



The Municipality of the County of Cumberland

In partnership with

Nova Scotia Community College

and

**The Nova Scotia Department of Energy,
Energy Resource Development Branch**

June 2025



Note: This Plan is a component of a broader and ongoing Cumberland Geothermal Research project undertaken by the Province of Nova Scotia, the Municipality of the County of Cumberland, and the Cumberland Campus of the Nova Scotia Community College.



Executive Summary

This Springhill Geothermal Greenhouse Action Plan (the “Action Plan”) has been developed by the Nova Scotia Community College Applied Energy Research Team in collaboration with the Municipality of the County of Cumberland and the Nova Scotia Department of Energy (Energy Resource Development Branch). It is a component of a broader and ongoing Cumberland Geothermal Energy Research project undertaken by the Province, the Municipality, and the Cumberland Campus of Community College in June 2022. In early 2024, at the suggestion of the Geothermal Research Advisory Committee which had been formed to help guide the broader project, a separate agreement was signed between the same parties to fund and develop an Action Plan to move the idea of a Community Mine Water Geothermal Greenhouse forward. The aim of the proposed Action Plan was to lay the groundwork for the development of a geothermal greenhouse that would demonstrate the capacity and sustainability of the Springhill mine water energy resource, while at the same time contributing to community development and food security in Cumberland County. This Action Plan is the result of that secondary agreement. Regardless of whether the greenhouse becomes a reality, the increased knowledge of the geothermal resource gained throughout this project could open the door to increased use of geothermal energy in the community (nearby municipal and educational facilities), which in turn could lead to increased use of geothermal energy in the region and beyond.

It should be noted at the outset that the Greenhouse project is not yet “shovel ready”. Although the Action Plan has narrowed the options and answered many questions about the feasibility of such a project, several key issues remain to be addressed. These “action

items” are outlined below and set out in more detail in Part 5. If these issues are not all resolved in a manner that supports development of a mine water geothermal greenhouse, that idea may have to be set aside.

The initiative is positioned against the backdrop of a rich mining history, dating back to the late 19th century, leading to the current utilization of geothermal energy for heating and cooling in various facilities, including a community center, a battery manufacturing facility, a plastic container manufacturing facility, and soon, a new fire station. The No. 2 Mine offers significant potential, with an estimated water volume of over 5.5 million m³ accessible for geothermal applications. Including the other former coal mines in Springhill, a potential resource of approximately 10 million m³ is available for mine water geothermal purposes.

This Action Plan outlines three scenarios for geothermal greenhouse development utilizing the mine’s water. These scenarios address small, medium, and large-scale greenhouses. Each scenario is evaluated for its alignment with the objectives of this project. Suggested crop selection and planning are components of this Action Plan.

The Action Plan culminates with action items aimed at fostering community engagement, demonstrating a new agricultural application for the mine water geothermal energy resource in Cumberland County, and building partnerships that enhance the local economy through the development of a geothermal greenhouse. By leveraging mine water geothermal resources, this initiative hopes to contribute to local food security, be a catalyst for regional economic development, and demonstrate emission reductions.

Based on research, consultations, and advice from experts, the project team has developed the following set of action items (described in more detail in Part 5), which the team hopes to address over three different but overlapping time frames:

1. June to November 2025 – Improve Project Readiness

- *Share Action Plan and Gather Feedback:* Develop the necessary partnerships and support for the next steps in geothermal greenhouse development, based on the results of this work.
- *Estimate Energy Savings for a Range of Mine Water Temperatures:* As the temperature of mine water that can be sustainably obtained from a relatively shallow depth (240 – 250 m) is still not known, developing estimates for the range of temperatures that might be found from drilling and testing the new mine water extraction well referred to below and described in more detail in sections 2.5. and 5.2.2. is recommended to prepare for a variety of results.
- *Develop Relationships with Potential Greenhouse Operating Partners:* Use informal discussions to identify potential greenhouse operators and gather information to guide planning for the greenhouse and an eventual process to seek an investor and operating partner.
- *Estimate Greenhouse Production and Conduct Market Study:* Determine the potential volume, market value, and market for the recommended crops.
- *Refine Choice of Location for the Proposed Greenhouse:* Use existing resources (including provincial, municipal, and NSCC staff) to review and refine the proposed greenhouse site and alternate locations, including

identification of potential risks, and preparation of rough cost estimates of providing services and site preparation.

- *Refine Capital Cost Estimates:* The capital estimates obtained for this Action Plan are higher than anticipated. Efforts need to be made to reduce contributing factors while maintaining confidence in the estimates.

2. June 2025 to June 2026 – Data Collection and Resource Management

- *Establish Consistent Data Collection for Water Temperatures:* Develop and implement a comprehensive data collection procedure and management plan for mine water temperatures, and where possible, collect data on the mine water volumes pumped.
- *Limit Surface Development Above No. 2 Mine Main Haulage Slope:* The information available at this time indicates the main slope of the No. 2 Mine may be one of the best sources of comparatively warm mine water. Various tools may be used to ensure access is maintained for development that will take best advantage of this potential resource.
- *Establish a New Extraction Well:* Following advice from the Falcon Engineering Technical Memorandum, establish a new supply well into the main slope of the No. 2 Mine. This step would only be undertaken when adequate funding can be secured.

3. September 2025 to December 2026 – Seek Funding and Investment Partner

- *Seek Funding Sources:* Continue to research and identify funding sources so that applications can be filed in a timely manner.

- *Investment Partner:* Use a fair, open, and transparent process to select an Investment Partner.

In summary, the Springhill Geothermal Greenhouse Action Plan presents a unique opportunity to innovate locally and build on local resources to create a model for adaptive and energy efficient use of abandoned and flooded mine workings for sustainable greenhouse agriculture. The collaborative efforts of stakeholders in producing this Action Plan underline a commitment to a greener future, ensuring that Cumberland is at the forefront of the sustainable energy transition by capitalizing on its geothermal resources.

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List of Abbreviations

Abbreviation	Meaning
ac	Acre
BTU	British Thermal Unit
COP	coefficient of performance
GJ	gigajoule
GTW	Geothermal well
ha	Hectare
kg	kilogram
km	kilometre
kWh	kilowatt-hour
m	metre
m ²	metres squared
m ³	metres cubed
MLA	Member of the Legislative Assembly
MWh	Megawatt hour
N	North
No.	number
NSCC	Nova Scotia Community College
SI	International System of Units (metric)
TJ	terajoule
W	West

List of Symbols

Symbol	Meaning
%	percent
°C	degrees Celsius
°C/km	degrees Celsius per kilometre
ΔT	delta temperature

Glossary

Acre – a unit of land area equal to 4,840 square yards (0.405 hectares).

British Thermal Unit – a measure of the heat content of fuels or energy sources. One Btu is the quantity of heat required to raise the temperature of one pound of liquid water by 1° Fahrenheit (F) at the temperature that water has its greatest density (approximately 39° F).

Coefficient of performance (COP) – the relationship between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied to the compressor.

Corrected temperature data – this data has been processed to correct for known biases and errors in the raw data. Adjustments are made to account for changes in measurement methods, locations, and other factors that could affect the accuracy of the data. Corrected data provides a more accurate and consistent record of temperature changes over time. Adjustments can include correcting for time-of-day recording differences, changes in instrumentation, and urban heat island effects.

Delta temperature – the difference of temperatures between two measuring points.

