 2010, and negative for 2014. The average difference between actual and predicted for those three years is positive (20.2%), implying that the linear relationship between MAP and elevation developed by Clearwater might underestimate total precipitation increase with elevation. A confounding factor is the assumed relationship between the proportion of total precipitation that falls as rain and elevation, which may also need to be refined. At the Valley Tailings station, the 2015 and 2016 dataset are complete and actual versus predicted rainfall are relatively similar (-2.6% and -3.3% difference respectively).

In the case of the District Mill, there is good agreement between predicted and measured total rain for the year 2012. In 2014, 2015 and 2016 however, comparison is made for total precipitation since a snowfall conversion adaptor was installed in 2013. In that case, the measured amount is considerably less than the predicted amount, indicating probable under catch of the snowfall conversion adaptor. Literature reports a cumulative winter catch efficiency of 0.66 for a Campbell Scientific TE525 tipping bucket gauge with a CS705 snow fall adaptor and alter screen (MacDonald and Pomeroy, 2007). Total precipitation data (2014-2016) from October through April were therefore corrected using this factor. Also, because the use of an alter screen for wind deflection has a documented improvement of 10 to 16% in snow collection efficiency and 6% to 10% for all types of precipitation (Belfort Instrument, 2013), average correction factors of 8% and 13% for summer and winter months respectively were applied to precipitation data collected prior to the installation of the alter screen in June 2015. Corrected total precipitation data are still below the values predicted from the MAP-elevation relationship, suggesting that the snowfall undercatch might be greater at this site than the average value reported in the literature, or that there is uncertainty in the MAP-elevation relationship. Refinement of the MAP-elevation relationship derived by Clearwater will be possible as more years of data become available at Galena Hill and at the District Mill, and as total precipitation data become available at the District Mill weather station.

7. REFERENCES

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

Belfort Instrument. 2013. Reducing Precipitation Gauge Inconsistencies Using Modern Wind Deflection Methodologies.

MacDonald, Jimmy P. and John W. Pomeroy. 2007. Gauge Undercatch of Two Snowfall Gauges in a Prairie Environment. 64th Eastern Snow Conference. St. John's, Newfoundland, Canada, 2007.

ATTACHMENT A: METEOROLOGICAL STATIONS COMPONENTS

Galena Hill HOBO Meteorological Station

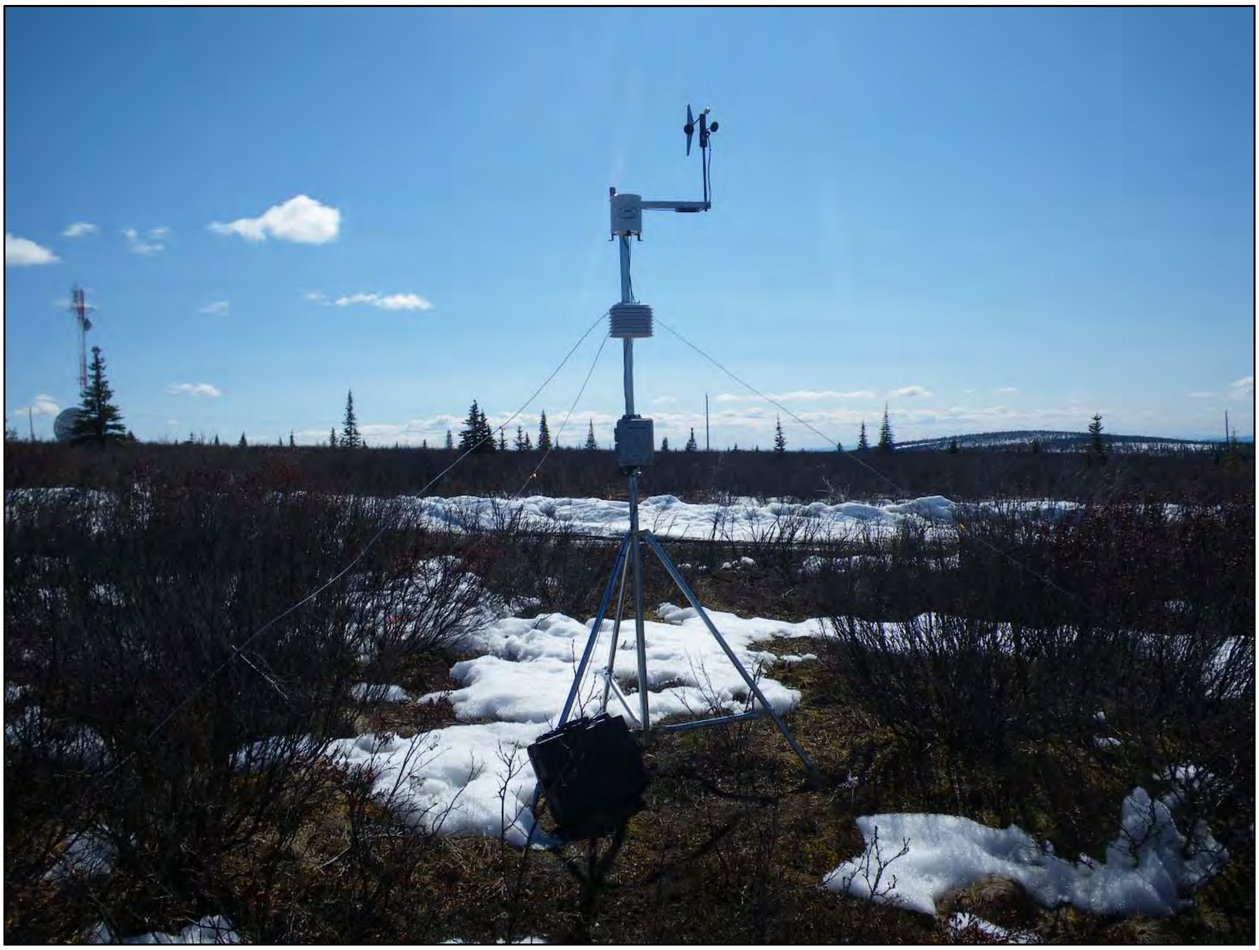
Component	Model	Serial Number
Datalogger	HOBO Weather Logger	1153440
Temp & RH Sensor	S-THB-XXXX	10064003
Soil Temp Sensor	S-TMB-XXXX	985390
Pyranometer	S-LIB-XXXX	1048627
Rain Gauge	S-RGB-M002	1017667
Wind Speed & Direction Sensor	S-WCA-XXXX	1254995
BP Sensor	S-BPA-XXXX	1037089

District Mill Campbell Scientific Meteorological Station

Component	Model	Serial Number
Air Temperature and Relative Humidity Sensor	HMP45C212	n/a
Tipping Bucket Rain Gauge	TE525M	45303-910
Wind Speed and Direction Sensor	05103AP-10-L	WM105907
Solar Panel	SX320J	T21008289B30EC8
Datalogger	CR800	16119
Battery	PS-12120 F2	06299-HC
Pyranometer	SP Lite2	125766

Valley Tailings HOBO Meteorological Station

Component	Model	Serial Number
Datalogger	U30 NRC	10231016
Input Expander kit		
Solar Panel	6W	
AC Power Adaptor	120V - 60Hz	
HOBOware	Pro	2580 2976 6309 4793
Temp & RH Sensor	THB-M002	10220040
Solar Radiation Shield	RS3	
Pyranometer	LIB-M003	10191222
Rain Gauge	RGB-M002	10222664
Light Sensor Bracket	LBB	
Light Sensor Level	LLA	
Wind Speed & Direction Sensor	WSET-A	10233230
Full Cross Arm	CAA	
BP Sensor	BPB-CM50	10212093
Soil Moisture Sensor	SMC-M005	10225679
Tripod	TPA-KIT 3m	



Galena Hill HOBO Meteorological Station

District Mill Campbell Scientific Meteorological Station

Valley Tailings HOBO Meteorological Station

APPENDIX 3
ENGINEERING SUPPORTING DOCUMENTS

APPENDIX 3.1
ENGINEERING DESIGN PACKAGE

Sheet List	
Sheet Number	Sheet Title
AKHM-13-01-G-0000	Sheet List
AKHM-13-01-S-0301	Rock Pile Portal Closure
AKHM-13-01-S-0302	Bulkhead Closure
AKHM-13-01-S-0303	Shaft Cap
AKHM-13-01-B-0301	Road Reclamation - typ.
AKHM-13-01-D-2102	Bellekeno Bioreactor
AKHM-13-01-D-2301	BioReactor Sections
AKHM-13-01-D-2601	Bellekeno P&ID
Reclamation Measures	
AKHM-13-01-C-1401	Flame & Moth Reclaim Measures
AKHM-13-01-C-2401	Bellekeno East Relcaim Measures
AKHM-13-01-C-2402	Bellekeno 625 Relcaim Measures
AKHM-13-01-C-3401	Lucky Queen Relcaim Measures
AKHM-13-01-C-4401	Onek Relcaim Measures
AKHM-13-01-C-5401	Bermingham Relcaim Measures
AKHM-13-01-C-6401	Mill Site Relcaim Measures
AKHM-13-01-C-7401	DSTF Relcaim Measures
AKHM-13-01-C-8401	Sludge Pond Relcaim Measures
AKHM-13-01-C-9401	Flat Creek Camp Relcaim Measures
Final Grading Details	
AKHM-13-01-B-2101	Bellekeno East Grading Plan
AKHM-13-01-B-2102	Bellekeno 625 Grading Plan
AKHM-13-01-B-3101	Lucky Queen Grading Plan
AKHM-13-01-B-3301	Lucky Queen Grading Sections
AKHM-13-01-B-4101	Onek Grading Plan
AKHM-13-01-B-4301	Onek Grading Sections
AKHM-13-01-B-5101	Bermingham Grading Plan
AKHM-13-01-B-5301	Bermingham Grading Section
AKHM-13-01-B-6101	Mill Site Grading Plan
AKHM-13-01-B-6301	Mill Grading Sections
AKHM-13-01-B-9101	Flat Creek Camp Grading
AKHM-13-01-B-9301	Flat Creek Camp Sections

Sheet Naming convention

A-1234
A = Discipline
1 = Site
2 = Sheet Type
3,4 = Sequential Number

Disciplines
G = General
H = Hazardous Materials
V = Survey/Mapping
B = Geotechnical
C = Civil
L = Landscape
S = Structural
A = Architectural
I = Interiors
Q = Equipment
F = Fire Protection
P = Plumbing
D = Process
M = Mechanical
E = Electrical
W = Distributed Energy
T = Telecommunications
R = Resource
X = Other Disciplines
Z = Contractor/Shop Drawings
O = Operations

Sites
0 = General (Not site specific)
1 = Flame & Moth
2 = Bellekeno
3 = Lucky Queen
4 = Onek
5 = Bermingham
6 = Mill Site
7 = DSTF
8 = KHSD Sludge Pond
9 = Flat Creek Camp

Sheet Types
1 = Plans (Horizontal Views)
2 = Elevations (Vertical Views)
3 = Sections (Sectional Views)
4 = Large Scale Views (Plans, Sections & Elevations that are not Details)
5 = Details
6 = Schedules and Diagrams
7 = User Defined
8 = User Defined
9 = 3D Representations (Isometrics, Perspectives and Photographs)

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-G-0000

Sheet List

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

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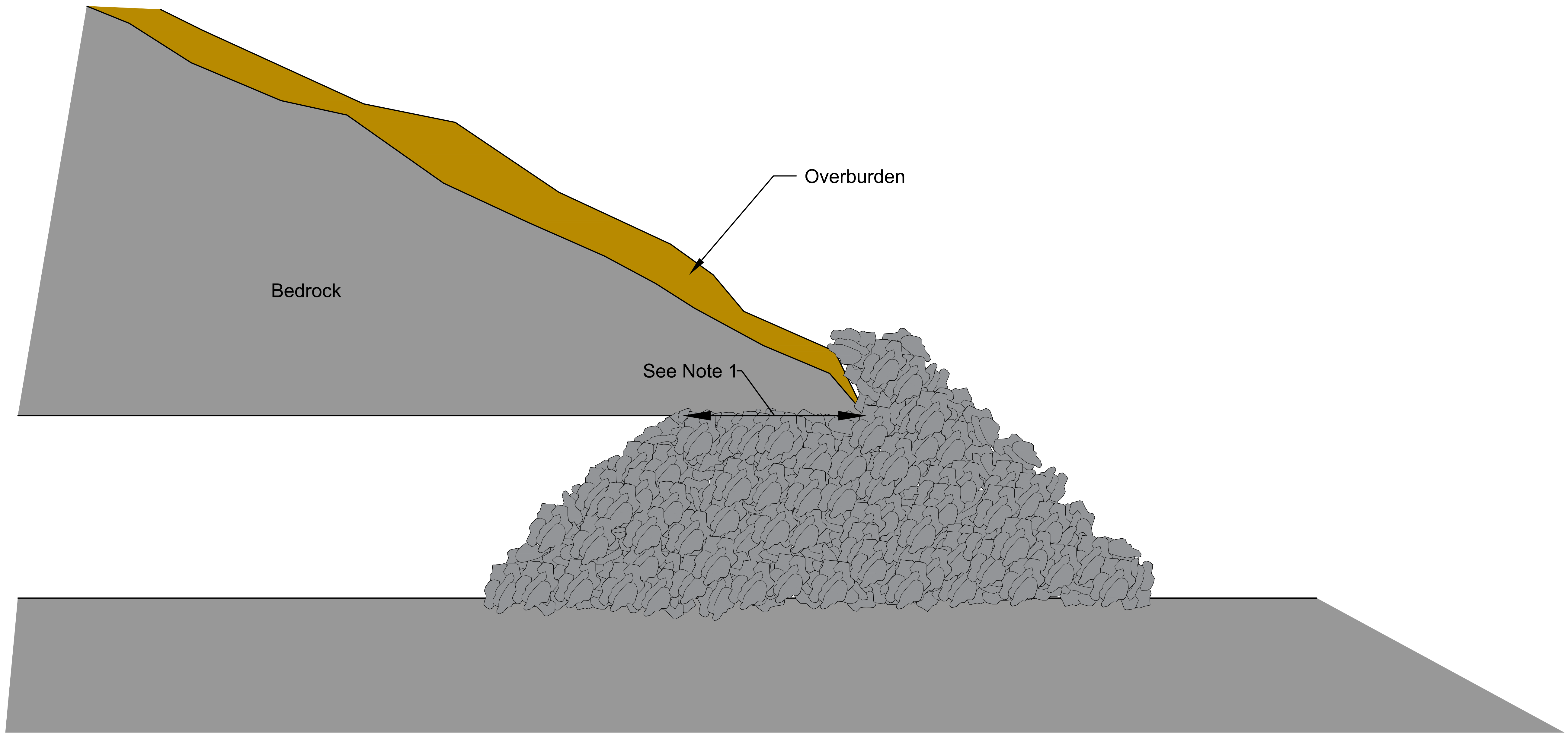

Notes:

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

Not to scale

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

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

Portal Closure
Typical Rock Pile Closure Design

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

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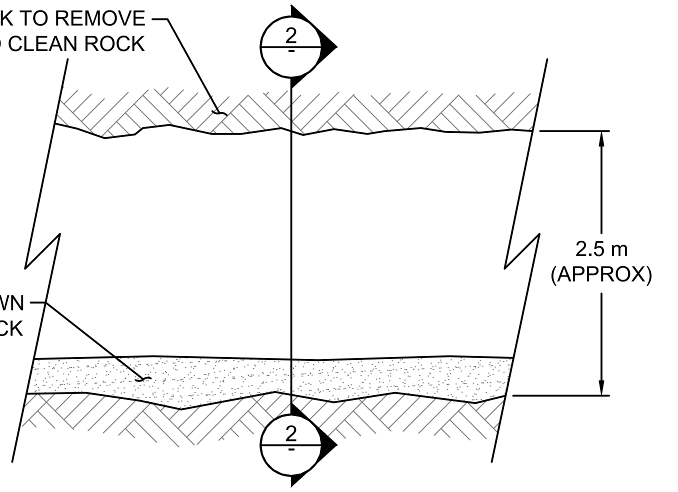

1 - PREPARE PLUG LOCATION - LONGITUDINAL SECTION VIEW
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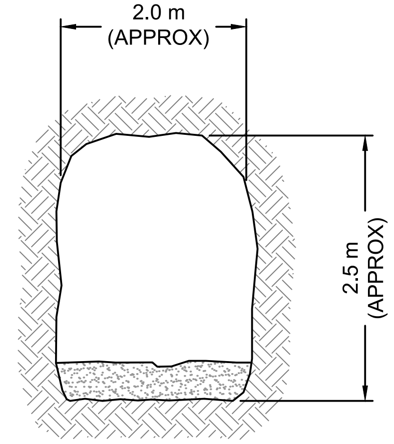

2 - ADIT CROSS SECTION
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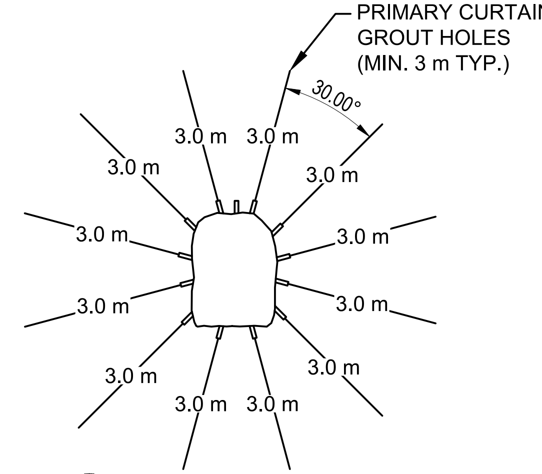

3 - PRESSURE GROUTING
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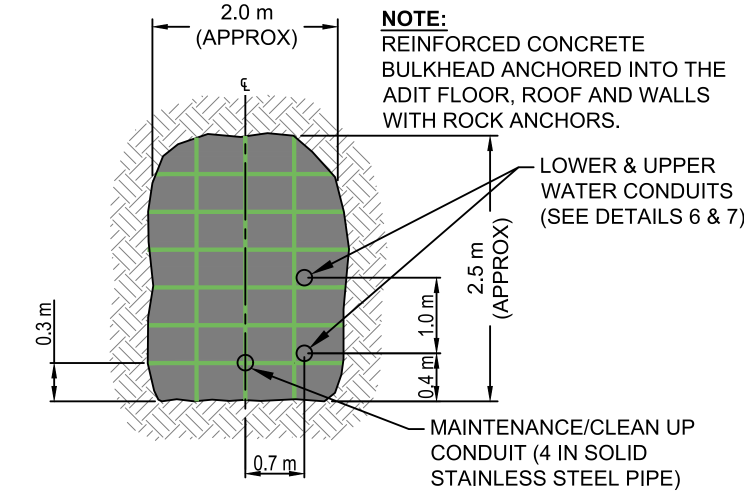

4 - BULKHEAD SITE - TRANSVERSAL SECTION VIEW
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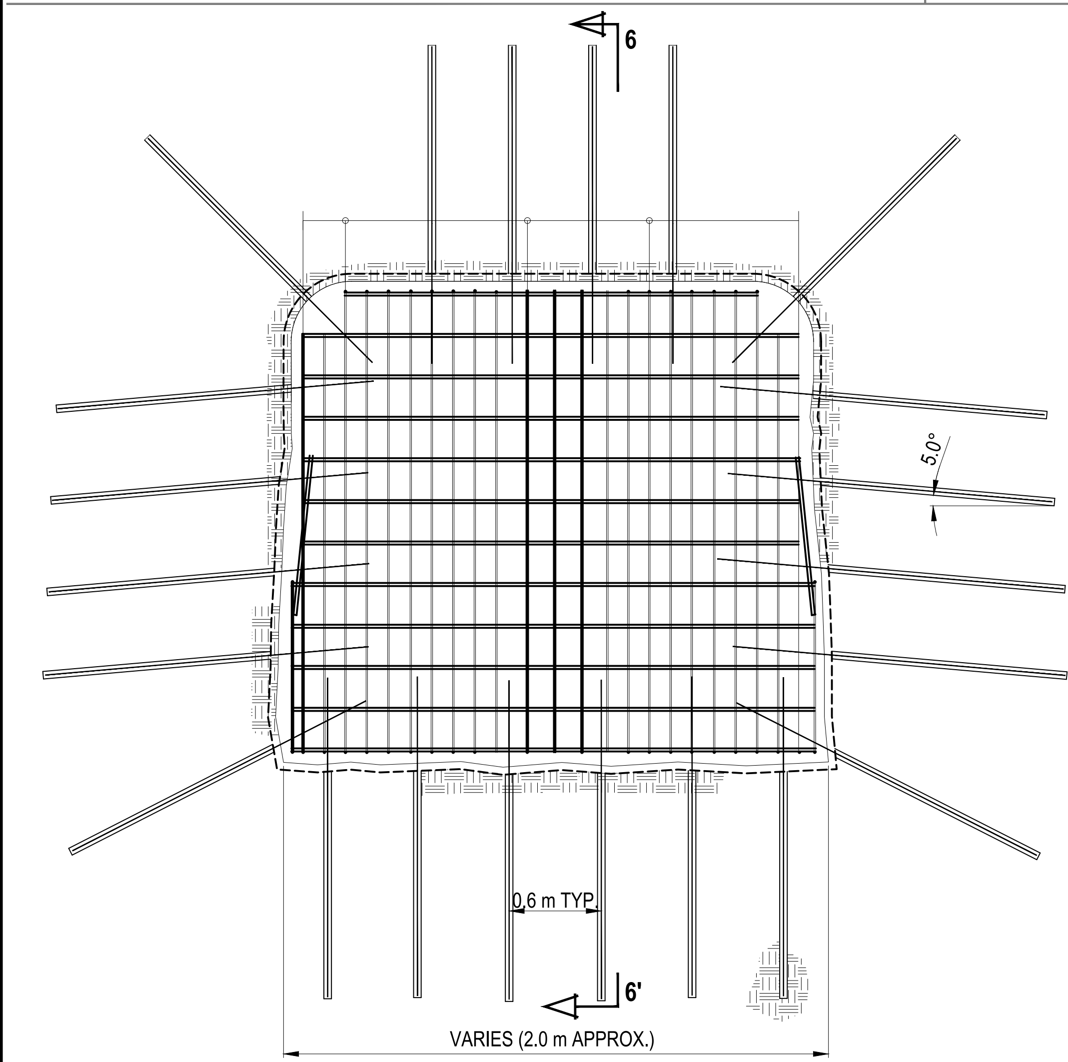

5 - BULKHEAD DOWNSTRAM ELEVATION
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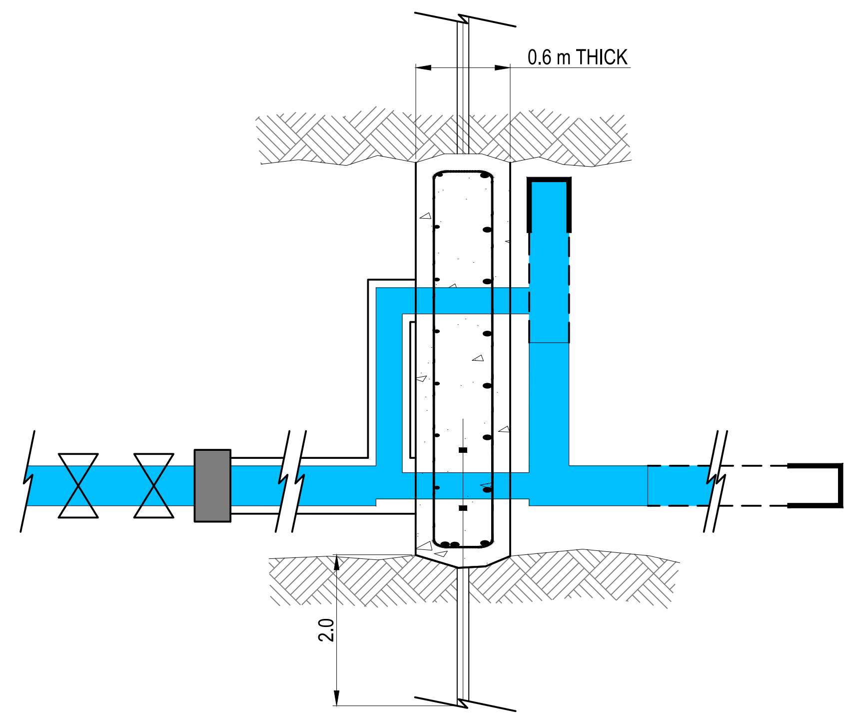

6 - BULKHEAD SITE - LONGITUDINAL SECTION VIEW
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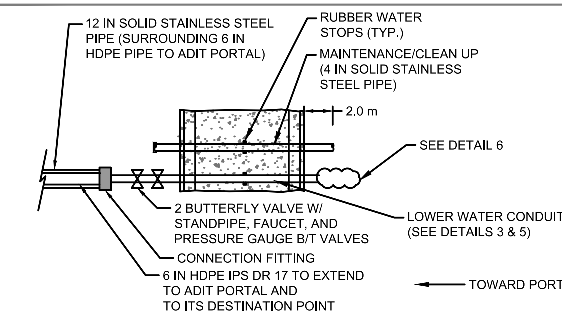

7 - BULKHEAD SITE - PLAN VIEW
NOT TO SCALE

NOTES:

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

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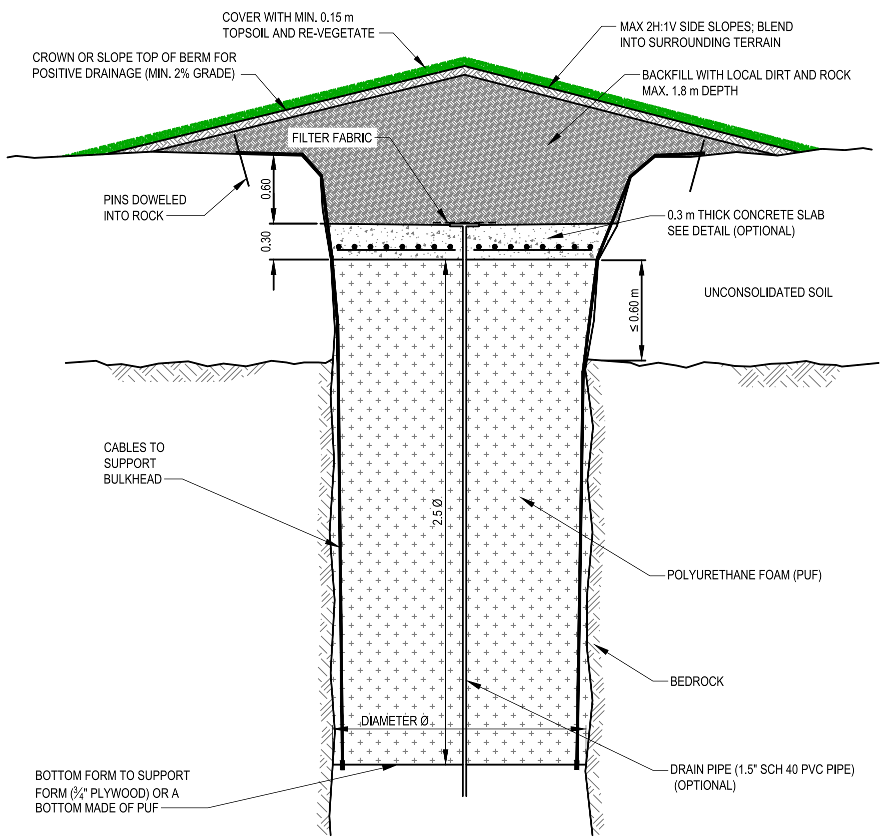
2018-02-05	Draft for review	A	TT	--

ALEXCO ENVIRONMENTAL GROUP
AKHM
TETRA TECH EBA

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

Portal Closure
Typical Concrete Bulkhead Design

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



SHAFT PUF WITH CONCRETE SLAB CLOSURE

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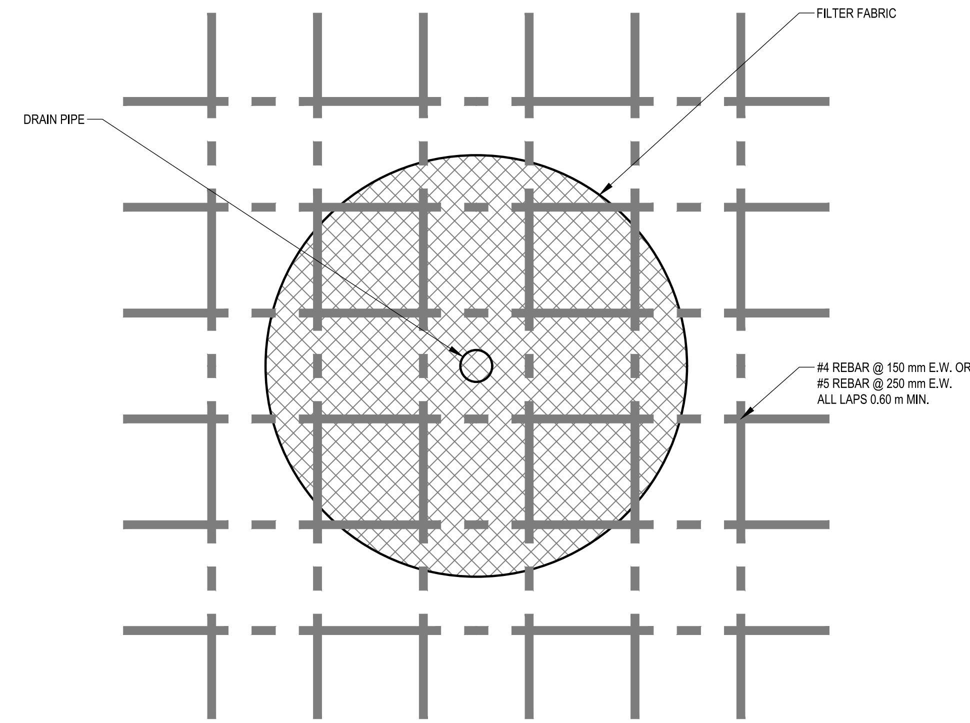

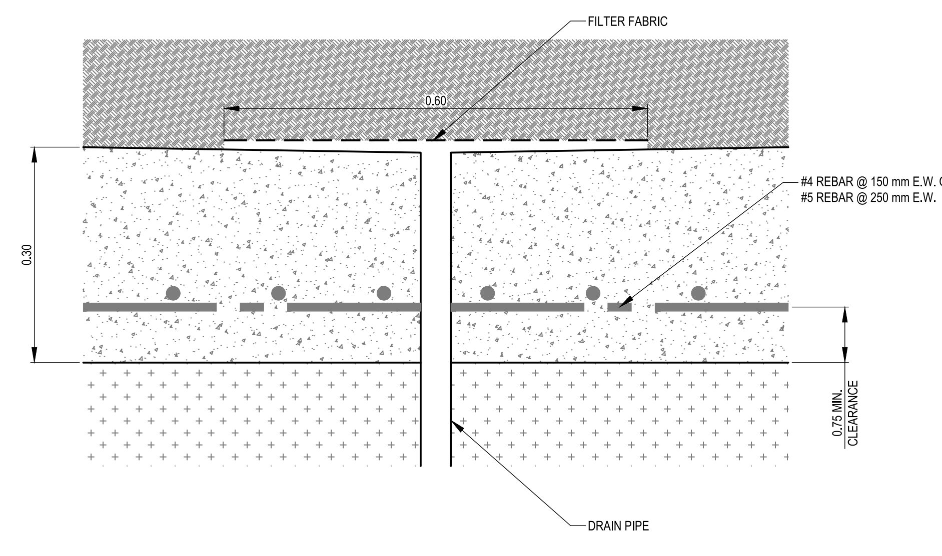

CONCRETE SLAB DETAILS

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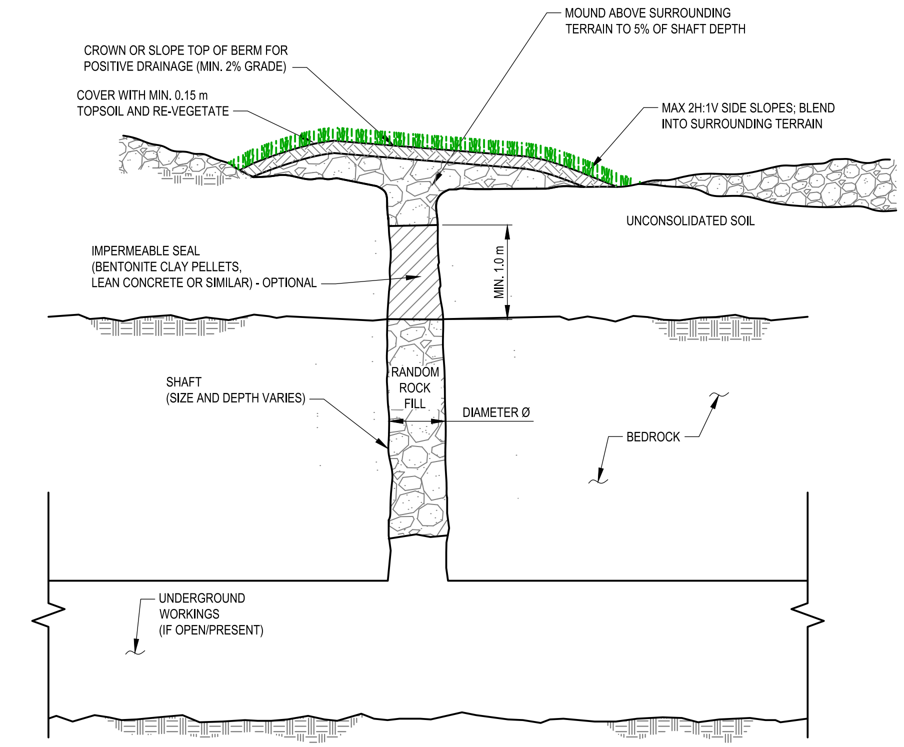

SHAFT BACKFILL (DRY SEAL) CLOSURE

NOT TO SCALE

NOTES

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

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. Quantities will vary with shaft depth, connection to underground workings, and other conditions.
3. Mobile equipment must never operate on ground that shows signs of subsidence without taking adequate precautions.
4. Remove as practical, if present, and dispose of timber, trash, brush, topsoil and other debris in and around shaft area, prior to backfilling. Strip down to bedrock surface at collar where practical.
5. Existing steel pipe, concrete rubble (if present) should be removed or incorporated into backfill as directed by engineer.
6. Random rock fill must be:
   a. Non-acid generating rock fill
   b. Sized to contain no rocks greater than ¼ the diameter of the shaft.
7. Every effort should be made to keep all debris other than rock fill from going underground.

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2018-02-05	Draft for review	A	TT	--

Alexco Environmental Group

AKHM

TETRA TECH EBA

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

Shaft/Raise to Surface
Typical Concrete Cap Design

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

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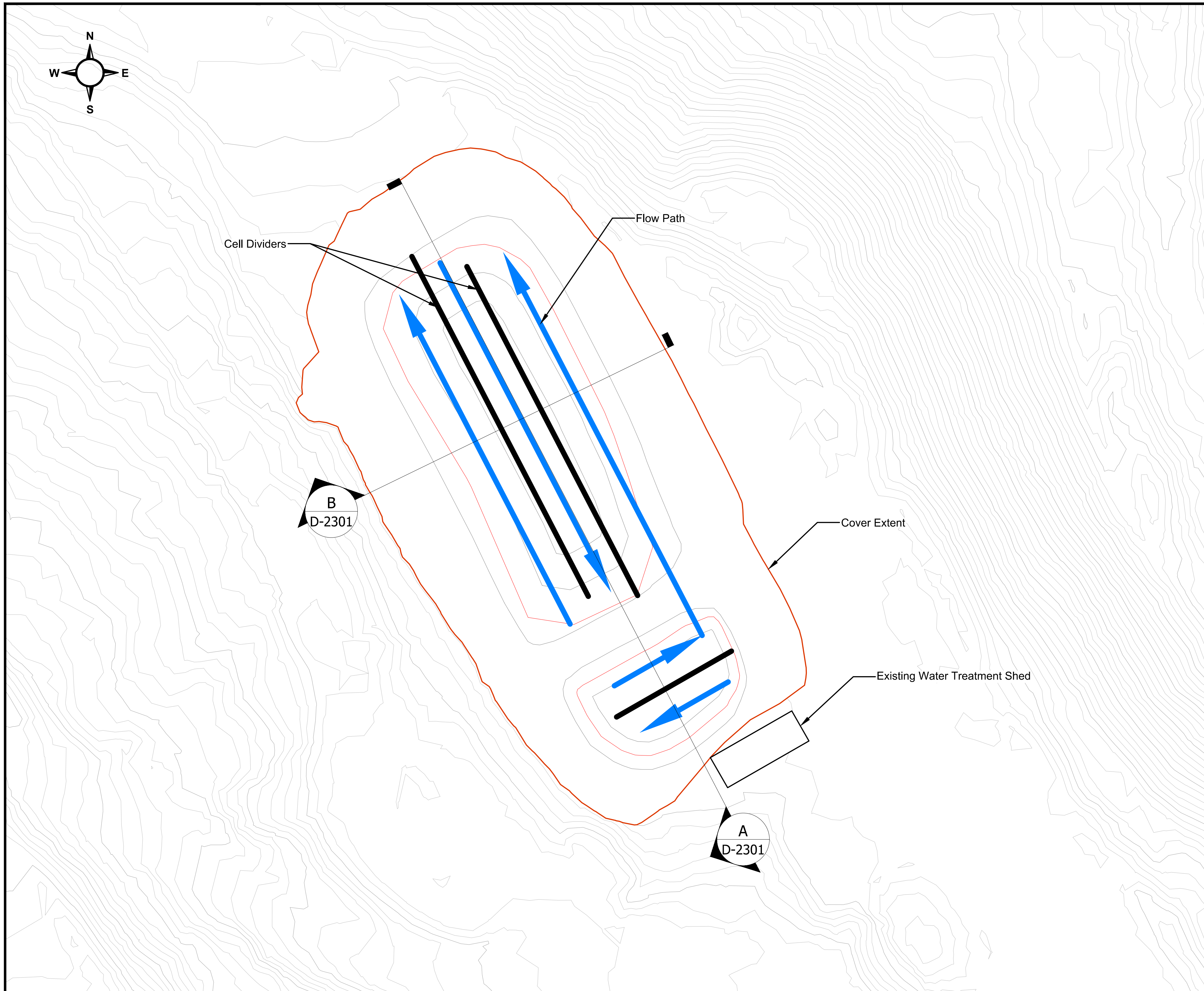

Notes:

Conceptual Design Assumptions:

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

Material Quantities:

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

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

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

Bellekeno 625
Bioreactor Design

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

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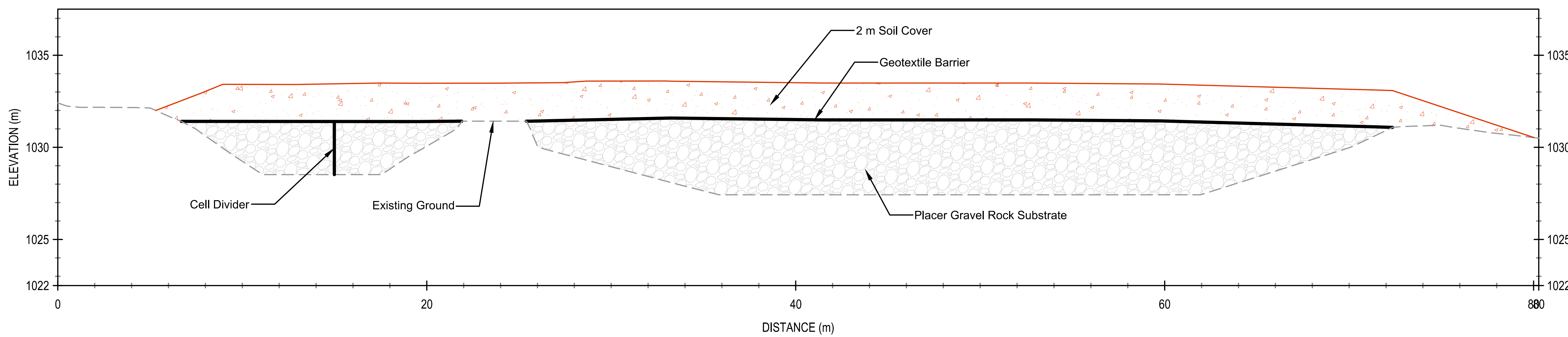
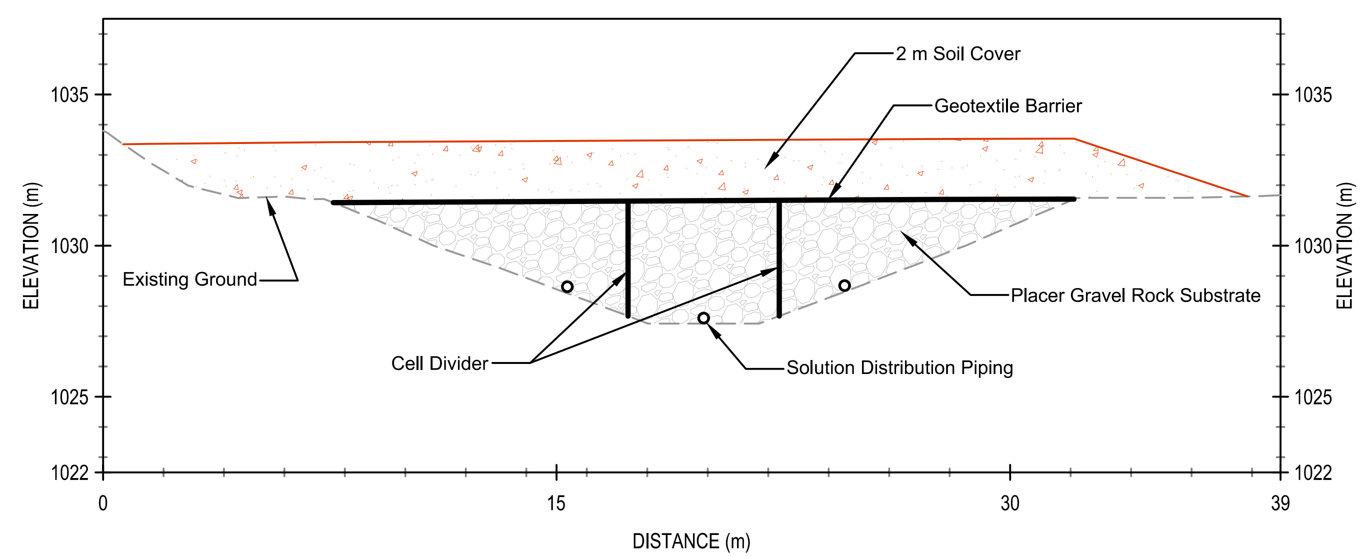


Section A



Section B

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

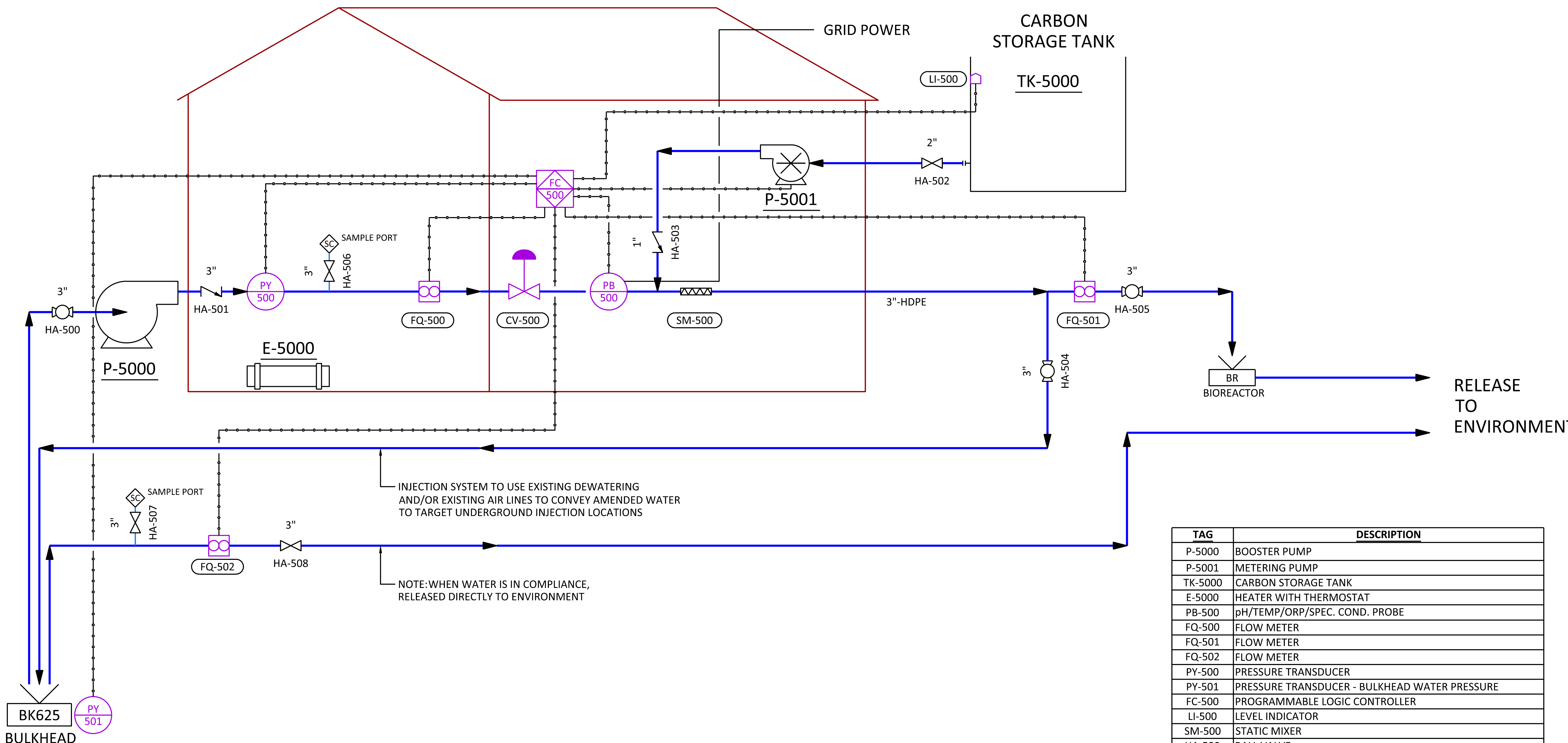
ALEXCO ENVIRONMENTAL GROUP

AKHM

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

Bellekeno 625
Bioreactor Design Sections

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



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

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

NOTES:

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

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

Bellekeno Closure Treatment System

Piping & Instrumentation Diagram

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

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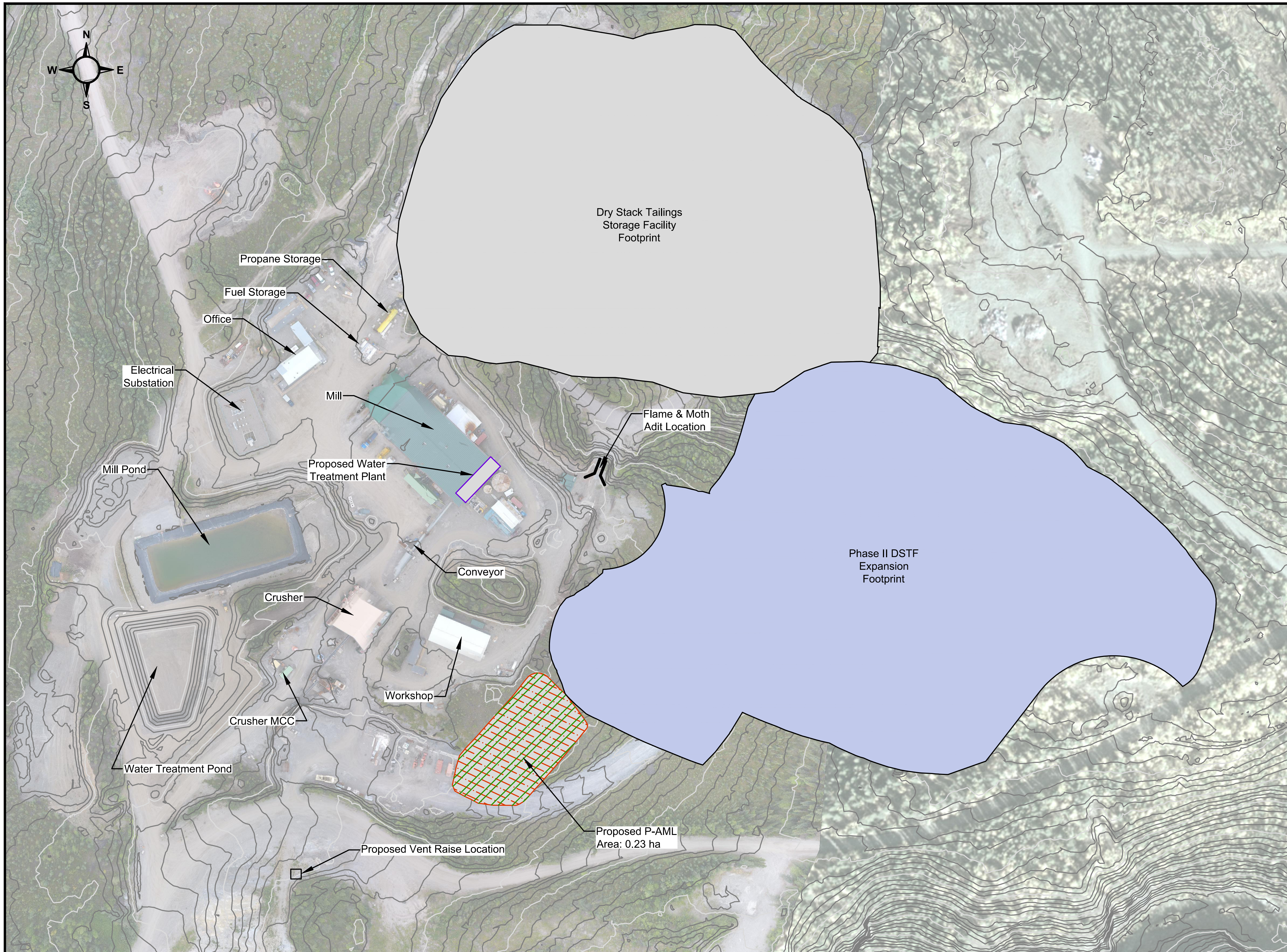

Notes:

1. Surface buildings associated with Flame and Moth are portable structures that will be removed and transported offsite for salvage.
2. P-AML rock stored within the temporary facility will be moved back underground as backfill.
3. Rock pile portal closure to be installed. See drawing AKHM-13-01-C-S0301.
4. Surface areas to be regraded as required for positive drainage, and scarified to promote revegetation
5. Further surface amendments detailed on drawings AKHM-13-01-C-6401 and AKHM-13-01-B6101.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-1401

Flame & Moth
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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Notes:

1. Remaining P-AML waste rock on surface, stored in the lined storage facility will be backfilled to underground.
2. The WRSF liner will be removed and disposed of in a waste facility.
3. The WRSF will be regraded to promote positive drainage and the area will be covered and revegetated.
4. The Bellekeno East portal will receive a rock pile closure. See drawing AKHM-13-01-S-0301.
5. The mine will be allowed to flood and will receive *in situ* mine pool treatment. Water will exit via the Bellekeno 625 adit. See drawing AKHM-13-01-C-2402
6. The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.
7. All the surface buildings at Bellekeno East are portable structures will be removed and transported offsite for salvage at closure.
8. Sediment ponds at Bellekeno East for the development of the decline will be progressively reclaimed prior to mine closure.
9. Contaminated soil will be removed and treated in a land treatment facility.
10. The Bellekeno East portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
11. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	7,400 m^2
Area of scarification and revegetation:	20,400 m^2

Scale: 1:3000

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2401

Bellekeno East
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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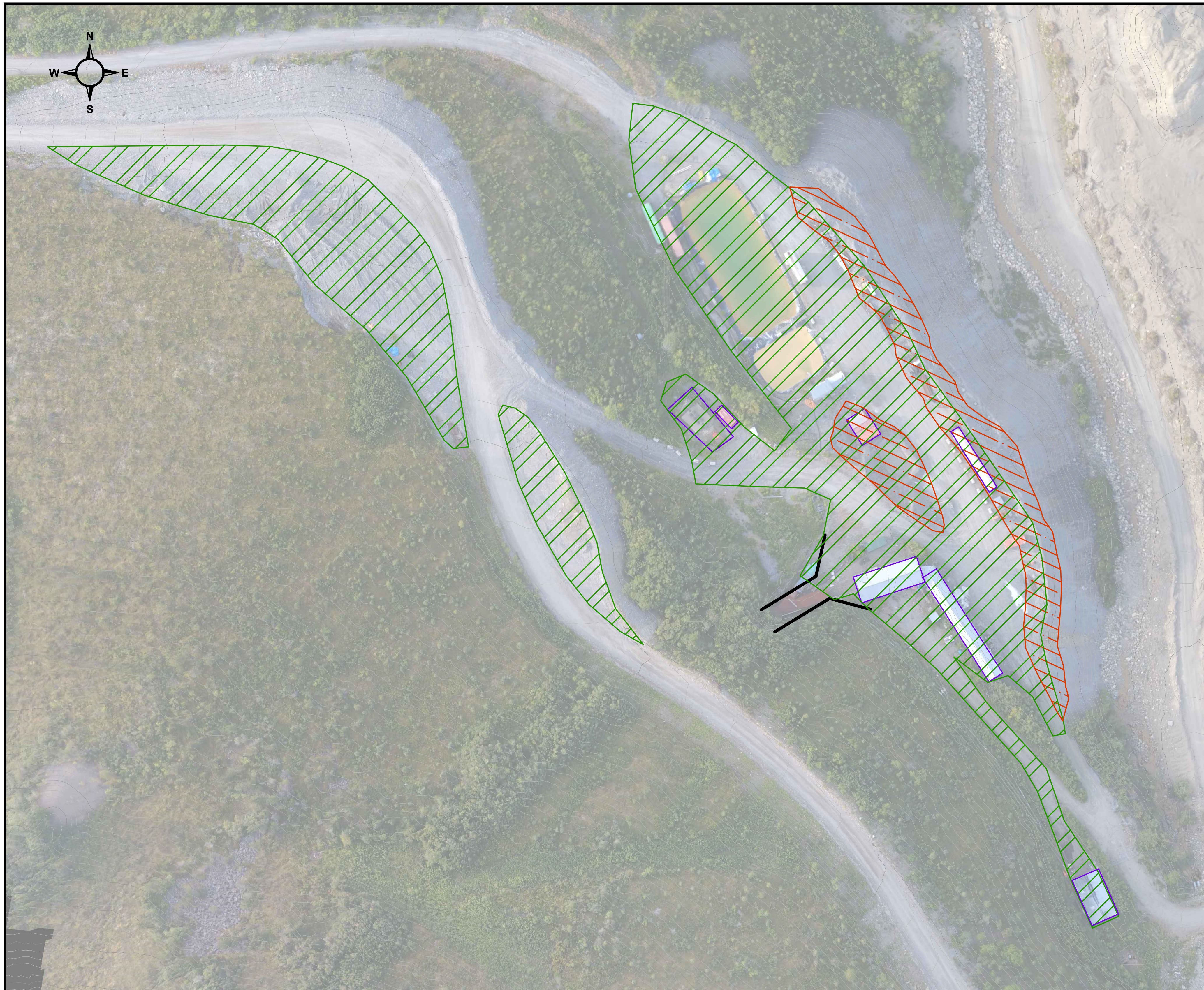

Notes:
1. The Bellekeno 625 adit will be sealed with a hydraulic bulkhead. See drawing AKHM-13-01-S-0302.
2. The mine will be allowed to flood and will receive *in situ* mine pool treatment.
3. Current water treatment ponds at the Bellekeno 625 adit will be converted into a bioreactor passive treatment system to treat mine water exiting the bulkhead. See drawing AKHM-13-01-D-2101.
4. The current water treatment facility will be shut down and decommissioned. The treatment buildings will be conveted into treatment sheds for *in situ* treatment.
5. The 200 level vent raise is an historic vent raise to surface that connected to the 99 zone of the Bellekeno mine. The 200 vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.
6. A WRDA was proposed to be constructed along the northeast flank of Sourdough Hill, but is not currently planned for construction. If constructed, at closure, the slopes will be regraded to 3H:1V. Surfaces will be scarified and revegetated.
7. The existing Bellekeno 625 WRDA will have surface equipment removed, the crests pulled back with an excavator, and flat surfaces will be scarified and revegetated.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	2,300 m^2
Area of scarification and revegetation:	12,900 m^2

Scale: 1:1250

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend
- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-2402

Bellekeno 625 Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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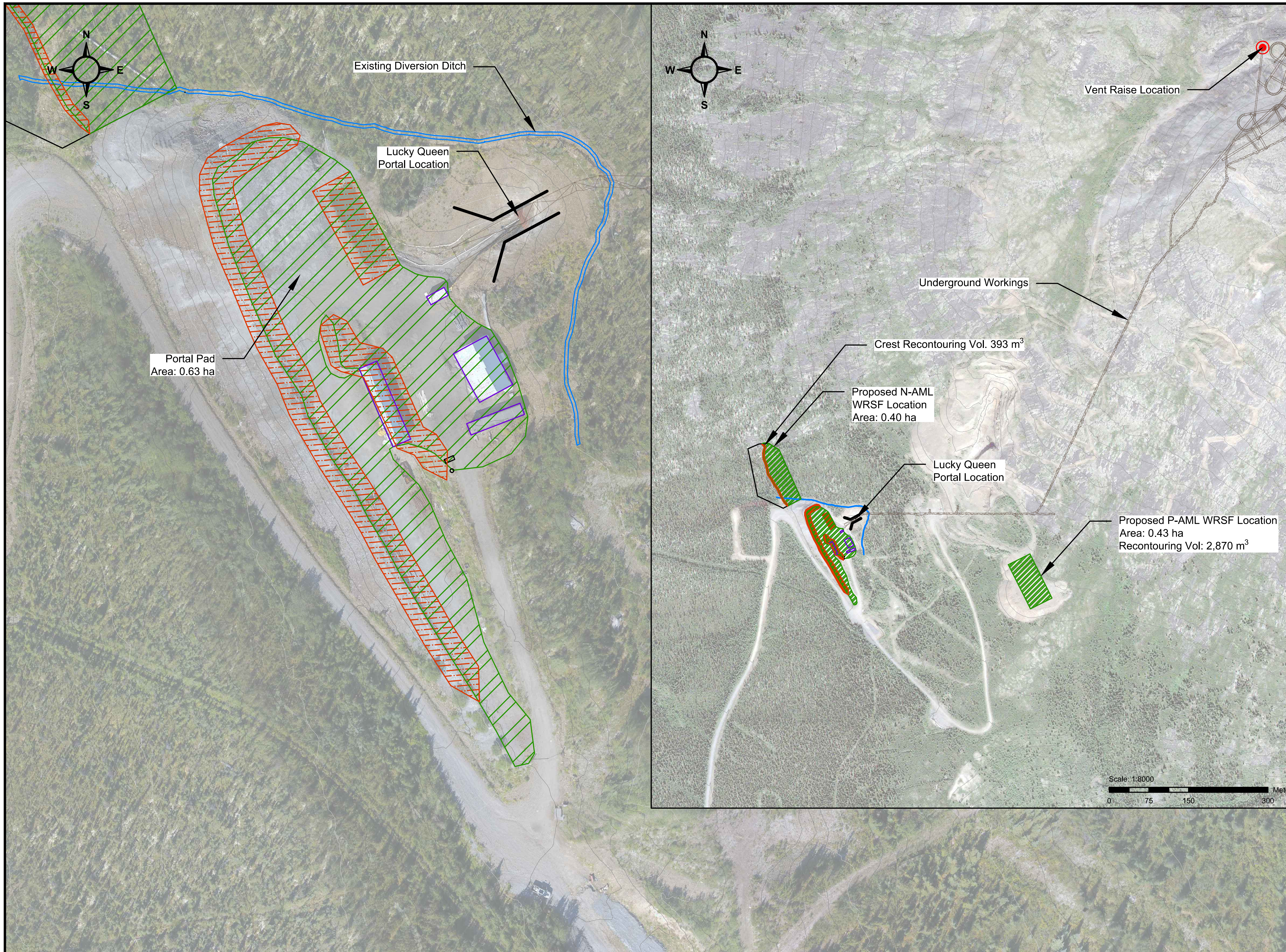

Notes:

1. Any remaining P-AML waste rock on surface will be backfilled to underground.
2. A concrete adit bulkhead will be constructed to close the portal. See drawing AKHM-13-01-S-0302.
3. If the P-AML WRSF is declared as part of the Production Unit Area, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope. The WRSF will receive a 0.5 m depth cover consisting of low permeability borrow material, as well as growth medium in the top portion of the cover which will be seeded for revegetation.
4. If a N-AML WRSF is constructed, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope.
5. Shop and other buildings and infrastructure will be removed for salvage or reuse.
6. Contaminated soil will be removed and treated in a land treatment facility.
7. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
9. The Lucky Queen vent raise will be capped with an engineered concrete cap. See drawing AKHM-13-01-S-0303.

Quatities:

Area of recontouring:	2,910 m^2
Area of scarification and revegetation:	14,600 m^2

Satellite imagery for inset obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-12.

Scale: 1:1250
Meters
0 10 20 40

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-3401

Lucky Queen Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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Notes:

1. A rock pile cover will be constructed to close the portal opening. See Drawing AKHM-13-01-S-0301.
2. The constructed P-AML WRSF contains no P-AML rock. Closure will include the removal of the liner, and recontouring of the containment berms, followed by scarification of the surface, and seeding.
3. If a N-AML WRDA is constructed, it will be recontoured by pulling back the crests. Flat surfaces will be scarified and revegetated. Slopes will be recontoured as required for a 3H:1V slope.
4. Shop and other buildings and infrastructure will be removed for salvage or reuse.
5. Contaminated soil will be removed and treated in a land treatment facility.
6. The portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
7. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
8. The Onek vent raise will be capped with an engineered concrete cap. See drawing AKHM-13-01-S-0303.

Quantities:

Area of recontouring:	5,600 m^2
Area of scarification and revegetation:	8,300 m^2

Scale: 1:3000

0 25 50 100 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-4401

Onek
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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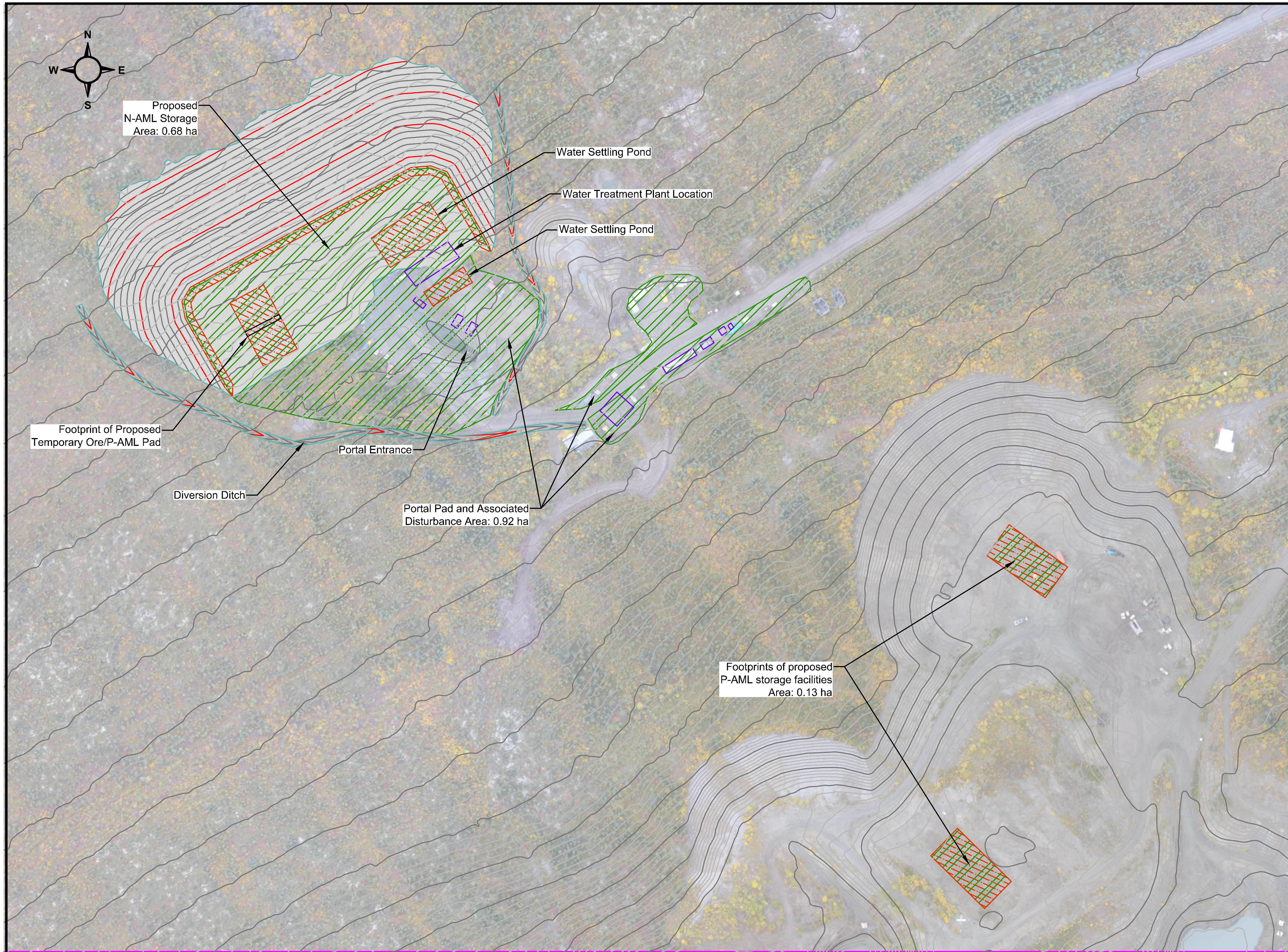

Notes:

1. A rock pile cover will be constructed to close the portal opening. See Drawing AKHM-13-01-S-0301.
2. P-AML waste rock contained in the P-AML WRSF will be relocated to underground.
3. The liner of the P-AML WRSF will be removed, and the containment berms will be recontoured, followed by scarification of the surface, and seeding.
4. The crest of the N-AML WRDA will be pulled back. Flat surfaces will be scarified and revegetated.
5. Shop and other buildings and infrastructure will be removed for salvage or reuse.
6. Contaminated soil will be removed and treated in a land treatment facility.
7. The surrounding portal site will be recontoured and scarified to establish drainage and facilitate revegetation.
8. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.
6. The vent raise will be capped with an engineered concrete cap. See Drawing AKHM-13-01-S-0303.

