FINAL REPORT

TECHNICAL FEASIBILITY STUDY OF THE GEOTHERMAL CAPABILITY OF THE PENOBSQUIS MINE SITE PENOBSQUIS NB

Submitted to:

Town of Sussex
Sussex, New Brunswick

Submitted by:

Amec Foster Wheeler Environment & Infrastructure,

a Division of Amec Foster Wheeler Americas Limited
Fredericton, New Brunswick

February 2018

TE174005

23 February 2018

TE174005

Mr. William Thompson
Economic Development Coordinator
Town of Sussex
524 Main Street
Sussex, NB E4E 3E4

Dear Mr. Thompson:

Re: Final Report: 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,

Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited

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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 metres (m^3) of heated brine.

The Town of Sussex, on behalf of the Sussex region, commissioned this Technical Feasibility Study 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.

This 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 example applications represented a range of: user types (individual vs district), facility type (greenhouse and refrigeration warehouses), facility size (1 to 20 Acres), periods of operation (4 or 12 months) and geothermal system loop type (open or closed loop). The modeled outputs for a given example were: capital costs, energy consumption, energy savings, maintenance costs and CO_2 emissions and a calculated discounted payback period. 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.

The presented capital costs for the selected example includes the installation of the open system wells, district loops and district loop heat exchangers and also the equipment for each of the users connected to the system (heat exchangers and building loops etc.). A cost sharing model, whereby a utility provider could install and operate the district system and offer a fee based connection to prospective business, creates an economic advantage for both the utility provider and prospective businesses. In the most favorable modeled example a utility constructing and operating the district system would have an estimated capital investment of approximately $5.7 Million.

Currently, the Avon Valley Floral greenhouse, in Penobsquis NB, employs 12 full time employees. During their growing season, this number rises to 50 to 60 employees. Installation of a district system could provide Avon Valley Floral the economic advantage to operate 12 months of the year. A district system could also provide an economic advantage to prospective proponents who connect to the district system (additional greenhouses, refrigeration warehouse and or data storage centers etc). This would create more jobs in the region and additional revenue for the utility provider which could prompt expansion of the district system.

The over 3 million m^3 of heated brine which will occupy the Penobsquis mine offers a unique investment opportunity. Documented studies and practical examples have proven that the geothermal potential of abandoned and flooded mines can offer an economic advantage. The assembled information and modelling of the 20 example geothermal applications suggest that:

- Open loop systems offer a better discounted payback period and lower capital costs compared to closed loop systems.
- The geothermal potential of the Penobsquis mine is economically attractive, provided the key assumptions made during the study (Section 13.0) can be confirmed.
- A district open loop geothermal system heating a 20 Acre greenhouse (with supplemental boiler) and cooling 10 refrigeration warehouses for a 12-month period carried an estimated capital cost of $11.3 Million dollars and a discounted payback period of approximately 7 years.
- Installation of a district system allow for a cost sharing arrangement which can provide beneficial economics to both a utility provider and prospective businesses.
- In a cost sharing arrangement, an investment from a utility provider to construct a district open loop geothermal system is estimated to be approximately $6.68 Million dollars (includes design and approval fees of 15% and 3% of the $5.7 Million capital cost, respectively).
- In the cost sharing arrangement, an investment from the prospective businesses (excluding fees for connection to district system, design and approvals) is estimated to be $3.9 Million for the 20 Acre Greenhouse and $173,000 for each of the individual refrigeration warehouses.
- Installation of a district system in the Penobsquis area could allow Avon Valley Floral to operate for a 12-month period and transition 38 to 48 seasonal jobs to full time employment.

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LIST OF ACRONYMS

Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CGC	Canadian Geo-Exchange Coalition
CoA	Conditions of Approval
CBA	Cost-Benefit Analysis
COP	Coefficient of Performance
EIA	Environmental Impact Assessment
EUB	Energy and Utilities Board
GHG	Greenhouse Gas
HDPE	High-density polyethylene
igpm	Imperial gallons per minute
KCl	Sylvite - potash
kW	Kilowatt
kWh	Energy consumption
L	Litres
LSI	Langelier Saturation Index
m^3	Cubic metres
mbgs	Metres below ground surface
m	metre
NaCl	Salt
NBENV	New Brunswick Department of Environment
Nutrien	formerly PotashCorp NB
PotashCorp	Potash Corporation of Saskatchewan Inc.
SC	Specific capacity
TDS	Total dissolved solids
TRC	Technical Review Committee
WAWA	Watercourse and Wetland Alteration
WSSA	Water Supply Source Assessment

1.0 INTRODUCTION AND BACKGROUND

The community of Penobsquis and the decommissioned Penobsquis Potash mine, formerly operated and still currently controlled by the Potash Corporation of Saskatchewan Inc. (PotashCorp), are located approximately 10 km north east of the Town of Sussex along Highway 114 (Figure 1.1) (Appendix A). In January of 2016, PotashCorp announced their intention to permanently close the Penobsquis mine. Closure and subsequent decommissioning of the mine resulted in the onset of flooding of the open underground mine workings.

The Town of Sussex retained the services of Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler) in the summer of 2017 to complete a Technical Feasibility Study of the Geothermal Capability of the decommissioned Penobsquis Mine. With the support of the Government of New Brunswick and PotashCorp, 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 costs of energy and carbon emissions are two very important factors in any business case. The benefits of a proven alternative energy source, such geothermal, is its ability to lower both overall energy consumption and carbon emissions, which both positively impact overall costs. In the mining context, the pioneering Springhill, Nova Scotia mine water project is a success story where a flooded coal mine has been supplying businesses and public facilities with heating and cooling capacity since 1989, greatly reducing their energy costs. Works undertaken by the Geological Survey of Canada has inventoried inactive mines in Quebec and Nova Scotia (Akray 1992). According to Raymond (2008) geothermal energy from abandoned mines attracted little interest in Quebec until the mid-2000s. More recently, Preen (2014), indicated that as of 2013 there are still less than 20 documented examples of operational geothermal systems on mine sites. However, from these examples it has been proven that, under the right conditions, utilizing abandoned and flooded mines as a source geothermal energy can have economic potential.

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 Technical Feasibility Study.

2.0 TECHNICAL FEASIBILITY STUDY OBJECTIVES AND APPROACH

The overall objective of the Technical Feasibility Study was to determine if the decommissioned and flooded Penobsquis mine is a viable source of geothermal energy. To achieve this objective, the Town of Sussex and Amec Foster Wheeler developed a scope of work and a series of deliverables aimed to investigate the potential at this mine and gather the necessary information and costs to assess its initial technical feasibility. To achieve the overall objective of the Study and provide the requested deliverables, Amec Foster Wheeler organized the scope of work to allow results from one phase to precede the next phase, which required those preceding and dependent results. The summarized and organized list of deliverables identified for the Technical Feasibility Study are presented below:

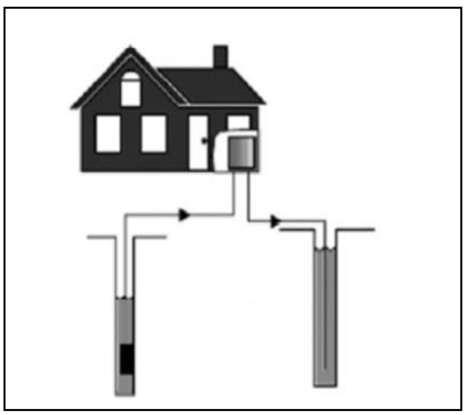
- Overview and presentation of open and closed loop geothermal systems in both individual user and district loop multiple user settings, including concise explanations concerning the strengths and challenges associated with each system type.
- Presentation of the available chemistry data for brine contained within the former underground mine workings and its suitability in geothermal applications.
- Presentation of available thermal profile data and the sustainable source capacity of the former mine.
- Presentation of a series of 2D and 3D maps of the study area and the underground mine workings to identify the area with best access to the geothermal reservoir.
- Identification and presentation of drilling techniques and conceptual well designs to access the geothermal reservoir for both open and closed individual and district systems with the intent to protect the potable aquifer level.
- Development and presentation of additional mapping data to identify the drilling depths required to access the geothermal reservoir from various locations.
- Overview and presentation of alternate individual geothermal systems which may not require access to the former mine workings.
- Development of costs estimates for preferred drilling technique(s) and well design(s).
- Identification of the potential reduction in greenhouse gases through use of the geothermal resource compared to other available New Brunswick energy options.
- Completion and presentation of a cost benefit analysis for the system configurations, identified jointly with the Town of Sussex, which present the fewest challenges and greatest strengths.
- An explanation, based on existing knowledge, of the current hydrogeological setting of the Penobsquis area and identification of potential causes of concern to the potable water resources caused by the development of the geothermal resource as well as the actions which can be taken to minimize and or mitigate those potential concerns.
- Identification of potential legal, regulatory, environmental challenges, considerations and/or constraints which could be associated with the development of the geothermal resource.

3.0 GEOTHERMAL SYSTEMS OVERVIEW

Geothermal systems, can be used for heating, cooling, or a combination of both. They operate either as open loop systems, in which groundwater is extracted using a well, or as the more common closed loop system, which involves no direct communication with the groundwater as closed pipes, containing a heat exchange fluid, are installed in the ground. The ground itself, surface water bodies, open pits, mines, and aquifers can all be considered as storage for heat (and cold) energy. The following sections will provide an overview of the basic concepts of open, closed and district geothermal systems and highlight their advantages and disadvantages. When discussing heat pumps and heat exchangers, the term Coefficient of Performance (COP) is used. The COP is the ratio of the energy transferred to the electric energy used to power the heat pump / exchanger. For example, a system with a COP of 4 would transfer 4 times as much energy compared to electric energy used to operate the heat pump / exchanger.

3.1 Open Loop Systems

In an open loop system example, water would be pumped from a borehole and circulated through a heat-pump and/or a plate heat exchanger and then discharged back into the ground (Figure 3.1). A typical flow rate for an open loop system is about 0.018 to 0.031 Litres (L)/second (0.24 to 0.41 imperial gallons per minute (igpm)) per Kilowatt (kW) of heating and cooling (Rafferty, 2009). There are three main designs of an open loop system: 1) a single well open loop; 2) a double well open loop (Illustrated in Figure 3.1); and 3) a surface water open loop. The single well open loop system uses an extraction well as a means of obtaining the ground water. After the ground water is used in the heat pump system, it is discharged to a stream, river, or lake. Depending on water quality, water treatment may be required. The double well open loop system is similar to the single well system, but a second well discharges the ground water back into the earth. The third design of an open loop system is a surface water system, which uses a large body of water to provide the water necessary for the heat pump system. Water is extracted from the body of water and utilized in the heat pump and discharged back to the body of water (Watzlaf and Ackman, 2006).



Lund (2004)

Figure 3.1 Basic Example of a Two-Well Open Loop Geothermal System

Some advantages of open loop geothermal systems include:

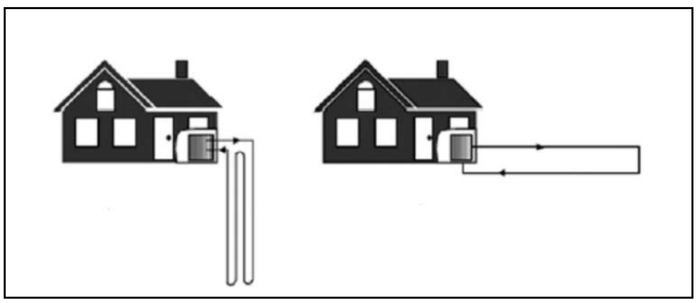
- Construction costs, which are typically lower compared to closed-loop systems. The main capital cost is for drilling water wells if the infrastructure does not currently exist.
- High heat pump energy efficiency (COP > 4-5) due to direct water contact with the heat-pump and/or a plate heat exchanger.

Some disadvantages of the open loop geothermal systems include:

- They require good hydrogeological conditions and a good understanding of those conditions.
- Thermal feedback between the production (withdrawal) and injection wells (wells in close proximity) is an important consideration and should be prevented.
- Water quality is an important aspect of open loop systems. Ideally water should be: clean, and non-corrosive to avoid/limit biofilm formation, scaling and corrosion.
- Higher pumping costs because of water lift from wells and addition of heat exchanger loop compared to closed loop system.

3.2 Closed Loop Systems

In a closed loop system, no water is extracted or discharged to the environment. Heat exchange occurs through a closed loop of piping buried in the ground inside which a working fluid that may contain an antifreeze or other heat exchange fluid is circulated. Vertical ground heat exchangers are constructed by placing two high-density polyethylene (HDPE) tubes, thermally fused at the bottom of the bore to a closed return U-bend, in a vertical borehole. Bore depth over 150 m (400ft) is not common and requires additional attention to offset the hydrostatic conditions and added pipe head losses. The piping can be oriented vertically, horizontally as shown in Figure 3.2 or following a defined angle, depending on the available land area and drilling costs.



Lund (2004)

Figure 3.2 Basic Example of a Vertical (left) and Horizontal (Right) Closed Loop Geothermal System

Some advantages of closed loop systems include:

- No extraction of groundwater;
- No risk of geochemical fouling of heat exchanger (no direct contact with plates);
- Mature technology – low maintenance and high durability; and
- Good heat pump energy efficiency (COP of 3 to 4).

Some disadvantages of closed loop systems include:

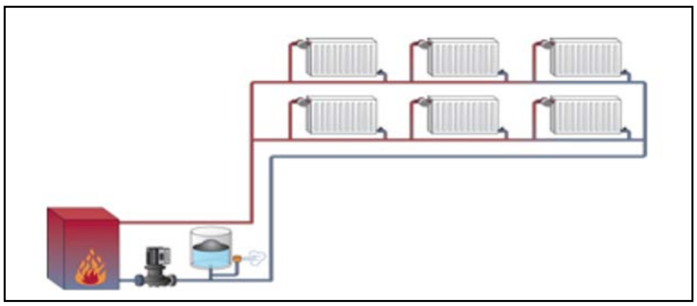
- Modest heat yield, advection (moving heat) in bore field can sometimes achieve greater heat yields; and
- Construction costs are proportional to:
    - Building loads; and
    - Thermal conductivity of the geological environment.

3.3 District Heating / Cooling Systems

In a district loop configuration, hot or cold water is distributed to several buildings through a pumped piping system. The primary heating or cooling source is a central geothermal wellfield (either an open or closed loop system). Depending on the temperatures, a supplemental boiler or cooling tower can be added to the loop to meet the peak load requirements. Long transmission piping is feasible. In the U.S., a district loop shorter than 8 km (5 miles) is generally considered economical, but it is dependent on the size of the heat load (Rafferty, 1991).

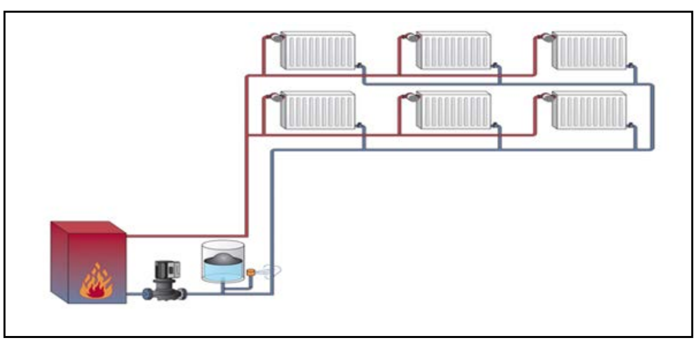
Where diversity exists between buildings (one building needs heat while another needs cooling), heat can also be transferred between buildings if the piping layout allows it. Piping layouts can either be a one or two pipe systems.

In a one-pipe heating system (Figure 3.3), all heating devices are connected to the same pipe, which acts as both inlet pipe and return pipe. This means that the temperature decreases along the pipe. For this reason, the heat pump's performance will also decrease along the pipe. A one-pipe system can be advantageous in the case of a cooling device preceding a heating device, as it preheats the water for the heating device.



(Groundfos.com)
Figure 3.3 Basic Example of a One-Pipe Layout, Heating

In a two-pipe heating system (Figure 3.4), all heating devices have the same entering temperature.



(Groundfos.com)
Figure 3.4 Basic Example of a Two-Pipe Layout, Heating

4.0 GEOTHERMAL PROPERTIES

The former mine, once completely flooded, could serve as a reservoir or source of geothermal energy. Before determining technical feasibility of the former mine for geothermal applications, it is important to first characterize its key properties, such as:

- **Geometry of the mine workings:** Where underground did mining take place; has that mined area been left open or backfilled; once the mine is flooded are the geothermal fluids accessible in these areas?
- **Water Levels:** What will the static water level be if/when the mine workings are accessed?
- **Water quality:** What is the known or expected water quality of the fluids within the mine workings?
- **Thermal gradient and thermal properties:** What is the known or expected temperature of the brine inside the mine workings and also the thermal properties of the brine and rocks inside and outside of the mine?

These properties are essential to calculate example cases of geothermal applications and evaluate the technical feasibility of the geothermal potential of the former mine. The following sections present the available, inferred and/or assumed information for each of the above items.

4.1 Underground Mine Workings

The community of Penobsquis and former mine are located approximately 10 km north east of the Town of Sussex along Highway 114. As presented in Figure 1.1 the underground mine workings projected to the ground surface are approximately 7.5 km long and range roughly in width from 400 to 800 m (Figure 4.1).

The generic cross section with approximate depths of the Penobsquis mine structure is presented in the left inset on Figure 4.1. The inset shows the contact between the Mabou Group sediments and the Windsor Group salts (Penobsquis Salt, Anhydrite Caprock and Upper, Middle, Basal Halite) as a dome type structure. The shape of this dome structure varies, but it is present over the entire length of the Penobsquis mine workings. This contact between the sandstones and Windsor salts is an important hydrogeological feature as the salt and cap rock are much less transmissive to groundwater and behave like a seal for the mine. The other inset on the right of Figure 4.1 presents the different stope types and other features of the mine workings. Labeled as feature 1 and 2 in Figure 4.1, the white and blue sections of the mine workings are the lower and upper salt stopes, respectively. These stopes were mined horizontally in the middle of the salt dome (see insets in Figure 4.1 for positions). Labeled as features 3 and 4 in Figure 4.1 the red and purple features represent the upper (1500 level) and lower (1900 level) potash stopes which extend up and down in a sub vertical orientation as shown in the insets of Figure 4.1. Lastly the yellow features labeled as number 5 are the access ways and shafts, which provide access to the mine sections.

These five features can be grouped into two main categories. Those developed or mined within potash ore seams and those developed or mined in salt. The two potash stopes (feature 3 and 4 Figure 4.1) are obviously developed in potash ore. As a result of the mining method at the Penobsquis mine, these stopes have been backfilled with tailings from the mining process which have left very little open space inside these mined features.

In comparison to the backfilled potash stopes, the access ways and salt stopes were developed or mined in more competent salt rock. The mining method for salt leaves open stopes which are not backfilled. Access ways are designed to remain open for travel and air exchange underground. The salt stopes exist as large open areas which were previously used to manage brine underground. These features developed or mined in salt rock represent mostly void spaces which will become or are flooded with brine.

4.2 Water Levels inside the Mine Workings

The inflow of groundwater into the Penobsquis Mine workings has been occurring since 1998 and had been successfully managed until mine closure when pumping was stopped in February 2017. Since that time, it is assumed that water levels inside the mine have been rising from the bottom up. These rising levels will ultimately result in complete flooding of the mine workings. At present, the current information and understanding of the flooding process does not allow for the determination or prediction of a static water level inside of a well accessing the mine workings.