Geothermal gradient – is the rate at which the temperature increases with depth below the Earth's surface. It is a measure of how temperature changes as you go deeper into the Earth's crust. The geothermal gradient is typically expressed in degrees Celsius per kilometre (°C/km).

Gigajoule – a unit of measurement of energy consumption; equal to one billion joules.

Headhouse – an addition or section of a greenhouse that serves as the “work center.” Headhouses provide additional functional workspace without sacrificing valuable growing area within the greenhouse. They are typically used for storage, office space, quarantine space, and potting areas.

Hectare – a metric unit of square measure, equal to 10,000 m² or 2.472 acres.

Joule – reference SI unit for energy, defined in base units as kg m²/s²

Kilowatt-hour – a non-SI unit of energy equal to 3.6 megajoules (MJ) in SI units, which is the energy delivered by one kilowatt of power for one hour.

Latitude – the angular distance of a place north or south of the earth's equator, or of a celestial object north or south of the celestial equator, usually expressed in degrees and minutes.

Longitude – the angular distance of a place east or west of the meridian at Greenwich, England, or west of the standard meridian of a celestial object, usually expressed in degrees and minutes.

Megawatt hour – a non-SI unit of energy equal to 3.6 gigajoules (MJ) in SI units, which is the energy delivered by one megawatt of power for one hour.

Raw temperature data – is the unprocessed data collected directly from measurement instruments like thermometers, weather stations, buoys, and satellites. Raw data can contain errors or inconsistencies due to various factors such as instrument calibration issues, changes in measurement locations, and human recording errors.

SI Units – Units of measurement recognized in the International System of Measurements (metric units).

Slope – an entrance to a mine driven down through an inclined coal seam.

Terajoule – a unit of measurement of energy consumption; equal to one trillion joules.

Venlo style greenhouse – a type of greenhouse that provides a high amount of light transmission and year-round climate control. The ridge vent opens from the roof's peak and can include both alternating (butterfly) and continuous styles, ensuring versatility and convenience in ventilation options.

Well collapse – occurs when the structural integrity of a well is compromised, leading to a partial or complete failure of the well casing or surrounding materials. This can result in reduced water flow or contamination of the water supply.

1. Introduction and Methodology

The overarching purpose of this Action Plan is to move the idea of a Mine Water Geothermal Community Greenhouse forward to the point where partnerships can be developed, detailed site planning can be prepared, and applications for funding can be submitted. To a large extent those steps cannot be completed until the Action Items listed in Part 5 of this Action Plan have been successfully completed. A Community Greenhouse has been proposed to conclusively demonstrate the general energy saving potential (and therefore GHG reduction potential) of mine water, to demonstrate specifically the suitability of mine water geothermal for greenhouse heating and cooling, and to help increase local food supply and security in Cumberland County.

The Community of Springhill (refer to Figure 1-1), in Cumberland County, Nova Scotia, is home to extensive and deep historical underground coal mines that began operating in the late 19th century and closed in the mid 20th century (Gregory et al., 1978). These abandoned mine workings eventually flooded and have since become world renowned as sources of warm water for heating and cooling. Since 1989, industrial, commercial, and institutional facilities in Springhill have been using the flooded mines as both a heat source and a heat sink (Jessop et al., 1995).

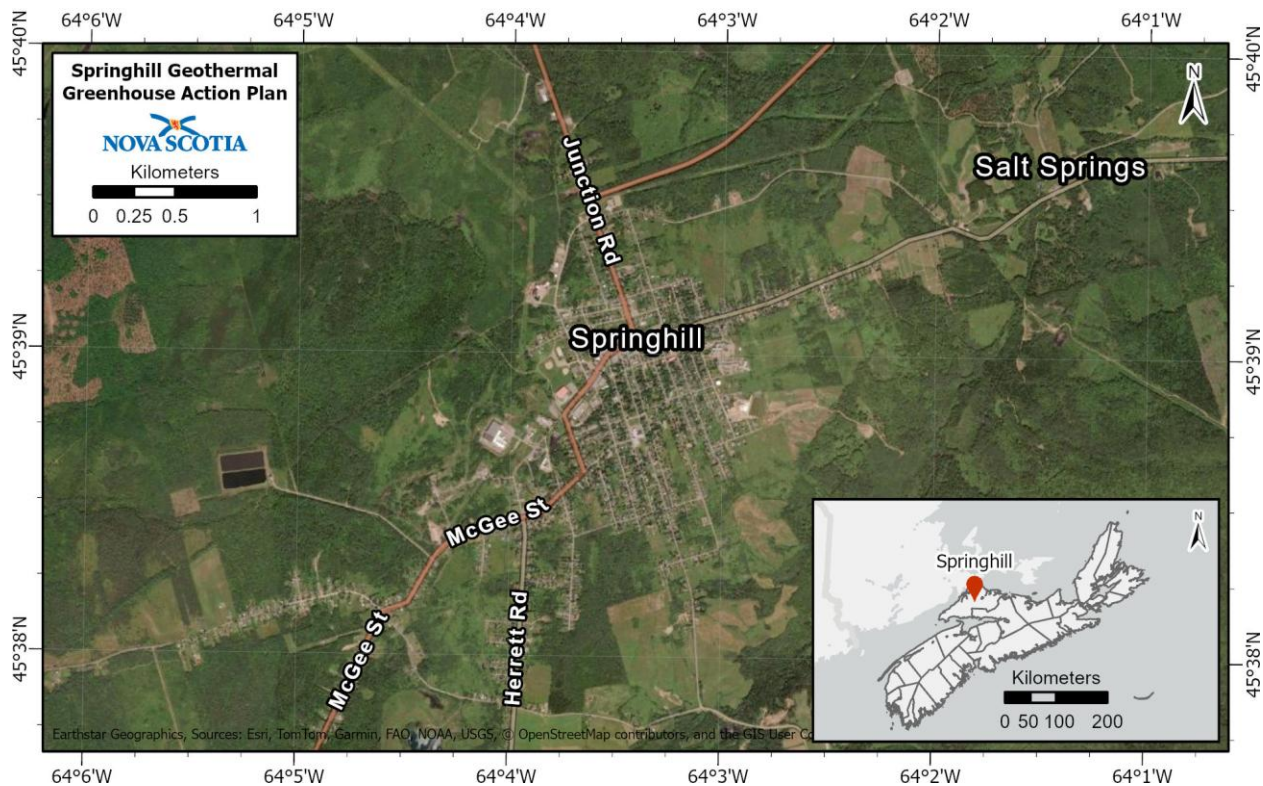


Figure 1-1: Location map of Springhill, Nova Scotia in Cumberland County.

Currently, four facilities in the area use the mine water for heating and cooling: a large community centre with an ice surface, a plastic container manufacturing facility, a battery manufacturing facility, and a new fire station (under construction at the time of writing). The NSCC Cumberland Campus uses mine water wells for training plus heating and cooling of the geothermal technician training lab.

Five distinct coal seams were mined in the Springhill area. The location of the mines underground is indicated in Figure 1-2 below. This report will focus on the No. 2 Seam because mining operations extended the deepest in this seam. Considered possibly the deepest coal mine in North America, the No. 2 Mine reaches a vertical depth of 1,325 m below surface (1,175 m below sea level) and extends over 4 km laterally from the location of the former mine entrance (Frost, 1962).