Quantities:

Total area of recontouring:	3,475 m^2
Total area of scarification and revegetation:	17,300 m^2

Scale: 1:2000

0 15 30 60 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2017-12-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-5401

Bermingham
Reclamation Measures

REVISION: A	2017-12-18	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: --

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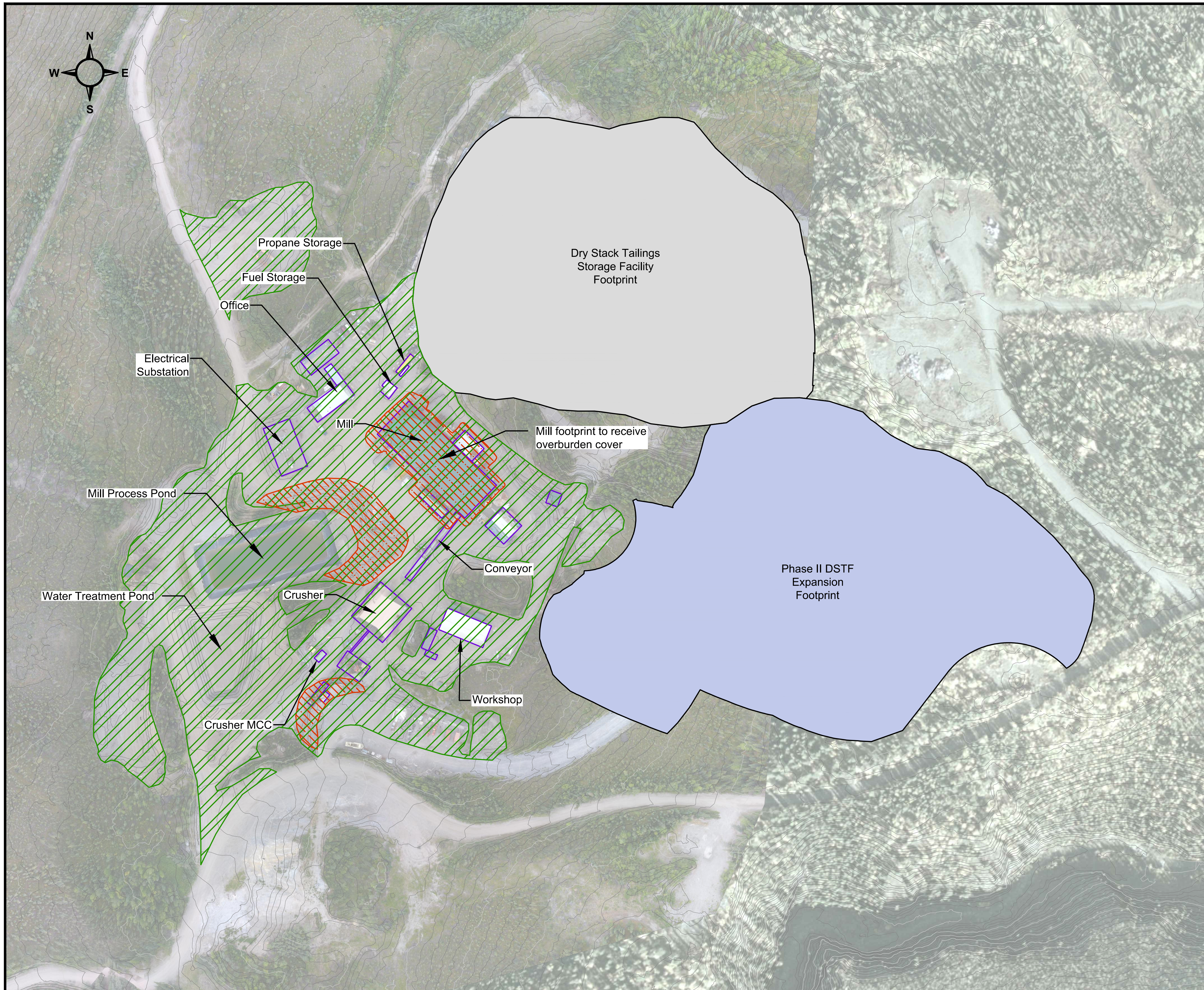

Notes:

1. Modular prefabricated trailer style buildings will be removed from site and salvaged.
2. Rigid steel frame buildings will be dismantled on site. The steel will be sold for salvage.
3. Concrete slabs and above grade footings and foundations will be broken up and covered with 1 m overburden cover, scarified, and revegetated.
4. Both the mill process pond and water treatment pond will have the liners removed. The slopes will be scarified and revegetated. The ponds will serve as a sedimentation ponds during closure until revegetation is stabilized.
5. Crusher equipment will be removed from site for salvage.
6. Sea-containers will be removed from site for salvage.
7. Any remaining fine ore will be excavated from the stockpile and milled.
8. The buried tunnel associated with the crushing plant and ore stockpile will be removed and salvaged.
9. Diesel storage tanks and propane tanks will be removed and returned to their suppliers.
10. Buried infrastructure will be left in ground and marked on a site plan to be submitted to regulatory authorities for future reference.
11. Surface piping will be decontaminated and removed for salvage or disposal.
12. Above ground electric cabling will be de-energized and removed for salvage or disposal.
13. Contaminated soil will be removed and treated in a land treatment facility.
14. The mill site will be recontoured and scarified to establish drainage and facilitate revegetation.
15. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Area of recontouring:	2,700 m^2
Area of scarification and revegetation:	47,900 m^2
Area to receive overburden cover:	3,150 m^2

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to receive overburden cover
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-6401

Mill Site Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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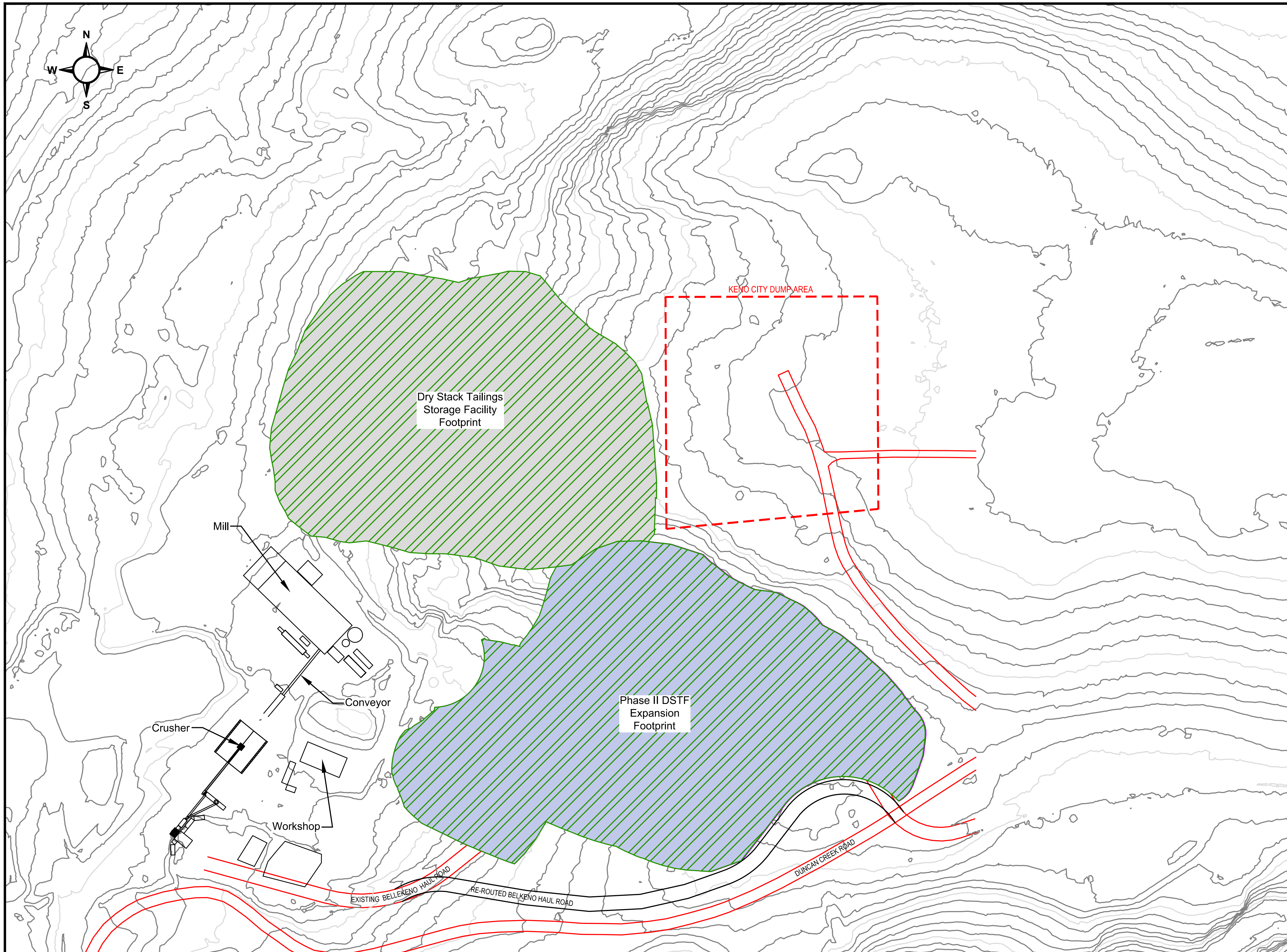
Notes:

1. The DSTF has been progressively reclaimed but recontouring to a 3H:1V slope, with the placement of a 0.25 - 0.5 m cover and seeding.
2. Upon closure, any remaining, unreclaimed areas of the DSTF will be recontoured, covered, and revegetated in the same manner.

Quantities:

Area of scarification and revegetation: 71,500 m^2



Scale: 1:2500

0 20 40 80 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-7401

Dry Stack Tailings Facility
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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Notes:

1. Sludge contained in the storage cells in the Valley Tailings will be transported either back underground in Bellekeno East decline, or placed in the DSTF.
2. The sludge storage cells are wholly contained within the area of the VTF which is to be excavated and relocated as part of the District Closure Plan. Therefore no other closure activities are planned within the Keno District Mine Operations RCP.

Scale: 1:5000

0 40 80 160 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-8401

KHSD Sludge Ponds
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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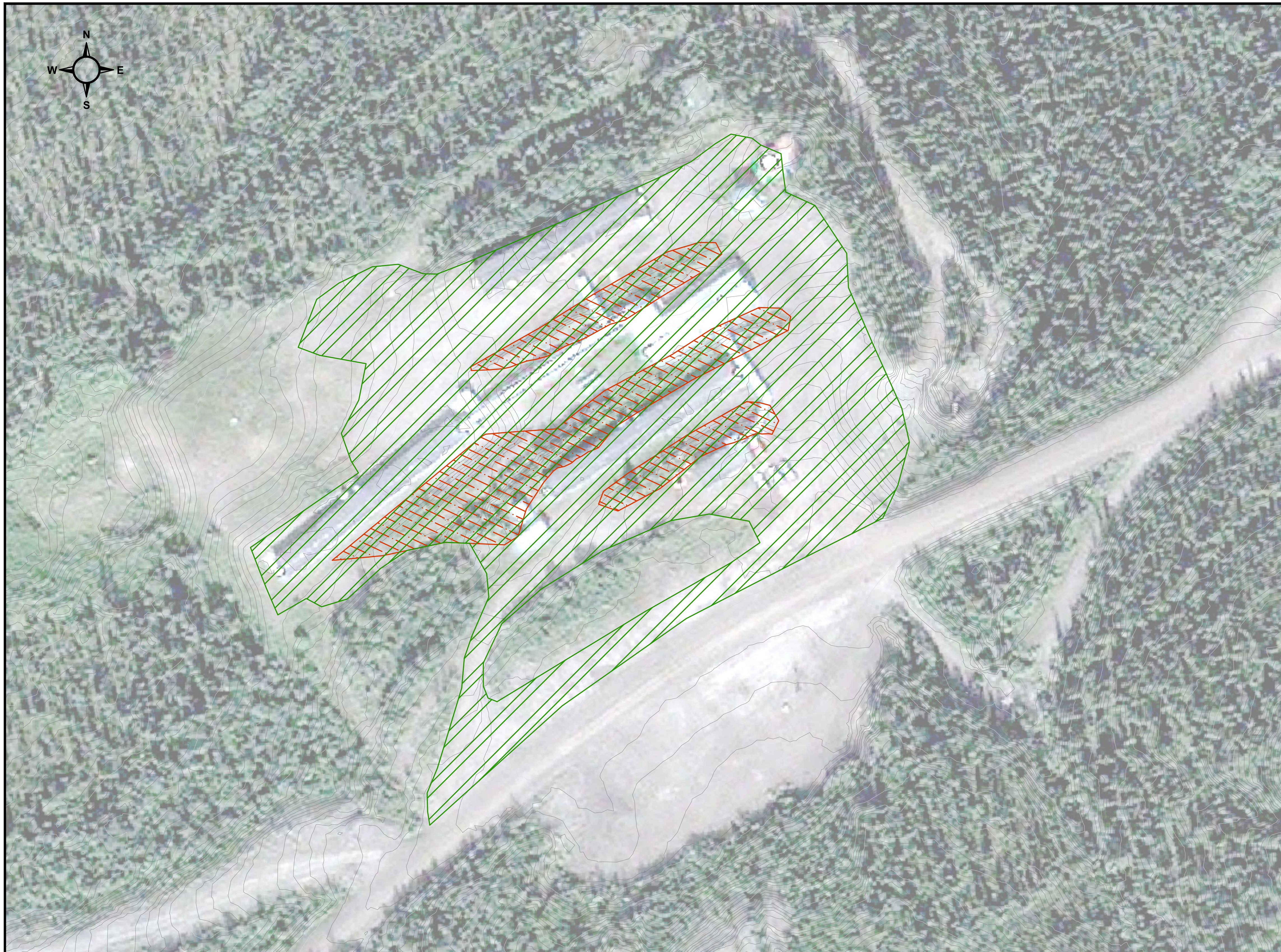

Notes:

1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:

Area of recontouring:	3,200 m^2
Area of scarification and revegetation:	18,000 m^2

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

Legend

- Infrastructure to be removed
- Area to be recontoured
- Area to be scarified and revegetated

Alexco Environmental Group

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-C-9401

Flat Creek Camp
Reclamation Measures

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: --	REVIEWED BY: --

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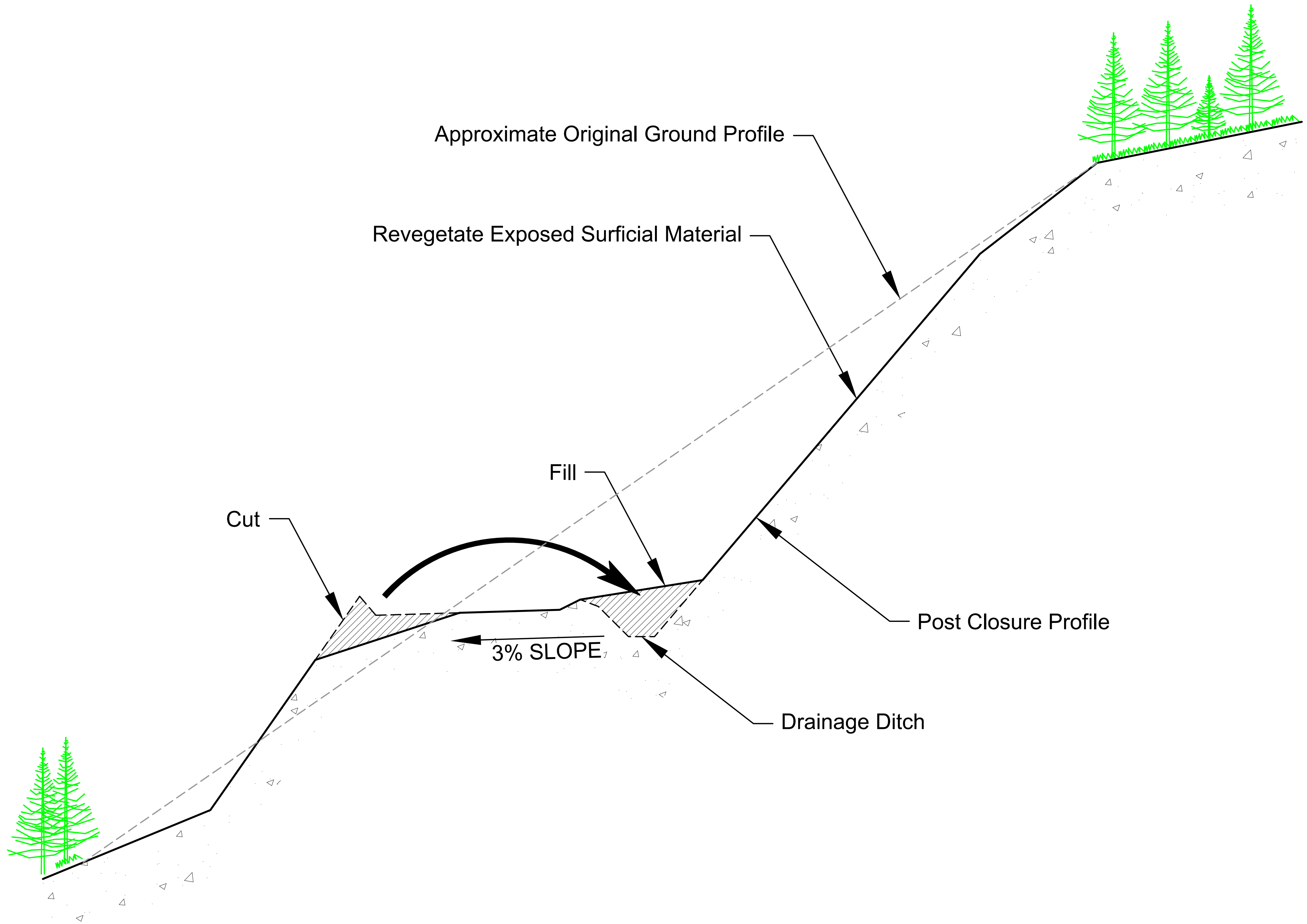
Notes:

1. Pull back slope and fill ditch.
2. Remove culverts.
3. Install erosion breaks on steep slopes as necessary.
4. Scarify road surface and prepare for natural revegetation.



DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-29	Draft for review	A	KAB	--

Sand & Gravel

Existing Vegetation

ALEXCO ENVIRONMENTAL GROUP

AKHM

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

Haul Road and Site Road Reclamation Typical Section

REVISION: A	2018-01-29	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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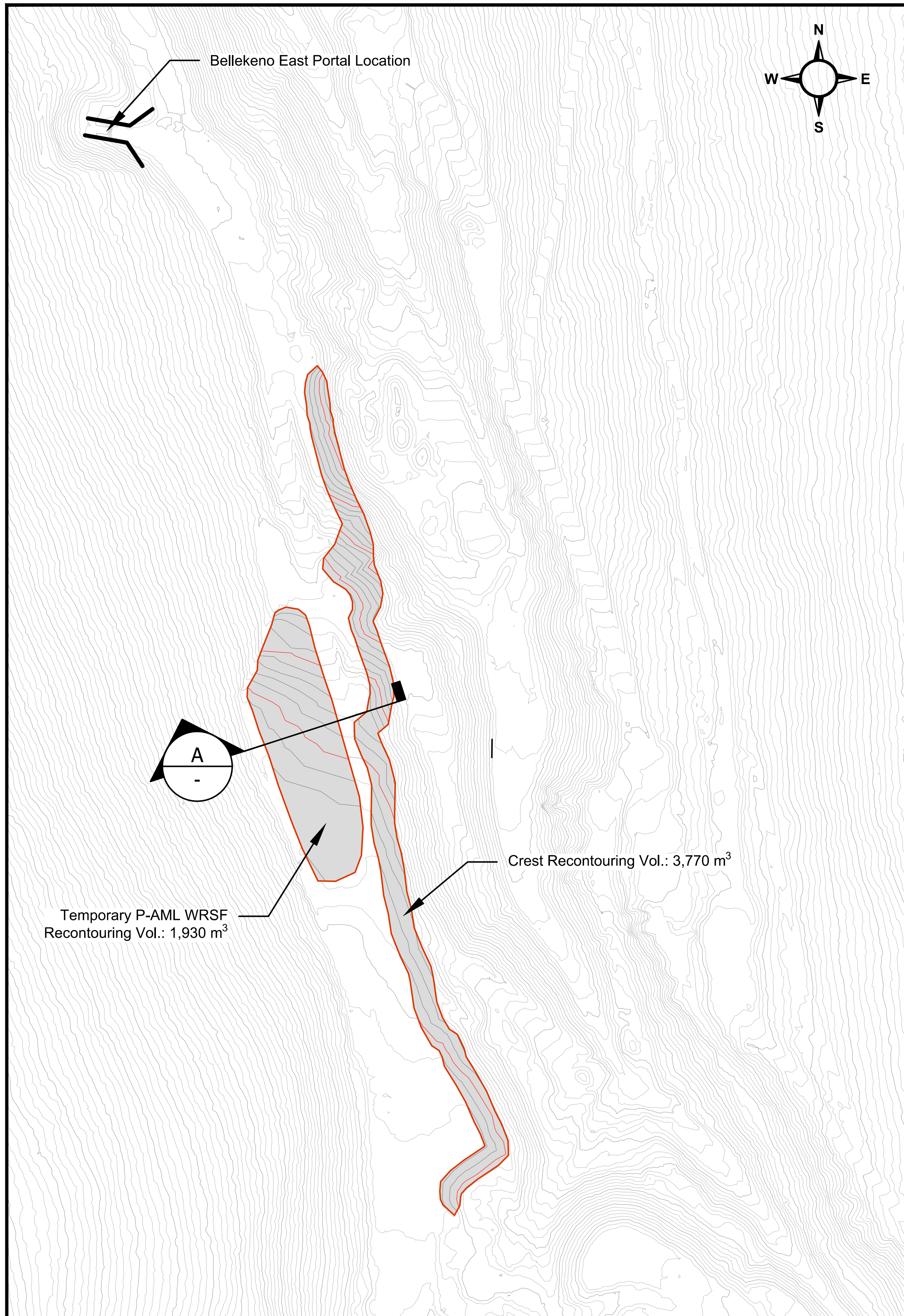
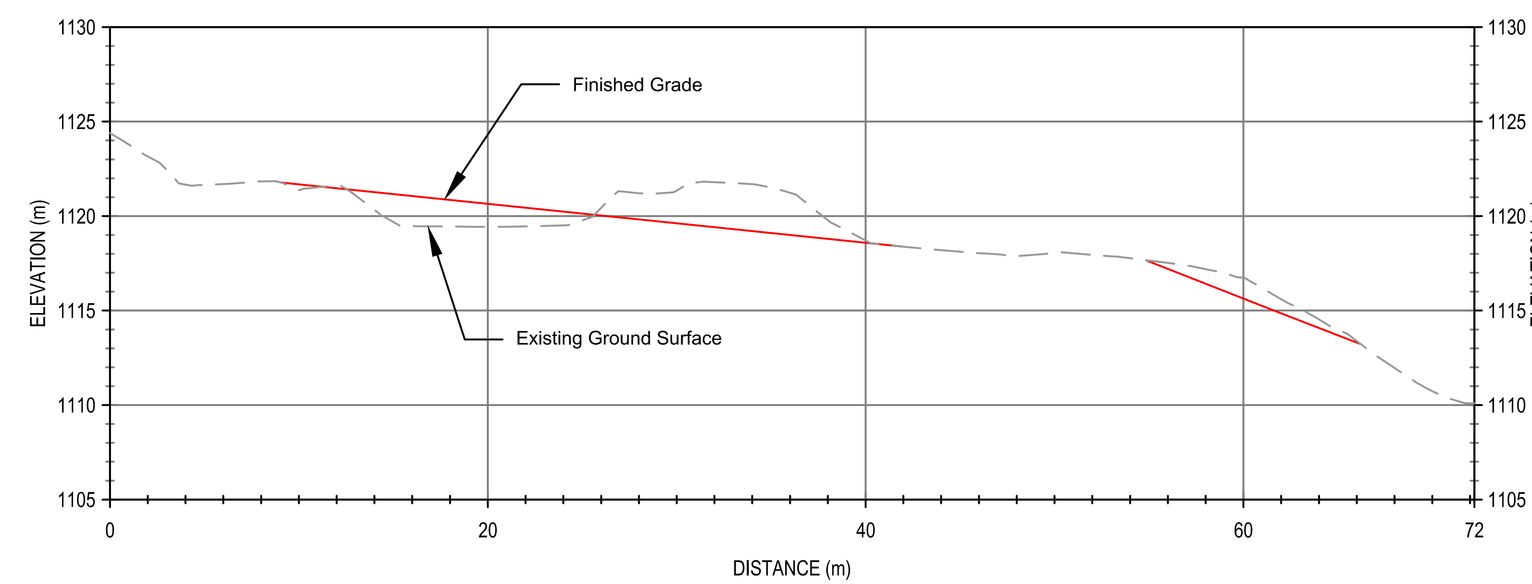


Notes:

1. Remaining P-AML waste rock on surface, stored in the lined storage facility will be backfilled to underground.
2. The WRSF liner will be removed and disposed of in a waste facility.
3. The WRSF will be regraded to promote positive drainage.
4. Portal area crests will be rolled back via excavator.

Quantities:

Volume of material to be recontoured: 5,700 m^3



Section A

Scale: 1:2500

0 20 40 80 Meters

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

ALEXCO ENVIRONMENTAL GROUP

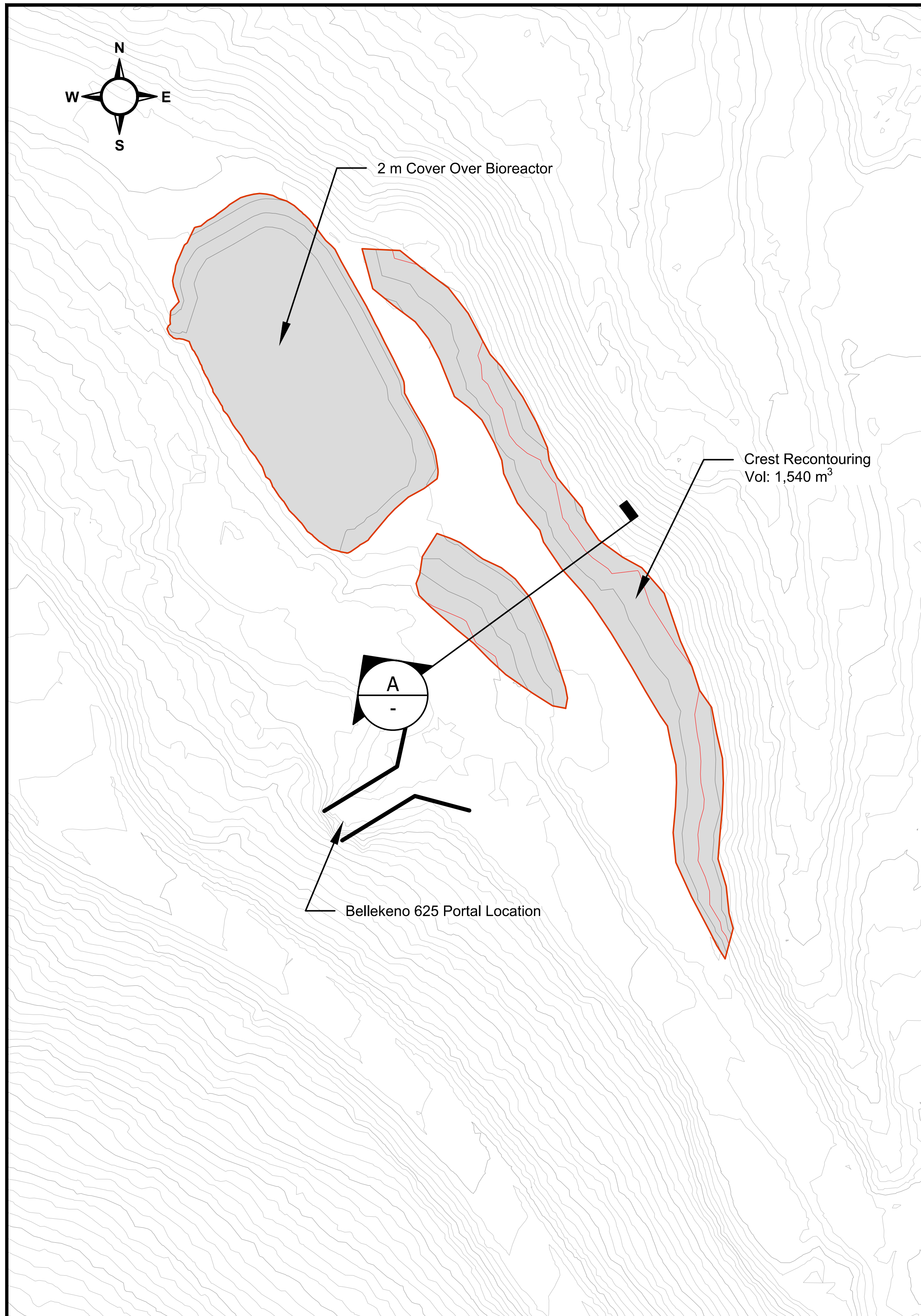
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-2101

Bellekeno East Grading
Plan and Cross Section

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

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\2-Bellekeno\B-Geotech\AKHM-13-01-B-2101-BK_East-Grading.dwg (last edited by: KBoldt; 2018/02/15 - 2:00 PM

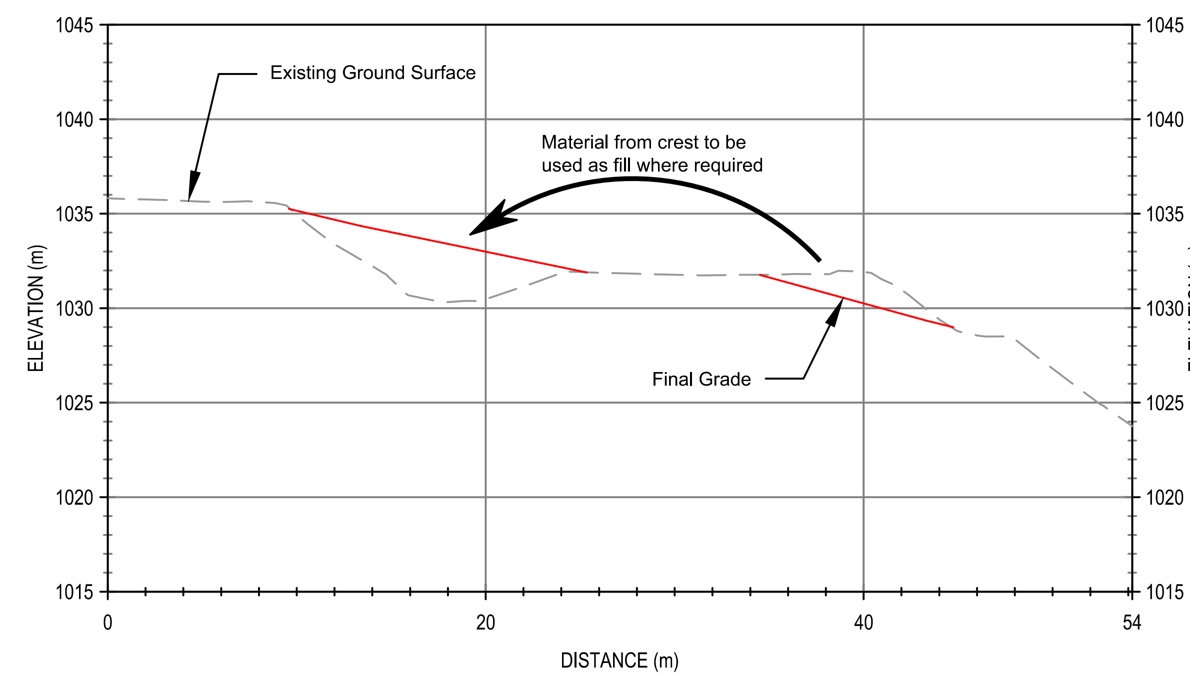


Notes:

1. Current water treatment ponds at the Bellekeno 625 adit will be converted into a bioreactor passive treatment system to treat mine water exiting the bulkhead. See drawing AKHM-13-01-D-2101.
2. A WRDA was proposed to be constructed along the northeast flank of Sourdough Hill, but is not currently planned for construction. If constructed, at closure, the slopes will be regraded to 3H:1V. Surfaces will be scarified and revegetated.
3. The existing Bellekeno 625 WRDA will have surface equipment removed, the crests pulled back with an excavator, and flat surfaces will be scarified and revegetated.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured*: 1,540 m^3
* Does not include cover material over bioreactor



Section A

Scale: 1:1250
0 12.5 25 50 m

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

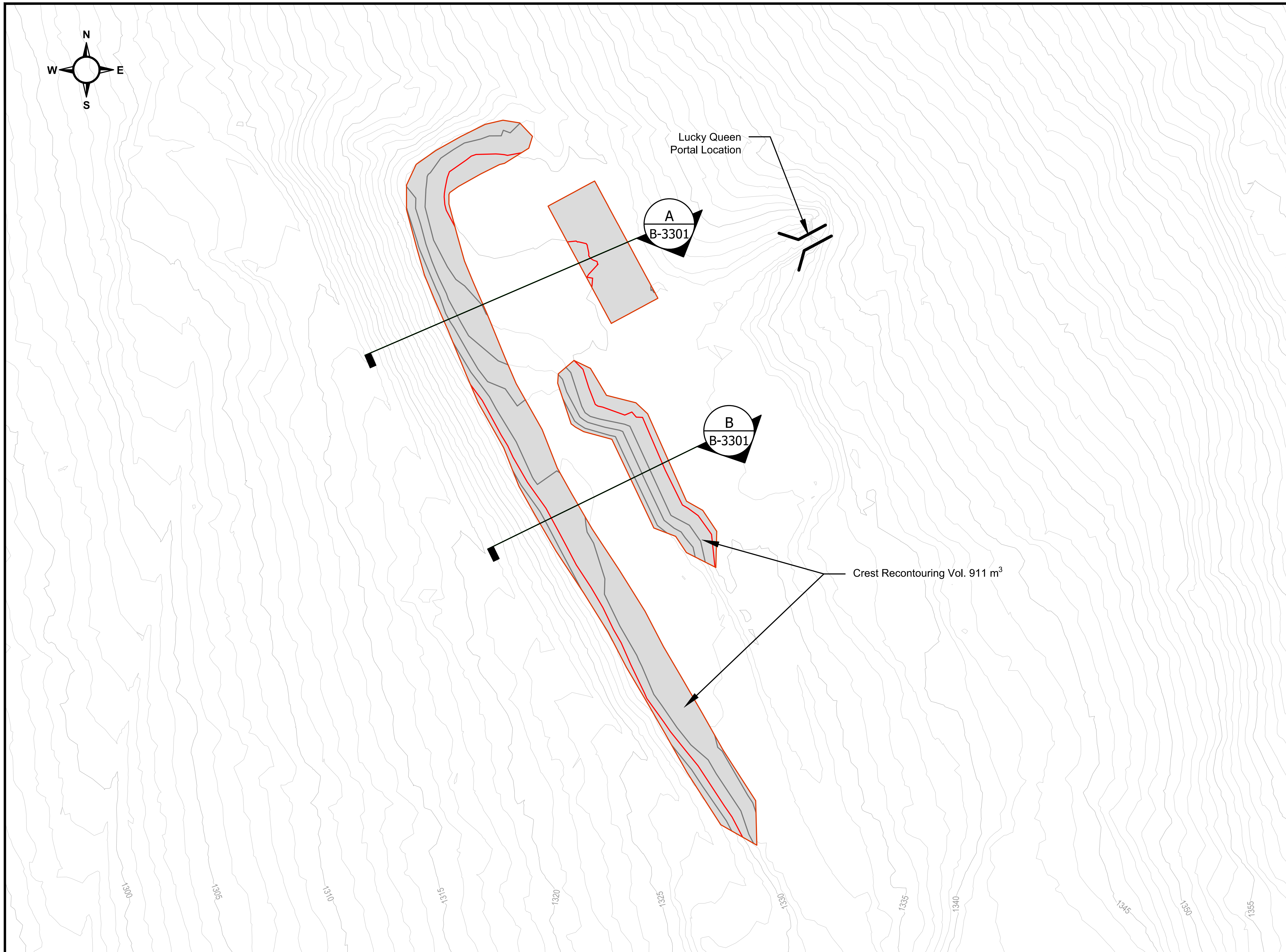
ALEXCO ENVIRONMENTAL GROUP
AKHM

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

Bellekeno 625 Grading
Plan and Cross Section

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

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\2-Bellekeno\B-Geotech\AKHM-13-01-B-2102-BK625-Grading.dwg (last edited by: KBoldt; 2018/02/15 - 2:01 PM



Notes:
1. Crest of the portal pad will be rolled back via excavator.
2. Existing settling pond will be recontoured to match surrounding grade.

Quatities:

Volume of material to be recontoured: 927 m^3

Satelite imagery for inset obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-12.

Scale: 1:1000

0 10 20 40 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-30	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

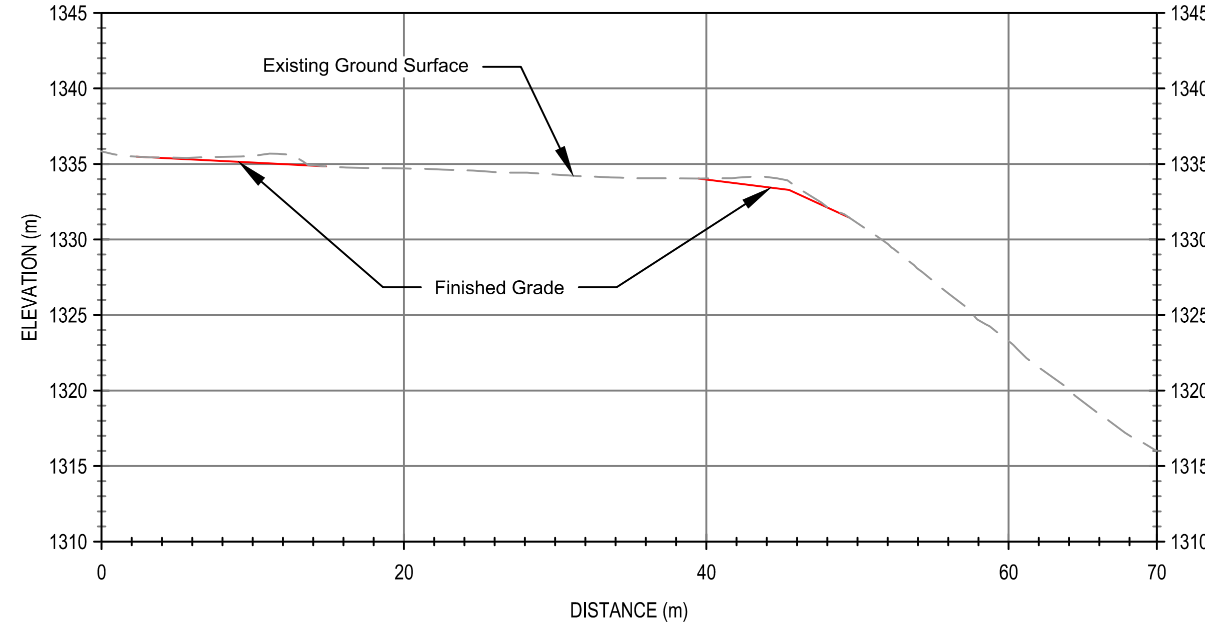
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3101

Lucky Queen Grading Plan

REVISION: A	2018-01-30	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\3-Lucky Queen\B-Geotech\AKHM-13-01-B-3101-LQGrading.dwg (last edited by: KBoldt; 2018/02/15 - 2:03 PM



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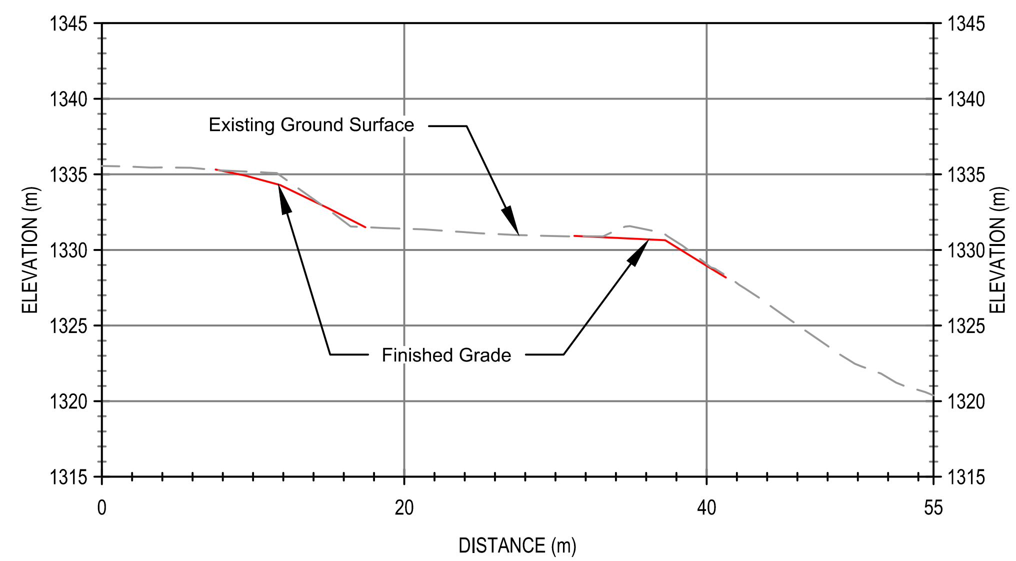


Section B

Scale: 1:500

0 5 10 20 m

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-30	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

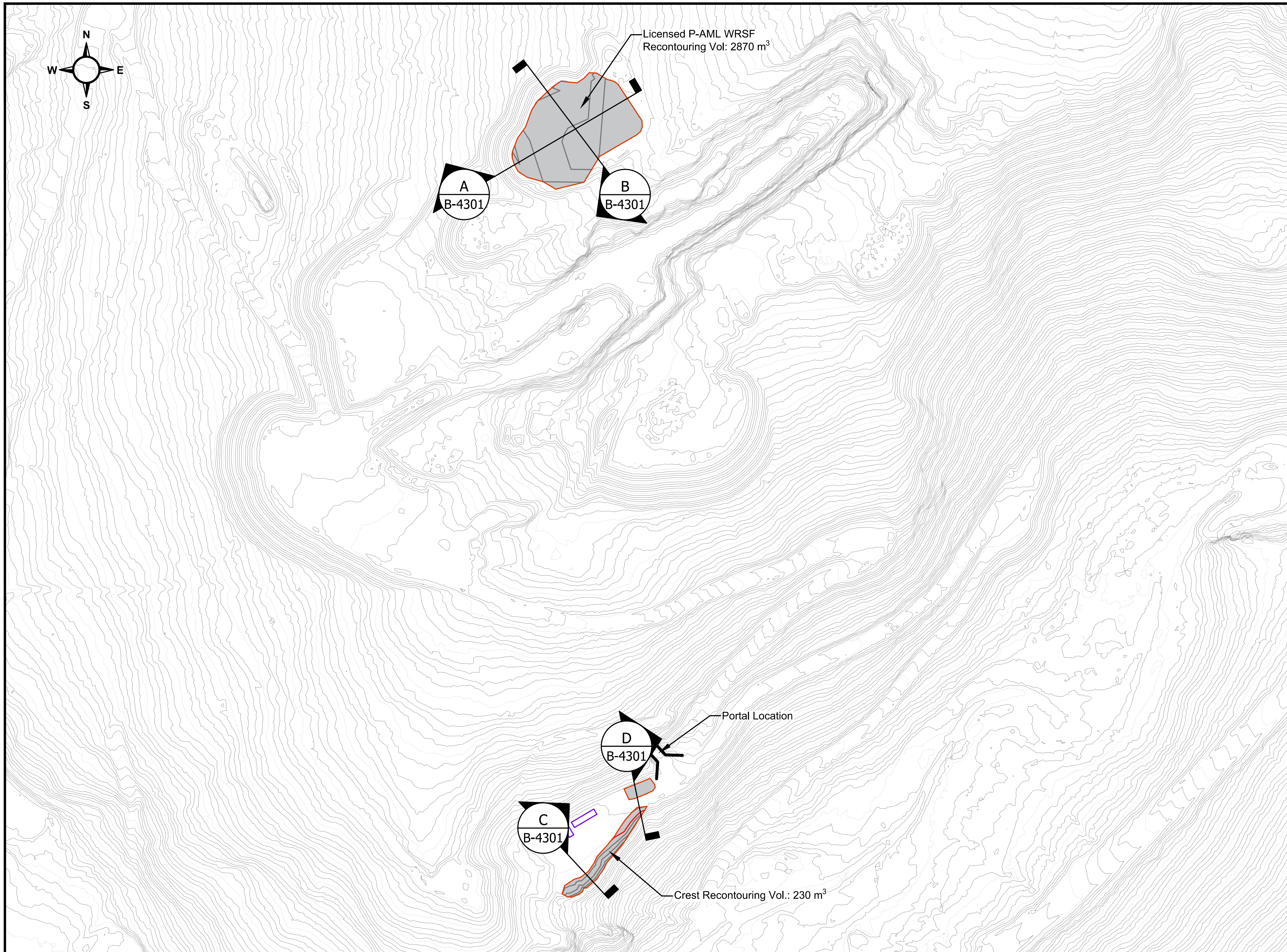
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-3301

Lucky Queen Grading
Cross Sections

REVISION: A	2018-01-30	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\3-Lucky Queen\B-Geotech\AKHM-13-01-B-3101-LQGrading.dwg (last edited by: KBoldt; 2018/02/15 - 2:03 PM



Notes:

1. The constructed P-AML WRSF contains no P-AML rock. Closure will include the removal of the liner, and recontouring of the containment berms, followed by scarification of the surface, and seeding.
2. The constructed settling pond will be recontoured to match surrounding grade.
3. The portal area crest will be rolled back via excavator.

Quantities:

Volume of material to be recontoured: 3,100 m^3

Scale: 1:3000

0 25 50 100 Meters

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-31	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

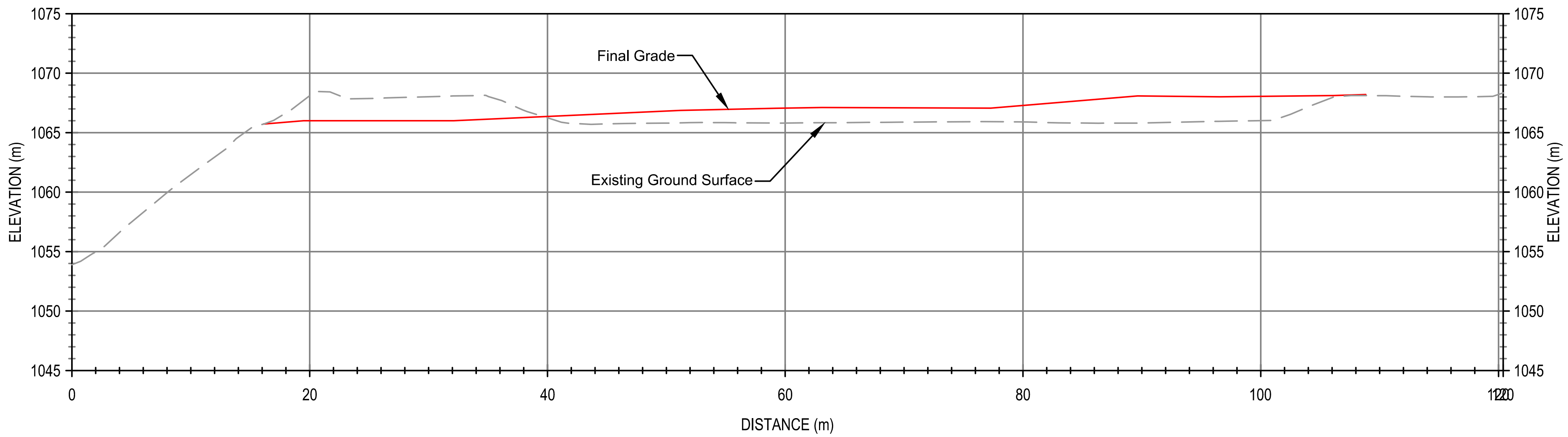
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4101

Onek Grading Plan

REVISION: A	2018-01-31	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\4-Onek\B-Geotech\AKHM-13-01-B-4101-OnekGrading.dwg (last edited by: KBoldt; 2018/02/15 - 2:09 PM



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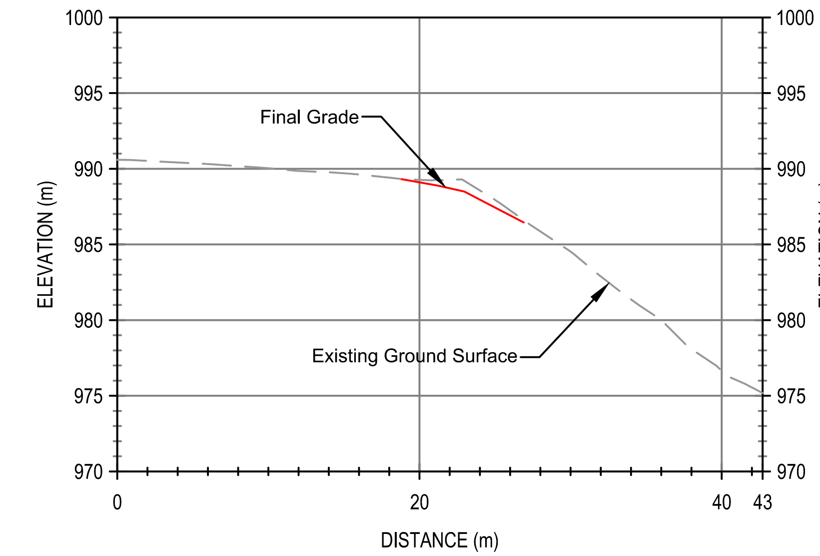

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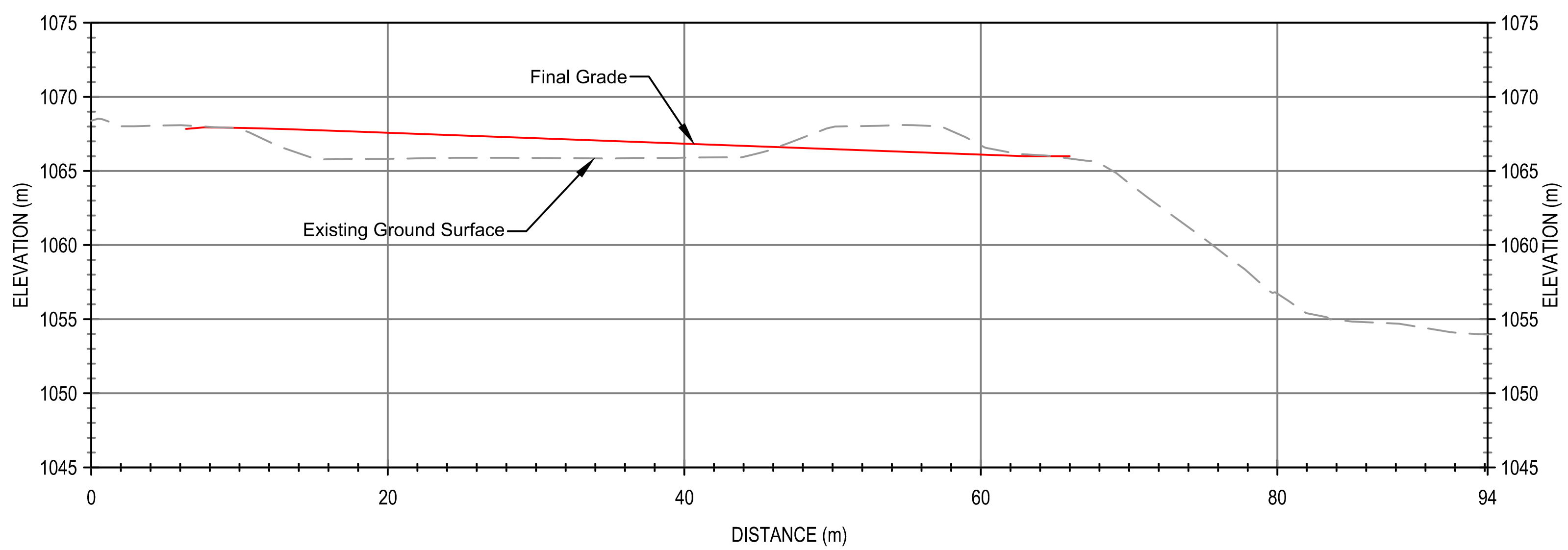

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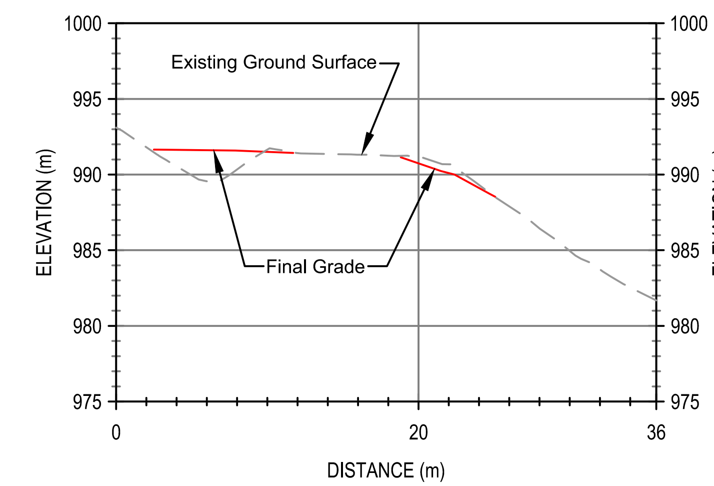

Section D

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-31	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-4301

Onek Grading
Sections

REVISION: A	2018-01-31	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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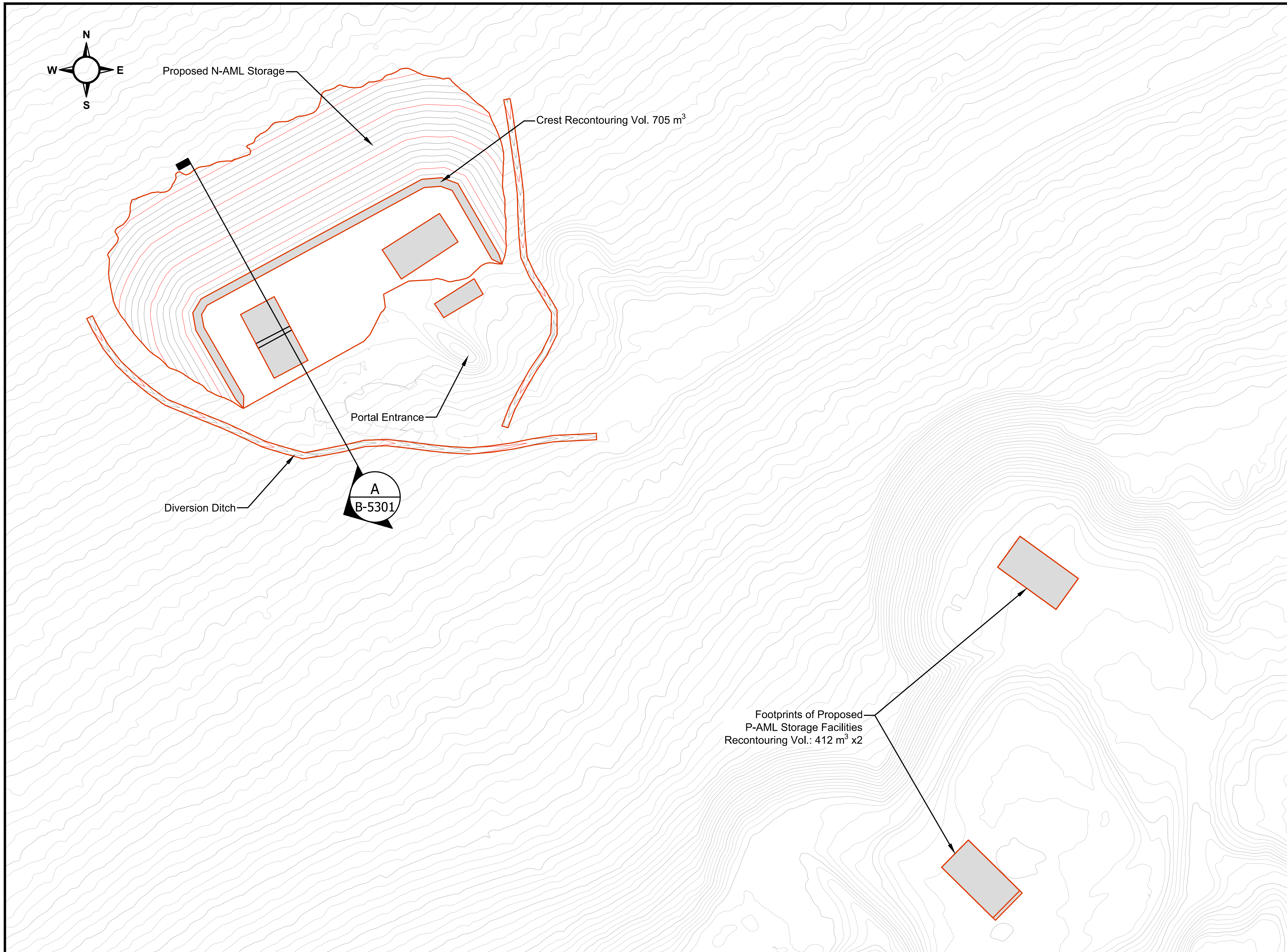

Notes:

1. P-AML waste rock contained in the P-AML WRSF will be relocated to underground.
2. The liner of the P-AML WRSF will be removed, and the containment berms will be recontoured, followed by scarification of the surface, and seeding.
3. The crest of the N-AML WRDA will be pulled back as required. Flat surfaces will be scarified and revegetated.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured: 420 m^3

Scale: 1:2000

0 12.5 25 50 m

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2018-02-05	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5101

Bermingham Grading Plan

REVISION: A	2018-02-05	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

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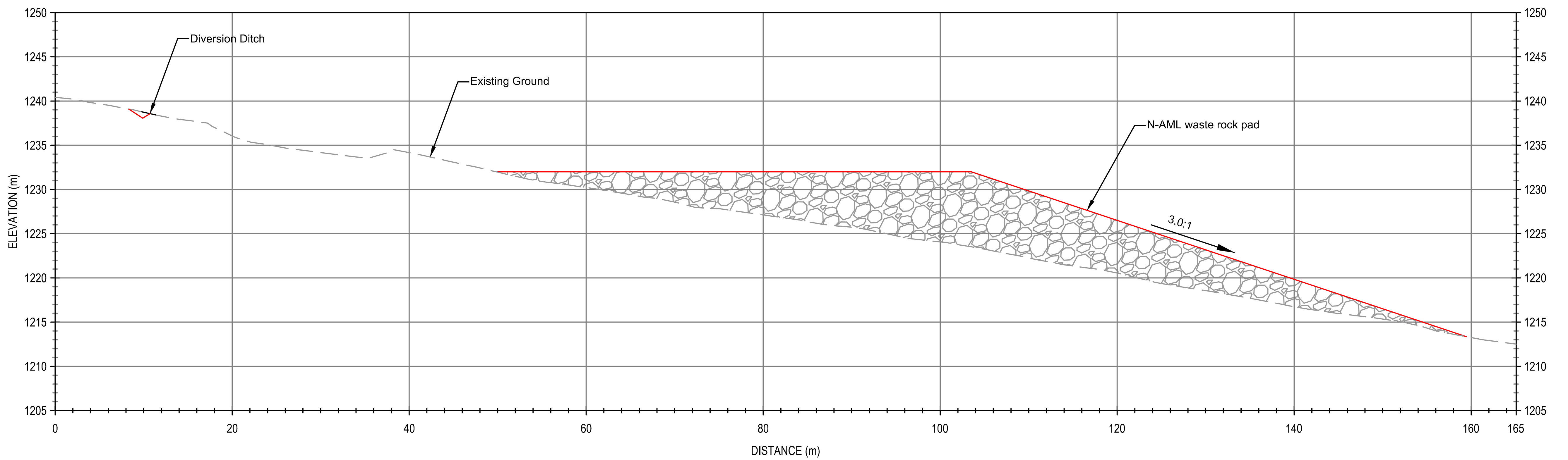


Section A

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

ALEXCO ENVIRONMENTAL GROUP

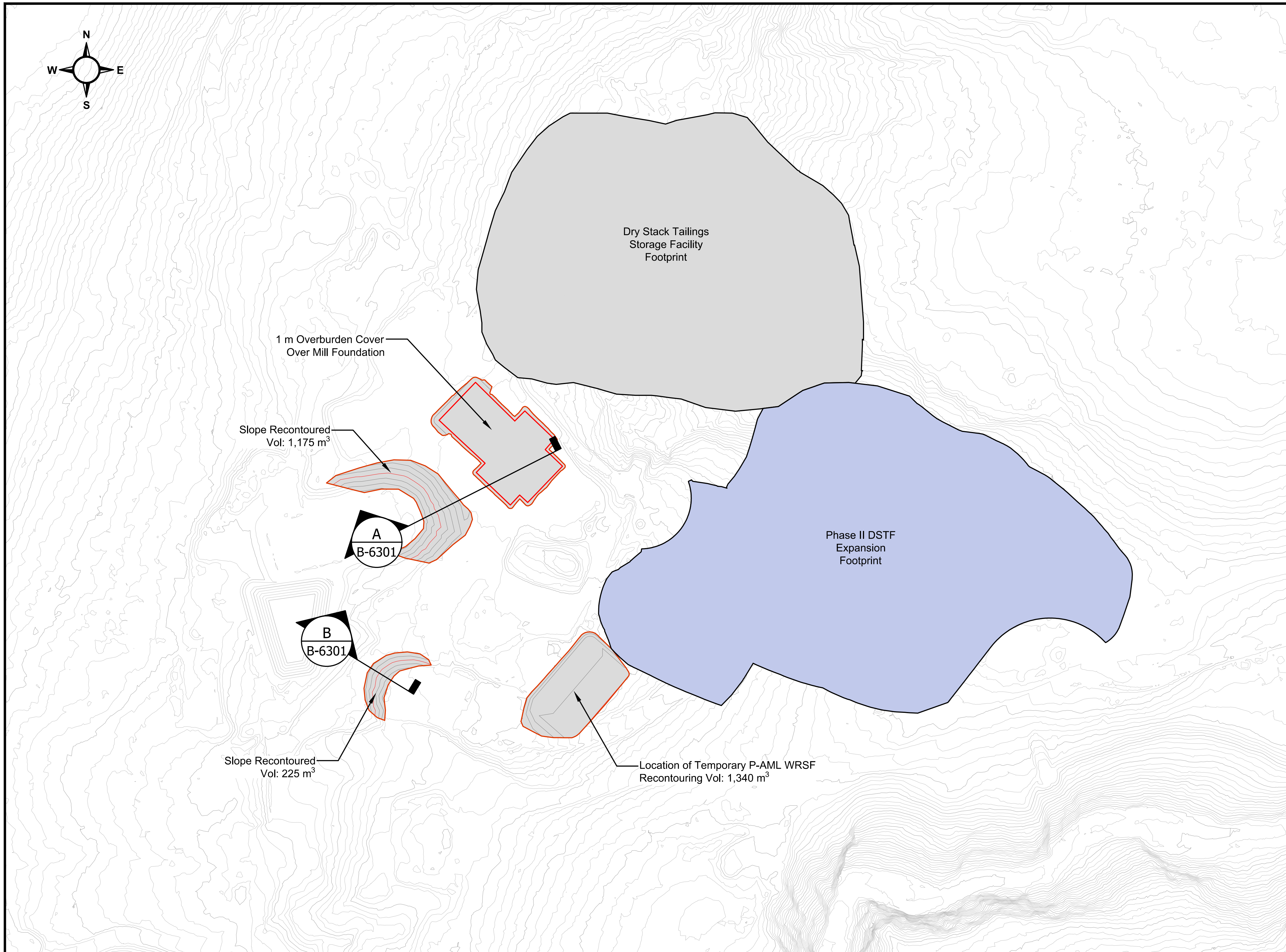
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-5301

Bermingham Grading
Cross Section

REVISION: A	2018-02-05	PRJ. No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\5-Bermingham\B-Geotech\AKHM-13-01-B-5101-BermGrading.dwg (last edited by: KBoldt; 2018/02/15 - 9:06 PM



Notes:

1. Concrete slabs and above grade footings and foundations will be broken up and covered with 1 m overburden cover, scarified, and revegetated.
2. The mill process pond will have the liner removed. The slopes will be scarified and revegetated. The pond will serve as a sedimentation pond during closure until revegetation is stabilized.
3. The mill site will be recontoured and scarified to establish drainage and facilitate revegetation.
4. Surface water diversion infrastructure (berms, ditches) will be maintained to manage runoff and limit erosion.

