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Phase II Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site, Penobsquis, NB

Final Report
TE183037

Prepared for:

Town of Sussex
524 Main Street, Sussex, NB   E4E 3E4

27-Aug-19

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27-Aug-19

Mr. Scott Hatcher P.Eng.
Chief Administrative Officer
Town of Sussex
524 Main Street
Sussex, NB E4E 3E4

Attn: Mr. Hatcher,

Re: **Final Report: Phase II Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site, Penobsquis, NB**

Please find the enclosed our Final Report for the above-noted project. Thank you for the opportunity to be involved in this very interesting and exciting project.

Sincerely,

**Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited**

Vernon Banks

Vernon Banks, M.Sc. P.Geo.
Senior Hydrogeologist / Project Manager
Direct Tel.:   506-450-0825
Direct Fax: 506-450-0829
E-mail: vernon.banks@woodplc.com

VB/cjy
cc: Mr. Doug Doney, PotashCorp (Nutrien)

Phase II Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site

Final Report

Penobsquis, NB

TE183037

Prepared for:
Town of Sussex
524 Main Street, Sussex, NB   E4E 3E4

Prepared by:
Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited
495 Prospect Street, Suite 1
Fredericton, NB   E3B 9M4
Canada
T: 506-458-1000

27-Aug-19

Executive Summary

The decommissioned Penobsquis Mine is in the stage of flooding and presents a unique investment opportunity. In early 2016, the Potash Corporation of Saskatchewan (PotashCorp) made the decision to decommission their Potash mine in Penobsquis New Brunswick. The mine's historical inflow, which had been successfully managed for approximately 20 years, will ultimately flood the void spaces left behind by the nearly 35 years of mining activity. As flooding progresses, geothermal energy will warm the brine filling the void spaces. Once completely flooded it is estimated that the mine workings could be host to over 3 million cubic meters (m^3) of heated brine.

The Town of Sussex, on behalf of the Sussex region, commissioned the original Technical Feasibility Study (Phase I) to determine if the decommissioned and flooding Penobsquis Mine is a feasible source of geothermal energy, and if feasible, could it be effectively developed thereby providing the community with an economic development advantage.

In 2017 and 2018, the first phase of the Technical Feasibility study assembled background data (ground temperatures, water levels, mining data, energy consumption etc.) from local Penobsquis industry partners, PotashCorp and Avon Valley Floral, to enable the modelling of 20 example geothermal applications. The most favorable example was a district open loop geothermal system heating a 20 Acre greenhouse (with supplemental boiler) and cooling 10 refrigeration warehouses for a 12-month period. The capital investment for this geothermal system example, not including the costs for engineering design, environmental permitting and approvals, was estimated to be $11.3 Million dollars and carried a discounted payback period of approximately 7 years.

In gathering the information and costs to investigate the potential for developing geothermal energy, a number of assumptions were made concerning the water and brine inside the Penobsquis Mine. Some assumptions might have resulted in minor impact whereas others could have a more substantial impact and, in some cases, significantly affect the feasibility of the geothermal source and accessing its potential. These assumptions include:

- Water / Brine Level

- Temperature of the Water / Brine; and

- Chemistry of the Water / Brine.

The objective of this second phase of study (Phase II) was intended to address these three key assumptions and collect real data from within the Penobsquis mine workings and update the findings of the Phase I study.

The desired data and sample were collected from the Nutrien owned Materials Delivery Hole (MDH) on May 2nd, 2019 and the subsequent modelling updated with the newly acquired physical and chemical parameters indicated that the capital investment for this revised geothermal system example, not including the costs for engineering design, environmental permitting and approvals, is estimated to be $14.39 Million dollars and carry a discounted payback period of approximately 9.8 years.

In a scenario where, a utility provider installed and operated the favored district system example and offered a fee-based connection to prospective business the utility would have an estimated capital investment of approximately $8.74 Million ($10.31 Million including design and approval fees of 15% and 3%, respectively). In a cost sharing arrangement, an investment from the prospective businesses (excluding fees for connection to district system, design and approvals) is estimated to be $3.92 Million for the 20 Acre Greenhouse and $173,000 for each of the individual refrigeration warehouses.

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Appendix E   Limitations

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1.0   Introduction and Objectives

At the request of the Town of Sussex, Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood) completed a second phase to their initial work on geothermal potential for the decommissioned Penobsquis Mine. This Phase II report is a direct continuation of the initial Phase I report by (Amec Foster Wheeler 2018) and should be read as an addendum to the previous Phase I report. The objective of first phase (Phase I) of the Technical Feasibility Study was to determine if the decommissioned Penobsquis mine could be a feasible source of alternative geothermal energy. In gathering the information and costs to investigate the potential for developing geothermal energy, the following key assumptions were made in the 2018 report:

- **Water / Brine Level inside the Penobsquis Mine** – At the time of completion of the Phase I work, the water / brine levels within the Penobsquis mine were not known. It was assumed that a water level at a depth of 166.5 mbgs would be representative of the flooded mine and was used as the static water level in open loop calculations. If the water level happens to be lower (deeper), the energy consumption costs of the geothermal system will increase, while if higher (closer to ground surface), the energy consumption costs could decrease. This is the largest assumption in the study and one which requires further evaluation.

- **Temperature of the Water / Brine within the Penobsquis Mine** – The temperature utilized in the calculation of the open loop examples in the Phase I report represents a value from the PotashCorp Cassidy Lake Mine Shaft 1 profile (Figure 4.4). It was assumed that this value was representative because it was collected inside a flooded mine setting. However, this value is from a mine which has equilibrated for 20 years as opposed to a mine that is currently flooding. This assumption links to the above assumption and the level of water inside the mine workings. Currently it is unknown how long it will take for the Penobsquis mine to flood and subsequently how long it will take for the temperature of the water / brine inside the workings to equilibrate. This value requires confirmation and a sensitivity analysis should be completed to assess how much of an impact temperature has on the cost and feasibility of modeled examples.

- **Chemistry of the Water / Brine within the Penobsquis Mine** – Similarly to the two previous assumptions, the same questions exist for the composition of the water / brine once the mine floods. A conservative approach was taken during the Phase I work when considering its aggressiveness on system components and the costs of these items. However, there are other effects beyond scaling and corrosion which must be considered such as precipitation of potassium from solution.

At the completion of the Phase I study, it was concluded that these identified assumptions could impact the feasibility of the geothermal source and were recommended to be studied further. The Town of Sussex retained the services of Wood in the fall of 2018 to undertake Phase II of the Technical Feasibility Study. The objective of this second phase of study is to address the three key assumptions presented above. The objective will be met through the collection of real data from the Penobsquis mine workings, then update the modelling of the preferred option from the Phase I study.

With the support of the Government of New Brunswick and Nutrien, the Town of Sussex, on behalf of the Sussex region, is leading an initiative to evaluate whether the geothermal capacity of the mine waters can be cost effectively developed to provide the community with an economic development advantage.

The figures and tables for this report are contained in Appendix A and B respectively, unless directly emplaced in the text of this report. Appendix C is a USB Drive which contains the referenced relevant spread sheets used in this updated Technical Feasibility Study.

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2.0   Study Approach

Data and samples were collected to determine representative physical (water / brine levels) and chemical (water quality) parameters that were assumed in the previous phase of the study. They were then used to update the preferred open loop system, which was modeled and costed during the Phase I study. The collection of representative data and a water sample was made possible by accessing the flooding mine through the Nutrien owned Materials Delivery Hole (MDH).

2.1   Materials Delivery Hole (MDH)

The MDH was installed in 2005 for purpose of accessing the open mine workings from surface and conveying grout to underground workings from ground surface, as part of a continuous underground grouting program to control mine inflows. For reference, Figure 2.1 shows the location of the MDH in relation to Penobsquis and the former underground Penobsquis mine workings.

The MDH was constructed with three casings: a 343 mm diameter surface casing extended to 18.3 meters below ground surface (mbgs); a 219 mm diameter casing installed into the top of Salt (TOS) to a depth of 244.1 mbgs; and a 178 mm diameter casing hung inside the 219 diameter casing and extending to the mine workings at a depth of 481.6 mbgs.

2.2   Materials Delivery Hole (MDH) Profiles

As previously stated, the objective was to collect physical (water / brine levels) and chemical (water quality) parameters which as best as possible represent the water / brine inside the mine workings. To increase the representativeness of the collected data, it was important to profile the MDH to determine if the water column within the MDH had stratified as a result of density (less dense fluid sitting on more dense fluids) or temperature (warmer fluids sitting on cooler fluids). Once profiled, the physical parameters and depth could be measured from which the water quality sample could be collected.

Several tools and monitoring passes were required to profile the brine/water column. These tools are summarized in Table 2.1.

Because of the limitations of the equipment mentioned in Table 2.1, the Table 2.2 presents the information provided from the two monitoring profiles completed on May 2 2019.

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Table 2.1   Data Collection and Sampling Tools used to profile the MDH

Commercial Name	Capabilities	Conductivity Maximum (µS/cm)	Temperature Range (˚C)	Pressure Range (m)[1]
Data Collection Tools				
LTC Levellogger Edge[2]	Pressure, Temperature, Conductivity	100,000	0-50	0-200
RBR XR-420[3]	Pressure, Temperature, Conductivity	125,000	-5 to 35	1000
Aqua Troll 600[4]	Pressure, Temperature, Conductivity	350,000	-5 to 50	229
Commercial Name	**Capabilities**			
Sampling Tools				
Snap Sampler	The snap sampler is a pneumatically activated device which can collect an in-situ sample from within a well or water body to a maximum fresh water depth of 609 m.			