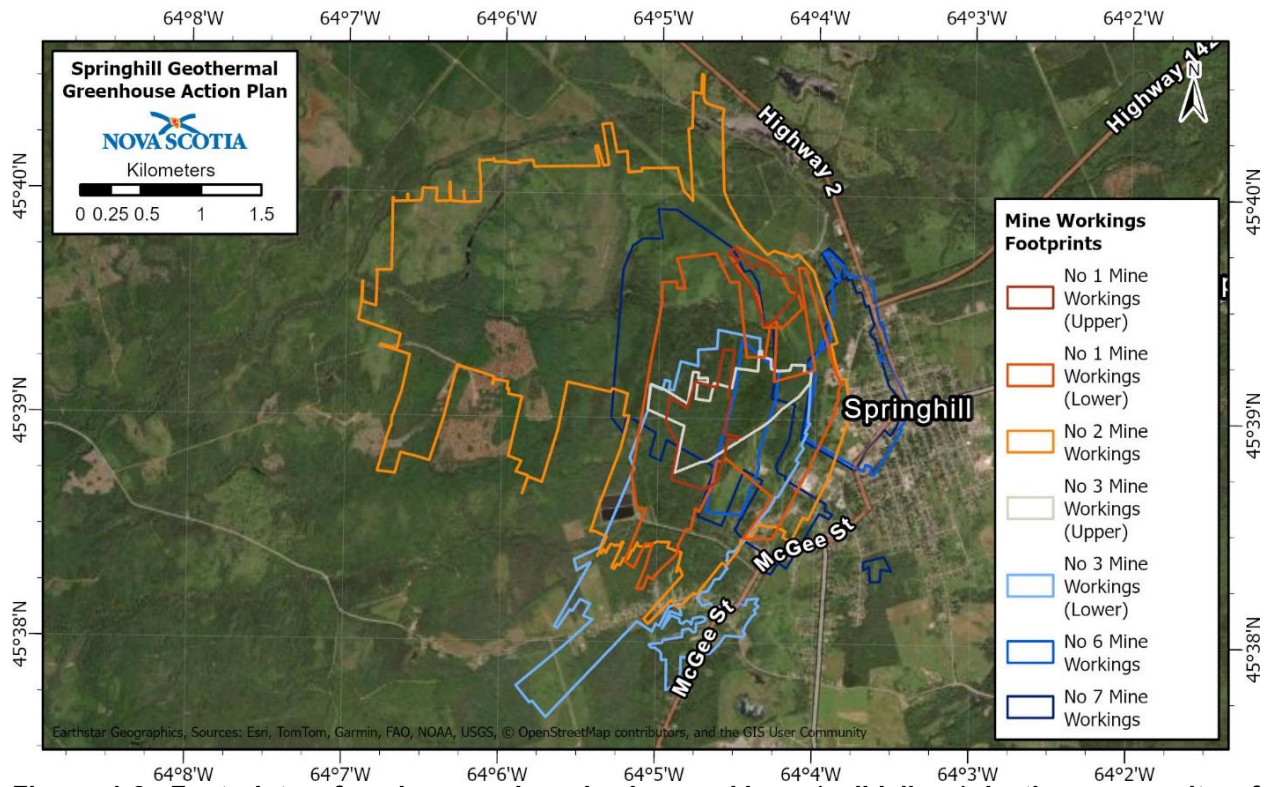


Figure 1-2: Footprints of underground coal mine workings (solid lines) in the community of Springhill. The largest is the No. 2 Mine.

Due to its great depth and the extent of its workings, the No. 2 Mine provides access to a substantial volume of mine water. Herteis (2006) estimated the water volume of the No. 2 Mine at 5,583,000 m³.

The first documented use of the mine water in Springhill as a geothermal reservoir was by Ropak Inc. (now Mauser Packaging), a plastic container manufacturing facility that first accessed mine water geothermal energy in 1989 and continues to use mine water geothermal energy to this day, saving tens of thousand of dollars per year on heating and cooling (Jessop et al., 1995 and MacAskill et al., 2015). They use heat pumps to transfer heat to and from the mine, providing space heating and cooling to their facility and cooling for the manufacturing process.

Over the decades since the geothermal energy in the mine water was first accessed, dozens of wells have been drilled, both as test sites and to provide heating and cooling. The data and results of those well drilling efforts are summarized in Part 2.

In those wells, water temperatures ranging from the normal near-surface groundwater temperature of 7°C to 8°C, through 14°C, and up to 22°C have been found at various locations and depths. This variation in temperature in geothermal wells shows that there is an advantage to choosing some locations and depths in the mine area over others for heating or cooling. The balance between the cost of drilling deeper and the benefit of a higher temperature for heating can possibly be tipped in the user's favour by choosing locations that yield the warmest possible water at the shallowest reliable depth.

The Geothermal Research Advisory Committee (GRAC), formed as a partnership between the Nova Scotia Department of Energy, the Municipality of the County of Cumberland, and the Nova Scotia Community College (NSCC), is tasked with guiding research related to the utilization of geothermal energy in the Municipality of the County of Cumberland, which includes Springhill. A primary goal of the GRAC is to facilitate the development of new and expanded uses of the geothermal resource in the mines.

Among several possibilities for expanded use of the geothermal reservoir, the Verschuren Centre recommended a greenhouse with instrumentation to document the capacity and effectiveness of the resource as a demonstration of the potential economic benefit (MacAskill et al., 2015). Following on this, in 2024 the GRAC made a community mine water geothermal greenhouse a priority. In addition to demonstrating the capacity of the mine water resource, such a project would result in multiple environmental, social,

and economic benefits, particularly with respect to food security and the enhancement of research capacity in protected agriculture.

As greenhouses in the Nova Scotia climate require large amounts of energy for heating in winter, and significant cooling in summer, they can make efficient use of mine water year-round at the temperatures available in Springhill. Heat pump systems to transfer heat between greenhouses and flooded mine workings can operate with a high efficiency due to the moderate temperature of the mine water in comparison with the outdoor air temperature, saving on operational costs related to heating and cooling while also reducing greenhouse gas emissions.

This report includes an assessment of the mine water geothermal resource as it pertains to supplying thermal energy for heating and cooling of greenhouse operations, estimates of the energy savings and operating cost benefits to be gained from using mine water for thermal energy exchange in a greenhouse, proposed scales and greenhouse types, and agricultural crop considerations for a community greenhouse.

1.1. Greenhouse Design and Heating Considerations

A primary objective of this Action Plan is to define greenhouse projects that will take advantage of the unique thermal resource of the mine water in Springhill effectively and efficiently, resulting in advantageous operating costs and greenhouse gas emission reductions. To optimize the energy efficiency of these greenhouses, the design temperature of the heating medium in the greenhouse is relevant because it affects the performance of the heat pumps that will use the mine water as a thermal reservoir to provide heating and cooling.

Evidence from various geothermal wells, discussed in greater detail in Part 2, indicates that the Springhill mine water is available at temperatures between 12°C and 28°C (at the toe of the No. 2 Mine), with a projected mean temperature of 18°C (Jessop et al., 1995). At these relatively moderate temperatures, a geothermal greenhouse for year-round food production will need to use a heat pump to extract heat from the mine water and transfer the heat to a heating medium such as air or water. The heating medium is circulated through the greenhouse and must be at a high enough temperature to meet the required operating conditions of the greenhouse, which vary based on greenhouse design, crop choice, and operational decisions.