Quantities:

Volume of material to be recontoured: 2,740 m^3
Volume of overburden cover: 1,800 m^3

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

ALEXCO ENVIRONMENTAL GROUP

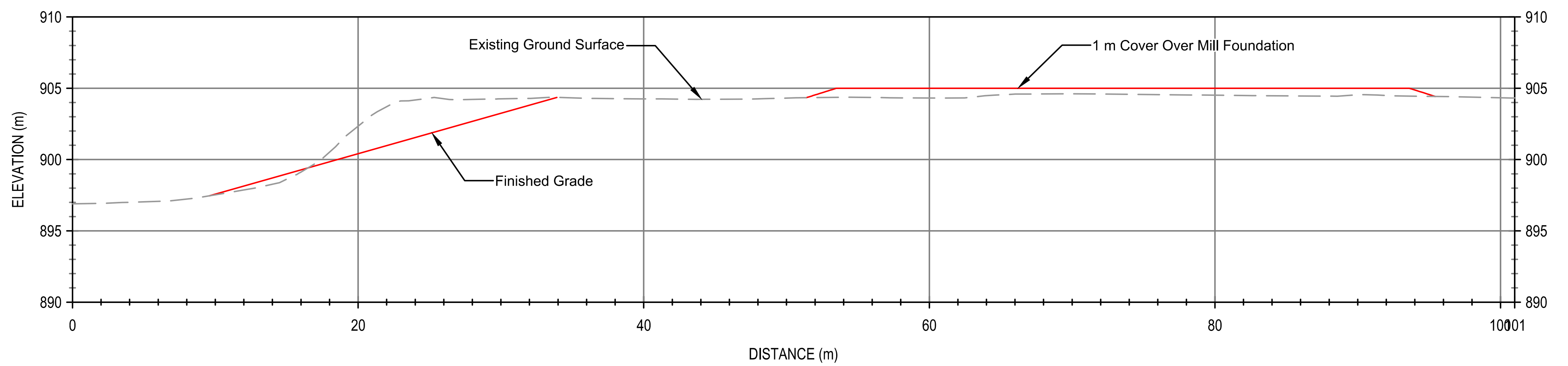
AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6101

Mill Site Grading
Plan

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

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\6-Mill Site\B-Geotech\AKHM-13-01-B-6101-MillSiteGrading.dwg (last edited by: KBoldt; 2018/02/15 - 4:44 PM



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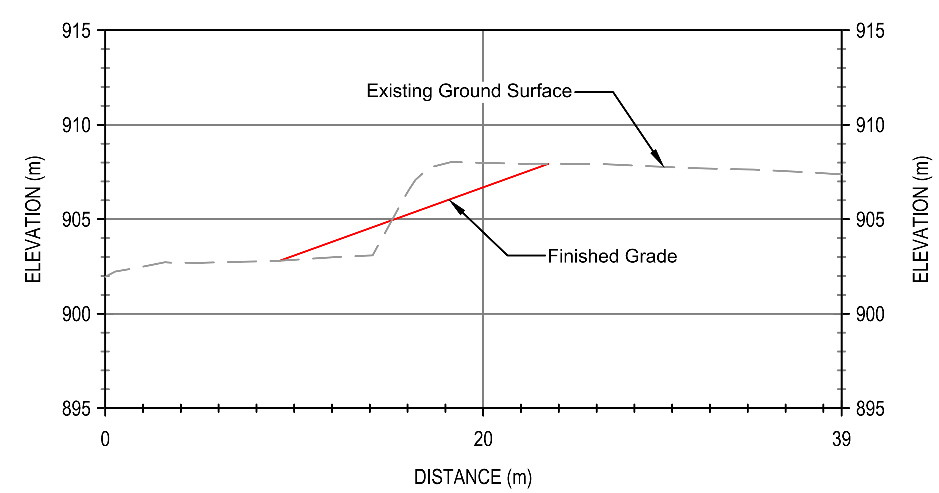

Section B

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

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-6301

Mill Site Grading
Cross Sections

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

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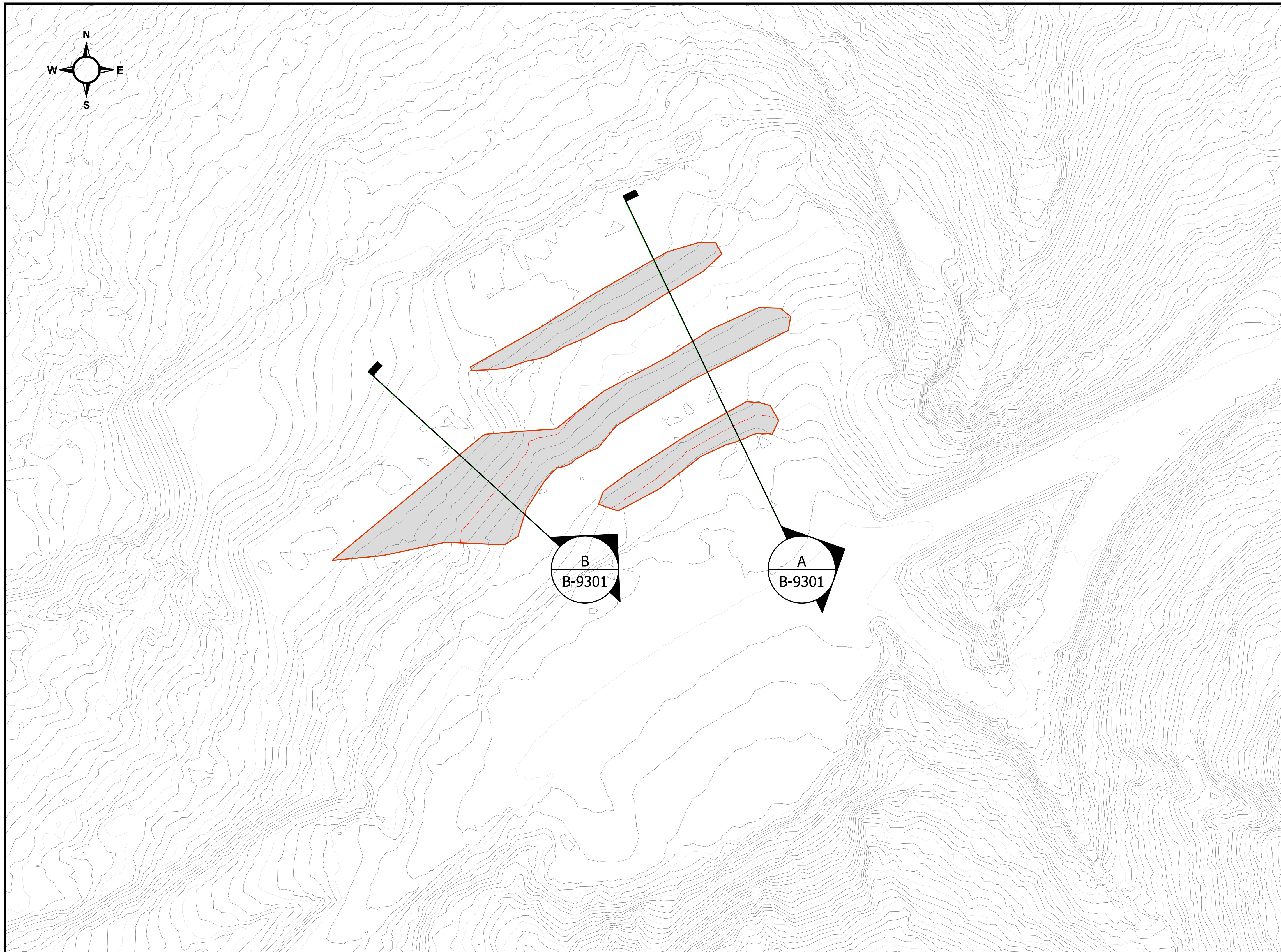

Notes:

1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:

Volume of material to be recontoured: 1,060 m^3

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
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ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9101

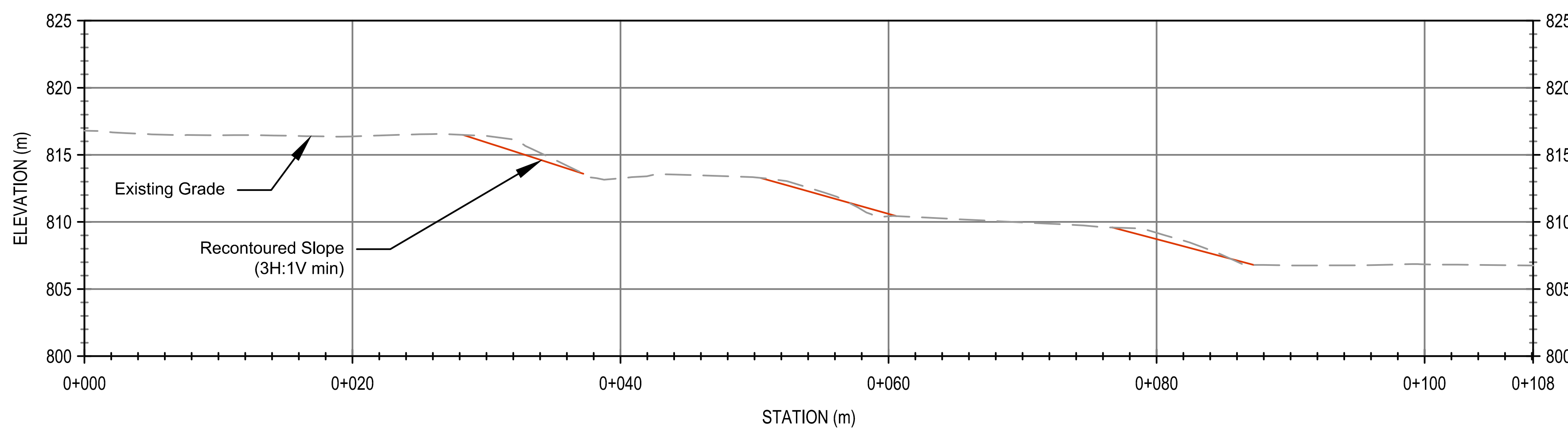
Flat Creek Camp
Grading Plan

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

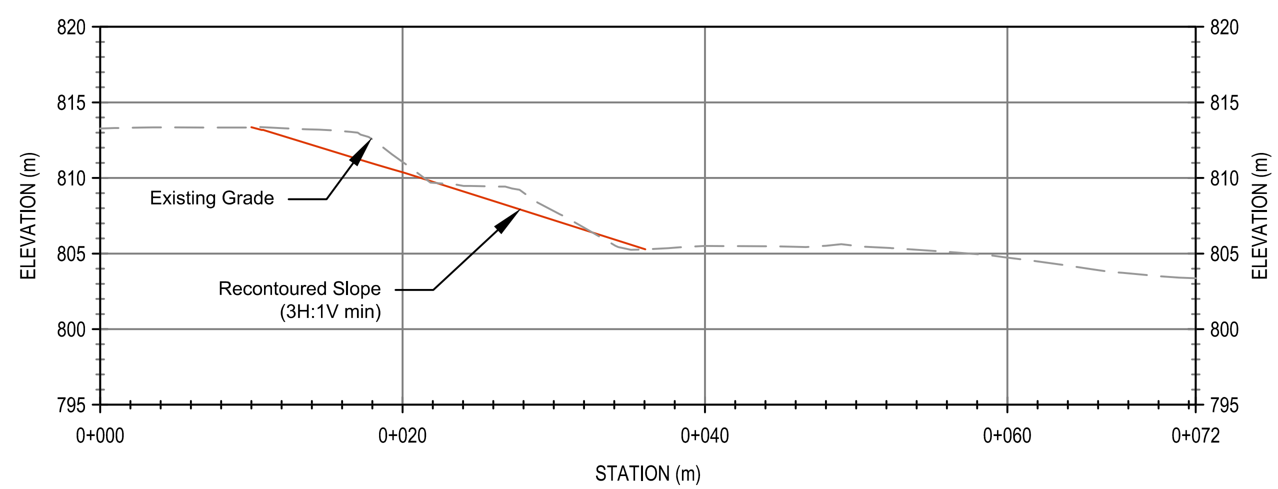
D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\9-Flat Creek Camp\B-Geotech\AKHM-13-01-B-9101-FlatCreekGrading.dwg (last edited by: KBoldt; 2018/02/15 - 2:14 PM

Notes:
1. Slopes will be recontoured as required for a 3H:1V slope.
2. Buildings and infrastructure will be removed for salvage or reuse.
3. Contaminated soil will be removed and treated in a land treatment facility.

Quantities:



Alignment-A



Alignment-B

Satelite imagery obtained from Yukon Geomatics map service http://mapservices.gov.yk.ca/ArcGIS/services on 2018-01-03.

DATE	ISSUE/REVISION	REV No.	DRW.	APP.
2018-01-18	Draft for review	A	KAB	--

ALEXCO ENVIRONMENTAL GROUP

AKHM

Keno District Mine Operations
Reclamation and Closure Plan
Drawing No: AKHM-13-01-B-9301

Flat Creek Camp
Grading Plan - Sections

REVISION: A	2018-01-18	PROJECT No.: AKHM-13-01
DRAWN BY: KAB	DESIGNED BY: KAB	REVIEWED BY: KSW

D:\Users\KBoldt\Projects\Alexco-Keno Mines\Production Drawings\9-Flat Creek Camp\B-Geotech\AKHM-13-01-B-9101-FlatCreekGrading.dwg (last edited by: KBoldt; 2018/02/15 - 2:14 PM

APPENDIX 3.2

TYPICAL WASTE CONTAINMENT FACILITY DESIGN, EBA 2008

Alexco Resource Canada Corp.

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

W14101142

July 2008

EBA Engineering Consultants Ltd.
p. 867.668.3068 • f. 867.668.4349
Calcite Business Centre • Unit 6, 151 Industrial Road • Whitehorse, Yukon Y1A 2V3 • CANADA

TABLE OF CONTENTS

APPENDICES

Section 1001

DEFINITIONS

DEFINITIONS

1.0 General

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

2.0 Definitions

Construction Drawings: the drawings, as issued for construction, of the Typical Waste Containment Facility Design.

Construction Specifications: this document.

Contract: the legal and binding agreement between the Contractor and Alexco Resource Corp. regarding construction of the Waste Containment Facility.

Contractor: the general contractor responsible for constructing the Waste Containment Facility.

Engineer: the Professional Geotechnical Engineer registered in the Yukon who is associated with the construction process.

Owner: Alexco Resource Corp.

Site: the area in which construction of the Waste Containment Facility or related activity is occurring.

Unsuitable: not meeting the requirements stated herein or not receiving the Engineer's approval.

Facility: all components of the Waste Containment Facility.

END OF SECTION

Section 1002

GENERAL

GENERAL

1.0 General

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

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

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

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

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

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

2.0 Scope of Work

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

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

d. Install the liner system consisting of a suitable liner material and if required, protective geotextile layers above and below the liner, and a geocomposite reinforcing layer;

e. Place and compact cover material, Zone A material, over the liner system;

f. Install vertical culvert as specified on the Construction Drawings;

g. Place and compact the waste material;

h. Regrade the waste material and place and compact capping material;

i. Install vegetative cover.

END OF SECTION

Section 1003

FILL MATERIALS

FILL MATERIALS

1.0 General

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

2.0 Reference Standards

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

3.0 Material Sources

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

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

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

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

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

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

4.0 Material Specifications

.1 Zone A Material

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

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

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

.2 Zone B Material

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

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

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

END OF SECTION

Section 1004

FILL PLACEMENT

FILL PLACEMENT

1.0 General

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

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

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

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

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

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

2.0 Zone B Material Placement

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

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

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

3.0 Zone A Material Placement

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

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

TABLE 1004.1: RECOMMENDED MINIMUM COVER THICKNESSES

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

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

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

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

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

END OF SECTION

Section 1005

LINER SYSTEM

LINER SYSTEM

1.0 General

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

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

2.0 Reference Standards

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

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

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

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

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

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

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

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

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

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

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

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

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

.2 Federal Test Method

a. FTM Standard 101.

3.0 Materials

.1 Geotextile

a. The non-woven geotextile shall have a weight of 542 g/m^2. The manufacturer shall, prior to shipment of materials, provide to the Engineer a signed manufacturing certification that materials to be shipped to site have test values that meet or exceed the requirements listed in Table 1005.1.

TABLE 1005.1: RECOMMENDED MINIMUM GEOTEXTILE PROPERTIES

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

b. Any visible damage to the shipment of geotextile shall be noted on the freight receipt and project records.

c. Storage of geotextile rolls on site shall be in a secure location that will minimize exposure to the elements, UV light and physical damage.

.2 Enviro Liner® 4040

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

TABLE 1005.2: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

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

b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.

c. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements and physical damage.

d. Enviro Liner® geomembrane is suitable for secondary containment of hydrocarbons and other chemicals, and primary containment of water and water based effluents or as approved by manufacturer.

.3 HDPE Liner

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

TABLE 1005.3: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

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

b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using welding techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.

c. Extrusion resin used for extrusion joining of sheets and for repairs should be HDPE from the same resin batch as the sheet resin. Physical properties must be the same as the liner sheets.

d. HDPE liner is suitable for containment of hydrocarbons and chemicals as well as water and water based effluents or as approved by manufacturer.

e. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements and physical damage.

.4 PVC Liner

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

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

TABLE 1005.4: RECOMMENDED MINIMUM GEOMEMBRANE PROPERTIES

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

b. The liner material supplied under the specifications shall not have any blisters, holes, undispersed raw materials or any signs of contamination or inclusions of foreign matter. Such defects shall be repaired using techniques in accordance with manufacturer's recommendations. Excessive defects may be grounds for rejecting the entire roll of liner.

c. PVC liner is suitable for containment of water and water based effluents or as approved by manufacturer. It is not suitable for containment of hydrocarbons.

d. Storage of geomembrane rolls on site shall be in a secure location that will minimize exposure to the elements, UV light and physical damage.

.5 Geocomposite

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

TABLE 1005.5: RECOMMENDED MINIMUM GEOCOMPOSITE PROPERTIES

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

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

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

.1 The liner system consists of the following layers (starting from the top layer):

- Geo-Comp 5 or equivalent geocomposite
- Enviroliner 4040 or equivalent geomembrane

.2 The liner should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor. The geocomposite material is only required on the floor and approach berm of the Facility.

.3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.

.4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.

.5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.

.6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

Enviro Liner® Installation

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

.8 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional piece of Enviro Liner® installed as per the manufacturer's specifications over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.

.9 Low ground pressure equipment should be used to deploy the liner material. No equipment shall be allowed on the liner.

Geocomposite Reinforcing Installation

.10 The geocomposite material should be deployed subsequent to the placement of the Liner.

.11 No equipment is permitted on the liner material during the placing of the geocomposite reinforcing material. The geocomposite reinforcing material must rolled out by hand and the cover material placed in accordance with Section 1004.

Material Quantities

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

TABLE 1005.6: MATERIAL QUANTITY ESTIMATES

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

5.0 Installation - HDPE 60 Design

.1 The liner system consists of the following layers (starting from the top layer):

- HDPE 60 mil or equivalent geomembrane

.2 The liner should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor.

.3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.

.4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.

.5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.

.6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

HDPE Liner Installation

.7 The HDPE liner should be deployed subsequent to the placement of Zone A bedding material. The liner should be placed with no horizontal seams on the slopes. Tie-in seams should be located on the floor at a minimum of 1.5 m from the toe of the slopes.

.8 The liner panels shall be welded together along the full length of the seam to the top of the berm.

.9 Both the wedge and the extrusion welding equipment should be qualified by conducting trial seam tests prior to start-up each day and at approximately 4-hour intervals during seaming operations. During the trial seam, the minimum peel and shear strength criteria set by the manufacturer for the 60 mil HDPE geomembrane should be met. The industry-accepted peel and shear strengths for 60 mil HDPE geomembrane are 78 ppi (pounds/inch) and 120 ppi, respectively.

.10 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional piece of HDPE liner extrusion welded over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.

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

Material Quantities

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

TABLE 1005.7: MATERIAL QUANTITY ESTIMATES

Material	Total Area (m^2)
HDPE 60 Liner	1900

6.0 Installation - PVC 40 Design

.1 The liner system consists of the following layers (starting from the top layer):

- Geo-Comp 5 or equivalent geocomposite
- PVC 40 mil or equivalent geomembrane

.2 The liner system should line the entire surface of the Facility, which includes the crest of the berms, inside slopes, and floor. The geocomposite material is only required on the floor and approach berm of the Facility.

.3 The Contractor shall ensure that the integrity of the liner system and its components are not compromised during construction. Precautions the Contractor may take to avoid damaging the liner system may include, but will not be limited to, providing light plants in the work area to improve visibility or using pylons to mark the lift/liner system interface.

.4 Any damage to the liner system and/or its components shall be repaired as soon as possible. Fill placement shall cease immediately in an area where the integrity of the liner system has been compromised. Fill surrounding the damaged liner system may have to be excavated, without further damaging the integrity of the liner, to permit repairs to be made. Hand excavation shall be used to expose damaged portions of the liner for repair.

.5 The liner system shall be anchored at the top of the berm so that movement downslope does not occur during backfilling at any stage of construction.

.6 The Contractor shall take the necessary steps to ensure that backfilling does not induce tensile stress in the liner system. Care shall be taken to avoid making sharp turns, sudden stops or sudden starts adjacent to the liner system. Non-essential heavy equipment traffic in the immediate vicinity of the liner system shall not be permitted.

PVC Liner Installation

.7 The PVC liner should be deployed subsequent to the placement of Zone A bedding material.

.8 The Engineer should walk the liner to observe for any defects caused by on-site equipment and tools. Any liner area showing injury due to excessive scuffing, puncture, or distress from any cause should be replaced or repaired with an additional piece of PVC liner installed as per the manufacturer's specifications over the defective area. All patches should have rounded edges and extend a minimum of 150 mm beyond the affected area.

.9 Low ground pressure equipment should be used to deploy the liner material. No equipment shall be allowed on the liner.

Geocomposite Reinforcing Installation

.10 The geocomposite material should be deployed subsequent to the placement of the Liner.

.11 No equipment is permitted on the liner material during the placing of the geocomposite reinforcing material. The geocomposite reinforcing material must rolled out by hand and the cover material placed in accordance with Section 1004.

Material Quantities

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

TABLE 1005.8: MATERIAL QUANTITY ESTIMATES

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

END OF SECTION

Section 1006

QUALITY ASSURANCE

QUALITY ASSURANCE

1.0 General

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

2.0 Reference Standards

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

a. ASTM C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

b. ASTM D698 – Standard -Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))

d. ASTM D4437 – Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes.

.2 Geosynthetic Research Institute

a. GRI Test Method GM6 – Pressurized Air Channel Test for Dual Seamed Geomembranes.

3.0 Fill Particle Size Testing Requirements

.1 Zone A Material

a. Samples of the Zone A material should be evaluated from locations within the borrow source prior to construction. One sample will be evaluated every 500 m^3 placed during construction to ensure the placed gradation meets the specification stated herein. The required tests and testing frequency for the Zone A material are presented in Table 1006.1.

TABLE 1006.1: TESTING AND FREQUENCY OF ZONE A MATERIAL

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

.2 Zone B Material

a. Samples of the Zone B material will be evaluated from the foundation material within the Facility prior to construction and every 2000 m^3 placed during construction to ensure the placed gradation meets the specification stated herein. The required tests and testing frequency for the Zone B material are presented in Table 1006.2.

TABLE 1006.2: TESTING AND FREQUENCY OF ZONE B MATERIAL

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

4.0 Fill Compaction Testing Requirements

.1 Zone A Material

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

.2 Zone B Material

a. Compact each lift with a minimum of six passes using a large smooth-drum, vibratory compactor. The optimum vibratory frequency and number of passes should be determined during construction using proof-roll tests, which demonstrate optimum compaction. The Engineer should inspect the compaction effort to ensure that this effort results in a density equivalent to about 98% MDD.

b. The foundation material (Zone B or subcut material) should also be compacted as specified in section 1006.4.1.

5.0 Geomembrane Testing Requirements

.1 General

a. The Contractor is responsible for obtaining mill certificates from the manufacturer and forwarding them to the Engineer.

b. If applicable, the Contractor shall record all seam parameters (i.e. time, date, operator, welding speed and temperature) on the liner.

c. If applicable, the Contractor shall be responsible for completing the vacuum box testing and pressure testing for the appropriate seams. The Contractor shall mark the test number and parameters on the liner.

d. If applicable, the Contractor shall supply and use a field tensiometer for testing liner seams for shear and peel strength.

e. The Contractor is responsible for maintaining testing records.

f. All coupons and test specimens remain the property of the Owner.

.2 Qualifying Welds

a. Qualifying seams shall be conducted on fragmented pieces of material at the following times:

- At the start of each shift of production seaming, and at 4 hour intervals during production seaming;
- When a new operator or new machine starts welding;
- When a machine is restarted after repairs;
- When welding is stopped for sixty (60) minutes or more;
- When there is a change in the ambient conditions; and
- At the discretion of the Engineer.

b. Qualifying seams shall be 1 m long, and shall be subject to shear and peel testing. The test seam shall meet the minimum requirements stated herein for seam strength, when tested on a field tensiometer. If a qualifying seam fails, the seaming procedure shall be reviewed and the test shall be repeated.

.3 Non-Destructive Testing

a. Test all wedge-welded seams over their full length using a vacuum unit or air pressure test.

- Seam intersections will also be subject to vacuum box testing, regardless of seaming method employed.
- The Contractor shall supply all apparatus and personnel for this type of test.
- The tests shall be witnessed and documented by the Engineer.

b. Clean all seams to permit proper inspection.

c. Repair any seams which fail non-destructive testing in accordance with this Specification. Repairs shall be fully documented by the Contractor.

.4 Vacuum Box Testing

a. Extrusion welded seams should be tested using either vacuum box testing or pick-testing. Vacuum box testing involves placing the extrusion weld under a vacuum. The weld is first coated with a soapy water solution and any holes in a weld would be indicated by a stream of bubbles when vacuum is applied.

b. No leaks shall be permitted while conducting vacuum box testing.

c. Pick-testing is conducted on uneven surfaces where a vacuum cannot be maintained. During pick testing, attention should be paid to the following specific items:

- The width of the weld;
- Weld bond to the underlying geomembrane;
- Joints between three panels ("T" joints);
- Defects such as bubbles created within the weld due to moisture; and
- Textured weld surfaces due to temperature fluctuation in the extrusion welder.

.5 Air Pressure Testing

a. Wedge welded seams should be air-pressure tested over their full lengths using an air pressure test. Air pressure testing involves pressurizing the air channel located between the dual tracks of the seams to a minimum pressure of 40 psi for a period of five minutes.

b. During the test, the air pressure is not allowed to drop more than 4 psi (10% allowance). Any leaks and bubbling in the seams found during the non-destructive tests must be repaired by extruding a patch of HDPE material over the defect.

c. Air pressure testing shall be carried out according to GRI Test Method GM6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

.6 Destructive Testing for Production Seams

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

b. All holes left by cut outs shall be patched immediately.

.7 Testing of Repairs

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

END OF SECTION

Section 1007

DESIGN ALTERNATIVES

DESIGN ALTERNATIVES

1.0 General

.1 This section provides design alternatives for the Facility should the fill materials available on or near site not adhere to the gradation specifications stated in Tables 1003.1 and 1003.2.

.2 Should Zone A, Zone B or both materials not meet the gradation specifications stated in Tables 1003.1 and 1003.2 then the recommended design alternatives are available in Table 1007.1.

TABLE 1007.1: RECOMMENDED DESIGN ALTERNATIVES FOR GRADATION NON-COMPLIANCE

		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	This section does not apply	This section does not apply	See Section 1007.2
	Gradation Below Fine Limit	See Section 1007.2	See Section 1007.2	See Section 1007.2
	Gradation Above Coarse Limit	See Section 1007.3	See Section 1007.3	See Section 1007.4

2.0 Detailed Design Alternatives – Non-Compliance Criteria I

.1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required at the interface between Zone A and Zone B materials.

.2 The geotextile material should be deployed prior to the placement of Zone A material.

.3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.

.4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

3.0 Detailed Design Alternatives – Non-Compliance Criteria II

.1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required above and below the liner system.

.2 The geotextile material should be deployed prior to the deployment of the liner system as well as subsequent to the deployment of the liner system.

.3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.

.4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

4.0 Detailed Design Alternatives – Non-Compliance Criteria III

.1 If the fill materials do not comply with gradation specifications as per Table 1007.1 geotextile material is required above and below the liner system as well as at the interface between Zone A and Zone B materials.

.2 The geotextile material should be placed prior to the placing of Zone A material, prior to the deployment of the liner system as well as subsequent to the deployment of the liner system.

.3 The geotextile should be placed with a minimum overlap of 150 mm and connected at the seam by heat bonding. If heat bonding is not available an overlap of 300 mm should be used. Horizontal seams should be kept to a minimum on the side slopes. If a horizontal seam is unavoidable, the overlap shall be capped with a 300 mm wide strip of the same geotextile and heat bonded to the underlying material.

.4 Any tears or holes made in the geotextile should be repaired by placing a patch of geotextile on the defect and held in place by heat bonding. The patch should extend at least 300 mm beyond the damage, in all directions.

END OF SECTION

Section 1008

OPERATION AND MAINTENANCE

OPERATION AND MAINTENANCE

5.0 General

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

6.0 Geomembrane Lined Pad

.1 Structure Maintenance

a. This section refers to the structure as the berm, side slopes, and floor of the Facility.

b. The structure shall be inspected regularly. Attention shall be concentrated on the following:

- Eroded and/or damaged granular slope and floor surfaces and
- Exposed liner material

c. Any identified problems should be repaired immediately. The repair can be conducted by reconstructing the damaged or eroded slopes with a material of similar gradation to Zone A material. Any exposed liner material can be recovered with Zone A material; however, if the liner material is damaged, liner installation personnel shall be retained to repair the liner.

.2 Surface Water Management

a. The Facility is designed to drain all surface water to the installed vertical culvert. Each month, the water lever must be inspected, pumped and disposed of appropriately.

b. The frequency of monitoring must be increased during times of high precipitation or snow melt within the Facility.

7.0 Filling Procedure

.1 The filling procedure for the Facility is as follows:

a. Waste material is not to exceed a height of 3.0 m above the level of the top of the berm unless approved by the Engineer;

b. Waste material is not to be placed higher than relative elevation 0.5 m below the crest of the liner unless approved by the Engineer.

8.0 Closure

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

TABLE 1008.1: CAPPING MATERIAL- PARTICLE SIZE DISTRIBUTION LIMITS

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

.2 The capping material shall have a minimum thickness of 0.5 m.

.3 The vegetative cover must be capable of self-regeneration without continuous dependence on fertilizer or re-seeding.

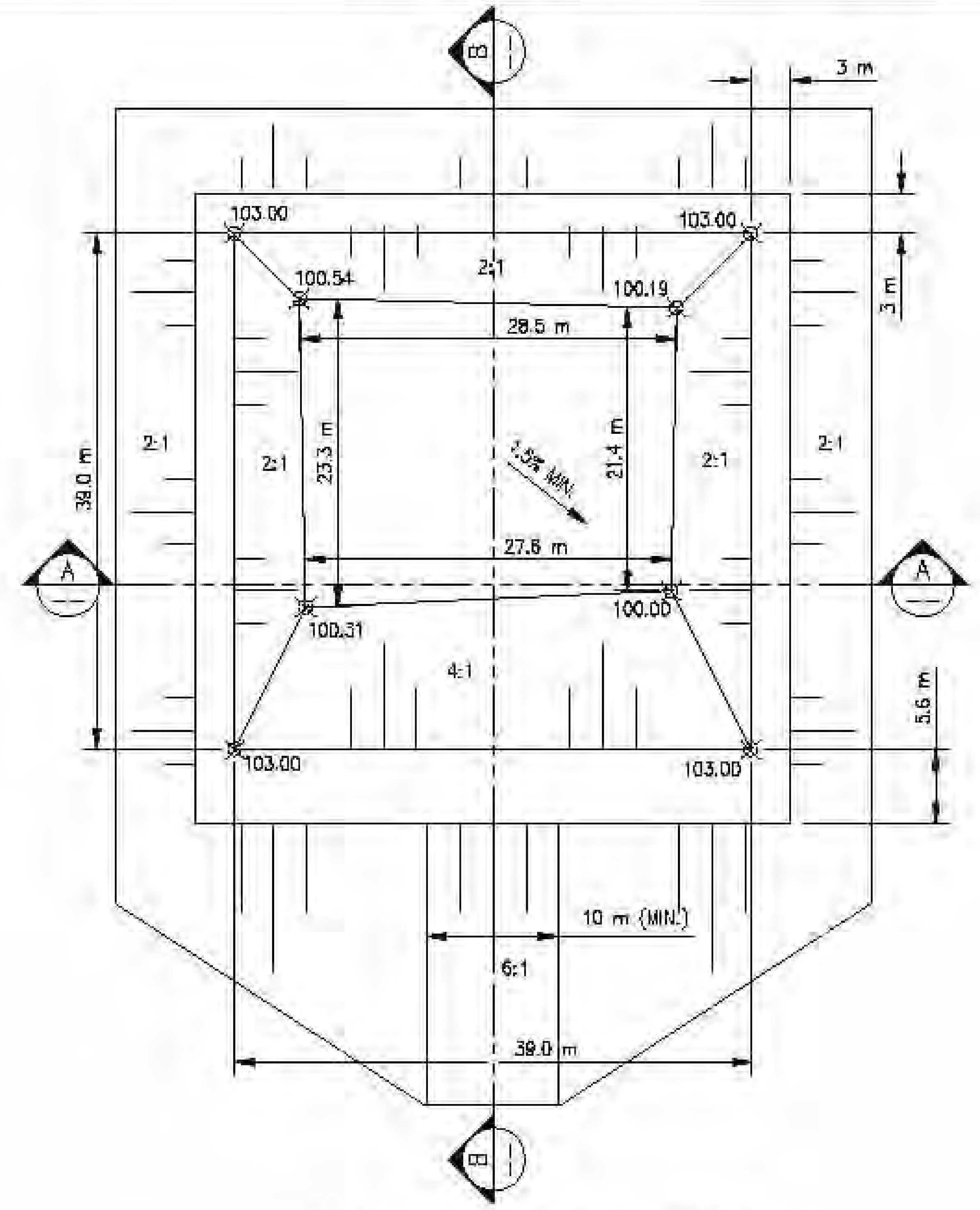
.4 The vegetative cover must have sufficient density and species diversity to stabilize the surface against the effects of long term erosion.

.5 Closure monitoring should include inspection for any ponding water. If ponded water is present capping material should be added or re-graded.

END OF SECTION

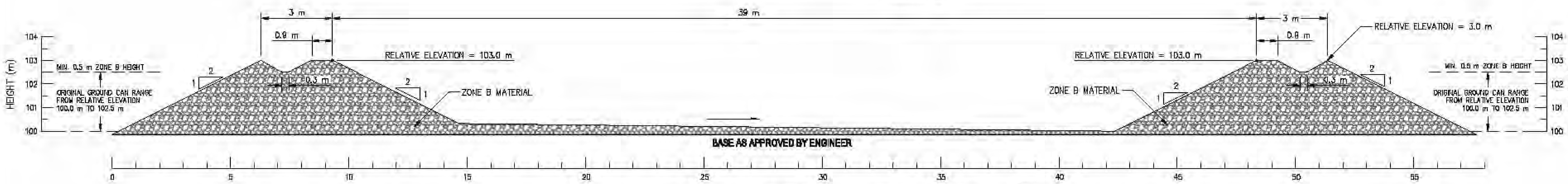
APPENDIX

APPENDIX A CONSTRUCTION DRAWINGS



PLAN – ZONE B MATERIAL

SCALE: 1 : 400



CROSS-SECTION A

SCALE: 1 : 100

CROSS-SECTION B

SCALE: 1 : 100

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1600 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEM AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.
3. ALL ELEVATIONS ON PLAN ARE FOR TOP OF ZONE B MATERIAL.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPS	ISSUED FOR CONSTRUCTION
A	08/06/26	JPS	ISSUED FOR REVIEW

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng.
Date: July 9, 2008

Seal: Jason Berkers, P.Eng.
Date: July 9, 2008

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ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE B MATERIAL PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DWN	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPS	0	WCF-1
DATE	SHEET No.	DWN	APR	STATUS	
June 26, 2008	1 of 4	KJT	JRT	B	

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1600 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.
3. ALL ELEVATIONS ON PLAN ARE FOR TOP OF ZONE A MATERIAL.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPB	ISSUED FOR CONSTRUCTION
A	08/06/26	JPS	ISSUED FOR REVIEW

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng. Date: July 8, 2008

Seal: Jason Berkers, P.Eng. Date: July 9, 2008

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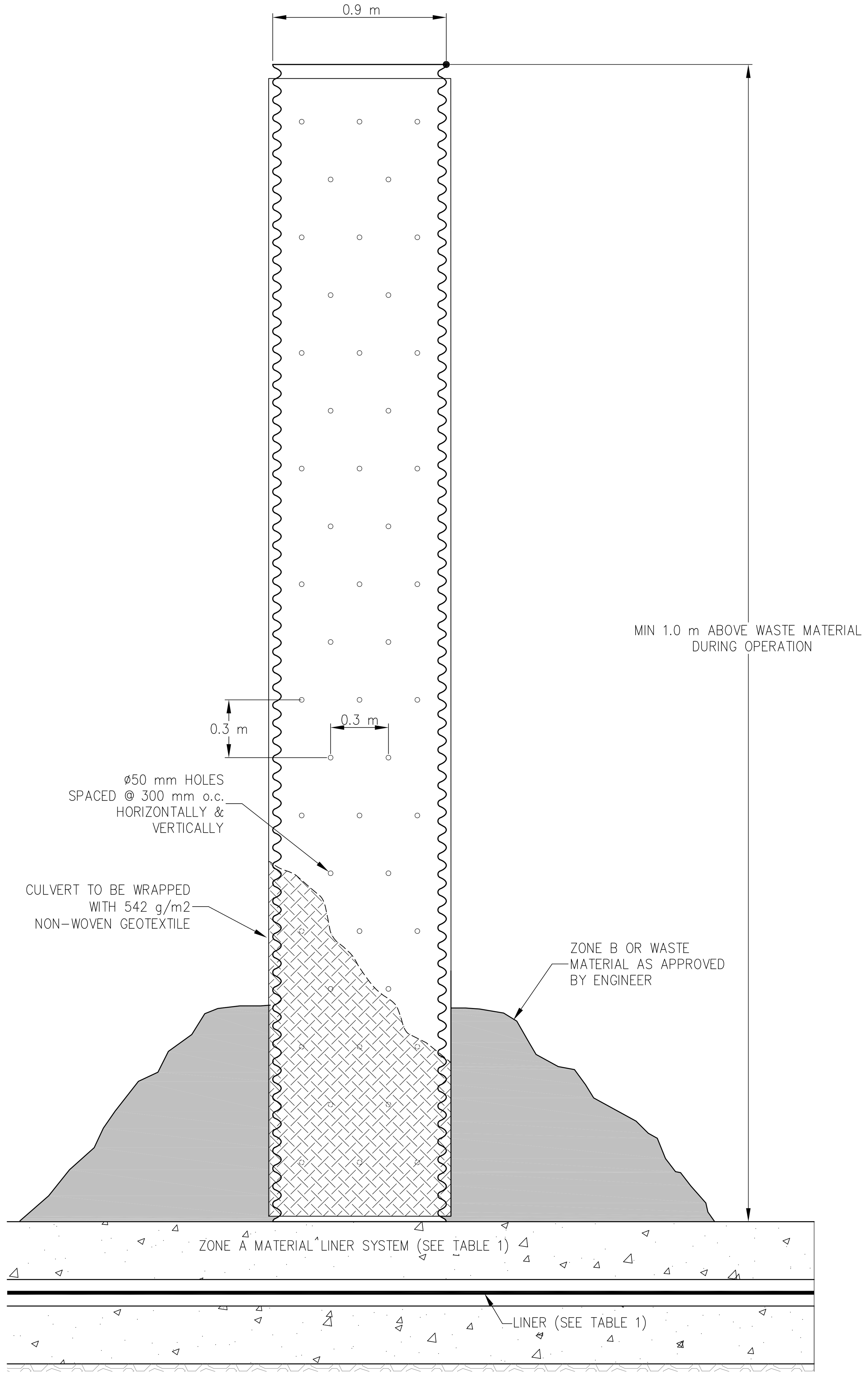
CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

ZONE A MATERIAL PLAN & CROSS SECTIONS

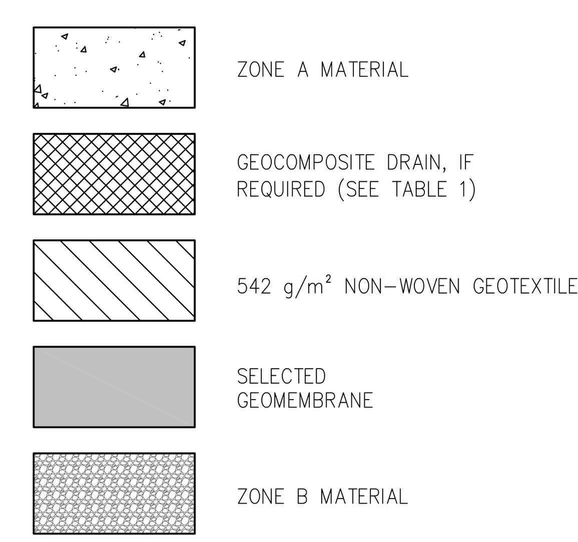
PROJECT No.	OFFICE	DSN	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPB	0	WCF-2
DATE: June 26, 2008	SHEET No. 2 of 4	DWN: KJT	APP: JRT	STATUS: B	



DETAIL 1 – VERTICAL CULVERT (9 / WCF-1)

SCALE: 1 : 20

LINER SYSTEM DETAIL KEY



LINER SYSTEM FLOOR & APPROACH BERM

LINER SYSTEM BERMS

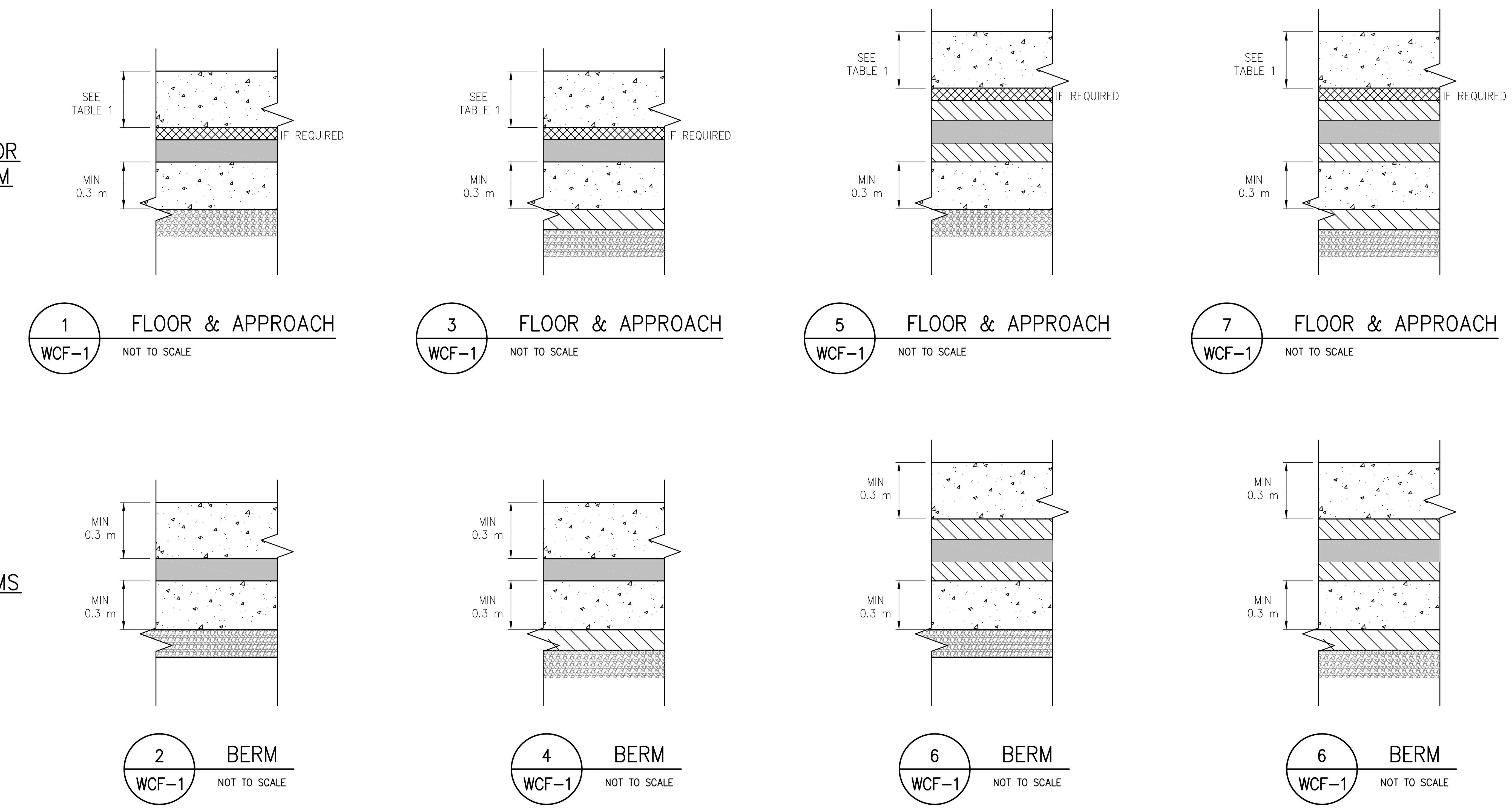


Table 1: Recommended Minimum Cover Thicknesses

Liner Material	Drainage Composite	Minimum Required Thickness
Enviro Liner® 4040 (Without Geocomposite)	Not Required	1.3 m
Enviro Liner® 4040 (With Geocomposite)	Required	0.3 m
HDPE 60	Not Required	0.3 m
PVC 40 (With Geocomposite)	Required	0.3 m

Table 2: Liner System Floor and Approach Berm

		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	Detail 1	Detail 1	Detail 3
	Gradation Below Fine Limit	Detail 3	Detail 3	Detail 3
	Gradation Above Coarse Limit	Detail 5	Detail 5	Detail 7

Table 3: Liner System Berm

		Zone B		
		Meets Specifications	Gradation Below Fine Limit	Gradation Above Coarse Limit
Zone A	Meets Specifications	Detail 1	Detail 1	Detail 3
	Gradation Below Fine Limit	Detail 3	Detail 3	Detail 3
	Gradation Above Coarse Limit	Detail 5	Detail 5	Detail 7

Table 4: Zone A Material (10 mm Minus) - Particle Size Distribution Limits

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

Table 5: Zone B Material (200 mm Minus) - Particle Size Distribution Limits

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

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1900 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTRUCTION.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
B	08/07/08	JPB	ISSUED FOR CONSTRUCTION
A	08/06/25	JPB	ISSUED FOR REVIEW

ORIGINAL SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng. Date: July 8, 2008

Seal: Jason Berkers, P.Eng. Date: July 8, 2008

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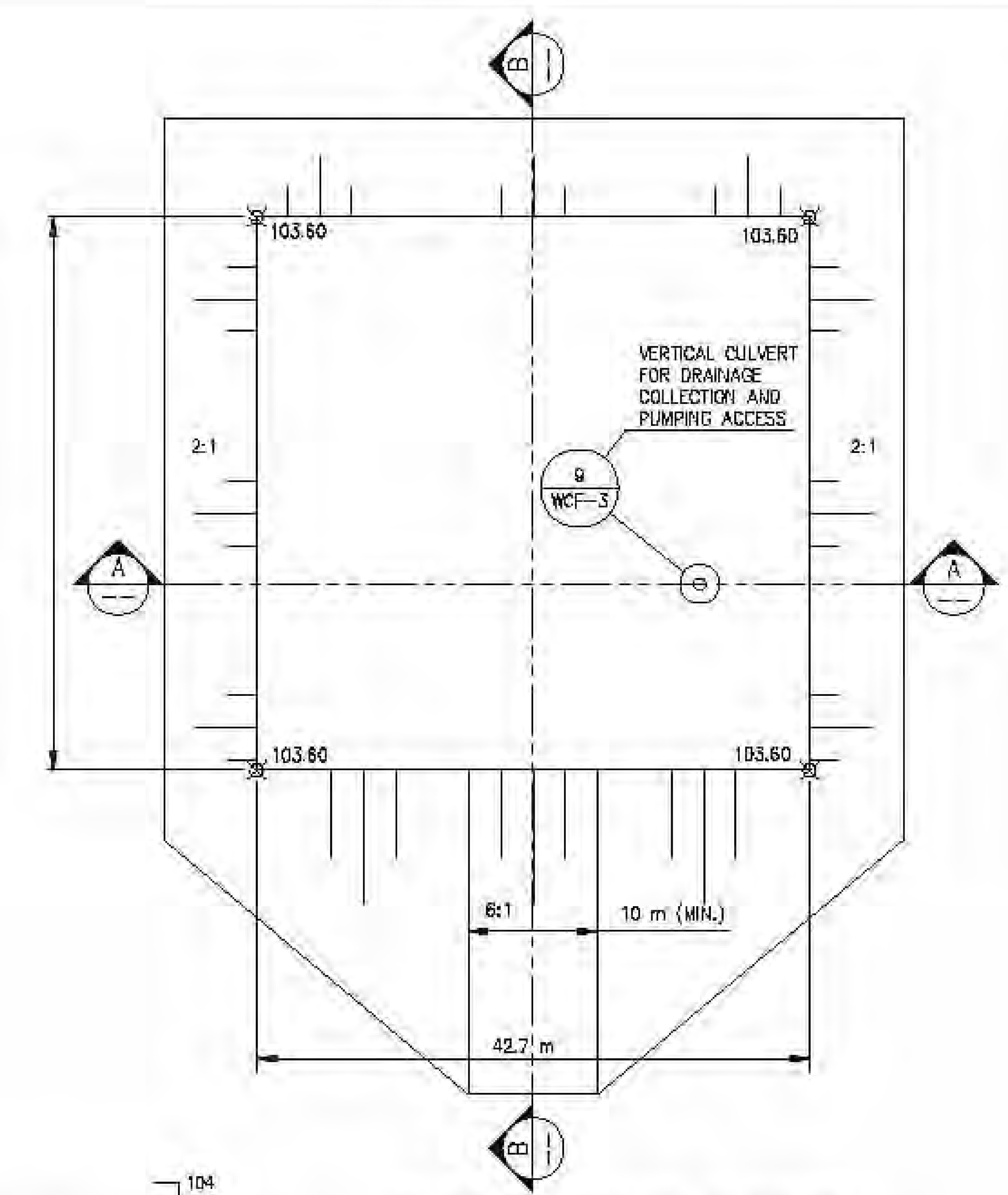
CLIENT: ALEXCO

EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

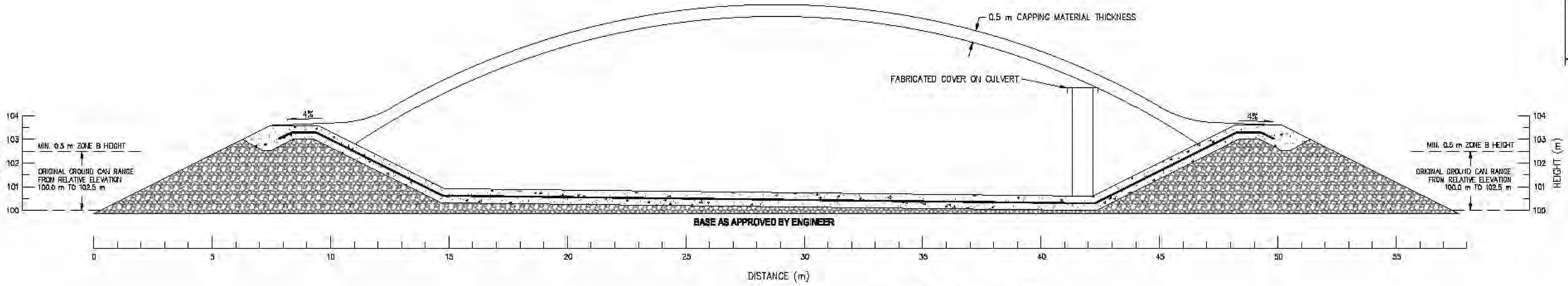
DETAILS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPB	0	WCF-3
DATE: JUNE 25, 2008	SHEET No. 3 of 4	DWN KJT	APP JRT	STATUS B	



PLAN – FACILITY CLOSURE

SCALE: 1 : 400



CROSS-SECTION A

SCALE: 1 : 100

CROSS-SECTION B

SCALE: 1 : 100

ISSUED FOR CONSTRUCTION

NOTES

1. CONTAINMENT FACILITY SIZED FOR 1800 m² OF GEOMEMBRANE. CONFIGURATION OF BASE AREA CAN BE MODIFIED SHOULD SITE CONDITIONS WARRANT. HOWEVER, SPECIFIED BERM CROSS-SECTION, FILL MATERIALS, LINER SYSTEMS AND GENERAL DESIGN CRITERIA MUST BE ADHERED TO.
2. SPECIFIC CONDITIONS AND FACILITY LOCATION HAVE NOT BEEN PROVIDED OR CONSIDERED. ONCE FACILITY LOCATION AND SITE SPECIFIC CONDITIONS ARE KNOWN, THEY MUST BE APPROVED BY THE ENGINEER PRIOR TO CONSTUCTION.

REVISIONS

NUM	DATE	DWN	CKD	APR	DESCRIPTION

DRAWING STATUS

NUM	DATE	APR	DESCRIPTION
2	08/07/08	JPB	ISSUED FOR CONSTRUCTION
1	08/06/26	JPS	ISSUED FOR REVIEW

ORIGINAL
SIGNED AND SEALED

Permit: J. Richard Trimble, P.Eng.
Date: July 8, 2008

Seal: Jason Berkers, P.Eng.
Date: July 9, 2008

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EBA Engineering Consultants Ltd.

TYPICAL WASTE CONTAINMENT FACILITY DESIGN
KENO HILL SILVER DISTRICT, YT

FACILITY CLOSURE PLAN & CROSS SECTIONS

PROJECT No.	OFFICE	DGN	CKD	REV	DRAWING
W14101142	WHSE	JTP	JPB	0	WCF-4
DATE	SHEET No.	DWN	APP	STATUS	
June 26, 2008	4 of 4	KJT	JRT	B	

APPENDIX 3.3

GEOCHEMISTRY SUMMARY FOR WASTE ROCK AND TAILINGS

Memorandum

To: Kai Woloshyn, Alexco Resource Corp.

From: Andrew Gault, Alexco Environmental Group Inc.

CC: Brad Thrall, Alexco Resource Corp.

Date: February 15, 2018

Re: AKHM ARD/ML Characterization Update – February 2018

1 INTRODUCTION

Acid rock drainage and metal leaching (ARD/ML) characterization of waste rock and tailings produced from prospective production areas in the Keno Hill District (KHSD) has been ongoing since Alexco Keno Hill Mining Corp. (AKHM) initiated exploration in 2006. This dataset includes static (e.g., acid base accounting, bulk metals, soluble metals) and kinetic (e.g., humidity cells and field barrels) of material from the following areas:

- Bellekeno;
- Onek;
- Lucky Queen;
- Flame & Moth;
- Silver King; and
- Bermingham.

This memorandum summarizes the static and kinetic data collected by AKHM to date. More detailed reporting can be found in the source documentation cited throughout.

2 REGIONAL AND DISTRICT GEOLOGY

The KHSD is primarily composed of Yukon Group metasedimentary rocks which are described in the Keno Hill Silver District Environmental Conditions Report (AEG, 2016a) and the NI43-101 technical report for the Bermingham Exploration Project (Roscoe Postle and Associates Inc., 2017). The mineralization of the KHSD is hosted within the Mississippian Keno Hill Quartzite Formation in the Tombstone Thrust Sheet, which conformably overlies the Devonian Earn Group to the north and is structurally overlain by the Upper Proterozoic Hyland Group Yusezyu Formation across the Robert Service Thrust Fault in the south (Roscoe Postle and Associates Inc., 2017).

The stratigraphic units in the district are mainly composed of the Earn Group and the Keno Hill Quartzite. The Earn Group comprises typically phyllitic, grey graphitic metasediments with an upper band of greenish chlorite-sericite meta-felsic volcanics, and minor interbedded quartzite proximal to the conformable transition to the overlying Keno Hill Basal Quartzite Member. The Keno Hill Quartzite is structurally approximately 1,900 m thick and contains the lower massive blocky Basal Quartzite Member (approximate structural thickness of 1,100 m) with thin to thick quartzite and graphitic schist interbeds and the Sourdough Hill Member (~800 m) with basal horizons of sericitic meta-rhyolite and graphitic schist, intermediate units of an Upper Quartzite, quartz eye grits, and chloritic schist that enter an overlying carbonate rich section containing well-defined black limestone beds. Mid-Triassic greenstone lenses up to 100 m thick are also contained within the Keno Hill sequence but only to the top of the Basal Quartzite Member (Roscoe Postle and Associates Inc., 2017).

One to two phases of deformation and chloritic grade regional metamorphism and isoclinic folding produced overturned isoclines in the Keno Hill Quartzite Basal Member overlying the Earn Group. The mineralization was developed in northeast striking, southeasterly dipping normal oblique normal faults with displacement of tens to hundreds of metres formed likely during the early stages of deformation.

The KHSD mineralization is in the form of silver-rich base metal quartz-carbonate veins that are predominantly present in steep southeasterly dipping vein-filled faults with deposits hosted by thick competent Basal Quartzite of the Keno Hill Quartzite or occasionally where greenstone forms part of the Earn Group wall rock (Roscoe Postle and Associates Inc., 2017).

A brief descriptive overview of the major lithology types is summarized below from Boyle (1962), Altura (2008a) and (Roscoe Postle and Associates Inc., 2017).

- Quartzite (QTZT): The dominant lithology unit at the Bermingham deposit development rock and occurs both as thickly and thinly bedded sequences with assemblages of graphitic schist. The quartzites are variably silicified with purer quartzites a few metres thick and darker grey, impure quartzites on to four metres thick. Quartzites are comprised primarily of quartz but also contain some mica, carbonate minerals and carbonaceous materials. Accessory minerals include leucoxene, tourmaline, zircon, apatite and pyrite. Calcareous quartzite (CQTZT) contains disseminated primary calcite that fizzes readily when subjected to dilute hydrochloric acid.

- Schist (SCH): The schist within the Bermingham development area are most commonly graphitic schist (GSCH), which are black or dark gray in color due to their significant carbon content, occur in beds from millimetre to many meters in scale, and can be intercalated with quartzites as well as the other lithologies. In addition to graphite; quartz, mica, carbonates, feldspar, chlorite, isotropic colloidal material and pyrite metacrysts have been identified in thin sections within these rocks. Although not anticipated to be present in significant quantities in the Bermingham development (i.e., <5%), other forms of schist are documented elsewhere in the KHSD. These include quartz sericite schist (SSCH) and chlorite schists (CHSCH), which are pale to dark green in colour. Thin sections of sericite schists show primarily quartz and sericite composition, with trace carbonate minerals and leucoxene. Accessory minerals include apatite, zircon, tourmaline and pyrite metacrysts. Calcareous schist (CSCH) contains disseminated primary calcite that fizzes readily when subjected to dilute hydrochloric acid (HCl). Interbedded carbonaceous quartzite and schist (ICQS) and thin bedded quartzite (TQTZT), the latter of which does occur in the Bermingham development area, are also included as their own lithologies, but these units are predominantly composed of schist.

- Greenstone (GNST): Greenstones vary from narrow (0.3 – 2 m wide) to 100 m thick and vary in color from greyish green to dark green. Greenstones occur in conformable elongated lenses and sills as a result of boudinage, particularly within the more ductile schist units. Greenstones units are generally more resistant than the quartzites and schists and appear geomorphologically as the prominent hills in the KHSD. Thin sections show significant variety in mineral composition and texture but generally show a high degree of alteration. The primary mineralogy of the greenstones includes hornblende, actinolite, saussurite (zoisite, epidote, albite, sericite, carbonate), plagioclase (oligoclase to andesine), chlorite, stilpnomelane, biotite, sericite, leucoxene, and carbonate minerals. Quartz, K-feldspar, ilmenite, magnetite, limonite and apatite are minor constituents with some pyrite. Chlorite is also generally present, which is primarily responsible for this rock's color.

3 DATA SOURCES

The data presented in this summary memorandum are primarily sourced from AKHM's growing database of ARD/ML static and kinetic testing of waste rock and tailings produced from exploration of deposits of interest in the KHSD. These largely comprise waste rock from:

- Bellekeno;
- Lucky Queen;
- Onek;
- Flame & Moth;
- Silver King; and
- Bermingham.

Tailings material has also been produced from ore and mineralized rock from the Bellekeno, Lucky Queen, Onek, Flame & Moth, and Bermingham deposits.

3.1 STATIC TESTING

Static testing of these materials has typically consisted of:

- Acid base accounting (ABA) analyses, including:
    - Paste pH;
    - Siderite-corrected neutralization potential (NP) using the method of Skousen et al. (1997);
    - Total sulphur by Leco;
    - Sulphate sulphur by HCl extraction;
    - Sulphide sulphur by difference, used to calculate acid potential (AP); and
    - Total inorganic carbon (TIC) by HCl leaching.
- Bulk element analysis by aqua regia digestion and ICP-MS analysis of digestate; and
- Shake flask extraction (SFE) to determine soluble constituents associated with these materials.

3.2 KINETIC TESTING

Kinetic testing has largely comprised either laboratory-based humidity cells or site-based field barrels. Humidity cells have been completed or are ongoing for the following materials:

- Flame & Moth non-acid generating/metal leaching (N-AML) waste rock composite (98 weeks, completed);
- Bermingham N-AML waste rock composite (18 weeks, ongoing);
- Bellekeno tailings (212 weeks, completed); and
- Flame & Moth tailings (113 weeks, completed).

Five field barrels have also been in operation at the KHSD site since June 2013 and comprise Flame & Moth waste rock drill core (280 to 340 kg) in barrels that are open to the atmosphere. The barrels contain a range of N-AML and potentially acid generating/metal leaching (P-AML) waste rock. Precipitation that percolates through the barrels is collected in pails that are sampled on a monthly basis during the ice-free months.

4 Static Testing Data

4.1 Waste Rock

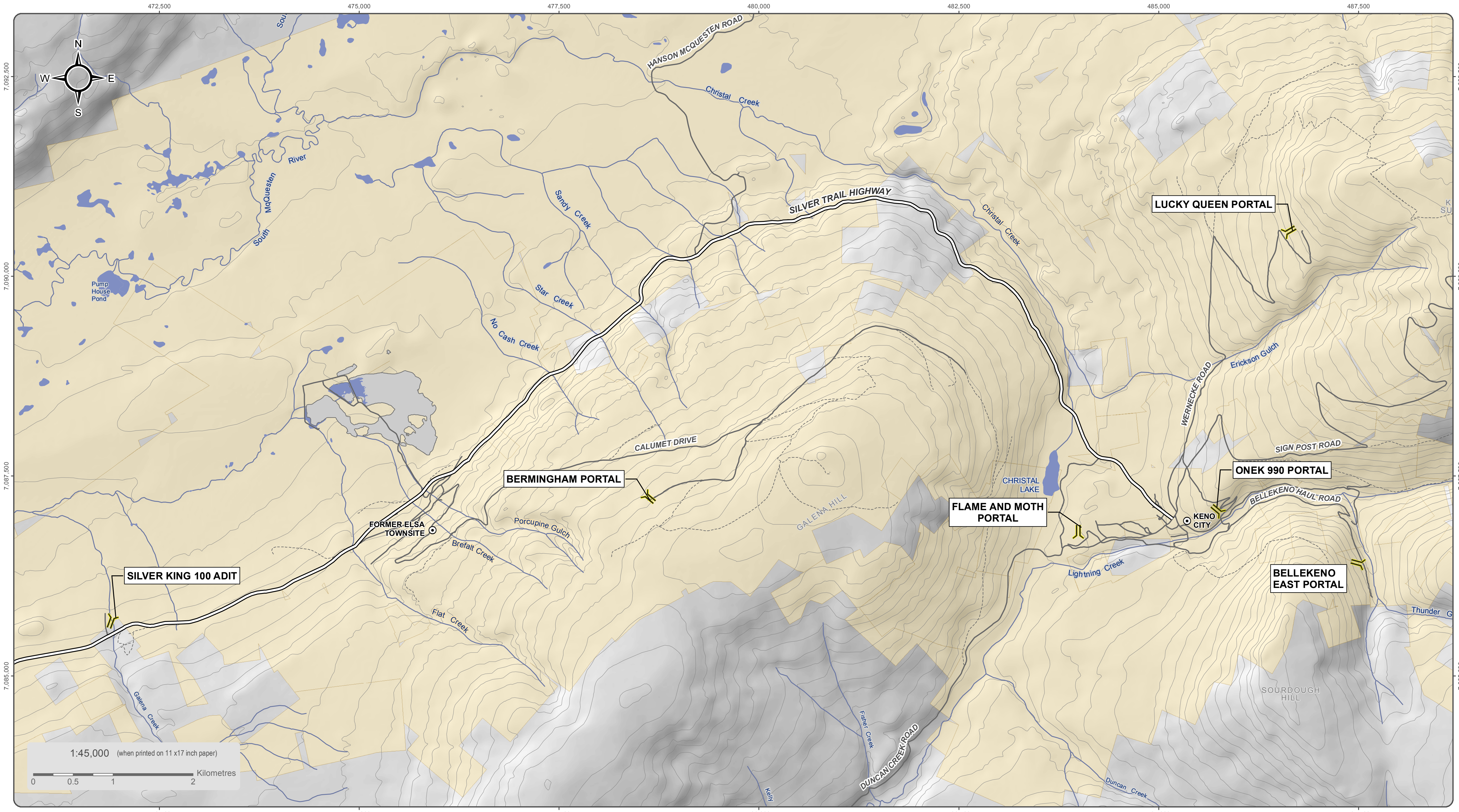
ARD/ML data from waste rock samples collected from exploration drill core at prospective production zones within the KHSD were compiled (Figure 4-1). These included the:

- Bellekeno (Altura, 2008a);
- Onek (ACG, 2011a);
- Lucky Queen (ACG, 2011b);
- Silver King (ACG, 2011c);
- Flame & Moth (AEG, 2016b); and
- Bermingham zones (AEG, 2017).