Note(s)

1. Presented as meters of fresh water with a density of 1.0 kg/m^3

2. Data sheet available @ https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/ltc-levelogger/datasheet.php

3. Data sheet available @ http://www.lunus.com.br/wp-content/uploads/2012/10/Registrador-multi-canais-XR.pdf

4. Data sheet available @ https://in-situ.com/wp-content/uploads/2015/09/AquaTROLL600_SS.pdf

5. Data sheet available @ http://www.geotechenv.com/pdf/ground_water_sampling_equipment/snap_sampler.pdf

Table 2.2   Profiles Obtained from within the MDH

Profile Run	Tool / Sampler	Accurate Data Profiles Provided	Maximum Depth Achieved (mbtoc)[1]
Static Data	LTC Levellogger Edge	Static water level	
Profile 1	RBR XR-420	Temperature (∘C) and Depth (m)	413 mbtoc [2]
	Aqua Troll 600	Conductivity (µS/cm) and Temperature (∘C)	
Profile 2	RBR XR-420	Temperature (∘C) and Depth (m)	457 mbtoc [2]
	Snap Sampler	No profile provided (sample collected)	

Note(s)

1. Meters Below Top of Casing (mbtoc).

2. The tools were deployed on a 6.35 mm stainless steel cable fed through a MOSDAX System Monopod (Model No. 3025). The Monopod was also equipped with a line counter which was zeroed at the beginning of each run.

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3.0 Summary of MDH Survey

3.1 Water Level Data

Without any additional data it can be reasonably assumed that at the time of measurement the water level in the MDH is a representative measure of the water level within the mine pool. The tools used in the MDH survey provided a pressure reading which can be corrected to the actual level accounting for the density of the water / brine. Table 3.1 below presents a summary of the water levels collected from the profiling work as the actual depth of water /brine from the top of the MDH casing.

Table 3.1   Summary of Water Level Data from MDH Survey

[Commercial Name	Tool Position (mbtoc)[1]	Head above tool position (m)[4]	Calculated Water Level (mbtoc)[5]
LTC Levellogger Edge	274.32[2]	125.39	168.95
RBR XR-420 (Profile 1)	413.00[3]	299.23	161.55
RBR XR-420 (Profile 2)	157.00[3]	353.71	160.92

Note(s)

1. Meters Below Top of Casing (mbtoc).

2. Tool position establish by length of cable suspending the logging tool.

3. The position of the tools was measured by the line counter attached to the Mosdax monopod system.

4. The represents the equivalent m of fresh water above the tool position assuming the density of the water is 1.0 kg/m^3

5. The calculated water level was determined by the following formula: Calculated Water Level (mbtoc) = Tool depth (mbtoc) – {Tool depth (mbtoc) -Measured Fresh Water (m)} / Density. The maximum density observed in the MDH was recorded by the Aqua Troll 600 to be 1.19 kg/m^3.

3.2 Temperature and Conductivity Profiles

The temperature and conductivity profiles are presented in Figure 3.1 (Appendix A). The profiles show that the water / brine column inside the MDH does vary slightly with depth. The first conductivity (red line and symbols) and temperature (blue line and symbols) profiling run were completed with the RBR XR-420 and Aqua troll 600. Because of the depth limitations of the aqua troll the maximum depth was 413 mbtoc.

The conductivity profile shows a sharp increase followed by a more gradual increase to the final depth of 413 mbtoc. The final conductivity at 413 mbtoc was recorded in excess of 240,000 μS/cm. The conductivity profile demonstrated that the brine / column was not stratified and that the bulk of profiled depth recorded similar conductivities exceeding 200,000 μS/cm (Figure 3.1).

The temperature profile of the first run recorded by the Aqua troll 600 agreed very well with the second profile completed by the RBR XR-420 up to the limit of the first run to 413 mbtoc with a maximum recorded temperature of 13.4 ℃ (Figure 3.1). Because of the depth capabilities of the RBR XR-420 the second run was completed to a depth of 457 mbtoc just 24.6 m above the mine workings. The temperature profile (green symbols and line) shows a sharp increase to 14.9℃ then decrease back to 13.2℃ at 457 mbtoc. From the profile it is clear that there is a zone of warmer water just above the mine workings which approaches 15℃.

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3.3   Water Quality Sampling

From the conductivity profiles, it is concluded that the brine / water column was not stratified. Based on the conductivity profile, it will be assumed that density and or total mineral and salt content is also not stratified. Because the conductivity was still increasing at the end of the first profile the water / brine sample was collected as deep as possible and nearest to the mine workings at 457 mbtoc. Because of the uncertain conditions within the open mine workings it was decided not to send the tools all the way into the mine workings but rather stop 24.6 m above the ceiling of the mine workings.

The snap sampler was activated at a depth of 457 mbtoc and the sample was collected and analyzed by Maxxam Analytica in Bedford Nova Scotia for general chemistry and trace metal parameters. The analytical results are presented in Appendix B. The intention of collecting a sample for water quality testing was to establish a conservative and representative sample to evaluate geothermal system components

4.0   Parameter Selection

As stated, the objective of this phase of the study is to advance the feasibility of the preferred option with measured parameters.   Table 4.1 shows the measured parameters along with previously assumed parameters along with the rationale for their selection.

Table 4.1   Phase II Parameter Selection and Rationale

Parameter]	Phase I Assumed Values	Phase II Measured Values	Rationale for Selection
Water Level (mbgs or mbtoc)!	166.5 mbgs	168.95 mbtoc	The lowest or most conservative values was selected from the values presented in Table 3
Temperature (°C)	14.7°C	13.4°C	This value was the maximum value from the bottom of the first profile. The maximum value of 14.9 °C was not used because of the uncertainty concerning the stratification in the well. The temperature value of 13.2 °C was also not used since the RBR factory calibration was older then the of the Aqua Troll 600.
Water Quality	Table A2(Appendix A)	Table A1 (Appendix A)	All chemical parameters are evaluated as part of this phase

Note(s)

1. The difference between the meters below ground surface (mbgs) and meters below top of casing (mbtoc) is only the stick of the MDH which is approximately 1.5 m.

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5.0   Phase II Modeling of Example Geothermal Systems

In consultation with the Town of Sussex and the Geothermal Study Steering Committee, the Phase I study concluded that the most favorable modeled example was a district open loop geothermal system heating a 20 Acre greenhouse (with supplemental boiler) and cooling 10 refrigeration warehouses for a 12-month period. This modeled option offered a discounted payback period or Return on Investment (ROI) of approximately 7 years (Detailed Spreadsheet for Original Example D O 6 is in Appendix C). This example was the only example updated as part of the Phase II work.

Because it was focused on one open loop district example, the updated modelling for this Phase II study was straightforward. All the heating and cooling loads remained the same as the Phase I work. The bulk of the physical parameters remained the same except for the water level and temperature which were changed as detailed in Table 4 above. The updated water quality / chemistry data was used to advance the evaluation of the scaling potential in the geothermal system. These changes will ultimately influence the ROI for the favoured system either through the energy balance or the capital costs of the system example.

The following sections present a brief discussion, and reference more detailed information, of how the updated information impacts the ROI for the open loop district system and the resulting estimated ROI for the modelled example system.

5.1   Updated Water levels and Temperature

The water level and temperature impact the ROI by changing the energy balance or the energy that must be put into the system to extract the heating or cooling energy of the mine water. A lower water level would result in increased energy costs to lift/pump water to surface and similarly a cooler water would offer less heat energy to satisfy heating demands.

However, because the change in the water level and temperature were fairly small the resultant impact on the energy balance / budget and the ROI were fairly small. The changed water level and temperature lowered the annual energy savings by $927.38 in the Phase II modeling as compared to the Phase I modelling.

5.2   Evaluation of Mine Water Scaling Potential

The updated water quality / chemistry data (presented in Appendix B) was used to advance the evaluation of the scaling potential in the geothermal system and to update the capital costs of the example system which will impact the ROI. The technical memo presented in Appendix D includes a detailed discussion of type of fouling that will occur as a result of the updated mine water chemistry. The memo also details the potential impacts of the fouling and recommends mitigation measures including: components, system configurations, cleaning and maintenance schedules. The capital and maintenance costs resulting from of these recommendations and the challenges presented by the use of this aggressive and corrosive mine water have been incorporated into the updated system modelling.

If should be noted that these updated costs have been estimated in this Final report based on conversations with industry suppliers, however more refined estimates will be incoming after considerations have been given to other alternate configurations and components. To be conservative, the highest potential costs for system components, maintenance and cleaning were used. Based on this most recent evaluation of mine water scaling potential the capital costs and maintenance costs were updated for the Phase II modeling and compared to the Phase I results as per Table 5.1 below.

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Table 5.1   Updated Capital and Maintenance Costs for Updated Water Quality

Phase of Study	Modeled System	Capital Costs (in thousands)	Operational and Maintenance Costs (annual)
Phase I	D O 6 - 20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$11,309	$97,896
Phase II		k$14,393	$236,473

5.3   Results of Phase II Modeling

The results of the Phase II modeling work indicated that the initially assumed temperature and water level were reasonable assumptions and the updated values did not significantly impact the overall feasibility or initially estimated costs and ROI. After more detailed evaluation, the mine water quality did not impact the feasibility of the of the modeled option but did impact the capital and maintenance costs. Overall, Table 5.2 summarizes the results of the Phase II updated modelling and the changes as compared to the Phase I results.