While a measured or predicted water level value from inside the mine is not available, there are some limited data available from the PotashCorp monitoring wells whose locations are show in Figure 4.2. The water levels vary with depth and with location. Estimating a static water level depends upon the location of access which will be discussed in Section 5.0.

4.3 Water Quality

In geothermal applications, depending on its chemistry, mine water can promote scaling, corrosion or both. Scale deposition can be due to the presence of various dissolved chemical species in water, notably salts or high pH. Hardness and alkalinity can be two reliable indicators of scaling potential. With respect to corrosion, seven key chemical species produce a significant corrosive effect including: oxygen, low pH, chloride, sulfide species, sulfate, carbon dioxide and ammonia species.

The future chemistry of the fluid inside the mine workings after flooding is not known, however, it could be expected that the brine inside the mine workings would come to equilibrium near the combined mutual saturation of both NaCl (salt) and KCl (sylvite - potash). Given the expected brine composition high scaling should be anticipated. With respect to corrosion, the anticipated high concentration of chloride suggests that corrosion-resistant materials will be required for the equipment in contact with the mine water (i.e. in open loop systems).

According to data from Efrid and Moller (1978), a fluid containing 100,000 ppm of chloride will produce localized corrosion of stainless steel type 304 or 316 regardless of the temperature. As a result of the anticipated scaling potential and corrosive nature of the brine, a plate heat exchanger should be used to isolate the building loop (and related heat pumps) in open loop applications. Plate heat exchangers, unlike heat pump exchangers, can be cleaned with a chemical and/or mechanical process. The plate heat exchanger will also reduce the amount of scale as a result of lower surface temperatures than in heat pumps, and the flow rate on the mine water side can be adjusted so that wall shear stress is high and scaling is minimal.

Another consideration of the unknown brine chemistry is the temperature change of the brine as it crosses the heat exchanger plates and the potential precipitation of potassium chloride. The actual chemistry of the brine inside the mine workings will be a critical factor in the selection of equipment and further evaluation will be required in the case of open loop systems.

4.4 Thermal Gradient and Thermal Properties

When assessing geothermal potential, ground properties play an essential role. With increasing depth from the ground surface, the temperature of the ground and groundwater increases.

With respect to available data, the PotashCorp monitoring well network, presented in Figure 4.2, records temperatures at numerous depths up to and beyond 700 metres below ground surface (mbgs). A plot of the average temperature (2008 to 2017) versus depth for these monitoring wells is presented as Figure 4.3. A straight line linear equation fitted to the data is presented on Figure 4.3 and can be used to determine a temperature using a depth value in mbgs. Temperature data was also available from the profiling of the former Cassidy Lake flooded mine shafts in 2016. The profiles extend to depths up to 730 mbgs. These data sets as well as generic geothermal gradient data (accessed online from the Schlumberger Oilfield Glossary http://www.glossary.oilfield.slb.com) are presented with the monitoring well data as Figure 4.4.

From Figure 4.4, it is evident that the monitoring well temperature values plot well below the generic geothermal gradients. The data indicated that a maximum recorded temperature outside the Penobsquis mine, workings deep within the Mabou Group sediments, was 14.7 ^{o}C at 714 mbgs. With respect to the mine shaft profiles temperature data the sharp inflection of the temperature in the shaft profiles occurs when the water column changes from fresh water to brine. The change in temperature at the interface could be assumed to be a result of either: higher thermal conductivity of the brine or advection of heat from mine workings. The analogous Cassidy Lake flooded mine shaft data shows brine temperatures of nearly 19 ^{o}C were observed at 730 mbgs. The future temperature of the brine contained within the Penobsquis mine working, once flooded, is uncertain however some warming of the water and advection (warmer water rising cooler water descending) could be expected based on the profiles observed in the Cassidy Lake flooded mine shafts.

The physical properties of the rocks and fluid (brine or groundwater) are also important parameters particularly for closed loop systems. Table 4.1 summarizes and presents ranges for the estimated thermal conductivity, thermal capacity, and density of the rocks and brine in the study area. The ranges are dependent on the simplified geology for the area where the depths up to 300 mbgs would be represented by the Mabou group sediments, and below 300 mbgs the Windsor group salts (halite) would be encountered. In Table 4.1 the average values for the ground between 0 and 500 mbgs were calculated using Maxwell equations for a homogenous medium. In this way, an average value for the differing geologies and assumed chemistry was accounted for. Based on typical values, the thermal conductivity of the Windsor group halite is expected to be greater than the Mabou group sediments. Therefore, a closed-loop system would benefit from accessing those Windsor group rocks with the higher thermal conductivity.

5.0 ACCESSING THE GEOTHERMAL SOURCE

To access the geothermal potential of the mine, drilling will be required. The following sections present the available mine working and surface feature data to identify surface location(s) where there is an increased probability of successfully drilling into the mine workings and a reduced probability of environmental impacts.

5.1 Description of Drilling Targets

As presented in Figure 4.1 the Penobsquis mine has been separated into five categories:

- 1900 Level Potash Stopes;
- 1500 Level Potash Stopes;
- Access Ways;
- Lower Salt Stopes; and
- Upper Salt Stopes.

These features represent known mined areas which could be targeted with drilling operations. The properties of these features can make them either more of less attractive as a potential drilling target. Table 5.1 below presents a brief description of the different mine sections with respect to their favourability as a potential drilling target intended to access the geothermal source.

Table 5.1 Attributes of Mine Workings for Geothermal Potential

<table>
<tr><th>Mine Section</th><th>Positive Attributes</th><th>Negative Attributes</th></tr>
<tr><td>1900 Level Potash Stopes</td><td>I. Accessible from the northern side of the highway.
II. Lower elevation (greater thermal gradient).</td><td rowspan="2">I. Highest potassium concentrations.
II. Lower volume of brine in backfilled stopes.
III. Smaller target for drilling.</td></tr>
<tr><td>1500 Level Potash Stopes</td><td>I. Accessible from the northern side of the highway.</td></tr>
<tr><td>Access Ways</td><td>I. Good Connection to all parts of the mine (Heat advection and brine flow).</td><td>I. Smaller target for drilling.</td></tr>
<tr><td>Lower Salt Stopes</td><td>I. Good drilling target (preferred orientation).
II. Good Connection to Access Ways and rest of mine.
III. Potential for lower potassium concentrations.
IV. Lower Elevation (Better Thermal Potential).
V. Open and Connected stops (better flow characters).</td><td>I. Accessible only from south of Hwy 114.
II. Deepest Target, increased drilling cost.</td></tr>
<tr><td>Upper Salt Stopes</td><td>I. Good drilling target (preferred orientation).
II. Good Connection to Access Ways and rest of mine.
III. Potential for lower potassium concentrations.
IV. Lower Elevation (Better Thermal Potential).
V. Open and Connected stops (better flow characteristics).</td><td>I. Accessible only from south of Hwy 114.</td></tr>
</table>

5.2 Surface Constraints and Drilling Target Areas

The intent of this subsection is to identify areas, at ground surface, where drilling programs have a higher probability of success and a lower probability for delays and/or additional costs associated with; additional permitting or studies and environmental impacts. Figure 5.1 presents a number of surface features, present at ground surface, which have the potential to increase the time frame and costs for approval of a prospective drilling sites. The types of surface features considered in this mapping exercise include:

- Watercourses;
- Wetlands;
- Historic Sites;
- Pre-historic Sites;
- Historical Structures;
- Cemetery;
- Roads;
- Natural Gas; and
- Rail lines.

Essentially, Figure 5.1 shows the areas where an application to drill might require additional permitting and investigation or simply be rejected. Figures 5.2 to 5.6 show each drilling target (as projected to surface) and the areas where they are constrained by surface features. The areas presented as potential drilling target areas on Figure 5.2 to 5.6 have the fewest (or no) identified constraints or impacts requiring mitigation. Other potential considerations such as; land ownership, residential dwellings and existing buildings and structures, were not considered as part of this mapping exercise.

5.3 Conceptual Well Designs

Drilling into the Penobsquis mine workings is a significant undertaking. The type of system the well(s) will be servicing (open or closed loop), the type of drill selected, the desired depth of the well(s), the number, type and diameter of casings required, the anticipated geology and avoidance of impacts are only a few items which must be carefully considered. Two conceptual well designs are presented below; one for an open loop system and another for a closed loop system. The conceptual design is followed by a brief description of the rational for the design and the drilling steps and well construction details designed to avoiding impacts to potable water resources.

5.3.1 Open Loop Conceptual Well Design

The conceptual well design for an open loop system presented in Figure 5.7 involves the drilling of a 381 mm boring and the installation of a 340 mm conductor to approximately 100 mbgs. This casing fully cemented back to ground surface, as indicated by the yellow triangles and grey bar lines, respectively in Figure 5.7. The next smaller diameter boring would be a 292 mm in diameter and proceed to the Windsor Group Salts (Caprock and Basal Halite) at approximately 175 – 420 mbgs (depending on its location). The 245 mm diameter casing would then be installed inside the conductor casing and also be cemented back to surface (Figure 5.7). The final 222 mm diameter boring would then extend through the Basal Halite Salt and into the open mine workings leaving an open borehole (Figure 5.7). It is feasible to install the conductor casing using a specialized air rotary drilling rig, however beyond that, the diameters and depths of this option requires a drilling rig similar to those used for natural gas exploration and development.

It should be noted that this option offers dual casing protection to the potable aquifer and also a large diameter boring accessing the mine workings (Figure 5.7).

5.3.2 Closed Loop Conceptual Well Design

It is important to note, that because close loop systems do not remove groundwater and rely on the exchange of heat to closed pipes installed in the open well, multiple wells or a field of wells are often required. The conceptual design for a single closed loop well, is presented in Figure 5.8. as a single 203 mm casing cemented into bedrock inside a 254 borehole and an 203 mm diameter hole extending to the target depth of 300 m outside the mine workings in the Mabou group sedimentary rocks. This conceptual design was selected for the closed loop systems based on the following factors:

- A closed loop well relies on heat exchange inside an open borehole filled with sand and the heat exchange pipe and would benefit from contact with the Windsor group salts. However, environmental concerns associated with having an uncased open borehole connecting the Mabou and Windsor group Rocks is not feasible.
- A closed loop system requires a well field comprised of multiple borings/wells and drilling multiple wells into the mine workings at a depth of approximately 578 mbgs is cost prohibitive.

In this design the closed loop pipes would be installed in the open well and then backfilled with sand (not illustrated in Figure 5.8). The only protection to the potable aquifer would be form the closed loop pipe installed in the open borehole.

6.0 EXAMPLE GEOTHERMAL APPLICATIONS

The following section presents the setup and evaluation of example geothermal applications. The examples can be grouped as:

- An individual system, heating 4 acres or 20 acres greenhouses for a 4 or 12-month period.
- A district loop system, heating two 4 acre or 20 acre greenhouses, for 4 or 12-month period, and cooling either one or ten refrigeration warehouses for a 12-month period.

In total, eleven example applications were prepared, open and closed loop systems were evaluated for each example, with the exception of example D5 and D6 (open loop only), yielding 20 example cases. Table 6.1 below presents the eleven examples, organized by their user type (individual or district), user need (heating or cooling), operation type (greenhouse / refrigeration plant) and their annual periods of operation.

Table 6.1 Example Geothermal Applications

Example ID	Individual or District System	Heating or Cooling	Operational Type	Operational Period
I 1A	Individual	Heating Only	4 Acre Greenhouse	4 months
I 1B	Individual	Heating Only	4 Acre Greenhouse	12 months
I 2A	Individual	Heating Only	20 Acre Greenhouse	4 months
I 2B	Individual	Heating Only	20 Acre Greenhouse	12 months
I 3	Individual	Heating Only	20 Acre Greenhouse (Supplemental Boiler)	12 months
D 1	District	Heating and Cooling	Two 4 Acre Greenhouses and One Refrigeration Warehouse (1 Pipe System)	4 months (greenhouse) 12 months (refrigeration warehouse)
D 2	District	Heating and Cooling	Two 4 Acre Greenhouses and One Refrigeration Warehouse (1 Pipe System)	12 months
D 3	District	Heating and Cooling	Two 4 Acre Greenhouses and One Refrigeration Warehouse (2 Pipe System)	12 months
D 4	District	Heating and Cooling	Two 4 Acre Greenhouses and Ten Refrigeration Warehouses (2 Pipe System)	12 months
D 5	District	Heating and Cooling	20 Acre Greenhouse and Ten Refrigeration Warehouses (2 Pipe System)	12 months
D 5	District	Heating and Cooling	20 Acre Greenhouse and Ten Refrigeration Warehouses (2 Pipe System) (Supplemental Boiler)	12 months

The first step to evaluate a potential example case is to determine the energy loads for that application, for either heating or cooling. The second step is to establish the general parameters for the open and closed loop systems which include but are not limited to: well design (depths and diameters); fluid temperature; ground temperature and thermal properties; drilling target location; static water depths etc.

Once energy loads and basic system parameters are established, each example case is modelled using both open loop and closed loop systems. The results of the modelling, which are all a function of the energy loads, become:

- **Capital costs** of the geothermal system required to meet the load.
- **Energy consumption** of the geothermal system required to meet the load.
- **Energy savings** provided by the geothermal system as compared to the baseline energy costs.
- **Maintenance costs** of the geothermal system required to meet the load.
- **CO^2 Emissions** of the geothermal system required to meet the load.

The following sections present the example case base loads and then the open and closed loop system parameters. To simplify the presentation of the results, the derivation of the costs (which requires outputs of the modelling) will be briefly discussed prior to the results.

6.1 Example Case – Greenhouse Heating Loads

Because of their location within the study area, the Town of Sussex requested the participation of Avon Valley Floral greenhouse in Penobsquis and their historical energy consumption data. Avon Valley Floral provided their consumption of cords of wood and litres of heating oil. Amec Foster Wheeler utilized this data to establish an energy profile of the 4-acre greenhouse utilizing the assumed conversion factors for the energy content of the wood and oil used by the facility, are presented in the Table 6.2 below.

Table 6.2 Energy Conversion Factors

General Conversion Factors				
3.78541 l/gal	947817 Btu/GJ	277.778 kWh/GJ		
Energy Content - Conversion Factors				
Wood (Maple, 20% Moisture Content) (Cornerstones Energy Group, 1979)	24,400,000	Btu/cord	25.74337	GJ/cord
Oil (No. 2) (Cornerstones Energy Group, 1979)	139,000	Btu/gal	0.038742	GJ/l

(Kavanaugh and Rafferty, 2014)

Monthly consumption values (only available from 2014 to 2017) represent the greenhouse operations between February and May when bedding plants are being grown. Data from 2016 was selected as a baseline for a 4-acre greenhouse operating for 4 months. The data provided indicated that Avon Valley Floral's energy consumption in 2016 was close to its average annual consumption between 2014 and 2017. The energy consumption during 2016 represents the impact of typical weather over the heating demand: the consumption of wood and oil peaks in the coldest months, before decreasing in the spring.

Trane TRACE 700, an energy modelling program, was used to simulate the greenhouse energy use for heating and determine both the peak and average heat loads in kilo watts (kW). The heat loads (kW) drive the size of the geothermal systems while energy consumption (kWh) is used to calculate savings. The original model was calibrated using the energy consumption of 2016, with additional heat loads added in February to simulate snow melting on the greenhouse roof. The original baseline data indicated a total of 4,258,140 kWh for 2016, assuming a heating plant efficiency of 75%. This is equivalent to a building energy need of 3,193,605 kWh, which compares well with the modelled total building energy of 3,174,736 kWh.

A model representing a greenhouse operating all-year round was also built and calibrated with the yearly energy consumption provided by Avon Valley Floral for 2008. In 2008, flowers were grown year-round, providing a baseline for a 4 acre greenhouse operating for 12 months. The modelled building energy need, simulating the greenhouse in operation year-round, was found to be 9,194,944 kWh. In comparison, the energy consumption of the greenhouse in 2008 was 11,535,421 kWh. However, assuming a heating plant efficiency of 75%, the building need in 2008 was 8,651,565 kWh.

For comparison purposes, typical greenhouse energy consumption is about 695 kWh/(m^2 ·yr) in the United states (https://www.fs.fed.us/rm/pubs/rmrs_p058/rmrs_p058_007_009.pdf). For the Avon Valley Floral greenhouse (16,679 m^2, excluding greenhouse 5 which is still under construction), the calculated average energy consumption compares well with the referenced value at 692 kWh/(m^2 ·yr) for 2008.

The heating load for the other individual heating example cases are scaled from these base load profiles. The load profiles for all example cases are presented on the USB drive in Appendix C.

6.2 Example Case - Refrigeration Warehouse Cooling Loads

To simulate cooling loads on the district systems, a 60m long by 70m wide refrigerated produce warehouse was simulated using the KeepRite design software (Loads profiles on USB drive in Appendix C). The KeepRite design software output report (Appendix C) shows the assumptions and results. Design loads were then extrapolated based on the outdoor temperature from the Fredericton International Airport (Fredericton Intl, NB, WMO# 717000) to generate a monthly load profile of the refrigerated warehouse and an annual load of 1,858,180 KWh.

6.3 Open Loop General System Parameters

The open loop general system parameters presented below in Table 6.3 are derived from several sources. Given the discussions above in Section 4.0 with respect to water levels, water chemistry, water temperature and in Section 5.0 with respect to well design and diameters, a number of assumptions are required to establish these general system parameters. The source of the data for each parameter is indicated in Table 6.3 with the conceptual well design for the open loop systems presented in Figure 5.7.

Table 6.3 Open Loop General System Parameters

Parameter	Value or Range	Comment / Assumptions
Drilling Target	Upper Salt Stopes	The shallower upper salt stope target area presented in Figure 5.5 was selected because of its size, geometry and depth (approximately 578 mbgs), and other favourable attributes.
Well Total Depth	578 mbgs	Depth required to reach the upper salt stope target area.
Brine Temperature	14.7°C	The temperature was selected based on the Cassidy Lake profile for Shaft 1 from Figure 4.4 at a depth of 570 mbgs.
Static Water Level	166.5 mbgs	The static water level within the upper salt stope is not known. There are two PotashCorp Monitoring wells at a distance of 1 and 1.5 km from the target area. It has been assumed that an average of two water level values collected from transducers (transducer depths of 618 and 434 mbgs) in these two wells outside the mine workings is representative of the static water level of a well accessing the upper salt stopes of the Penobsquis Mine. This is a significant assumption and requires further evaluation as the water levels connected to the mine are not understood. This assumption is discussed further in Section 13.0.
Aquifer Thickness	411.5 m	It is estimated that the aquifer extends from the Static Water Level (166.5 mbgs) to the bottom of the well (578 mbgs).
Well Design	See Figure 6.1 Conceptual Well Design	The well design is a modified version of Option 2. With some of the casing diameters changed. All costs for open loop wells are based on this conceptual well design.
Well Casing Diameter	0.203 m	This larger casing diameter and resulting screen diameter is used to accommodate larger pump sizes and assumed higher flows. This casing and screen size should be updated and re-checked depending on the pumping flow rate.
Well Screen Diameter	0.203 m	
Well Pump Type	Submersible	Common well pump type.
Well Pumping Requirement	0.015 to 0.045 L/s.kW	This is a typical range. The maximum pumping flow rate (L/s) should not exceed the maximum flow available from the well.
Maximum Flows from Pumping and to Injection Wells	80.3 L/s	The historical Penobsquis mine inflow rate was selected as the maximum pumping and injection rate.
Well Specific Capacity	1.66 L/s.m	Specific capacity (SC) is an index of the well's ability to deliver water. It is calculated by dividing the pumping rate by the drawdown. In all reality, SC is not a constant value (a pumping test is required). A typical value was used (Rafferty, 2009).
Heat Exchanger Type	Plate - Titanium	Chloride ppm > 1000, titanium is recommended (Kavanaugh and Rafferty, 2014).
Heat Exchanger Approach Temp	1.4°C	To minimize scaling, a low approach temperature (difference between fluid entering heat exchanger and leaving heat exchanger) needs to be maintained. The closer the approach, the more efficient the operation of the heat pumps as a result of more favourable temperatures but pipes, pumps, and heat exchangers are more expensive due to increased water flow rate, and pumping costs are therefore higher.