The lithological distribution of samples in each production zone is presented in Table 4-1.

Table 4-1: AKHM Prospective KHSD Production Zones Sample Lithologies Sampled for ARD/ML Characterization

Production Zone	Lithology (Number of Samples)									Total
	GNST	GSCH	QTZT	SSCH	TQTZT	ICQS	CQTZTZ	CHSCH	CSCH	
Bellekeno	12	13	12	11	0	0	12	1	0	61
Onek	4	14	17	8	0	0	0	1	0	44
Lucky Queen	0	2	13	0	9	0	0	0	0	24
Silver King	1	2	7	3	7	4	0	0	0	24
Flame & Moth	1	5	28	6	7	0	2	0	1	50
Bermingham	0	14	29	0	11	0	0	0	0	54
Total	**18**	**50**	**106**	**28**	**34**	**4**	**14**	**2**	**1**	**257**



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

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

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

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

AKHM

ALEXCO ENVIRONMENTAL GROUP

ALEXCO KENO HILL MINING CORP.

FIGURE 4-1

LOCATIONS OF WASTE ROCK ARD/ML STUDIES TO SUPPORT ALEXCO KHSD DEVELOPMENT

SEPTEMBER 2017

D:\Project\AllProjects\ALEX-05-01\gis\mxd\Overview_Maps\Property_Overviews\Alexco_Proposed_Deposits_Overview_20170914.mxd
(Last edited by: amattashevska;15/09/2017/12:55 PM)

4.1.1 ABA

The purpose of ABA is to quantify the content and ratio of potentially acid producing and potentially acid consuming minerals in each sample. This is an indication of the acid generation potential of geologic materials.

Plots of NP versus AP, which provide an overview of the potential for net acid generation, are displayed for all the KHSD production unit waste rock samples in Figure 4-2, and broken out by lithology in Figure 4-3 to Figure 4-7. In general, three categories of potential acid generation can be defined based on the NP/AP ratio (or neutralization potential ration; NPR) of a sample (Price, 2009):

- NPR<1 samples are potentially acid generating (PAG);
- 1<NPR<2 samples are capable of acid generation but with some uncertainty; and,
- NPR>2 samples are not potentially acid generating (non-PAG).

In general, the majority of waste rock samples collected from potential production zones across the KHSD are non-PAG (i.e., NPR>2; Figure 4-2). Samples from Silver King had the highest proportion that were PAG (i.e., NPR<1; 68%), largely due to their low NP content (Figure 4-2). Onek also had a handful of samples that were PAG (16%); however, these were generally high AP and NP. The majority of the Lucky Queen, Onek, Flame & Moth, Bermingham, and Bellekeno waste rock samples were non-PAG (58%, 73%, 74%, 80%, and 87% of samples, respectively). Overall, waste rock from the easternmost deposits (e.g., Bellekeno, Onek, and Flame & Moth) tended to have higher NP than that found in samples from the deposits located in the western portion of the KHSD (i.e., Silver King and Bermingham).

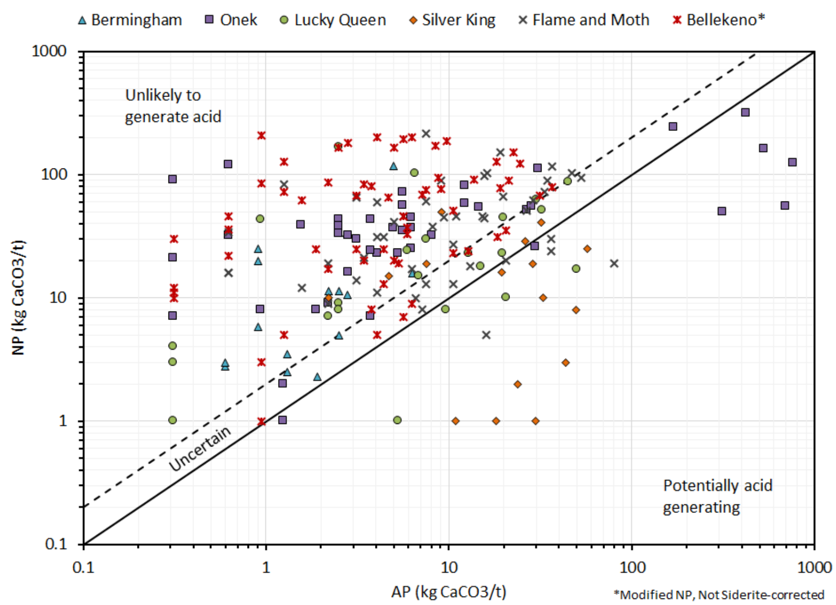
Broken down by major lithology, the QTZT, TQTZT, an GSCH samples broadly reflected the bulk NPR sample distribution (11% to 14% PAG samples; 72% to 76% non-PAG; Figure 4-3 to Figure 4-5), consistent with the numerical dominance of these lithologies. The GNST and SSCH samples are predominantly non-PAG (Figure 4-6 and Figure 4-7).

4.1.2 Bulk Chemistry

Bulk concentrations of antimony, arsenic, selenium, silver, cadmium, and zinc often exceed their crustal abundance by an order of magnitude (CRC, 2005) in waste rock from the KHSD. Although the bulk concentration of an element does not offer a direct measure of how mobile an element may be during weathering, it can provide a preliminary indication of constituents that should be monitored in subsequent leach and/or kinetic test. The concentrations of these elements in waste rock (as accessed by aqua regia digestion) from the Bermingham, Bellekeno, Onek, Lucky Queen, Silver King, and Flame & Moth deposit areas are displayed in Figure 4-8.

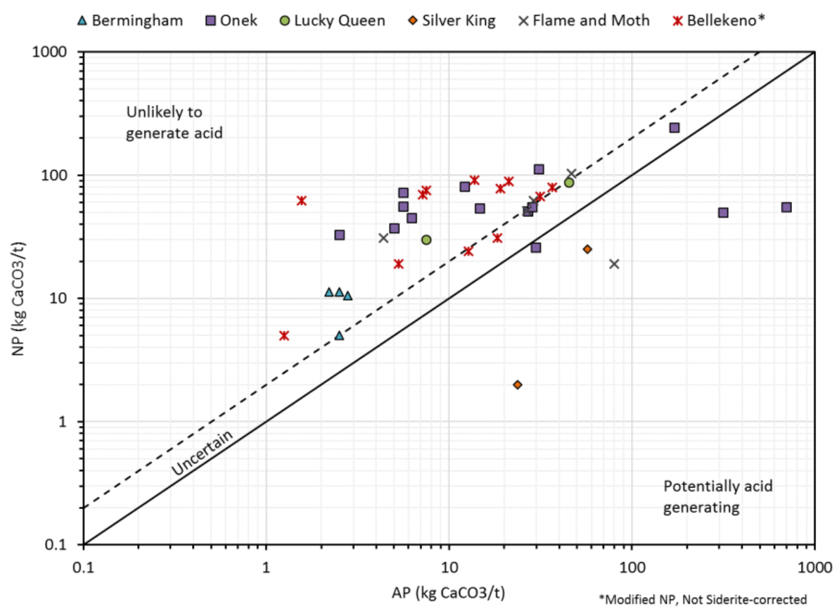
Bulk antimony and silver concentrations were higher than their respective 10x crustal abundance (2 and 0.85 ppm, respectively) for the majority of waste rock samples from Bellekeno, Onek, Lucky Queen, and Silver King. Lower concentrations were observed for Bermingham and Flame & Moth waste rock. Bulk selenium concentrations were elevated (>10x crustal abundance; 0.5 ppm) in the majority of Bermingham and Flame & Moth samples. Poor detection limits (10 ppm) prevented interpretation of the Lucky Queen and Silver King selenium dataset, while selenium was not analyzed in the aqua regia digests of Bellekeno or Onek waste rock.

The highest arsenic, cadmium, and zinc concentrations were observed in waste rock from Onek and Bellekeno. The lowest concentrations were returned by Flame & Moth waste rock, which were consistent with crustal abundance for all three elements. Bulk cadmium ad zinc concentrations were also relatively low in Bermingham waste rock.



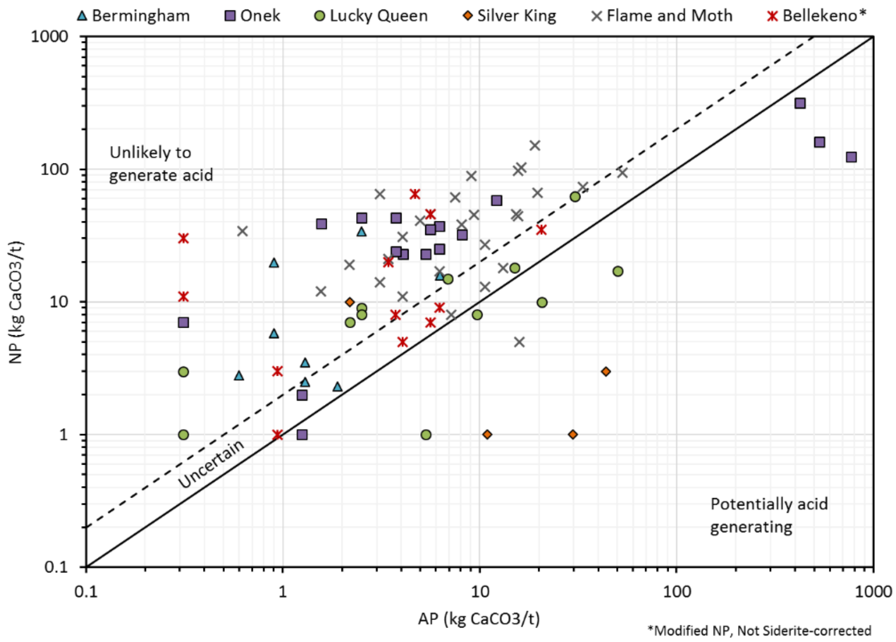
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-2: Variability in NP and AP of Waste Rock Samples from KHSD Deposits



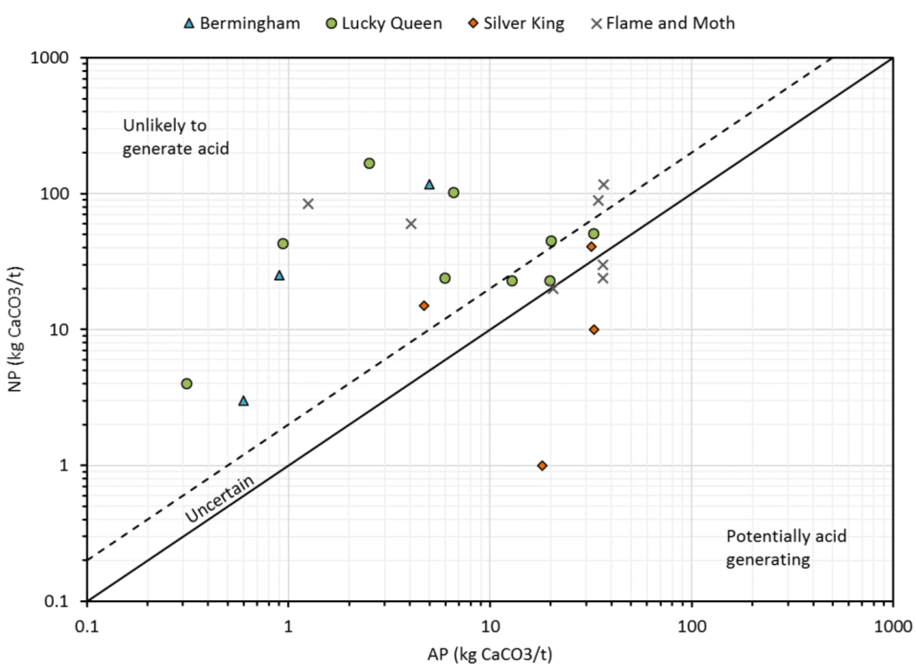
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-3: Variability in NP and AP of GSCH Lithology Waste Rock Samples from KHSD Deposits



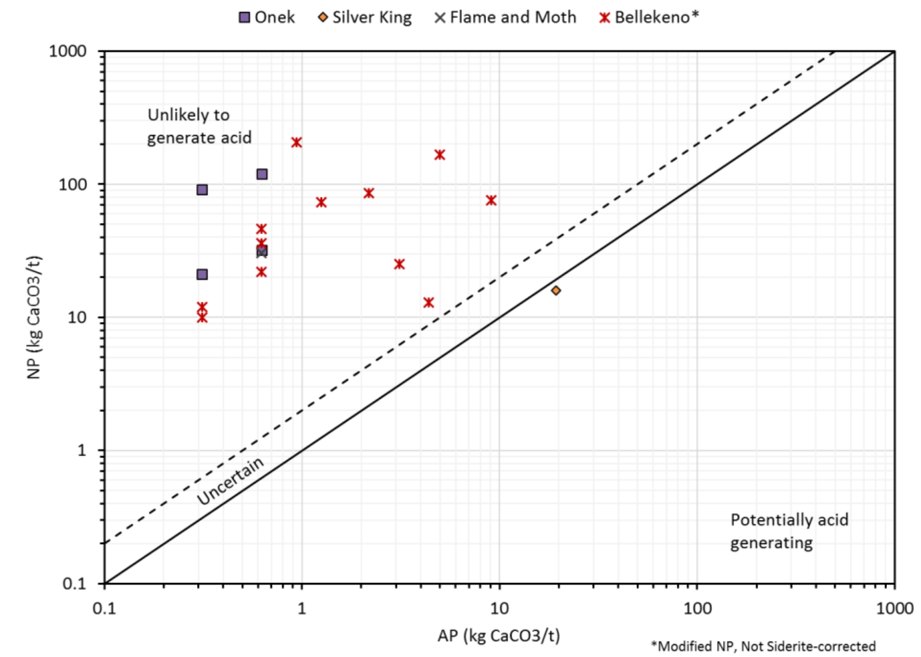
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-4: Variability in NP and AP of QTZT Lithology Waste Rock Samples from KHSD Deposits



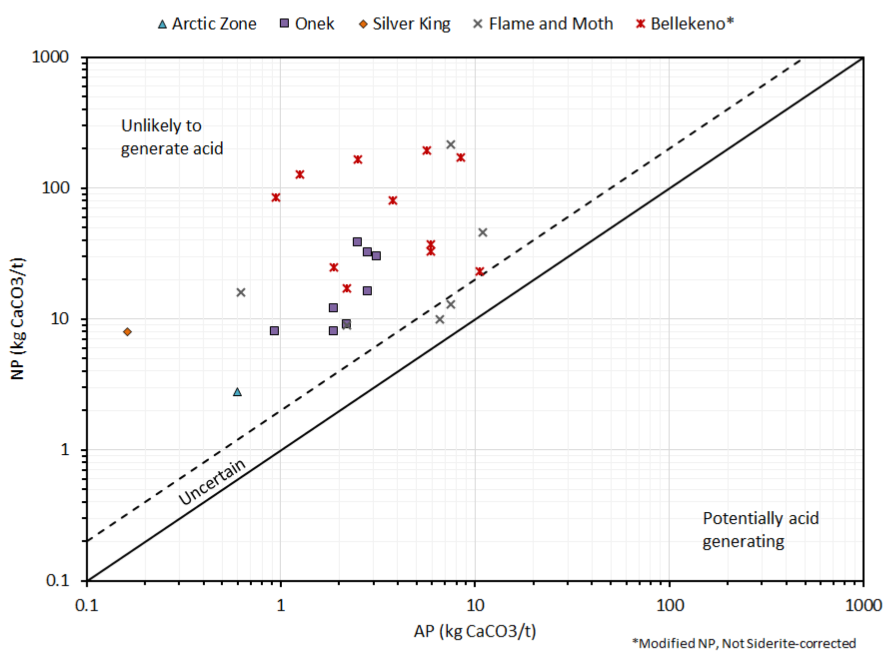
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-5: Variability in NP and AP of TQTZT Lithology Waste Rock Samples from KHSD Deposits



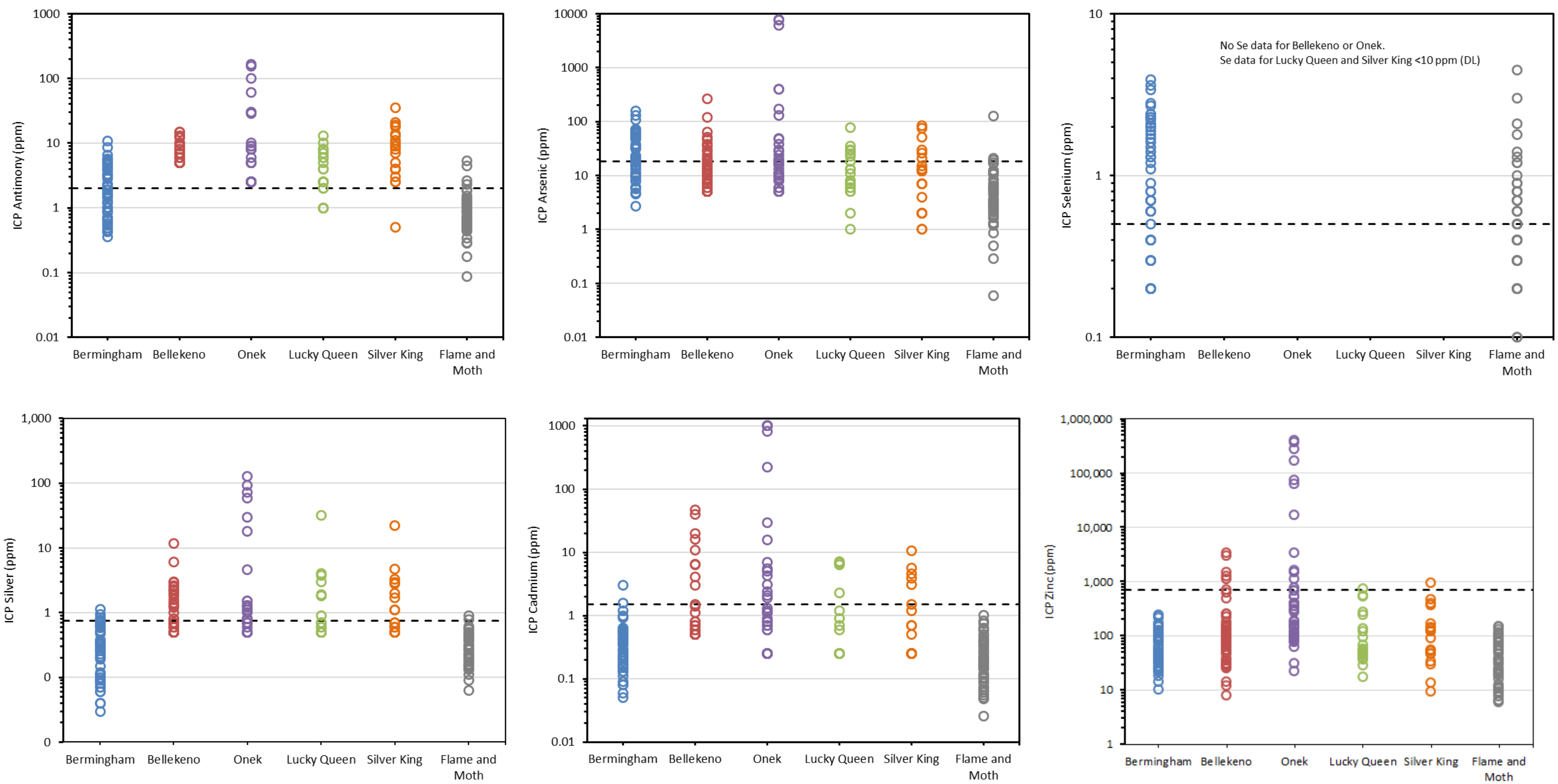
Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-6: Variability in NP and AP of GNST Lithology Waste Rock Samples from KHSD Deposits



Solid and dashed lines indicate NPR = 1 and NPR = 2, respectively.

Figure 4-7: Variability in NP and AP of SSCH Lithology Waste Rock Samples from KHSD Deposits



Dashed line represents 10x crustal abundance

Figure 4-8: Distributions of Bulk Concentrations of Antimony, Arsenic, Selenium. Silver, Cadmium, and Zinc by Deposit

4.1.3 SFE

SFE provides a measure of the soluble metals in the sample that may be mobilized in the short term upon flushing. A summary of SFE leachate concentrations of Flame & Moth zone samples (n=50) analysed by AEG (2016b) is shown in Table 4-2. No SFE data are available for the other deposit areas that have appropriate trace element detection limits.

The discussion of the results is focussed on constituents that were found to be elevated relative to crustal abundance from bulk elemental analysis and/or had SFE test data that were elevated relative to Canadian Council of Ministers of the Environment (CCME, 2017) or British Columbia Ministry of the Environment (BCMoE, 2016) long-term water quality guidelines for freshwater aquatic life. Where both CCME and BCMoE guidelines were available for a constituent, the most recently updated guideline was used since this captures the most recent science. Although such short-term leach extractions are not strictly comparable to water quality guidelines, such comparison aids the identification of elevated soluble constituent concentrations and the potential for trace element leaching. This comparison is strictly for reference purposes and does not indicate compliance or otherwise with CCME, BCMoE or other water quality guidelines.

The pH of both sets of SFE sample datasets was circumneutral to alkaline, with a few samples (three Bermingham and two Flame & Moth) in exceedance of the upper CCME pH guideline (pH 9.0). Elevated concentrations of SFE leachable fluoride (92% of samples exceeded 0.12 mg/L CCME guideline) and aluminum (76% of samples exceeded 0.1 mg/L CCME guideline) were observed in the Flame & Moth samples, whereas a lower proportion of exceedances (and lower concentrations) were obtained for the Bermingham samples (53% and 33% of samples exceeded guidelines for fluoride and aluminum, respectively).

A high proportion of SFE leachable antimony concentrations exceeded the BCMoE interim guideline (0.009 mg/L; 78% of samples) in the Flame & Moth dataset, whereas no exceedances were observed for the Bermingham samples despite higher bulk antimony concentrations in the Bermingham waste rock samples (Figure 4-8 and Figure 4-9). Conversely, a higher proportion of Bermingham samples had SFE leachable arsenic concentrations that exceeded the CCME water quality guideline (0.005 mg/L; 27% of samples) compared with the Flame & Moth SFE results (6% of samples), although both sets of data spanned a similar concentration range (Figure 4-9). Similarly, a lower proportion of Flame & Moth SFE leachable selenium concentrations exceeded the BCMoE guideline for selenium (0.002 mg/L; 46% of samples) compared with the Bermingham dataset (73% of samples), although both sample datasets spanned a similar concentration range (Figure 4-9).

Broadly positive correlations were observed between SFE leachable and aqua regia bulk concentrations of aluminum and selenium (Figure 4-9), although the selenium correlation appears stronger within each deposit area's lithology rather than for the entire dataset.

Overall, the same constituents (fluoride, aluminum, and selenium) were observed at elevated levels in the SFE leachate from both the Bermingham and Flame & Moth samples. The only notable differences were the elevated arsenic concentrations observed in a quarter of the Bermingham samples, but only 6% of the Flame & Moth samples, and the elevated antimony concentrations which were recorded in the majority of Flame & Moth dataset, but which were below water quality guidelines in the Bermingham samples.

Table 4-2: Comparison of SFE Concentrations from Flame & Moth Zone Samples with Water Quality Guidelines

n = 50	pH	Fluoride	Aluminum	Antimony	Arsenic	Selenium
		mg/L	mg/L	mg/L	mg/L	mg/L
Guideline for Comparison	**CCME**	**CCME**	**CCME**	**BCMoE**	**CCME**	**BCMoE**
Aquatic Life Guideline	**6.5 - 9.0**	**0.12**	**0.1 [a]**	**0.009**	**0.005**	**0.002**
Maximum	9.2	4.49	6.2	0.13	0.012	0.030
3rd Quartile	8.7	0.94	0.63	0.027	0.0018	0.0036
Median	8.6	0.51	0.29	0.013	0.0012	0.0018
1st Quartile	8.4	0.28	0.10	0.0094	<0.0005	0.00085
Minimum	7.9	0.068	0.017	0.00099	<0.0005	0.00025
Samples >CCME/BCMoE	4%	92%	76%	78%	6%	46%
Highlighted Results Exceed CCME/BCMoE						

[a] Guideline based on receiving waters with pH>6.5

Table 4-3: Comparison of SFE Concentrations from Bermingham Zone Samples with Water Quality Guidelines

n = 15	pH	Fluoride	Aluminum	Arsenic	Selenium
		mg/L	mg/L	mg/L	mg/L
Guideline for Comparison	**CCME**	**CCME**	**CCME**	**CCME**	**BCMoE**
Guideline Value	6.5 - 9.0	0.12	0.1 [a]	0.005	0.002
Method Detection Limit	-	0.01	0.0005	0.00002	0.00004
Maximum	9.34	0.8	0.45	0.022	0.011
3rd Quartile	8.83	0.29	0.14	0.0064	0.0051
Median	8.53	0.13	0.065	0.0029	0.0031
1st Quartile	7.81	0.1	0.025	0.0019	0.0021
Minimum	7.09	0.04	0.0080	0.00074	0.00050
Samples >CCME/BCMoE	20%	53%	33%	27%	73%
Highlighted Results Exceed CCME/BCMoE					

[a] Guideline based on receiving waters with pH>6.5

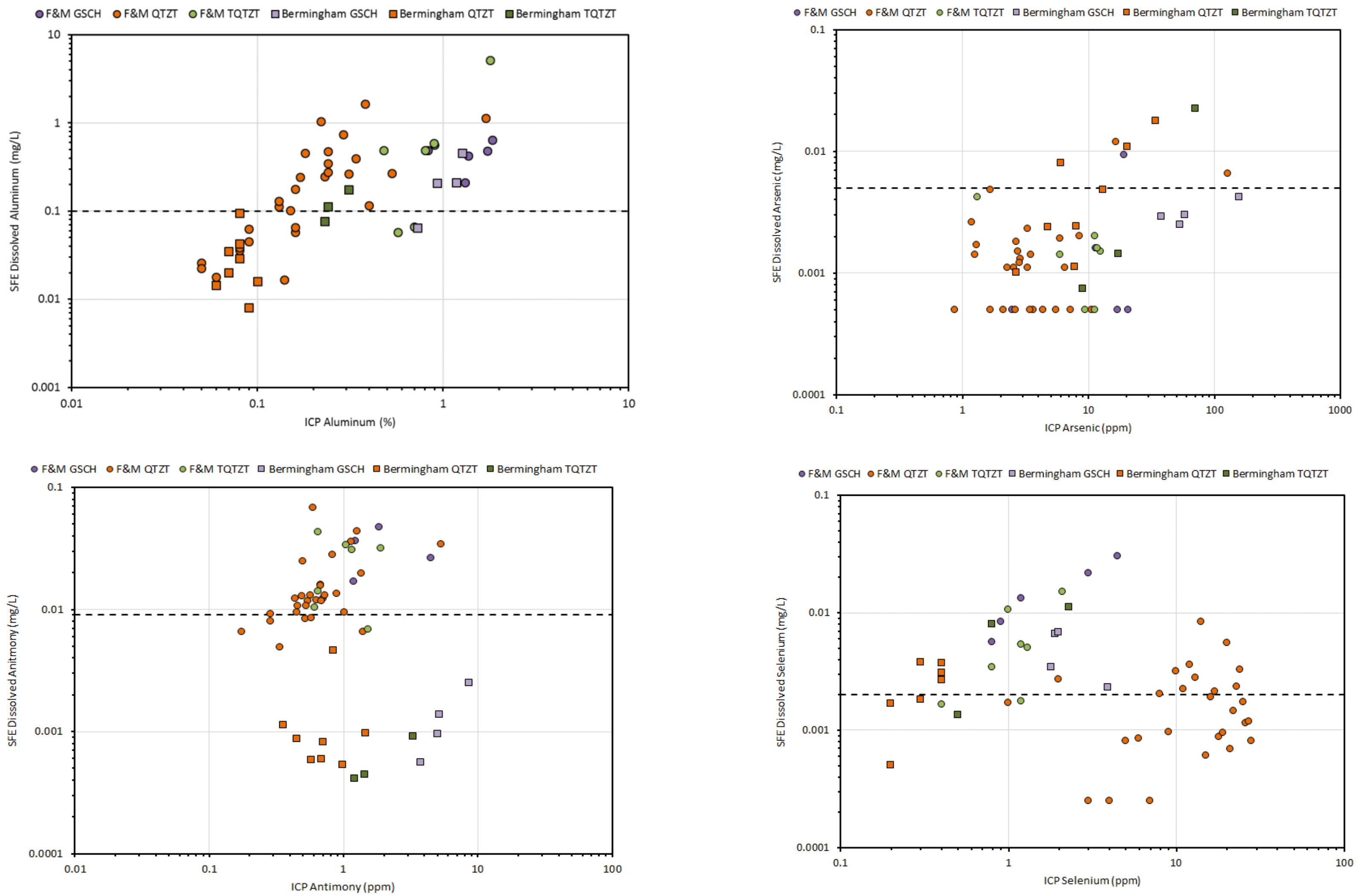


Figure 4-9: Comparison of SFE Leachable and Aqua Regia Bulk Concentrations of Aluminum, Antimony, Arsenic, and Selenium in Bermingham (squares) and Flame & Moth (circles)

4.2 TAILINGS

4.2.1 ABA

The ABA characteristics of the Bermingham tailings sample (Berm LCT2) are displayed in Table 4-4 alongside the ABA analysis of the Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, Flame & Moth F4+F5 composite tailings and the average of monthly ABA analyses of composite tailings samples produced from Bellekeno ore between January 2011 and July 2013 (ACG, 2015). All five tailings exhibited a slightly alkaline paste pH (7.8 to 8.2) and high carbonate neutralization potential (204 to 389 kg $CaCO_3$/t). The carbonate-NP of the Berm LCT2 sample (204 kg $CaCO_3$/t) was significantly higher than the siderite-corrected NP (56.3 kg $CaCO_3$/t), which indicates that ferrous carbonates such as siderite ($FeCO_3$) comprise a substantial portion of the carbonate mineralogy in the Bermingham tailings. The Flame & Moth and Bellekeno tailings also returned much lower siderite-corrected NP measurements than carbonate-NP, also reflecting the presence of a significant ferrous carbonate component in these samples.

Table 4-4: ABA characteristics of Bermingham, Onek, Lucky Queen, Flame & Moth and Bellekeno tailings

Sample	Paste pH	Total Sulphur	Sulphate-Sulphur	Sulphide-Sulphur	CO_2	CO_3-NP	NP	AP	NPR
	Unity	%	%	%	%	kg $CaCO_3$/t			Unity
Berm LCT2	8.15	1.39	0.01	1.38	8.96	204	56.3	43.1	1.3
Onek F7 + F8 average	7.8	0.16	0.04	0.12	n/a	n/a	31.4	3.8	8.4
Lucky Queen F9 + F10 average	7.85	0.19	0.04	0.15	n/a	n/a	19.1	4.5	4.2
Flame & Moth F4+F5 Composite Tailings	8	0.45	0.02	0.43	17.1	389	100	14.1	7.1
Bellekeno Tailings, Jan 11-July 13 Monthly Avg.	8.1	2.3	0.02	2.21	12	273	132	71.7	1.9

n/a denotes not available

The hydrogen peroxide used in the siderite-corrected NP method oxidizes the Fe(II) liberated from siderite dissolution, which then hydrolyzes rapidly at pH>7 to precipitate poorly ordered iron (oxyhydr)oxides. This process produces an equal amount of acid as that neutralized from the carbonate portion of the siderite, hence ferrous carbonates do not contribute to acid neutralization under pH neutral oxidizing conditions. It should be noted that the siderite associated with ore in the KHSD is typically manganiferous (Cathro, 2006), resulting in manganoan siderite in tailings material (SRK, 2009). The siderite-corrected NP method will also oxidize Mn(II); however, Mn(II) oxidation and subsequent precipitation (which is acid generating and balances the acid neutralization from the carbonate component) under oxidizing weathering conditions is typically much slower than that of Fe(II). Therefore, the siderite-corrected NP may underestimate the amount of NP available for acid neutralization since it assumes that all the manganese released during carbonate dissolution will oxidize and precipitate *in situ*, which may not be the case.

The Bellekeno tailings contained the highest total sulphur content (2.3 wt.%), followed by the Berm LCT2 tailings (1.39 wt.%). The other three site tailings samples had much lower sulphur concentrations (0.16 to 0.45 wt.%; Table 4-4). Sulphide-sulphur comprised the bulk of total sulphur in Berm LCT2, similar to the other KHSD tailings.

The NPR of the Berm LCT2 tailings sample (1.3) is lower than the other five tailings, of which the remainder ranged from 1.9 (Bellekeno) to 8.4 (Onek). Despite having a lower sulphide-sulphur content (and hence lower AP) than the Bellekeno tailings, the siderite-corrected NP of the Berm LCT2 was much lower than both the other two samples, resulting in the lowest NPR of all five samples. An NPR>2 typically indicates that acid generation is not expected whereas an NPR of between 1 and 2 indicates that the potential to generate acid is uncertain (Price, 2009). Given that the NP available for acid neutralization may be underestimated due to the oxidation of Mn(II) during the siderite-corrected NP method as discussed above, the NPR calculated for the Bermingham sample may be viewed as a lower bound, and may be considerably higher. This is supported by detailed mineralogical examination of historic tailings deposited in the KHSD in which material identified as potentially acid generating (i.e., NPR<2) by conventional ABA analysis was likely not potentially acid generating (i.e., NPR>2) when its manganese carbonate content was included in the NPR calculation (SRK, 2009).

4.2.2 Bulk Chemistry

The ICP metals composition of the Bermingham tailings sample (Berm LCT2) is shown in Table 4-5, alongside that of the Flame & Moth F4+F5 composite tailings, Onek F7+F8 tailings, Lucky Queen F9+F10 tailings, and the average of monthly ICP analyses of composite tailings samples produced from Bellekeno ore between July 2012 and August 2013 (when Bellekeno mining and milling operations occurred). Concentrations of antimony, arsenic, bismuth, cadmium, lead, manganese, selenium, silver, and zinc typically exceeded 10x their respective crustal abundance (CRC, 2005). The Bellekeno tailings generally had the highest concentration of these elements, with arsenic, antimony, cadmium, lead and zinc concentrations present at three- to seven-fold higher levels than those in the Berm LCT2. The Berm LCT2 and Bellekeno tailings contained comparable concentrations of selenium and silver (0.5 to 0.8 ppm and 50 to 56 ppm, respectively; Table 4-5). The Berm LCT2 tailings contained similar arsenic content to the Onek and Flame & Moth tailings, but were an order of magnitude higher than the arsenic concentration in the Lucky Queen tailings. The cadmium and zinc concentration in the Berm LCT2 tailings was higher than that of both the Lucky Queen (*ca.* 4- to 6-fold higher) and Flame & Moth (*ca.* 2- to 3-fold higher) tailings, but approximately 3- to 4-fold lower than the Onek tailings (Table 4-5). Finally, the lead content of the Berm LCT2 tailings was approximately 3- to 6-fold higher than the Onek, Lucky Queen, and Flame & Moth tailings (Table 4-5).

4.2.3 SFE

SFE data for the Bermingham tailings sample, the Flame & Moth tailings composite and the average Bellekeno tailings composite are shown in Table 4-6. Leachable metal(loid) concentrations were consistently lower from the Berm LCT2 sample than from the Bellekeno tailings and the Flame & Moth tailings (with exception of aluminum, lead and thallium which were marginally higher than the Flame & Moth tailings sample only). Metal(loid)s with elevated bulk ICP concentrations in Berm LCT2 relative to either of the other tailings samples, generally did not correspond to similarly relatively elevated SFE leachable concentrations. For example, although the ICP selenium in the Berm LCT2 sample was greater than the ICP selenium in the other two samples, leachable selenium was one and two orders of magnitude lower than the Flame & Moth and Bellekeno tailings leachable selenium, respectively. Of particular interest, SFE leachable cadmium and zinc concentrations – primary constituents of concern in surface waters of the KHSD (Minnow, 2015) – were both significantly lower from the Berm LCT2 sample than from the Flame & Moth and Bellekeno samples.

Table 4-5: Elemental composition of Bermingham, Onek, Lucky Queen, Flame & Moth and Bellekeno composite tailings

Element	Unit	Berm LCT2	Onek F7 + F8 average	Lucky Queen F9 + F10 average	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite Jul 12 - Aug 13	Crustal Abundance
Aluminum (Al)	%	0.16	0.36	0.74	0.2	0.2	8.23
Antimony (Sb)	ppm	44.6	<5	9	41	120.6	0.2
Arsenic (As)	ppm	401	375	17.5	699	2147	1.8
Barium (Ba)	ppm	30	24	125	11.5	16.4	425
Bismuth (Bi)	ppm	0.04	<2	<2	6.59	2.1	0.0085
Cadmium (Cd)	ppm	23.4	72.8	3.95	7.19	165.8	0.15
Calcium (Ca)	%	0.73	0.47	0.38	0.59	1.52	4.15
Chromium (Cr)	ppm	115	174	265.5	185.5	5.5	102
Cobalt (Co)	ppm	4.3	2	3	2.7	9.9	25
Copper (Cu)	ppm	57.5	377	254	565	242.4	60
Iron (Fe)	%	7.07	18.6	6.4	16.3	10.1	5.63
Lead (Pb)	ppm	2330	413	555	789	6359	14
Magnesium (Mg)	%	0.36	0.47	0.34	0.31	0.31	2.33
Manganese (Mn)	%	4.43	5.19	2.47	4.28	3.22	0.095
Mercury (Hg)	ppm	0.13	n/a	n/a	0.055	0.19	0.085
Molybdenum (Mo)	ppm	2.02	<1	2	3.74	1.16	1.2
Nickel (Ni)	ppm	49.1	44	51	86.6	19.5	84
Phosphorus (P)	%	0.032	0.014	0.013	0.01	0.02	0.105
Potassium (K)	%	0.08	0.08	0.275	0.03	0.04	2.09
Selenium (Se)	ppm	0.8	n/a	n/a	0.1	0.52	0.05
Silver (Ag)	ppm	56.4	6.4	16.4	12.35	50.1	0.075
Sodium (Na)	%	<0.01	0.02	0.025	0.006	0.014	2.36
Strontium (Sr)	ppm	15	11	15	4.81	24	370
Thallium (Tl)	ppm	1.9	17.5	11	0.652	0.129	9.6
Tin (Sn)	ppm	2	n/a	n/a	32.9	17.6	2.3
Titanium (Ti)	%	<0.005	<0.01	0.02	0.001	0.002	0.56
Uranium (U)	ppm	0.38	n/a	n/a	0.406	1.052	2.7
Vanadium (V)	ppm	5	5.5	12.5	9.4	5.18	120
Zinc (Zn)	ppm	2080	8784	557	1265	12623	70

Highlighted cells indicate concentrations greater than 10x crustal abundance; n/a denotes not available

Table 4-6: SFE leachable metals from Bermingham, Flame & Moth and Bellekeno tailings composites

Leachable Metals	Unit	Berm LCT2	Flame & Moth F4+F5 Composite	Bellekeno Tailings Monthly Composite July 12 - Aug 13
Aluminum (Al)-Leachable	mg/L	0.0214	0.0109	0.0282
Antimony (Sb)-Leachable	mg/L	0.0111	0.0217	0.0387
Arsenic (As)-Leachable	mg/L	0.000331	0.0061	0.0072
Barium (Ba)-Leachable	mg/L	0.0134	0.0253	0.0234
Beryllium (Be)-Leachable	mg/L	<0.000010	<0.00050	<0.00050
Bismuth (Bi)-Leachable	mg/L	<0.0000050	<0.00050	<0.00050
Boron (B)-Leachable	mg/L	<0.050	0.071	0.0942
Cadmium (Cd)-Leachable	mg/L	0.000309	0.0024	0.00318
Calcium (Ca)-Leachable	mg/L	12.4	105	138
Chromium (Cr)-Leachable	mg/L	<0.00010	<0.00050	<0.00050
Cobalt (Co)-Leachable	mg/L	0.000099	0.0004	0.00031
Copper (Cu)-Leachable	mg/L	0.000334	0.0271	0.0096
Iron (Fe)-Leachable	mg/L	<0.0010	<0.030	<0.030
Lead (Pb)-Leachable	mg/L	0.0188	0.0144	0.0593
Lithium (Li)-Leachable	mg/L	0.00294	0.0071	0.0339
Magnesium (Mg)-Leachable	mg/L	0.988	6.9	6.01
Manganese (Mn)-Leachable	mg/L	0.445	1.95	0.797
Mercury (Hg)-Leachable	mg/L	<0.000050	0.0001	<0.000050
Molybdenum (Mo)-Leachable	mg/L	0.000928	0.0024	0.0108
Nickel (Ni)-Leachable	mg/L	0.000368	0.0012	0.0009
Phosphorus (P)-Leachable	mg/L	0.0414	<0.30	<0.30
Potassium (K)-Leachable	mg/L	1.7	2.04	10.6
Selenium (Se)-Leachable	mg/L	0.000041	0.0009	0.00106
Silicon (Si)-Leachable	mg/L	0.45	1.55	3.4
Silver (Ag)-Leachable	mg/L	0.00003	0.0009	0.0018
Sodium (Na)-Leachable	mg/L	0.596	2.36	24.1
Strontium (Sr)-Leachable	mg/L	0.0172	0.38	0.515
Thallium (Tl)-Leachable	mg/L	0.000177	0.0001	0.0002
Tin (Sn)-Leachable	mg/L	<0.00020	<0.00050	<0.00050
Titanium (Ti)-Leachable	mg/L	<0.00050	0.01	0.012
Uranium (U)-Leachable	mg/L	<0.0000020	0	0.00162
Vanadium (V)-Leachable	mg/L	<0.00020	<0.0010	<0.0010
Zinc (Zn)-Leachable	mg/L	0.0172	0.156	0.051

5 KINETIC TESTING DATA

Concentrations of constituents of interest in the leachate from the kinetic experiments conducted using waste rock and tailings material are presented here. The effluent quality standards (EQS) set out in water licence QZ09-092 and CCME or BCMOE (whichever is the most recent) water quality guidelines for the protection of aquatic life are also displayed where applicable for comparative purposes. The lower (i.e., 25th) percentile hardness for the nearest receiving environment was used to calculate hardness-dependent guidelines based on the 2013 to 2017 dataset:

- Station KV-51 in Christal Creek was used for Flame & Moth waste rock and Bellekeno and Flame & Moth tailings (25th percentile hardness 527 mg/L); and
- Station KV-21 in No Cash Creek was used for Bermingham waste rock (25th percentile hardness 316 mg/L).

It should be noted that any seepage generated by the dry stack tailings facility is collected and routed to the Mill Pond for use in the processing circuit and any discharges from the Mill Pond require treatment to achieve the EQS under QZ09-092. Where measurements were below detection, the detection limit was used for display purposes.

5.1 WASTE ROCK

5.1.1 Humidity Cells

5.1.1.1 Flame & Moth

One humidity cell was conducted using a composite of N-AML Flame & Moth waste rock. Details regarding the composition (ABA, metal content) of this humidity cell can be found in AEG (2016b). The humidity cell was run for 98 weeks.

pH, Acidity, Alkalinity and Sulphate

Throughout the monitoring, the Flame & Moth N-AML humidity cell leachate remained slightly alkaline, ranging from pH 7.5 to 8.4 (Figure 5-1). Alkalinity declined from a peak of 127 mg/L $CaCO_3$ at week 1 to stabilize between 49 and 61 mg/L $CaCO_3$ since week 60 (Figure 5-1). Acidity was not measured during the first 9 weeks of humidity cell operations. At week 10, acidity was 16.9 mg/L $CaCO_3$, but since then remained below 6 mg/L $CaCO_3$, typically ranging between 1 and 2 mg/L $CaCO_3$ (Figure 5-1). Dissolved sulphate levels were the highest during the initial rinse cycle (183 mg/L at week 0) as soluble metal sulphate salts, which likely accumulated during sample storage, were washed out of the column. Sulphate concentrations then declined slightly before reaching a plateau of between 98.9 and 129 mg/L for weeks 2 to 11 (Figure 5-1), which was likely due to a supply of metal sulphides undergoing weathering within the humidity cell. Sulphate levels declined thereafter, stabilizing between 20 and 28 mg/L since week 66 (Figure 5-1). Sulphate concentrations remained below the BCMOE guideline (429 mg/L) at all times.

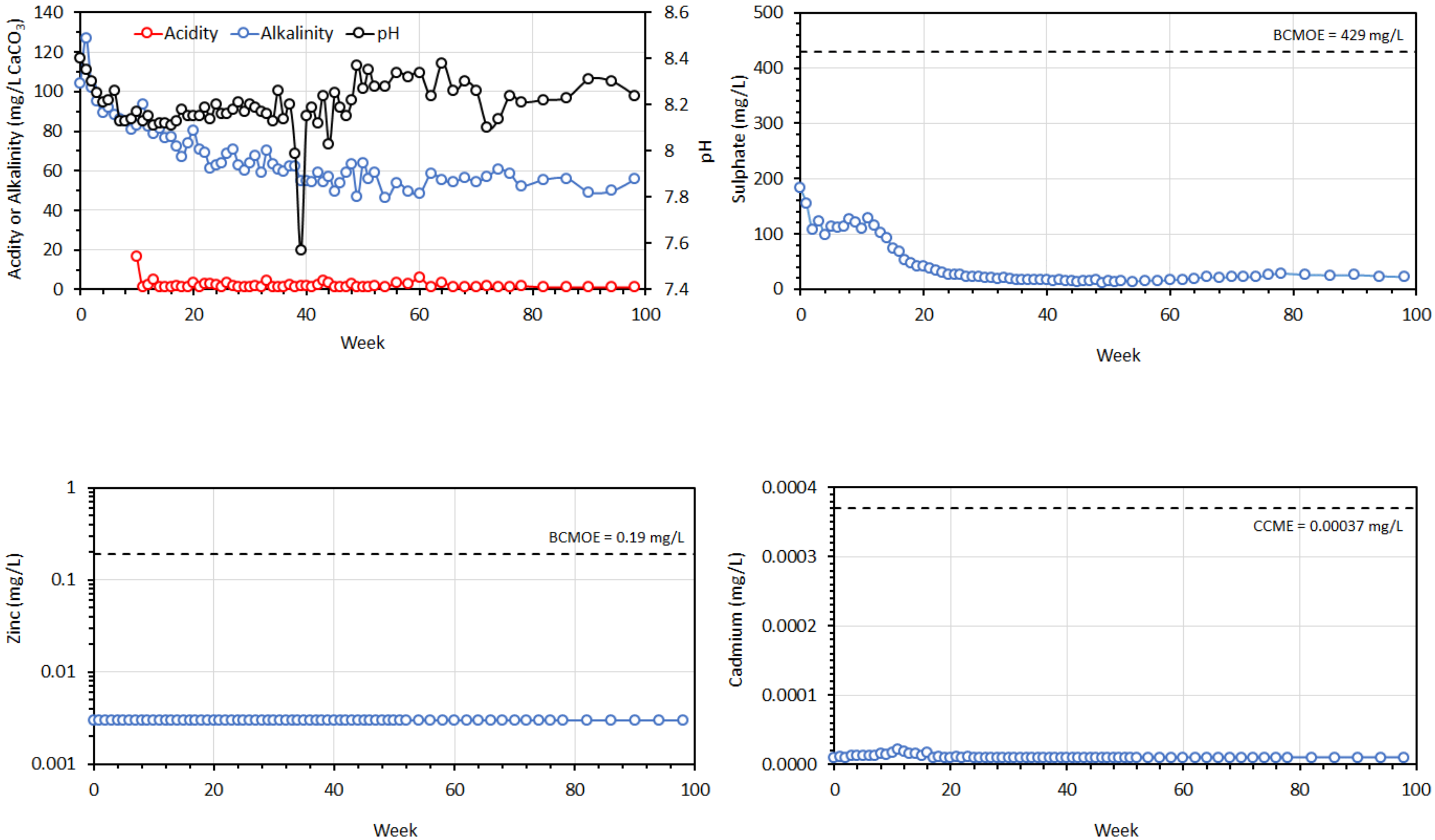


Figure 5-1: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

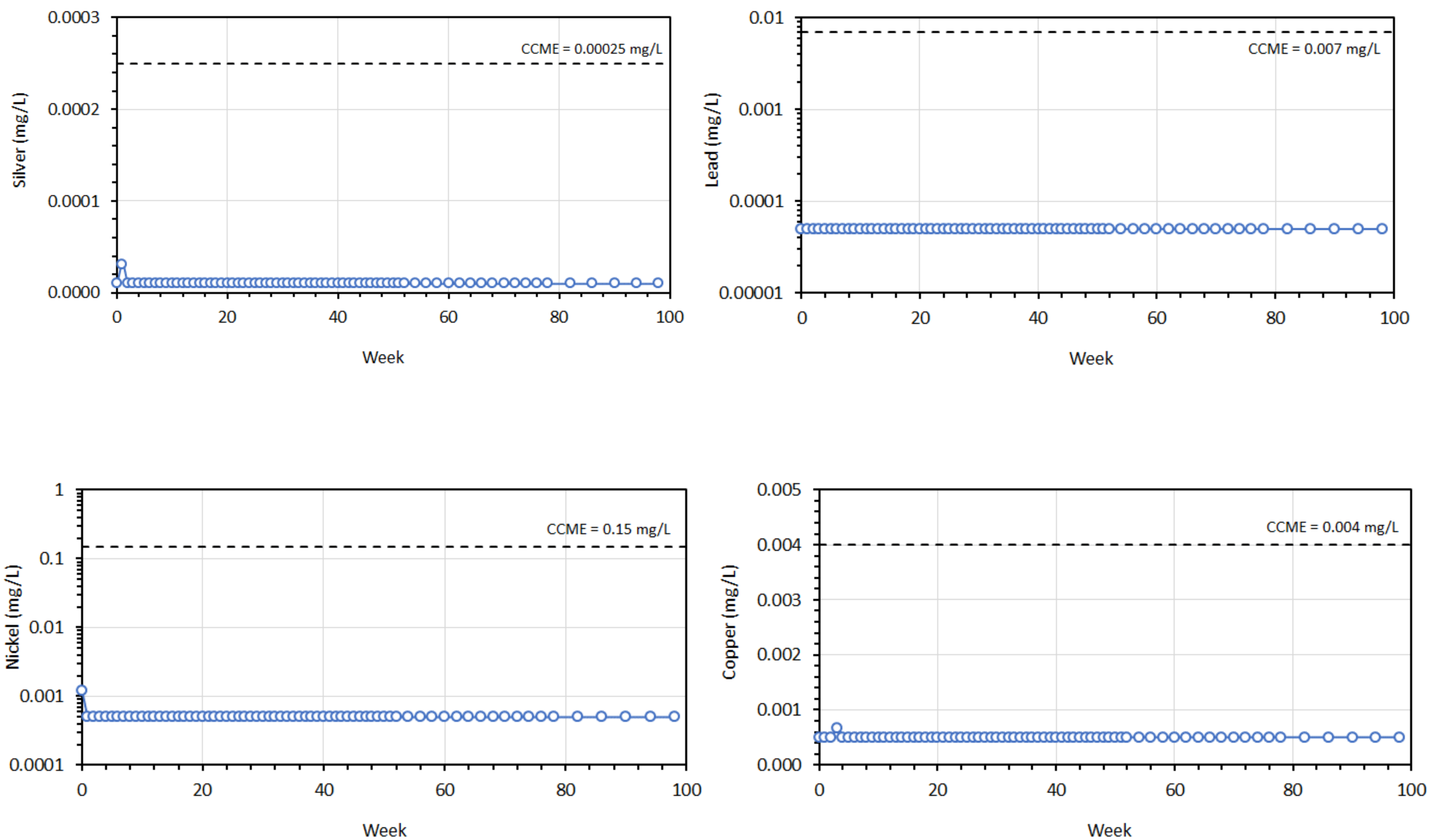


Figure 5-2: Silver, Lead, Nickel, and Copper Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

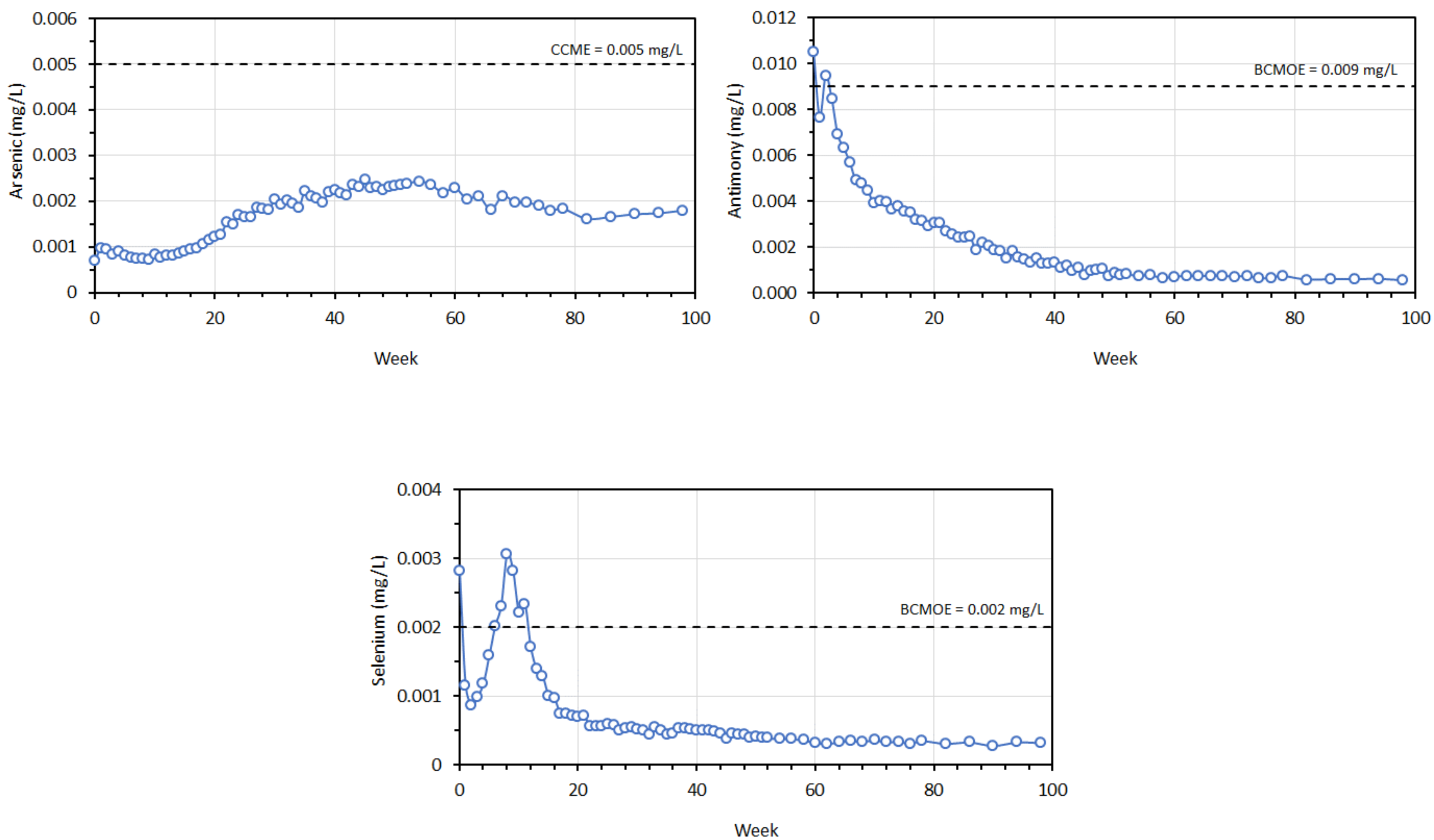


Figure 5-3: Arsenic, Antimony and Selenium Trends within the Flame & Moth N-AML Waste Rock Humidity Cell

Trace Elements of Interest

Concentrations of cadmium, zinc, silver, lead, nickel, and copper in the Flame & Moth N-AML humidity cell leachate were typically below their respective detection limits for the majority of the 98 week operation, and well below their respective water quality guidelines (Figure 5-1 and Figure 5-2).

Antimony concentrations were highest for week 0 or the initial rinse (0.011 mg/L), marginally exceeding the BCMOE working water quality guideline (0.009 mg/L), before they gradually declined over time. Antimony levels remained ≤0.001 mg/L since week 41 (Figure 5-3). Arsenic concentrations exhibited a stable concentration between 0.00071 and 0.00091 mg/L until week 15 (Figure 5-3). After week 15, arsenic levels began to slowly rise, reaching 0.0024 mg/L by week 54, before declining slightly and stabilizing between 0.0016 and 0.002 mg/L since week 70 (Figure 19). Throughout the testing, the humidity cell leachate arsenic concentration was still at least two times lower than the CCME guideline (0.005 mg/L).

Selenium concentrations in the humidity cell leachate initially declined from 0.0028 mg/L to approximately 0.001 mg/L over the first two weeks before rising to a peak concentration of 0.0031 mg/L at week 8 (Figure 5-3). The peak in selenium coincides with the sustained elevated sulphate levels, suggesting that the dissolution of selenium-bearing metal sulphides are the likely release mechanism for selenium, and hence result in these higher selenium concentrations. Dissolved selenium concentrations then tailed off, stabilizing between 0.00028 and 0.0005 mg/L from week 31 onwards (falling below the BCMOE guideline of 0.002 mg/L after week 12).

5.1.1.2 Bermingham

One humidity cell was conducted using a composite of N-AML Bermingham waste rock. This humidity cell is ongoing and at the time of writing, 18 weeks of data were available. Figure 5-4 to Figure 5-6 present the humidity cell leachate data collected to date for constituents of interest.

pH, Acidity, Alkalinity and Sulphate

The humidity cell leachate was circumneutral (pH 6.7 to 7.5) with relatively low levels of alkalinity (6 to 11 mg/L as $CaCO_3$) and negligible acidity (<0.5 mg/L as $CaCO_3$; Figure 5-4). Sulphate concentrations were also low, ranging between 5 and 15 mg/L, over an order of magnitude lower than the BCMOE guideline (429 mg/L; Figure 5-4).

Trace Elements of Interest

Aside from selenium, the concentrations of all constituents of interest in the Bermingham N-AML humidity cell leachate were well below their respective CCME or BCMOE water quality guidelines (Figure 5-4 to Figure 5-6). Selenium concentrations peaked at 0.009 mg/L after week one, then declined gradually such that by week 11 (0.0018 mg/L) they were below the BCMOE guideline (0.002 mg/L).

It is expected that this humidity cell will continue to run for at least 40 weeks after which time it may be terminated if the concentration of constituents of interest has stabilized.

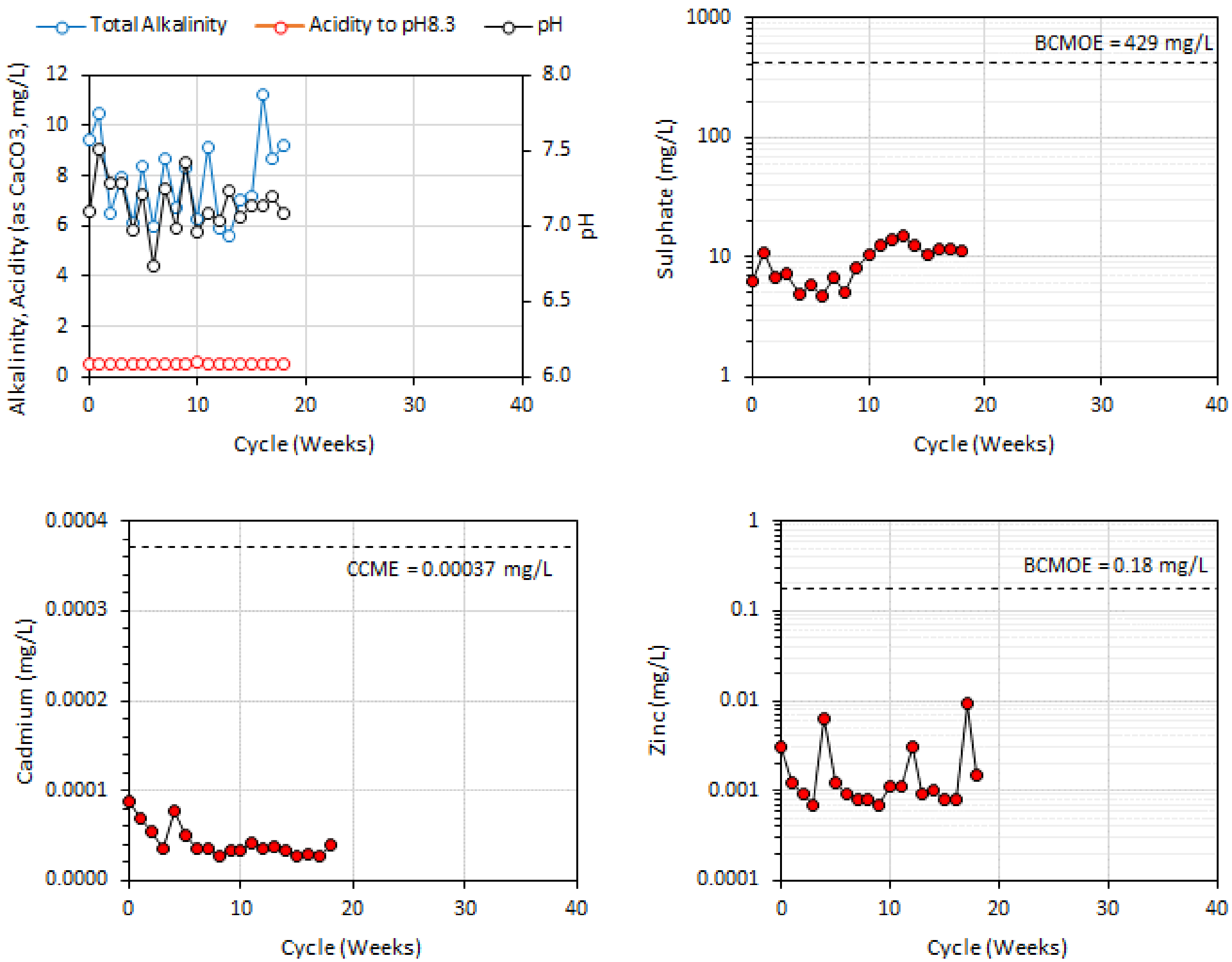


Figure 5-4: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Bermingham N-AML Waste Rock Humidity Cell

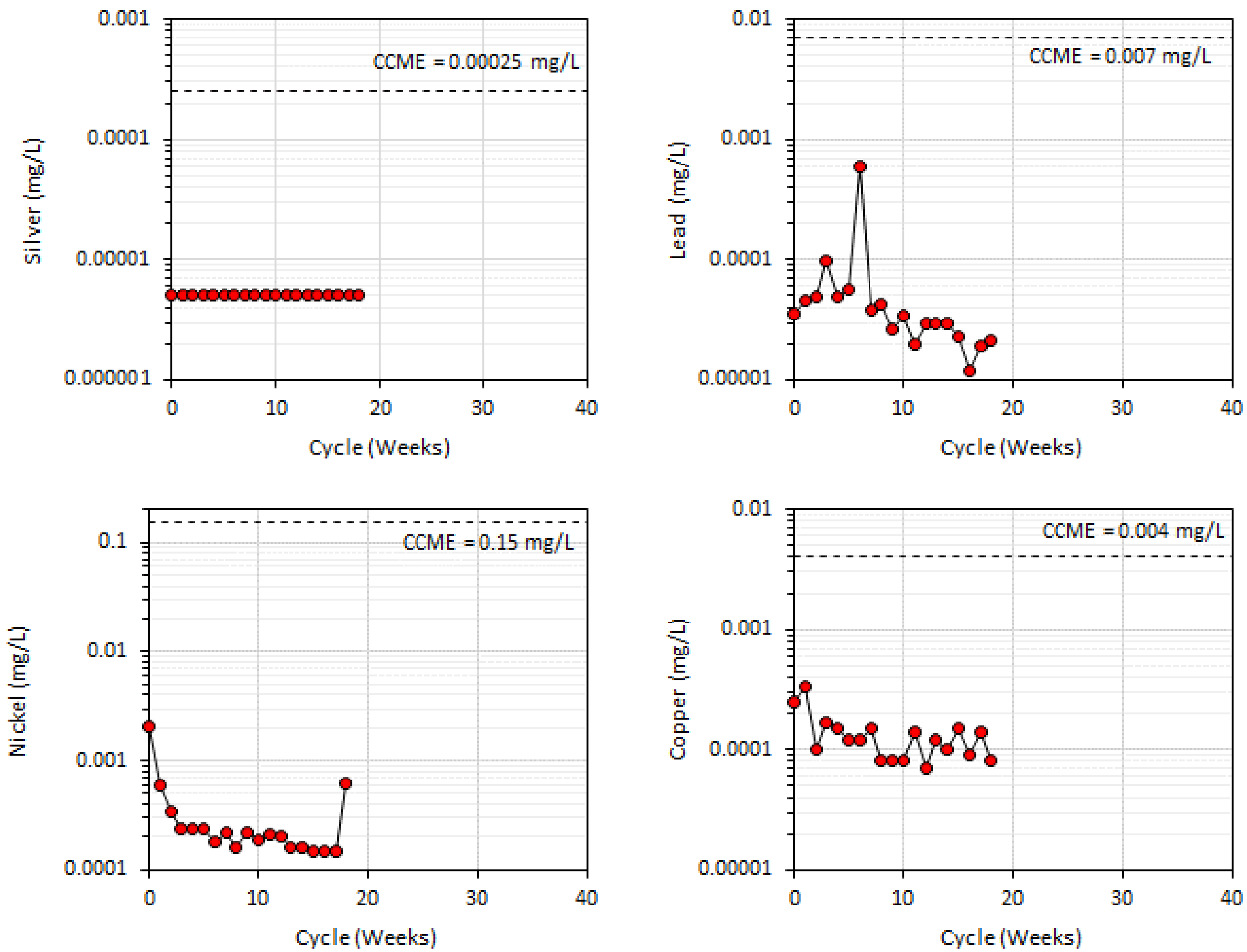


Figure 5-5: Silver, Lead, Nickel, and Copper Trends within the Bermingham N-AML Waste Rock Humidity Cell

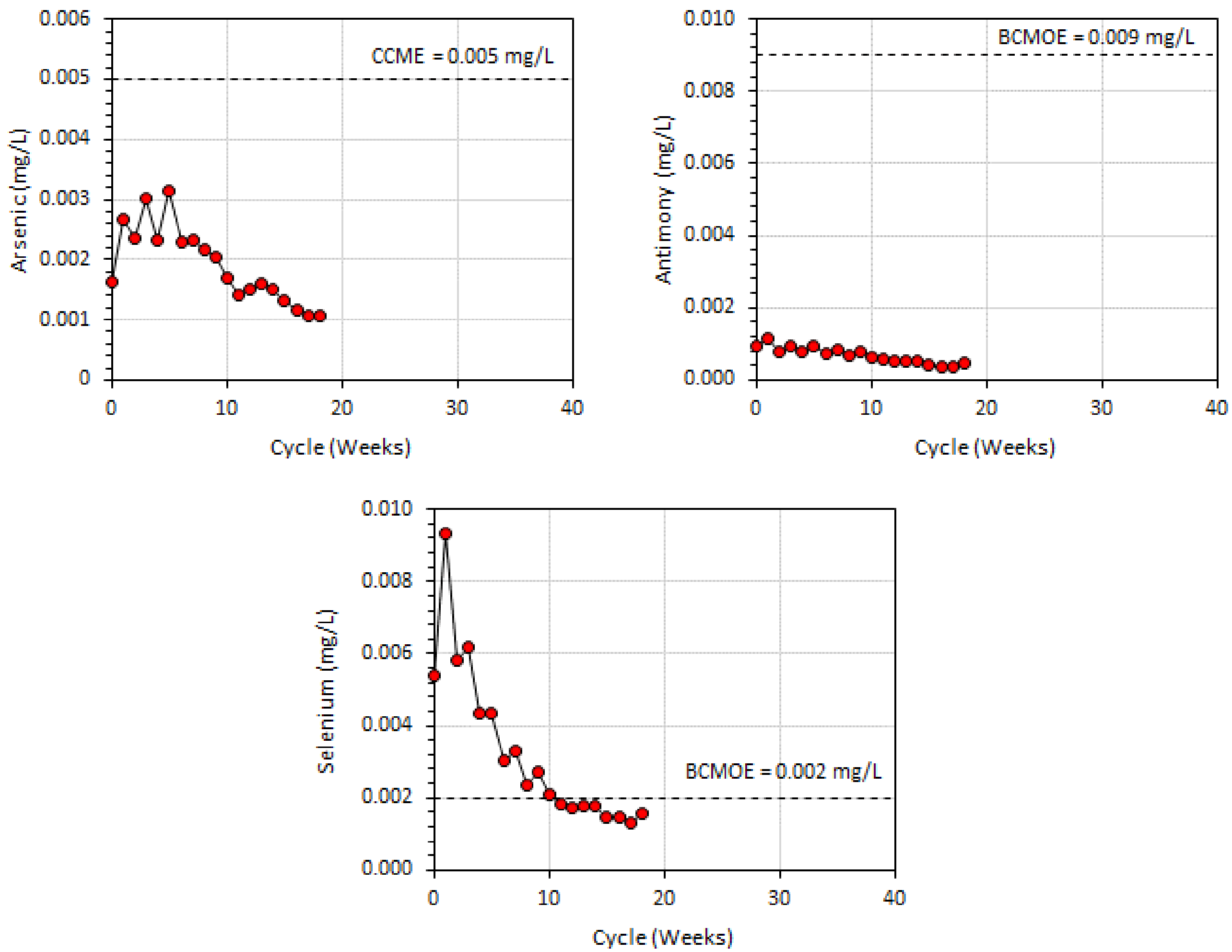


Figure 5-6: Arsenic, Antimony and Selenium Trends within the Bermingham N-AML Waste Rock Humidity Cell

5.1.2 Field Barrels

Five field barrels containing Flame & Moth waste rock were setup in June 2013 at site and continue to be monitored. Of the five barrels, only results from barrels 1 to 4 are displayed here since the contents of barrel 5 are not representative of the material to be generated by the waste rock management screening criteria proposed for Flame & Moth.