Table 5.2   Results of Phase II Modeling

Phase of Study	Phase I	Phase II
Modeled System	D O 6 - 20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System	
Capital Costs (in thousands)	k$11,309	k$14,393
Operational and Maintenance Costs (annual)	$97,896	$236,473
System Consumption (annual) [1]	$1,969,341	$1,970,268
System Savings [2]	$1,709,885	$1,708,958
Discounted Pay Back Period (years) [3]	7	9.8

Note(s)

1. System Consumption is the cost of energy to power the geothermal system.

2. System Savings is the revenue generated by the geothermal system. It is calculated as the cost of baseline energy to replace it. More Details in (Amec Foster Wheeler 2018).

3. The discounted payback period is discussed in Section 6.5.3 Amec Foster Wheeler 2018.

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6.0 Closing

This report was prepared by Vernon Banks, M.Sc., P.Geo., and Mathilde Krebs, M.Eng and reviewed by Gil Violette, M.Sc.E., P.Eng.

This report was prepared for the exclusive use of the Town of Sussex, New Brunswick, for specific application to the Penobsquis Mine. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of the third party. Should additional parties require reliance on this report, written authorization from Wood Environment and Infrastructure (A division of Wood Canada). With respect to third parties, Wood Environment and Infrasrtructure has no liability or responsibility for losses of any kind whatsoever, including direct or consequential financial effects on transactions or property values, or requirements for follow-up actions and costs.

The report is based on data and information and approved for use Nutiren and collected on May 2nd 2019 by Wood Environment and Infrastructure. Except as otherwise maybe specified, Wood Environment and Infrastructure disclaims any obligation to update this report for events taking place, or with respect to information that becomes available to Wood Environment and Infrastructure after the time during which Wood Environment and Infrastructure completed this report.

Wood Environment and Infrastructure makes no other representations whatsoever, including those concerning the legal significance of its findings, or as to other legal matters touched on in this report, including, but not limited to, ownership of any property, or the application of any law to the facts set forth herein. With respect to regulatory compliance issues, regulatory statutes are subject to interpretation and change. Such interpretations and regulatory changes should be reviewed with legal counsel.

This report is also subject to the further Limitations attached in Appendix D.

Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited

 Prepared by:

Vernon Banks, M.Sc., P.Geo
Hydrogeologist / Project Manager
Direct Tel.:   (506) 450-0825
E-mail: Vernon.banks@woodplc.com

Mathilde Krebs, M.Eng.
Mechanical Engineer
Direct Tel.:   (207) 828-2640
E-mail: mathilde.krebs@woodplc.com

 Reviewed by:

Gil Violette, M.Sc.E., P.Eng.
Senior Reviewer

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Appendix A

Figures

LEGEND:

⊙ Material Delivery Hole

⋀⋁ Railway Network

▬ Waterbody

PENOBSQUIS MINE WORKINGS

① White - lower salt stopes
② Blue - Upper salt stopes
③ Red - 1500 level potash stopes
④ Purple - 1900 level potash stopes
⑤ Yellow Access Ways

Kennebecasis River

CROCKETS CORNER

NB 114

NB 1

NB 114

N
W E
S

0   250   500   1,000   1,500
Metres

The map shown here has been created with all due and reasonable care and is strictly for use with Wood Number: TE183037. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. Wood assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

CLIENT:

Sussex
NEW BRUNSWICK
Gateway to the Fundy Experience

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PROJECT:

Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site - Phase 2

TITLE:

Materials Delivery Hole Location

DATUM:	DWN BY:	DATE:
NAD 83 CSRS	SM	July 2019
PROJECTION:	CHK'D BY:	SCALE:
UTM Zone 20 North	VB	1:25,000
PROJECT NO:	REV NO:	FIGURE NO:
TE183037	R0	2.1

Service Layer Credits: Service New Brunswick/Service Nouveau Brunswick

Path: H:\PROJECTS\SITE183037_Sussex_GeothermalPenobsquisMine\MXD\CURRENT\20190716_TE183037_MaterialsDeliveryHoleLocation_Fig3.1_R0.mxd   User: suzanne.monette   Date: 7/16/2019

Figure 3.1:

Temperature (°C) and Specific Conductivity (µS/cm) Profile
of Nutrien Materials Delivery Hole (MDH) Vs Meters of Fresh Water (m)
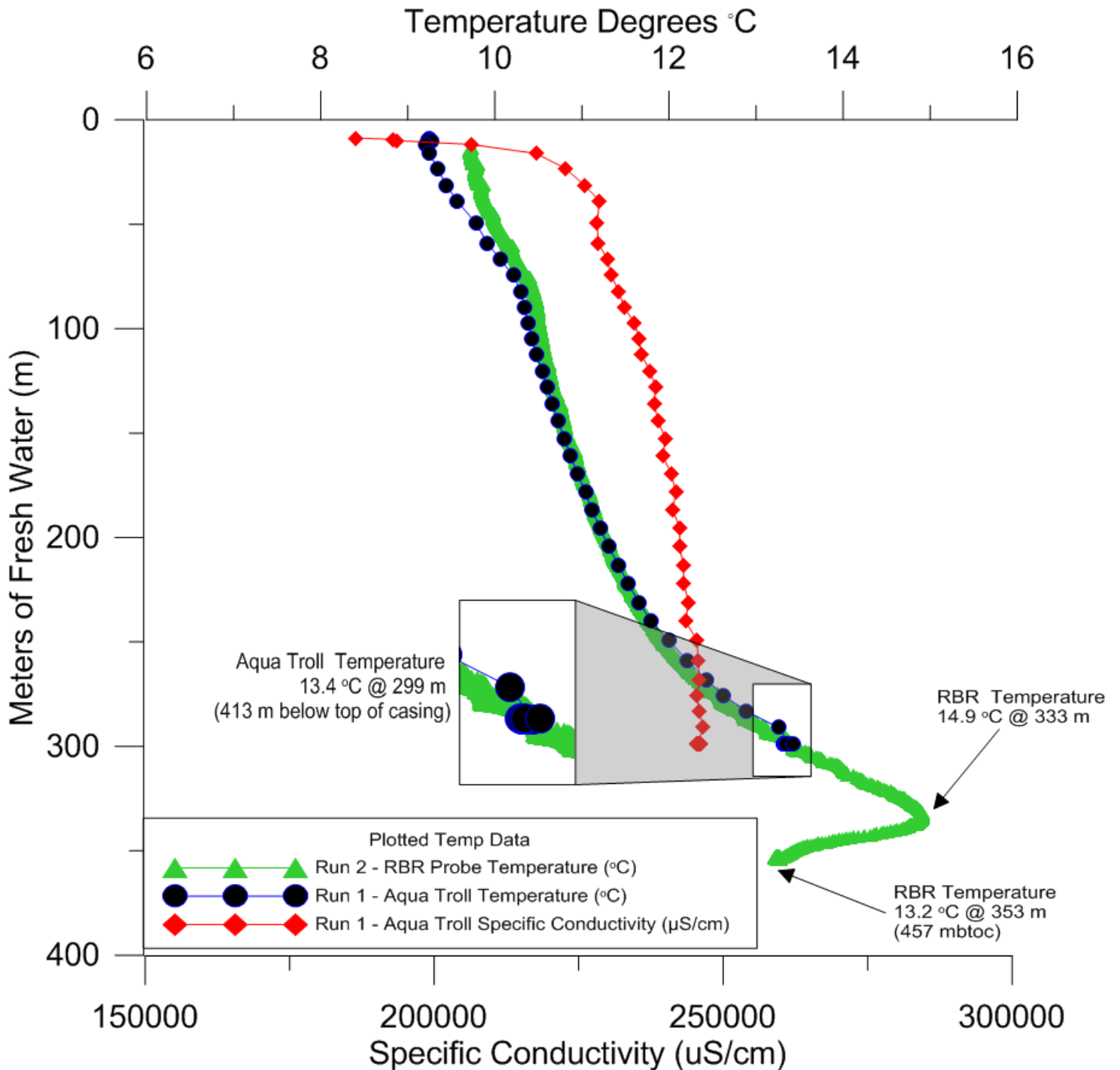
Appendix B