Parameter	Value or Range	Comment / Assumptions
Building Loop Flow Rate	0.05 L/s.kW	Typical (Rafferty, 2009).
Building Loop Length	2000 m	Longer building loop will increase pumping pressure loss and piping length. The costs involved in increasing the building loop length are small in comparison to the cost of installing the well system.
Surface Piping Loss	0.04 m/m	(Kavanaugh and Rafferty, 2014).
Fitting Adjustment	25 %	(Kavanaugh and Rafferty, 2014).
Heat Exchanger Loss	3.5 m	Equivalent to 35kPa or 5 psi – typical selection point.
Pump Efficiency	70%	(Kavanaugh and Rafferty, 2014).
Motor Efficiency	80%	

6.4 Closed Loop System Parameters

In a closed loop system, the number of boreholes required to meet a given energy load are dependent on various properties. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Borehole Sizing spreadsheet (www.ashrae.org/borehole.xls) can be used to get a quick estimate of the total required borehole length in a closed loop system. The equation used to perform the calculation was proposed by Bernier (2006). The equation has the following form:

$$L = \frac{q_h\, R_h + q_y R_{10y} + q_m R_{1m} + q_h R_{6h}}{T_m - (T_g + T_p)}$$

Where

- L is the total borehole length,
- T_m is the mean fluid temperature in the borehole,
- T_g is the undisturbed ground temperature,
- T_p, the temperature penalty, represents a correction to the undisturbed ground temperature due to thermal interference between boreholes. In our case, we consider a single borehole, $T_p = 0$,
- q_y, q_m and q_h represent, respectively, the yearly average ground heat load (thermal annual imbalance), the highest monthly ground load and the peak hourly ground load. The values were obtained from the Trace model results,
- R_{10y}, R_{1m} and R_{6h} are effective ground thermal resistances corresponding to 10 years, one month and six hours ground loads, and
- R_b is the effective borehole thermal resistance.

In this context, with greenhouses and refrigerated warehouses heated and / or cooled by the geothermal system, the borehole sizing spreadsheet was not usable to size a multiple boreholes system.

The borehole sizing spreadsheet was used to calculate the total length of borehole required to provide the required peak loads, as if it was only 1 borehole. It was then assumed that the number of boreholes would be calculated based on a depth of 300 metres (m) deep and a spacing of 12 m. The 12 m spacing should be sufficient to minimize the thermal interferences between boreholes.

In the case of a closed loop system, the values presented in Table 6.4 were used as general parameters.

Table 6.4 Closed Loop General System Parameters

	Variable	Unit	Value	
Ground Loads				
Peak hourly ground load	q_h	W	-	Calculated following Bernier, M. 2006. “Closed loop ground coupled heat pump systems” ASHRAE Journal 48(9):12-19
Monthly ground load	q_m	W	-	
Yearly average ground load	q_y	W	-	
Ground Properties				
Thermal conductivity	k	$W.m^{-1}K^{-1}$	1.87	For a borehole down to 300 mbgs
Thermal diffusivity	α	$m^2.day^{-1}$	0.062	For a borehole down to 300 mbgs
Undisturbed ground temperature	T_g	°C	9.1	For a borehole down to 300 mbgs (based on fitted equation in Figure 4.3)
Fluid Properties				
Thermal heat capacity	Cp	$J.kg^{-1}.K^{-1}$	4182	Water
Total mass flow rate per kW of peak hourly ground load	m_{fls}	$kg.s^{-1}.kW^{-1}$	-	Adjusted for each case
Max/min heat pump inlet temperature	T_{inHP}	°C	8	Provides best efficiency without using glycol
Borehole Characteristics				
Borehole radius	r_{bore}	m	0.100	
Pipe inner radius	r_{pin}	m	0.0190	Given the flowrates, larger pipes are used
Pipe outer radius	r_{pext}	m	0.0260	
Grout thermal conductivity	k_{grout}	$W.m^{-1}.K^{-1}$	3.00	100% sand
Pipe thermal conductivity	k_{pipe}	$W.m^{-1}.K^{-1}$	0.80	High thermal conductivity HDPE gives better payback in our cases
Center-to-center distance between pipes	L_U	m	0.1480	Pipes set to touch the outside of the borehole
Internal convection coefficient	h_{conv}	$W.m^{-2}.K^{-1}$	1000	Typical

6.5 Financials

The estimated costs are discussed in this subsection, divided into capital costs and maintenance costs.

6.5.1 System Capital Costs

The costs used to estimate the capital investment for each scenario in this study are based on geothermal and drilling experience, construction cost data from RSMeans (including a cost adjustment for New Brunswick of 93.1), and component costs found in other referenced literature (Kavanaugh and Rafferty, 2014; Rafferty, 1991).

To simplify this analysis, component costs were set as a function of units whose amounts were dependent on the system's design. In this way, the equations allowed the costs to be automatically updated when the system design was modified. Where indicated, specific costs derived as part of this study are presented. All capital costs carried as part of the evaluation are captured below in Table 6.5.

Table 6.5 Geothermal Systems Capital Costs

Item	Cost	Unit	Source
Drilling (0.203m) – Open Loop Conceptual Design Figure 6.1 (includes casing)	\$3,549,100	Per Well Pair (pumping and injection)	Existing Quotations and Experience
Drilling (0.203m) – Closed Loop Conceptual Design Figure 6.2 (includes casing)	\$31,540	Per Well	
Well Screen	$604 * diameter - 9.4$	\$CAD/m	RSMeans – Mechanical – 2017 – 33 21 Water Supply Wells
Flow Test – Step Drawdown	710	EA	Kavanaugh and Rafferty, 2014
Well Pump	$1230 * kW + 1320$	EA	RSMeans – Mechanical – 2017 – 33 21 Water Supply Wells
Well Pump Installation	20% of well pump	EA	Kavanaugh and Rafferty, 2014
Heat Exchanger	$35 * kW + 5754$	EA	Kavanaugh and Rafferty, 2014
Heat Exchanger – Titanium Premium	50% of heat exchanger	EA	Rafferty, 1991
Mechanical Room Piping	25% of heat exchanger	EA	Kavanaugh and Rafferty, 2014
Strainer – Iron body basket strainers	$377 * exp^{12*diameter}$	EA	RSMeans – Mechanical – 2017 – 23 21 Hydronic Piping and Pumps
Buried Piping – HDPE	$317 * diameter - 5$	\$CAD/m	Experience
Heat Pump	$322 * kW + 868$	EA	RSMeans – Mechanical – 2017 – 23 81 Decentralized Unitary Equipment
Excavation, filling and paving a trench (2m deep, 1m wide)	115	\$CAD/m	Experience
Circulation Pump	$906 * kW + 7695$	EA	RSMeans – Mechanical – 2017 – 23 21 Hydronic Piping and Pumps

Item	Cost	Unit	Source
Oil-Fired Boiler	$0.0231 * kW^2 + 9.84 * kW + 11762$	EA	RSMeans – Mechanical – 2017 – 23 52 23.40 – Oil-Fired Boilers
Bentonite Grout (k=1.25 W/m°C)	1000	$CAD/m^3	Experience
Quartz Sand (k=3 W/m°C)	280	$CAD/m^3	Experience
Supplement for HDPE with high thermal conductivity (k=0.8 W.m°C)	+ 25 % of regular HDPE		Experience
Spacer Installation	3 (every 3 m)	EA	Experience
Contingency	15% of total cost		Experience

6.5.2 Estimated Maintenance Costs

The maintenance costs for an open loop system are based on (Kavanaugh and Rafferty, 2014) these equations which are automatically updated at the same time as the system's design is modified. The maintenance costs include:

- Water well maintenance: 10% of the well construction cost, every 8 years (assumes the geology to be a combination of consolidated/unconsolidated materials).
- Heat exchanger maintenance: 8 hours with 2 workers, once a year.
- Strainer blowdown: 8 times per year, 15 minutes each time.
- Well pump(s) replacement: every 15 years.

Maintenance costs for an open loop system are difficult to estimate, due to the variable water quality on the ground water side of the system. The well system, can be affected by more scaling and/or corrosion than expected and then requires additional heat exchanger and piping cleaning, which can be substantial.

With respect to closed loop systems, they require very little maintenance, due to controlled quality of water used to fill the system. In the following comparisons cases of open loop vs closed loop, system maintenance costs were assumed to be negligible. In reality, there is some maintenance cost for a closed system, however those same costs apply to an open loop system so when comparing the two, these costs cancel out.

6.5.3 Discounted Pay Back Period Factors

Essentially, the discounted payback period is the time (in years) for the savings generated by the geothermal system to pay off the initial capital investment as well as operational costs and energy consumption. The discounted payback period presented with the results is calculated using a general inflation rate of 2% (Bank of Canada), an energy inflation rate of 3% (National Energy Board Canada), and a discount rate of 3% (Bank of Canada). The capital costs, operation and maintenance costs, as well as energy savings (consumption of energy by the system - the energy revenue provided by the system), are all included in the calculation of the discounted payback period.

7.0 RESULTS OF EXAMPLE CASES

7.1 Results of Individual Users Example Cases

In our presentation of example geothermal applications, we presented Table 6.1, which has five examples of individual users. The results of evaluating those five examples using both open and closed loop systems examples is presented in Table 7.1. The detailed spreadsheets used to model the example cases are presented on the USB drive in Appendix C.

7.1.1 Individual User Example Cases – Open Loop System Highlights / Comments

- Scaling risks in an open loop system, with pipes and heat exchangers exposed to groundwater, are very difficult to estimate and can greatly penalize the global system's performance. Scaling decreases heat exchange rates, increases pumping requirements, and increases maintenance and replacement costs.
- (Example I 1A O) Building an individual open loop system for a 4 acre facility operating for 4 or 12 months of the year does not return a favorable discounted payback period.
- (Example I 2A O and I 2B O) It is not possible to scale up the current open loop system to heat a 20 acres greenhouse. The flow rate required exceeds the historical inflow rate for the Penobsquis mine.
- (Example I 3 O) As an alternative, a supplemental boiler could be used to provide heat to the building water loop when the building load is above the well capacity (about 6,000 kW). This option provides the best discounted payback period of all the individual example cases at 11 year.
- The amount of energy that can be harvested with an open loop system, thanks to direct heat exchange with the mine water, is attractive.

7.1.2 Individual Users Example Cases – Closed Loop Systems Observations

- Specific ground heat transfer calculations will need to be performed to calculate the thermal interference between the boreholes and select an adequate arrangement.
- Even without additional calculations, a decrease of the average ground temperature is expected over the years, associated with a decrease of the system's overall performance. This is due to a highly imbalanced building load: heat is discharged at a high rate, all year-round, from the ground to the building but never recharged.
- Contrary to the open loop systems, the proposed closed loop systems are no deeper than 300 mbgs, to protect from potential environmental impacts, and are not taking advantage of the thermal properties of the mine workings or the Windsor group salt rock. By not accessing the workings or the salt, the thermal conductivity and undisturbed ground temperature are lower, diminishing the potential heat yield. However, limiting the depth to 300 mbgs allows for lower installation costs.
- In the conditions simulated, closed loop systems do not seem to provide a good payback and come with a high capital investment.
- Ground heat loads should be reduced by using a supplemental boiler for example, or balanced by adding buildings with cooling loads on the loop. Otherwise the geothermal field size will become un-realistic.

Table 7.1 Results of Example Cases for Individual Users

Example ID 1	User Type and Period	Capital Costs (in thousands)	Operational and Maintenance Costs (annual)	System Consumption (annual) 2	System Savings 3	Discounted Pay Back Period (years) 4	Comments
I 1A O	4 Acre Green House (4 months)	k$6,051	$68,754	$101,218	$59,635	1727	1 pair of wells
I 1A C		k$21,216	$0	$60,426	$100,428	218	420 bores. 300m deep
I 1B O	4 Acre Green House (12 months)	k$6,044	$68,688	$292,355	$173,522	53	1 pair of wells
I 1B C		k$26,510	$0	$174,499	$305,810	89	531 bores. 300m deep
I 2A O	20 Acre Green House (4 months)	k$14,312	$159,030	$509,436	$294,834	90	**1 pair of wells – Max flow well is 80.3L/s. Required flow is 165 L/s.**
I 2A C		k$104,754	$0	$305,113	$499,153	216	2100 bores. 300m deep
I 2B O	20 Acre Green House (12 months)	k$12,280	$159,030	$1,517,069	$884,475	17	**1 pair of wells – Max flow well is 80.3L/s. Required flow is 165 L/s.**
I 2B C		k$131,056	$0	$908,585	$1,492,959	90	2651 bores. 300m deep
I 3 O	20 Acre Green House (12 months) Supplemental Boiler	k$9,484	$102,893	$1,352,951	$1,470,400	11	1 pair of wells. Flow is ok.
I 3 C		k$89,897	$0	$746,428	$1,582,958	59	1693 bores. 300m deep.

Notes:
1. Example ID – I = Individual, O = Open Loop, C = Closed Loop.
2. System Consumption is the cost of energy to power the geothermal system.
3. System Savings is the revenue generated by the geothermal system. It is calculated as the cost of baseline energy – cost of the energy consumption of the system. In all examples the baseline energy costs is the cost of wood at $270 / cord to supply the calculated heating loads with an efficiency of 75%.
4. The discounted payback period is discussed in section 6.5.3.

7.2 Results of Multiple User District Loop Example Cases

In our presentation of example geothermal applications, we presented Table 6.1 which showed 6 district user examples. The results of evaluating those six examples using both open and closed loop systems examples, with the exception of D5 and D6 (open loop only), is presented in Table 7.2. The detailed spreadsheets used to model the example cases are presented on the USB drive in Appendix C.

7.2.1 District Users Example Cases – Highlights / Comments

- A “1 Pipe” system (D 1 and D 2) is the most efficient at taking advantage of a loop with heating and cooling needs. By placing the building requiring cooling first on the loop, the water getting to the second building, with heating loads, will be pre-heated and its heat pumps will be more efficient. Tuning 1 Pipe systems is difficult and adding buildings to the loop is more challenging than with a “2 Pipe” system.
- In a “2 Pipe” system (D 3, D 4, D5 and D 6), the district loop fluid enters all the heat pumps at the same temperature. Contrary to a 1 Pipe system, heat pumps are not in series, but in a parallel configuration. While not necessarily the most efficient configuration, a 2 Pipe system allows greater flexibility for adding buildings at any location on the district loop.
- By combining buildings with cooling loads and building with heating loads on the loop, reasonable payback can be achieved in the case where the greenhouse is producing year-round.

Table 7.2 Results of Example Cases for District Users

Example ID 1	User Type and Period	Capital Costs (in thousands)	Operational and Maintenance Costs (annual)	System Consumption (annual) [2]	System Savings 3	Discounted Pay Back Period (years) [4]	Comments
D 1 O	2 (4 Acre Green Houses) (4 months) and 1 Refrigeration Warehouse (12 months) 1 Pipe System	k$7,673	$88,890	$251,529	$205,238	60	1 pair of wells
D 1 C		k$40,862	$0	$140,058	$316,709	133	833 bores. 300m deep
D 2 O	2 (4 Acre Green Houses) and 1 Refrigeration Warehouse (12 months) 1 Pipe System	k$7,665	$88,804	$622,919	$443,896	21	1 pair of wells
D 2 C		k$52,417	$0	$362,155	$704,660	77	1054 bores. 300m deep
D 3 O	2 (4 Acre Green Houses) and 1 Refrigeration Warehouse (12 months) 2 Pipe System	k$8,166	$89,080	$746,735	$320,079	34	1pair of wells. 2-PIPE
D 3 C		k$54,341	$0	$368,176	$698,639	80	1093 bores. 300m deep. 2-PIPE
D 4 O	2 (4 Acre Green Houses) and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$8,558	$74,061	$993,503	$1,228,092	7	1 pair of wells. 2-PIPE
D 4 C		k$26,100	$0	$608,653	$1,672,942	16	478 bores. 300m deep. 2-PIPE
D 5 O	20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$14,150	$127,205	$2,185,387	$1,493,840	11	1 pair of wells. 2-PIPE
D 6 O	20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System (Supplemental Boiler)	k$11,309	$97,896	$1,969,341	$1,709,885	7	1 pair of wells. 2-PIPE. Supplemental Boiler

Notes:

1. Example ID – D = District, O = Open Loop, C = Closed Loop.
2. System Consumption is the cost of energy to power the geothermal system.
3. System Savings is the revenue generated by the geothermal system. It is calculated as the cost of baseline energy – cost of the energy consumption of the system. In all examples the baseline energy costs is the cost of wood at $270 / cord to supply the calculated heating loads with an efficiency of 75%.
4. The discounted payback period is discussed in Section 6.5.3.

8.0 CALCULATION OF GREEN HOUSE GAS REDUCTIONS

In 2016, the Federal Government and most Provinces and Territories, including New Brunswick, committed to objectives and actions in the Pan-Canadian Framework on Clean Growth and Climate Change (http://publications.gc.ca/site/eng/9.828774/publication.html). In this plan, each jurisdiction has established targets for 2030 and 2050 to reduce Greenhouse Gas (GHG) emissions, increase the percentage of clean energy sources, and establish a carbon pricing mechanism by 2018. As part of its response, New Brunswick has established a climate change action plan titled "Transitioning to a Low-Carbon Economy"; which re-dedicates the Provincial government to the national plan and identifies 118 specific actions to implement GHG reductions and climate adaptation planning. These include supporting the transition from traditional fossil fuels to clean energy such as wind, nuclear, hydroelectric, and geothermal, and the establishment of a carbon price in 2018. The carbon price per tonne is expected to rise from $10 to $50 by 2022. The details of such planning have not yet been provided but is likely to include a levy on fuel consumption and/or a cap-and-trade price for large emitters (such as power utilities). These levies are typically transferred to the customers as direct taxes or increased fuel/energy costs.

The implication of these policies for the development of geothermal energy in NB is mainly that long term savings in fuel costs are possible by reducing consumption of fossil fuels (including grid electricity, which is based partly on fossil fuel generation). It is also possible that the Province may fund incentive programs for installation or conversion to geothermal energy from fossil fuels.