Five field barrels were constructed onsite in the summer of 2013, while only barrels 1 to 4 were used to evaluate the proposed Flame & Moth geochemical screening criteria. The bulk composition of field bin 5 is not representative of the material to be generated by the screening criteria proposed for Flame & Moth, therefore the results have not been discussed in this memorandum. Field barrels one through four were built to examine P-AML and N-AML from the dominant lithologies to be encountered in the development of the Flame & Moth deposit, specifically in the area of the decline. Field barrel 1 (FMB1) was filled with P-AML rock as indicated by its elevated sulphur content (median 2.79% sulphur), median NPR <1, and high maximum metal concentrations. Field barrel 2 (FMB2) was filled entirely with N-AML rock using the Bellekeno geochemical screening criteria, and has the highest median NP, relatively low sulphur content and lowest median and maximum metal content of all the field bins. Field barrels 3 and 4 (FMB3 and FMB4) were filled with N-AML rock using the proposed Flame & Moth screening criteria, but which according to the Bellekeno screening criteria contained portions of P-AML designated waste rock. This is primarily reflected in the sulphur (median 0.39% and 0.43% for FMB3 and FMB4, respectively) and NPR (median 1.9 and 3.1 for FMB3 and FMB4, respectively) for these field barrels. These field barrels were constructed to examine the impact of P-AML rock on the overall acid rock drainage/metal leaching (ARD/ML) behaviour from the dominantly N-AML waste rock materials that would be extracted and stored within surface waste dumps during the development of the Flame & Moth decline/deposit. Further details regarding the composition of the field barrels can be found in AEG (2016b).

5.1.2.1 pH, Acidity, Alkalinity and Sulphate

Throughout the monitoring conducted to date, the field barrel leachate pH has remained circumneutral to slightly alkaline, ranging from pH 5.9 to 8.7 (Figure 5-7). FMB1 generally displayed the lowest pH values, whereas the highest pH values were often recorded in the leachate from FMB3. This trend reversed for the acidity levels, where FMB1 consistently exhibited acidity levels (9 – 226 mg/L $CaCO_3$) that were significantly higher than FMB2, FMB3 and FMB4 (1.8 – 3.2 mg/L $CaCO_3$; Figure 5-7). FMB1 and FMB3 showed the highest and lowest dissolved sulphate concentrations, respectively (Figure 5-7). Dissolved sulphate concentrations were typically highest in the warmer summer months and lowest for the spring and fall sampling events, except for the 2017 dataset, which showed a general increase in sulphate concentrations through the year (Figure 5-7). Indeed, leachate from the P-AML FMB1 recorded its highest sulphate concentrations to date (2,870 mg/L) in the September 2017 sampling event. Only leachate from FMB3 generally had sulphate concentrations below the BCMOE guideline (429 mg/L). Sulphate concentration in FMB2 and FMB4 oscillated about the BCMOE guideline, whereas FMB1 sulphate concentrations always exceeded the guideline. Alkalinity levels showed some limited correlation with pH, as FMB1, which was at the lower end of the leachate pH range also had the lowest alkalinity (<0.5 – 56 mg/L $CaCO_3$). This is consistent with the P-AML bulk rock materials composition that comprised FMB1. In general, alkalinity levels were the highest at the start of the field barrel experiment, declined over the next few months, and then stabilized.

5.1.2.2 Trace Elements of Interest

The trace element leaching trends were broadly in line with the P-AML / N-AML classification of the rock that comprised each field barrel. FMB1 was composed of P-AML material and the leachate from this bin regularly contained the highest concentrations of zinc, cadmium, nickel, lead, copper, and silver (Figure 5-8 and Figure 5-9). FMB2, FMB3, and FMB4 were primarily composed of N-AML rock. These field barrels generally exhibited much lower zinc, cadmium, nickel, lead, copper, and silver leachate concentrations, and did not exceed any QZ09-092 EQS (Figure 5-8 and Figure 5-9).

Zinc

Leachate from the N-AML rock-bearing materials found within FMB4 had the lowest zinc concentrations that were consistently below the BCMOE guideline (0.19 mg/L; Figure 5-8). Leachate zinc concentrations from FMB2 were also typically low than the BCMOE guideline. FMB1 consistently showed the highest zinc concentrations (0.4 – 105 mg/L). Almost all the FMB1 samples exceeded the effluent quality standard (EQS) for zinc (0.5 mg/L), and were an order of magnitude higher than the zinc levels recorded in the other field barrels. Zinc concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. This metal leaching behaviour is in line with the predominantly P-AML rock that comprises FMB1. The zinc concentration in leachate collected from the N-AML field barrels FMB1, FMB2, and FMB3 has not exceeded the EQS to date.

Cadmium

Cadmium concentrations followed a similar trend to those of zinc (Figure 5-8). The cadmium concentration in the leachate for all the field barrels exceeded the CCME guideline (0.00037 mg/L) for all FMB1 and FMB3 samples collected to date. FMB2 leachate cadmium concentrations occasionally dipped below the CCME guideline, whereas FMB4 cadmium concentrations were regularly lower than CCME (Figure 5-8). FMB1 displayed the highest leachate cadmium levels (0.01 – 1.5 mg/L), all of which exceeded the EQS (0.1 mg/L), further confirming the P-AML nature of the rock used for this field barrel. Cadmium concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. Leachate from the other three N-AML rock filled field barrels contained cadmium levels that were below the EQS, although a rise in cadmium concentration over the summer of 2014 was noted for FMB2 and FMB3. Contrasting behaviour was noted in 2015, when the cadmium concentration in the FMB2 and FMB3 leachates peaked in July, then declined throughout the subsequent summer and fall sampling events.

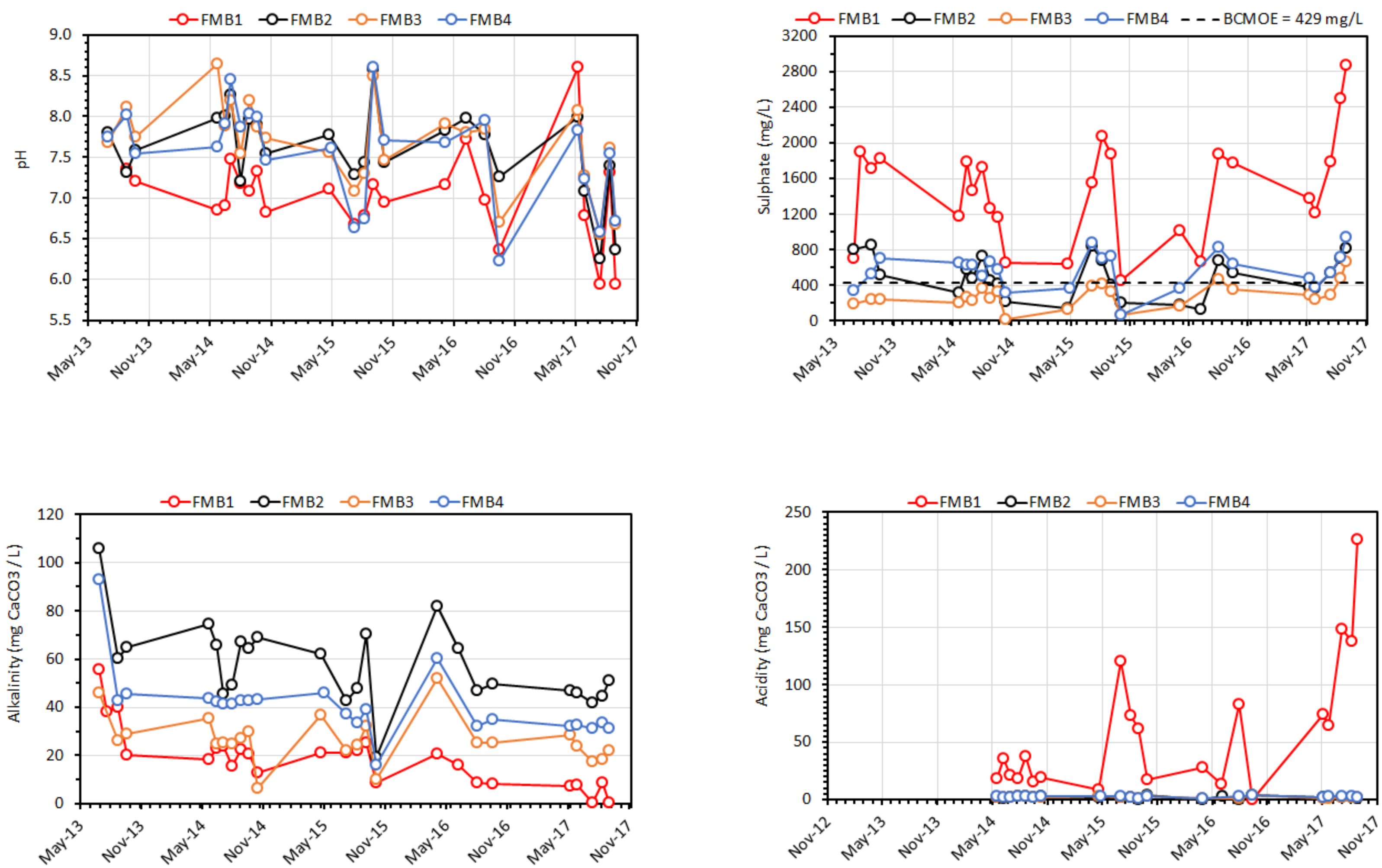


Figure 5-7: Trends in Flame & Moth Waste Rock Field Barrel pH, Sulphate, Alkalinity and Acidity Levels

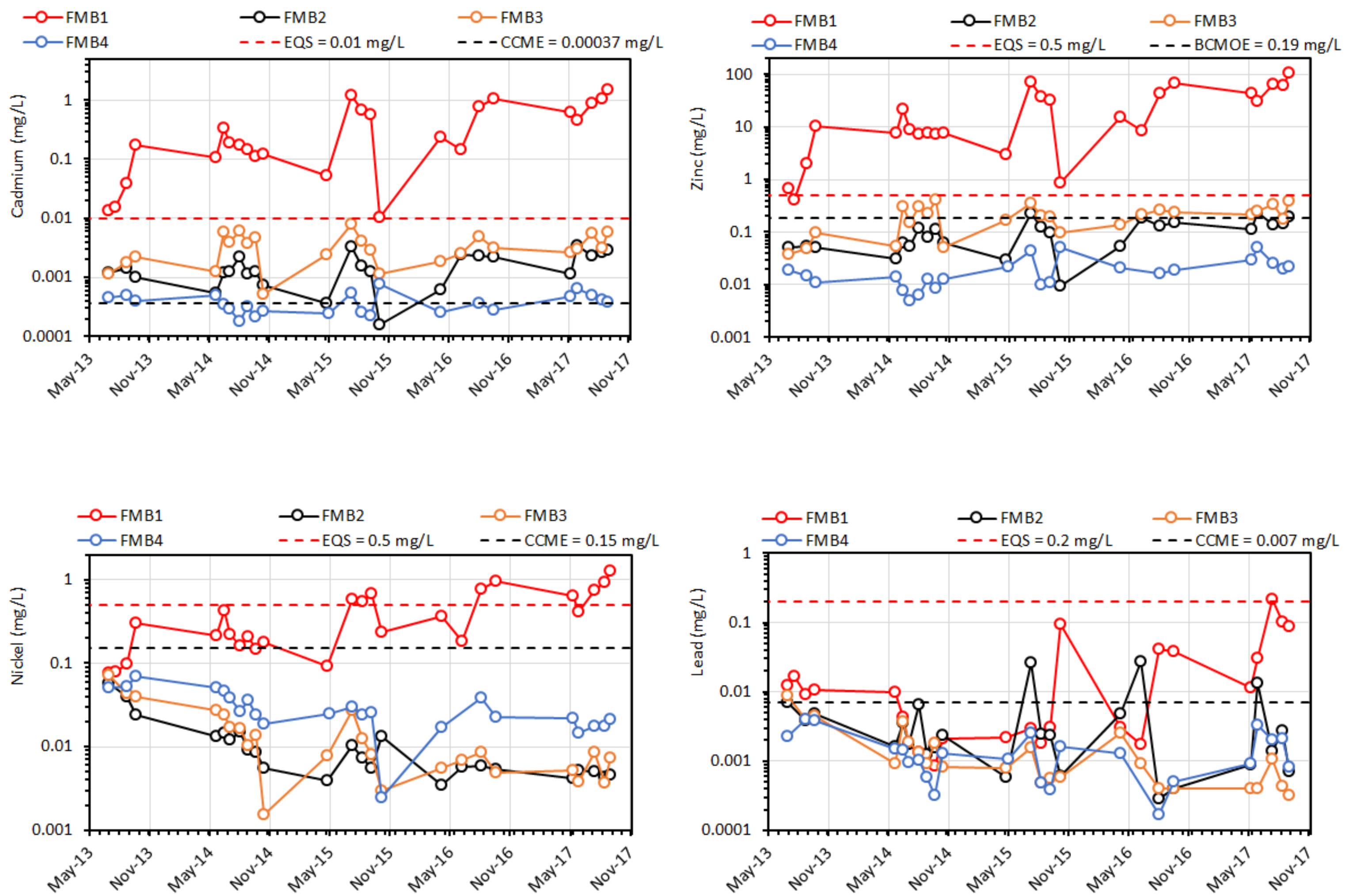


Figure 5-8: Trends in Flame & Moth Waste Rock Field Barrel Cadmium, Zinc, Nickel, and Lead Concentration

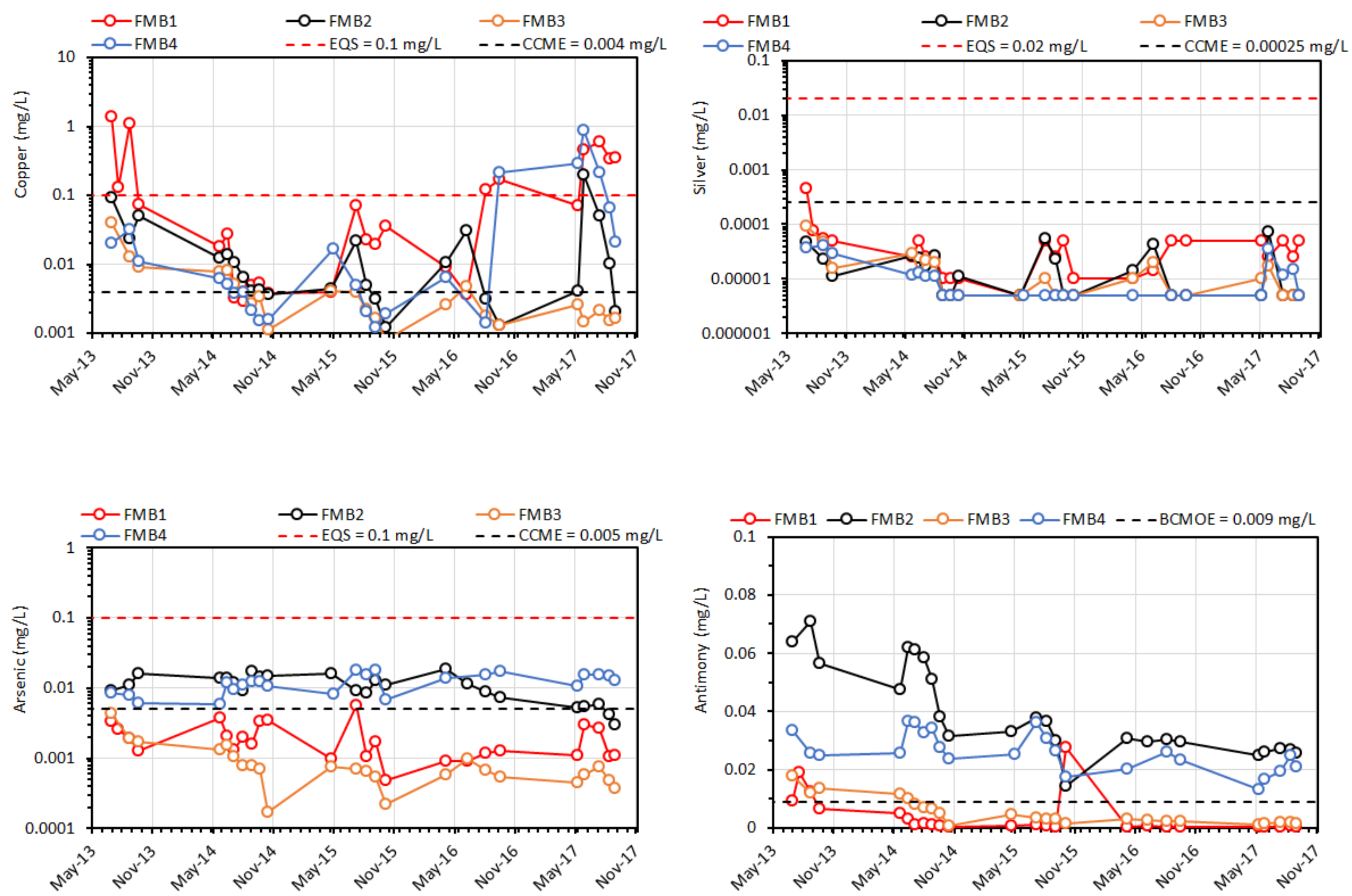


Figure 5-9: Trends in Flame & Moth Waste Rock Field Barrel Copper, Silver, Arsenic, and Antimony Concentrations

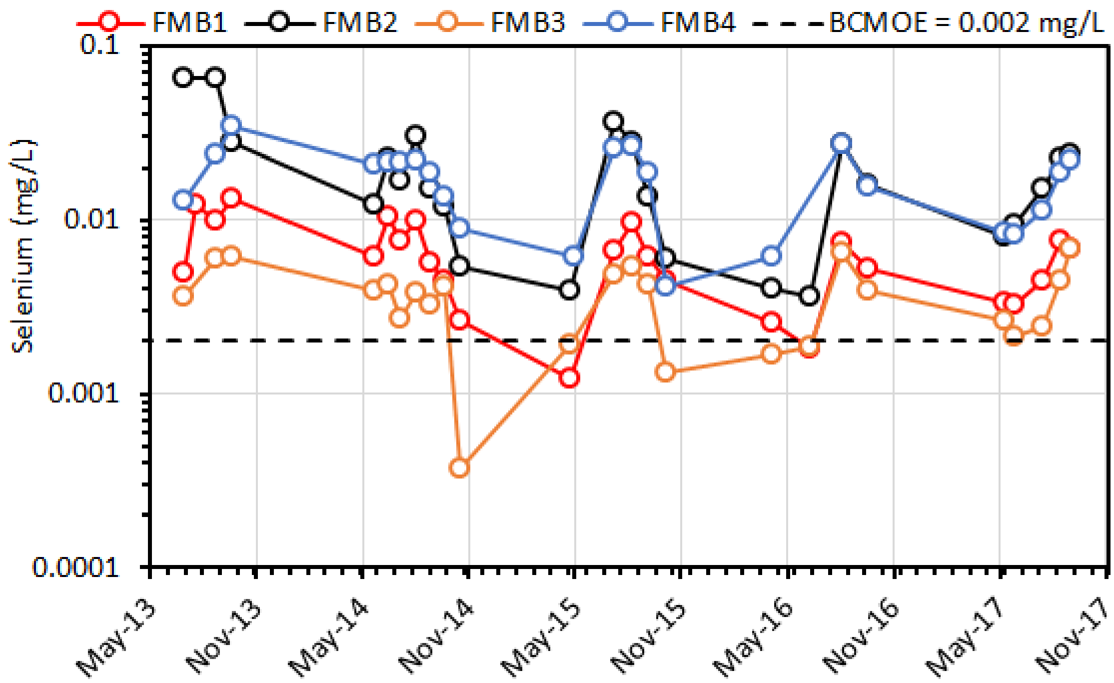


Figure 5-10: Trends in Flame & Moth Waste Rock Field Barrel Selenium Concentrations

Nickel

Nickel concentrations were highest in the leachate derived from the P-AML rock-bearing materials found within FMB1 (Figure 5-8). The nickel level exceeded the CCME threshold (0.15 mg/L) for all FMB1 samples collected since June 2015, with the EQS threshold (0.5 mg/L) exceeded in three consecutive sampling events in the summer and fall of 2015, and the majority of sampling events since July 2016. Nickel concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. The nickel concentrations in the leachate collected from the three N-AML field barrels (FMB2, FMB3 and FMB4) have gradually declined over the monitoring period and did not exceed the CCME guideline (Figure 5-8).

Lead

The leachate from FMB1 generally contained the highest lead concentrations (0.0013 – 0.22 mg/L), exceeding the CCME threshold (0.007 mg/L; Figure 5-8), and hence confirmed the P-AML nature of the rock materials assembled in this field barrel. Lead concentrations observed in 2017 in FMB1 leachate were generally higher than in previous years, consistent with the higher sulphate and acidity levels in 2017. The lead concentrations in the leachate from the three N-AML field barrels (FMB2, FMB3 and FMB4; 0.00017 – 0.027 mg/L) were typically below the CCME guideline (0.007 mg/L).

Copper

Copper concentrations followed a similar trend to those observed for lead. The P-AML rock-bearing field barrel FMB1 (0.003 – 1.4 mg/L) generally exhibited the highest leachate copper concentrations over the monitoring period, exceeding the EQS (0.1 mg/L) in the first three monitoring events in 2013 and for the majority of the 2017 sampling events (Figure 5-9). Copper concentrations in leachate from N-AML FMB3 has remained below the EQS, and below the CCME guideline (0.004 mg/L) for the majority of sampling events since late 2014. Conversely, FMB2 and FMB4 periodically exceeded the copper EQS in 2017 and exceeded the CCME threshold more often than not (Figure 5-9).

Silver

The P-AML FMB1 displayed the highest silver concentration in its leachate (<0.00005 – 0.00046 mg/L), although it was not particularly elevated with respect to the other N-AML field barrels (<0.00001 - 0.0001 mg/L; Figure 5-9). Only the first FMB1 sampling event (0.00046 mg/L) exceeded the silver CCME guideline (0.00025 mg/L); silver levels in leachate from the other FMB1 sampling events and all the N-AML field barrels were below the CCME threshold and more than two orders of magnitude lower than the EQS (0.02 mg/L).

Arsenic

The leachate from FMB1 and FMB3 contained similar levels of arsenic (typically 0.0005 – 0.005 mg/L), which were below the CCME threshold (0.005 mg/L) for all but one sample collected to date (Figure 5-9). Arsenic concentrations in leachate from FMB2 and FMB4 were also comparable (0.006 – 0.016 mg/L), but exceeded the CCME limit for all the samples collected to date except for the final two 2017 sampling events for FMB2 (Figure 5-9). All the field barrel leachate was well below the EQS (0.1 mg/L).

Antimony

The antimony leaching behaviour was similar to that of arsenic. The lowest antimony concentrations were observed in leachate from FMB1 and FMB3 (0.0013 – 0.028 mg/L), in which the majority of the samples collected to date were at, or below the BCMOE working guideline (0.009 mg/L) (Figure 26). The antimony levels in the leachate from FMB4 and FMB2 were all above the BCMOE guideline, with the latter field barrel showing the highest antimony concentrations (0.014 – 0.071 mg/L). A declining trend in the leachate antimony concentration from the field barrels is broadly observed.

Selenium

The leachate selenium concentrations exceeded the BCMOE guideline (0.002 mg/L) for all samples collected to date from the FMB2 and FMB4 field barrels, and for the majority of samples collected from FMB1 and FMB3 (Figure 5-10). The lowest (FMB3: 0.00037 – 0.0069 mg/L) and highest (FMB2: 0.0037 – 0.065 mg/L; FMB4: 0.0041 – 0.034 mg/L) selenium concentrations were observed in the leachate from the N-AML field barrels, suggesting that the leaching behaviour of this element cannot be predicted based on AML classification.

5.2 TAILINGS

5.2.1 Humidity Cells

Two tailings-bearing humidity cells were performed:

- Flame & Moth F4+F5 size fraction tailings (run for 113 weeks); and
- Bellekeno tailings composite from tailings produced by the District Mill between January and June 2011 (run for 212 weeks).

Concentrations of constituents of interest in the leachate from the Bellekeno and Flame & Moth tailings humidity cells are displayed in Figure 5-11 to Figure 5-13. For comparison the effluent quality standards (EQS) set out in water licence QZ09-092 and CCME or BCMOE (whichever is the most recent) water quality guidelines for the protection of aquatic life are also presented for comparative purposes. The lower (i.e., 25th) percentile hardness (460 mg/L) for the Christal Creek monitoring site nearest to the dry stack tailings facility (KV-51) was used to calculate hardness-dependent guidelines; however, it is noted that any DSTF seepage is collected and routed to the Mill Pond for use in the processing circuit and any discharges from the Mill Pond require treatment to achieve the EQS under QZ09-092.

5.2.1.1 pH, Acidity, Alkalinity and Sulphate

Acidity, alkalinity and pH levels observed in the Flame & Moth tailings humidity cell are similar to those observed within the humidity cell for the Bellekeno tailings (Figure 1). Both humidity cells exhibited high alkalinity, low acidity, and stable pH values of between 7.7 and 8.2. This corroborates the static geochemical data which indicated that the Flame & Moth tailings would have a very low potential for net acid generation.

The Flame & Moth humidity cell dissolved sulphate concentrations followed the same trend as those found within the Bellekeno tailings (Figure 5-11). The sulphate concentration in the leachate from both humidity cells was highest during the first few leaches as soluble sulphate salts were rinsed out (400 to 600 mg/L peak concentration). In the Flame & Moth sulphate concentration declined by an order of magnitude over the first 26 weeks of operation before stabilizing between 20 and 35 mg/L. The Bellekeno tailings exhibited similar behaviour, but took longer to decline (~70 weeks) and stabilized at a higher sulphate concentration range (40 to 60 mg/L), consistent with the higher total sulphur content of these tailings.

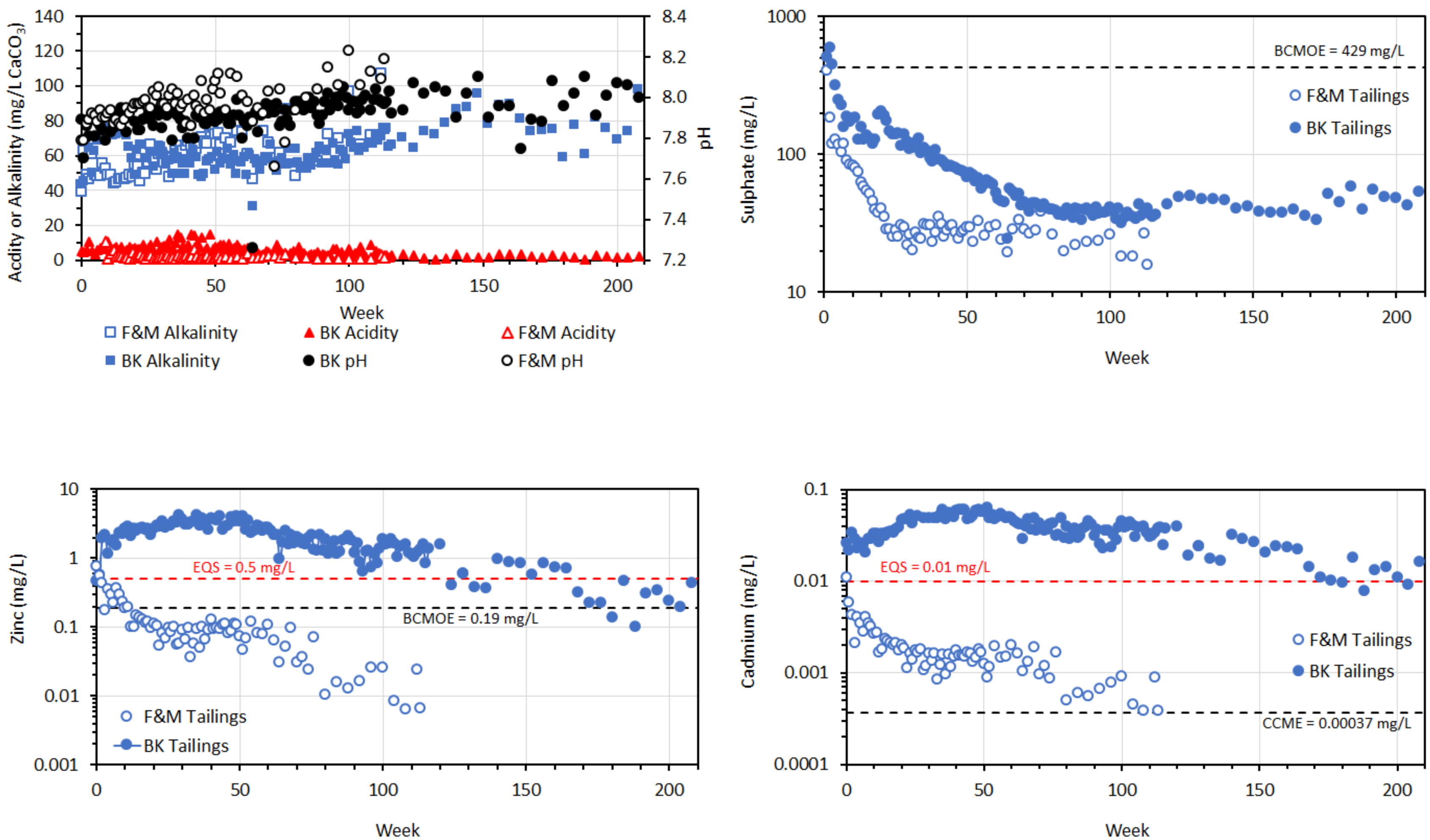


Figure 5-11: Acidity, Alkalinity, pH, Sulphate, Zinc and Cadmium Trends within the Flame & Moth (F&M) and Bellekeno (BK) Tailings Humidity Cells

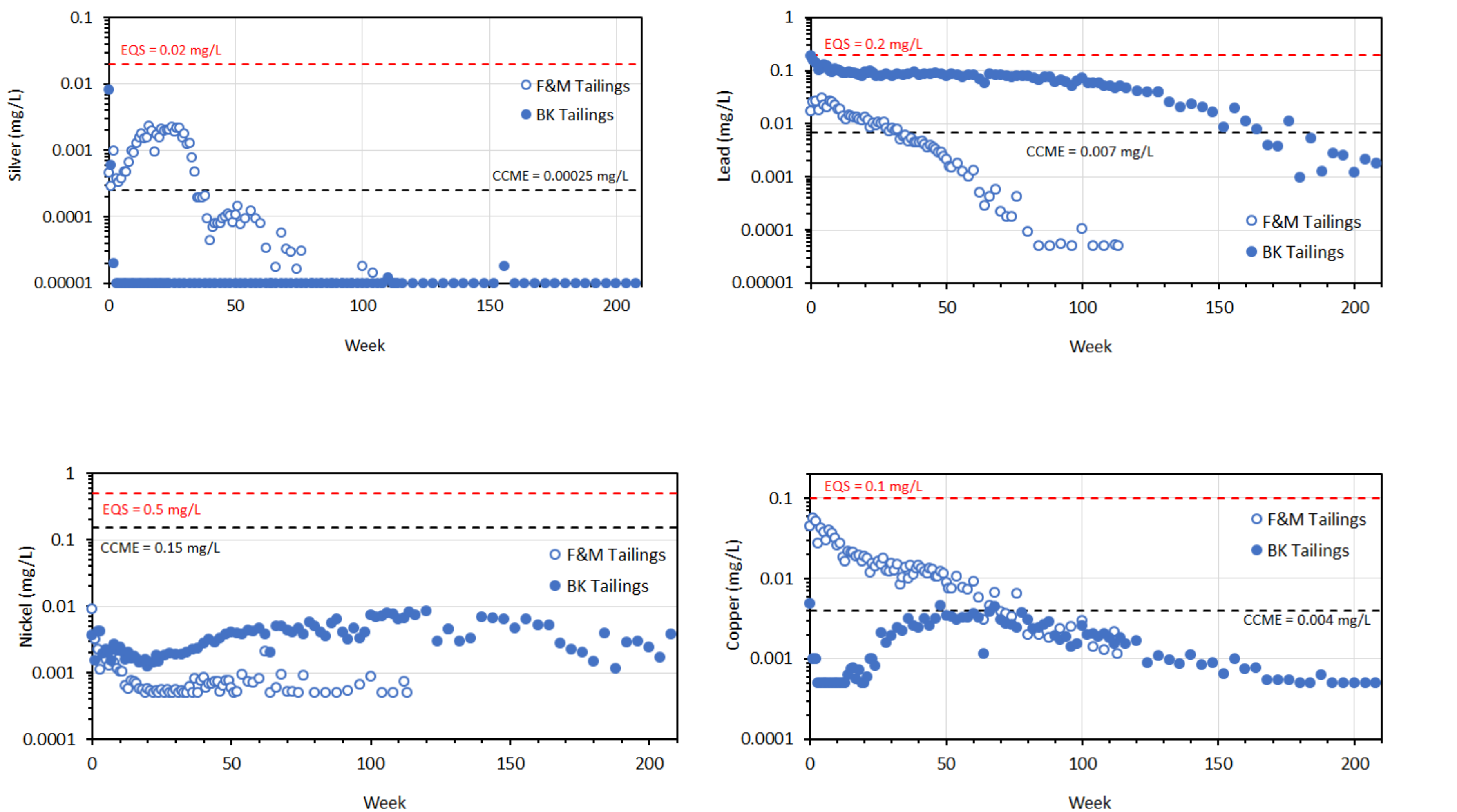


Figure 5-12: Silver, Lead, Nickel, and Copper Trends within the Flame & Moth (F&M) and Bellekeno (BK) Tailings Humidity Cells

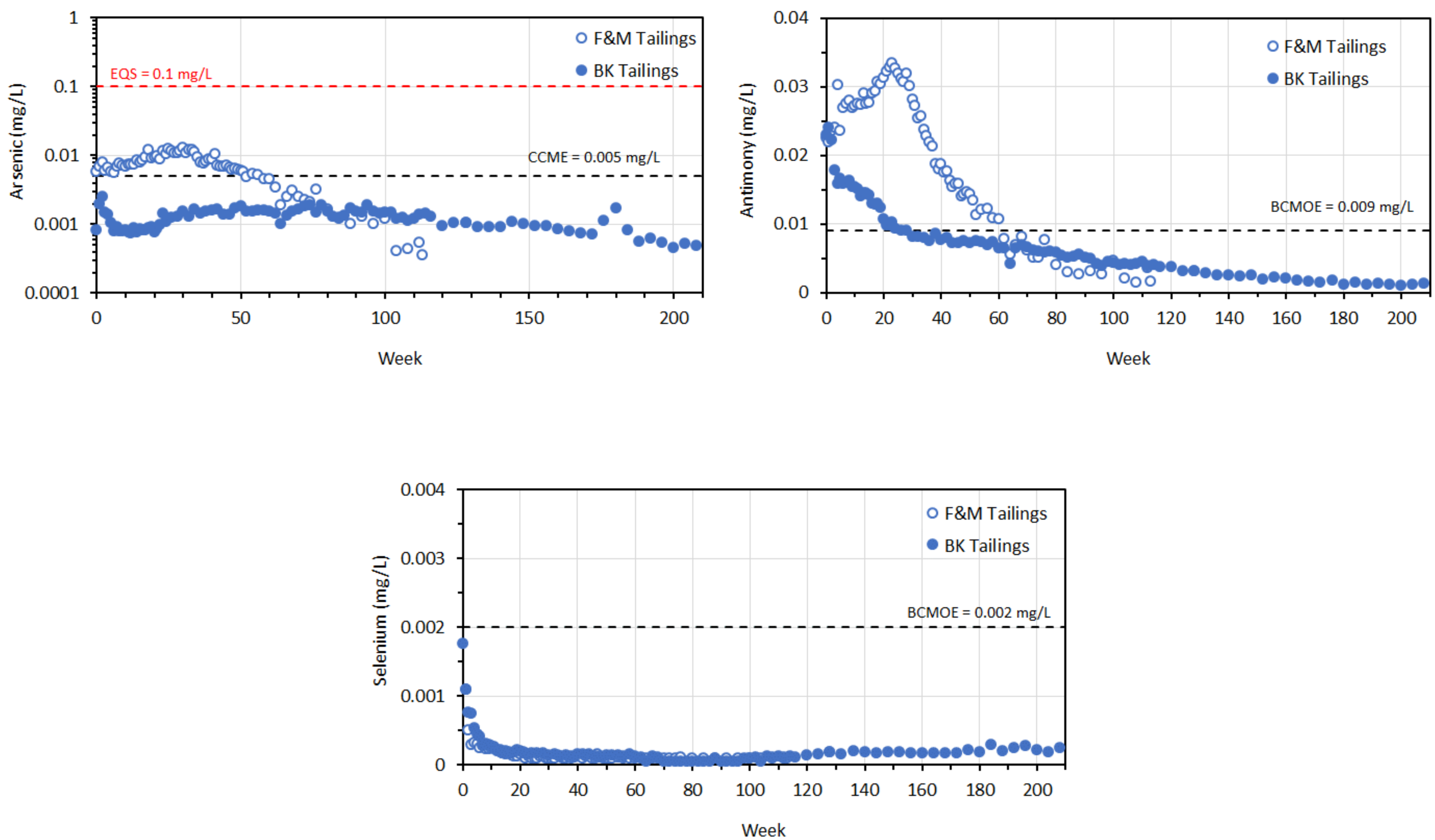


Figure 5-13: Arsenic, Antimony and Selenium Trends within the Flame & Moth (F&M) and Bellekeno (BK) Tailings Humidity Cells

5.2.1.2 Trace Elements of Interest

The concentrations of zinc, cadmium and lead found within the Flame & Moth tailings humidity cell's leachate were significantly lower (an order of magnitude) than those observed from the Bellekeno humidity cell (Figure 5-11 and Figure 5-12), likely reflecting the order of magnitude lower concentration of these elements in the Flame & Moth tailings. For the majority of its operation, cadmium and zinc concentrations in the Bellekeno tailings humidity cell leachate typically exceeded their EQS (0.01 and 0.5 mg/L, respectively), whereas the concentrations in the Flame & Moth leachate were almost all below the EQS, declining to approximately 0.002 and 0.1 mg/L, respectively after 20 leaching cycles (Figure 5-11).

Lead concentrations in the Bellekeno tailings humidity cell leachate stayed at approximately 0.1 mg/L for the first 80 leaching cycles before slowly declining by almost two orders of magnitude to ~0.002 mg/L after 180 cycles (Figure 5-12). In the Flame & Moth tailings leachate, lead concentrations steadily declined from 0.02 mg/L to below detection (<0.00005 mg/L) over the first 80 humidity cell cycles. Silver concentrations were generally higher in the Flame & Moth humidity cell leachate than Bellekeno, peaking at 0.002 mg/L between week 15 and 30, before declining rapidly below the CCME threshold (0.00025 mg/L) by week 40, and stabilizing at approximately 0.00001 mg/L) since week 80. Conversely, silver concentrations in the Bellekeno tailings humidity cell leachate were below detection (i.e., <0.00001 mg/L) for almost all leaching cycles (Figure 5-12).

Nickel and copper concentrations remained below their EQS (0.5 and 0.1 mg/L, respectively) in the leachate from both the tailings humidity cells (Figure 5-12). Higher nickel concentrations were observed in the Bellekeno tailings humidity cell leachate (peak ~0.01 mg/L) than the Flame & Moth tailings leachate (frequently below detection; <0.0005 mg/L), but all samples from both humidity cells were below the CCME nickel guideline (0.15 mg/L). Coper concentrations were highest in the Flame & Moth tailings leachate, which declined from 0.06 mg/L in week 1 to 0.002 mg/L in week 84. Conversely, Bellekeno tailings humidity cell leachate copper concentrations rose to ~0.03 mg/L by week 50, then gradually declined to 0.001 mg/L by week 124, and often below detection (i.e., <0.0005 mg/L) after that. Since week 80, copper concentrations in both humidity cell leachates remained below the CCME guideline (0.004 mg/L); copper concentrations in the Bellekeno leachate were below the CCME guideline for almost all leaching cycles.

Arsenic concentrations in the leachate from both tailings humidity cells was below the EQS (0.1 mg/L) for the duration of the experiments (Figure 5-13). Concentrations were highest in the Flame & Moth leachate over the first 70 weeks of its operation, peaking at 0.013 mg/L at week 30, then declined gradually by an order of magnitude and below the CCME guideline (0.005 mg/L). Bellekeno tailings leachate arsenic concentrations remained relatively stable throughout at approximately 0.001 mg/L and were uniformly lower than the CCME guideline (Figure 5-13). Like arsenic, antimony concentrations in the Flame & Moth humidity cell leachate rose initially and peaked at 0.033 at week 24 before declining to ~0.003 mg/L by week 80 (Figure 5-13). Bellekeno antimony concentrations declined from 0.023 mg/L at the start of the humidity cell operation, to 0.009 mg/L at week 25, equivalent to the working BCMOE antimony guideline. Antimony concentrations then gradually declined to stabilize at 0.001 to 0.002 mg/L after week 150 (Figure 5-13) and shared a similar concentration range as that observed in the Flame & Moth humidity cell leachate from week 60 onwards (Figure 5-13). Selenium concentrations were similar and uniformly low in the leachate from both the Bellekeno and Flame &

Moth humidity cell leachates, stabilizing at 0.0002 mg/L from week 12 onwards, an order of magnitude below the BCMOE guideline (0.002 mg/L; Figure 5-13).

6 SUMMARY

6.1 WASTE ROCK

- Waste rock generated from deposits of interest within the KHSD is expected to be predominantly non-acid generating. Only waste rock from Silver King is expected to have a sizeable PAG component, perhaps reflecting a regional control on waste rock ARD potential;

- SFE testing suggested elevated soluble concentrations of fluoride, aluminum, antimony, arsenic, and selenium; and

- Kinetic testing of N-AML waste rock indicated that long term metal leaching was expected to be low, although antimony, arsenic, and selenium concentrations in leachate from some Flame & Moth N-AML field barrels exceeded CCME and BCMOE guidelines by up to an order of magnitude.

6.2 TAILINGS

- Tailings produced from processing of Bellekeno, Flame & Moth, Onek, and Lucky Queen ore are expected to be non-PAG, whereas Bermingham tailings are of uncertain ARD potential;

- SFE testing returned soluble antimony, cadmium, copper, lead, selenium, silver, and zinc concentrations that were marginally greater than their respective water quality guidelines in some tailings samples; and

- Humidity cell testing indicated elevated cadmium and zinc concentrations above their respective EQS in the Bellekeno tailings. Lead concentrations were also elevated in the Bellekeno tailings humidity cell leachate, but below the EQS. In the Flame & Moth tailings humidity cell, constituent concentrations remained below their EQS and were generally lower than those observed in the Bellekeno tailings, except for arsenic, antimony, copper, and silver which were higher for the first year of operations during which time they declined to levels comparable to Bellekeno tailings leachate and below CCME and BCMOE water quality guidelines.

7 ONGOING WORK

At the time of writing, static ARD/ML characterization of waste rock from the Bermingham decline cover hole and the Bermingham N-AML waste rock humidity cell and Flame & Moth waste rock field barrels are ongoing. A humidity cell with Bermingham tailings will be initiated once they are available.

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APPENDIX 3.4

FLAME AND MOTH WASTE STORAGE FACILITY DESIGN

TETRA TECH EBA

October 2, 2014

ISSUED FOR USE
FILE: W14103485
Via Email: kwoloshyn@alexcoresource.com

Alexco Resource Corp.
3-151 Industrial Road
Whitehorse, YT Y1A 2V3

Attention: Kai Woloshyn, Environmental Manager

Subject: Waste Storage Facility Design – Revision I
Flame & Moth Property, Keno City, Yukon

1.0 INTRODUCTION

Alexco Resource Corp. (Alexco) retained Tetra Tech EBA Inc. (Tetra Tech EBA) to provide a preliminary design for a waste containment facility for the storage of potentially acid metal leaching (P-AML) material at their Flame & Moth property west of Keno City, Yukon.

This letter summarizes the site specific foundation conditions, provides foundation preparation recommendations, and includes facility design drawings for two proposed facility locations. It also includes recommendations for the disposal of P-AML within the existing Dry Stacked Tailings Facility (DSTF). Tetra Tech EBA has reviewed the structural stability of the DSTF assuming co-mingling of produced tailings and P-AML waste rock. We have assumed the chemical implications of P-AML disposal in the DSTF will be reviewed by others. For additional information regarding the use of this report, please refer to Tetra Tech EBA's General Conditions included in Appendix A.

2.0 FLAME & MOTH WASTE STORAGE FACILITY

The Flame & Moth waste storage facility design is based on the previously completed "Typical Waste Containment Facility Design, Keno Hill Silver District, YT – Construction Specifications" (EBA 2008). The overall facility dimensions were determined based on the storage of 4,500 m^3 of waste material, as requested by Alexco.

2.1 Location I

Location I for the proposed Flame & Moth facility is southeast of the existing mill building between the Flame and Moth portal and the proposed Dry Stack Phase II Expansion. The proposed facility location and footprint are shown on the attached Figure 1.

Tetra Tech EBA has site specific historic subsurface information from a testpit excavated within the proposed footprint in 2009. W14101178.002-TP03 was excavated to a final depth of 4.0 m through roughly 3.5 m of frozen peat and SILT, over ice-poor SAND. The detailed testpit log is included in Appendix B.

2.1.1 Location I Waste Storage Facility Recommendations

Tetra Tech EBA considers Location I for the Flame & Moth waste storage facility suitable provided the following recommendations are adhered to and the facility is constructed to the dimensions and specifications in the attached Drawings.

- Tetra Tech EBA understands Alexco is currently excavating a pad for access to the Flame & Moth portal to an elevation of 907 m adjacent to the proposed waste storage facility footprint. The excavation will be about 2 m

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below existing grade, exposing frozen peat and silt in the upslope wall. The disturbance caused by the portal pad excavation increases the potential for thaw settlement in the ice rich peat and silt under the proposed facility – it should be removed.

- The portal pad excavation should be extended under the facility footprint to remove all frozen peat and silt, exposing the underlying sand. Any visible ice in the sand must also be removed.
- Subsequent to peat removal, 16 oz. non-woven geotextile should be placed over the entire footprint of the facility (including beneath perimeter berms and armoured slopes graded to meet original ground).
- 0.6 m of "Zone B" material should be placed and compacted over the frozen sand prior to facility construction.
- If thicker peat/silt deposits are encountered, additional "Zone B" material will be required to prepare a level working surface. The "Zone B" material should be placed in lifts no thicker than 0.5 m in uncompacted thickness and compacted to at least 95% of maximum dry density using standard effort (as per ASTM D698).
- The excavation walls beyond the footprint of the facility should be shaped at 1.5:1 (horizontal:vertical) to meet original ground, lined with non-woven geotextile as described above, and armoured with waste rock as shown on the attached Drawings.

2.2 Location II

Location II for the proposed Flame & Moth facility is east of the existing coarse ore stockpile concrete pads. The proposed facility location and footprint are shown on the attached Figure 1.

Tetra Tech EBA has site specific historic subsurface information from a testpit excavated near the proposed footprint in 2009. W14101178.002-TP07 was excavated to a final depth of 5.4 m through shallow frozen peat, 2.5 m of gravelly SAND, and 3 m SILT (till). The detailed testpit log is included in Appendix B.

2.2.1 Location II Waste Storage Facility Recommendations

Tetra Tech EBA considers Location II for the Flame & Moth waste storage facility suitable provided the following recommendations are adhered to and the facility is constructed to the dimensions and specifications in the attached Drawings.

- The existing organic cover should be left in place to reduce the risk of thaw related settlement of the facility after construction.
- A level surface for facility construction should be prepared by constructing a waste rock pad as shown on the attached Drawings.

3.0 DSTF WASTE STORAGE

The existing DSTF is a lined facility designed for the long term storage of tailings waste generated during the milling process. Tetra Tech EBA has reviewed the stability of the DSTF with respect to the storage of P-AML waste rock and determined that the calculated factors of safety increase slightly with its inclusion. This is expected as the waste rock has a larger angle of internal friction due to its angularity. Additionally, its placed weight is less than that of tailings due to its clast nature and the associated voids.

The calculated factors of safety in the most critical scenario (permafrost condition) originally presented in the "Dry Stacked Tailings Facility – Risk Assessment Stability Model Update" (EBA 2013) are compared with the calculated factors of safety when waste rock is co-mingled with tailings in the following Table 1. Detailed stability results, including critical failure surfaces, are available upon request.

Table 1: DSTF Slope Stability Factors of Safety – Fully Frozen Case

Stability Condition	Factor of Safety Suggested Minimum[1]	Calculated Factor of Safety		Calculated Factor of Safety (Waste Rock Included)	
		Alignment A	Alignment B	Alignment A	Alignment B
Stability of Surface					
Short-term (during construction – static)	1.0	2.0	2.2	2.1	2.3
Long-term (after construction – static)	1.1	2.0	2.3	2.1	2.3
Deep Seated Stability					
Short-term (during construction – static)	1.1-1.3	2.0	2.0	2.0	2.0
Short-term (during construction – pseudo-static)	1.0	1.4	1.4	1.4	1.5
Long-term (after closure – static)	1.3	1.5	1.4	1.5	1.4
Long-term (after closure – pseudo-static)	1.0	1.4	1.5	1.4	1.5

[1] Mined Rock and Overburden Piles Investigation and Design Manual (BC Mine Waste Rock Pile Research Committee, 1991)

3.1 DSTF Disposal Recommendations

Tetra Tech EBA considers the disposal of P-AML waste rock within the DSTF acceptable provided the following recommendations are adhered to:

- Waste rock should be placed in lifts no thicker than 1.0 m to limit the risk of void formation within the facility as tailings naturally filter into the voids within the placed rock during and after compaction.
- At least 0.5 m of tailings must be placed and compacted between subsequent waste rock lifts to reduce the risk of preferred pathways for water infiltration through the DSTF.
- Waste rock should not be placed within 1.0 m of the extents or final surface of the DSTF to allow for adequate encapsulation.
- Waste rock may be placed in isolated partial lifts at differing locations throughout the DSTF. In fact this approach is preferred to limit the regional variability of material used to construct the DSTF.

4.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Alexco Resource Corp and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Alexco Resource Corp, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

5.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

PROFESSIONAL ENGINEER
YUKON TERRITORY
JUSTIN PIGAGE
Oct.2/14

Justin Pigage, P.Eng.
Geotechnical Engineer, Arctic Region
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PERMIT TO PRACTICE
TETRA TECH EBA INC.
SIGNATURE
Date 04/2/2014
PERMIT NUMBER PP003
Association of Professional
Engineers of Yukon

REVISION I SUMMARY:

Added recommendations for alternate facility location (Location II).

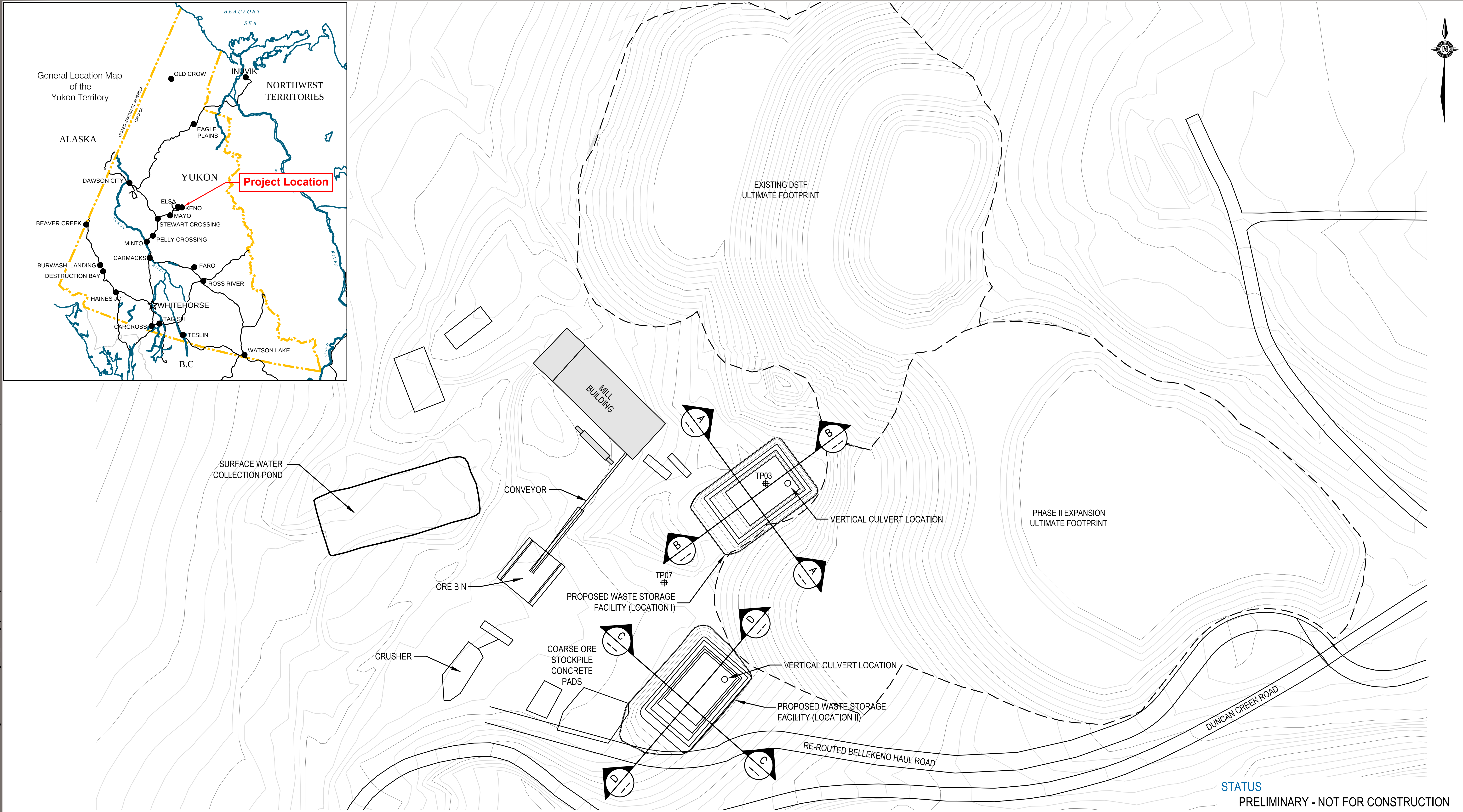
REFERENCES

EBA, A Tetra Tech Company "Dry Stacked Tailings Facility – Risk Assessment Stability Model Update, Keno Hill District Mill Site, Yukon" February 2013.

EBA Engineering Consultants Ltd. "Typical Waste Containment Facility Design, Keno Hill Silver District, YT – Construction Specifications" July 2008.

Piteau Associates Engineering Ltd. "Investigation and Design of Mine Dumps – Interim Guidelines." Prepared for British Columbia Mine Waste Rock Pile Research Committee, May 1991.