Tables
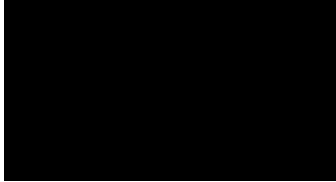
CERTIFICATE OF ANALYSIS

Samples Received: 1

| Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Reference
Carbonate, Bicarbonate and Hydroxide	1	N/A	2019/05/05	N/A	SM 23 4500-CO2 D
Alkalinity	1	N/A	2019/05/06	ATL SOP 00013	EPA 310.2 R1974 m
Chloride	1	N/A	2019/05/06	ATL SOP 00014	SM 23 4500-Cl- E m
Colour	1	N/A	2019/05/06	ATL SOP 00020	SM 23 2120C m
Conductance - water	1	N/A	2019/05/06	ATL SOP 00004	SM 23 2510B m
Hardness (calculated as CaCO3)	1	N/A	2019/05/07	ATL SOP 00048	Auto Calc
Metals Water Diss. MS (1)	1	N/A	2019/05/07	ATL SOP 00058	EPA 6020B R2 m
Ion Balance (% Difference)	1	N/A	2019/05/07	N/A	Auto Calc.
Anion and Cation Sum	1	N/A	2019/05/07	N/A	Auto Calc.
Nitrogen Ammonia - water	1	N/A	2019/05/06	ATL SOP 00015	EPA 350.1 R2 m
Nitrogen - Nitrate + Nitrite	1	N/A	2019/05/06	ATL SOP 00016	USGS I-2547-11m
Nitrogen - Nitrite	1	N/A	2019/05/06	ATL SOP 00017	SM 23 4500-NO2- B m
Nitrogen - Nitrate (as N)	1	N/A	2019/05/06	ATL SOP 00018	ASTM D3867-16
pH (2)	1	N/A	2019/05/04	ATL SOP 00003	SM 23 4500-H+ B m
Phosphorus - ortho	1	N/A	2019/05/07	ATL SOP 00021	SM 23 4500-P E m
Sat. pH and Langelier Index (@ 20C)	1	N/A	2019/05/07	ATL SOP 00049	Auto Calc.
Sat. pH and Langelier Index (@ 4C)	1	N/A	2019/05/07	ATL SOP 00049	Auto Calc.
Reactive Silica	1	N/A	2019/05/06	ATL SOP 00022	EPA 366.0 m
Sulphate	1	N/A	2019/05/06	ATL SOP 00023	ASTM D516-16 m
Total Dissolved Solids (TDS calc)	1	N/A	2019/05/07	N/A	Auto Calc.
Organic carbon - Total (TOC) (3)	1	N/A	2019/05/06	ATL SOP 00203	SM 23 5310B m
Turbidity	1	N/A	2019/05/05	ATL SOP 00011	EPA 180.1 R2 m

Remarks:

Maxxam Analytics' laboratories are accredited to ISO/IEC 17025 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by Maxxam are based upon recognized Provincial, Federal or US method compendia such as CCME, MDDELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in Maxxam's profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and Maxxam in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, Measurement Uncertainty has not been accounted for when stating conformity to the referenced standard.
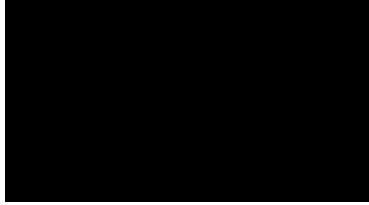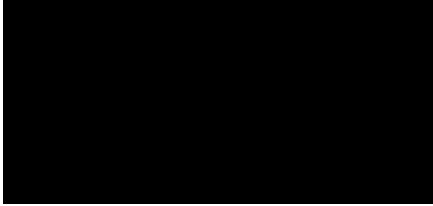
Report Date: 2019/05/07

Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: ▮▮▮▮▮▮▮

Received: 2019/05/03, 09:20

Maxxam Analytics' liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. Maxxam has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by Maxxam, unless otherwise agreed in writing. Maxxam is not responsible for the accuracy or any data impacts, that result from the information provided by the customer or their agent.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods.

Results relate to samples tested. When sampling is not conducted by Maxxam, results relate to the supplied samples tested.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.

Reference Method suffix "m" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

(1) Sample filtered in laboratory prior to analysis for dissolved metals.

(2) The APHA Standard Method require pH to be analyzed within 15 minutes of sampling and therefore field analysis is required for compliance. All Laboratory pH analyses in this report are reported past the APHA Standard Method holding time.

(3) TOC / DOC present in the sample should be considered as non-purgeable TOC / DOC.

Encryption Key

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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.

ATL. RCAP-MS DISSOLVED (LABFILT) IN W

Maxxam ID				
Sampling Date		2019/05/02 16:00		
COC Number		N/A		
	UNITS	MDH 457M	RDL	QC Batch
Calculated Parameters				
Anion Sum	me/L	5190	N/A	6101780
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	<1.0	1.0	6101776
Calculated TDS	mg/L	300000	1.0	6101785
Carb. Alkalinity (calc. as CaCO3)	mg/L	<1.0	1.0	6101776
Cation Sum	me/L	4660	N/A	6101780
Hardness (CaCO3)	mg/L	3700	1.0	6101778
Ion Balance (% Difference)	%	5.33	N/A	6101779
Langelier Index (@ 20C)	N/A	NC		6101782
Langelier Index (@ 4C)	N/A	NC		6101783
Nitrate (N)	mg/L	<0.050	0.050	6101781
Saturation pH (@ 20C)	N/A	NC		6101782
Saturation pH (@ 4C)	N/A	NC		6101783
Inorganics				
Total Alkalinity (Total as CaCO3)	mg/L	<5.0	5.0	6104792
Dissolved Chloride (Cl-)	mg/L	180000	5000	6104797
Colour	TCU	<5.0	5.0	6104804
Nitrate + Nitrite (N)	mg/L	<0.050	0.050	6104810
Nitrite (N)	mg/L	<0.010	0.010	6104813
Nitrogen (Ammonia Nitrogen)	mg/L	3.9	0.25	6104919
Total Organic Carbon (C)	mg/L	2.4	0.50	6104795
Orthophosphate (P)	mg/L	<0.010	0.010	6104806
pH	pH	7.53	N/A	6103900
Reactive Silica (SiO2)	mg/L	<0.50	0.50	6104802
Dissolved Sulphate (SO4)	mg/L	3900	100	6104799
Turbidity	NTU	24	0.10	6104433
Conductivity	uS/cm	>110000	1.0	6105316
Metals				
Dissolved Aluminum (Al)	mg/L	<0.50	0.50	6105137
Dissolved Antimony (Sb)	mg/L	<0.10	0.10	6105137
Dissolved Arsenic (As)	mg/L	<0.10	0.10	6105137
Dissolved Barium (Ba)	mg/L	0.23	0.10	6105137
Dissolved Beryllium (Be)	mg/L	<0.10	0.10	6105137

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch
N/A = Not Applicable
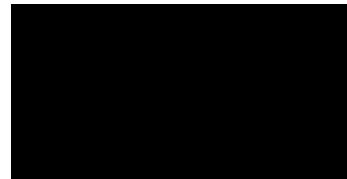
ATL. RCAP-MS DISSOLVED (LABFILT) IN W

Maxxam ID					
Sampling Date			2019/05/02 16:00		
COC Number			N/A		
		UNITS	MDH 457M	RDL	QC Batch
Dissolved Bismuth (Bi)		mg/L	<0.20	0.20	6105137
Dissolved Boron (B)		mg/L	5.4	5.0	6105137
Dissolved Cadmium (Cd)		mg/L	<0.0010	0.0010	6105137
Dissolved Calcium (Ca)		mg/L	1500	10	6105137
Dissolved Chromium (Cr)		mg/L	<0.10	0.10	6105137
Dissolved Cobalt (Co)		mg/L	<0.040	0.040	6105137
Dissolved Copper (Cu)		mg/L	<0.050	0.050	6105137
Dissolved Iron (Fe)		mg/L	<5.0	5.0	6105137
Dissolved Lead (Pb)		mg/L	<0.050	0.050	6105137
Dissolved Magnesium (Mg)		mg/L	11	10	6105137
Dissolved Manganese (Mn)		mg/L	0.59	0.20	6105137
Dissolved Molybdenum (Mo)		mg/L	<0.20	0.20	6105137
Dissolved Nickel (Ni)		mg/L	<0.20	0.20	6105137
Dissolved Phosphorus (P)		mg/L	<10	10	6105137
Dissolved Potassium (K)		mg/L	10000	10	6105137
Dissolved Selenium (Se)		mg/L	<0.10	0.10	6105137
Dissolved Silver (Ag)		mg/L	<0.010	0.010	6105137
Dissolved Sodium (Na)		mg/L	100000	10	6105137
Dissolved Strontium (Sr)		mg/L	30	0.20	6105137
Dissolved Thallium (Tl)		mg/L	<0.010	0.010	6105137
Dissolved Tin (Sn)		mg/L	<0.20	0.20	6105137
Dissolved Titanium (Ti)		mg/L	<0.20	0.20	6105137
Dissolved Uranium (U)		mg/L	<0.010	0.010	6105137
Dissolved Vanadium (V)		mg/L	<0.20	0.20	6105137
Dissolved Zinc (Zn)		mg/L	<0.50	0.50	6105137

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

GENERAL COMMENTS

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

Package 1	1.7°C

Sample JPO884 [MDH 457M] : Elevated reporting limits for trace metals due to sample matrix.

Poor RCAp Ion Balance due to sample matrix.