In terms of environmental benefits, the use of geothermal energy to displace fossil fuels will reduce GHG emissions and eliminate local air contaminants (especially fine particulate) that is produced by burning wood or fossil fuels. Comparing to grid electricity, the reduction in GHG emissions for the example applications ranges from less than approximately 800 tonnes to 14,000 tonnes per year. The CO_2 emitted by the proposed geothermal systems was estimated using the following factors:

- 280 g CO_2/kWh of electricity consumed (Environment and Climate Change Canada, 2017); and
- 257 g CO_2/kWh of heating oil consumed (Environment and Climate Change Canada 2017) when a supplemental boiler was simulated.

The CO_2 emitted by the proposed geothermal systems is compared to CO_2 emitted by the baseline system for each design case. CO_2 emissions for the baselines are assuming facilities using 100% electricity for heating and cooling. The carbon emissions for the 18 example cases are presented below in Table 8.1.

Table 8.1 Calculated CO_2 Emissions

Example ID 1	System Emissions (tonnes of CO2 emitted)		
	Proposed System	Baseline Energy (Grid Electricity)	Reduction (Baseline – proposed)
I 1A O	389	1,185	796
I 1A C	232	1,185	953
I 1B O	1,126	3,433	2,307
I 1B C	672	3,433	2,761
I 2A O	1,957	5,926	3,969
I 2A C	1,172	5,926	4,754
I 2B O	5,843	17,696	11,853
I 2B C	3,500	17,696	14,196
I 3 O	7,550	17,164	9,614
I 3 C	5,810	17,164	11,354
D 1 O	963	2,891	1,928
D 1 C	536	2,891	2,355
D 2 O	2,395	7,386	4,991
D 2 C	1,393	7,386	5,993
D 3 O	2,858	7,386	4,528
D 3 C	1,416	7,386	5,970
D 4 O	3,891	12,068	8,177
D 4 C	2,363	12,068	9,705
D 5 O	8,285	22,367	14,082
D 6 O	9,947	22,367	12,420

Notes:

1. Example ID D = District, O = Open Loop, C = Closed Loop.

Until recently, GHG by relatively small emitters (under 50,000 tonnes per year) were not captured in the national registry or in provincial accounting of total GHG emissions. However, the federal government beginning in 2017 and some other jurisdictions like Ontario are proposing to include all emitters above 10,000 tonnes per year; which would be in the possible range of geothermal development examined in this study.

9.0 COST BENEFIT ANALYSIS

There are many known beneficial impacts associated with the use of geothermal technology to produce energy, compared with other energy sources. These benefits, can broadly be grouped into two categories: environmental and economic. The environmental benefits are essentially that there are relatively few negative impacts for such a development, especially with closed loop systems. It should be noted that additional considerations should be made concerning open loop systems which use brine as a geothermal fluid. There are few emissions (air, water), few public health concerns (noise, visual), which would likely require very limited mitigation measures. The economic benefits may include revenue generation for the community (taxes, royalties), job creation from the construction and operations/maintenance, and other potential benefits. Both environmental and economic benefits associated with the use of the geothermal technology, relative to other energy producing technologies, are applicable across all the options being discussed for this project.

Amec Foster Wheeler considers a Cost-Benefit Analysis (CBA) for a project to be an analysis which estimates the dollar value of costs and benefits to a community to establish if it is worthwhile (Watkins 2018). For the sake of this analysis, identified costs and benefits can fall within different categories: direct/indirect, tangible/intangible, and real/transfer (Holquist 2013). These analyses are generally conducted when assessing a proposed development in direct comparison with the status quo and/or relative to different but comparable developments. A CBA would be appropriate for a comparison of a proposed geothermal power generation plant with the development of different energy source, such as gas, coal, nuclear, or wind.

A CBA includes an extensive analysis of community environmental variables (i.e. pollution, land degradation, health risks) and economic variables (i.e. employment and revenue generation). Many of these costs and benefits are “externalities”, which can be monetary or non-monetary and do not enter into commercial accounts. This makes them difficult to quantify (Cameron 2011). Externalities can include:

- Aesthetic concerns (viewscape);
- Environmental concerns;
- Water usage;
- Waste and wastewater disposal;
- Transportation;
- Land degradation;
- Pollution (land, water, air, noise); and
- Zoning.

A more appropriate analysis for the present project is a comparative analysis of the financial elements which are used to calculate the discounted pack back periods for the numerous different options for geothermal applications. As such, Amec Foster Wheeler has combined the following elements of our analysis to provide a financial comparison of the previous 20 examples. The parameters include:

- the capital and operational costs;
- the energy consumption costs and revenue (as energy savings); and
- the discounted payback period (assuming no financing of the capital costs).

The results are shown in Table 9.1 entitled Financial Comparison of Example Applications.

With the primary variables between the cases being:

1. Open vs Closed Loop Systems.
2. Individual vs. District systems.

We can begin to compare the costs and savings (revenue) generated for the 18 cases with respect to these variables in Table 9.1. Without question, under the conditions and settings modelled the open loop capital costs are more attractive compared to the closed loop systems. In comparison, maintenance costs, energy consumption, and savings are more favourable for closed loop systems. While most of the metrics are better for the closed loop system the return on investment favours open loop systems because of the lower capital costs. These same observations hold true with respect to the district systems.

Table 9.1 Financial Comparison of Example Applications

Example ID 1	User Type and Period	Capital Costs (in thousands)	Operational and Maintenance Costs (annual)	System Consumption (annual) 2	System Savings 3	Discounted Pay Back Period (years) 4
I 1A O	4 Acre Greenhouse (4 months)	k$6,051	$68,754	$101,218	$59,635	1727
I 1A C		k$21,216	$0	$60,426	$100,428	218
I 1B O	4 Acre Greenhouse (12 months)	k$6,044	$68,688	$292,355	$173,522	53
I 1B C		k$26,510	$0	$174,499	$305,810	89
I 2A O	20 Acre Greenhouse (4 months)	k$14,312	$159,030	$509,436	$294,834	90
I 2A C		k$104,754	$0	$305,113	$499,153	216
I 2B O	20 Acre Greenhouse (12 months)	k$12,280	$159,030	$1,517,069	$884,475	17
I 2B C		k$131,056	$0	$908,585	$1,492,959	90
I 3 O	20 Acre Greenhouse (12 months) Supplemental Boiler	k$9,484	$102,893	$1,352,951	$1,470,400	11
I 3 C		k$89,897	$0	$746,428	$1,582,958	59
D 1 O	2 (4 Acre Greenhouses) (4 months) and 1 Refrigeration Warehouse (12 months)	k$7,673	$88,890	$251,529	$205,238	60
D 1 C		k$40,862	$0	$140,058	$316,709	133
D 2 O	2 (4 Acre Greenhouses) and 1 Refrigeration Warehouse (12 months)	k$7,665	$88,804	$622,919	$443,896	21
D 2 C		k$52,417	$0	$362,155	$704,660	77
D 3 O	2 (4 Acre Greenhouses) and 1 Refrigeration Warehouse (12 months)	k$8,166	$89,080	$746,735	$320,079	34
D 3 C		k$54,341	$0	$368,176	$698,639	80
D 4 O	2 (4 Acre Greenhouses) and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$8,558	$74,061	$993,503	$1,228,092	7
D 4 C		k$26,100	$0	$608,653	$1,672,942	16
D 5 O	20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$14,150	$127,205	$2,185,387	$1,493,840	11
D 6 O	20 Acre Greenhouse and 10 Refrigeration Warehouse (12 months) 2 Pipe System	k$11,309	$97,896	$1,969,341	$1,709,885	7

Notes:
1. Example ID – I = Individual, D = District, O = Open Loop, C = Closed Loop.
2. System Consumption is the cost of energy to power the geothermal system.
3. System Savings is the revenue generated by the geothermal system. It is calculated as the cost of baseline energy to replace it. In these examples the baseline energy the costs of wood at $270 / cord to supply the calculated heating loads with an efficiency of 75%.
4. The discounted payback period is discussed in Section 6.5.3.

There are also a number of other capital costs associated with a geothermal development, which are not calculable for this simple comparative analysis without in-depth site-specific information. While not exhaustive, the following is a list of tangible cost variables that could apply to this development:

- Property costs;
- Property taxes;
- Insurance costs, including liability;
- Power sales agreement with NB Power;
- Provincial royalty costs;
- Possible environmental assessment costs (EIA triggered?);
- Permitting (regulatory planning) costs;
- Public consultation; and
- Other property land use/easements (process and cost).

A number of these listed potential costs are associated with the size of the development. For an individual, off-grid, self-sufficient energy user, many of these would not apply. However, at the other end of the spectrum, for a large-scale district “energy provider” or local “utility”, these would all apply. Given the wide variability of these costs and the lack of project site-specific information, an accurate calculation of these potential costs cannot be made at this time.

10.0 ENVIRONMENTAL CONCERNS FOR POTABLE GROUNDWATER

Potable groundwater is typically found a few mbgs in bedrock and at depths of 30 to 100 mbgs.

The likely concerns associated with any development with the potential to impact potable groundwater is that the activity will impact the groundwater quality and or quantity. The following sections will present an overview of the hydrogeology and groundwater quantity and quality of the study area. The section will conclude with a summary of potential actions to minimize or mitigate potential impacts to potable groundwater during the development of the geothermal resource.

10.1 Overview of Hydrogeology of the Area

10.1.1 Groundwater Quantity

Most of the available groundwater information (reports, databases and mapping) with respect to quantity and quality is for the potable water depth or from approximately 30 to 100 mbgs. A study of a representative portion of the Maritimes Carboniferous Basin (Rivard et. al, 2008a), which extends into the Penobsquis area, indicates that the glacial tills that overlie the sedimentary rocks within the Maritimes Carboniferous Basin are considered poor aquifers. However, unconsolidated sandy and gravelly sediments can form aquifers with significant potential, such as those observed in the communities of Sussex and Sussex Corner approximately 10 km south west of the Mine site. The surficial mapping (Pronk, 2005b) indicates that the largest yielding wells in the Sussex and Sussex Corner wellfields are established within glaciofluvial outwash deposits that exist near the Penobsquis mine site.

With respect to bedrock, the Rivard (2008b) study also suggests that as hydrostratigraphic units (aquifers), the Mabou Group and the Boss Point formations exhibit poor and variable aquifer potential, respectively. However, while considered to be variable, with aquifer quality from good to poor, the Boss Point formation, which lies just northeast of the mine site, was considered to be the best aquifer within the Moncton Basin by Carr (1964). Carr also noted that the base of the Boss Point formation, and contact with the finer Mabou group, was often a source of springs, an example of which can be seen in the community of Springdale.

Generally, the project area and mine site are situated within the Kennebecasis River valley between two long parallel ridges trending northeast-southwest. As expected, overall drainage from the two highland ridges is toward the Kennebecasis River. These two highlands are suspected to serve as recharge zones for the surficial deposits and potable depth bedrock aquifers (Boss Point and Mabou Group). As precipitation falls and drains towards the river, infiltration and recharge of the shallow and potable levels generally occurs. In some locations, this recharge from higher elevations likely drives the artesian pressures often observed along the edges of the river valley where the coarse-grained Boss Point sandstone overlies the fine grained Mabou group sediments as referenced by Carr (1964).

With increasing depth, the hydrogeology of the area becomes increasingly complex. The presence of the mine and its geological structure and mapped geological faults can sometimes impart influence on groundwater flow. The interaction of deep seated groundwater with the historical mine inflow is also another consideration, at present, the current information and understanding of the flooding process is not fully understood. This means that the water levels in the deep aquifers and within the mine workings are not known. These are two very important factors in the overall understanding of the hydrogeology of the Penobsquis area.

10.1.2 Groundwater Quality

With respect to water quality from the potable levels the New Brunswick Groundwater Chemistry Atlas (New Brunswick Department of Environment (NBENV) 2008), a comparison of SA results with those from the NBENV Atlas (2008), show that the water chemistry at the potable depths in the Penobsquis area are acceptable.

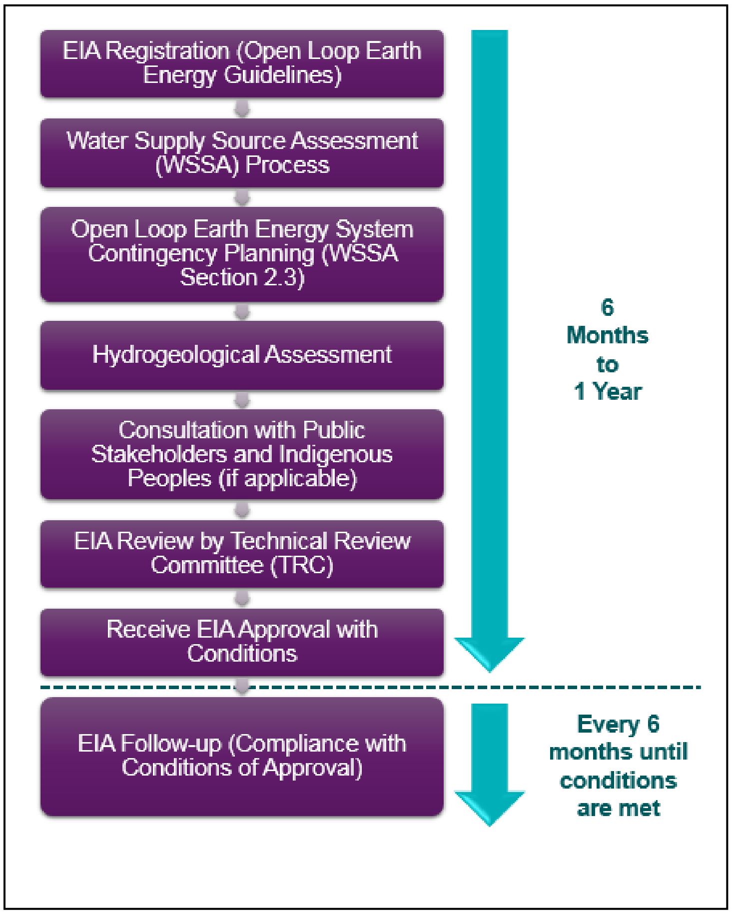
With respect to the quality of water beyond the potable depth, it is common to observe an increasing trend with depth for parameters such as chloride, sodium and total dissolved solids (TDS) when drilling to depths beyond 100 mbgs in the Maritimes Carboniferous Basin. Therefore, it would be typical to observe poorer quality water beyond the potable water depths and at the depths where the geothermal wells would be installed.

10.2 Mitigation Action to Protect Potable Groundwater

As discussed above, drilling to access the geothermal potential proceeds to depths of 300 to 570 mbgs well below the conceptual potable groundwater depths. Protection of the potable groundwater resource and mitigation of potential impacts during the development of the geothermal resource can be accomplished if proponents can demonstrate:

- A comprehensive understanding of the hydrogeology of the study area;
- A well design which provides adequate protection for the potable aquifer; and
- Short-term (during construction) and long term (during operation) monitoring programs which detail both potential impacts and mitigation measures to address them.

11.0 REGULATORY ROAD MAP



This discussion of regulatory requirements focusses on an open loop system, based on the range of options modelled in this study. A closed loop system would not generally require an EIA or any environmental approval, unless it was proposed in a sensitive habitat area or was deemed to have some other EIA trigger. The feasible open loop systems in this study require relatively large volumes of groundwater, ranging from approximately 2,800 to 6,800 cubic metres per day (m^3/d). Projects using greater than 50 m^3/d must be registered under the NB *Environmental Impact Assessment (EIA) Regulation*. Several open loop geothermal projects have been approved in NB and there is a sector specific EIA guideline for "Open Loop Earth Energy Systems" (Sector Guideline). The entire process can take from six months to one year to obtain the Approval. This process is presented in Figure 11.1.

Figure 11.1 Regulatory Road Map for Open Loop Earth Energy Systems

The registration consists of a project description, characteristics of the ecological and socio-economic environment, potential impacts and standard mitigation that will be applied to minimize or eliminate impacts. In compliance with the Sector Guideline, specific sensitive areas must be avoided, such as protected wellfield areas and protected watershed areas; none of which are present within the conceptual development areas associated with the former mine sites. Legal access to the proposed project footprint must be demonstrated, either through ownership of the property by the proponent or landowner agreements. A registration fee must also be provided with the registration; in this case $1,100.

The Sector Guidelines require a Water Supply Source Assessment (WSSA) as a key component of the EIA review, to evaluate the quantity (sustainability), water quality and potential impacts to existing water users. As part of the WSSA, a Contingency Plan must be developed (Section 2.3 of the WSSA Guidelines), to address such issues as artesian flowing wells, insufficient return well capacity, potential reduced return well capacity due to biofouling, known poor water quality groundwater (e.g. saline groundwater), and leakage of refrigerant (if applicable). If there is the potential for saltwater to be encountered, the Contingency Plan must outline the mitigation measures that will be undertaken during well construction, aquifer testing and installation phases to ensure re-injection occurs in the same or similar quality aquifer and to minimize the risk of contaminating freshwater aquifers. The Contingency Plan must be prepared by a Canadian Geo-Exchange Coalition (CGC) certified industry professional in conjunction with either a New Brunswick licensed water well driller or a Professional Engineer and/or Geoscientist registered in New Brunswick. The WSSA Permit Application and the Contingency Plan are submitted with the EIA registration for review. When the Contingency Plan has been approved, the WSSA field component (a hydrogeological assessment) can be conducted. The results of the WSSA are then provided in a report.

Public and stakeholder consultation will be required, the scope of which would be determined by the regulators. This may include consultation with Indigenous Peoples, subject to regulatory review. At a minimum, it is expected that standard EIA registration notices would be posted in local and regional newspapers by the proponent. Additional direct communication (letters to adjacent landowners or public open house) may be required.

A Technical Review Committee (TRC) will be formed by the regulators to review the EIA registration, WSSA report, and any other required submissions. The TRC may request additional information. When all information has been provided to the satisfaction of the TRC, the review is completed and an Approval is issued with Conditions. The Conditions of Approval (CoA) may include specific mitigation measures, construction standards, operational limitations (e.g. maximum daily water use), and monitoring/reporting requirements. The CoA must be complied with during construction and operation and the status of compliance must be reported to the regulators every six months until all CoA have been met.

The systems modelled in this study will require pipelines connecting the production and return injection wells between 180 to 800 m in length. These pipelines may require technical review and inspection by a specialist regulator. The NB Energy and Utilities Board (EUB) has regulatory jurisdiction over pipelines transporting petroleum products, minerals, and water produced by petroleum exploitation activities. It may also be requested by the TRC to review and oversee other kinds of pipelines (such as brine). It is possible that the pipelines can be approved within the context of the EIA with standards and monitoring requirements specified within the CoA. However, if the TRC refers the pipeline review to the EUB, the proponent will likely be required to submit a formal permit application to the EUB, according to the Pipeline Act and regulations. This permit mainly deals with safety and protection of employees, the public, property, and the environment. Pipelines are often built in easements (i.e., not land owned by the proponent), so issues of abandonment and liability are also addressed.

Other environmental approvals may be required depending on site specific conditions. If parts of the proposed system are located in/across or within 30 m of a watercourse or wetland, then a Watercourse and Wetland Alteration (WAWA) permit will be required. Sensitive features such as species at risk or archaeological sites would also require permits. Since there is considerable flexibility in the siting of facility infrastructure, the drilling targeting exercise in section 5.0 was intended to avoid all sensitive environmental features. It is possible that some watercourses cannot reasonably be avoided by pipeline routes.