To maintain an average operating temperature of 20°C in the greenhouse in winter, the required temperature of the heating medium (air or water), could range from 35°C to 80°C, depending on how the greenhouse is designed. Many standard greenhouses for production of crops such as tomatoes, peppers, and cucumbers use water as a heat distribution medium at temperatures in this range circulated through heat pipes to distribute sufficient heat to the air and the plants in the greenhouse. Some businesses using these methods include the largest commercial greenhouse in Nova Scotia and the greenhouses visited in the Netherlands during this project.

The energy efficiency of a heat pump for heating is often expressed as the coefficient of performance (COP), which is the ratio of the amount of heat energy delivered to the amount of electricity used and can typically range from below 2.0 to above 7.0. If the COP is 5.0, for example, 5 units of heat are delivered for each unit of electricity consumed by the heat pump. The COP is a primary determining factor for the total energy bill.

The main determinant of COP is the temperature difference (ΔT) between the heat source and the greenhouse heat distribution system (Mouzeviris and Papakostas, 2021). The smaller ΔT is, the higher the COP will be and the more efficiently the heat pump will operate. This relationship with ΔT is relatively strong. For example, if starting with 18°C source water from the mine, supplying the working fluid for heating at 80°C will require 2.6 times more electricity than supplying it at 40°C, for the same amount of heat used (Mouzeviris and Papakostas, 2021).

The temperature dependence of the efficiency of heat pumps is a guiding factor in this work. Recommendations are made for how greenhouse design and location can make optimal use of the existing geothermal mine water resource in Springhill.

1.2. Methodology

To prepare this Action Plan, we completed the following steps:

1.2.1. Literature Review

Multiple previous studies of the Springhill geothermal resource were consulted and provided tremendous value to this work in terms of characterizing this resource and its potential applications. Many of these previous studies are listed in the references. However, for convenience of those who may continue this research, key consideration may be given to the following:

- Comeau, F.A., Sèjournè, S, Raymond, J. 2020. Assessment of geothermal resources in onshore Nova Scotia (Phase 1).
- Frost, L. 1962. The Louis Frost Notes 1685 to 1962.
- Grasby, S.E. et al. 2011. Geothermal Energy Resource Potential of Canada.

- Herteis, B. 2006. Geothermal Resources Assessment, No. 2 Seam, Springhill, Nova Scotia.
- Jessop, A. M., MacDonald, J.K., and Spence, H. 1995. Clean energy from abandoned mines at Springhill, Nova Scotia.
- MacAskill, D., Power, C., and Mkandawire, M. 2015. Researching the Geothermal Potential of the Former Springhill Mine.

1.2.2. Investigation of Existing Mine Water Resources

Depth, temperature, and flow data from previous geothermal wells and the Nova Scotia Well Logs Database has been compiled and used to estimate the available geothermal resource and determine optimum conditions for using this resource for a greenhouse.

1.2.3. Strategic Engagement

The project team has conducted the following interviews, site visits, and consultations to gather information and guidance for this project. A summary of the engagement activities and rationale are as follows:

- Two interviews with Brian Herteis, Capital Projects Engineer (retired). He is an expert on the characterization of Springhill mine water with experience in well testing and temperature measurements for wells drilled into the mined area.
- Commercial greenhouse site visit and meeting with Luke den Haan, owner of den Haan Greenhouses, the largest commercial greenhouse grower in Nova Scotia. Den Haan has approximately 3 ha (8 ac) under glass in the Annapolis Valley and provided valuable information and insight into the logistics and energy consumption of commercial greenhouse growing.

- Commercial geothermal greenhouse site visit and interview with Mijnhardt Geothermie, a company that designs and manages the construction of large geothermal greenhouse heating systems in the Netherlands.
- Four meetings with the Geothermal Research Advisory Committee for Cumberland County, a body that includes the mayor, three councillors, the MLA for the area, and the principal of the NSCC Cumberland Campus, supported by staff from the Department of Energy, NSCC, and the Municipality of Cumberland.
- Participating in the Food Security Summit held in Springhill in March 2024, to learn more about the needs and opportunities in local food security.

1.2.4. Retaining Technical Consultants

Expert consultants were engaged to provide technical expertise and research to support the Action Plan, in specific areas related to greenhouse design and costing, energy consumption estimates, and crop planning.

- ***Mijnhardt Geothermie*** (Jean-Pierre Schenkeveld, the Netherlands): A design and project management consultancy specializing in large commercial geothermal greenhouse projects worldwide, Mijnhardt Geothermie provided conceptual level designs, drawings, and energy calculations for Section 3.4 – Large Commercial Geothermal Greenhouse.
- ***Ceres Greenhouse Solutions*** (Kendl Santelli, USA): A designer and manufacturer of energy efficient greenhouses for cold climates was consulted. They provided a case study for Section 3.3, mid-sized greenhouse, including cost estimates, design renderings, and energy consumption estimates.

- ***Perennia Food and Agriculture Corporation*** (Talia Plaskett, Nova Scotia): Nova Scotia’s Food Development Agency, Perennia is a provincial corporation that supports agricultural development and innovation in Nova Scotia. They have recently started a Protected Crops division, with a specialist focusing on supporting production of greenhouse, containerized, and other enclosed or protected crop systems. We engaged Talia Plaskett and the Perennia team to provide recommendations on the kinds of crops that could be successfully grown in a community geothermal greenhouse in Springhill. They considered Scenario 1 (Mid-Size Mine Water Geothermal Greenhouse), which we consider to be the most relevant scale for local food security.
- ***Additional Technical Expertise***: Local contractors and well drilling companies were also contacted for technical guidance and cost estimates for construction and well drilling.

1.3. Greenhouse Scenario Development

Guided by the input from consultations and the review of existing reports, three scenarios for greenhouse development projects were proposed and explored. These three proposals are as follows:

1. Mid-size mine water geothermal greenhouse
2. Large geothermal commercial greenhouse
3. Small greenhouse using waste heat from the Community Centre

These three greenhouse scenarios are described in detail in Part 3.

2. Thermal Architecture of the Springhill Mines

The Springhill Mines lie within the Cumberland Basin, a geological zone with a set of underground layers that includes a salt dome and multiple coal seams. Both the coal and the salt have been attractive resources for mining activity in the Cumberland Basin, and the historical drive to extract the coal has led to the opening of the geothermal mine water resource in the present day. Currently, five existing users now benefit from the mine water resource, and evidence indicates that a large amount of residual thermal energy is available for new applications.

Jessop et al. (1995) estimated that the Springhill Mines water contains about 250 TJ of thermal energy. More recently, in a comprehensive study of geothermal potential in Nova Scotia, Comeau et al. (2020) estimated that the Springhill No. 2 Mine (workings shown two-dimensionally on Figure 2-1 and three-dimensionally on Figure 2-2) water resource could supply 58 TJ of heat energy annually. While this is only one of the mines in the area, it is the largest, the deepest, and the most likely to provide suitably warm water temperatures. Estimates of the annual amount of energy that the six major coal mines in Springhill could provide are given in Table 2-1.

Table 2-1: Summary of the six major coal mines in Springhill, Nova Scotia with the estimated heating and cooling capacities in MWh and GJ. The operating periods are provided by Frost (1962), and the production amounts and thermal capacities are provided by Comeau et al. (2020).