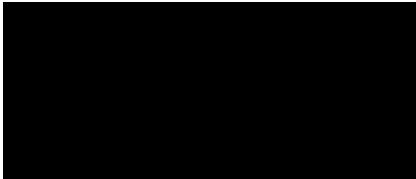**Results relate only to the items tested.**

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QUALITY ASSURANCE REPORT

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
6103900	KMC	QC Standard	pH	2019/05/04		101	%	97 - 103
6103900	KMC	RPD	pH	2019/05/04	0.29		%	N/A
6104433	KMC	QC Standard	Turbidity	2019/05/05		100	%	80 - 120
6104433	KMC	Spiked Blank	Turbidity	2019/05/05		98	%	80 - 120
6104433	KMC	Method Blank	Turbidity	2019/05/05	<0.10		NTU	
6104433	KMC	RPD	Turbidity	2019/05/05	NC		%	20
6104792	NRG	Matrix Spike	Total Alkalinity (Total as CaCO3)	2019/05/06		100	%	80 - 120
6104792	NRG	Spiked Blank	Total Alkalinity (Total as CaCO3)	2019/05/06		104	%	80 - 120
6104792	NRG	Method Blank	Total Alkalinity (Total as CaCO3)	2019/05/06	<5.0		mg/L	
6104792	NRG	RPD	Total Alkalinity (Total as CaCO3)	2019/05/06	0.52		%	25
6104795	SSI	Matrix Spike	Total Organic Carbon (C)	2019/05/06		99	%	85 - 115
6104795	SSI	Spiked Blank	Total Organic Carbon (C)	2019/05/06		99	%	80 - 120
6104795	SSI	Method Blank	Total Organic Carbon (C)	2019/05/06	<0.50		mg/L	
6104795	SSI	RPD	Total Organic Carbon (C)	2019/05/06	NC (1)		%	15
6104797	NRG	Matrix Spike	Dissolved Chloride (Cl-)	2019/05/06		NC	%	80 - 120
6104797	NRG	Spiked Blank	Dissolved Chloride (Cl-)	2019/05/06		98	%	80 - 120
6104797	NRG	Method Blank	Dissolved Chloride (Cl-)	2019/05/06	<1.0		mg/L	
6104797	NRG	RPD	Dissolved Chloride (Cl-)	2019/05/06	0.32		%	25
6104799	NRG	Matrix Spike	Dissolved Sulphate (SO4)	2019/05/06		99	%	80 - 120
6104799	NRG	Spiked Blank	Dissolved Sulphate (SO4)	2019/05/06		99	%	80 - 120
6104799	NRG	Method Blank	Dissolved Sulphate (SO4)	2019/05/06	<2.0		mg/L	
6104799	NRG	RPD	Dissolved Sulphate (SO4)	2019/05/06	1.6		%	25
6104802	NRG	Matrix Spike	Reactive Silica (SiO2)	2019/05/06		96	%	80 - 120
6104802	NRG	Spiked Blank	Reactive Silica (SiO2)	2019/05/06		101	%	80 - 120
6104802	NRG	Method Blank	Reactive Silica (SiO2)	2019/05/06	<0.50		mg/L	
6104802	NRG	RPD	Reactive Silica (SiO2)	2019/05/06	0.14		%	25
6104804	NRG	Spiked Blank	Colour	2019/05/06		98	%	80 - 120
6104804	NRG	Method Blank	Colour	2019/05/06	<5.0		TCU	
6104804	NRG	RPD	Colour	2019/05/06	15		%	20
6104806	NRG	Matrix Spike	Orthophosphate (P)	2019/05/07		92	%	80 - 120
6104806	NRG	Spiked Blank	Orthophosphate (P)	2019/05/07		97	%	80 - 120
6104806	NRG	Method Blank	Orthophosphate (P)	2019/05/07	<0.010		mg/L	
6104806	NRG	RPD	Orthophosphate (P)	2019/05/07	NC		%	25
6104810	NRG	Matrix Spike	Nitrate + Nitrite (N)	2019/05/06		94	%	80 - 120
6104810	NRG	Spiked Blank	Nitrate + Nitrite (N)	2019/05/06		94	%	80 - 120
6104810	NRG	Method Blank	Nitrate + Nitrite (N)	2019/05/06	<0.050		mg/L	
6104810	NRG	RPD	Nitrate + Nitrite (N)	2019/05/06	2.1		%	25
6104813	NRG	Matrix Spike	Nitrite (N)	2019/05/06		98	%	80 - 120
6104813	NRG	Spiked Blank	Nitrite (N)	2019/05/06		103	%	80 - 120
6104813	NRG	Method Blank	Nitrite (N)	2019/05/06	<0.010		mg/L	
6104813	NRG	RPD	Nitrite (N)	2019/05/06	NC		%	20
6104919	SRM	Matrix Spike	Nitrogen (Ammonia Nitrogen)	2019/05/06		NC	%	80 - 120
6104919	SRM	Spiked Blank	Nitrogen (Ammonia Nitrogen)	2019/05/06		103	%	80 - 120
6104919	SRM	Method Blank	Nitrogen (Ammonia Nitrogen)	2019/05/06	<0.050		mg/L	
6104919	SRM	RPD	Nitrogen (Ammonia Nitrogen)	2019/05/06	4.2		%	20
6105137	BAN	Matrix Spike	Dissolved Aluminum (Al)	2019/05/06		102	%	80 - 120
			Dissolved Antimony (Sb)	2019/05/06		102	%	80 - 120
			Dissolved Arsenic (As)	2019/05/06		96	%	80 - 120
			Dissolved Barium (Ba)	2019/05/06		96	%	80 - 120
			Dissolved Beryllium (Be)	2019/05/06		101	%	80 - 120
			Dissolved Bismuth (Bi)	2019/05/06		97	%	80 - 120
			Dissolved Boron (B)	2019/05/06		100	%	80 - 120

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Dissolved Cadmium (Cd)	2019/05/06		98	%	80 - 120
			Dissolved Calcium (Ca)	2019/05/06		NC	%	80 - 120
			Dissolved Chromium (Cr)	2019/05/06		97	%	80 - 120
			Dissolved Cobalt (Co)	2019/05/06		99	%	80 - 120
			Dissolved Copper (Cu)	2019/05/06		94	%	80 - 120
			Dissolved Iron (Fe)	2019/05/06		98	%	80 - 120
			Dissolved Lead (Pb)	2019/05/06		98	%	80 - 120
			Dissolved Magnesium (Mg)	2019/05/06		89	%	80 - 120
			Dissolved Manganese (Mn)	2019/05/06		90	%	80 - 120
			Dissolved Molybdenum (Mo)	2019/05/06		102	%	80 - 120
			Dissolved Nickel (Ni)	2019/05/06		95	%	80 - 120
			Dissolved Phosphorus (P)	2019/05/06		105	%	80 - 120
			Dissolved Potassium (K)	2019/05/06		NC	%	80 - 120
			Dissolved Selenium (Se)	2019/05/06		95	%	80 - 120
			Dissolved Silver (Ag)	2019/05/06		90	%	80 - 120
			Dissolved Sodium (Na)	2019/05/06		NC	%	80 - 120
			Dissolved Strontium (Sr)	2019/05/06		NC	%	80 - 120
			Dissolved Thallium (Tl)	2019/05/06		99	%	80 - 120
			Dissolved Tin (Sn)	2019/05/06		102	%	80 - 120
			Dissolved Titanium (Ti)	2019/05/06		99	%	80 - 120
			Dissolved Uranium (U)	2019/05/06		105	%	80 - 120
			Dissolved Vanadium (V)	2019/05/06		99	%	80 - 120
			Dissolved Zinc (Zn)	2019/05/06		96	%	80 - 120
6105137	BAN	Spiked Blank	Dissolved Aluminum (Al)	2019/05/06		104	%	80 - 120
			Dissolved Antimony (Sb)	2019/05/06		97	%	80 - 120
			Dissolved Arsenic (As)	2019/05/06		98	%	80 - 120
			Dissolved Barium (Ba)	2019/05/06		99	%	80 - 120
			Dissolved Beryllium (Be)	2019/05/06		98	%	80 - 120
			Dissolved Bismuth (Bi)	2019/05/06		100	%	80 - 120
			Dissolved Boron (B)	2019/05/06		96	%	80 - 120
			Dissolved Cadmium (Cd)	2019/05/06		99	%	80 - 120
			Dissolved Calcium (Ca)	2019/05/06		102	%	80 - 120
			Dissolved Chromium (Cr)	2019/05/06		98	%	80 - 120
			Dissolved Cobalt (Co)	2019/05/06		100	%	80 - 120
			Dissolved Copper (Cu)	2019/05/06		100	%	80 - 120
			Dissolved Iron (Fe)	2019/05/06		101	%	80 - 120
			Dissolved Lead (Pb)	2019/05/06		100	%	80 - 120
			Dissolved Magnesium (Mg)	2019/05/06		106	%	80 - 120
			Dissolved Manganese (Mn)	2019/05/06		101	%	80 - 120
			Dissolved Molybdenum (Mo)	2019/05/06		100	%	80 - 120
			Dissolved Nickel (Ni)	2019/05/06		99	%	80 - 120
			Dissolved Phosphorus (P)	2019/05/06		105	%	80 - 120
			Dissolved Potassium (K)	2019/05/06		103	%	80 - 120
			Dissolved Selenium (Se)	2019/05/06		96	%	80 - 120
			Dissolved Silver (Ag)	2019/05/06		97	%	80 - 120
			Dissolved Sodium (Na)	2019/05/06		99	%	80 - 120
			Dissolved Strontium (Sr)	2019/05/06		100	%	80 - 120
			Dissolved Thallium (Tl)	2019/05/06		102	%	80 - 120
			Dissolved Tin (Sn)	2019/05/06		99	%	80 - 120
			Dissolved Titanium (Ti)	2019/05/06		105	%	80 - 120
			Dissolved Uranium (U)	2019/05/06		105	%	80 - 120
			Dissolved Vanadium (V)	2019/05/06		100	%	80 - 120