12.0 OTHER CONSIDERATIONS

The proposed use of the Penobsquis former underground mine works as a geothermal energy source has implications on the remaining potash resource. Under the NB Mining Act and regulations, subsurface mineral rights are held by the Crown and rights to exploit the resource are granted through a mining lease. The potash resource is protected by regulation from activities that would harm the resource or limit exploitation potential. The mining lease holder (currently Nutrien; formerly PotashCorp NB) also has non-exclusive rights, meaning that the proposed geothermal development would need to be reasonably consistent with any current or future mining activities. The potential for the geothermal development to negatively impact the remaining potash resource or to infringe on the mining lease holder’s ability to exploit the resource would be assessed during the required EIA, including stakeholder consultation. The Crown or the mining lease holder may require conditions on the geothermal development as part of the EIA CoA or separate agreements between the mining lease holder and the geothermal developer (with oversight by NB Dept. of Energy and Resource Development).

13.0 KEY ASSUMPTIONS

The objective of this Technical Feasibility Study was to determine if a decommissioned and flooded Penobsquis mine is a feasible source of alternative geothermal energy. In gathering the information and costs to investigate the potential for developing geothermal energy, a number of assumptions were made. Some assumptions may result 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. The major assumptions made during this study are presented below with some supporting discussion:

- **Water / Brine Level inside the Penobsquis Mine** – At present, the water / brine levels within the Penobsquis mine are not known. It was assumed that a water level at a depth of 166.5 mbgs would be representative of the flooded mine. This water level is 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 and 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 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 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.

- **Conceptual Open Loop Well Design** – The conceptual well design for the open loop system is presented in Figure 6.1. It was developed with the objectives to: 1) access the upper salt stopes, 2) have adequate casing to protect the potable aquifer, and 3) to have an 8” diameter casing to accommodate larger pump sizes. All of these elements could significantly impact the drilling costs. However, diameter of the boring and resultant casing size is a significant factor in those costs. Further consideration should be given to confirm that the diameter of the casing and screens are sufficient to accommodate the pumping flow rates calculated or if their diameter and subsequent costs can be reduced.

- **Conceptual Closed Loop Well Design** – The conceptual well design for the closed loop systems is presented in Figure 6.2. It was developed with the objectives to: 1) be 300 m deep and access only the Mabou group above the mine, and 2) to have an 8" diameter casing to accommodate the closed loop systems (HDPE and Sand). The decision to limit the depth of these wells was based on: 1) environmental concerns associated with having uncased and open borehole connecting the Mabou and Windsor group Rocks, and 2) extending the fully cased wells into the mine workings appeared to be cost prohibitive. It is assumed that this approach balances the drilling cost while accessing the best geothermal potential. Because of its apparent lower consumption costs and higher savings, additional work should be completed to maximize a closed loop system in this setting.

- **Calculation of Energy Savings** – The system energy savings (the revenue generated by the geothermal system) is assumed to be conservative. It is calculated as: (the cost of baseline energy) – (the cost of the energy consumption of the system). In all examples the calculated baseline energy costs are based on wood heat (efficiency of 75%) costing $270 / cord and not a more expensive grid electricity. The savings were calculated using this approach: 1) to remain consistent with the baseline energy costs for the original base example (Avon Valley Floral), which utilized wood as their energy source and 2) to avoid over estimating the savings generated by using grid electricity as a baseline cost.

- **Discounted Payback Period** – Essentially the discounted payback period is the time (in years) for the savings generated by the geothermal system to pay off the initial capital investment as well as operational costs and energy consumption. The discounted payback period presented with the results is calculated using a general inflation rate of 2% (Bank of Canada), an energy inflation rate of 3% (National Energy Board Canada), and a discount rate of 3% (Bank of Canada). The capital costs, operation and maintenance costs, as well as energy savings (consumption of energy by the system - the energy revenue provided by the system), are all included in the calculation of the discounted payback period.

14.0 RECOMMENDED NEXT STEPS

Investigation of the identified key assumptions is the recommended next step in progressing and affirming the Feasibility of the Geothermal Capability of the Penobsquis mine. The five principal areas in need of further evaluation are:

- Determine the water / brine level inside the Penobsquis mine workings (if possible), then re-calculate open loop option with revised static water levels.
- Determine the expected water / brine chemistry inside the Penobsquis mine then further evaluate the mine water scaling potential, the scaling rate in the heat exchanger, and the decrease of heat transfer in the exchanger due to scaling as well as other potential effects.
- Determine the water / brine temperature inside the Penobsquis mine, then revisit open loop calculations with revised temperatures and complete a sensitivity analysis to determine the effect of temperature on the system performances.
- Confirm the feasibility of the open loop conceptual well design to meet the modeled flow rates.
- Complete additional closed loop scenarios with different well depths and designs to determine if an example system can be developed which has a more favorable capital cost.

15.0 CLOSING

This report was prepared by Vernon Banks, M.Sc., P.Geo., and Mathilde Krebs, P.Eng. Reviewed by Janet Blackadar, M.Sc.F., CCEP, Gil Violette, M.Sc.E., P.Eng., Jacques Paynter, P.Eng, MCIP and Brian Roulston, P.Geo.

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 Amec Foster Wheeler will be required. With respect to third parties, Amec Foster Wheeler 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 by PotashCorp, collected between 2008 and 2017. Except as otherwise maybe specified, Amec Foster Wheeler disclaims any obligation to update this report for events taking place, or with respect to information that becomes available to Amec Foster Wheeler after the time during which Amec Foster Wheeler completed this report.

Amec Foster Wheeler 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.

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Senior Reviewer

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Appendix A
Figures

Appendix A – Figures

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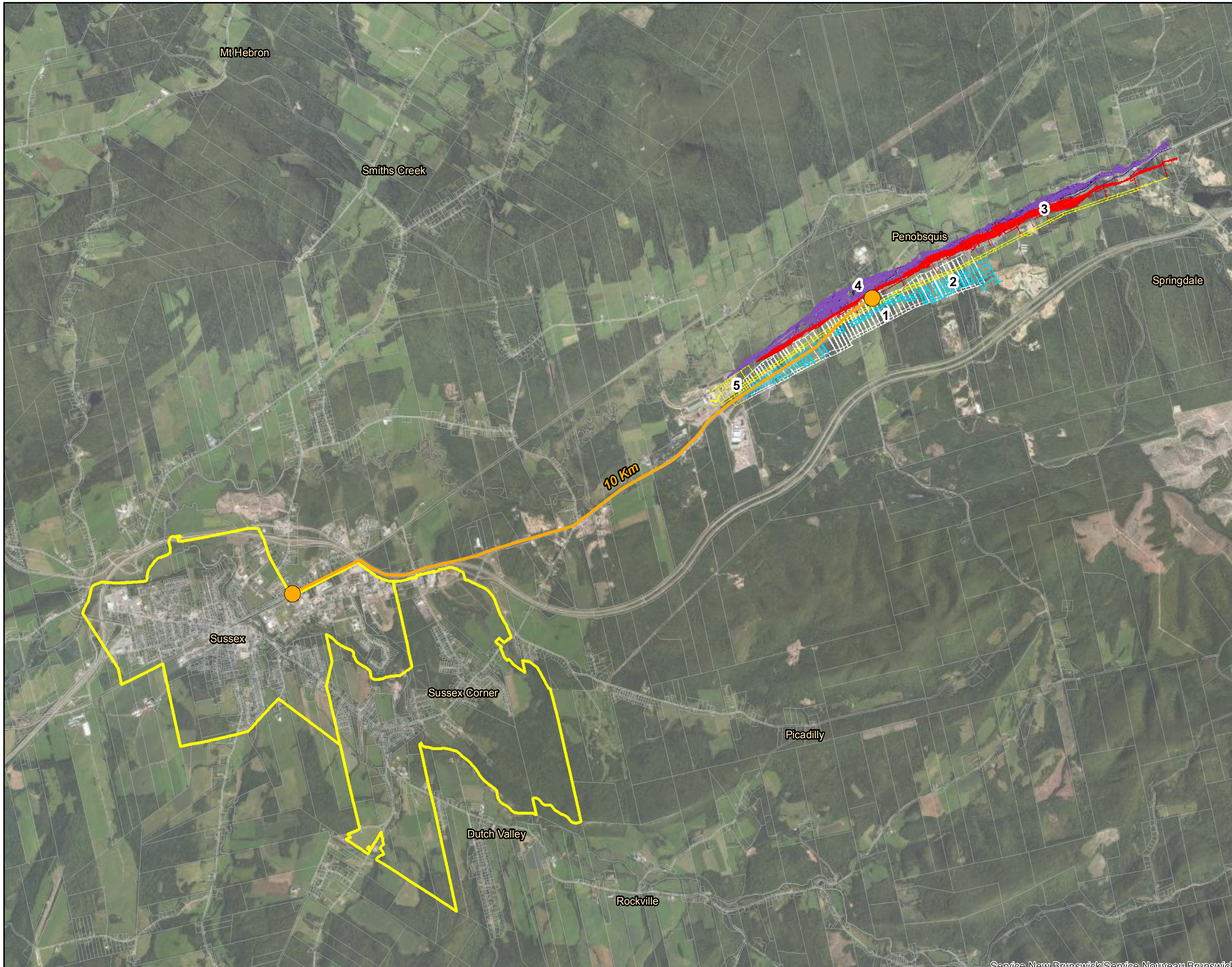

LEGEND:

- Municipality Footprint
- *SNB Property Boundary (Kings County)*

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

CLIENT:

PotashCorp New Brunswick Penobsquis

PotashCorp New Brunswick

amec foster wheeler

PROJECT:

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

TITLE:

Site Location Plan

DATUM:	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
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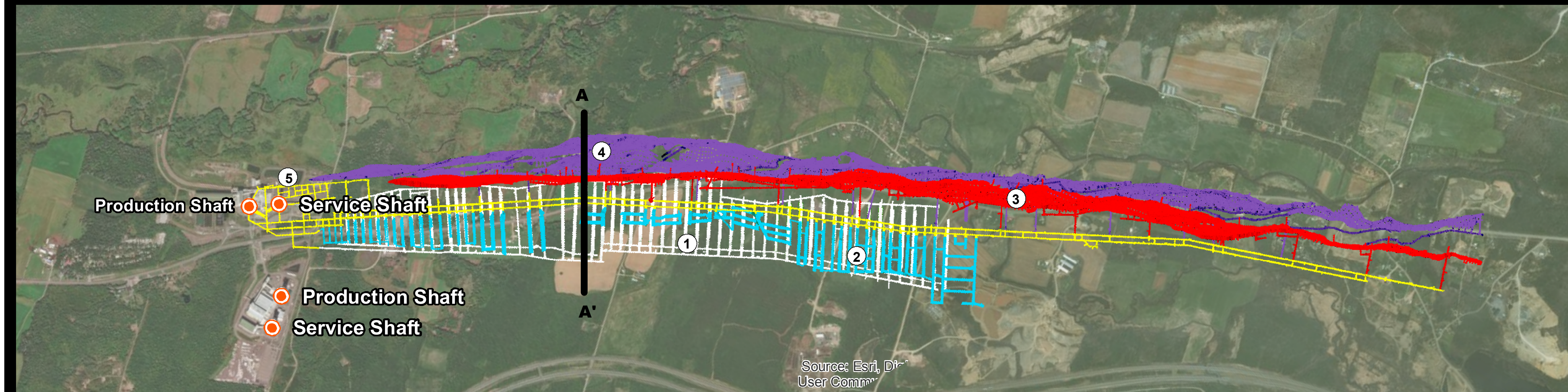
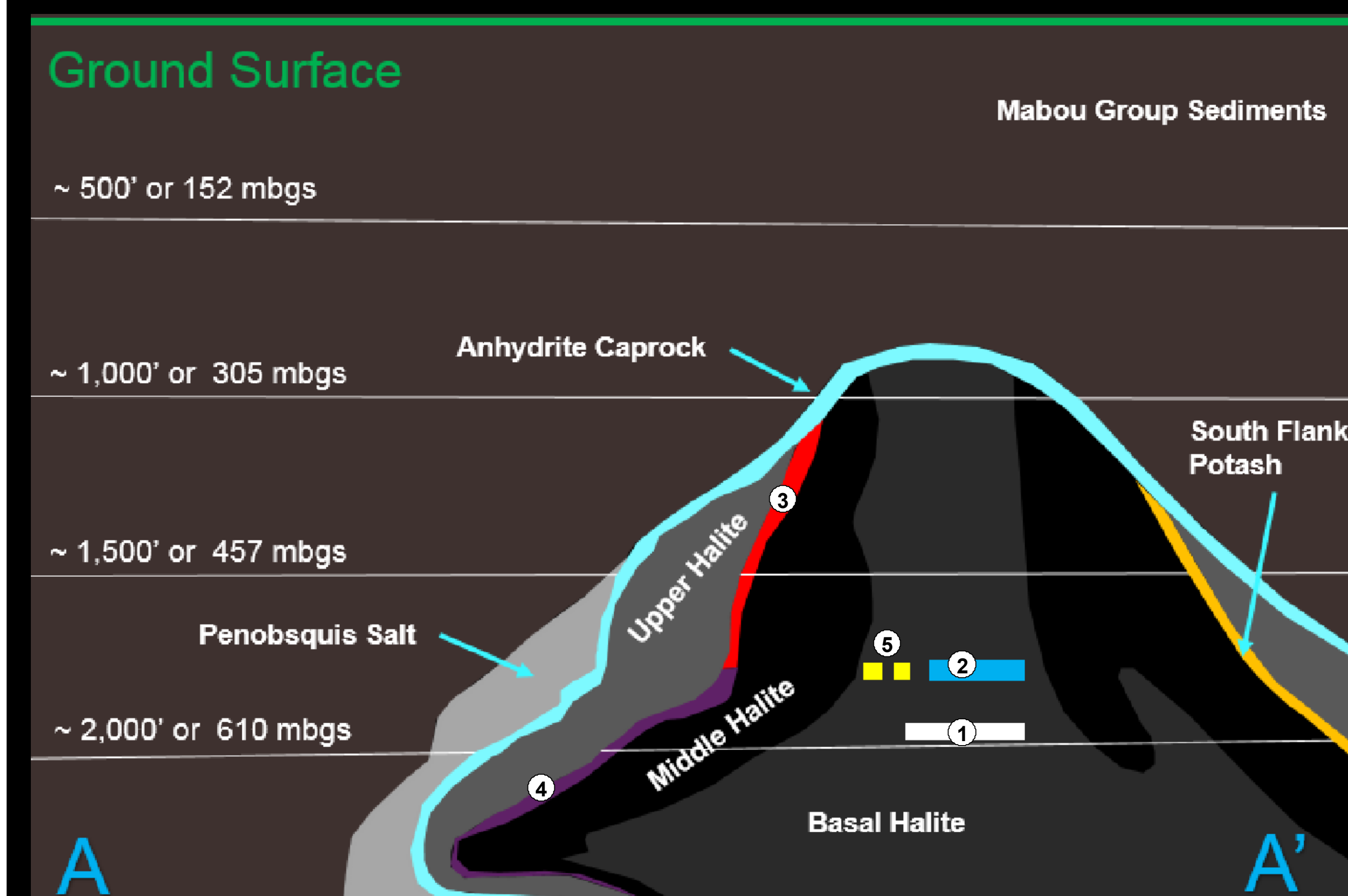
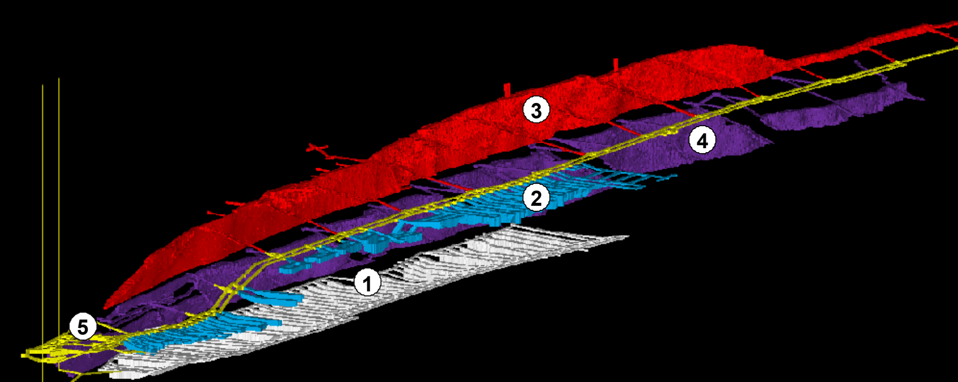


Generic Cross Section A-A'

Looking Downward and Northeast





LEGEND:

- Shaft
- A —— A' Cross Section

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

0 500 1,000 2,000 3,000 4,000 5,000 6,000
Feet

CLIENT:
PotashCorp New Brunswick Penobsquis

PotashCorp New Brunswick

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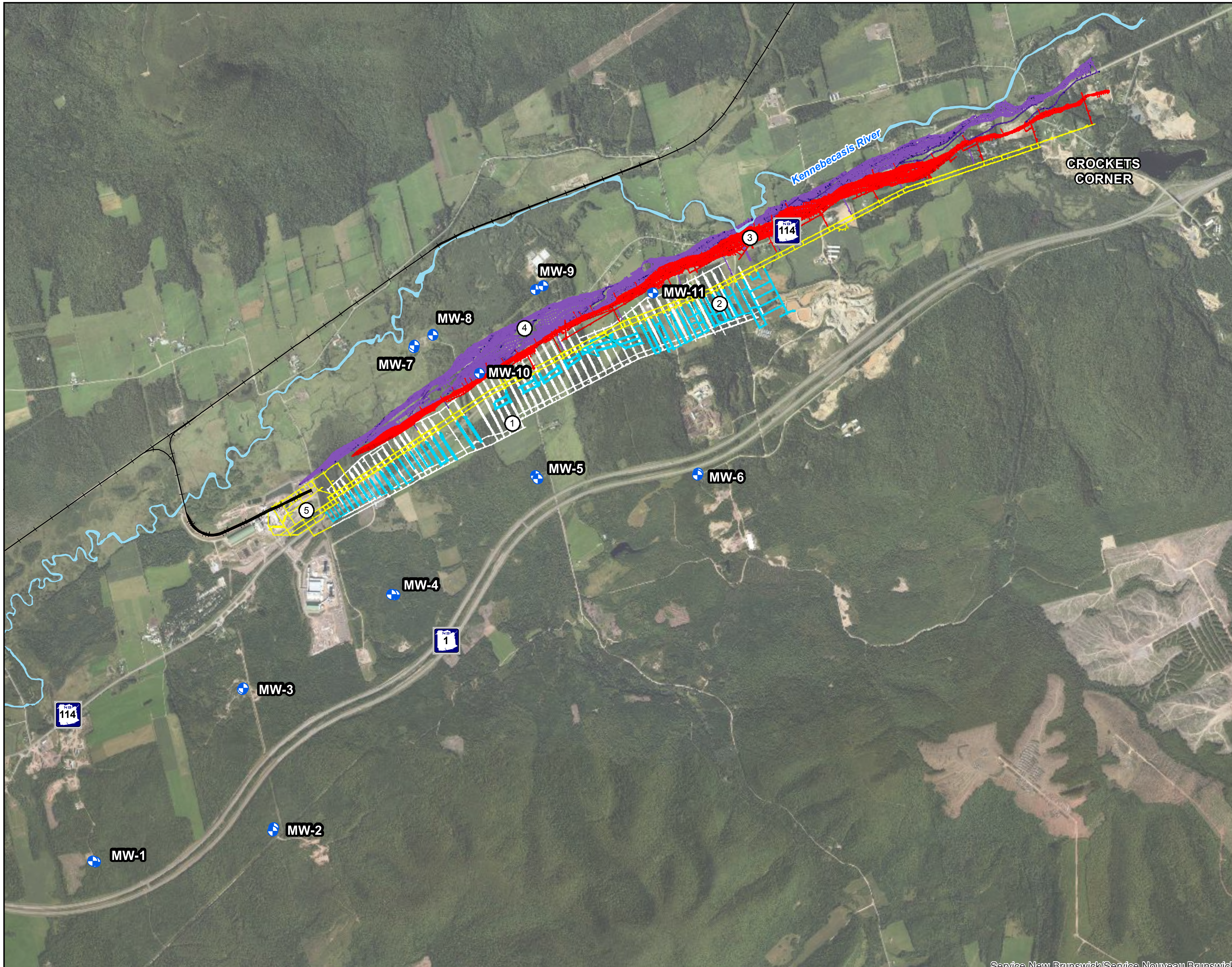
Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site