Name	Operating Period	Total Production (tonnes)	Heating Capacity (MWh)	Heating Capacity (GJ)	Cooling Capacity (MWh)	Cooling Capacity (GJ)
No.1	1872-1954	3,052,000	4,594	16,538	1,342	4,831
No.2	1873-1958	10,822,000	16,289	58,640	4,760	17,136
No.3	1882-1930	258,000	388	1,397	136	490
No.4	1928-1956	3,509,000	5,282	19,015	1,543	5,555
No.6	1918-1936	1,376,000	2,071	7,456	675	2,430
No.7	1919-1933	925,000	1,392	5,011	473	1,703
	Totals	19,942,000	30,016	108,057	8,929	32,145

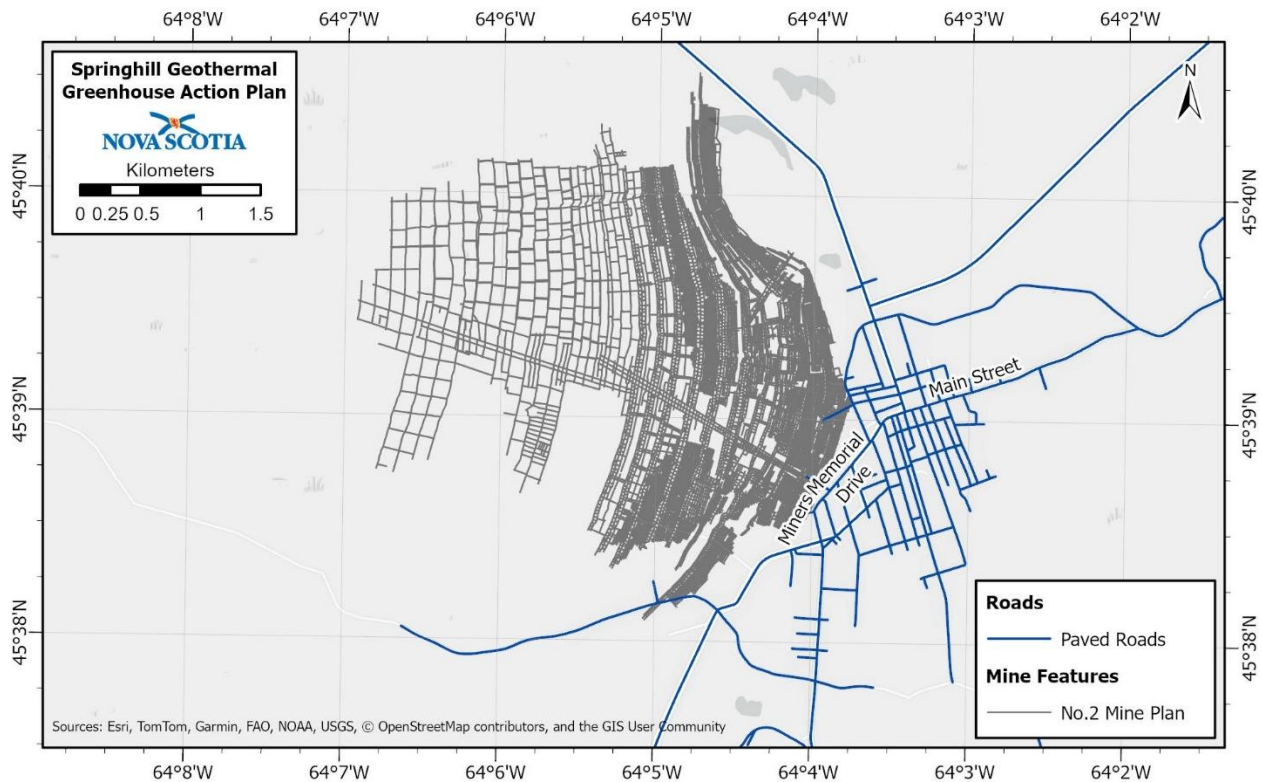


Figure 2-1: Plan view map showing the paved road infrastructure (blue lines) in the community of Springhill with the No. 2 Mine workings (grey lines) superimposed.

When Mauser Packaging first began using the mine water for heating and cooling, measurements indicated that their operations drew approximately 0.89 TJ of heat from the mine per year for space heating in winter and returned 1.5 TJ of heat in the summer for cooling. As an industrial facility with process equipment that generates heat, this facility

requires more cooling than heating, leading to a small net positive contribution of 0.66 TJ of heat energy to the mine water on an annual basis (Jessop et al. 1995). These figures give an indication of the scale of heating and cooling required by industrial facilities in the area now.

Taken together, the evidence above indicates that there is substantial additional capacity to supply heat to more facilities in Springhill. Considering the above estimates, even if the Mauser Packaging facility were to take 1 TJ of heat from the mine and not return it, the estimate from Comeau et al. (2020) suggests that at least 50 times that amount of energy is available in the mine. Within that context, planning for additional heat loads such as greenhouses must focus on where to extract the heat, understanding what temperature of water can be expected, and where to return water to the mines so as to minimize any impact on the resource for all users of the mine water.