FIGURES



STATUS

PRELIMINARY - NOT FOR CONSTRUCTION

LEGEND

⊕ - TESTPIT LOCATION (2009)

0 — 100 m

Scale: 1 : 1750 @ 11"x17"

CLIENT

ALEXCO

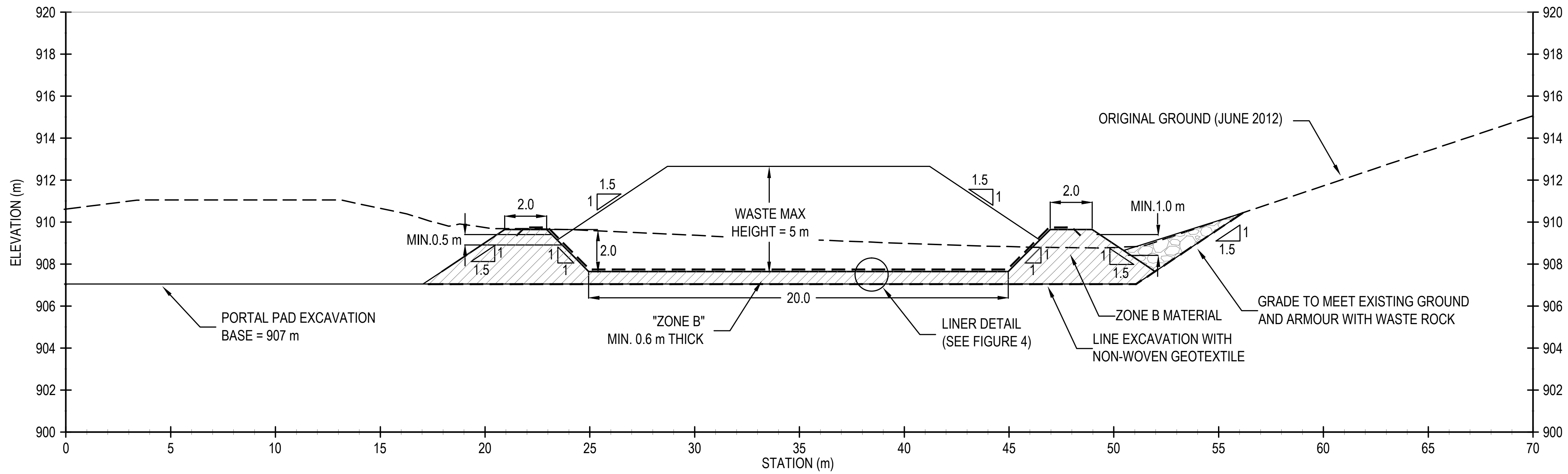
TETRA TECH EBA

FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

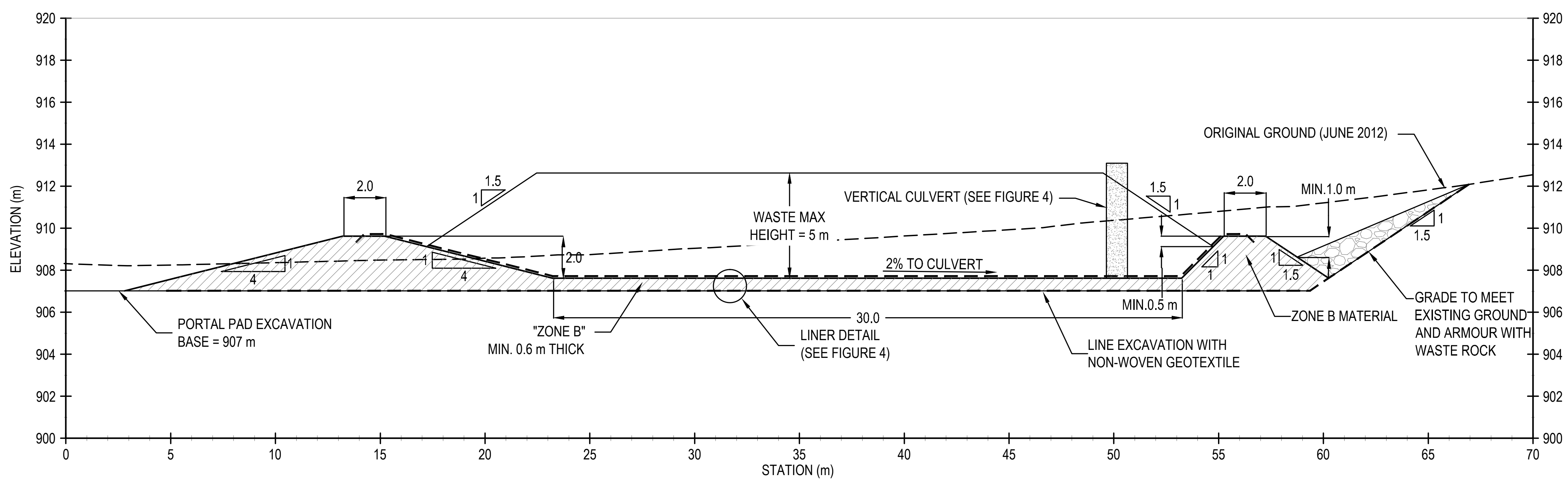
SITE PLAN

PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE	DATE		
EBA-WHSE	September 25, 2014		

Figure 1



SECTION A - A'



SECTION B - B'

STATUS
PRELIMINARY - NOT FOR CONSTRUCTION

0 10 m
Scale: 1:250 @ 11"x17"

CLIENT
ALEXCO

TETRA TECH EBA

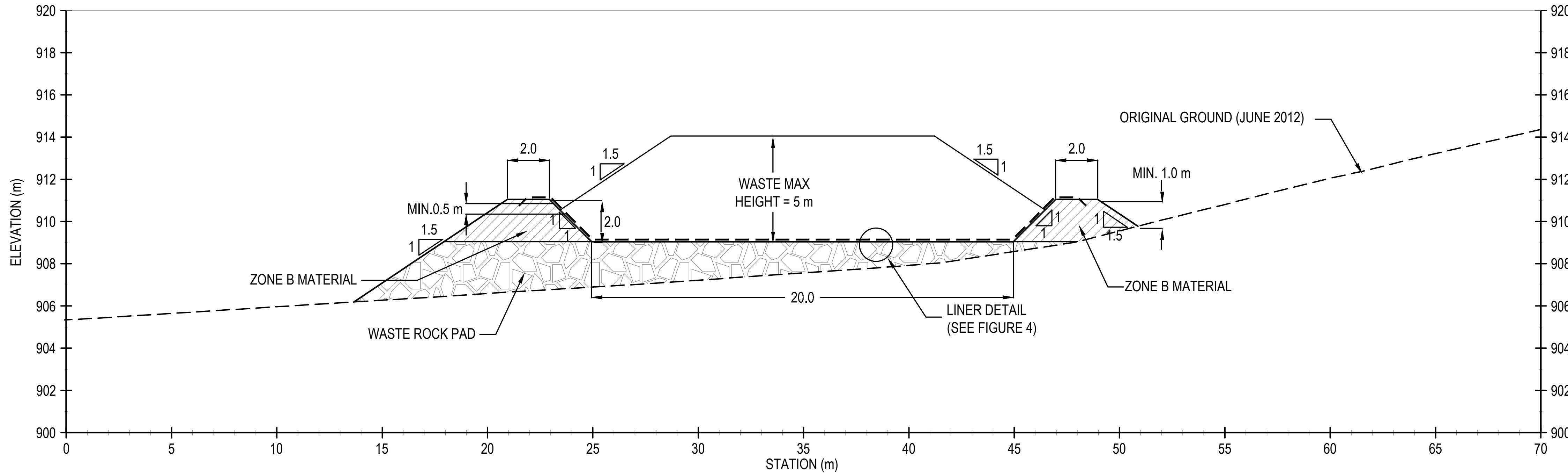
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

LOCATION I CROSS-SECTIONS

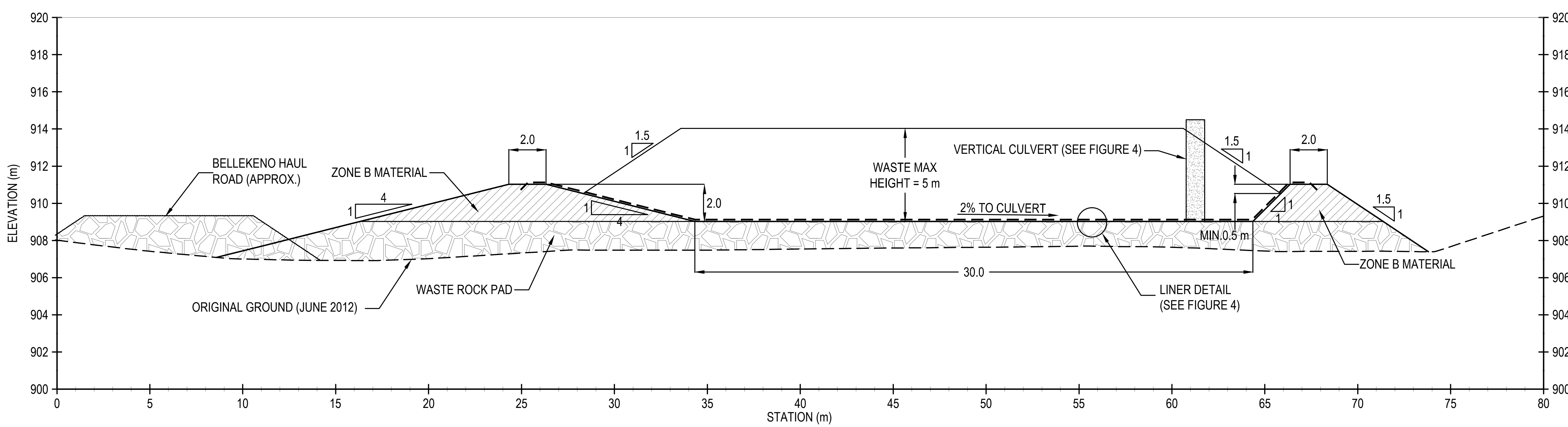
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE	DATE		
EBA-WHSE	September 25, 2014		

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

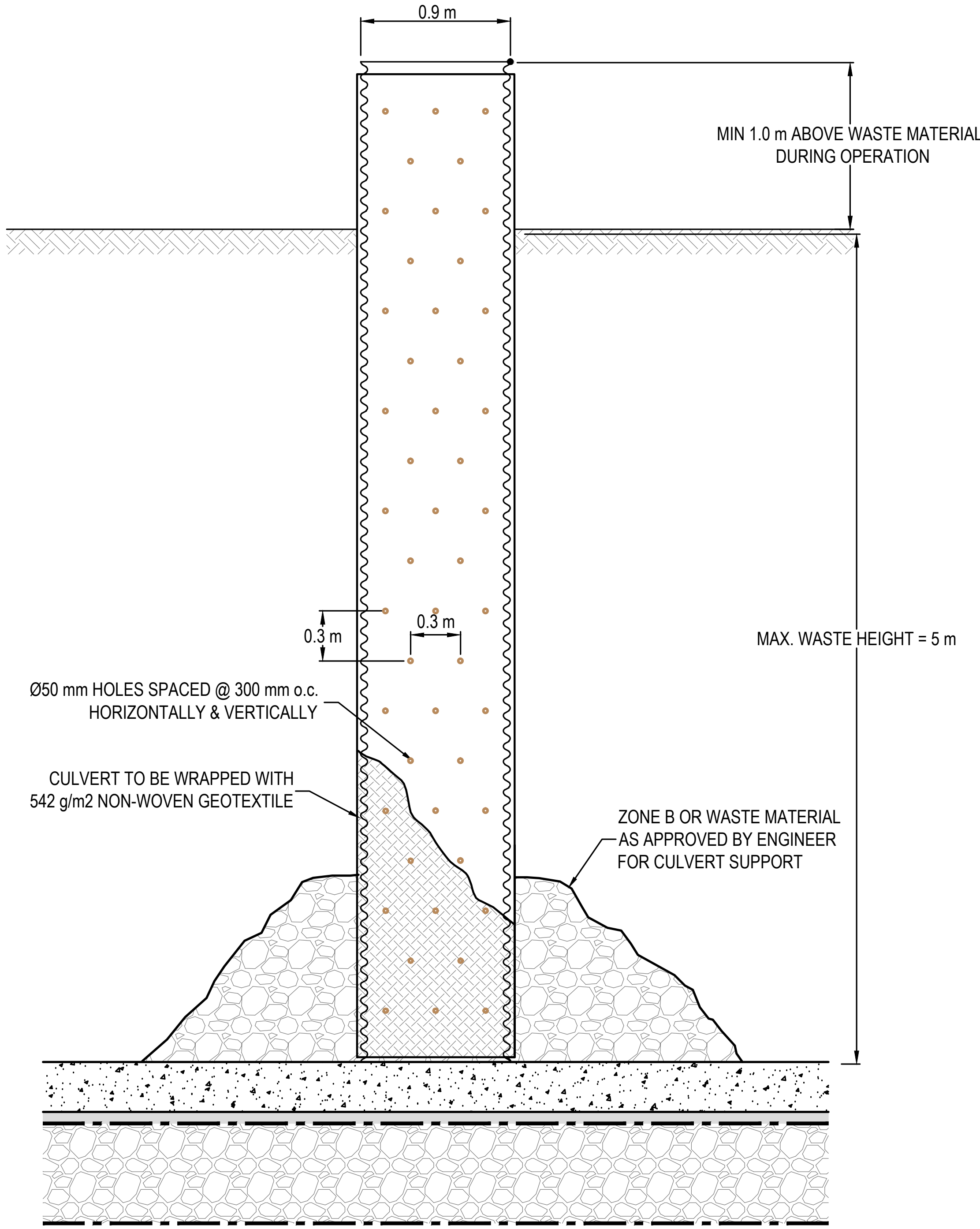
FLAME AND MOTH WASTE STORAGE FACILITY
KENO HILL DISTRICT, YUKON

LOCATION II CROSS-SECTIONS

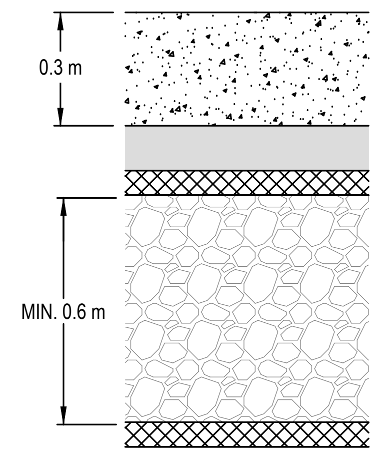
PROJECT NO.	DWN	CKD	REV
W14103485-01	CB	JTP	0
OFFICE	DATE		
EBA-WHSE	September 25, 2014		

Figure 3

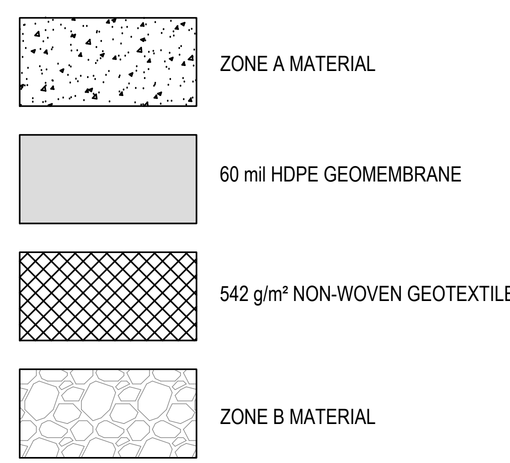
Q:\Whitehorse\Data\0201drawings\Keno\W14103485-01 Flame & Moth P-AML Design\W14103485-01 Figs 1-3_R0.dwg [FIGURE 3] October 01, 2014 - 2:21:44 pm (BY: BUCHAN, CAMERON)



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	DATE		
EBA-WHSE	September 26, 2014		

Figure 4

APPENDIX A

TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA's Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B

HISTORIC TESTPIT LOGS

Flame and Moth Mill & DSTF	CLIENT: Alexco	PROJECT NO. - TESTPIT NO.
Mill Pad	EXCAVATOR: Hitachi 270 LC	W14101178.002-TP03
near Keno City, YT	7086760N; 484004E; Zone 8	ELEVATION: 907.4m

SAMPLE TYPE: DISTURBED, NO RECOVERY, SPT, A-CASING, SHELBY TUBE, CORE

BACKFILL TYPE: BENTONITE, PEA GRAVEL, SLOUGH, GROUT, DRILL CUTTINGS, SAND

Depth (m)	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NUMBER	TEMP (°C)	■ STANDARD PENETRATION (N) ■ 20 40 60 80 / ▲ POCKET PEN. (kPa) ▲ 100 200 300 400 / PLASTIC M.C. LIQUID 20 40 60 80	GROUND ICE DESCRIPTION	Elevation (m)
0	PEAT - amorphous granular, roots, organics, black and brown, frozen					Frozen	907.0
1		Disturbed	SA01		354		906.0
		Disturbed	SA02		1158		905.0
2							
3	SILT - some sand, trace clay, soft (est.), low-plastic, massive, frozen, olive grey	Disturbed	SA03	-1.7		Vs (35%) ice lens up to 10cm thick	904.0
	SAND - silty, gravelly, trace clay, firm (est.), non-plastic, massive, frozen, olive grey	Disturbed	SA04			Vs and Vc (5%)	
4	EOH - target depth						903.0
5							902.0
6							

EBA Engineering Consultants Ltd.	LOGGED BY: CJD	COMPLETION DEPTH: 4m
	REVIEWED BY: JRT	COMPLETE: 5/6/2009
	DRAWING NO: Figure 2	Page 1 of 1

Flame and Moth Mill & DSTF	CLIENT: Alexco	PROJECT NO. - TESTPIT NO.
Mill Pad	EXCAVATOR: Hitachi 270 LC	W14101178.002-TP07
near Keno City, YT	7086712N; 483955E; Zone 8	ELEVATION: 906.7m

SAMPLE TYPE: DISTURBED, NO RECOVERY, SPT, A-CASING, SHELBY TUBE, CORE

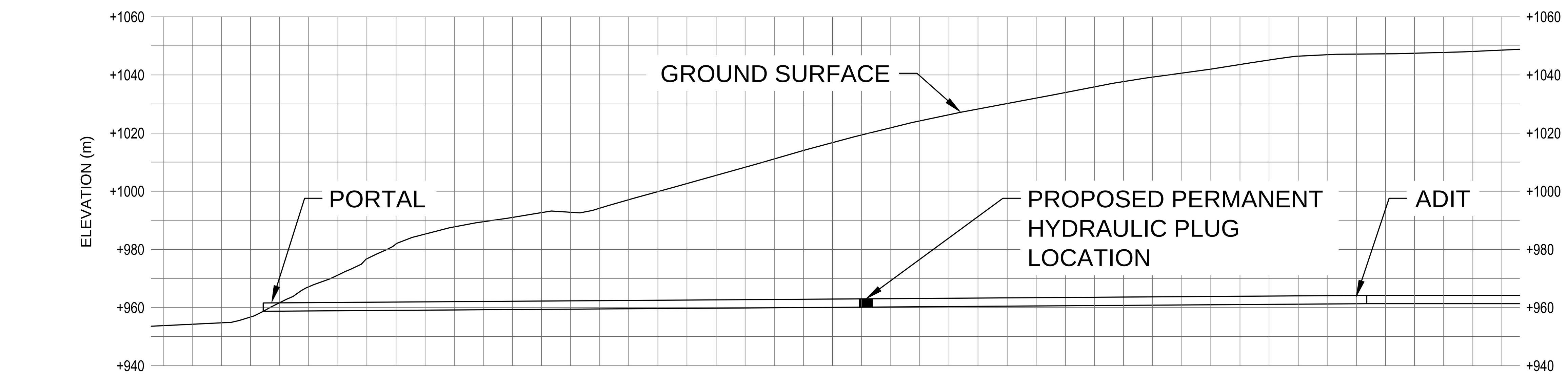
BACKFILL TYPE: BENTONITE, PEA GRAVEL, SLOUGH, GROUT, DRILL CUTTINGS, SAND

Depth (m)	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NUMBER	TEMP (°C)	STANDARD PENETRATION (N) 20 40 60 80 / POCKET PEN. (kPa) 100 200 300 400 / PLASTIC M.C. LIQUID 20 40 60 80	GROUND ICE DESCRIPTION	Elevation (m)
0	PEAT - some silt, woody, roots, black					Frozen	
	SILT - sandy, some gravel, medium, non-plastic, frozen, brown, organics, roots	Disturbed	SA01				
	SAND - gravelly, trace cobbles, trace silt,, compact (est.), medium grained, well graded, damp to moist, brown, sub-rounded						906.0
1		Disturbed	SA02				
						Unfrozen	905.0
2	- seepage					Frozen Nbn	
	SILT - sandy, some gravel, trace clay, stiff (est.), low plastic, massive, olive grey						904.0
3		Disturbed	SA03	-0.1		Vx, Vc (<5%)	
						Unfrozen	903.0
4							
		Disturbed	SA04	1.5			902.0
5							
	EOH - refusal at probable bedrock (quarzite)						901.0
6							

EBA Engineering Consultants Ltd.	LOGGED BY: CJD	COMPLETION DEPTH: 5.4m
	REVIEWED BY: JRT	COMPLETE: 5/6/2009
	DRAWING NO: Figure 2	Page 1 of 1

APPENDIX 3.5

PRELIMINARY SHAFTS AND ADITS BULKHEAD DESIGN



NO CASH 500 ADIT

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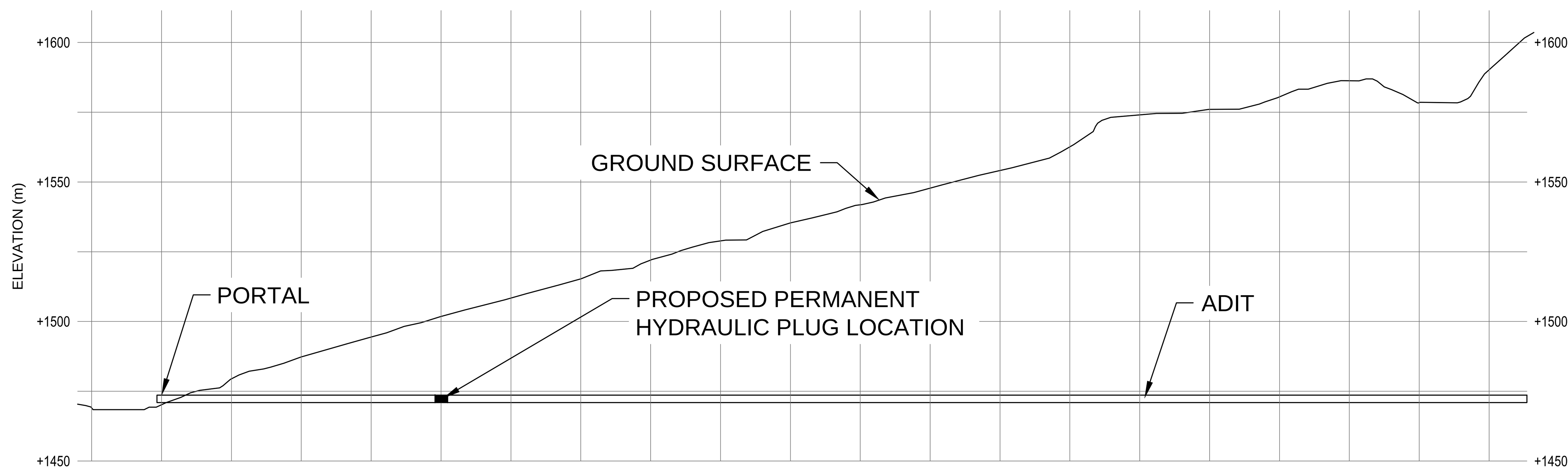

KENO 700 ADIT

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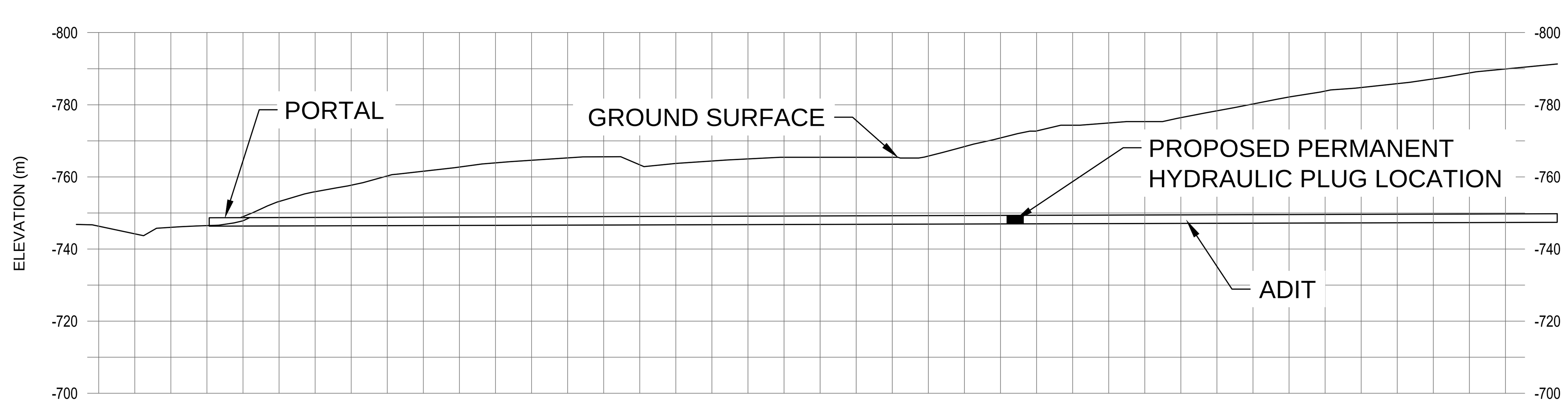
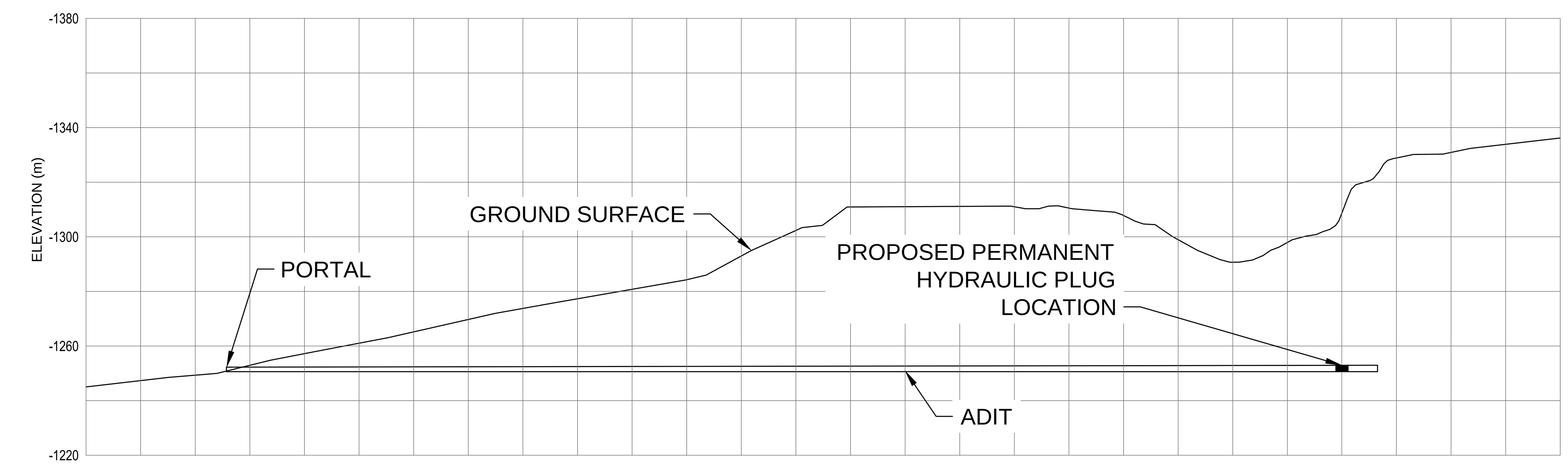


SILVER KING 100 ADIT

SCALE 1:1250



BERMINGHAM CROSS SECTION ALONG ADIT

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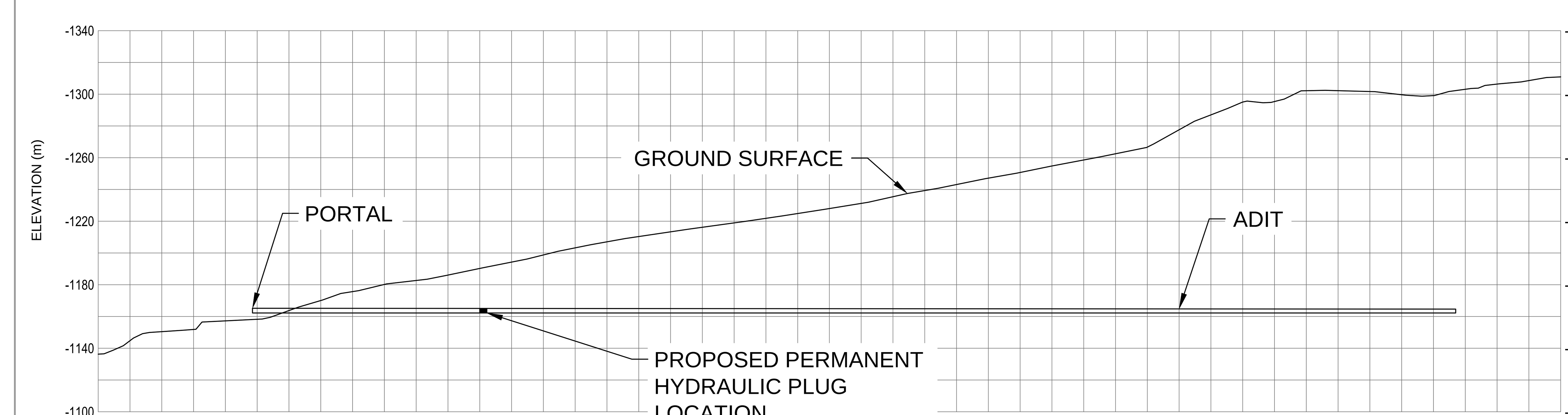


RUBY CROSS SECTION ALONG ADIT

SCALE 1:2500

NOT ISSUED FOR CONSTRUCTION

LEGEND

NOTES

1. ALL UNITS ARE IN METERS UNLESS NOTED OTHERWISE.

NUM	DATE	DWN	CKD	APR	DESCRIPTION

REVISIONS

NUM	DATE	APR	DESCRIPTION

DRAWING STATUS

PERMIT

PROFESSIONAL SEAL

CLIENT

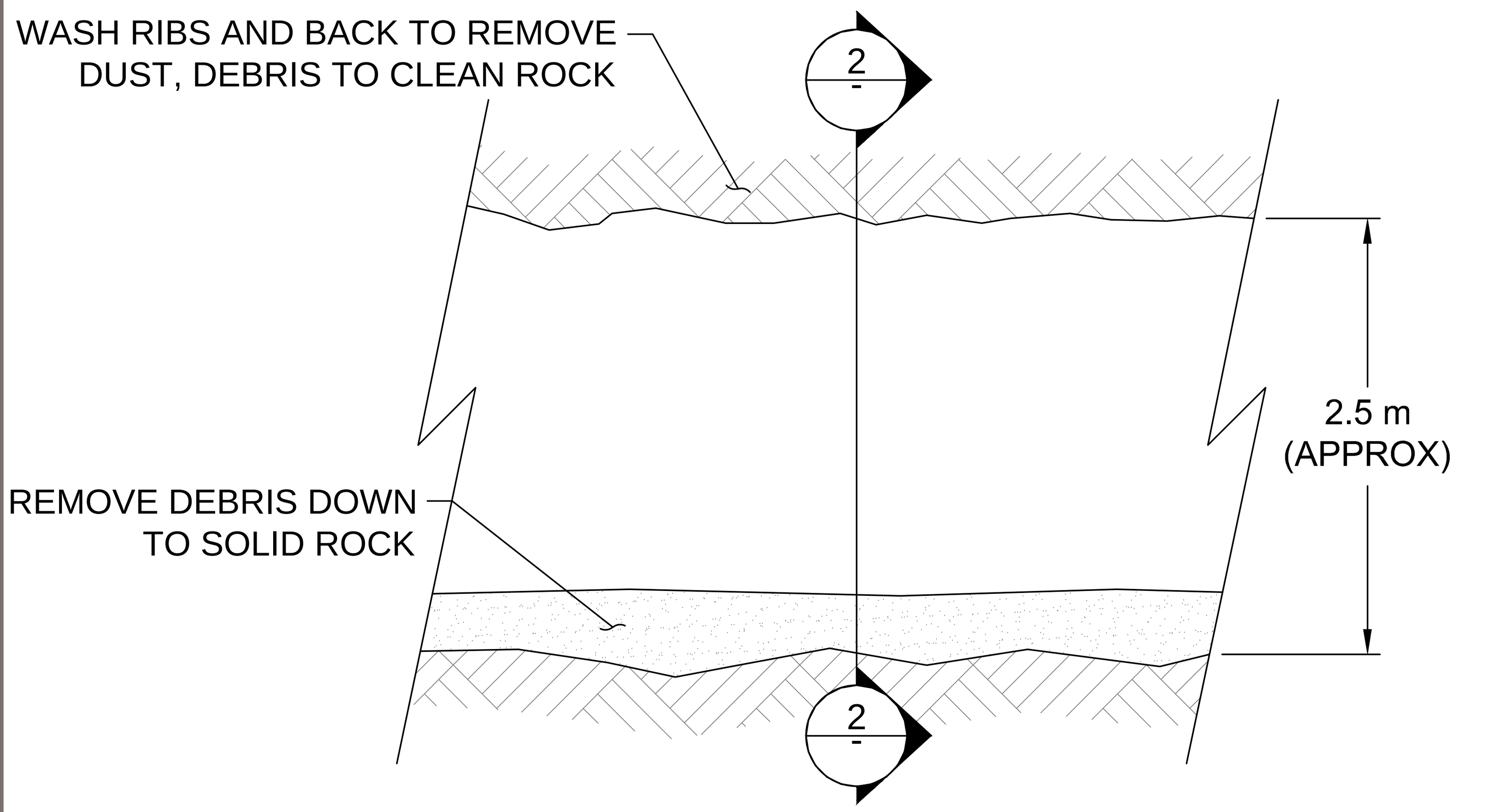
ERDC

TETRA TECH EBA

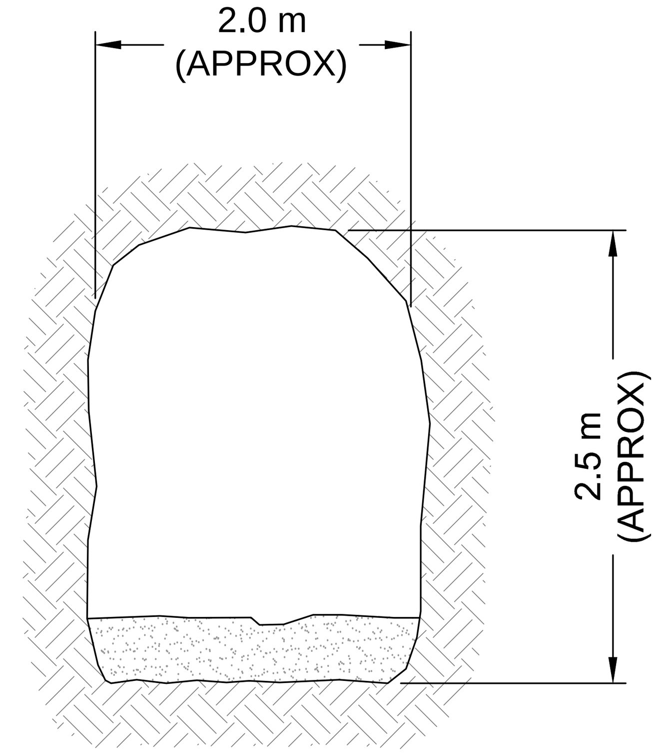
ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

HYDRAULIC ADIT PLUG DETAILS
NO CASH 500, KENO 700, SILVER KING 100, BERMINGHAM AND RUBY ADITS

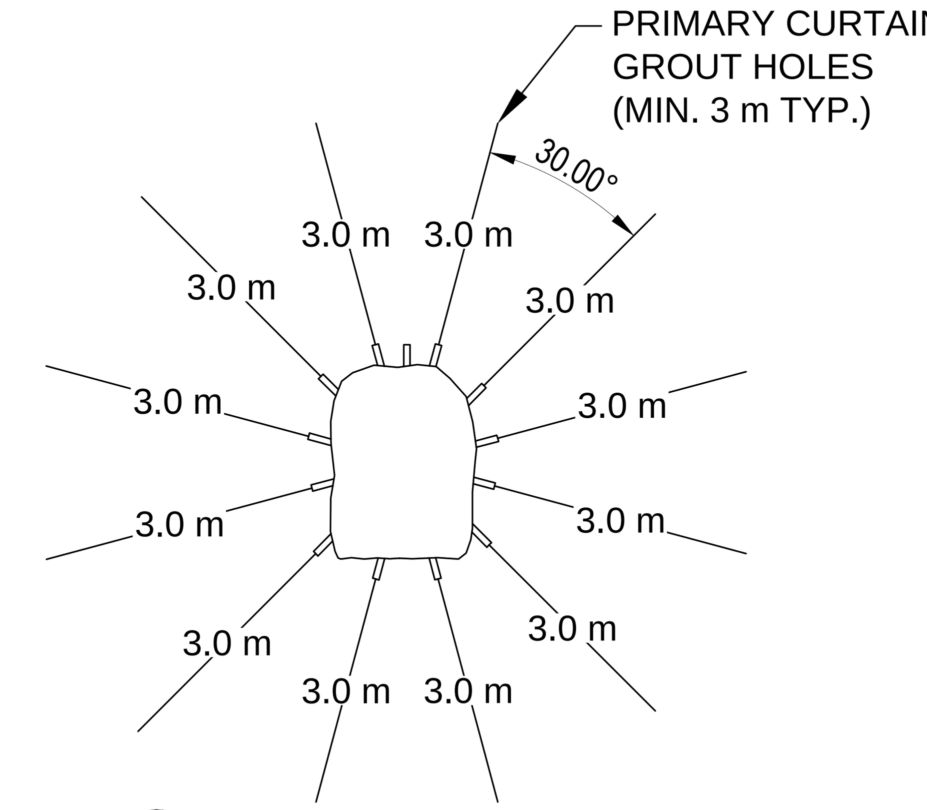
PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D101c
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	4 of 7	SF	MH	A	



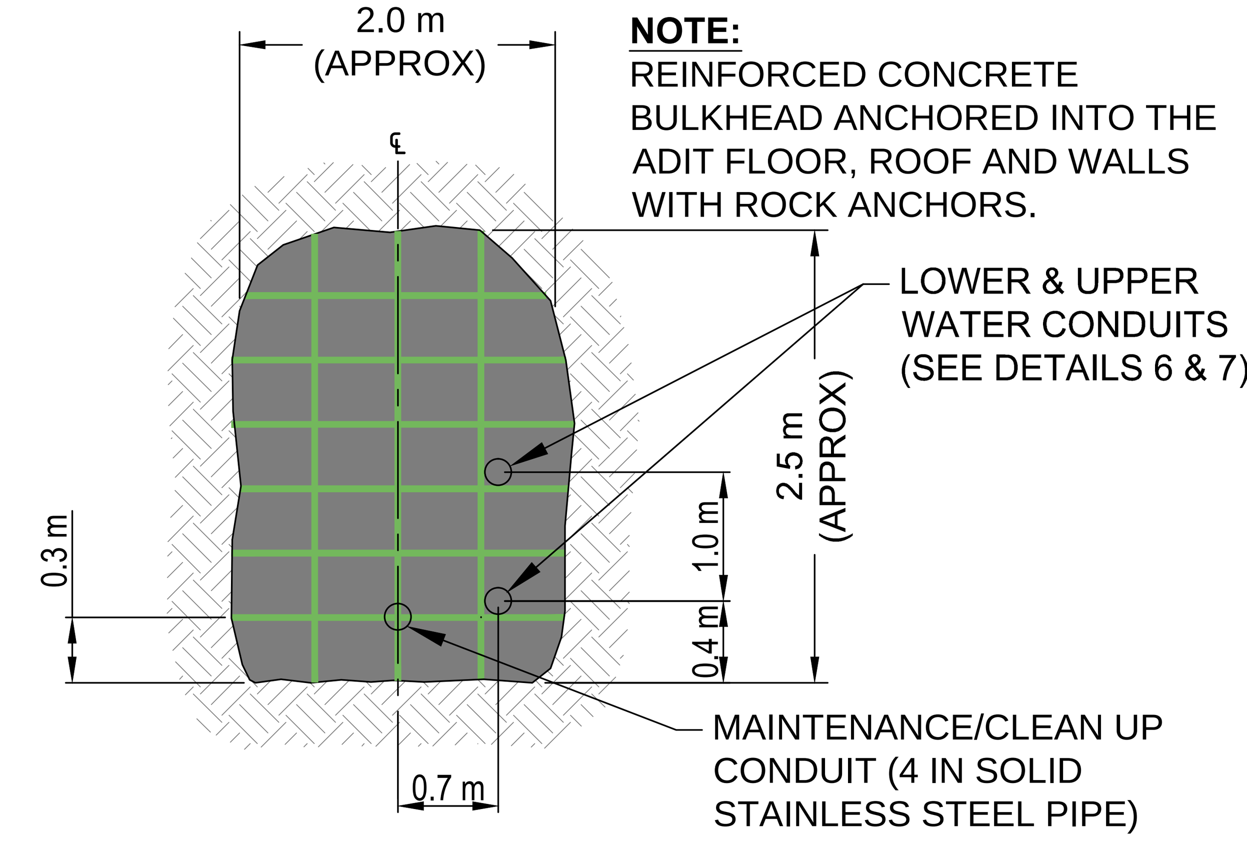
1 PREPARE PLUG LOCATION - LONGITUDINAL SECTION VIEW
NOT TO SCALE



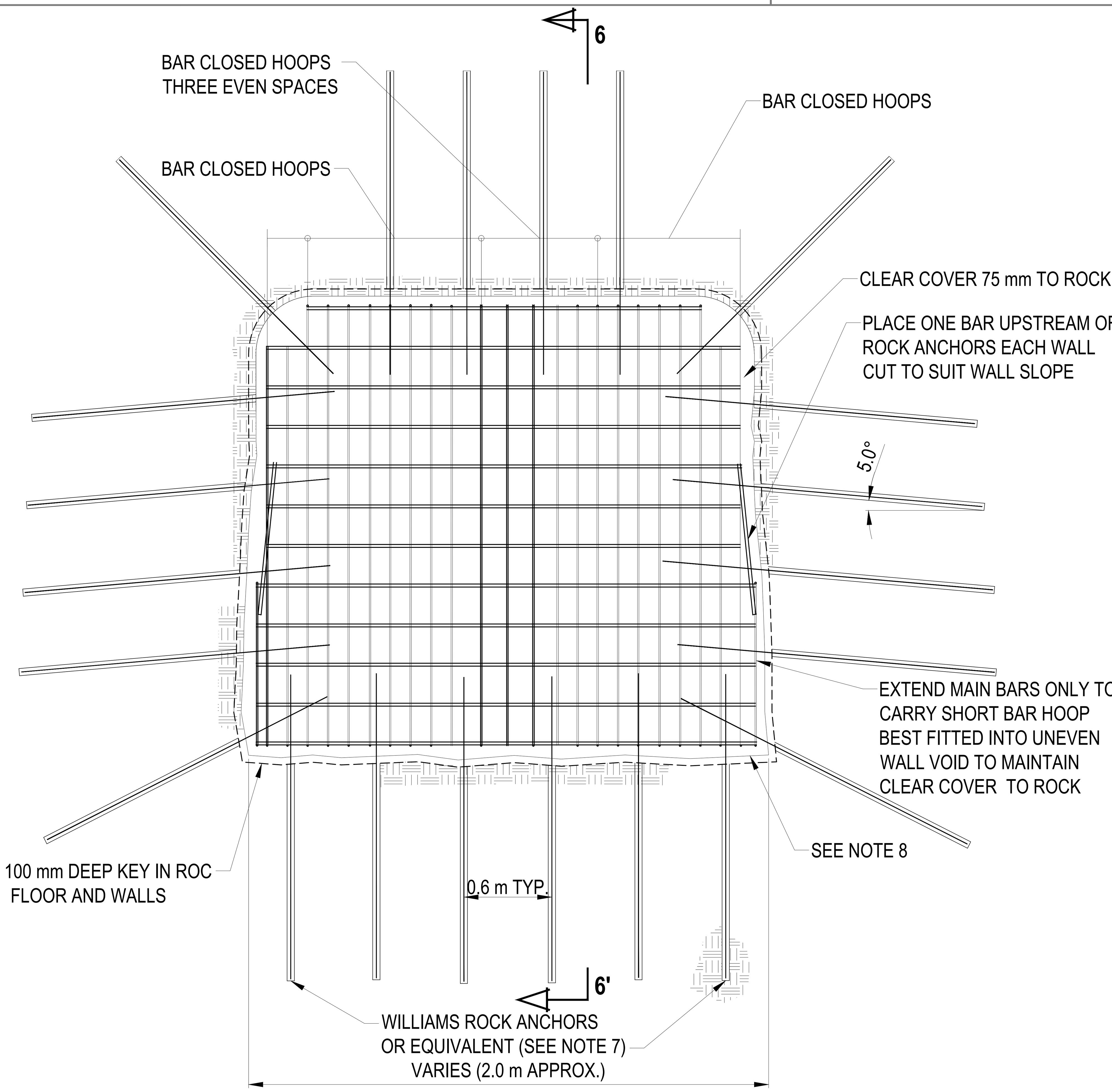
2 ADIT CROSS SECTION
NOT TO SCALE



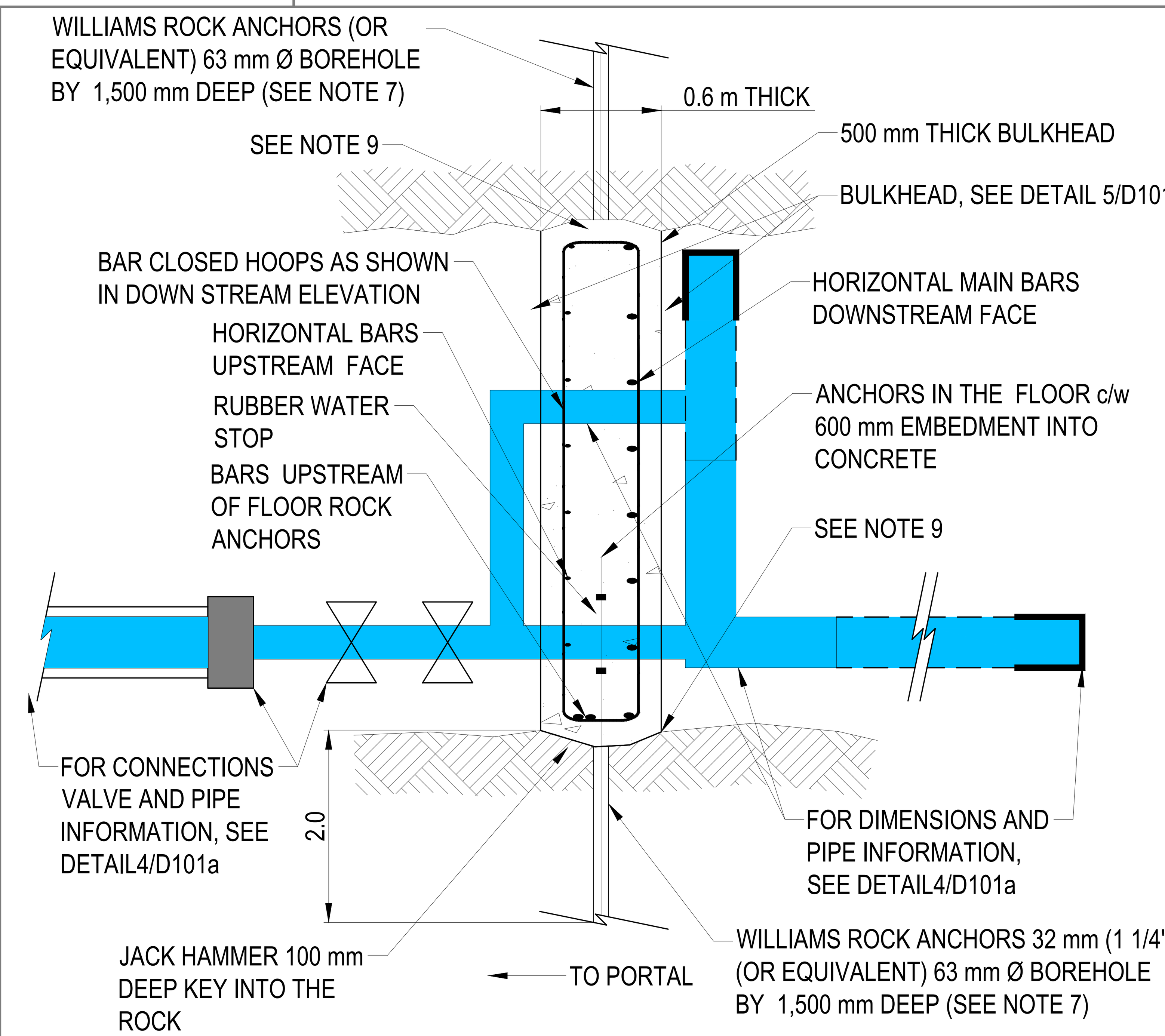
3 PRESSURE GROUTING
NOT TO SCALE



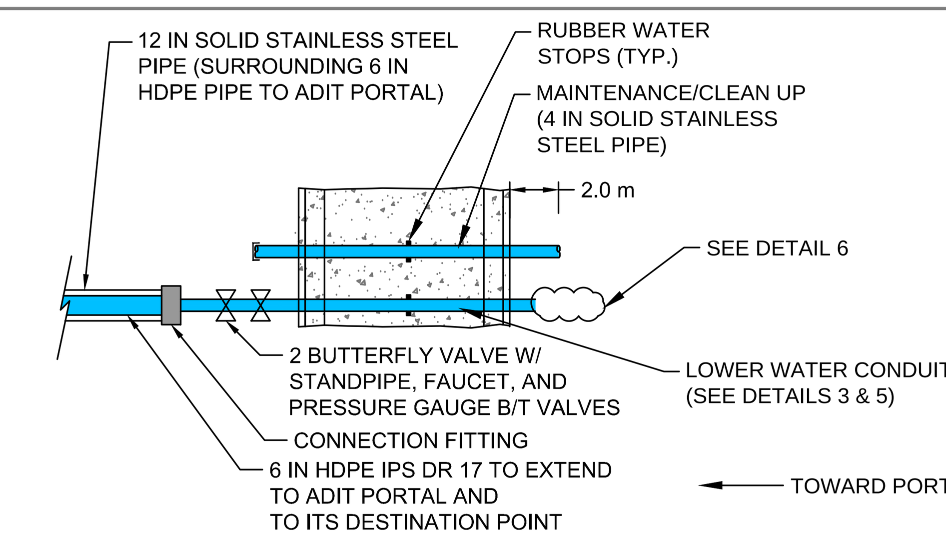
4 BULKHEAD SITE - TRANSVERSAL SECTION VIEW
NOT TO SCALE



5 BULKHEAD DOWNSTRAM ELEVATION
NOT TO SCALE



6 BULKHEAD SITE - LONGITUDINAL SECTION VIEW
NOT TO SCALE



7 BULKHEAD SITE - PLAN VIEW
NOT TO SCALE

NOTES:

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

BULKHEAD LOCATIONS AND DETAILS

MINE SITE	APPROX. DIST. FROM PORTAL (m)	ROCK TYPE	BULKEAD WIDTH, W (m)	APPROX. VOLUME (m^3)	DESIGN HYDRAULIC HEAD[1](m)	GROUTING RING	AIM	ADIT ICE PLUG PREVENTION
GALKENO 300	AT 110 m (±10)	QUARTZITE	0.5	2.5	2	YES	DIRECT WATER IN A CONTROLLED MANNER TO WATER TREATMENT PLANT	AT ONEK 400 AND GALKENO 300, INSTALL HEAT TRACING ALONG PIPE FROM PLUG LOCATION TO PORTAL FOR ADIT ICE PLUG PREVENTION
GALKENO 900	AT 75 m (±10)	QUARTZITE	0.5	2.5	2	YES		
ONEK 400	AT 105 m (±10)	QUARTZITE	0.5	2.5	2	YES		

[1] DESIGN HYDRAULIC HEAD ABOVE ADIT ROOF (APPROXIMATELY 4.5 m ABOVE ADIT INVERT)

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LEGEND

NOTES
1. ALL UNITS ARE IN METERS UNLESS NOTED OTHERWISE.

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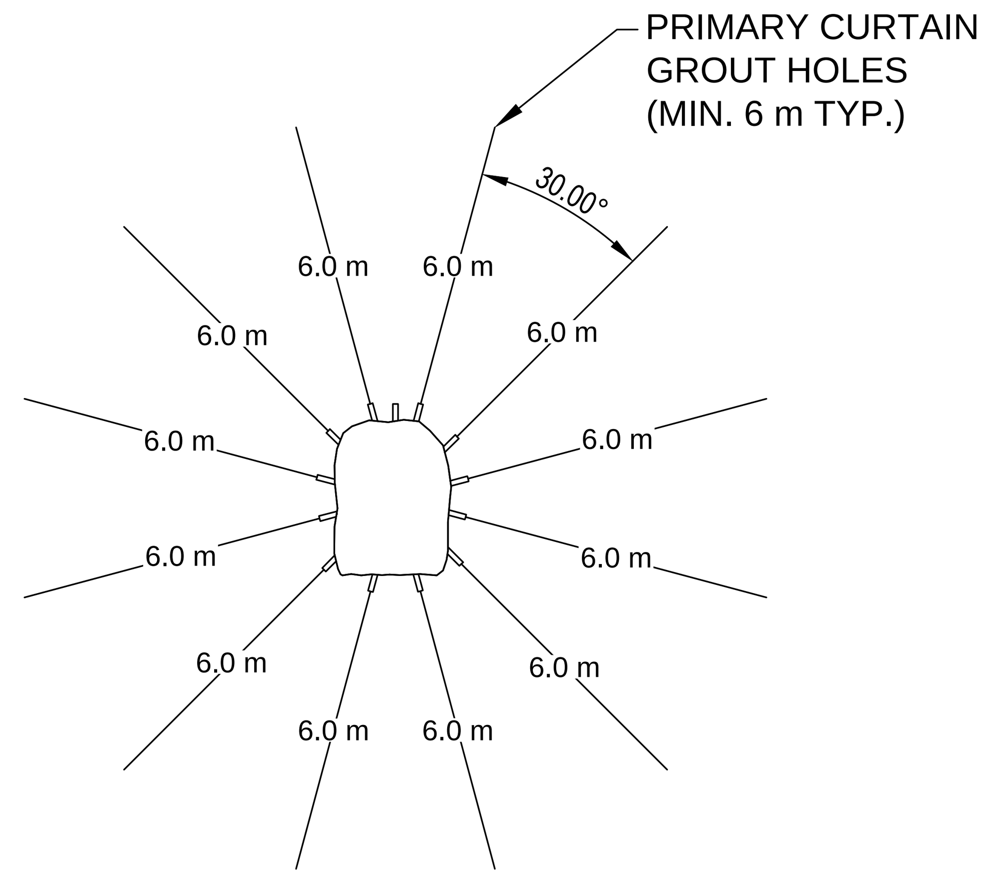
ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

CONCRETE BULKHEAD GALKENO 300, GALKENO 900 AND OVER 400 ADITS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D102a
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	5 of 7	SF	MH	A	



8 PRESSURE GROUTING
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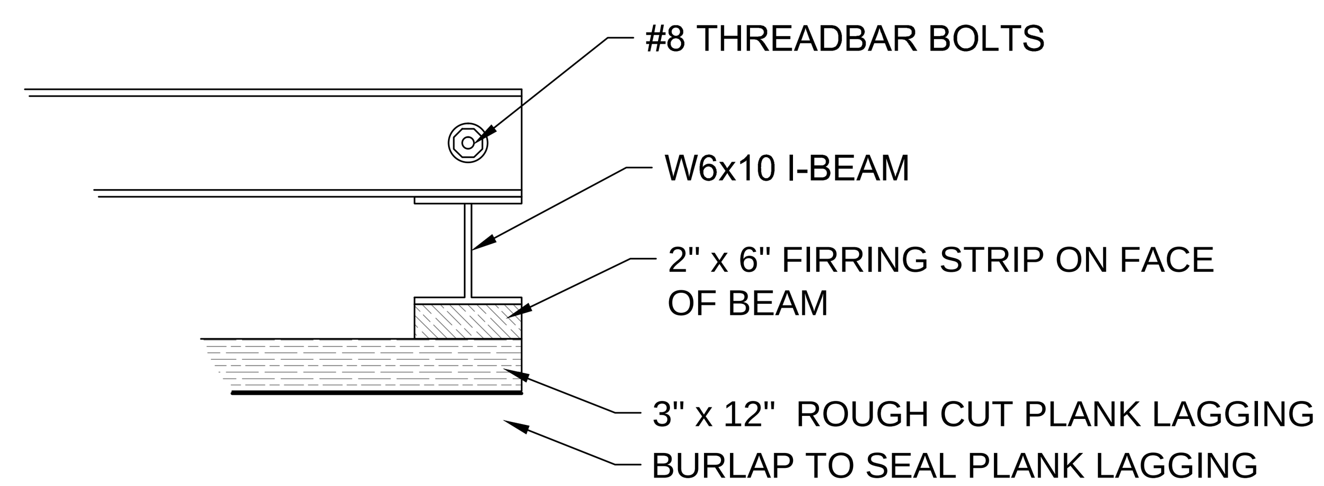
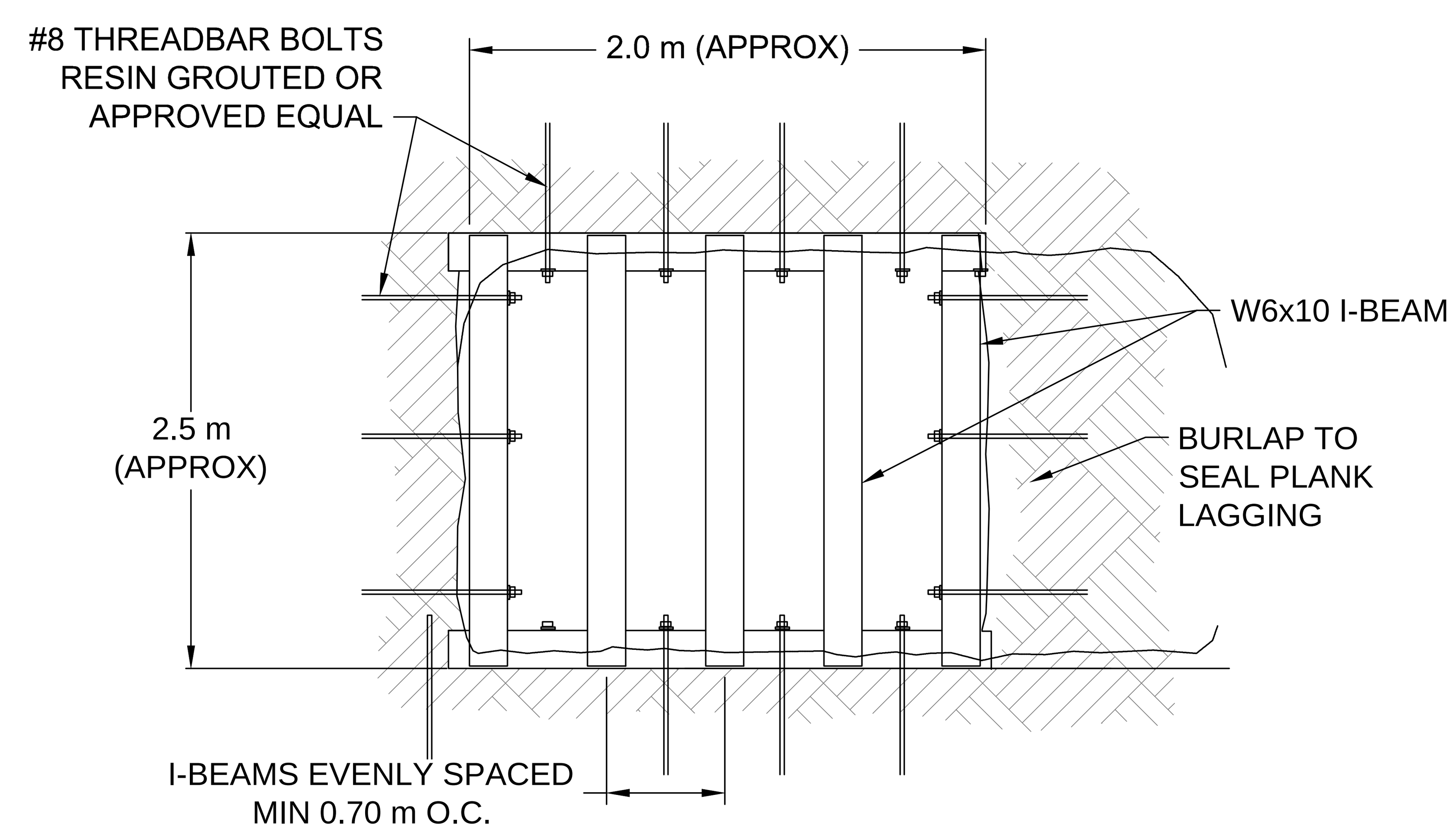
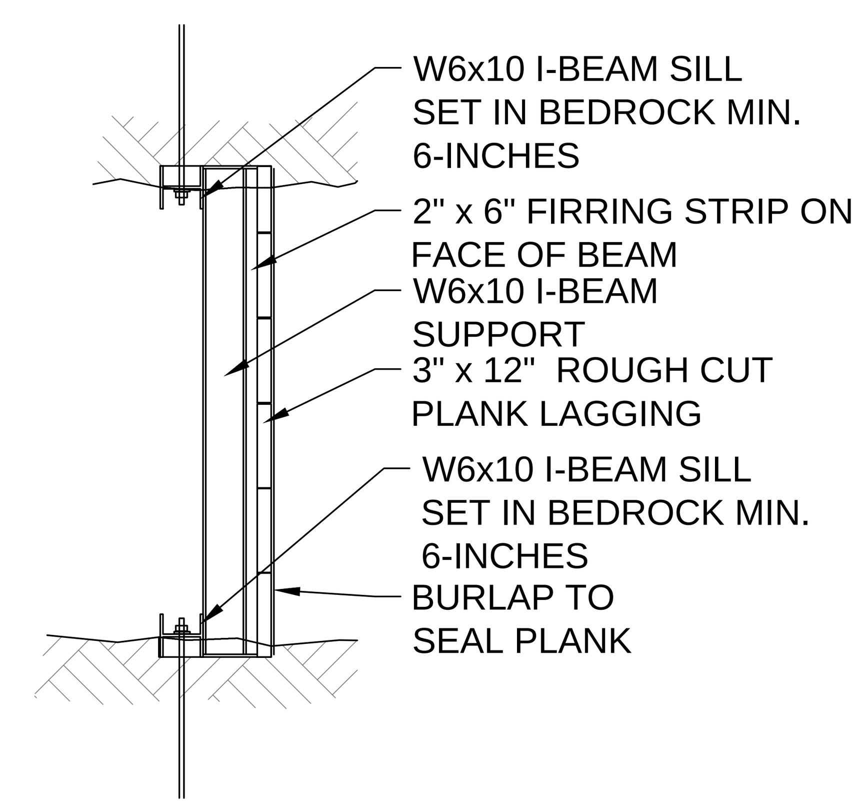


TOP VIEW



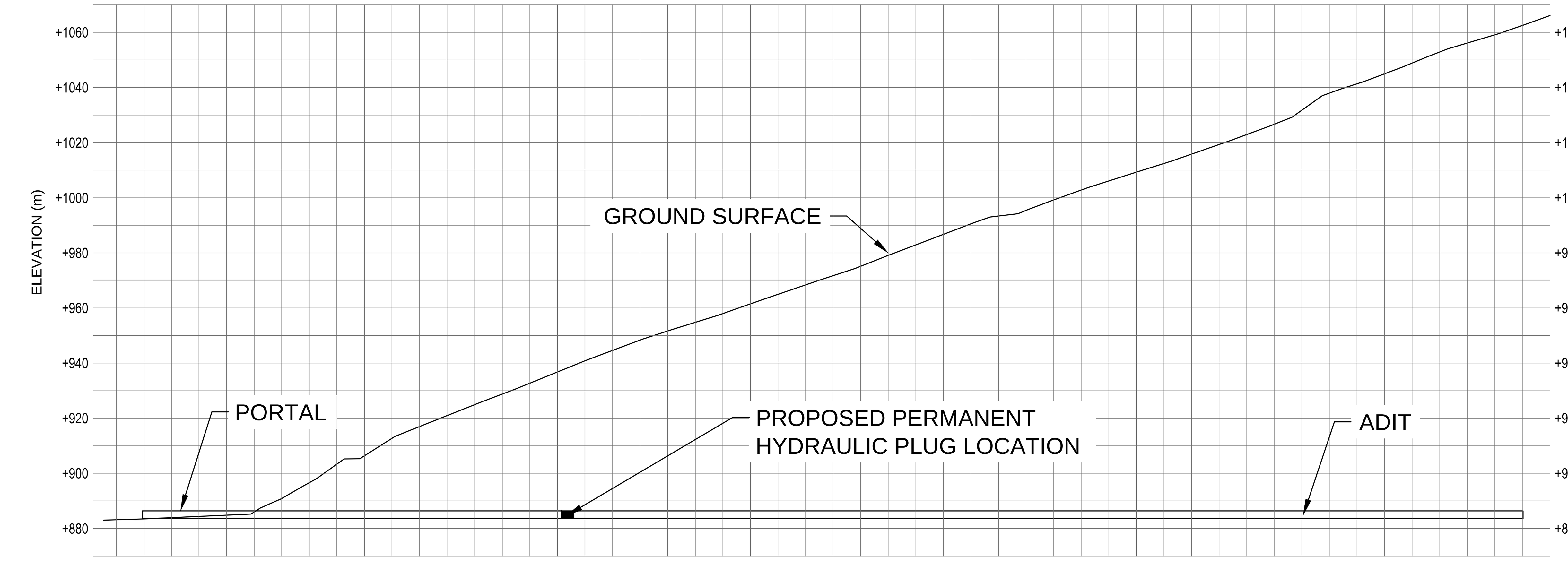
FRONT VIEW



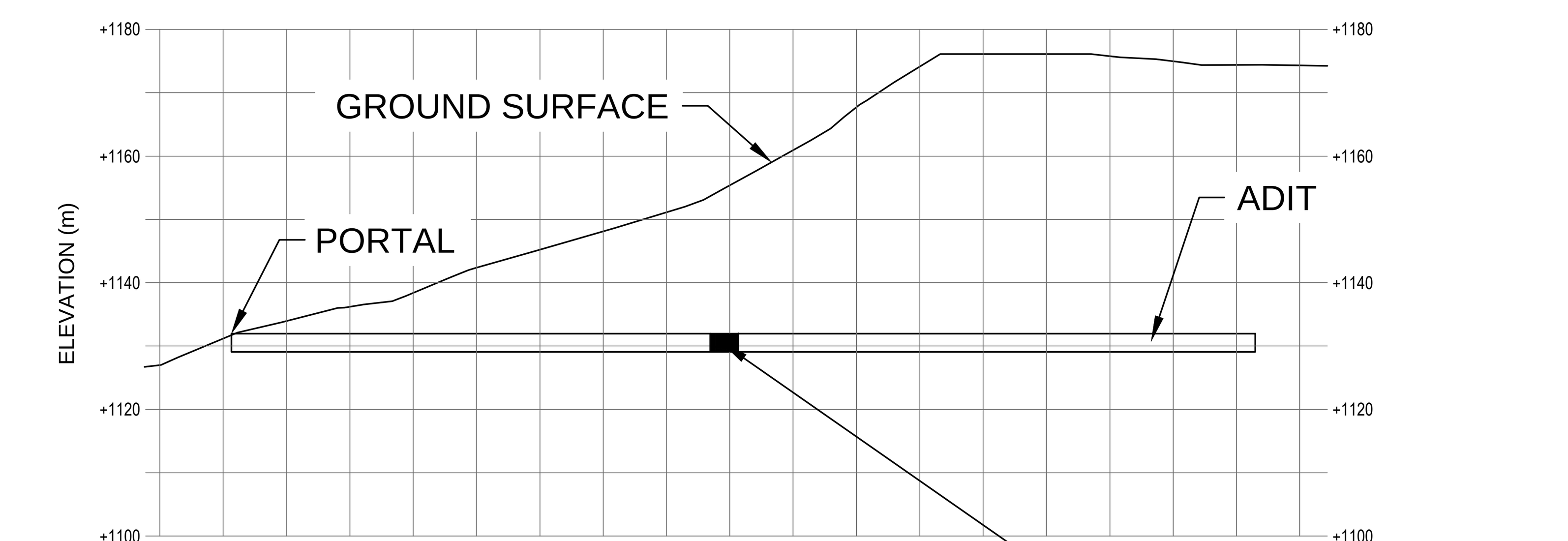
SIDE VIEW

9 TEMPORARY BULKHEAD DETAIL
NOT TO SCALE

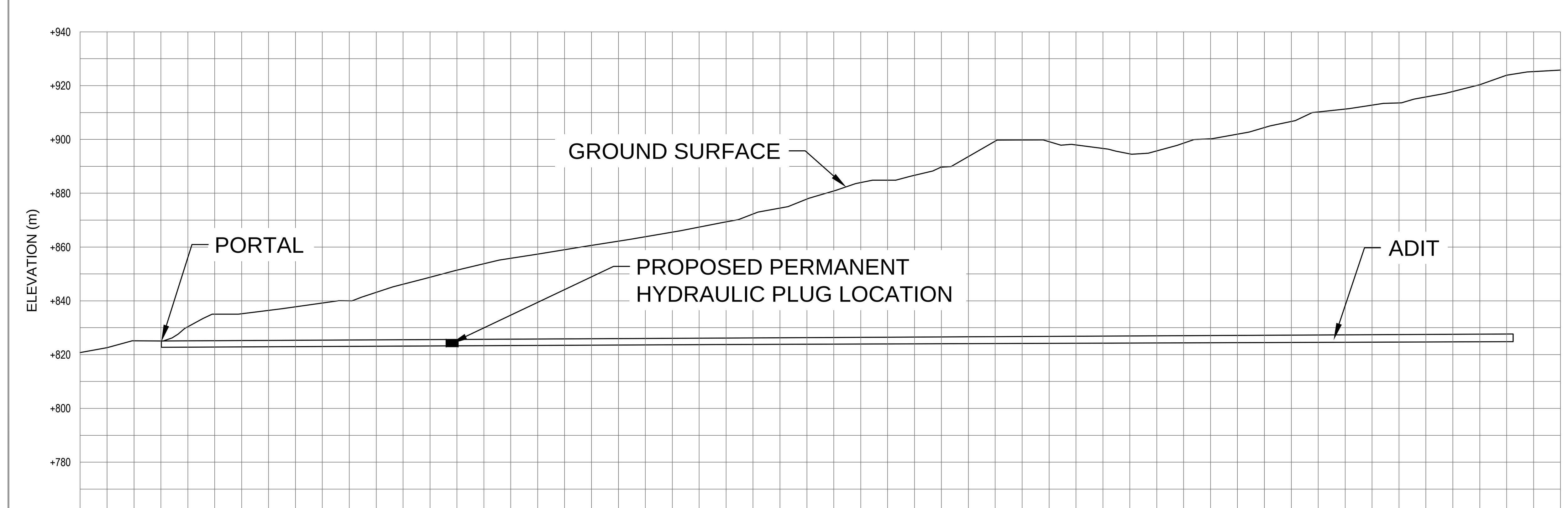
NOTES
1. TOP AND BOTTOM BEAMS INSET IN BEDROCK
2. EMBEDMENT DISTANCE FOR ROCK BOLTS IS 6-FT



GALKENO 300 ADIT
SCALE 1:1500



GALKENO 900 ADIT
SCALE 1:1000



ONEK 400 ADIT
SCALE 1:1500

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ESM RECLAMATION PLAN - ADIT & SHAFT CLOSURE, KENO HILL, YT

CONCRETE BULKHEAD GALKENO 300, GALKENO 900 AND OVER 400 ADITS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D102b
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	6 of 7	SF	MH	A	