Penobsquis Mine Underground Workings

	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
	CHK'D BY:	SCALE:
UTM Zone 20 North	VB	1:30,000
PROJECT NO:	REV NO:	FIGURE NO:
TE174005	R0	4.1



LEGEND:

Monitoring Wells

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

N W E S

0 500 1,000 2,000

Metres

CLIENT:

PotashCorp
New Brunswick
Penobsquis

PotashCorp New Brunswick

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PROJECT:

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

TITLE:

PotashCorp
Penobsquis Mine
Monitoring Well Locations

DATUM:	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
PROJECTION: UTM Zone 20 North	CHK'D BY: VB	SCALE: 1:30,000
PROJECT NO: TE174005	REV NO: R0	FIGURE NO: 4.2

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Figure 4.3:
PotashCorp Monitoring Wells Temperature (°C) Vs Depth (mbgs) with Linear Trend Line and Equation

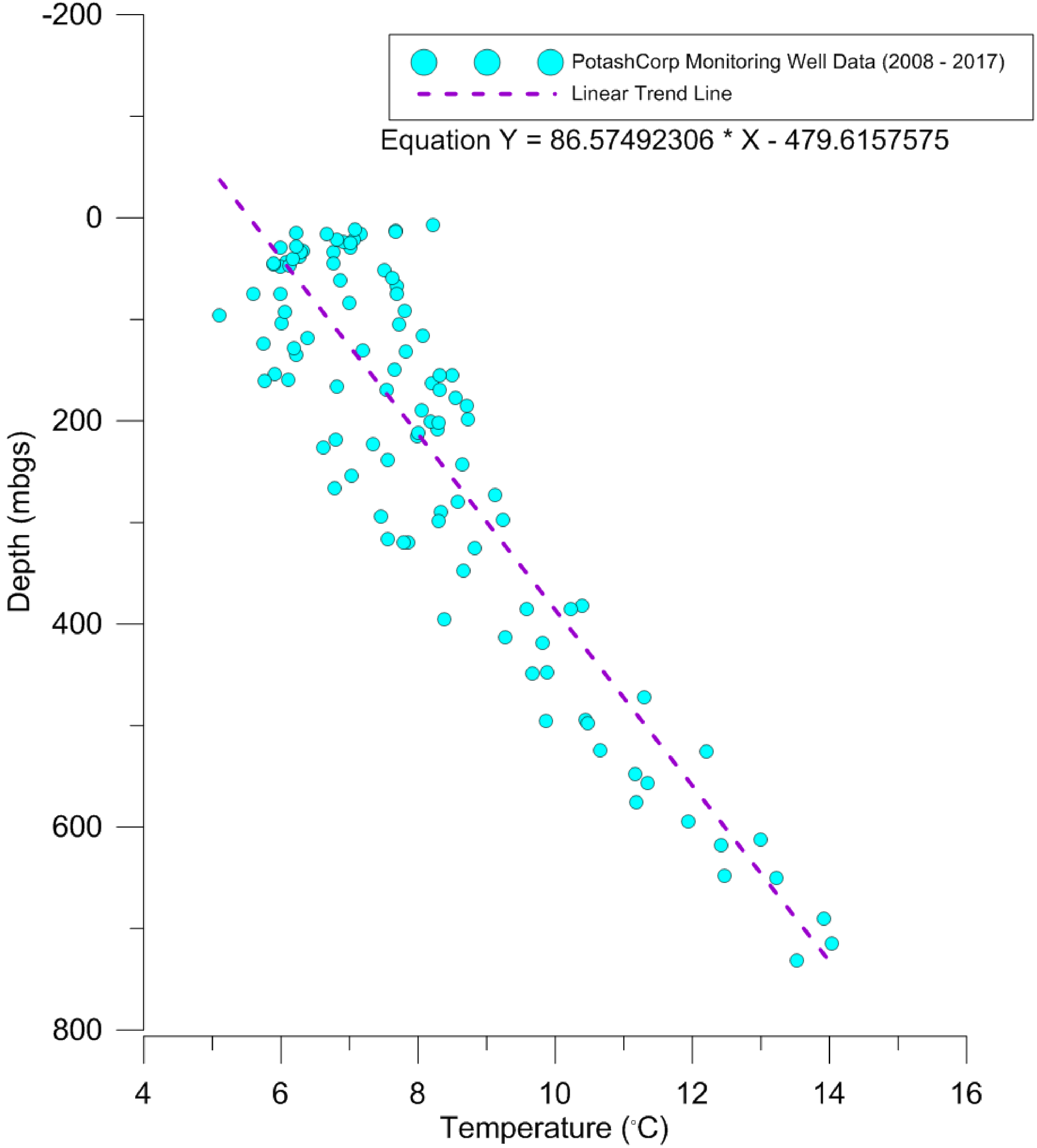
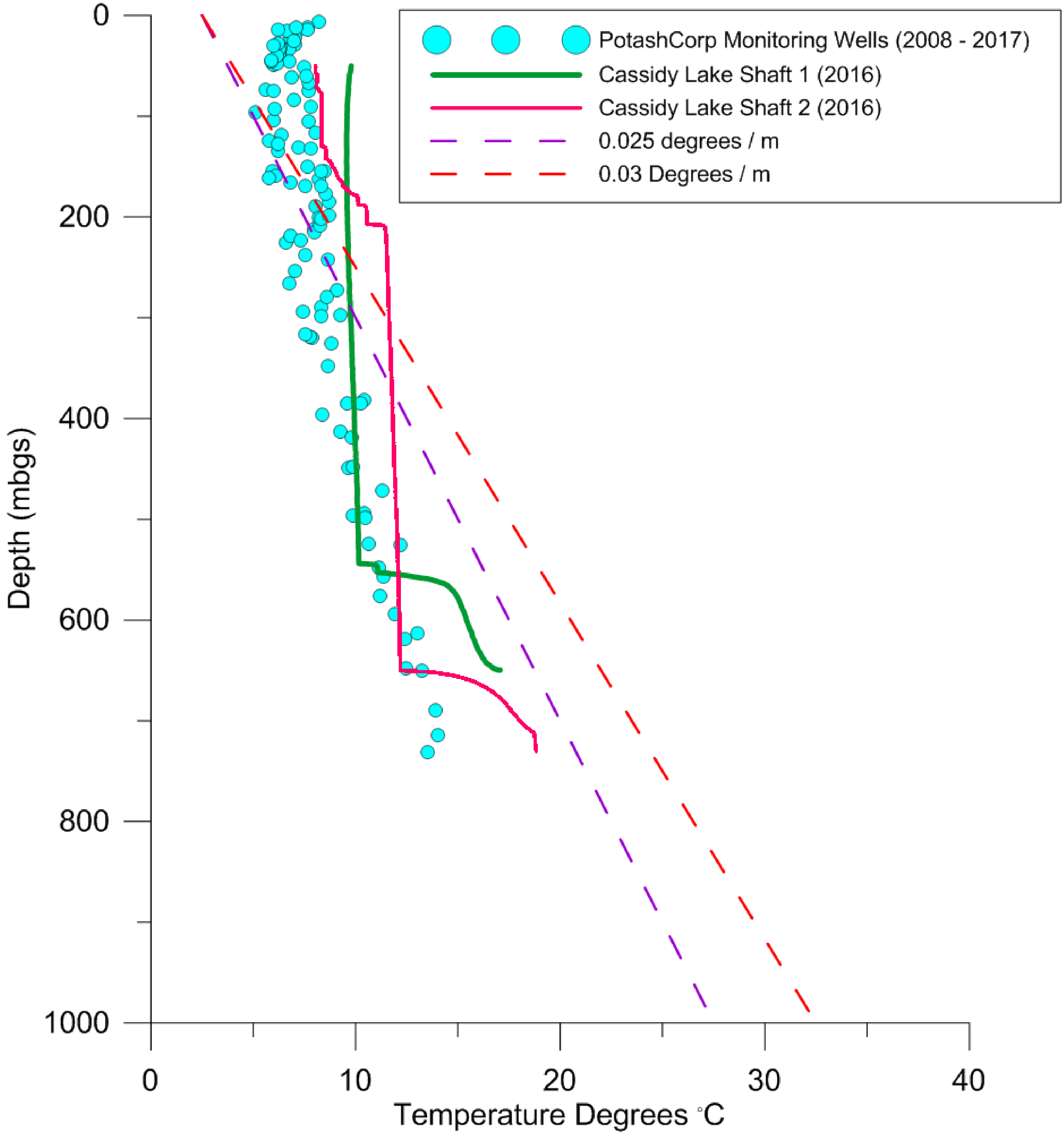


Figure 4.4:

PotashCorp Temperature Data (°C)
(Monitoring Wells, Cassidy Lake Mine Shaft Profiles) Vs Depth (mbgs) with
Generic Thermal Gradients of (0.25 and 0.30 °C / meter)



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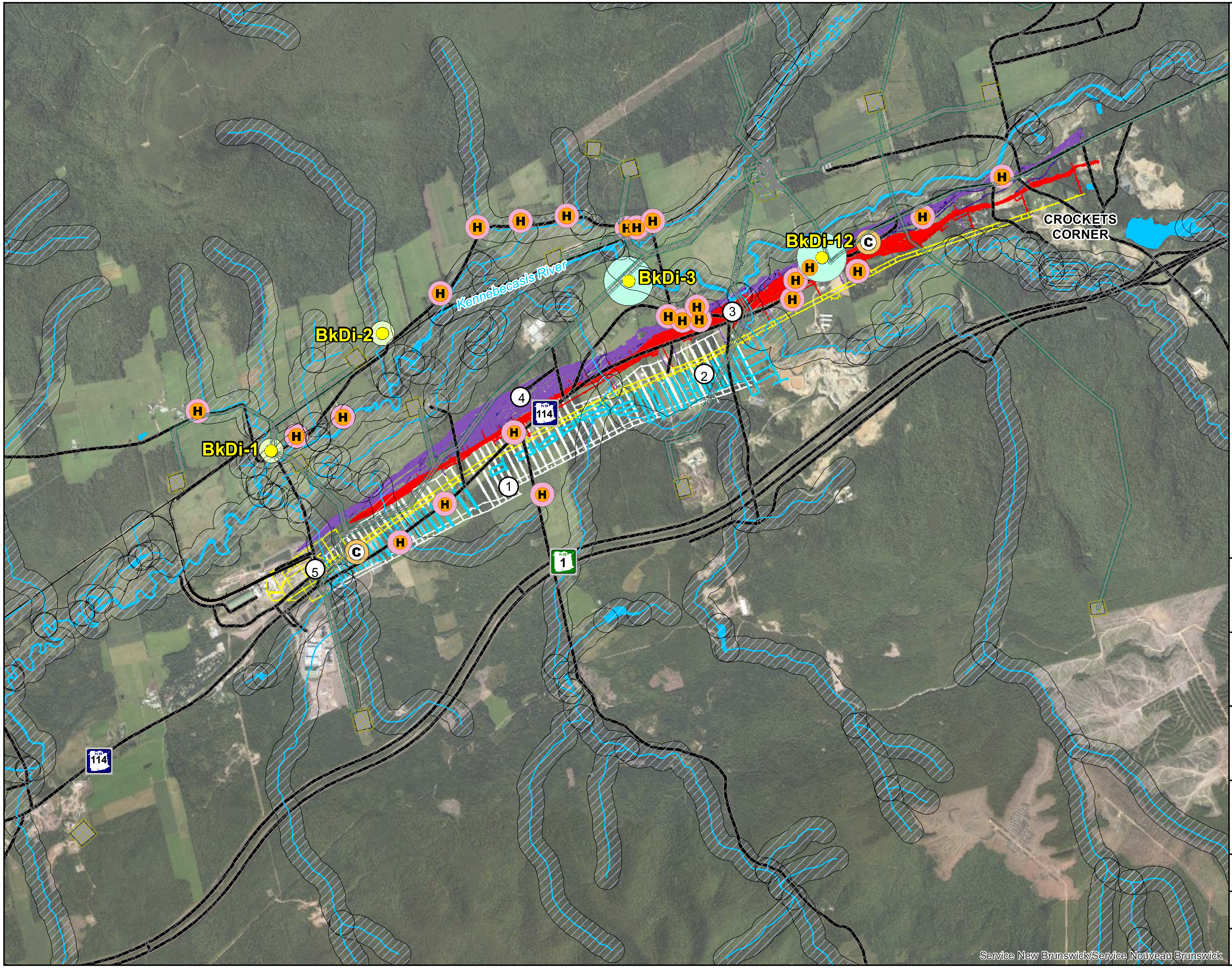

LEGEND:

- Registered Archaeological Site
- Historic Structures
- Cemetery
- Archeological Site (200m Buffer)
- Archeological Site (100m Buffer)
- Historic Structures (100m Buffer)
- Cemetery (100m Buffer)
- Natural Gas Distribution Line
- Natural Gas Distribution Line (15m Buffer)
- Existing Wellpad
- Existing Wellpad (15m Buffer)
- Watercourse
- Watercourse (100m Buffer)
- Railway Network
- Road Network
- Road Network (15m Buffer)

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

0 200 400 800 1,200 1,600 2,000
Metres

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PotashCorp New Brunswick Penobsquis
PotashCorp New Brunswick

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PROJECT:
Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site

TITLE:
Surface Contraints Above the Penobsquis Mine Underground Workings

DATUM:	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
PROJECTION:	CHK'D BY:	SCALE:
UTM Zone 20 North	DD	1:30,000
PROJECT NO:	REV NO:	FIGURE NO:
TE174005	R0	5.1

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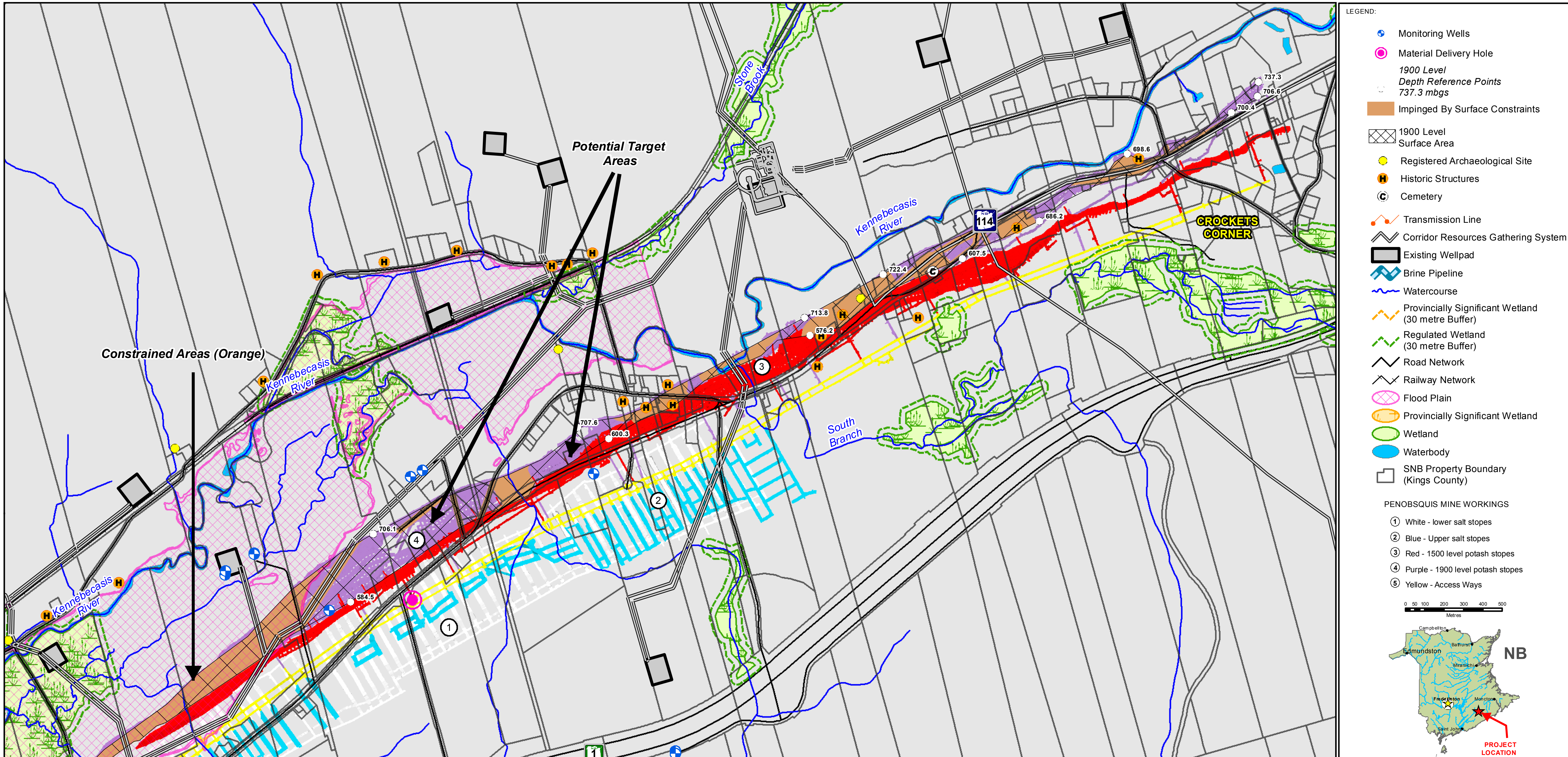

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CLIENT: Sussex New Brunswick — Gateway to the Fundy Experience