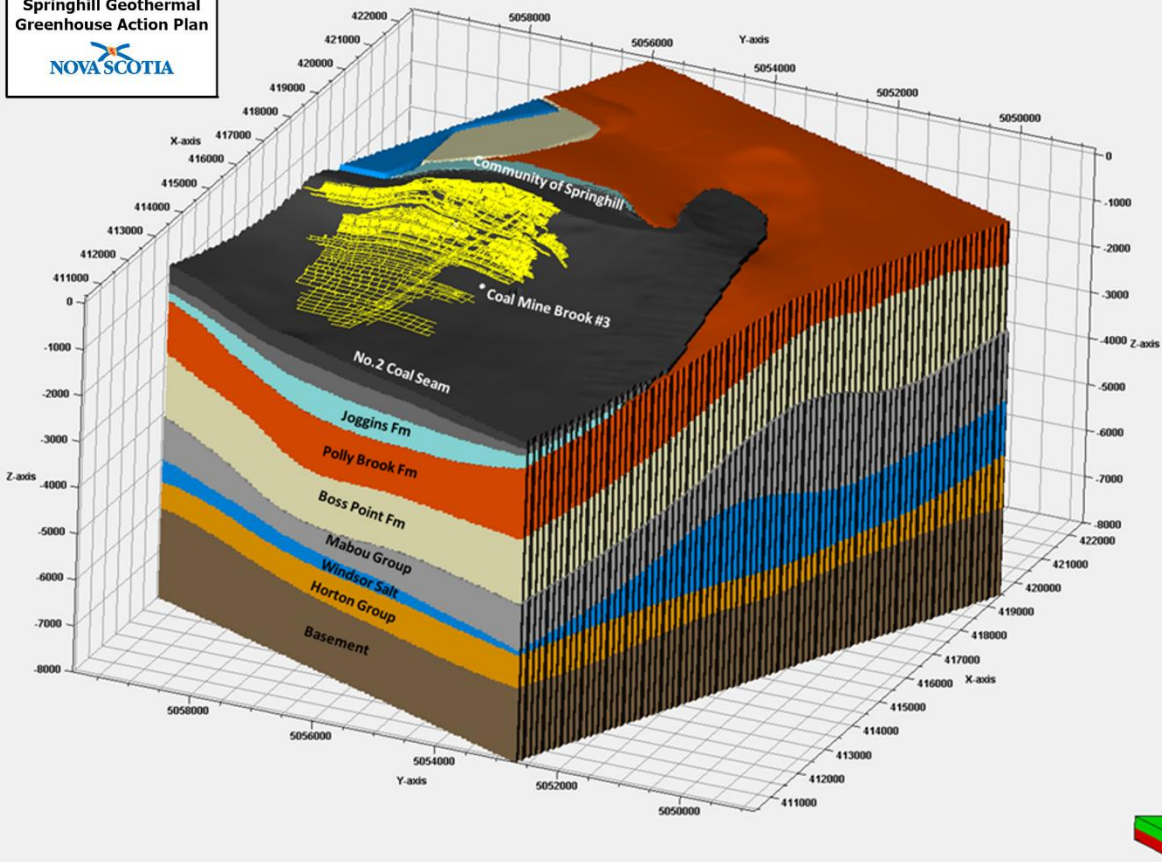


Figure 2-2: Three-dimensional geological model for the community of Springhill and surrounding area showing the underlying geology. The subsurface layers have been labelled (e.g., Joggins Fm, etc.) The yellow lines depict the workings of the No. 2 Mine draped onto the No. 2 Coal Seam. The location of the Coal Mine Brook # 3 coal bed methane exploration well is also shown.

2.1. Surface Location and Depth of No. 2 Mine Slope

The mine workings ultimately reached a vertical distance from the surface of approximately 1,325 m or about 1,175 m below sea level (Frost, 1962). The approximate depth of the main slope of the deepest mine in the area, the No. 2 Mine, at locations along the slope, is shown on an aerial image of the Springhill area in Figure 2-3. At approximately 800 m depth, the slope is shifted laterally to accommodate the limits of hauling and pumping equipment at the time the mine was created. Mine workings spread north and south of the slope. Land at the surface over the mine is municipally owned out to approximately 270 m mine depth, and the property from mine depths between about

1,010 m to almost the deepest extent is Crown land, while the intervening property is privately owned. Property lines are shown in Figure 2-3.

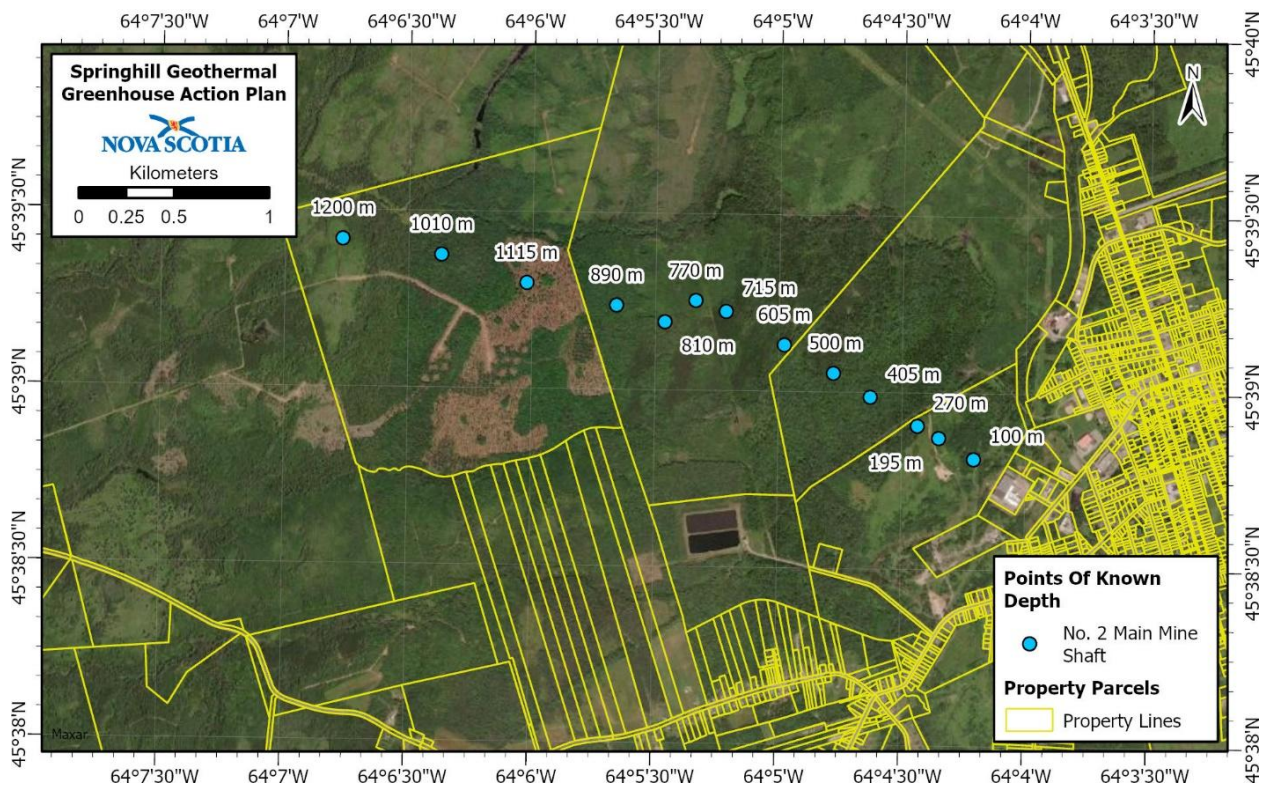


Figure 2-3: Map showing location of No. 2 Mine Slope by approximate surface location and depth.

2.2. Baseline Geothermal Gradient

The deepest well in the Springhill area for which we have corrected temperature data (Coal Mine Brook # 3) was drilled in the year 2006 as an exploratory well for coal bed methane. It was not a mine water geothermal well and did not intersect any of the coal mine workings. This well is much deeper than the existing geothermal wells, extending to nearly 1,270 m in depth, effectively a very similar depth as the workings of the No. 2 Mine. The location of this well, at 45°38'49.00 N (Latitude) and 64°05'30.00 W (Longitude) is indicated in Figures 2-2 and 2-5. This well can be considered as a measure of the baseline geothermal gradient with depth below the surface, relatively unaffected by mining activity. The geothermal gradient is consistent in this well and can be approximated

with a best-fit linear or quadratic equation, to estimate the baseline temperature underground as a function of depth in the absence of the mine workings. The best-fit equations are shown in Figure 2-4.