Shaft Closure Methods

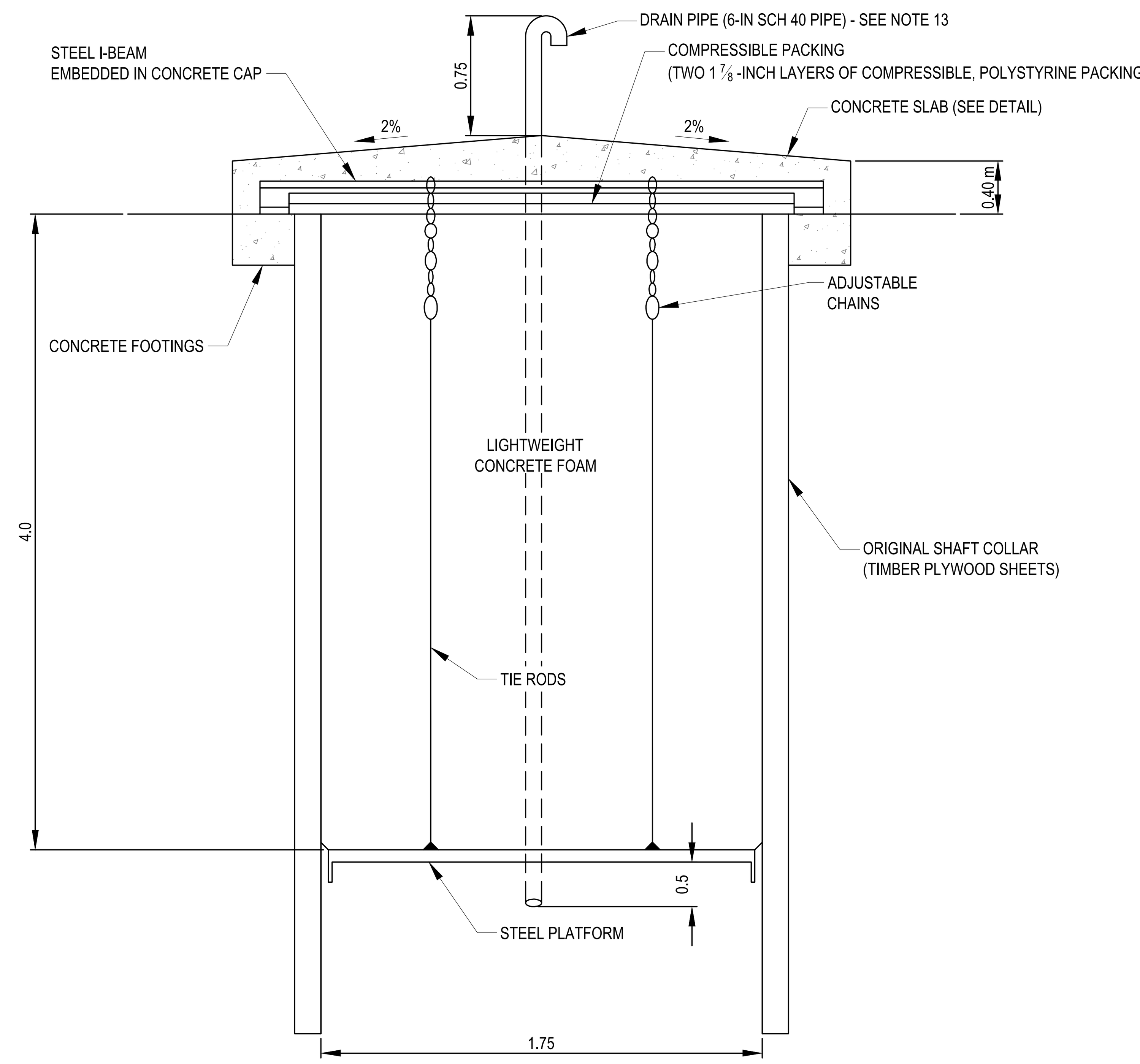
SHAFT NAME	PWGSC REF SITE	SHAFT CLOSURE METHOD [3]
Silver King Vent Raise	Silver King	Light concrete with concrete slab cap [1]
Silver King Shaft #1 (Open Pit Shaft)	Silver King	Light concrete with concrete slab cap [1]
Silver King Shaft #2	Silver King	Shaft Backfill (Dry Seal) [4]
Silver King Raise #1	Silver King	Shaft Backfill (Dry Seal) [4]
Husky Raise	Husky #2	Light concrete with concrete slab cap [1]
Husky Shaft	Husky #2	Light concrete with concrete slab cap [1]
Husky SW Shaft	Husky SW	Light concrete with concrete slab cap [1]
Ruby Shaft	Bermingham & Ruby	Light concrete with concrete slab cap [2]
McLeod shaft	Galkeno Mine	Shaft PUF with Concrete Cap[3]
Shafts SW of Gravel Level Adit	Elsa Mine	Shaft PUF with Concrete Cap[3]
Dixie Shaft	Dixie	Light concrete with concrete slab cap [1]
Brefalt Shaft	No Cash Mine	Light concrete with concrete slab cap [1]
Jock Shaft	Hector-Caulmet	Shaft PUF with Concrete Cap[3]
Coral and Wigwam Shaft #1	Coral and Wigwam	Shaft Backfill (Dry Seal) [4]
Coral and Wigwam Shaft #2	Coral and Wigwam	Shaft Backfill (Dry Seal) [4]
Betty shafts	Betty	Shaft Backfill (Dry Seal) [4]
Tin Can Shaft #1	Tin Can	Shaft Backfill (Dry Seal) [4]
Tin Can Shaft #2	Tin Can	Shaft Backfill (Dry Seal) [4]
Rico Shaft	Rico	Shaft Backfill (Dry Seal) [4]
Sadie Ladue Shaft (No. 1 Shaft)	Sadie Ladue - Wernecke	Light concrete with concrete slab cap [1]
Lucky Queen Shaft #1	Lucky Queen	Light concrete with concrete slab cap [1]
Lucky Queen Shaft #2	Lucky Queen	Shaft PUF with Concrete Cap[3]
Shamrock J18 Raise	Keno No. 9	Shaft PUF with Concrete Cap[3]
Prospect Shaft	Shamrock (Original)	Shaft Backfill (Dry Seal) [4]
Porcupine Shaft	Porcupine Comstock	Shaft Backfill (Dry Seal) [4]
Unknown Shaft near 5-2 Adit	Keno	Shaft PUF with Concrete Cap[3]
Lower Lake Shaft	Lake	Shaft Backfill (Dry Seal) [4]
Upper Lake Shaft	Lake	Shaft Backfill (Dry Seal) [4]
Silver Basin Hand Shafts (Shaft #1)	Silver Basin	Shaft Backfill (Dry Seal) [4]
APEX Shaft	APEX	Shaft Backfill (Dry Seal) [4]
Christal Shaft #1	Christal	Shaft Backfill (Dry Seal) [4]
Christal Shaft #2	Christal	Shaft Backfill (Dry Seal) [4]

[1] Remove steel pits, cables wihin the shaft to bottom of further light concrete

[2] Presently filled with waste dump fill; remove waste material to bottom of further light concrete

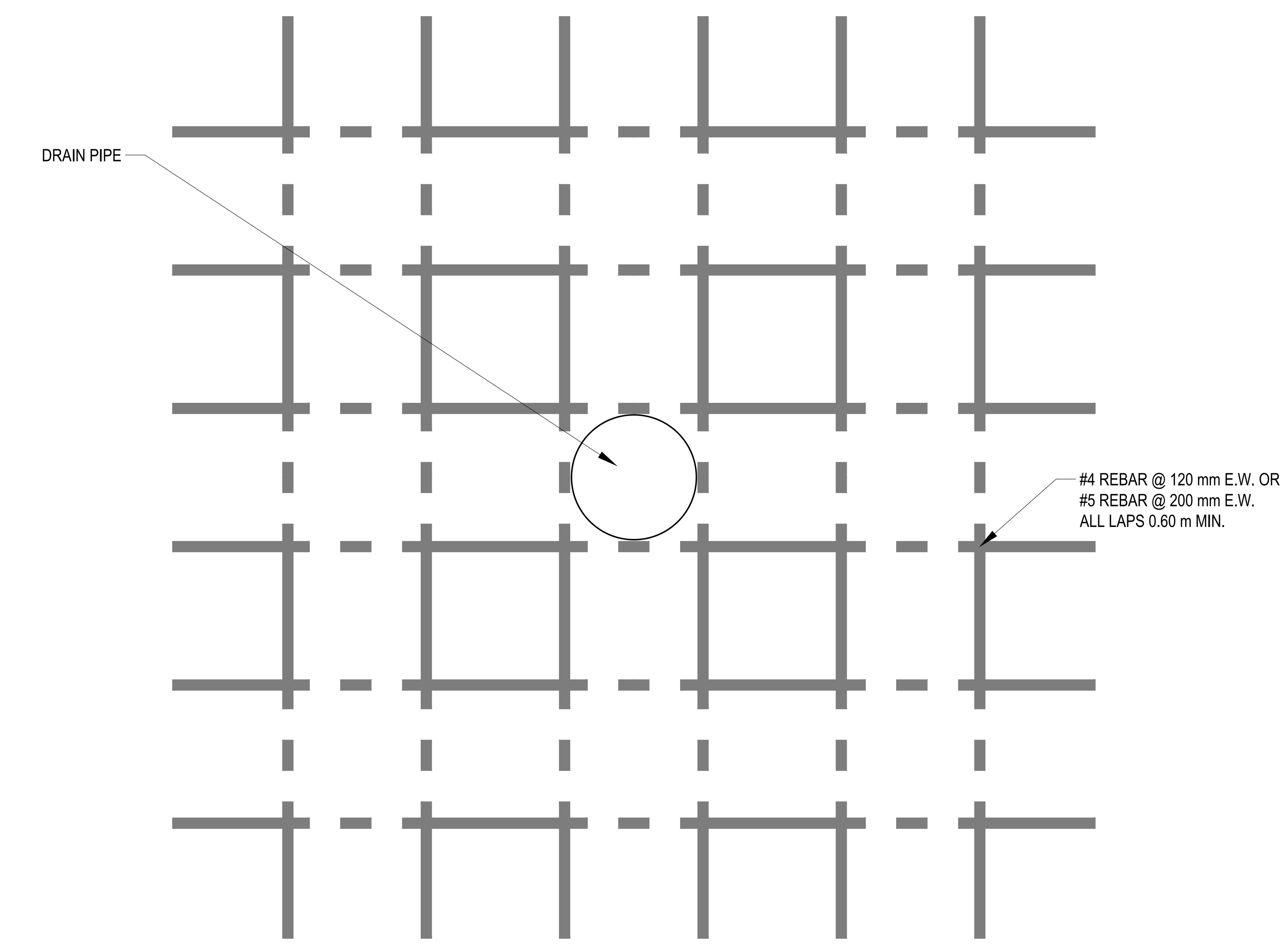
[3] If presentely backfilled, remove backfill material to bottom of further further PUF

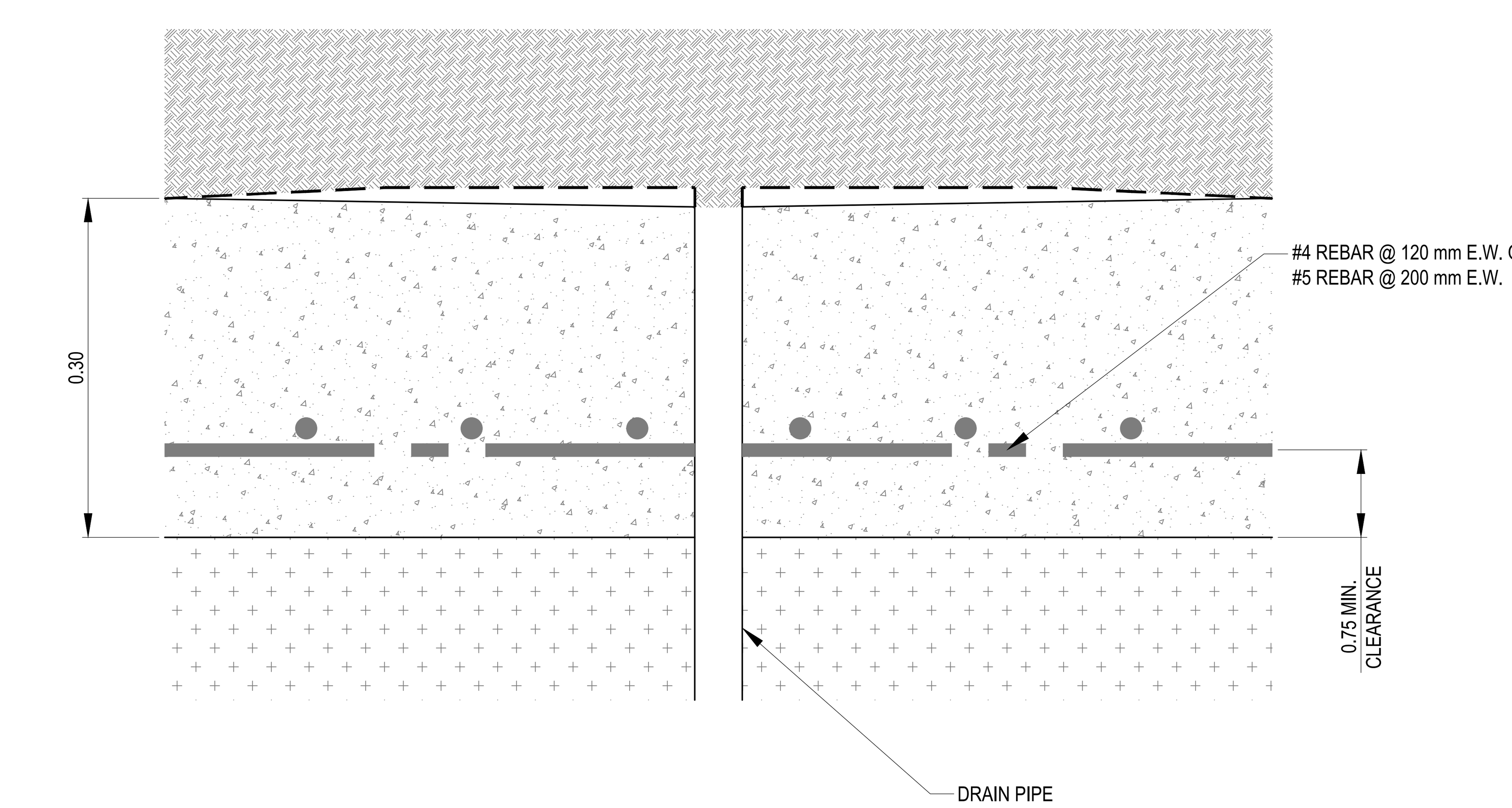
[4] If presentely backfilled, complete backfilling (if needed) and make ground surface to conform as presented in this drawing.



LIGHTWEIGHT CONCRETE WITH CONCRETE SLAB CAP CLOSURE

NOT TO SCALE





CONCRETE SLAB DETAILS

NOT TO SCALE

NOTES

1. Safety protocols related to working near or in the shaft should be followed during the project implementation.
2. A Geotechnical Engineer should assess the ground conditions at the site to determine the bearing capacity of the ground for footing design. Footing design should be completed by a qualified Geotechnical Engineer.
3. Existing steel pipe, cables and other utilities and materials inside the shaft shall be removed to the depth of the lightweight concrete foam
4. Clean the shaft walls to a minimum depth of 300 mm below the base of the steel platform by power-washing to provide a suitable construction surface.
5. All construction surfaces and material should have a water proofing sealant applied. Cover the steel platform and shaft walls with a geomembrane prior to placing concrete.
6. The reinforced concrete cap designed for a 20 KPa (3 psi) live load not designated to resist hydrolic uplift loads..
7. Install a layer of compressible packing (Styrofoam polystyrene or similar) between the lightweight concrete and the concrete cap to allow for differential movement.
8. Install a 6 in SC 40 PVC drain pipe extending from below the steel platform, through the lightweight concrete, to above the concrete cap. Use an 8 inch SC 40 PVC as a sleeve pipe between 1 m below the bottom of concrete slab to 0.2 m above the top of the concrete slab.
9. Concrete shall have a minimum 20 MPa compressive strength at 28 days
10. The Sub-Contractor will retain an independent testing agency recommended by the Consultant for the testing of concrete to establish that minimum strength required for concrete slab has been obtained.
11. Concrete mix for lightweight (foam) concrete:
    - Type II cement……326.6 kg (720 lb)
    - Water……134.8 L (35.62 gal)
    - Foaming Agent ……0.5 m3 (18.62 ft3)
    - Superplasticizer……0.81 L/m3 (1 qt per yd3)
    - Silica fume (6.5% by weight)……0.5 kg/m (50lb/yd)
    - Water/Cement Ratio……0.41
    - Calculated Wet Density……714.4 kg/m3 (44.6 lbs/ft3)
    - 28-day compressive strength (average) ……1.6 MPa (226 psi)
    -
12. Concrete mix for the footings and concrete cap:
    - Type II cement……213.2 kg (470 lb)
    - Fly Ash……31.8 kg (70 lb)
    - Water……104.5 L (27.6 gal)
    - Sand……600.6 kg (1324 lb)
    - No. 57 limestone……807.4 kg (1780 lb)
    - Water-reducing admixture……2.8 g/kg (5 ozs/cwt)
    - Air-entraining agent……0.6 g/kg (1.10 ozs/cwt)
    - Design Unit Weight……2298.3 kg/m3 (143.48 lb/ft3)
    - Slump……76 mm (3in)
    - Air Content……7.5%
    - Water/Cement Ratio……0.426
    - 28-day compressive strength (average) ……1.6 MPa (226 psi)
13. Capture water at exit of drain pipe and route it to the assigned destination.

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GENERAL NOTES
ALL UNITS ARE IN METERS IN UNLESS NOTED OTHERWISE.

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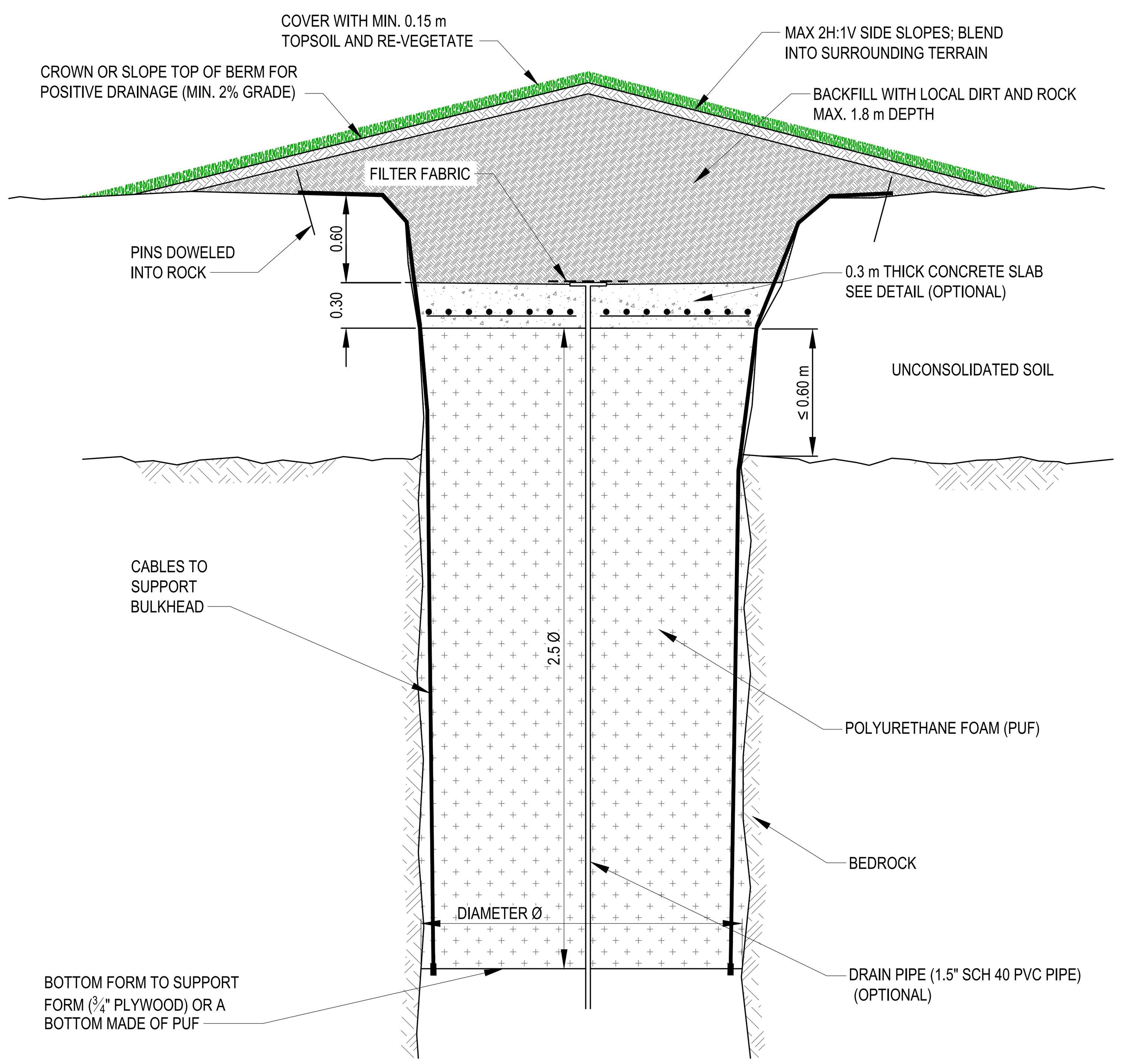
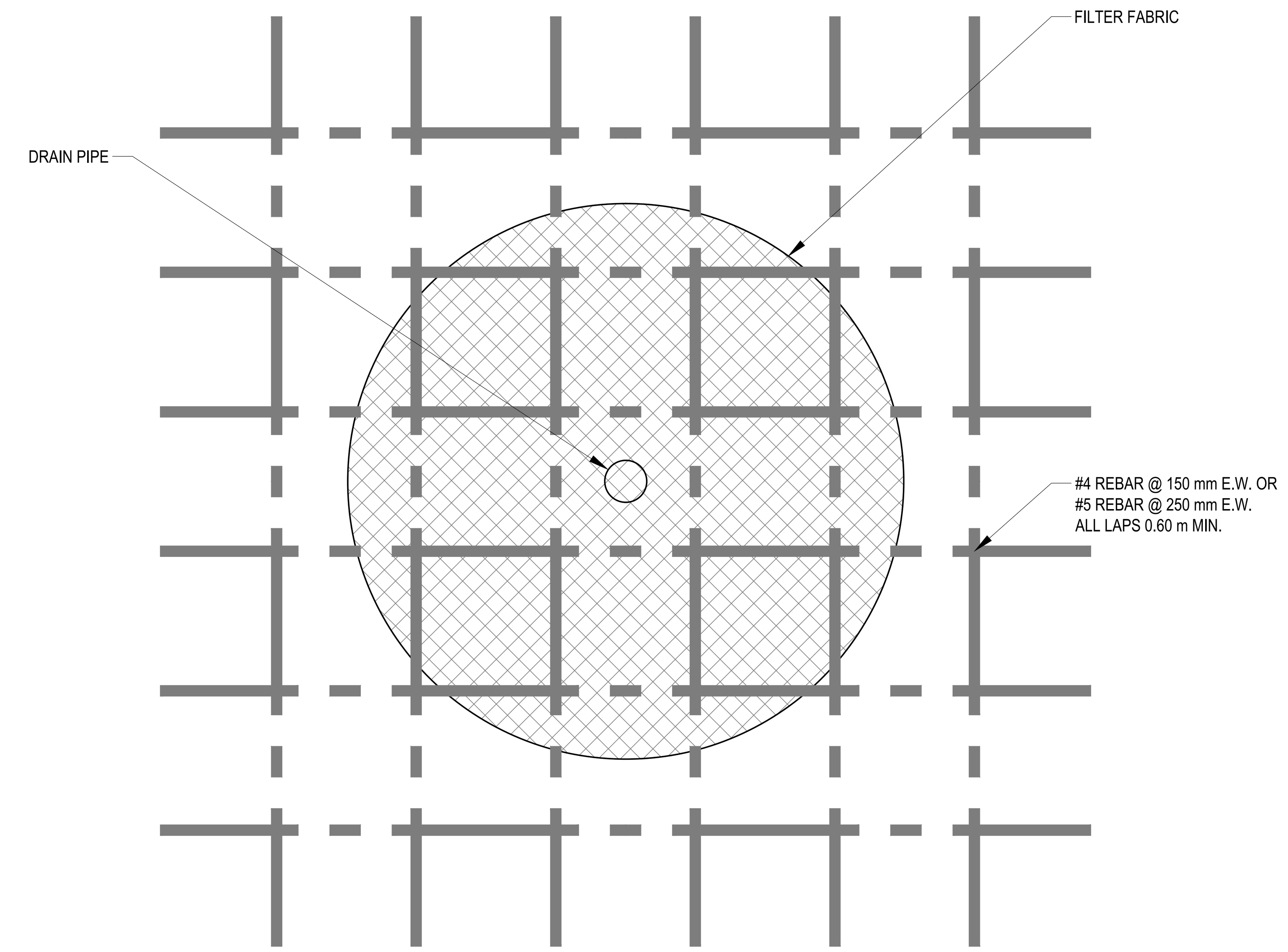
SHAFT CLOSURE METHODS AND DETAILS

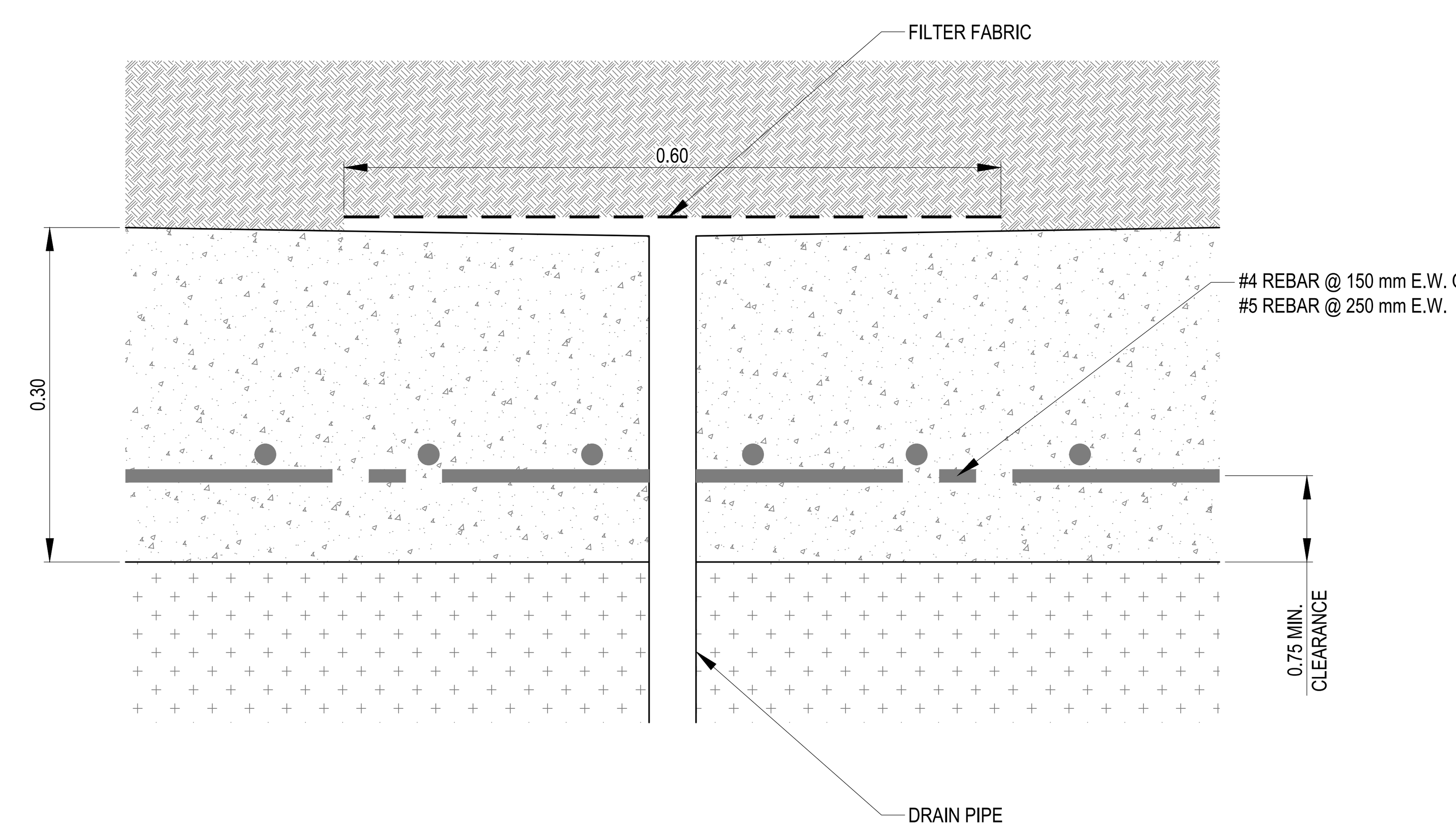
PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D103a
DATE:	SHEET No.	DWN	APP	STATUS	
March 27, 2015	6 of 7	SF	MH	A	



SHAFT PUF WITH CONCRETE SLAB CLOSURE

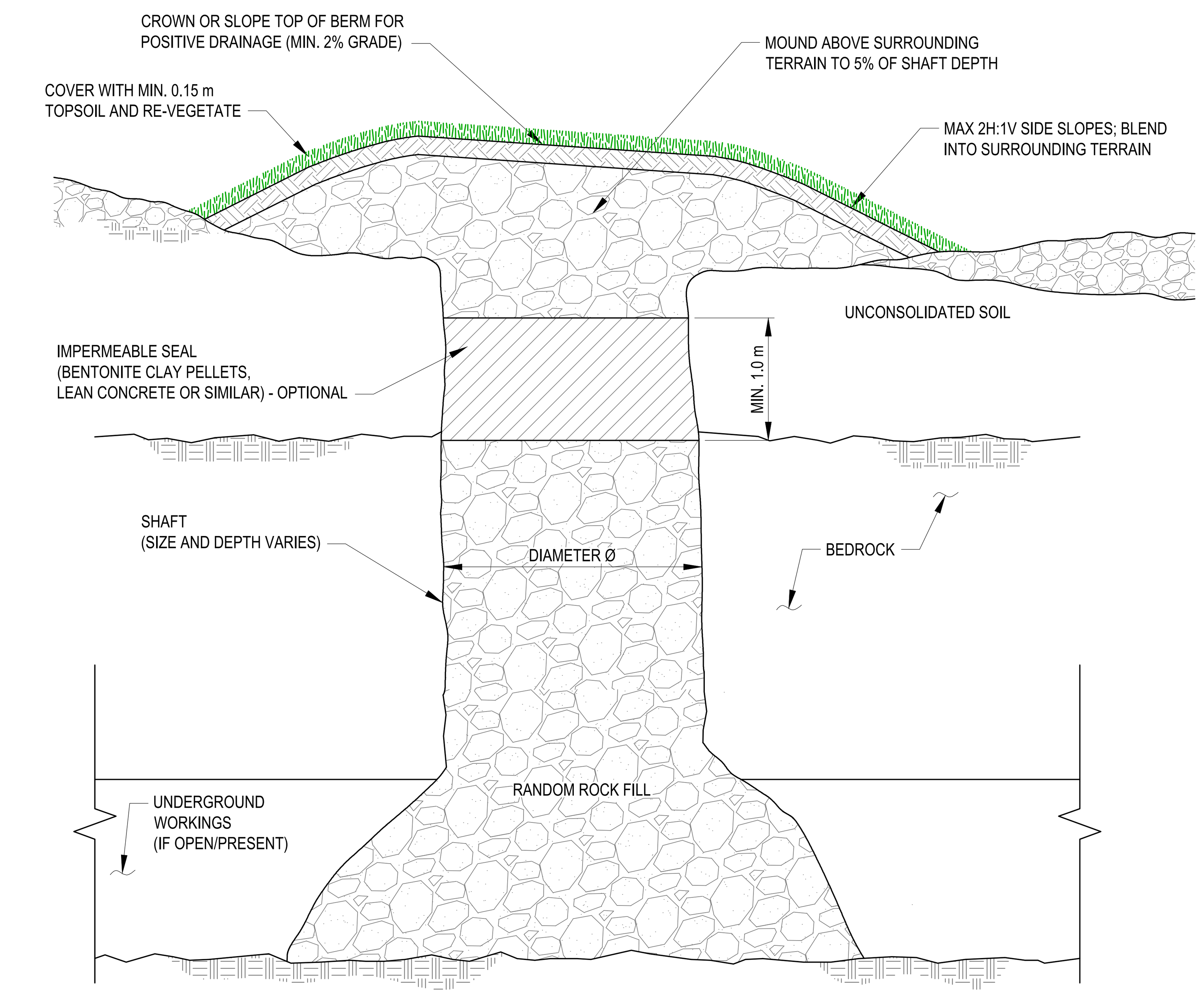
NOT TO SCALE





CONCRETE SLAB DETAILS

NOT TO SCALE



SHAFT BACKFILL (DRY SEAL) CLOSURE

NOT TO SCALE

NOTES

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

NOTES

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

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GENERAL NOTES

1. All units are in meters unless noted otherwise.

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SHAFT CLOSURE CAPPING METHODS AND DETAILS

PROJECT No.	OFFICE	DES	CKD	REV	DRAWING
W14103428-01.003	VANC	CC	CC	0	D103b
DATE: March 27, 2015	SHEET No. 7 of 7	DWN SF	APP MH	STATUS A	

APPENDIX A

HYDRAULIC PLUG AND BULKHEAD CLOSURE – CONSTRUCTION STEPS

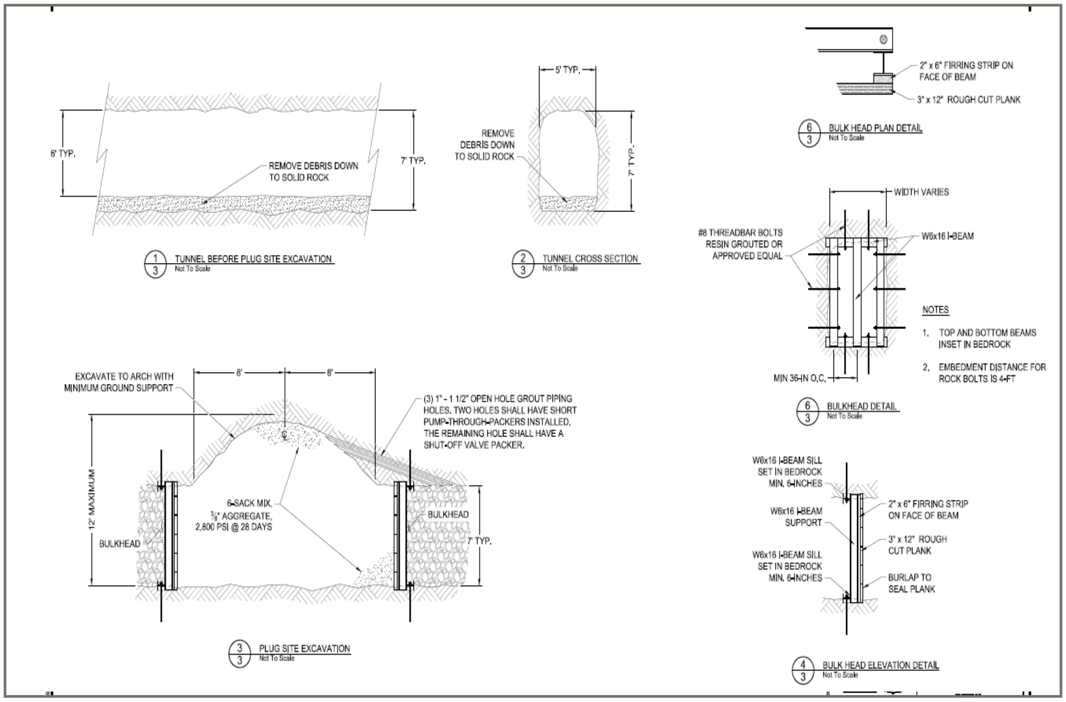

Photo 1: Hydraulic Adit Details

Photo 2: Geotechnical mapping of adit to determine plug site suitability. All ribs (walls) and back (roof) are to be removed of existing electrical and mechanical appurtenances, if present shall be removed from the plug footprint.

Photo 3: Intersected location of the workings is located and installation of grout and cement pumping lines.

Photo 4: Installation of grout rings All walls and roof should be cleaned and washed free of dust and debris. Grouting rings are installed around the hydraulic plugs and proposed bulk head location.

Photo 5: Building of the temporary bulkheads.
6 Inch Steel High beams installed in preparation for lower seal.

Photo 6: Temporary bulkhead
Braced timber sets for back end of the plug.

Photo 7: Jimmy window allows for access and installation and inspection of cement and grout pumping lines.

Photo 8: Pumping of grout / cement in several stages

Photo 9: Temporary Bulkhead - Perimeter of lagging packed with burlap and grouted

Photo 12: Water tight temporary Bulkhead

APPENDIX B

HYDRAULIC PLUG AND BULKHEAD CLOSURE – GEOTECHNICAL ASSESSMENT AND CALCULATIONS

1.0 ROCK MASS CHARACTERIZATION AND PERMANENT HYDRAULIC PLUGS AND BULKHEADS PRELIMINARY DESIGN

Two important parameters relating to bulkhead design are rock mass strength, which in part will control the position and length of the hydraulic plugs and bulkheads, and rock mass permeability, which will control the risk of leakage past the bulkhead. These parameters are both functions of rock mass quality.

Section 2.0 presents the rock mass classification methods used to assess the quality of the rock mass. Section 3.0 a preliminary geotechnical characterization of the adits based on available information, and Section 4.0 the preliminary design of the permanent hydraulic plugs and bulkheads.

2.0 ROCK MASS CLASSIFICATION

As described in Section 4.0 of the report the geotechnical information was obtained from:

- Tetra Tech's site visit in September 2014. During the site visit, only the first 30 m of the Galkeno 300 adit, the first 50 m of the Silver King 100 and the first 100 m of the Ruby adit (from their portals) were accessed for inspection.
- Rock Quality Designation (RQD) data included in the logs of boreholes drilled between 2006 and 2014.

Rock mass classification systems to estimate rock mass properties (rock quality) constitute an integral part for decision making for design. These systems are used to group areas of similar geomechanical characteristics, based on ratings of three principal properties: the intact rock strength, the frictional properties of the discontinuities, and the geometry of intact blocks of rock defined by the discontinuities.

Table B-1 provides comparison of RMR and NGI-Q ratings to the quality of rock. Sections 2.1 and 2.2 below present an overview of the classification systems. Table B-2 presents the Rock Quality Designation (RQD) ratings to the quality of the rock, and Section 2.3 presents an overview of the RQD classification system.

Table B-1: Summary RMR and Q Rating Values

RMR Value	RMR Rating	Q Value	Q Rating
0	Very Poor Rock	0.001-0.01	Exceptionally Poor
<20	Very Poor Rock	0.01-0.1	Extremely Poor
21-40	Poor Rock	0.1-1	Very Poor
41-60	Fair Rock	1-4	Poor
		4-10	Fair
61-80	Good Rock	10-40	Good
		40-100	Very Good
81-100	Very Good Rock	100-400	Extremely Good
		400-1000	Exceptionally Good

Table B-2: Summary of RQD Rating Values

RDQ (%)	Rock Quality
<25	Very Poor

25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

2.1 Overview of Rock Mass Rating System

The RMR system is a geomechanical classification system for rocks, developed by Z.T. Bieniawski (1989). The following six parameters are used to classify a rock mass using the RMR system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (RQD).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

Each of the six parameters is assigned a value corresponding to the characteristics of the rock. The sum of the six parameters is the "RMR value", which ranges between 0 and 100.

2.2 Overview of NGI Q-System

The NGI Q-system is an empirically based system developed by Barton, Lien, and Lund (1974) through analysis (initially) of over 200 case studies. Further development since the initial publication of the paper has refined the system based on over 1,000 case studies.

The NGI Q-system uses six parameters to determine a numerical value (Q) which represents the quality of a given rock mass. The parameters assign numerical values to various features of the rock mass, including RQD, number of joint sets, joint alteration, joint surface roughness, stress conditions, and water inflow intensity. These are combined in a simple formula to derive a "Q-value", which is indicative of the overall quality of the rock mass for the purpose of underground excavation and support design. This formula can be thought of as the function of three geomechanical rock properties:

- Block size given by RQD/Jn.
- Inter-block shear strength given by Jr/Ja.
- Active stress given by Jw/SRF.

The formula for determining Q is as follows:

$$Q = \left(\frac{RQD}{Jn}\right) \cdot \left(\frac{Jr}{Ja}\right) \cdot \left(\frac{Jw}{SRF}\right)$$

Where: *RQD* = rock quality designation.

Jn = joint set number.

Jr = joint roughness number.

Ja = joint alteration number.

Jw = joint water reduction number.

SRF = stress reduction factor.

The description of the six parameters can be found in the report by Barton et al. (1974). The numerical value of Q ranges from 0.001 (for exceptionally poor quality, squeezing ground) to 1000 (for exceptionally good quality, massive rock).

The formula for determining Q is as follows:

$$Q = \left(\frac{RQD}{Jn}\right) \cdot \left(\frac{Jr}{Ja}\right) \cdot \left(\frac{Jw}{SRF}\right)$$

2.3 Overview of Rock Quality Designation (RQD)

RQD was introduced by D.U. Deere (1964) as an index of assessing rock quality quantitatively. It is a more sensitive index of core quality than the core recovery.

The RQD is a modified percent core recovery which incorporates only sound pieces of core that are 100 mm (4 inches) or greater in length along the core axis,

RQD (%) = ((Sum of core pieces ≥ 10cm)/(total drill run))* 100

3.0 GEOTECHNICAL CHARACTERIZATION

Geotechnical characterization was based on the data collected during the Tetra Tech's site visit in September 2014, and the RQD data recorded on logs of boreholes drilled between 2006 and 2014..

3.1 September Site Visit

As described in Section 4.0 of the report, Tetra Tech's visited the project site in September 2014. During the site visit, only the first 30 m of the Galkeno 300 adit, the first 50 m of the Silver King 100 and the first 100 m of the Ruby adit (from their portals) were accessed for inspection.

3.1.1 Intact Rock Strength

The ISRM (1981) divides the rock strengths from R0 to R6 according to the UCS of the intact rock. R0 has UCS<1 MPa, R1: 1≤UCS1≤5 (very weak), R2: 5≤UCS1≤25 (weak), R3:25≤UCS1≤50 (medium strong), R4:50≤UCS1≤100 (strong), R5:1005≤UCS1≤250 (very strong), R6:> 250 (extremely strong),

Intact rock strength was estimated from field identification using a geological hammer. The rock at the adit location described above required more than one blow of geological hammer to fracture, and in occasions required many blows. This indicate the uniaxial compressive strength varies between strong and very strong rocks.

3.1.2 Material Properties - Strength

The permanent hydraulic plugs and bulkheads and the surrounding rock can be regarded as a discontinuum consisting of a series of blocks of intact rock and concrete, separated by various planes of weakness. The behavior of this system will be controlled by both the strength and deformation moduli of the intact material and the strength and stiffness along the planes of weakness.

The rock mass quality was estimated from field observations and measurements carried out during the September 2014 site visit. Tables B-3, B-4 and B-5 presents the estimated rock mass quality based on the RQD, RMR and NGI-Q classification systems, respectively.

Table B-3: RQD Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist
Rock Quality Designation (RQD).	50-60%	50-60%	50-60%

Table B-4: RMR89 Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist
Strength of intact rock (Uniaxial compressive strength of rock material)	12	12	7
Rock Quality Designation (RQD).	13	13	13
Spacing of discontinuities.	10	10	10
Condition of discontinuities.	20	20	20
Groundwater conditions.	10-15	10-15	10-15
Adjustment for Joint Orientation	-5	-5	-6
Total RMR Rating	60-65	60-65	55-60

Table B-5: NGI Q Rating Values

Geotechnical Parameter	Location		
	Galkeno 300 Adit 20-30 m from Portal	Silver King 100 Adit 40- 50 m from Portal	Ruby Adit 60- 80 m from Portal
Primary rock type	Quartzite with interbedded schist	Quartzite with interbedded schist	Quartzite with interbedded schist

RQD	55	50	55
Number of Discontinuity Sets	4	4	5
Roughness of Most Unfavorable Discontinuity	2	2	2
Degree of Alteration of Filling along the Weakest Discontinuity	1	1	1
Water Inflow	0.66	0.66	0.66
Stress Condition	2.5	2.5	2.5
Total NGI Q Rating	7.2	6.6	5.8

From Tables B-3, B-4 and B-5, the quality of the rock mass according to the RQD, RMR89 and NGI-Q designations, is 'fair' for all the rock mass classifications.

It should be emphasized that the ratings presented in Tables B-3, B-4 and B-5 are from data collected within 100 m from the portal. The rock mass quality further into the adits is expected to improve as the adits are deeper in relation to the ground surface.

3.2 RQD from Boreholes

Tetra Tech EBA received spread sheets with RQD records for 180 boreholes drilled between 2006 and 2014. Tetra Tech reviewed the RQD data and split it by its lithology. The depths of the boreholes varies mostly from 100 to 400 m.

Tables B-6 through B-10 presents the average of the RQD for each lithology unit for each boreholes. Also presents the average RQD of all the boreholes at the same location. The RQD data is not in agreement with the data presented in Section 3.1. The RQD data from boreholes are much lower. Tetra Tech believes that one of the main reasons of this is that the drill holes were targeting the vein zones where the rock quality is of poorer conditions. Also, in Tetra Tech EBA's experience when RQD data is collected as part of a geological investigation, the measurements also considers mechanical fractures which should not be part of the RQD ratings.

It is important the dedicated geotechnical boreholes be drilled to investigate it further.

4.0 PRELIMINARY DESIGN

Two important parameters relating to bulkhead design are rock mass strength, which in part will control the position and length of the hydraulic plugs and bulkheads, and rock mass permeability, which will control the risk of leakage past the bulkhead. These parameters are both functions of rock mass quality.

This section presents the preliminary design of the permanent hydraulic plugs and bulkheads.

TABLE B-6: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-06-0028			9.8	16.7		2.6												BERMINGHAM
K-06-0029			0.0															BERMINGHAM
K-06-0031			28.1															BERMINGHAM
K-09-0219			38.5	33.4	56.4						24.4							BERMINGHAM
K-09-0220			39.9	32.9	49.8													BERMINGHAM
K-10-0287	0.0		42.3	29.5	48.7		30.6				51.0	36.9		48.0	0.0	60.9		BERMINGHAM
K-10-0290	0.0		48.0	22.3	40.8							46.1		43.9	8.4	82.0		BERMINGHAM
K-10-0293			40.4	39.1	35.6		57.8				70.1	52.9		38.7	5.7			BERMINGHAM
K-10-0301			51.2		46.7		86.2					49.2		38.1	19.6	44.3	62.9	BERMINGHAM
K-10-0307	7.4		37.8	28.9	28.1							35.4		31.2	24.4		47.9	BERMINGHAM
K-10-0310			40.6	40.1	45.7		51.3				60.1	32.6		35.3	10.7	13.2	51.2	BERMINGHAM
K-10-0315	20.9		40.7	10.2	64.6		90.2				27.1	37.0		38.7	27.6	23.9	54.7	BERMINGHAM
K-10-0319			60.3	65.6	37.0	59.6	67.2					43.9		35.6	12.2		42.4	BERMINGHAM
K-11-0358	6.0		52.6	32.6	38.1							39.7			16.3	13.0		BERMINGHAM
K-11-0359	0.0		49.2	56.3	35.3		17.3					40.7			16.0	39.5		BERMINGHAM
K-11-0360	0.0		65.6	43.3	9.3							42.6				52.2	47.9	BERMINGHAM
K-11-0361	0.0		45.2	17.6	50.2	52.8						51.2			29.2		50.6	BERMINGHAM
K-11-0363	0.0		43.6	39.6								49.3			0.0	40.7		BERMINGHAM
K-11-0364	5.0		26.6	22.1	20.4		7.5								2.7	19.7	10.0	BERMINGHAM
K-11-0366	6.0		11.5	16.3	6.3							3.2			1.0	69.7		BERMINGHAM
K-11-0368	28.0		21.2	15.8	38.4	3.6	15.8					24.9			0.0	37.0		BERMINGHAM
K-11-0369	22.1		48.4	36.6	29.1		72.2					28.5				40.0	41.3	BERMINGHAM
K-11-0370	42.2		29.0	3.3								20.9			2.5			BERMINGHAM
K-11-0372	0.0		54.8	36.5			49.3				11.3	22.3			18.5		45.1	BERMINGHAM
K-11-0373	0.8		40.9	34.5	34.5		63.9					14.7			26.3			BERMINGHAM
K-11-0376	0.0		56.7	39.7	35.6		74.5					32.1			12.6	45.2		BERMINGHAM
K-11-0378	1.4		40.6	33.7			46.9								16.2			BERMINGHAM
K-11-0380	0.0		29.6	19.2								26.3			6.5			BERMINGHAM
K-11-0381	0.0		54.9	40.2		63.4	72.3	64.5				49.4			23.9		27.3	BERMINGHAM
K-11-0385			49.2	30.9	6.3		56.3					30.3			10.5			BERMINGHAM
K-11-0388			66.0	48.2	12.3							41.7				47.3	46.5	BERMINGHAM

TABLE B-6: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-11-0389	5.0		52.8	40.7	43.9		64.3				45.3	53.7			22.4	38.3	64.9	BERMINGHAM
K-11-0390	0.0		26.6	21.8	37.1		47.3					38.9			14.3	41.0	44.0	BERMINGHAM
K-11-0392	6.9		40.9	25.8	71.7		87.1					45.5			15.3	66.4		BERMINGHAM
K-11-0393	3.6		47.0	25.0	56.3							35.7			16.0			BERMINGHAM
K-11-0394			66.3	37.5	44.1							55.2				69.9		BERMINGHAM
K-11-0395	6.0		51.2	35.4	49.2		85.1					61.6			15.0	68.7		BERMINGHAM
K-12-0403	11.8		21.6	0.0	38.2		23.0					31.7			7.7			BERMINGHAM
K-12-0408	5.4		25.4	29.8	29.4		83.6					7.3			58.2		13.7	BERMINGHAM
K-12-0412			24.8	41.0	48.0	37.8	31.1				3.3	33.9						BERMINGHAM
K-12-0415	0.0		40.5	29.5	45.3		75.7				83.3	32.7			11.5		18.7	BERMINGHAM
K-12-0422	0.0		42.2	27.1	51.9		15.8	57.2				36.7			9.3		41.9	BERMINGHAM
K-12-0426	0.0		37.8	37.9	29.7		37.5	38.6			33.0	40.1			29.7		20.8	BERMINGHAM
K-12-0434	11.5		59.6	41.7	58.3		79.7					47.1			26.8			BERMINGHAM
K-12-0440	3.8		31.6	36.5	28.9		53.8				48.0	30.6			31.0		57.3	BERMINGHAM
K-12-0444	0.0		33.3	22.9		11.5	39.5				33.7	25.1			12.7		20.3	BERMINGHAM
K-12-0446	0.0		39.3	28.1	17.3		48.3	21.0			38.7	32.9			25.0		64.4	BERMINGHAM
K-12-0449	0.0		35.6	32.5			40.8				38.7	29.3			31.1			BERMINGHAM
K-12-0452	1.8		42.5	37.8	47.0		42.4	45.0			35.0	24.8			18.0		56.0	BERMINGHAM
K-12-0459	0.0		39.0	20.8	30.7		46.7	44.0				33.7			28.0	74.7	46.7	BERMINGHAM
K-12-0465	0.0		37.9	28.6	21.8		42.4	12.0			40.1	34.1			29.3		29.6	BERMINGHAM
K-12-0473	0.0		29.7	20.9	31.2		34.9					22.7			34.1			BERMINGHAM
K-14-0524			14.2	20.4			16.7				6.3				1.3	56.7		BERMINGHAM
K-14-0529	0.0		20.0	22.1	26.3		7.9								4.1	25.3		BERMINGHAM
K-14-0531	225.0		26.1	16.8	7.1		66.8				33.3				20.4	44.7	43.8	BERMINGHAM
K-14-0535	0.0		48.0	10.9	62.7		33.7					26.1			4.0		43.5	BERMINGHAM
K-14-0537			10.4	14.2	24.1		31.0					133.4			0.0	25.3		BERMINGHAM
K-14-0538	2.5		26.3	9.3	3.8		22.4					12.8			3.0		8.3	BERMINGHAM
K-14-0539	8.3		88.2	5.5	8.1		48.0				3.9	10.8			2.2		451.7	BERMINGHAM
K-14-0542			93.4	21.1	188.3		47.8					32.3			8.3	33.0		BERMINGHAM
Average RQD	**9.8**		**40.2**	**28.5**	**39.0**	**33.1**	**49.1**	**40.3**			**36.1**	**36.4**		**38.7**	**15.4**	**45.1**	**55.5**	
Standard Deviation	**33.9**		**17.9**	**13.1**	**27.8**	**27.4**	**24.1**	**22.4**			**22.4**	**19.3**		**13.8**	**11.9**	**20.7**	**78.6**	

TABLE B-7: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-11-0389	41.0		54.2	11.1				50.3				36.0		36.7				GALKENO
K-10-0292			47.4	32.4		30.8		72.1				32.5		35.0	0.0	5.9	52.6	GALKENO
K-10-0297	2.2		56.5	0.0	2.3							42.9		44.5	0.0			GALKENO
K-12-0439	0.0		32.5	21.6				40.8			14.7				17.4			GALKENO
K-12-0447	0.0		37.1	22.4	56.3		77.3	53.6							10.3		15.2	GALKENO
K-14-0522	5.0		47.2	22.0				22.0			32.7	25.1			5.6			GALKENO
Average RQD	**9.6**		**45.8**	**18.2**	**29.3**	**30.8**	**77.3**	**47.7**			**23.7**	**34.1**		**38.7**	**6.7**	**5.9**	**33.9**	
Standard Deviation	**17.7**		**9.4**	**11.2**	**38.2**			**18.3**			**12.7**	**7.4**		**5.1**	**7.4**		**26.5**	

TABLE B-8: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-08-0160			31.5	15.1	39.3		57.6		32.1	0.0								KENO
K-08-0162				35.9			67.5											KENO
K-08-0163	4.1		37.7	13.8	15.5	26.3	60.2											KENO
K-08-0165	0.0	25.3	35.6		14.0	17.8	68.6											KENO
Average RQD	**2.0**	**25.3**	**34.9**	**21.6**	**22.9**	**22.1**	**63.5**		**32.1**	**0.0**								
Standard Deviation	**2.9**		**3.1**	**12.4**	**14.2**	**6.0**	**5.4**											

TABLE B-9: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-07-0069	2.3	31.2	46.7		23.8													ONEK
K-07-0072		37.2	42.3		30.5	18.7	61.6											ONEK
K-07-0074			53.2	25.7	42.8													ONEK
K-07-0116		31.4	36.0				49.8	62.4	27.7									ONEK
K-07-0118			40.6	39.5	33.2		66.9			0.0								ONEK
K-07-0119		40.6	35.5	26.8	32.8		60.0	40.7										ONEK
K-07-0120			39.8	24.9	45.9		42.1											ONEK
K-07-0121		26.1	32.7	44.7			54.2											ONEK
K-07-0122		51.8	30.9	31.3	25.4		65.1											ONEK
K-07-0123	0.0		33.0	28.5		21.6	64.1											ONEK
K-07-0124			38.7	41.9		73.1	64.5	51.8										ONEK
K-07-0125		19.9	20.8			31.8	45.9											ONEK
K-07-0126	0.0		21.5	9.5		5.3												ONEK
K-08-0129			55.3	32.6				60.3	64.3									ONEK
K-08-0134			54.8	64.0	79.4	86.1	86.6			0.0								ONEK
K-08-0135		21.0	26.4	27.6	61.4		35.8	31.4	17.5	0.0								ONEK
K-08-0136			44.6	41.8			60.3	56.4										ONEK
K-08-0137	0.0		30.9	28.5		47.5	76.1											ONEK
K-08-0138		41.6	42.3	41.4	65.5		60.8	53.2										ONEK
K-08-0139		34.6	28.6	18.4			47.2	29.4		0.0								ONEK
K-08-0140			43.2	40.2	55.9		35.3	71.8		0.0								ONEK
K-08-0141			49.3	45.1		60.9	68.0			0.0								ONEK
K-08-0142			42.3	28.1	63.9	56.9	65.6	43.6										ONEK
K-08-0143		31.8	45.7	22.2	52.5		69.9	44.9		0.0								ONEK
K-08-0144	0.0			73.6			73.1	37.6										ONEK
K-08-0145	0.0	75.4	40.3	10.2		36.9	62.3											ONEK
K-08-0146			46.4	40.5			63.9	71.2		0.0								ONEK

TABLE B-9: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-08-0147	0.0		45.2	56.3	88.2		26.5	27.7										ONEK
K-08-0148		45.6	47.0	17.7			27.6	62.4	75.7	4.8								ONEK
K-08-0149			51.7	54.9	53.0					0.0								ONEK
K-08-0150	0.0	87.5	33.8	40.2	39.5		51.2	20.0										ONEK
K-08-0151			46.4	15.0		24.8	49.9	41.2		0.0								ONEK
K-08-0152			59.6	61.1	88.6		77.6	75.0										ONEK
K-08-0153		54.0	72.6			91.4	89.7			0.0								ONEK
K-08-0154	0.0	77.3	70.8		87.1		91.1		83.6									ONEK
K-08-0155			70.3	47.1	89.6		92.5			0.0								ONEK
K-08-0156	0.0		69.1	70.0														ONEK
K-08-0157			68.0	55.6					49.2	0.0								ONEK
K-08-0158	0.0		62.9	70.0	56.0													ONEK
K-08-0175			40.6	38.6		63.9	94.0	60.4										ONEK
K-08-0177			56.6	52.1		58.4	76.3		56.7									ONEK
K-10-0237			21.2									26.6		6.4				ONEK
K-10-0239			12.2											5.1		26.9		ONEK
K-10-0240			49.3											9.7		49.6		ONEK
K-10-0241	12.8		46.5	16.6								30.7		15.0		34.9		ONEK
K-10-0244			30.2	12.5	17.2							30.5		24.8		53.1		ONEK
K-10-0245			28.0	48.2	50.8							41.1		34.1		69.6		ONEK
K-10-0247	5.1		72.6		10.7		63.2					31.1		36.4		45.7		ONEK
K-10-0248			50.2	24.7	15.1							40.2		16.7	20.3	54.5		ONEK
K-10-0249	5.1		40.2	41.9	36.7		52.9					36.1		30.1		61.1		ONEK
K-10-0250	3.8		76.7	65.2	80.4		82.8					67.7		75.5		77.1		ONEK
K-10-0251			51.4		71.2		84.1					50.4		65.1	66.9			ONEK
K-10-0252	6.4		40.3		70.0		82.6					61.0		21.9				ONEK
K-10-0253	0.0		34.4		61.2		67.4					34.6		12.0	6.8	27.5		ONEK
K-10-0254	0.0		74.8		52.5		85.0					42.9		10.0	31.8	78.7		ONEK
K-10-0255	28.7		39.5	15.1			57.1					36.3		23.4		0.0		ONEK
K-10-0256	0.0		54.7				41.7					30.5		26.9		49.2		ONEK

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TABLE B-9: RQD DATA SUMMARY – CONTINUATION

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-10-0262			44.8		45.1		62.6					30.7		26.4		78.4		ONEK
K-10-0263			25.0		37.5	15.3	41.9					20.6		3.3				ONEK
K-10-0265	0.0		28.1			42.7	43.4					36.6		44.4		28.0		ONEK
K-10-0267			70.3	35.8			92.4					61.8		45.5		44.3		ONEK
K-10-0306	12.4		16.9		25.6		57.9					21.5		16.2	25.3	56.9		ONEK
K-10-0308			41.2	34.4		56.7	64.4					35.2		29.0	43.3	51.5	62.1	ONEK
K-10-0309	0.0		42.1		61.0		46.6					37.9		34.9		46.1	42.8	ONEK
K-10-0311	0.0		50.9				40.3					50.0		36.2		57.6	55.7	ONEK
K-11-0324	0.0		54.4				35.4					29.8		0.0	15.5			ONEK
K-11-0325	0.0		41.4		41.5		87.6					28.2		17.9	26.2	9.2		ONEK
K-11-0326	0.0		52.2	47.6	33.3		86.9					41.1		18.3		93.4	66.6	ONEK
K-11-0327	5.6		55.7	36.1	77.1		92.2					31.6		23.5		29.0		ONEK
K-11-0328			40.0	15.6			51.4					28.6		47.3				ONEK
K-11-0329			51.7	35.1	47.7		61.1					36.3		25.7			35.4	ONEK
K-11-0330			49.8	24.4	34.4		63.3					49.7		33.7	29.5			ONEK
K-11-0331			33.2	27.6			31.8					38.8		28.0	28.3	51.5		ONEK
K-11-0332			52.9				58.6					36.6		21.2		53.6	25.9	ONEK
K-11-0333			44.7	30.1			54.1	51.0				42.2		44.9				ONEK
K-11-0334			46.2	4.3			62.4					36.9		22.8	52.7	50.8		ONEK
K-11-0335			58.8	51.1	26.1		40.8					54.5		36.2				ONEK
K-11-0337			42.5	7.7		56.7	59.3					27.8	28.8	43.8				ONEK
K-11-0339			52.1	25.2			60.3					42.8		43.6	23.5	36.5		ONEK
K-12-0488	0.0		39.7	30.1	7.7		76.6	29.3										ONEK
K-12-0491	34.3		38.8	39.9	46.7		68.2	65.3										ONEK
Average RQD	**3.9**	**44.2**	**45.2**	**35.7**	**49.2**	**47.2**	**62.3**	**49.4**	**53.5**	**0.3**		**38.3**	**28.8**	**27.8**	**30.8**	**48.7**	**48.1**	
Standard Deviation	**8.1**	**23.9**	**15.4**	**17.7**	**24.1**	**27.2**	**20.2**	**20.6**	**31.6**	**1.2**		**13.7**		**17.0**	**18.8**	**23.8**	**26.0**	

TABLE B-10: RQD DATA SUMMARY

Borehole I.D.	OVB	SCH	QTZT	GSCH	SSCH	CHSCH	GNST	CQTZT	CSCH	CAS	VN	TQTZT	MCQ	ICQS	FLT	VM	SM	Location
K-06-0001	0.0	26.1	51.5	28.4	33.8													SK
K-06-0002	0.0		54.4	28.9		38.7												SK
K-06-0003	0.0		43.4	30.5														SK
K-06-0004	0.0		46.2	26.5			0.0											SK
K-06-0006	0.0		42.8	32.2	46.3													SK
K-06-0007	0.0	20.1	53.9	18.8	56.1		23.3											SK
K-06-0009	0.0		48.0	41.7	75.5													SK
K-07-0112		81.0	75.2	15.0	85.4													SK
K-07-0113		43.1	48.0		18.4		34.1											SK
K-09-0218	0.0		54.4	47.1	61.1		82.3											SK
K-10-0221			39.3	9.7	54.9					15.8		53.4	17.7	53.0				SK
K-10-0222			61.7	19.9	45.1		85.6			0.0		52.8	0.0	42.9	0.0			SK
K-10-0223	33.9		59.4	38.2	45.8		59.0					46.7	48.5	31.2	16.4			SK
K-10-0224			53.8	23.6	23.6		35.2			1.4		38.7	0.0	40.1				SK
K-10-0225	54.3		60.8	37.8	74.0							48.7	17.1	44.2	8.5			SK
K-10-0226	28.9		25.7	8.0								37.2	32.8	33.2				SK
K-10-0227	3.2		45.5	22.7			51.6					33.5		32.7				SK
K-10-0228	35.8		45.5	15.9			31.4					60.4		27.7				SK
K-10-0229	5.4		69.6	4.8								58.4	56.4	42.4				SK
K-10-0230	0.0		50.6	10.8	62.3		61.6					41.2		48.3		10.9		SK
K-10-0231	0.0		28.1	54.0	32.2		52.8					29.2		39.1		28.2		SK
K-10-0232	1.2		50.6	18.7	47.7		71.2					38.4	41.8	36.2	0.0			SK
K-10-0233			52.9	14.8			46.7					44.4	37.7	19.7	57.4			SK
K-10-0234	2.1		50.9	41.0	20.0							38.9		35.0	60.9			SK
K-10-0236	15.7		67.0	0.0	56.9							45.6		55.5	13.9	73.4		SK
K-10-0238	4.3		45.2	19.9	11.8					4.9		40.8		32.7		42.3		SK
K-10-0242	1.9		17.6	1.4	0.0		56.1					29.0	72.8	16.0		38.7		SK
K-10-0243	8.1		54.6		18.7		59.2					39.4		21.8	0.0			SK
K-10-0246	3.0		71.4	0.0								40.5		30.6				SK
Average RQD	**8.6**	**42.6**	**50.6**	**22.6**	**43.5**	**38.7**	**50.0**			**5.5**		**43.0**	**32.5**	**35.9**	**19.6**	**38.7**		
Standard Deviation	**14.9**	**27.4**	**12.8**	**14.6**	**23.2**		**22.6**			**7.2**		**8.8**	**23.9**	**10.6**	**25.2**	**22.9**		

Lithology Codes 2012

BX	Hydrothermal Breccia	Typically zones of monomictic breccia typically composed of angular rock and/or vein clasts cementedby later quartz, carbonate (calcite, dolomite, siderite) with pyrite, galena or sphalerite.
CHSCH	Chlorite Schist	Light green to green-grey, or silvery green chlorite - sericite schist (phyllite), locally containing siliceous laminations. May have prominent lineation. Possible meta-tuffaceous rock. If rock makes up less than 5% of unit the chloritic modifier "chl" can be used.
CQTZT	Calcareous Quartzite	Quartzite characterized by brownish speckled texture or banding of primary carbonate that reacts to acid test. If rock makes up less than 5% of unit the calcareous modifier "c" can be used.
CSCH	Calcareous Schist	Light coloured schist, with carbonate as a major constituent. If rock makes up less than 5% of unit, the calcareous modifier "c" can be used.
DM	Disseminated Mineralization	Zone of disseminated galena or sphalerite (excluding pyrite), shown in Lith_2
FLT	Fault	Always placed in Lith_1 except where VM or VL occupies the same interval, when it is placed in Lith_2. Use Lith_2 if the rubbled or gouged rock type can be determined, but do not show it asa > 49% as the presence of the fault is more important. Includes Fault Breccia.
GNST	Greenstone	Generally massive greyish green to dark green, chlorite - actinolite - calcite sills locally with relict phaneritic texture and sometimes schistose particularly on margins.
GRIT	Gritty Schist	Schist containing clear, grey, and/or blue quartz grains (to 1mm) in a quartz-mica schist matrix. The quartz grains can generally only be seen on a freshly broken surface and not on the drill core surface. Petrology suggests these rocks may be meta-felsic volcanics.
GSCH	Graphitic Schist	Grey to dark grey to black schist (phyllite) with graphite as a major constituent, with well developed foliation, comprising > about 80%, with common quartzite bands generally < 1cm thick. A soft, Weak rock that breaks along foliation. Commonly contain plications, wrinkle laminations, small drag folds and crenulations. Most contain irregular masses of quartz as stringers or boudins. If rock makes up less than 5% of unit the graphite modifier "g" can be used.
LMST	Limestone	Light - medium grey to black crystalline limestone, sometimes banded with irregular lens-like layers of white or buff carbonate, or schistose (phyllitic) limestone.
NR	No Recovery	Loss of core, record in the Lith_2 field if VM or VL is present as these must show in Lith_1. Outside of mineralized zones, the % of the interval that NR represents determines its placement in Lith_1 or Lith_2, because core loss commonly represents faults.
OVB	Overburden	Quartenary alluvium, colluvium comprising interbeded sandy to bouldery fluvio-glacial beds.
QFP	Quartz Feldspar Porphyry	Fine to medium grained, brown to pinkish, quartz porphyritic ± biotite-bearing, felsic (dyke) intrusive.