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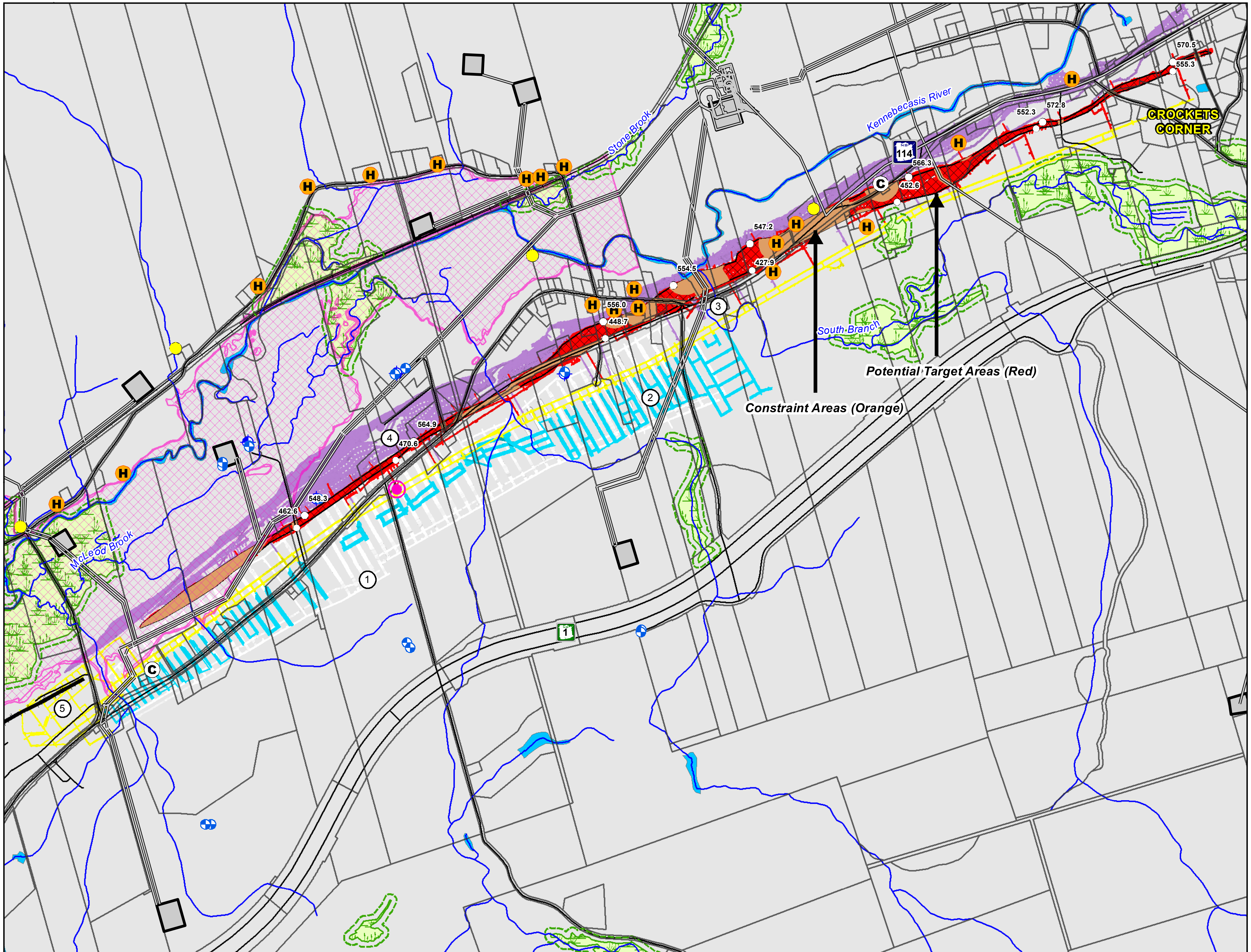
PROJECT: **Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site**

TITLE: **Potential Drilling Targets within the 1900 Level Potash Stopes**

DATUM: NAD 83 CSRS	DWN BY: RE	DATE: January 2018
PROJECTION: UTM 20 NORTH	CHK'D BY: VB	SCALE: 1:20,000
PROJECT NO: TE174005	REV NO: R0	FIGURE NO: 5.2



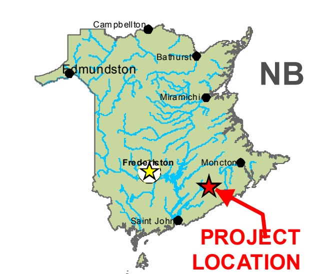
LEGEND:

- Monitoring Wells
- Material Delivery Hole
- 1500 Level Depth Reference Points 572.8 mbgs
- Impinged By Surface Constraints
- 1500 Level Surface Area
- Registered Archaeological Site
- Historic Structures
- Cemetery
- Groundwater Monitoring Well Location
- Transmission Line
- Corridor Resources Gathering System
- Existing Wellpad
- Brine Pipeline
- Watercourse
- Provincially Significant Wetland (30 metre Buffer)
- Regulated Wetland (30 metre Buffer)
- Road Network
- Railway Network
- Flood Plain
- Provincially Significant Wetland
- Wetland
- Waterbody
- SNB Property Boundary (Kings County)

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

0 50 100 200 300 400 500
Metres



CLIENT:

PROJECT: **Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site**

TITLE: **Potential Drilling Targets within the 1500 Level Potash Stopes**

DATUM:	NAD 83 CSRS	DWN BY:	RE	DATE:	January 2018
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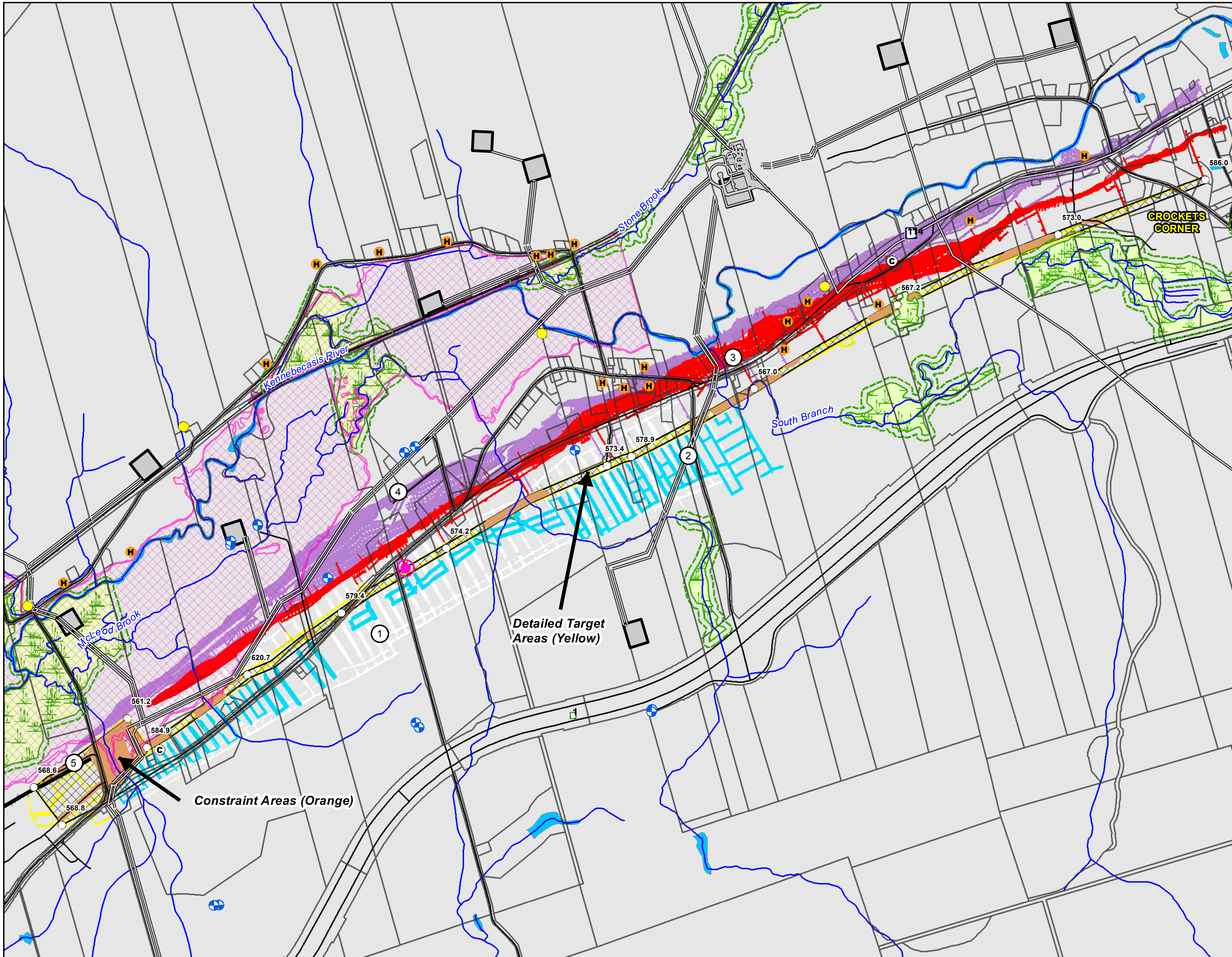

CLIENT: Sussex

PROJECT: **Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site**

TITLE: **Potential Drilling Targets within the Mine Access Ways**

DATUM:	NAD 83	DWN BY:	RE	DATE:	January 2018
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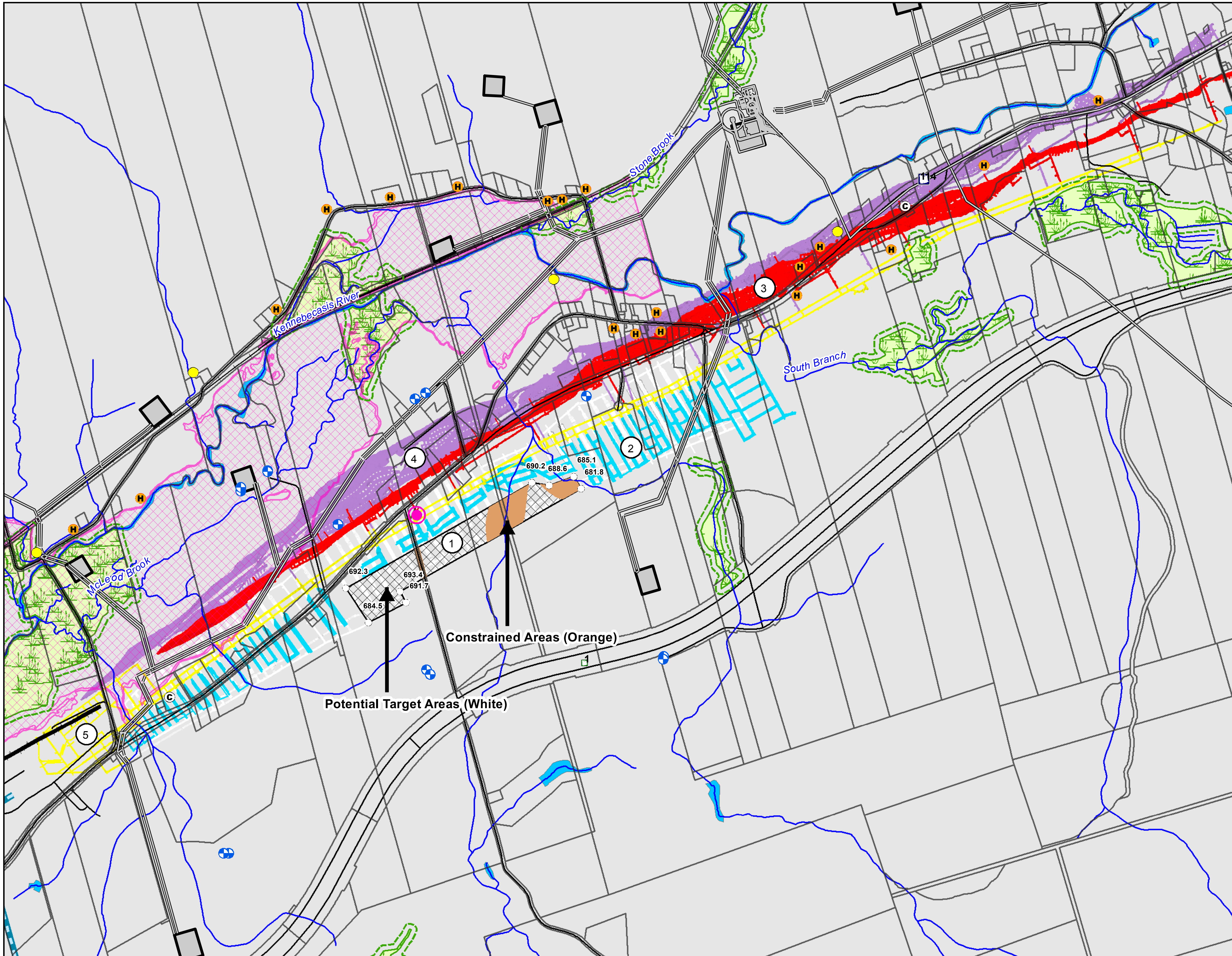


LEGEND:

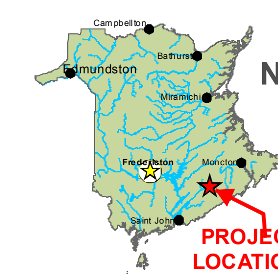
- Monitoring Well
- Lower Salt Depth Reference Points 693.4 mbgs
- Registered Archaeological Site
- Historic Structures
- Cemetery
- Inpinged by Surface Constraint
- Lower Salt Suface Area
- Transmission Line
- Corridor Resources Gathering System
- Existing Wellpad
- Brine Pipeline
- Watercourse
- Provincially Significant Wetland (30 metre Buffer)
- Regulated Wetland (30 metre Buffer)
- Road Network
- Railway Network
- Flood Plain
- Provincially Significant Wetland
- Wetland
- Waterbody
- SNB Property Boundary (Kings County)

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

0 50 100 200 300 400

Metres



CLIENT: Sussex New Brunswick — Gateway to the Fundy Experience

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PROJECT: **Technical Feasibility Study of the Geothermal Capacity of the Penobsquis Mine Site**

TITLE: **Potential Drilling Targets within the Lower Salt Stopes**

DATUM:	NAD 83	DWN BY:	RE	DATE:	January 2018
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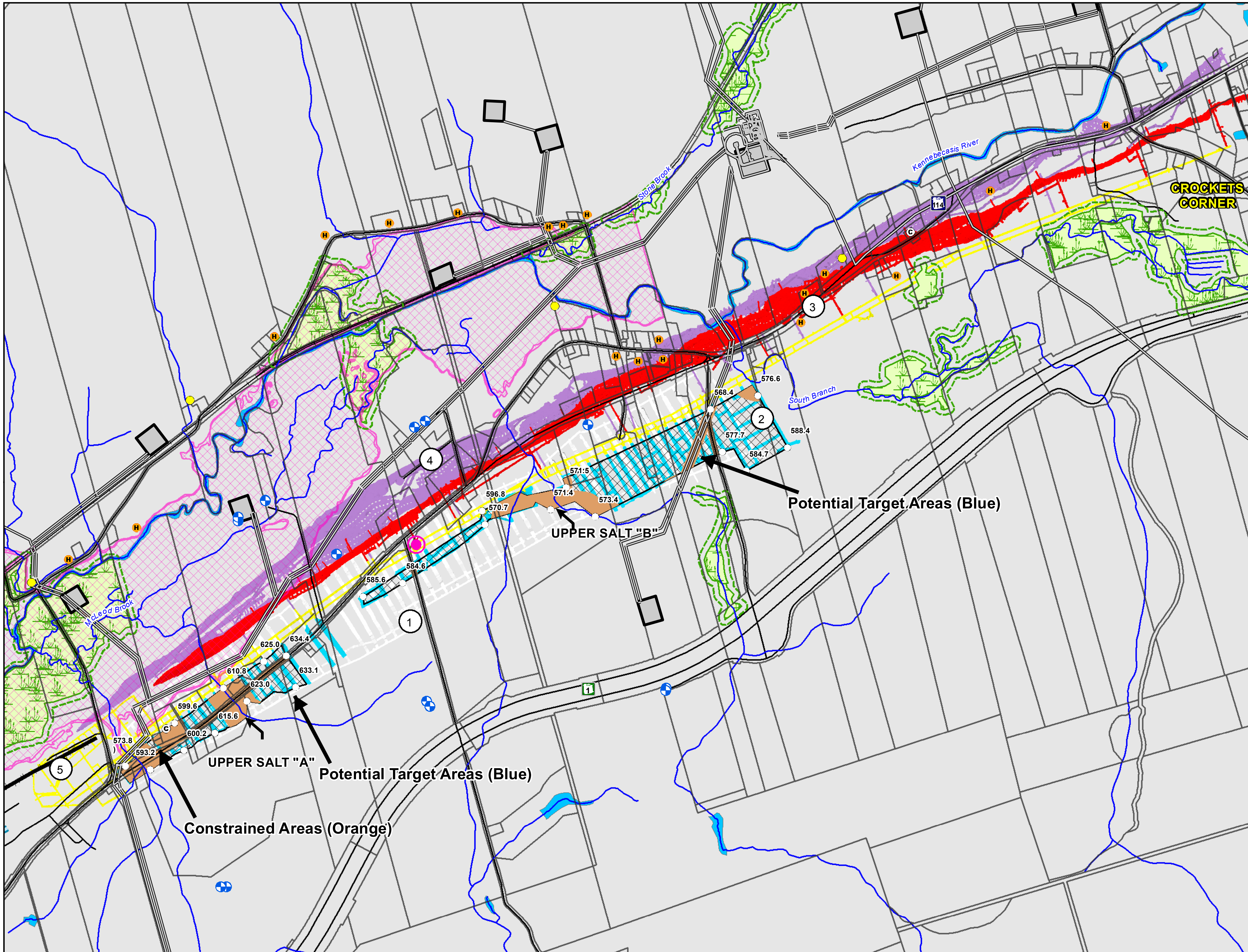

LEGEND:

- Monitoring Wells
- Upper Salt Depth Reference Points 634.4 mbgs
- Impinged By Surface Constraints
- Upper Salt Surface Area
- Registered Archaeological Site
- Historic Structures
- Cemetery
- Transmission Line
- Corridor Resources Gathering System
- Existing Wellpad
- Brine Pipeline
- Watercourse
- Elevation Contours (10 metre Interval) GeoNB 2013
- Provincially Significant Wetland (30 metre Buffer)
- Regulated Wetland (30 metre Buffer)
- Road Network
- Railway Network
- Flood Plain
- Provincially Significant Wetland
- Wetland
- Waterbody
- SNB Property Boundary (Kings County)

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

0 50 100 200 300 400
Metres

CLIENT: Sussex New Brunswick — Gateway to the Fundy Experience

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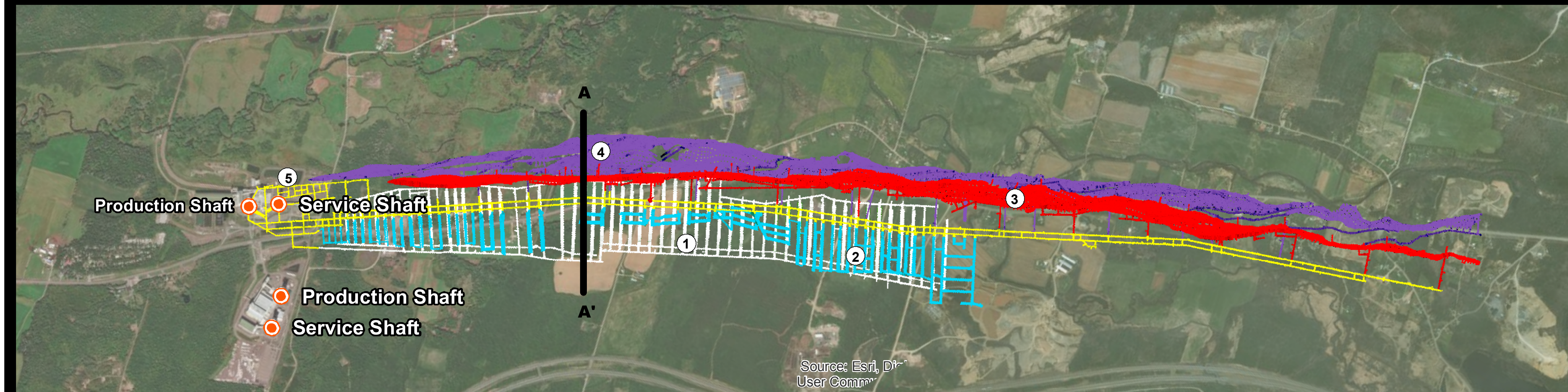
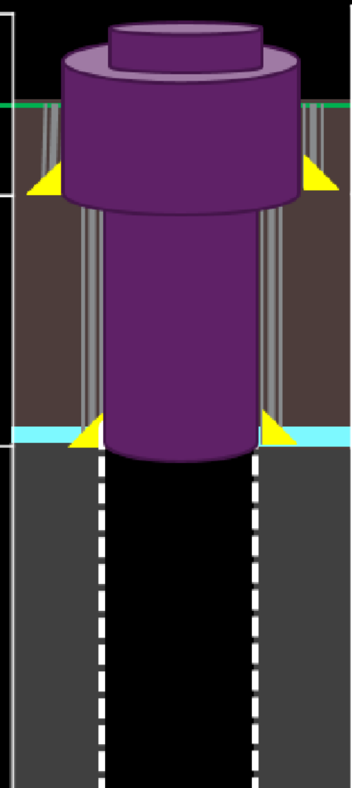
PROJECT: Technical Feasibility Study of the Geothermal Capability of the Penobsquis Mine Site