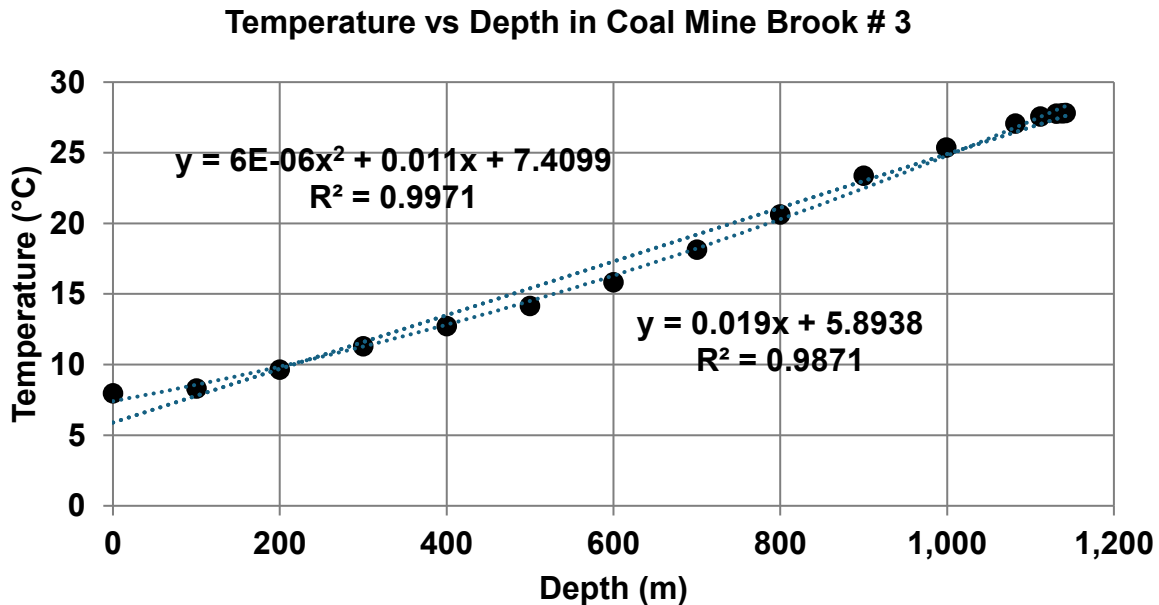


Figure 2-4: Corrected temperature as a function depth for the Coal Mine Brook # 3 well showing best fit linear and quadratic equations for baseline geothermal gradient.

The linear best fit line gives a surface temperature of 5.9°C and a linear thermal gradient of 19°C/km. The quadratic equation yields a slightly better fit. Using the quadratic best fit and the depth of the deepest temperature measurement from the Coal Mine Brook # 3 well (1,142 m), the estimated temperature at the bottom of the No. 2 Mine is approximately 27.8°C. This is in close agreement with earlier estimates from Jessop et al. (1995).

The most important implication of this result is that, if drilling is done to the bottom of the No. 2 Mine to access water for geothermal heating, the highest temperature of mine water that can be expected to be obtained is 28°C. At shallower depths, the temperature of the mine water can be expected to be between the surface temperature of 6°C and the bottom temperature of 28°C, however historical geothermal mine water temperature

readings indicate the mine water does not follow the consistent baseline (or substrate) temperature pattern found in Coal Mine Brook # 3, with many higher temperatures having been measured. The temperature differences between the known geological baseline and the mine water have been theorized to be due to convection of warm water within the mine workings, especially the main slopes, or some other connectivity between the shallow and deep mine water, however this has not been proven. The estimated temperature gradient throughout the depths of the mine substrate are shown in plan view on Figure 2-5 and three-dimensionally on Figure 2-6. Previously measured and theorized mine water temperatures are not shown. The average temperature of the water in the No. 2 Mine was estimated to be about 18°C by Jessop et al. (1995).

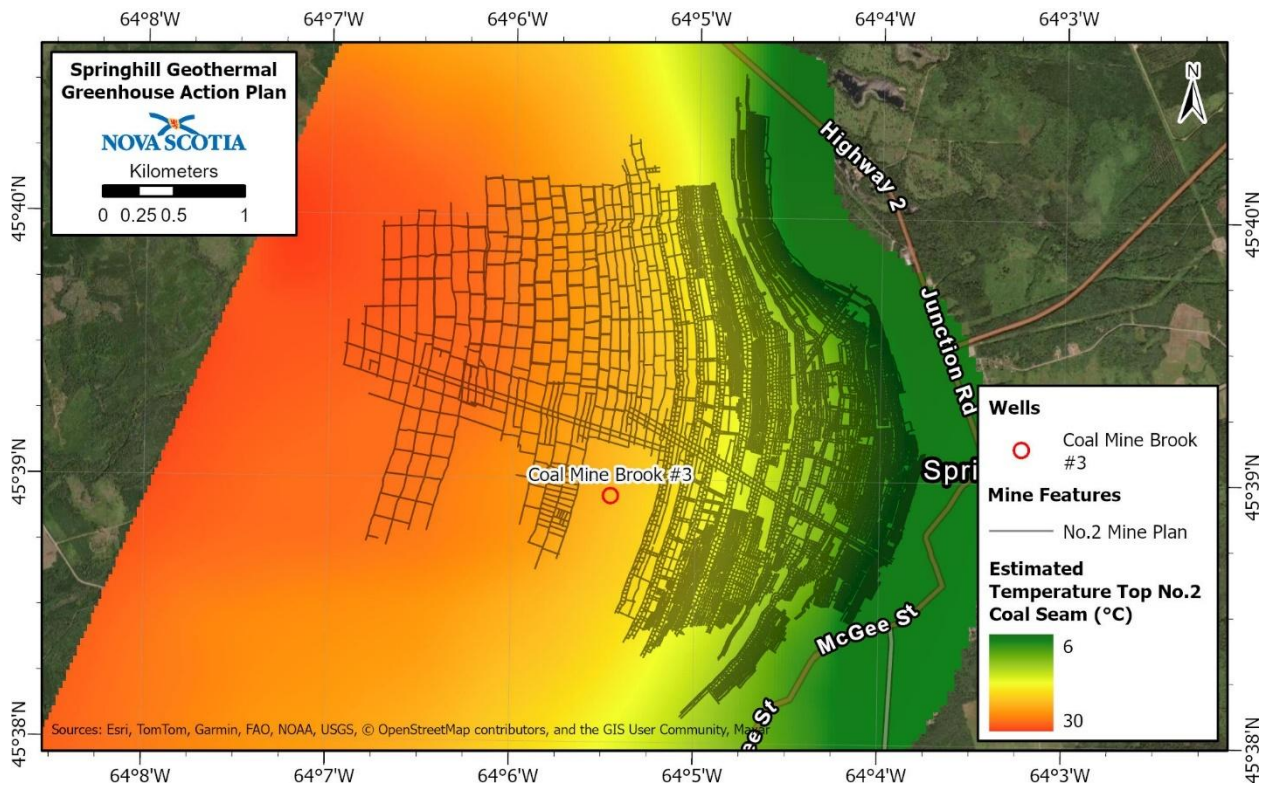


Figure 2-5: Plan view map showing the No. 2 Mine workings with estimated substrate temperature coloured based on the corrected downhole temperature measurements from the Coal Mine Brook # 3 well (red circle). Previously measured mine water temperatures are not shown.