QTZT	Quartzite	Massive buff, light to medium grey to white or bluish grey, may have a weak schistosity defined by sericite. Some are very fine grained, white and resemble re-crystallized cherts. Bedding may be visible throughout. Some are very fine grained, with a sugary texture and resemble re-crystallized cherts. Minor GSCH (to about 5%) is generally present as very narrow bands.
SCH	Undifferentiated Schist (Phyllite)	Fine grained, light to dark greyish - black or green depending on the dominant mineral content. Fracture surfaces generally have a distinctive sheen and show well developed foliation. Generally plications, wrinkle laminations, small drag folds and crenulations. Most contain irregular masses of quartz as stringers or boudins. Siliceous schist may be interbedded throughout, but must comprise less than 10% of the unit.
SM	Stringer Mineralization	Zone of stringers (< 1 cm true width) that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_2 field unless they comprise > 25% of the interval in which case put in Lith_1.
SSCH	Sericite Schist	Light green or mottled greenish yellow fine grained schist (phyllite), commonly with a silvery luster. Commonly show marked schistosity, plications, crenulations and contain numerous stringers, masses and boudins of white quartz. If rock makes up less than 5% of unit the sericite modifier "s" can be used.
TQTZT	Thin Bedded Quartzite	Grey quartzite bands 5 - >10 cm in thickness, with mud/graphitic schist bands up to about 20% (ONLY TO BE USED IN MSQ)
VL	Mineralized Veinlet	Zone of veinlets (1 - 10 cm true width) comprising > 25% of interval, that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_1 field.
VM	Mineralized Vein	Zone of veins (> 10 cm true width) that contain hypogene mineralization (not syngenetic sulphide). Put in Lith_1 field.
VN	Unmineralized Vein	Veins, veinlets and stringers lacking hypogene mineralization, but usually containing quartz, calcite or dolomite

Lithology Modifiers	
a	argillaceous
c	calcareous
chl	chloritic
cty	cherty
g	graphitic
m	massive (quartzite or schist)
s	sericitic
tnb	Thin bedded <30 cm bands QTZT, GSCH
mb	Medium bedded 30-120 cm bands QTZT, GSCH
tkb	Thick bedded >120 cm bands QTZT, GSCH

TETRA TECH EBA

Contract/Client	Alexco Environmental Group	Job Number	W14103428-01.003
Design Topic	Plug DimensionDesign	Sheet No.	1 of 2
	10 m Hydraulic Head	Made by	JV
		Date	17/03/2015
		Reviewed by	CC

NELPCo NND-EBA LAND PROTECTION CORP

1.) Punching Shear Design

Shear Strength for unreinforced concrete

$f'_s =$ 107.7 psi — concrete shear strength
742.2 Kpa

Inputs

where $f'_c =$ 2900.75476 — concrete compressive strength **(psi)**

NOTES:

* **Changing from kPa to to psi**

$f'_c =$ 20000 (kPa)

$f'_c =$ 2900.8 (psi)

Shear Strength of the rock mass (U)

Use the fair rock in the table on the right

This corresponds to U = 600 kPa

Therefore, punchiing shear failure is controlled by the shear strenght of the rock mass.

Recommended design shear strengths and hydraulic gradients for tunnel plugs (after Lang, 2012)

Rock Condition CSIR Rock Mass Rating	Design Shear Strength (kPa)	Allowable Hydraulic Gradient*
Very Good Rock Massive, hard, widely jointed 81<RMR<100	1500	15-30
Good Rock Hard to Moderately hard, moderately jointed 61<RMR<80	900	10-14
Fair Rock Moderate to Weak, Moderately jointed 41<RMR<60	600	7-9
Poor Rock Weak, closely jointed or sheared 21<RMR<40	300	5-6
Poor Rock Very weak, possible erodible RMR<20	150	3-4

*Allowable gradients can be higher if formation grouting is performed.

2.) Plug length for static loading

L = 0.0908 — Length without considering F.S

L = 0.2725 — **Final length considering F.S.**

		Inputs	
where	**h**	2.5	Adit height **(m)**
	w	2	Adit width **(m)**
	U	600000	**(Pa)** Allowable shear strength rock mass, **U** should be substituted for ***f's*** if ***f's*** is lower
	H	10	Head of fluid on plug **(m)**
	ρ	1000	Density of fluid **(kg/m^3)**
	g	9.81	Gravitational constant **(9.81 m/s^2)**
	FS	3	Factor of Safety

3.) Additional Pressure (Seismic)

PH 144 (kPa) considering Vmax

		Inputs		
where	**c**	1437	acoustic velocity of water **(1437 m/s)**	1437
	v		ground velocity **(m/s)**	
	ρ	1000	Density of fluid **(kg/m^3)**	1000
	V_{max}	0.1001	**m/s**	0
	a_{max}	0.182	**g**	0.182

The relationship between Vmax and amax is given approximately by Seed and Idriss (1983) as

$$\frac{V_{max}}{a_{max}} = \frac{55\,\frac{cm}{seg}}{g}\,(for\ rock)$$

* $V_{max}/a_{max}=$ 55 cm/seg/g

NOTES:

*notice V_{max} is dependent on a_{max}

TETRA TECH EBA

		Job Number	W14103428-01.003
		Sheet No.	2 of 2
Contract/Client	Alexco Environmental Group	Made by	JV
Design Topic	Plug DimensionDesign	Date	17/03/2015
	10 m Hydraulic Head	Reviewed by	CC

NELPCO NND-EBA LAND PROTECTION CORP

4.) Hydraulic Jacking

CRM = minimum rock cover measured to the nearest point on the ground surface

		CRM	5.3209	m Condition met
		Inputs	Inputs	
where	h_s		10	**(m)** static design water head
	γ_w		1000	**(kg/m³)**unit weight of water
	γ_r		2600	**(Kg/m³)**unit weight of rock
	β (°)	**20**	0.3491	slope angle of topography
	F		1.3	FoS (**between 1.1 and 1.3** Bergh-Christiansen and Dannevig, 1971)

NOTES:

C_{RM} = minimum rock cover measured to the nearest point on the ground surface

* **β (°)** **degree**: enter value in degrees on green celd

5.) Allowable Hydraulic Gradient

The length of the plug is reviewed by the allowable hydraulic gradient for the rock condtitions that will prevent piping and downstream erosion of the adit walls or by maximum accetable seepage

$$\text{Hydraulic Gradient} = \frac{\text{Design head of water [m]}}{\text{Lengh of the plug [m]}}$$

$$\text{Length of Plug [m]} = \frac{\text{Design head of water [m]}}{\text{Hydraulic Gradient}}$$

Hydraulic gradient = 8 Based on a fair rock (from table on previous page)

Design of head water = 10 m

Then length of Plug = 1.3 m However, 3 m long is recommended to meet conditions of plug length > adit width or height

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX 3.6
DSTF RISK ASSESSMENT

Bellekeno Mine - Dry Stack Failure Modes and Effects Analysis Final Draft

Prepared for

Alexco Resource Corp.

Prepared by

srk consulting

SRK Consulting (Canada) Inc.
1CA009.006
July 2013

Bellekeno Mine - Dry Stack Failure Modes and Effects Analysis
Final Draft

July 2013

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Project No: 1CA009.006

File Name: BellekenoMine_DryStackFMEA_Report_1CA009.006_dvz_ccs_20130703_FNL DRAFT.docx

[illegible]

[illegible]

[illegible]

1 Introduction

Alexco Resource Corp. entered into a contract with SRK Consulting (Canada) Inc. to perform a Failure Modes and Effects Analysis (FMEA) for the Ken District Mill Dry Stack Tailings Facility. Alexco owns and operates the Bellekeno Mine (silver, lead and zinc) in the Keno Hill Silver District of the central Yukon.

Based on concerns raised by technical staff and consultants of Na-cho Nyak Dun regarding the suitability and long-term stability of the DSTF and ice rich permafrost in foundation soils, Alexco commissioned the FMEA workshop to address these concerns using an objective risk-based approach. Following some preparatory work, the FMEA for the DSTF was completed in a workshop on September 24, 2012 at the Whitehorse, Yukon office of Alexco. This report describes the approach to the project and the results.

[illegible]

The overall objective of the FMEA for the Bellekeno Dry Stack Tailings Facility is to evaluate the risks associated with the presence of permafrost in the foundation materials adjacent to the dry stack facility. The objectives of the workshop were to evaluate the likelihood of occurrence and consequences associated with a series of failure modes for the dry stack at the site and to identify high concern issues.

[illegible]

The physical boundaries of the FMEA were the immediate surroundings of the dry stack, however; surface water impacts on facilities downstream of the facility, e.g. Christal Lake, were included. The temporal boundaries included operations as well as long-term considerations, assumed to be about 50 years.

4 FMEA Process

4.1 Preparation

Preparation for the workshop included the following activities:

- Review of site information;
- Identification of workshop participants; and
- Circulation of failure likelihood and severity of consequence descriptions for review by the participants.

4 [illegible]

The FMEA workshop was held on September 24, 2012 at the Alexco's office in Whitehorse, Yukon. The workshop participants and their affiliations were:

- Brad Thrall, Alexco Resource Corp.;
- Richard Trimble, EBA, a Tetra Tech Company;
- Justin Pigage, EBA, a Tetra Tech Company;
- Kim Winnicky, consultant to First Nation of Na-cho Nyak Dun (NND);
- Bill Slater, consultant to First Nation of Na-cho Nyak Dun (NND);
- Rob McIntyre, Alexco Resource Corp.; and
- Dirk van Zyl, SRK Consulting (Canada) Inc. (facilitator).

As an introduction to the workshop, EBA made a presentation of site conditions. The presentation is provided in Appendix A.

Failure modes were identified, described and discussed during the workshop. A participant described the failure mode and its effect (or manifestation of the failure mode). During this discussion, descriptions were added in the FMEA table for the columns labelled ID, Failure Mode and Consequence Type.

There was open discussion amongst the workshop participants to review and agree on the description of the failure mode and its effects, i.e. reach consensus on the description in the FMEA table for the columns above. Based on this discussion, initial suggestions for the following columns in the FMEA table were made: Likelihood (using the descriptions in Table 1 as guidance) and Consequence Severity (using the descriptions in Table 2 as guidance).

Participants discussed the initial ratings with a view to obtaining consensus on the likelihood, severity, and notes for further consideration. The Risk Rating Descriptive Column was completed using the Risk Matrix in Table 3.

[illegible]

In total, 15 failure modes were identified and discussed at the workshop. The FMEA outcome for the workshop is presented in Table 4.

The cells in Table 4 describing the risks are shaded using the colors in the attached Risk Table (Table 3). The colors indicate the various risks posed by a combination of the likelihood of a failure occurring and the consequence severity of the failure mode if it should occur. For example, dark orange to red correspond to high to very high risk failure modes while the green colors correspond to a low risk failure mode. None of the failure modes identified in the workshop received a high or very high risk rating.

Twelve of the fifteen failure modes identified resulted in a low risk rating (refer to Table 4). Two resulted in medium risk and one in a moderately high risk rating. The failure modes resulting in medium risk ratings are:

- Large differential settlement in the long-term (~50 years) leading to tailings exposure on the surface from compromised covers (environmental consequence).
- Large precipitation event erodes through the surface cover, exposes the tailings resulting in transport of tailings into natural environment (special considerations consequence).

The moderately high risk rating was linked to large differential settlement in the long-term (~50 years) leading to tailings exposure on the surface from compromised cover (special considerations consequence).

The special considerations consequences were identified as being of specific concern to the NND and comments are provided in Table 4 for the further evaluation and mitigation of these, as well as the medium risk associated with the environmental consequences.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Happens often	High frequency (more than once every 5 years)	98%	17.8%
[illegible]	Could easily happen	Event does occur, has a history, once every 15 years	75%	6.7%
[illegible]	Could happen and has happened elsewhere	Occurs once every 40 years	40%	2.5%
[illegible]	Hasn't happened yet but could	Occurs once every 200 years	10%	0.5%
[illegible]	Conceivable, but only in extreme circumstances	Occurs once every 1000 years	2%	0.1%

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	No impact.	Minor localized or short-term impacts.	Significant impact on valued ecosystem component.	Significant impact on valued ecosystem component and medium-term impairment of ecosystem function.	Serious long-term impairment of ecosystem function.
[illegible]	Some disturbance but no impact to traditional land use.	Minor or perceived impact to traditional land use.	Some mitigable impact to traditional land use.	Significant temporary impact to traditional land use.	Significant permanent impact on traditional land use.
[illegible]	Informal advice from a regulatory agency.	Technical/Administrative non-compliance with permit, approval or regulatory requirement. Warning letter issued.	Breach of regulations, permits, or approvals (e.g. 1 day violation of discharge limits). Order or direction issued.	Substantive breach of regulations, permits or approvals (e.g. multi-day violation of discharge limits). Prosecution.	Major breach of regulation – wilful violation. Court order issued.
[illegible]	< $100,000	$100,000 - $500,000	$500,000 - $2.5 Million	$2.5-$10 Million	>$10 Million
[illegible]	Local concerns, but no local complaints or adverse press coverage.	Public concern restricted to local complaints or local adverse press coverage.	Heightened concern by local community, criticism by NGOs or adverse local /regional media attention.	Significant adverse national public, NGO or media attention.	Serious public outcry/demonstrations or adverse International NGO attention or media coverage.
[illegible]	Low-level short-term subjective symptoms. No measurable physical effect. No medical treatment.	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization.	Moderate irreversible disability or impairment to one or more people.	Single fatality and /or severe irreversible disability or impairment to one or more people.	Multiple fatalities.

□□□□□□□□ □□□M□r□□

□□□□□□□□d□	□□□□□□□□□□□□□□r□□				
	□□□□	M□□□r□	M□d□r□□□□	M□□□r□	□r□□□□□□
□□ □□□□□ □r□□□□	M□d□r□□□□	M□d□r□□□□□□□ □□□□	□□□□□	□□r□□□ □□□□	□□r□□□ □□□□
□□□□□□	M□d□r□□□□	M□d□r□□□□	M□d□r□□□□□□□ □□□□	□□□□□	□□r□□□ □□□□
□□□□□□□□	□□□□	M□d□r□□□□	M□d□r□□□□□□□ □□□□	□□□□□	□□□□□
□□□□□□□□	□□□□	□□□□	M□d□r□□□□	M□d□r□□□□□□□ □□□□	M□d□r□□□□□□□ □□□□
□□r□□□ □□□□□□□	□□□□	□□□□	□□□□	M□d□r□□□□	M□d□r□□□□□□□ □□□□

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Large differential settlement in the long-term (~50 years) leading to tailings exposure on surface from compromised cover.	Env. Imp.	Minor	Likely	Moderate	Check for other examples in the district for settling. Look at additional modeling with real data.
2	Large differential settlement in the long-term (~50 years) leading to tailings exposure on surface from compromised cover.	Spec. Cons.	Moderate	Likely	Moderately High	Check for other examples in the district for settling. Look at additional modeling with real data. Cover maintenance.
3	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in contamination of localized GW from tailings porewater.	Env. Imp.	Minor	Unlikely	Low	
4	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in upwelling of GW/melt water into the tailings resulting in slope instability	Env. Imp.	Minor	Very Unlikely	Low	
5	Large differential settlement in the long-term (~50 years) leading to breach of liner/drainage blanket/containment system resulting in contamination of surface water (i.e. Christal Lake)	Env. Imp.	Minor	Very Unlikely	Low	Took into account present state of Christal Lake.
6	Large precipitation event erodes through surface cover, exposes tailings resulting in transport of tailings into natural environment	Env. Imp.	Minor	Unlikely	Low	
7	Large precipitation event erodes through surface cover, exposes tailings resulting in transport of tailings into natural environment	Spec. Cons.	Moderate	Unlikely	Moderate	Mitigate by cleaning up the tailings released during the large precipitation event.
8	Poor cover performance (vegetation, other) leads to increased infiltration and increased pore water transport resulting in metals migration	Env. Imp.	Minor	Unlikely	Low	
9	Metals uptake in soil cover vegetation leads to introduction into food chain and human health impacts	Human H&S	Low	Unlikely	Low	Used guidance from Env. Impact to rate.
10	Metals uptake in soil cover vegetation leads to introduction into food chain and human health impacts	Spec. Cons.	Minor	Unlikely	Low	
11	Earthquake larger than design event leads to slope failure resulting in exposure of tailings long-term	Env. Imp.	Minor	Very Unlikely	Low	
12	Earthquake larger than design event leads to slope failure resulting in exposure of tailings long-term	Spec. Cons.	Moderate	Very Unlikely	Low	
13	Modeling has underestimated the foundation pore pressures leading to slope failure and exposure of tailings long-term	Env. Imp.	Minor	Very Unlikely	Low	
14	Failure to follow OMS manual leads to stack not performing to design, resulting in environmental impacts	Env. Imp.	Minor	Unlikely	Low	OMS in place, 3rd party QA/QC every 6 weeks.
15	Dust migration from DSTF leads to (i.e. temporary closure, construction, not following OMS) environmental impacts	Env. Imp.	Minor	Unlikely	Low	OMS in place, 3rd party QA/QC every 6 weeks.

This final draft report, "Bellekeno Mine - Failure Modes and Effects Analysis", was prepared by SRK Consulting (Canada) Inc.

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Principal Consultant (Associate)

and reviewed by

Cam Scott, P.Eng.
Principal Consultant

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

Appendix A: Introductory PowerPoint Presentations

DSTF Risk Assessment

- Introductions
- Participants
- Objectives
- Risk Assessment Process Overview
- DSTF Overview
- DSTF Risk Assessment

Keno District Timeline

- **2005** Company Founded
- **2006** Acquired Keno Hill Silver District, Care maintenance change over
- **2007** District wide closure plan studies begins
- **2008** Advanced exploration/development Bellekeno
- **2009** QML Granted - Bellekeno Construction Begins
- **2010** Comprehensive Cooperation Agreement with FNNND
- **2010** Water License Granted – mill/DSTF commissioned
- **2011** Commercial Production – Bellekeno mine/mill
- **2012** Lucky Queen/ Onek new mine development, YESAB/QML

Dry Stack Tailings Technology

ALEXCO

- **Advantages**
  - Reduced makeup water – increased recycle
  - Progressive reclamation enhanced
  - Decreased footprint from higher compaction, stack heights
  - Higher geotechnical stability if constructed appropriately
  - Pore water seepage significantly reduced – groundwater contamination eliminated if operated appropriately

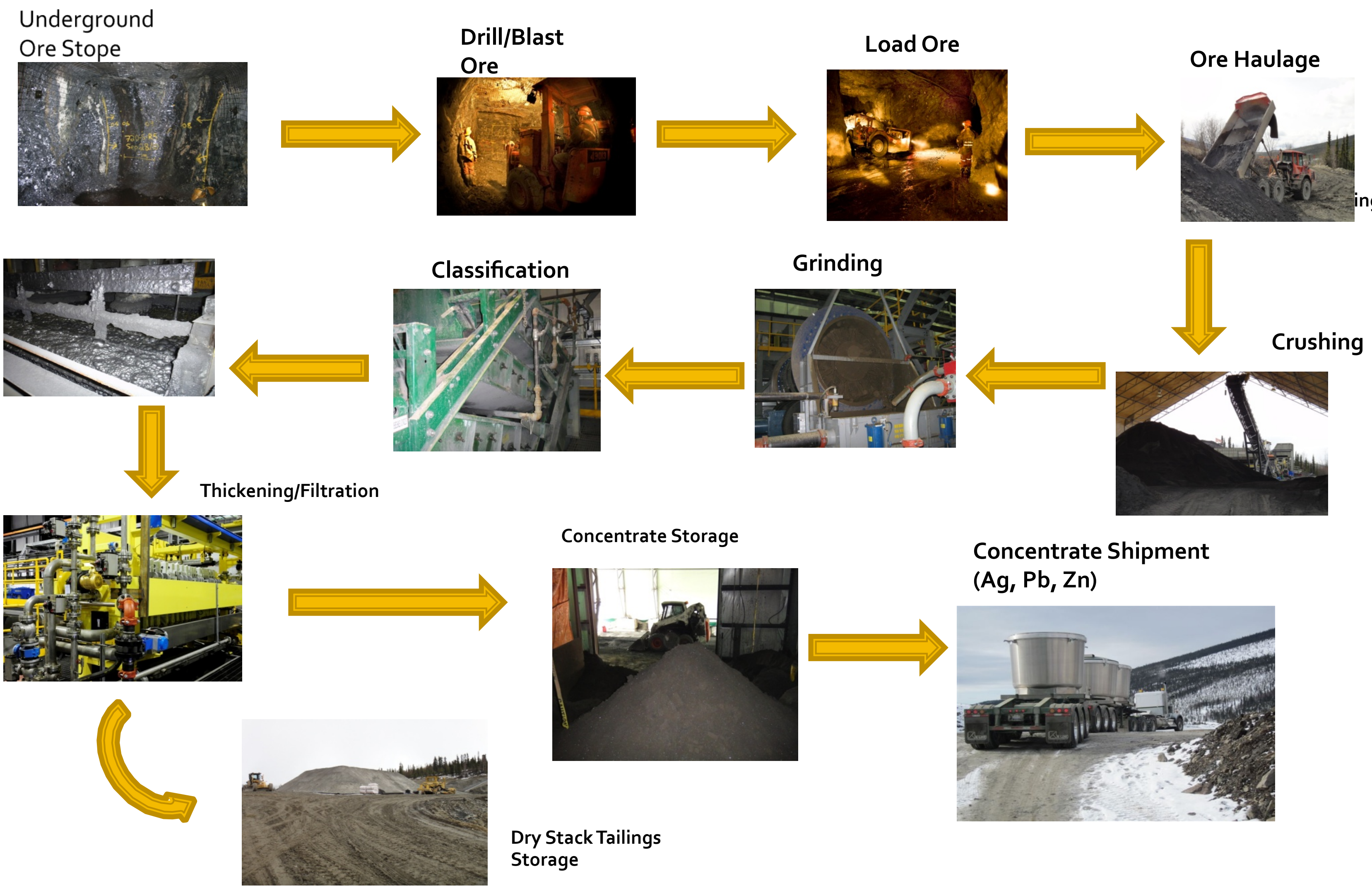
Dry Stack Tailings Technology

ALEXCO

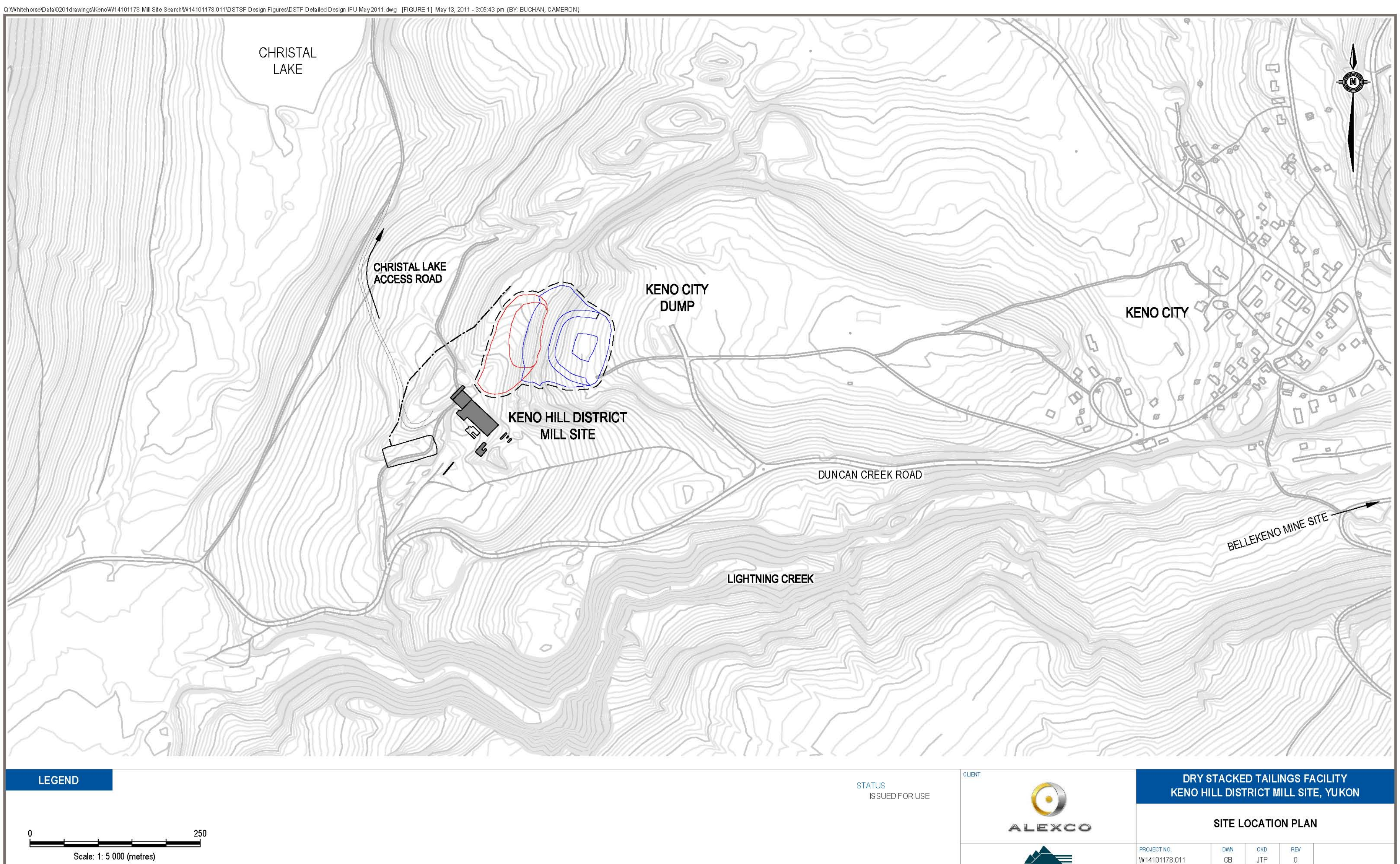
- **Disadvantages**
  - Increased capital and operating costs
  - Increased process bottlenecks – decreased operating flexibility
  - Potential dust migration due to lower moisture content

Mill Area Layout

Mill Process Flowsheet

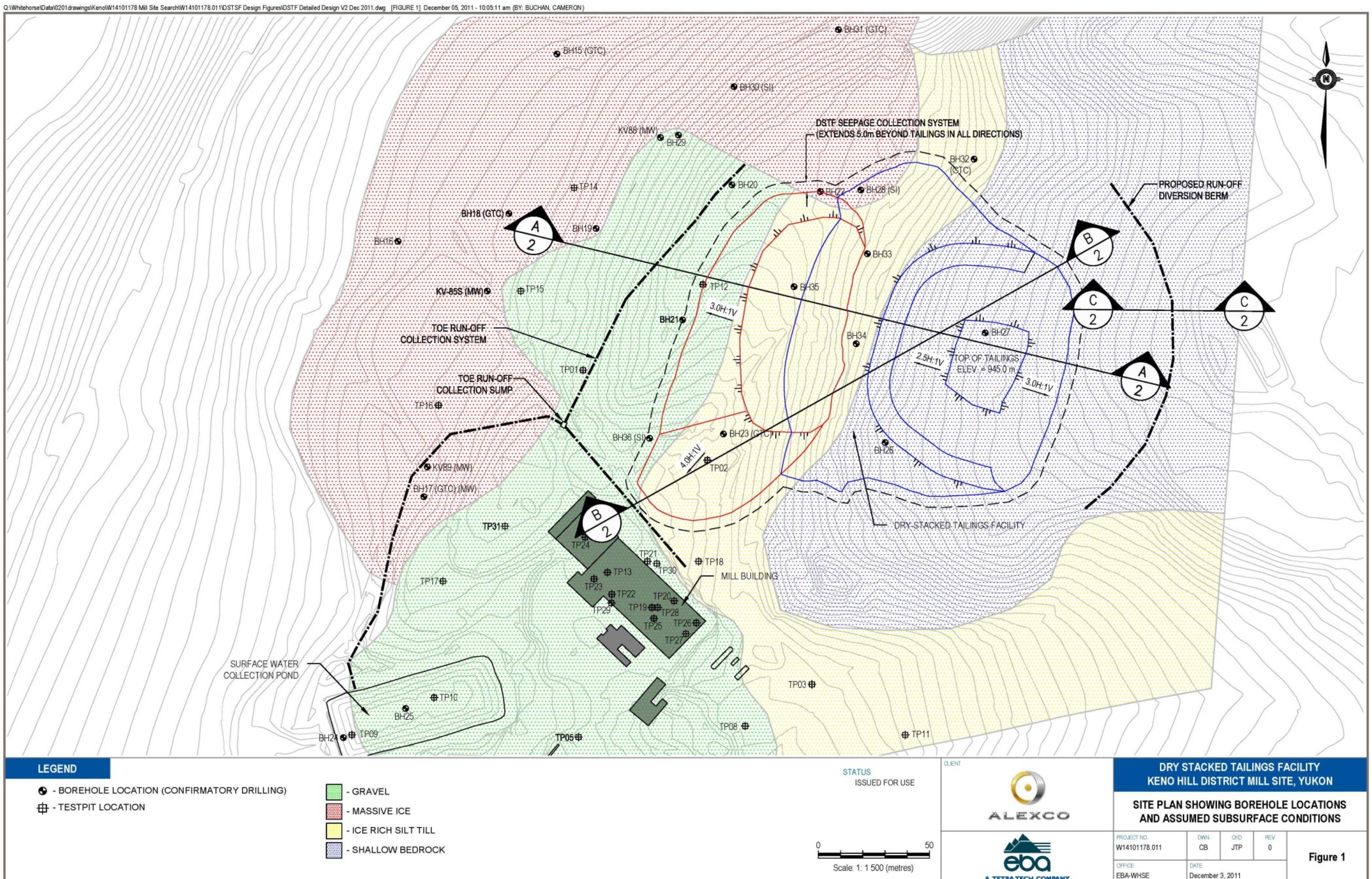


DSTF Design

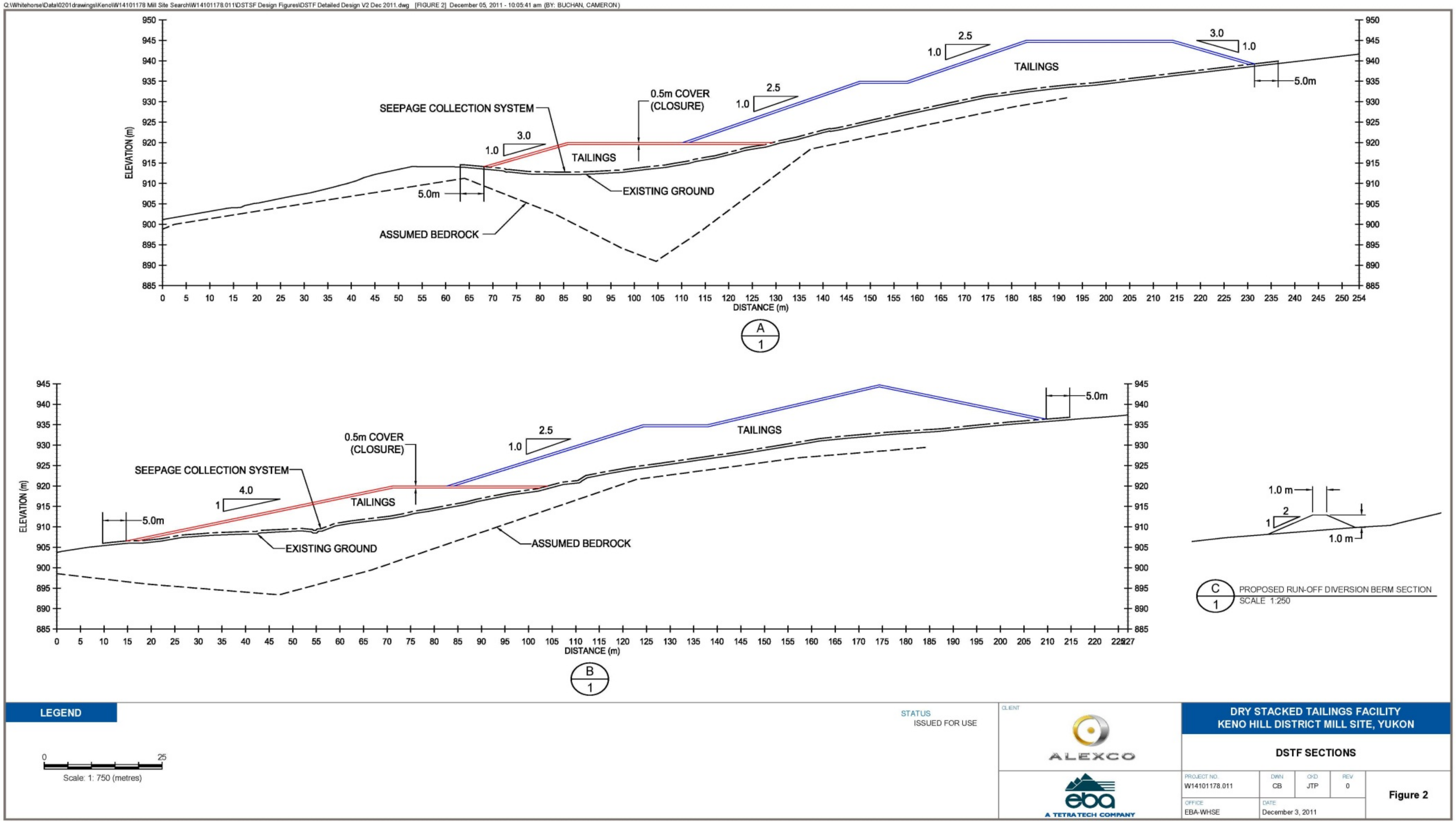


Q:\Whitehorse\Data\0201drawings\Keno\W14101178 Mill Site Search\W14101178.011\DSTSF Design Figures\DSTF Detailed Design IFU May2011.dwg [FIGURE 1] May 13, 2011 - 3:05:43 pm (BY: BUCHAN, CAMERON)
CHRISTAL LAKE
CHRISTAL LAKE ACCESS ROAD
KENO CITY DUMP
KENO CITY
KENO HILL DISTRICT MILL SITE
DUNCAN CREEK ROAD
BELLEKENO MINE SITE
LIGHTNING CREEK
N
LEGEND
0
250
Scale: 1: 5 000 (metres)
STATUS
ISSUED FOR USE
CLIENT
ALEXCO
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
SITE LOCATION PLAN
PROJECT NO.
W14101178.011
DWN
CB
CKD
JTP
REV
0

DSTF Design

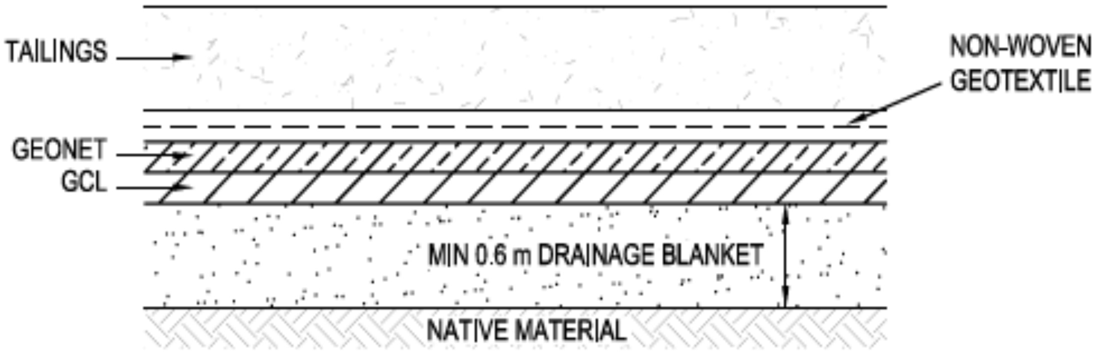

DSTF SEEPAGE COLLECTION SYSTEM (EXTENDS 5.0m BEYOND TAILINGS IN ALL DIRECTIONS)
PROPOSED RUN-OFF DIVERSION BERM
TOE RUN-OFF COLLECTION SYSTEM
TOE RUN-OFF COLLECTION SUMP
TOP OF TAILINGS ELEV. = 945.0 m
DRY-STACKED TAILINGS FACILITY
MILL BUILDING
SURFACE WATER COLLECTION POND
3.0H:1V
2.5H:1V
4.0H:1V
LEGEND
- BOREHOLE LOCATION (CONFIRMATORY DRILLING)
- TESTPIT LOCATION
- GRAVEL
- MASSIVE ICE
- ICE RICH SILT TILL
- SHALLOW BEDROCK
STATUS
ISSUED FOR USE
Scale: 1: 1 500 (metres)
ALEXCO
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
SITE PLAN SHOWING BOREHOLE LOCATIONS AND ASSUMED SUBSURFACE CONDITIONS
W14101178.011
CB
JTP
0
EBA-WHSE
December 3, 2011
Figure 1

DSTF Design



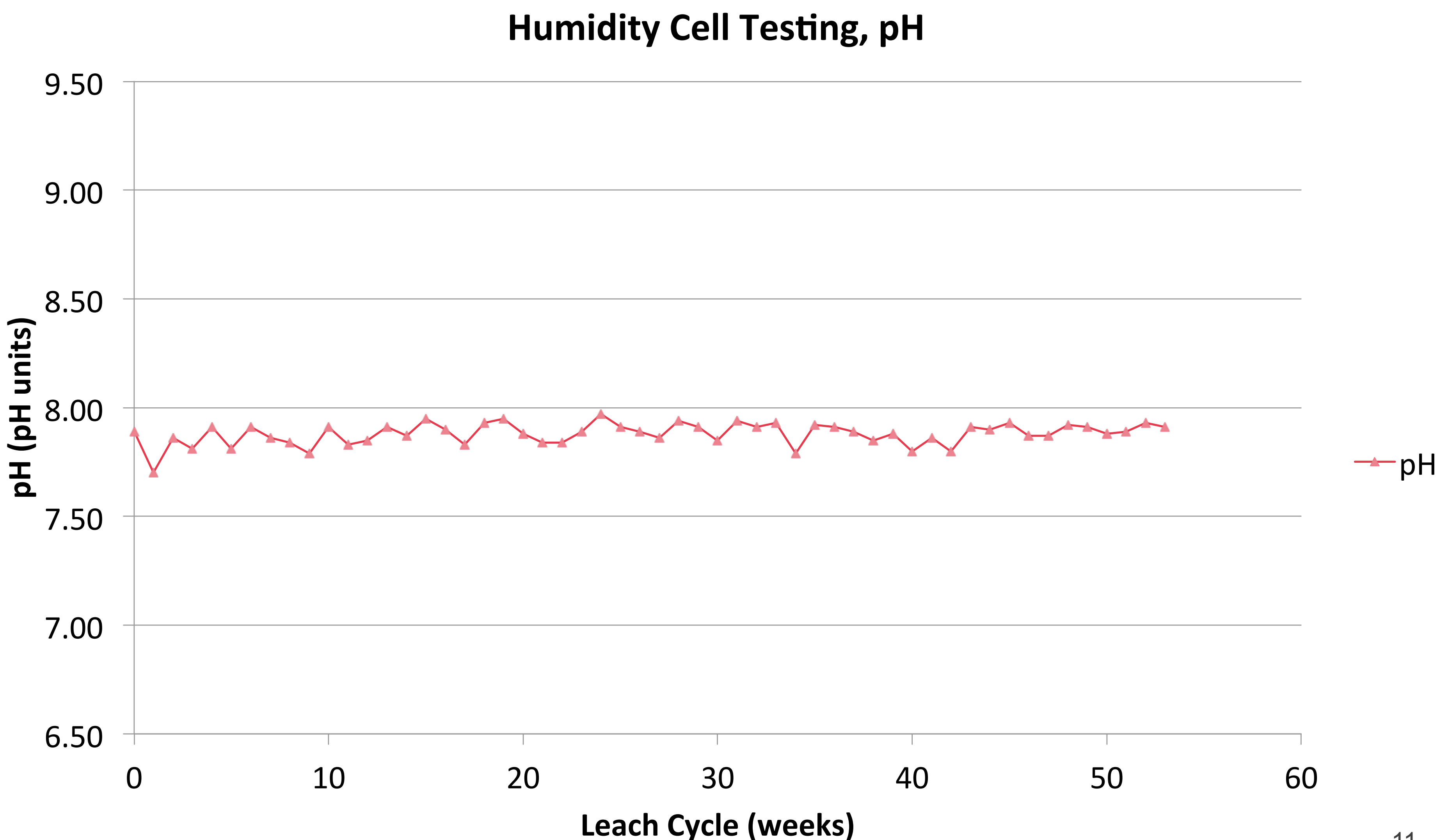
SEEPAGE COLLECTION SYSTEM
0.5m COVER (CLOSURE)
TAILINGS
EXISTING GROUND
ASSUMED BEDROCK
5.0m
ELEVATION (m)
DISTANCE (m)
A 1
B 1
C 1 PROPOSED RUN-OFF DIVERSION BERM SECTION
SCALE 1:250
LEGEND
Scale: 1: 750 (metres)
STATUS
ISSUED FOR USE
DRY STACKED TAILINGS FACILITY
KENO HILL DISTRICT MILL SITE, YUKON
DSTF SECTIONS
PROJECT NO. W14101178.011
DWN CB
CKD JTP
REV 0
OFFICE EBA-WHSE
DATE December 3, 2011
Figure 2

DSTF Design

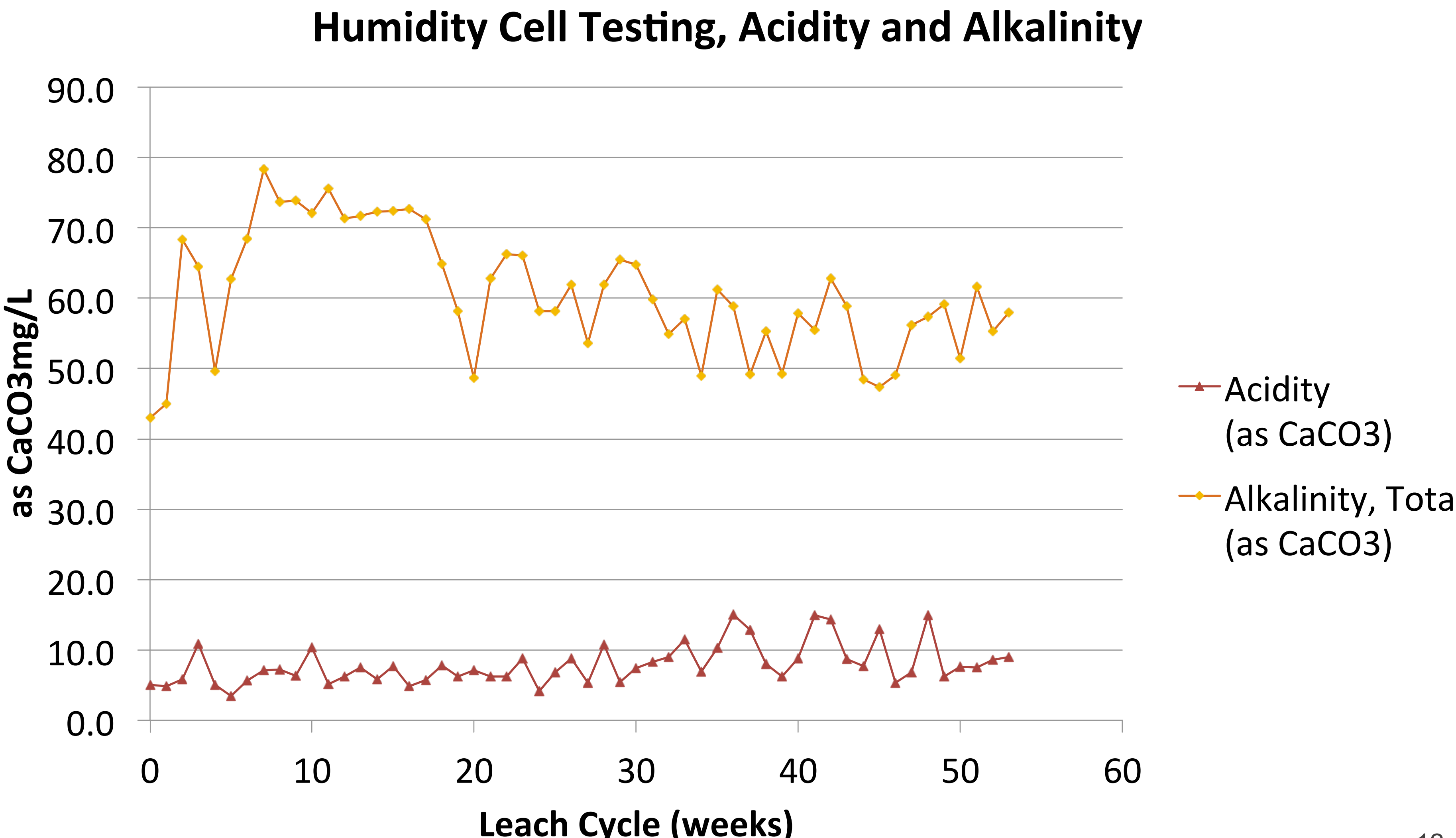


SEEPAGE COLLECTION SYSTEM DETAIL

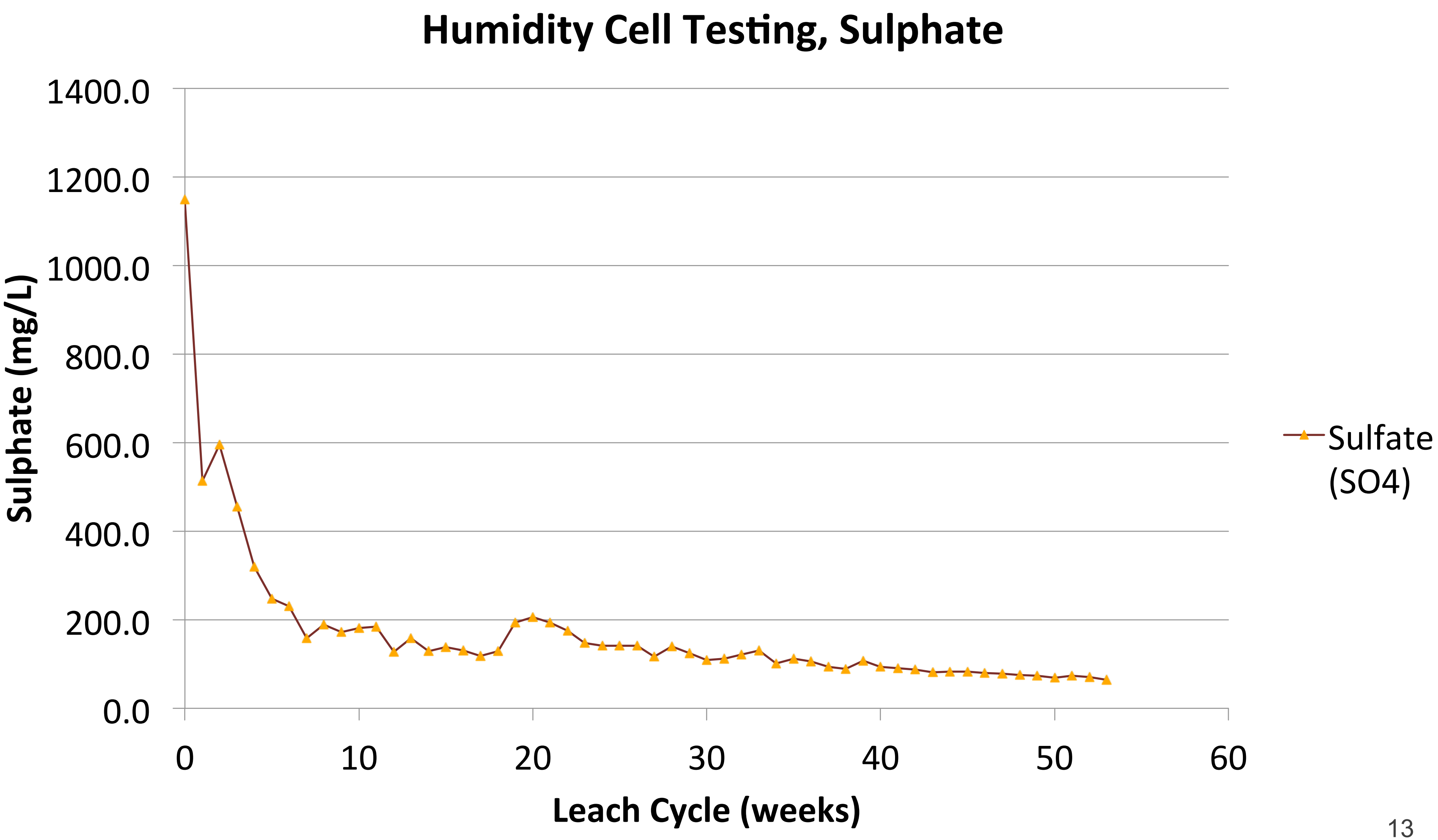
DSTF Performance



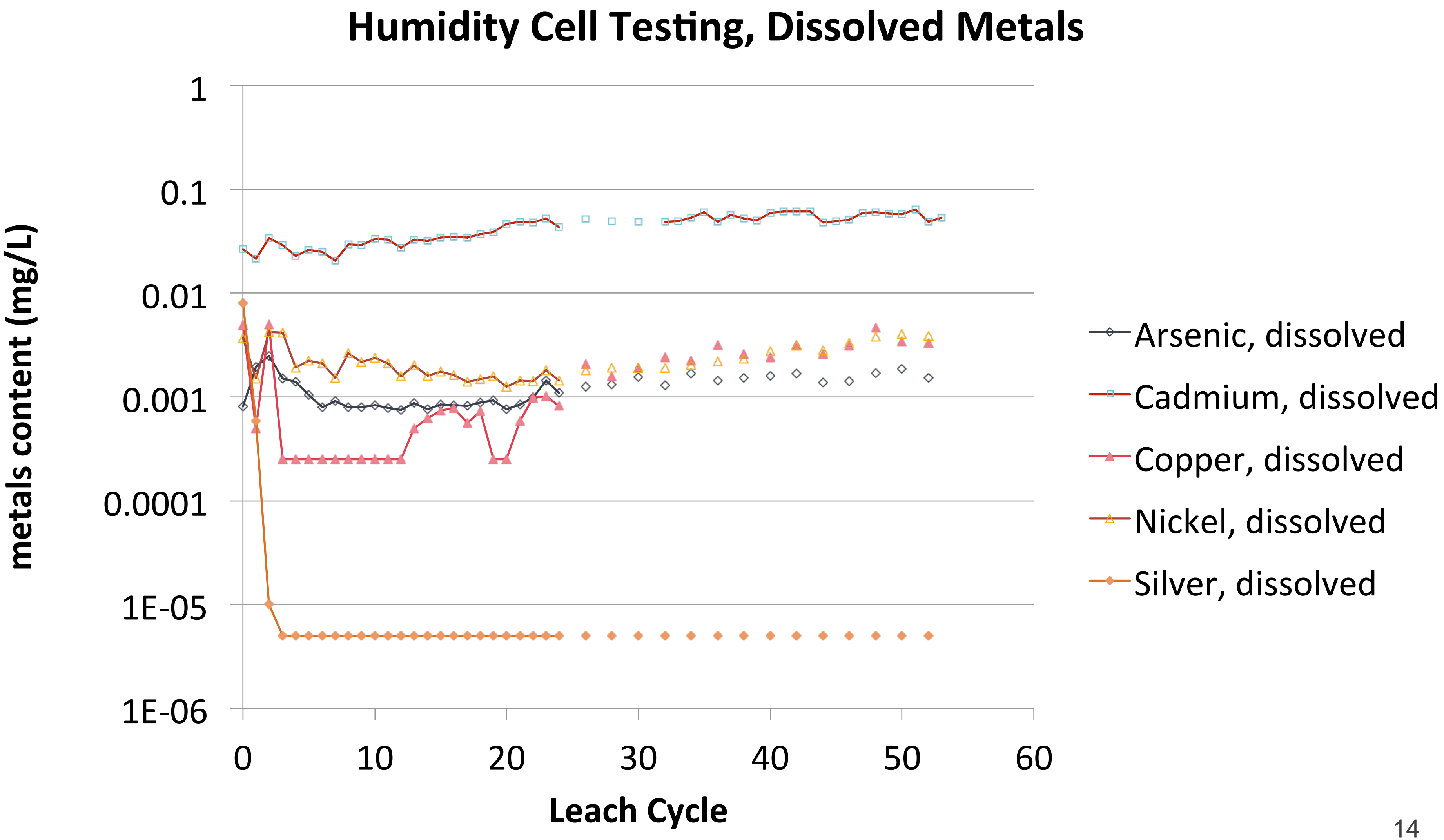
DSTF Performance



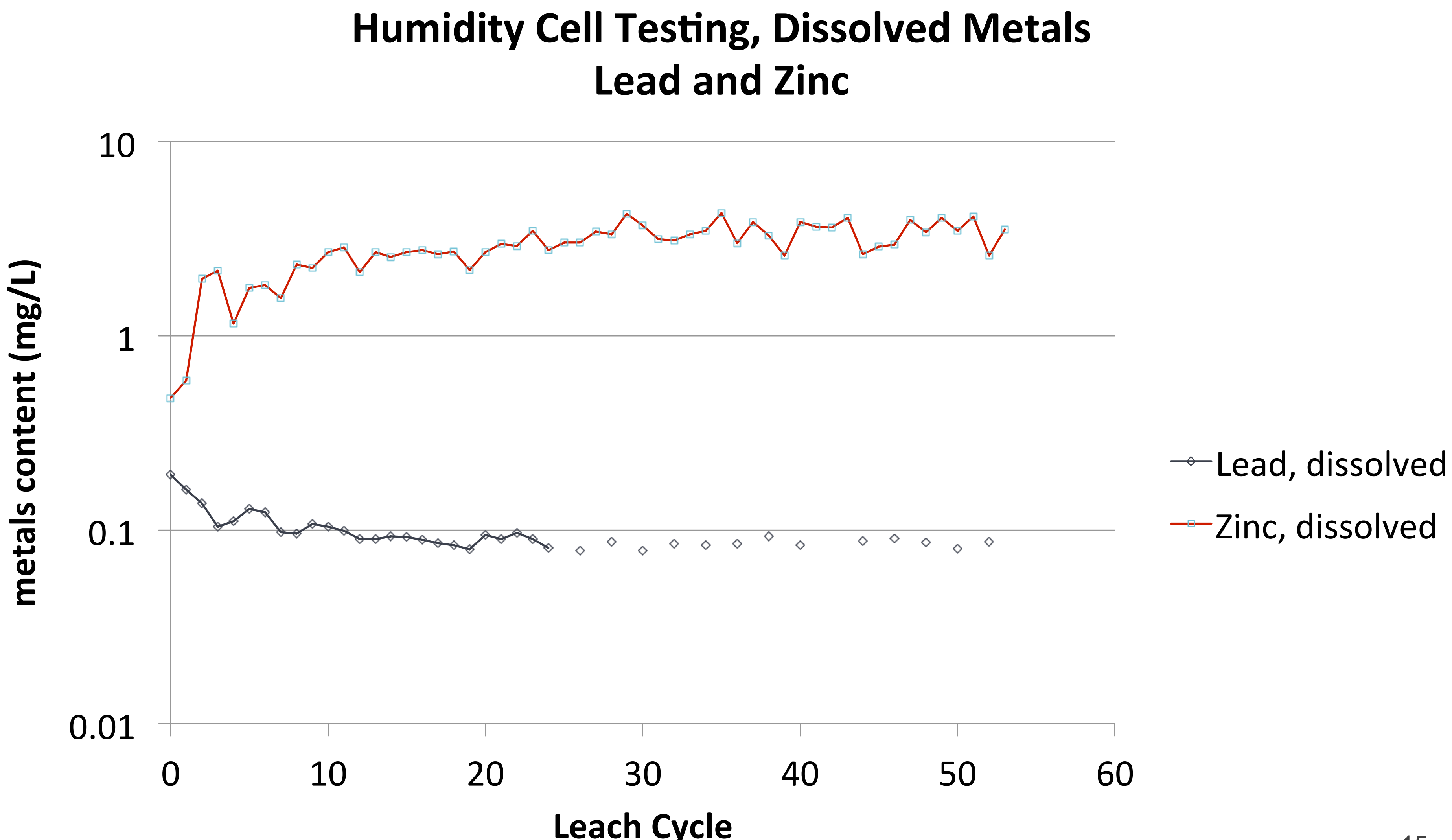
DSTF Performance



DSTF Performance

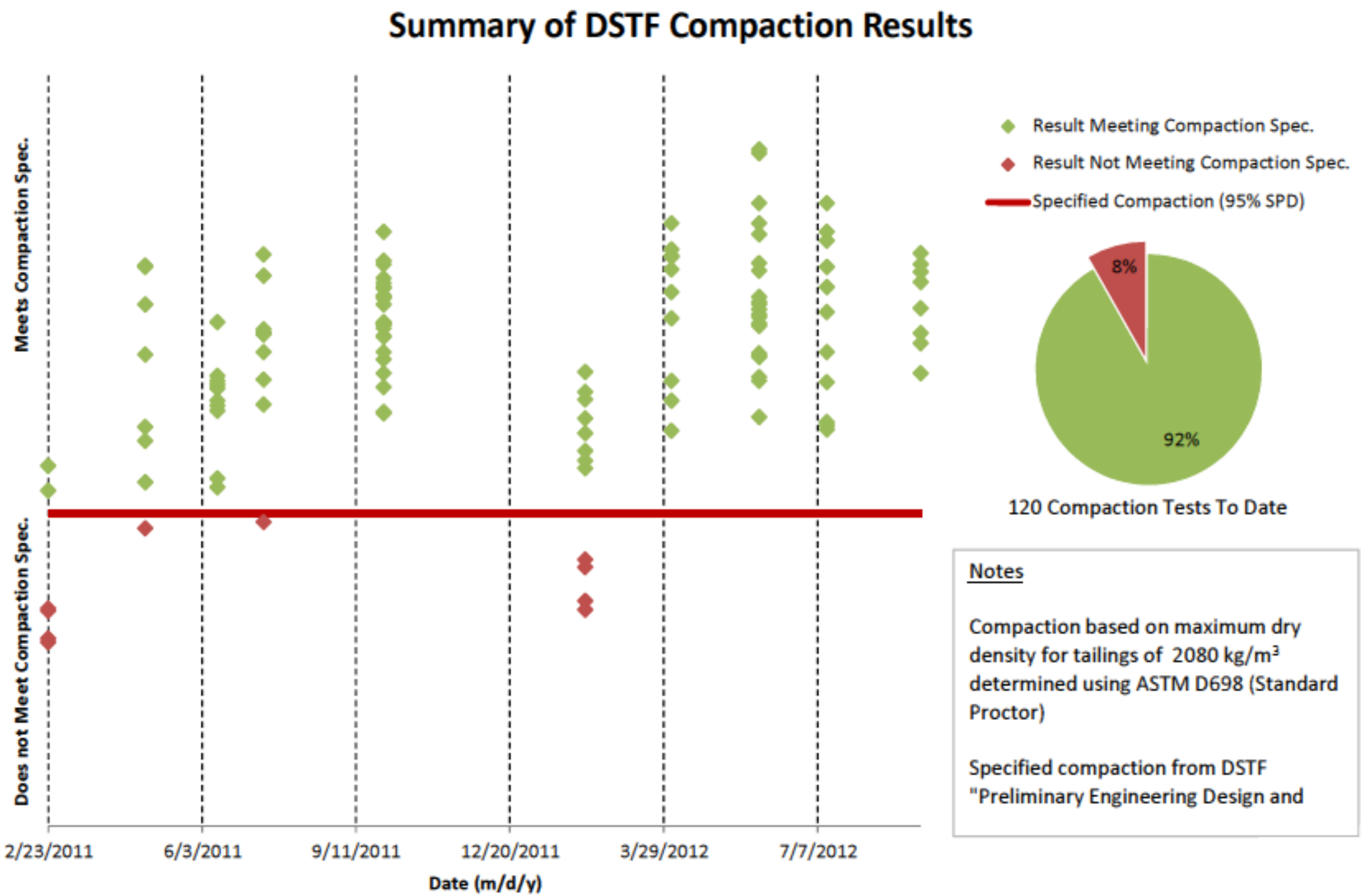


DSTF Performance



DSTF Performance - Compaction

ALEXCO

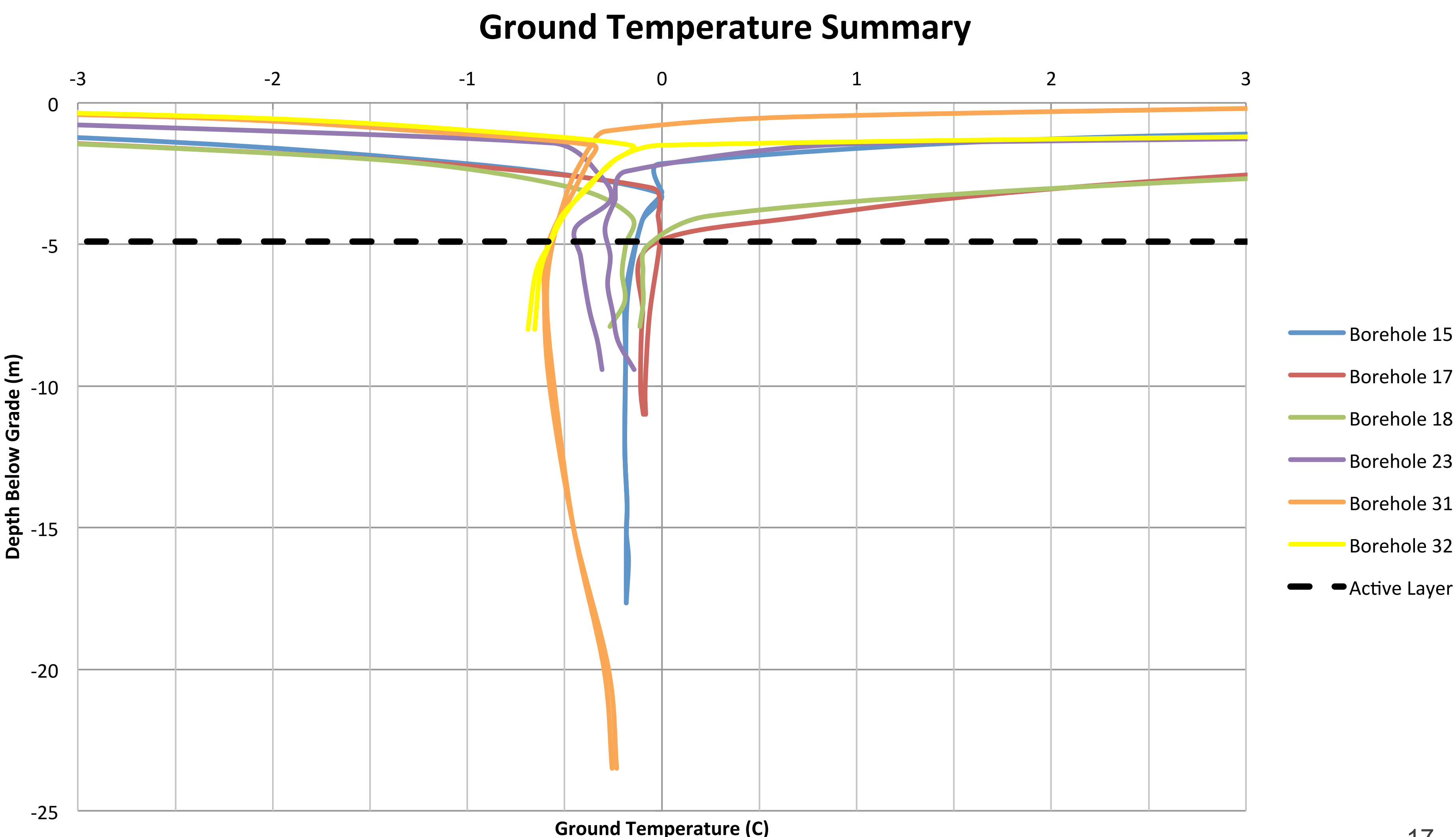


Notes

Compaction based on maximum dry density for tailings of 2080 kg/m³ determined using ASTM D698 (Standard Proctor)

Specified compaction from DSTF "Preliminary Engineering Design and

DSTF Performance - Temperature



DSTF Progressive Reclamation

ALEXCO

DSTF Progressive Reclamation

DSTF Progressive Reclamation

ALEXCO