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QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Dissolved Zinc (Zn)	2019/05/06		104	%	80 - 120
6105137	BAN	Method Blank	Dissolved Aluminum (Al)	2019/05/06	<0.0050		mg/L	
			Dissolved Antimony (Sb)	2019/05/06	<0.0010		mg/L	
			Dissolved Arsenic (As)	2019/05/06	<0.0010		mg/L	
			Dissolved Barium (Ba)	2019/05/06	<0.0010		mg/L	
			Dissolved Beryllium (Be)	2019/05/06	<0.0010		mg/L	
			Dissolved Bismuth (Bi)	2019/05/06	<0.0020		mg/L	
			Dissolved Boron (B)	2019/05/06	<0.050		mg/L	
			Dissolved Cadmium (Cd)	2019/05/06	<0.000010		mg/L	
			Dissolved Calcium (Ca)	2019/05/06	<0.10		mg/L	
			Dissolved Chromium (Cr)	2019/05/06	<0.0010		mg/L	
			Dissolved Cobalt (Co)	2019/05/06	<0.00040		mg/L	
			Dissolved Copper (Cu)	2019/05/06	<0.00050		mg/L	
			Dissolved Iron (Fe)	2019/05/06	<0.050		mg/L	
			Dissolved Lead (Pb)	2019/05/06	<0.00050		mg/L	
			Dissolved Magnesium (Mg)	2019/05/06	<0.10		mg/L	
			Dissolved Manganese (Mn)	2019/05/06	<0.0020		mg/L	
			Dissolved Molybdenum (Mo)	2019/05/06	<0.0020		mg/L	
			Dissolved Nickel (Ni)	2019/05/06	<0.0020		mg/L	
			Dissolved Phosphorus (P)	2019/05/06	<0.10		mg/L	
			Dissolved Potassium (K)	2019/05/06	<0.10		mg/L	
			Dissolved Selenium (Se)	2019/05/06	<0.0010		mg/L	
			Dissolved Silver (Ag)	2019/05/06	<0.00010		mg/L	
			Dissolved Sodium (Na)	2019/05/06	<0.10		mg/L	
			Dissolved Strontium (Sr)	2019/05/06	<0.0020		mg/L	
			Dissolved Thallium (Tl)	2019/05/06	<0.00010		mg/L	
			Dissolved Tin (Sn)	2019/05/06	<0.0020		mg/L	
			Dissolved Titanium (Ti)	2019/05/06	<0.0020		mg/L	
			Dissolved Uranium (U)	2019/05/06	<0.00010		mg/L	
			Dissolved Vanadium (V)	2019/05/06	<0.0020		mg/L	
			Dissolved Zinc (Zn)	2019/05/06	<0.0050		mg/L	
6105137	BAN	RPD	Dissolved Aluminum (Al)	2019/05/06	NC		%	20
			Dissolved Antimony (Sb)	2019/05/06	5.5		%	20
			Dissolved Arsenic (As)	2019/05/06	9.1		%	20
			Dissolved Barium (Ba)	2019/05/06	0.57		%	20
			Dissolved Beryllium (Be)	2019/05/06	NC		%	20
			Dissolved Bismuth (Bi)	2019/05/06	NC		%	20
			Dissolved Boron (B)	2019/05/06	NC		%	20
			Dissolved Cadmium (Cd)	2019/05/06	NC		%	20
			Dissolved Calcium (Ca)	2019/05/06	0.94		%	20
			Dissolved Chromium (Cr)	2019/05/06	NC		%	20
			Dissolved Cobalt (Co)	2019/05/06	1.8		%	20
			Dissolved Copper (Cu)	2019/05/06	1.5		%	20
			Dissolved Iron (Fe)	2019/05/06	NC		%	20
			Dissolved Lead (Pb)	2019/05/06	NC		%	20
			Dissolved Magnesium (Mg)	2019/05/06	0.48		%	20
			Dissolved Manganese (Mn)	2019/05/06	0.035		%	20
			Dissolved Molybdenum (Mo)	2019/05/06	2.4		%	20
			Dissolved Nickel (Ni)	2019/05/06	0.40		%	20
			Dissolved Phosphorus (P)	2019/05/06	NC		%	20
			Dissolved Potassium (K)	2019/05/06	3.4		%	20
			Dissolved Selenium (Se)	2019/05/06	2.1		%	20
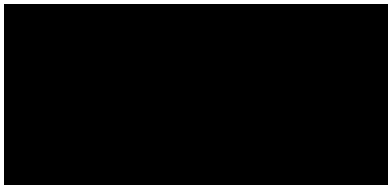
QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Dissolved Silver (Ag)	2019/05/06	NC		%	20
			Dissolved Sodium (Na)	2019/05/06	0.77		%	20
			Dissolved Strontium (Sr)	2019/05/06	2.0		%	20
			Dissolved Thallium (Tl)	2019/05/06	NC		%	20
			Dissolved Tin (Sn)	2019/05/06	NC		%	20
			Dissolved Titanium (Ti)	2019/05/06	NC		%	20
			Dissolved Uranium (U)	2019/05/06	6.3		%	20
			Dissolved Vanadium (V)	2019/05/06	NC		%	20
			Dissolved Zinc (Zn)	2019/05/06	NC		%	20
6105316	KMC	Spiked Blank	Conductivity	2019/05/06		102	%	80 - 120
6105316	KMC	Method Blank	Conductivity	2019/05/06	<1.0		uS/cm	
6105316	KMC	RPD	Conductivity	2019/05/06	0.29		%	10

N/A = Not Applicable

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 sample of known concentration prepared by an external agency under stringent conditions. Used as an independent check of method accuracy.

Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.

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 spike amount was too small to permit a reliable recovery calculation (matrix spike concentration was less than the native sample concentration)

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (absolute difference <= 2x RDL).

(1) Elevated reporting limit due to turbidity.

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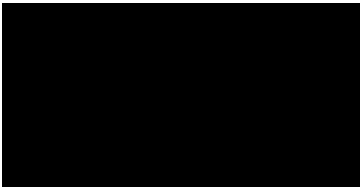
VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).
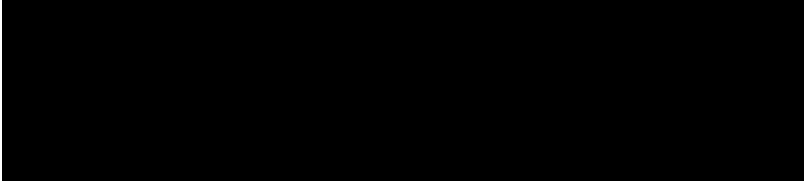
Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

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Appendix C

Reference Sheets (USB)

Appendix D

Technical Memo

Town of Sussex Geothermal Design, Penobsquis Phase 2 Geothermal Design Analysis

VIA EMAIL

August 2019

RE: Town of Sussex Geothermal Design
Penobsquis Phase 2 Geothermal Design Analysis

Dear Mr. Vernon Banks,

This report is a continuation of the "Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site," dated the 23rd of February 2019, proposed for the Town of Sussex, New Brunswick. This report, "Penobsquis Phase 2 Geothermal Design Analysis" examines the proposed open loop system, with a focus on the heat exchanger (HX), and the impact of the water chemistry on the system.

Background

The "Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site" report presented multiple options for a geothermal design. The selected design option, O.I.3, is an open loop system with a supplemental boiler. Water flows from the Penobsquis mine, through the HX where heat transfer occurs, to the supplemental boiler, and back into the mine. A supplemental boiler is recommended for the system to reduce ground heat loads, and to provide heat to the system when the building loads are above the well's capacity. A plate-and-frame HX is recommended to protect the buildings HVAC equipment from brine, which is corrosive and can cause high levels of scaling. In addition, this type of HX has easy accessibility which reduces the amount of time required for maintenance. These HXs operate by allowing a flow of hot and cold fluid into alternating channels, where heat is transferred from the hot fluid to the cold fluid. The efficiency of the HX is influenced by the chemistry of the fluid running through it.

Maxxam Analytics analyzed water samples from the Penobsquis Mine Site and displayed the findings in a report dated May 7th, 2019. The water is mildly alkaline (pH of 7.53), very hard (hardness value of 3700 mg/L), and corrosive to HX system (180,000 ppm chloride). The conditions of the water suggest that fouling will occur, which will introduce operational preventative maintenance and design requirements for the HX.

The following memo discusses the general effects of fouling on HXs, the expected types of fouling that will occur to the proposed system, and the impact fouling will have on the system. It also discusses general operations and maintenance of the plate and frame HX. The maintenance section further details the types of cleaning that can be performed on the HX, the recommended cleaning schedule, and what actions to take to mitigate fouling, given the water quality of the mine.

Types of Fouling

Depending on the chemistry of the water, fouling can occur which can compromise the integrity of the HX. Fouling is the accumulation of material on the heat transfer surface, which leads to a decrease in thermal efficiency of the HX. Different types of fouling can occur in a HX, including: scaling, particulate fouling, biological growths, and corrosion.

Scaling on a HX is the accumulation of solid salts, oxides, and hydroxides (such as calcium carbonate or calcium sulphate) that are present in a fluid. Scaling is mainly influenced by temperature, turbulence (i.e. fluid velocity), surface finish, water hardness, and the composition and concentration of salts in the water. Scaling can be mitigated by adding chemical inhibitors to the fluid or by running the system at a high velocity. Both methods help prevent the formation of crystals and the attachment of material to the HX.