TITLE: Potential Drilling Targets within the Upper Salt Stopes

DATUM:	NAD 83 CSRS	DWN BY:	RE	DATE:	January 2018
PROJECTION:	UTM 20 NORTH	CHK'D BY:	VB	SCALE:	1:20,000
PROJECT NO:	TE174005	REV NO:	R1	FIGURE NO:	5.6

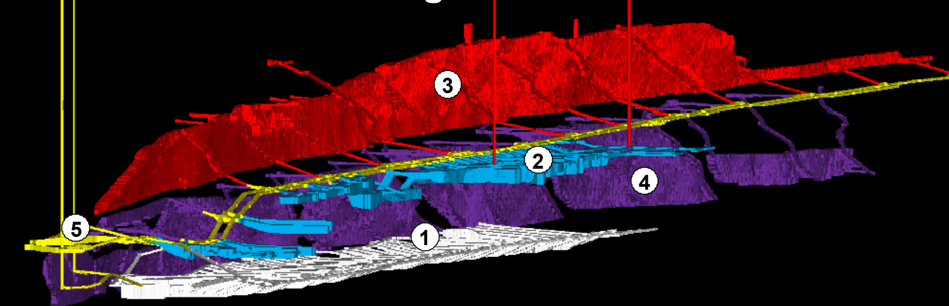


Conceptual Open Loop Well Design

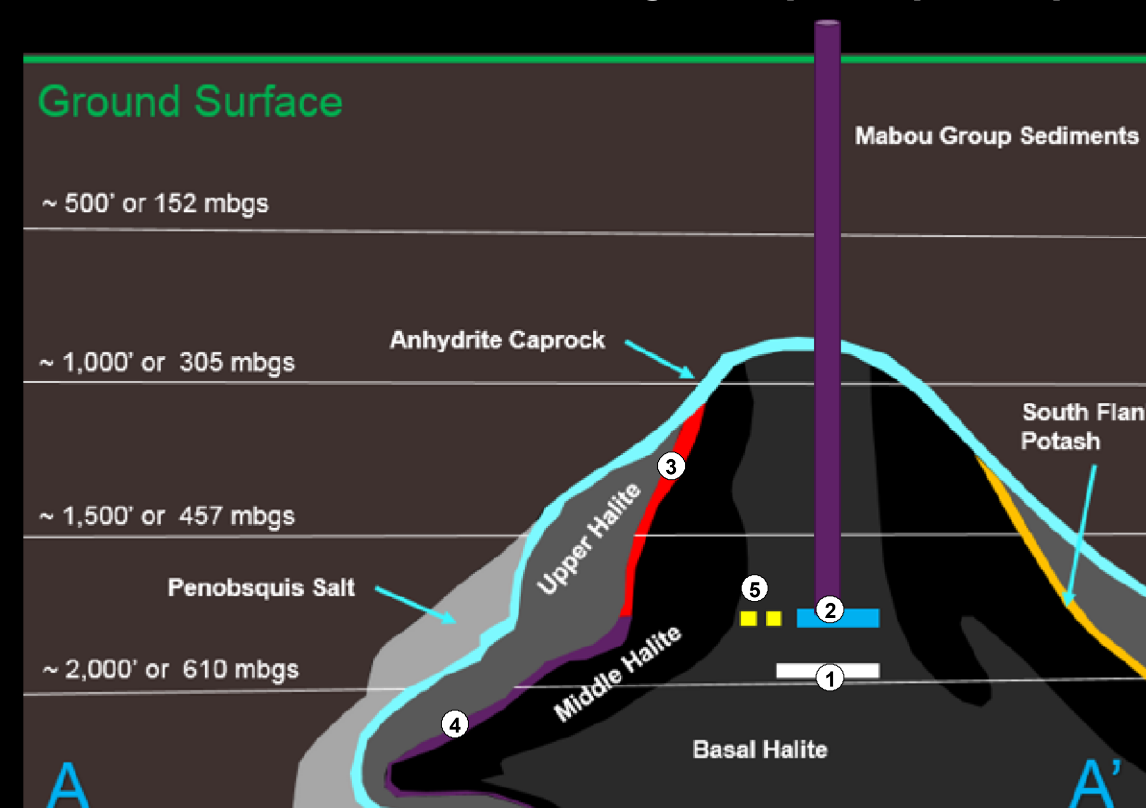


Borehole Diameter	Casing Diameter	Unit	Approximate Depth
15 “	13.38 “	Mabou Group	~100 mbgs
11.5 “	9.63 “	Mabou Group / Caprock	~ 175 to 420 mbgs
8.75“	Open Hole	Basal Halite	~ 570 mbgs
Open Hole	Open Hole	Open Mine Workings	~ 590 mbgs

View of Conceptual Loop Production and Injection Wells Looking Downward Northeast



Generic Cross Section Showing Conceptual Open Loop Well

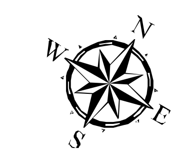


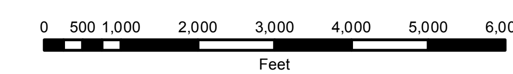
LEGEND:

- Shaft
- A —— A' Cross Section

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





CLIENT:

PotashCorp
New Brunswick
Penobsquis

PotashCorp New Brunswick

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

Conceptual Well Design for Open Loop Geothermal Wells Accessing the Upper Salt Stope

	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
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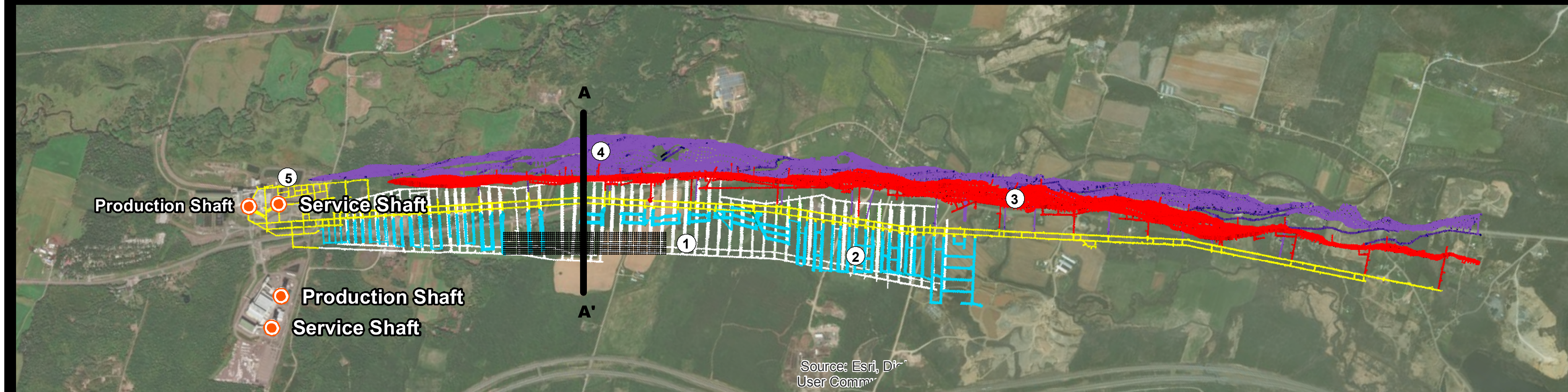
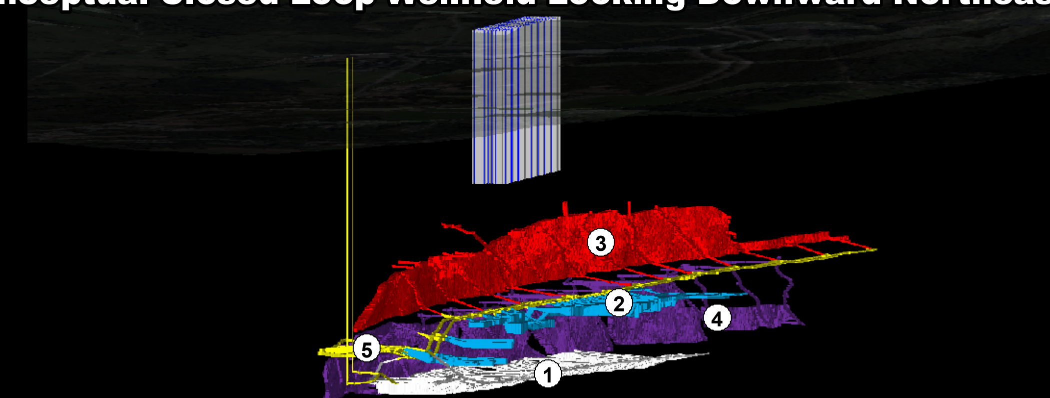
TE174005	R0	5.7

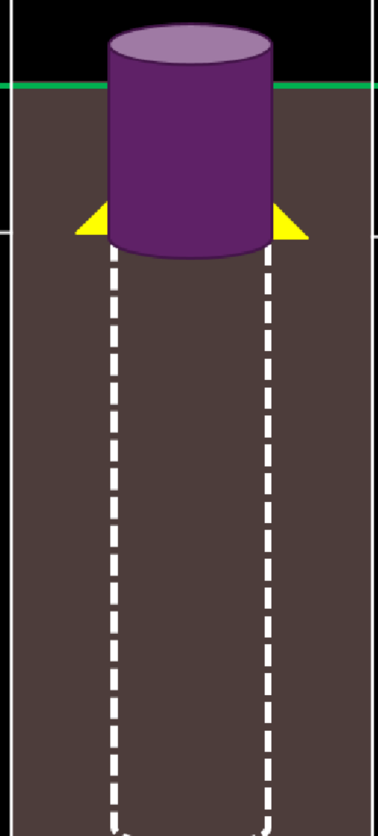


Conceptual Closed Loop Well Design

View of Conceptual Closed Loop Wellfield Looking Downward Northeast

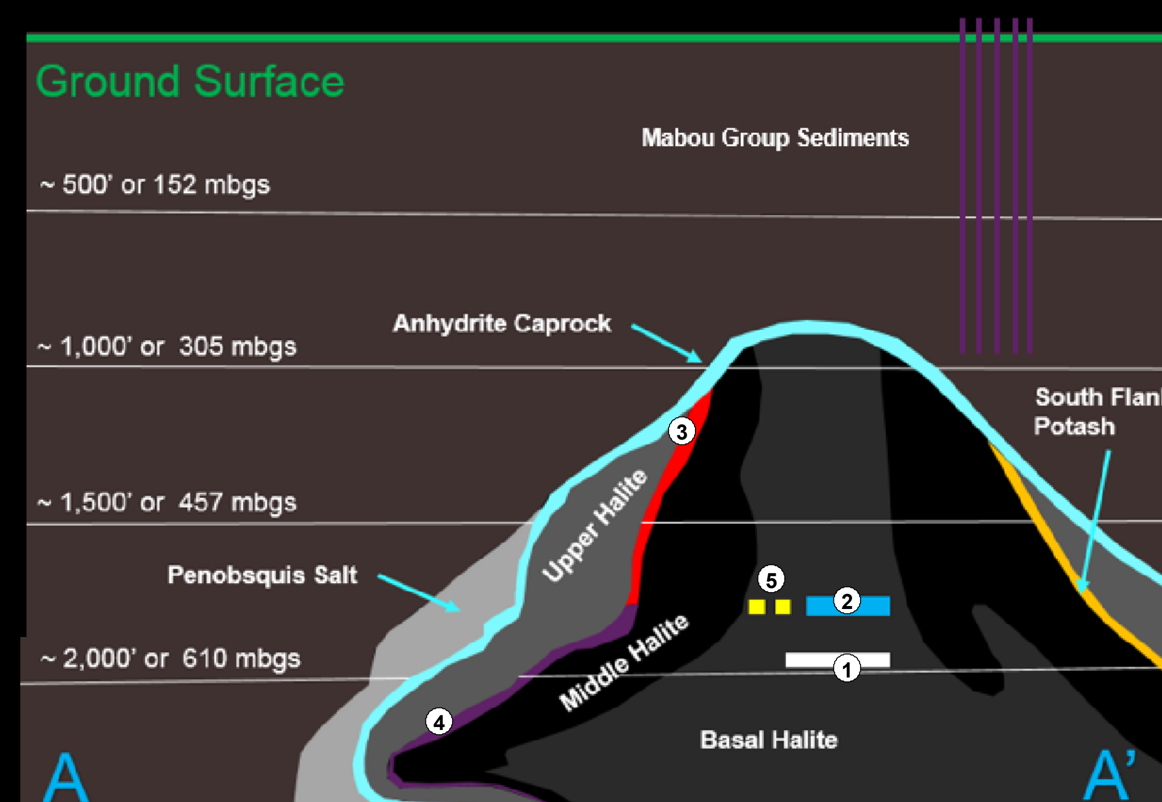


Borehole Diameter	Casing Diameter
10 "	8 "
8 "	Open Hole



Unit	Approximate Depth
Mabou Group	~ 20 mbgs
Mabou Group	~ 300 mbgs

Generic Cross Section Showing Conceptual Closed Loop Well



LEGEND:

- Shaft
- A —— A' Cross Section
- ********* Boreholes

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

0 500 1,000 2,000 3,000 4,000 5,000 6,000
Feet

The map shown here has been created with all due and reasonable care and is strictly for use with Amec Foster Wheeler Project Number: TE174005. 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. Amec Foster Wheeler assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

CLIENT:

PotashCorp New Brunswick Penobsquis

PotashCorp New Brunswick

amec foster wheeler

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

Conceptual Well Design for Closed Loop Geothermal Well Field Accessing the Mabou Group Sediments above the Windsor Group Salts

DATUM	DWN BY:	DATE:
NAD 83 CSRS	RE	January 2018
PROJECTION	CHK'D BY:	SCALE:
UTM Zone 20 North	VB	1:30,000
PROJECT NO:	REV NO:	FIGURE NO:
TE174005	R0	5.8

Path: H:\PROJECTS\PCS_Penobsquis_Picadilly\TE174005_TOS_Penobsquis_Geothermal\MXD\Geothermal_FeasibilityStudy_2018\PGFS_REV01\FIG_5.8_TE174005_ConceptualAccessMGS_R0.mxd User: rene.essiembre Date: 2/2/2018

Appendix B
Tables

Appendix B – Tables

Table Number	Table Title
Table 4.1	Ground Thermal Properties in the Penobsquis Mine Study Area
Table 5.1	Attributes of Mine workings for Geothermal Potential (in text)
Table 6.1	Example Geothermal Applications (in text)
Table 6.2	Energy Conversion Factors (Kavanaugh and Rafferty, 2014) (in text)
Table 6.3	Open Loop General System Parameters (in text)
Table 6.4	Closed Loop General System Parameters (in text)
Table 6.5	Geothermal Systems Capital Costs (in text)
Table 7.1	Results of Example Cases for Individual Users (in text)
Table 7.2	Results of Example Cases for District Users (in text)
Table 8.1	Calculated CO_2 Emissions (in text)
Table 9.1	Financial Comparison of Example Applications (in text)

Table 4.1 Ground Thermal Properties in the Penobsquis Mine Study Area

All values are listed at atmospheric pressure	
BRINE	
Salinity (g/kg)[1]	98
Brine Conductivity (W/mK) [2]	0.585
Brine Capacity (J/kgK) @ 15°C [2]	3690
Brine Density (kg/m3) [1]	1200
ROCKS	
From 0-300 mbgs	Mabou Group Sediments (carboniferous)
Conductivity (W/mK) [3]	2.5
Capacity (J/kgK) [3]	840
Density (kg/m^3) [3]	2700
From 300-500 mbgs	Windsor Group Salts (Halite)
Conductivity (W/mK) [4]	6.2
Capacity (J/kgK) [4]	800
Density (kg/m3) [4]	2166
BRINE+ROCKS MATRIX (MAXWELL EQUATION)	
Porosity	20%
From 0-300 mbgs	Mabou Group Sediments (carboniferous)
Conductivity (W/mK)	1.87
Capacity (J/kgK)	1129 - 1143
Density (kg/m3)	2296
From 300-500 mbgs	Windsor Group Salts (Halite)
Conductivity (W/mK)	3.867
Capacity (J/kgK)	1088 - 1094
Density (kg/m3)	1925
AVERAGE From Conductivity (W/mK) (0 to 500 mbgs)	**2.669**
AVERAGE From Capacity (J/kgK) (0 to 500 mbgs)	**1112**
AVERAGE From Density (kg/m3) (0 to 500 mbgs)	**2148**
Data Refrences:	
1. Assumed Brine Composition.	
2. Nayar K.G., Sharqawy M.H., Lienhard J.H. 2016. Seawater Thermophysical Properties Library. MIT.	
3. Chi G., Savard M. 1998. Basinal Fluid Flow Models Related to Zn-Pb Mineralization in the Southern Margin of the Maritimes Basin, Eastern Canada. NRCAN	
4. Banks D. 2008. An Introduction to Thermogeology: Ground Source Heating and Cooling. Blackwell Publishing, Oxford.	

Appendix C

Referenced Spreadsheets USB Drive

Appendix D
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 Amec Foster Wheeler'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, Amec Foster Wheeler must be notified in order that it may determine if modifications to the conclusions in the report are necessary.
8. The utilization of Amec Foster Wheeler's services during the implementation of any remedial measures will allow Amec Foster Wheeler to observe compliance with the conclusions and recommendations contained in the report. Amec Foster Wheeler'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. Amec Foster Wheeler 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 Amec Foster Wheeler.
11. Provided that the report is still reliable, and less than 12 months old, Amec Foster Wheeler 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 Amec Foster Wheeler's report, by such reliance agree to be bound by our proposal and Amec Foster Wheeler's standard reliance letter. Amec Foster Wheeler's standard reliance letter indicates that in no event shall Amec Foster Wheeler be liable for any damages, howsoever arising, relating to third-party reliance on Amec Foster Wheeler's report. No reliance by any party is permitted without such agreement.

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