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Particulate fouling is caused by the presence of solid sediments in the fluid. These solids build-up on the heat transfer surface which reduces heat transfer efficiency. Particulate fouling can be reduced by utilizing a filtration system. The filtration system would remove large sediments from the fluids prior to entering the HX.

Biological growths are build-ups of algae, fungi, and bacteria on the heat transfer surface. These build ups lead to a reduced flow which correlates to a decrease in efficiency. Biological growths can be inhibited by using a filtration system or by using chemical treatments, such as adding chlorine to the system.

Corrosion fouling is caused by extreme pH levels in the fluid and the level of chloride in parts per million (ppm). Corrosion degrades the inside of the heat transfer system and can lead to a build-up of deposits created by the corrosion. Corrosion can be mitigated by utilizing a more durable material, such as titanium, in the HX. It can also be prevented by controlling and monitoring the pH levels of the entering fluids, so that the fluids are not extremely acidic or basic. Moreover, corrosion can be mitigated by controlling the amount of oxygen dissolved in water, which oxidizes and forms insoluble deposits, through the addition of chemicals (such as hydrazine).

Figure 1   Scaling on Frame and Plate Heat Exchangers

Fouling causes build ups and damages within the HX; it reduces the fluid flow, and causes pressure and temperature issues, which lead to a decrease in thermal efficiency and overall functionality of the HX.

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Impact of Fouling on Heat Exchangers

Fouling reduces the efficiency of the heat exchanger by creating blockages and build-ups. These impediments impact the HX performances in two major ways: it reduces the thermal efficiency and increases the pressure drop.

The material which builds up on the HX due to fouling has a lower conductivity than the plates, which causes thermal resistance to increase and heat transfer to decrease. Even so much as $^{1}/_{16}$ of an inch of scaling can reduce the heat transfer ability in such a way that is equivalent to adding 3 inches of steel between the plates ("Sum-Kool"). The build-up also causes a change in the surface roughness which impacts the heat transfer ability and velocity of the fluid.

Fouling increases the turbulence of the fluid by restricting the flow area, which in turn increases the pressure drop. This increase in pressure drop can lead to the system being unable to maintain fluid flow. Moreover, this can cause failure in the connections of the HX due to the high pressure needed to drive the fluid through the HX with restricted flow area because of the build-up. Thus, as the pressure differential starts to increase, or the temperature difference starts to decrease, cleaning and maintenance should be scheduled to remove the build-up and return the HX to proper functionality.

Fouling in a HX can be detected by visual inspection, an extreme change in flow rate of the system, an increase in pressure differential, or a decrease in temperature difference on either side of the HX.

Given the water quality of the mine, fouling is expected to occur (Table 1). Since the hardness level and concentration of chloride are both very high, scaling and corrosion are expected to occur frequently. The conditions of the water make it very similar to seawater (which is also very hard and has a high level of chloride). Thus, it is suggested that, like seawater, a fouling factor of 0.000026 m^2 K/W be taken into account for how much scaling may occur when selecting the heat exchanger (Pugh, Hewitt, & Muller). This fouling factor impacts the design of the system by increasing the thermal resistance, which contributes to a need for an increase in surface area and consequently increases the price of the HX. Scaling and corrosion interfere with the ability of the HX to allow fluid flow through the plates. They can also cause the system's pressure to fluctuate which may compromise the integrity of the HX. The build-up produced by these forms of fouling leads to further inefficiencies and a significant reduction in heat transfer capabilities. Failure to mitigate fouling can lead to frequent down time of the HX (for cleaning and maintenance), heat production losses, and drastic cost increase (time down for repairing and the cleaning measures that would need to be taken if not properly maintained).

Impacts of fouling on heat exchangers can be mitigated by integrating materials, design considerations, and operation and maintenance recommendations as described in the next sections.

Recommended Materials and Design Considerations

Based on the water chemistry, properties of materials available and discussions with manufacturers, recommendations are made to provide a robust system that retains its performance level over time and is easily maintainable.

- The well pump shall be custom designed for corrosion resistance. Submersible or dry pumps are both viable options that will likely feature titanium parts.

- Piping that does not react to water, like the Aquatherm® Blue Pipe, is recommended to be used anywhere piping is in contact with the mine water to avoid the fouling that would occur with steel pipe.

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- At a minimum, titanium plate and frame HX is recommend due to the high chloride content of the water. At 180,000ppm of chloride, titanium is at its corrosion resistance limit. A palladium-titanium metal would have superior corrosion resistance but is not seen as cost-efficient. Note that corrosion resistance is not covered by manufacturers' warranties.

- A filtration system should be in place to protect the HX from suspended solids which can cause particulate fouling and encourage biological growths. It is recommended to use a system type Amiad® SpinKlin with self-cleaning features. The HX should nonetheless have an automated back-flush valve system that can operate on a timer or differential pressure command to actively mitigate fouling. Temperature and pressure gauges should be installed on either side of the HX to monitor the HX's functionality. If the pressure differential increases and/or the temperature difference decreases, it is a signal that scaling has occurred and the HX requires maintenance and/or cleaning. Discharges from the cleaning processes will have to be sent to a waste system independent from the wells' loop.

Water chemistry, temperature and pressure differentials, as well as the load of the system are all factors which impact the sizing of the HX. The greater the load and differentials, the larger surface area the HX will have to have in order to deliver the peak load. Moreover, the HX should be sized with a maximum excess surface area of between 20-25% of the clean surface requirements. The following sections describe the recommended velocities, temperatures, and loads, as well as preventative measure for fouling.

Recommended Operations & Maintenance

Maintenance and cleaning are recommended to be regularly scheduled, and, at a minimum, performed annually. Daily and weekly procedures for maintaining the HX should be in the instruction manual provided by the manufacturer. The main cause of failure in plate and frame HXs is fouling. However, this type of HX also commonly fails in its OEM gaskets, nozzles, frames, and guide bars. Failures in these parts can lead to leakages, structural failure, and an overall decline in thermal efficiency. These parts are also impacted by the fouling of the plates. A reduction in fouling of the HX can reduce the risk of failure in these parts and decrease the frequency at which these parts must be replaced. Fouling can be removed during regularly scheduled cleanings by a variety of methods including chemically and mechanically cleaning in place, as well as utilizing an off-site cleaning facility.

Types of Cleaning

Cleaning in Place (CIP) is a process that clears fouling from a HX and is often used for high fouling situations. CIP includes draining the HX and flushing warm water through it, followed by running a cleaning solution through the system for 4-6 hours (or until the proper pressure levels are met). For situations with high scaling, CIP may also include the removal of the plates from the HX for mechanical or chemical cleaning.

Chemical CIP can be performed with different cleaning agents to help remove scaling and biological growths. The cleaning agent should be back flushed through the heat exchanger at about 1.5 times the normal flow rate to optimize the dissolution of scaling. During the process of chemical cleaning, an alkali, like caustic soda (NaOH), should be run through the system to help remove any fats and oils. Additionally, a cleaning acid, like diluted hydrochloric acid or diluted citric acid, should be run through the system to remove ionic deposits. A biocide, like chlorine dioxide, should be used to remove microbes, biofilms, and phenols. Depending on the level of scaling, chemical CIP may also include placing the plates in a chemical bath. A high level of scaling would lead to soaking the plates in phosphoric or nitric acid, followed by passivation with a neutralizer (such as 1-2% sodium hydroxide or bicarbonate), to remove the scaling and to decrease the risk of corrosion.

Cleaning the plates of deposits can also be performed mechanically by circulating hot water through the HX and using a soft brush to remove deposits. This method may also require removal of the plates from the frame to access the deposits. To remove stronger deposits, a high-pressure cleaner, such as a pressure washer, along with the soft brush, can be used. This washing method can be used if the equipment is at a sufficient distance from the pressure washer, so to not damage the integrity of the plates.

Utilizing an authorized off-site cleaning facility is also an alternative for cleaning the HX. The cleaning facility inspects each area of the HX, check for cracks and leaks via ultraviolet testing, and thoroughly clean the plates of the HX by hydro-blasting and chemical soaking. This method of cleaning would require the shut down and removal of the HX to an off-site facility, which would extend the down time of the HX.

Specific, detailed cleaning and maintenance instructions are provided in the HX manufacturer's operations and maintenance book.

Recommendations

Cleaning and maintenance are recommended to occur, at minimum, once a year. If any changes occur regarding the temperature or pressure of the HX, as detailed above, cleaning should occur to remove scaling. It is recommended that both mechanical and chemical CIP are used to remove scaling during annual and intermediate cleanings. A trial and error process will have to be followed to determine whether the fouling can be addressed with chemical cleaning only, or if the HX will have to be opened and mechanically cleaned as well. In terms of the chemical cleaning agent, it is recommended that the solution is made from 5% diluted acid (e.g. diluted citric acid, hydrochloric acid, or oxalic acid)- and run through the system to dissolve the calcium carbonate and other scale. Additionally, a solution of 3-4% caustic soda, serving as the alkali, should be run through the system to help remove the organic fouling and oil build-ups. Specifics of the particles in the water and the treatment for such are detailed further in Table 1. The methods for cleaning the specific HX that is used are detailed in the previous section, as well as in the operations and maintenance manual provided by specific manufacturer of the HX.

Table 1 Breakdown of Water Chemistry and Correlating Cleaning Options

Component of Water Chemistry	Impact on the System	Treatment Required
Hardness Level ($CaCO_3$--3700 mg/L)	Leads to insoluble mineral deposit build up, scaling, which degrades the efficiency of heat transfer within the HX	Use a backflush valve to backflush the HX every hour, clean with diluted acid if temperature/ pressure differentials change, extra connections for frequent cleaning
Dissolved Chloride (Cl^- ---180000 mg/L)	Very hard water can cause corrosion of parts that are not titanium	Back flushing each hour, filtration system prior to the HX, monitoring pressure and temperature differentials, visual inspection
Metals (various types and quantities)	Sticks to and corrodes the interior of the HX,	Back flushing the HX each hour, filtration system prior to the HX, washing with warm water during cleaning
Inorganics (variety of types and levels)	Impacts the pH, leads to scaling, and can cause particulate fouling by the settling of particles	Back flushing the HX each hour, filtration system prior to the HX, clean with caustic soda if pressure/temperature differentials change
Turbidity (24 NTU)	High turbidity causes blockages throughout the system, sediment build up, and particulate fouling	Back flushing each hour, refined filtration system prior to the HX, washing with warm water during cleaning

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Including extra connections on the back of the HX for CIP piping is recommended, since the water is so hard, and cleaning is likely to be performed frequently. These extra connections will allow for the solution to be circulated through the HX without having to entirely disassemble it, which can help reduce the "down time" of the HX during cleaning. If there is a drastic change in HX performance, off-site cleaning, through an authorized company, is suggested, since they can detect any cracks or other occurrences that may also be impacting the efficiency of the HX. CIP can take around 1-2 work days to complete, during which the HX would not be functional for normal operations. The amount of time that off-site cleaning takes depends on the company that is used, but it can take up to a full business week to be completed. Thus, the system would be essentially non-operational for that extended time. At a minimum, n+1 HXs is recommended, so that the system would still be semi-operational during the cleaning of one of the HXs.

The key components needed in this system are the plate and frame HX, a filtration system, and a back-flushing system. These components are rather large, and it is recommended that they be stored within an enclosed temperature-controlled building to help avoid external damage due to harsh weather conditions. This equipment building is recommended to be at minimum 18 m x 12 m x 10 m to provide enough space for the necessary items.

It is recommended that the plate and frame HX be Sondex® Free Flow model (Table 2). This sized HX should be used because it is able to maintain the high load and temperature differential that is needed in this situation. This HX allows particles of about 2 mm or less to travel through the system. While this will help reduce particulate fouling (by preventing larger particulates from being in the HX), a filtration system is still needed to filter particles at a smaller scale and further prevent sediment build-up.

To filter out the contaminants in the water, which may damage the HX, it is recommended that Amiad® SpinKlin Disc Filter 4" Galaxy Battery filtration system be set up prior to HX to filter the water from the mine. This filtration system will filter out contaminants at micron level, specifically down to 100 microns. This level of filtration helps reduce scaling and particulate fouling within the HX. This system also automatically cleans itself by back flushing every hour (a process which takes 20 seconds). The back flushing serves as a self-cleaning which further helps to reduce sediment build-up and improves the quality of the water entering the HX. This filtration system will require an additional feed pump and a backflush pump for the filtration to work properly. The feed pump must work at 78 L/s (1240 gpm) with a pressure of 30 psi, and the backwash pump must work at 15.77 L/s (250 gpm) at 70 psi. Thus, it is recommended that a 152.4 (6") hydronic pump be used for the feed pump, and a 101.6 (4") hydronic pump be used for the backwash pump. These two pumps allow for the system to maintain proper flow velocity and help the system maintain integrity.

In addition to the filtration system, an automatic backflush valve, such as that provided by Ekström&Son®, is recommended to be in place with each HX. This system can operate on a time or pressure differential, reversing the flow direction within the HX which loosens and removes any build-up that may have occurred, and helps further particulate build-up, including calcium carbonate, within the HX. Additionally, pressure and temperature gauges should be installed on either side of the HX to help monitor its functionality. These gauges would serve as signals to the operator when the system may need cleaning. Options of technology to potentially use in this system are displayed in Table 2.

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Table 2 Technologies and Correlating Key Aspects for the Heat Exchanger and Filtration System

Equipment	Sizing[b] (mm)	Filtration Ability	Cost[a] (each)	Additional Notes
Amiad® SpinKlin Disc Filters- 4" Galaxy Battery (external source backwash) Systems Filter (Qty: 1)	2,540 x 1,982 x 1,778	100 microns	$93,500 CAD ($71,900 USD)	This filter utilizes backwashing to clean filters, this process takes approx. 20s. Cost does not include backflush pump or feed pump.
Sondex® Free Flow Plate, Plate & Frame HX (Qty: 2- based on n+1)	3,349.78 x 1,120 x 2,781	Particles less than 2mm will pass through the HX	$146,000 CAD ($110,000 USD) (multiply cost by 2 based on n+1 Qty)	Cost does not include backflush valve. Much less sensitive to particulate fouling.
Sondex® Traditional Plate & Frame HX (Qty: 2- based on n+1)	2,072.64 x 970.03 x 1,955.04	Particles less than 2mm will pass through the HX	$63,000 CAD ($48,000 USD) (multiply cost by 2 based on n+1 Qty)	Cost does not include backflush valve
Ekström&Son® SmartLoop, Automatic Titanium Backflush Valve (Qty: 2- based on n+1)	Sized for Sondex® HX	N/A	$28,000 CAD (198,000 kr) (multiply cost by 2 based on n+1 Qty)	Back flushing should occur hourly, cost is strictly back flush valve price
Pressure Gauge (Qty: 2- based on n+1)	216 (8.5") dial	N/A	$600 CAD ($460 USD) (multiply cost by 2 based on n+1 Qty)	Steel Case, able to measure high pressures. Sizing based on 2019 Plumbing costs with RSMeans data (see references)
Temperature Gauge (Qty: 2- based on n+1)	304.8 (12") Mercury filled, industrial, separable socket type	N/A	$340 CAD x 2 ($260 USD) (multiply cost by 2 based on n+1 Qty)	Sizing based on 2019 Plumbing costs with RSMeans data (see references).
Back Wash Pump (Qty: 1)	101.6 (4") hydronic pump (sizing based on GPM)	N/A	$16,000 CAD ($12,000 USD)	Sizing based on 2019 Plumbing costs with RSMeans data (view references)

Notes: a. Cost does not include tax or labour, b. Sizing is Length x Width X Height

Please contact Mathilde Krebs at 207-828-2640 or mathilde.krebs@woodplc.com, if you have questions regarding this recommendation.

Sincerely,

**Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited**

**Mathilde Krebs, M.Eng.
Mechanical Engineer
Direct Tel.:   (207) 828-2640
E-mail: mathilde.krebs@woodplc.com**

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Figure 1 Images (Cited from Left to Right)

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Appendix E

Limitations

LIMITATIONS

1. The work performed in the preparation of this report and the conclusions presented are subject to the following:

    (a) The Standard Terms and Conditions which form a part of our Professional Services Contract;

    (b) The Scope of Services;

    (c) Time and Budgetary limitations as described in our Contract; and

    (d) The Limitations stated herein.

2. No other warranties or representations, either expressed or implied, are made as to the professional services provided under the terms of our Contract, or the conclusions presented.

3. The conclusions presented in this report were based, in part, on visual observations of the Site and attendant structures. Our conclusions cannot and are not extended to include those portions of the Site or structures, which are not reasonably available, in Wood's opinion, for direct observation.

4. The environmental conditions at the Site were assessed, within the limitations set out above, having due regard for applicable environmental regulations as of the date of the inspection. A review of compliance by past owners or occupants of the Site with any applicable local, provincial or federal by-laws, orders-in-council, legislative enactments and regulations was not performed.

5. The Site history research included obtaining information from third parties and employees or agents of the owner. No attempt has been made to verify the accuracy of any information provided, unless specifically noted in our report.

6. Where testing was performed, it was carried out in accordance with the terms of our contract providing for testing. Other substances, or different quantities of substances testing for, may be present on Site and may be revealed by different or other testing not provided for in our contract.

7. Because of the limitations referred to above, different environmental conditions from those stated in our report may exist. Should such different conditions be encountered, Wood must be notified in order that it may determine if modifications to the conclusions in the report are necessary.

8. The utilization of Wood's services during the implementation of any remedial measures will allow Wood to observe compliance with the conclusions and recommendations contained in the report. Wood's involvement will also allow for changes to be made as necessary to suit field conditions as they are encountered.

9. This report is for the sole use of the party to whom it is addressed unless expressly stated otherwise in the report or contract. Any use which any third party makes of the report, in whole or the part, or any reliance thereon or decisions made based on any information or conclusions in the report is the sole responsibility of such third party. Wood accepts no responsibility whatsoever for damages or loss of any nature or kind suffered by any such third party as a result of actions taken or not taken or decisions made in reliance on the report or anything set out therein.

10. This report is not to be given over to any third party for any purpose whatsoever without the written permission of Wood.

11. Provided that the report is still reliable, and less than 12 months old, Wood will issue a third-party reliance letter to parties that the client identifies in writing, upon payment of the then current fee for such letters. All third parties relying on Wood's report, by such reliance agree to be bound by our proposal and Wood's standard reliance letter. Wood's standard reliance letter indicates that in no event shall Wood be liable for any damages, howsoever arising, relating to third-party reliance on Wood's report. No reliance by any party is permitted without such agreement.

Wood Environment & Infrastructure Solutions,
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