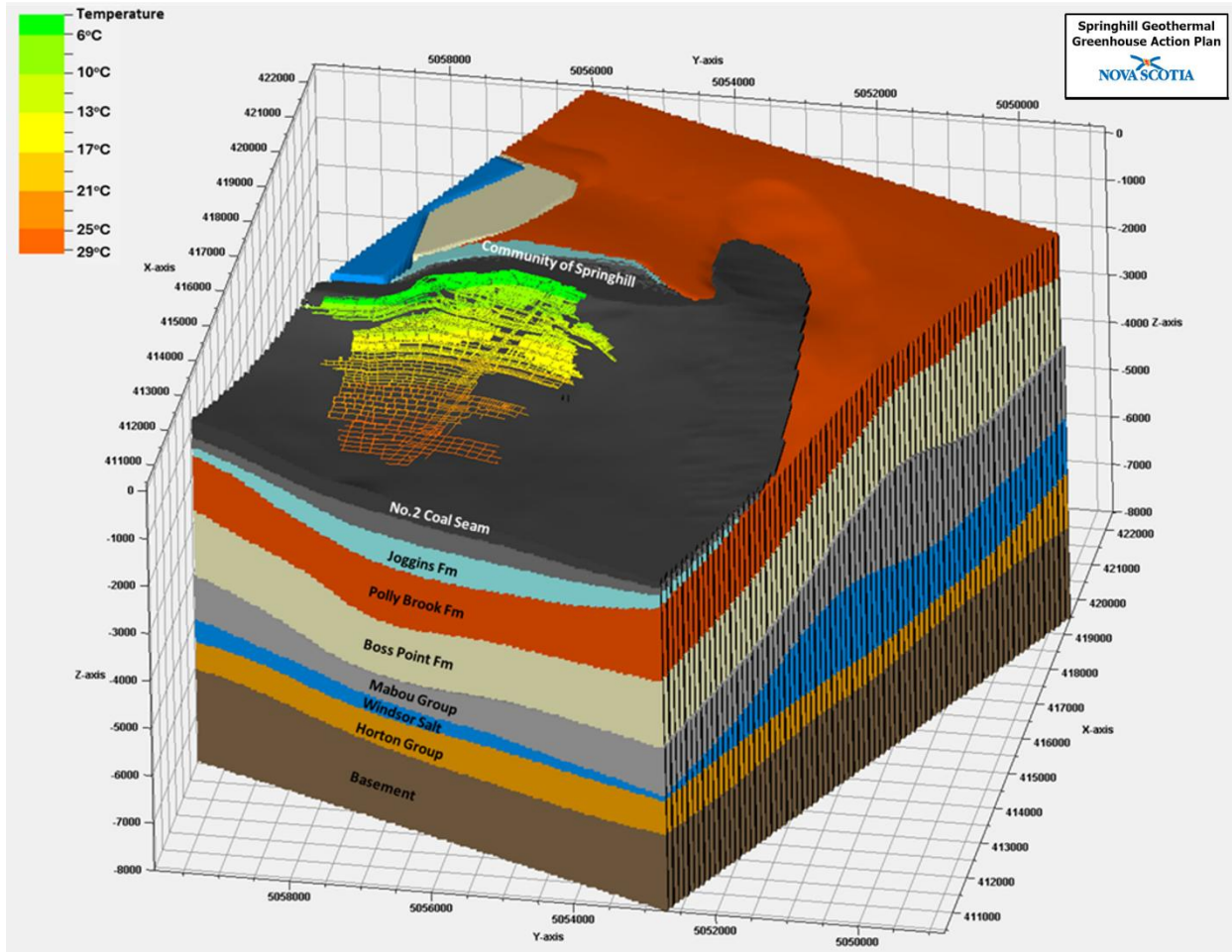


Figure 2-6: Three-dimensional view showing the No. 2 Mine workings with estimated substrate temperature coloured based on the corrected downhole temperature measurements from the Coal Mine Brook # 3 well. The mine workings have been draped onto the No. 2 Coal Seam (dark grey layer). Previously measured mine water temperatures are not shown.

2.3. Location of Wells

The locations of the wells for which data were assembled are shown in Figure 2-7 below. This location information was compiled by Trevor Kelly (Geothermal Energy Technical Coordinator with the Municipality of the County of Cumberland) in 2024 from available records, including legacy reports and the online Nova Scotia Well Logs Database. The compiled summary of well records is attached as Appendix A.

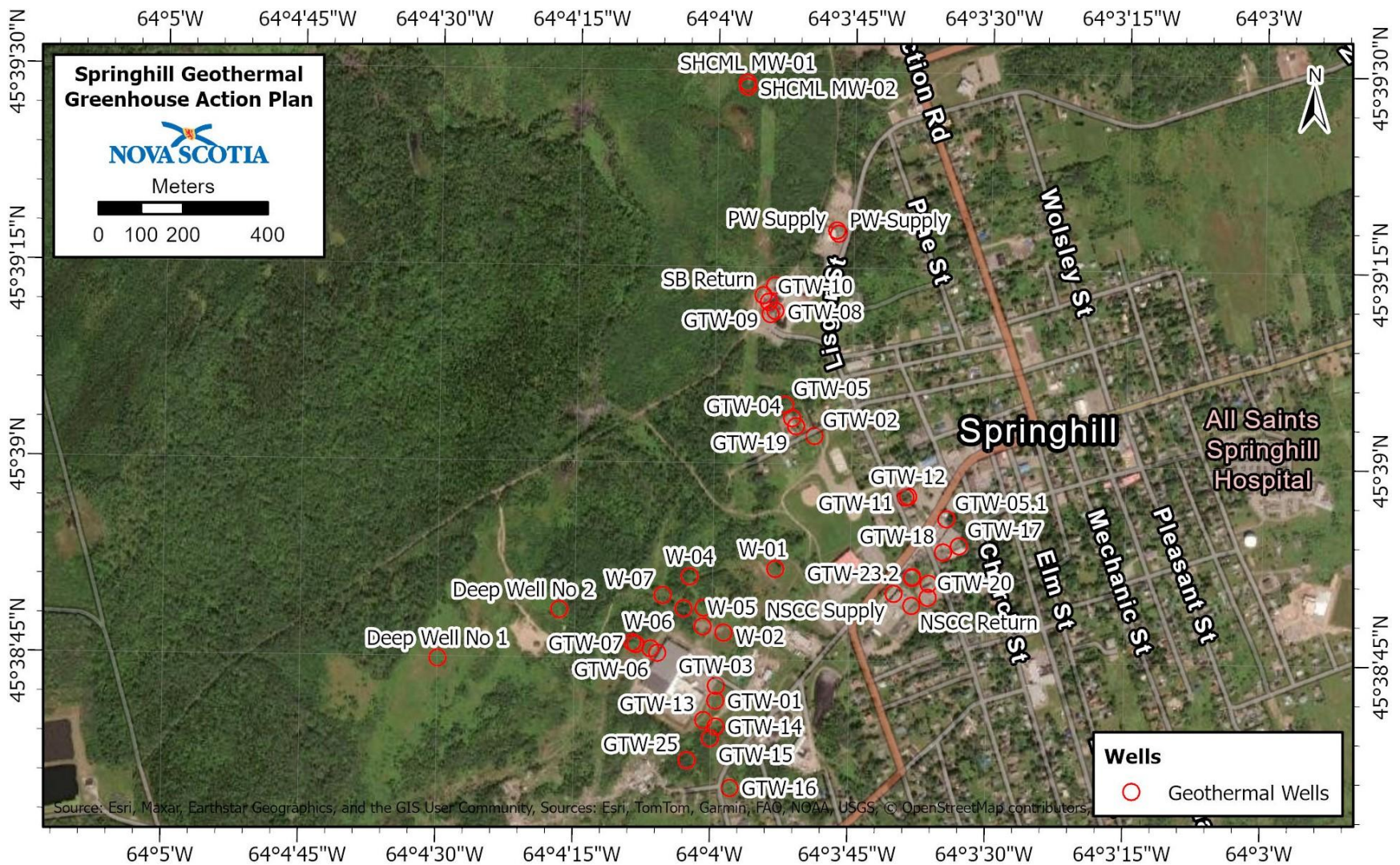


Figure 2-7: Locations of geothermal wells whose data were included in this study. The Coal Mine Brook # 3 coal bed methane exploration well is outside the range of this figure.

Many of the wells were drilled for testing purposes, while others actively supplied, and in some cases continue to supply, water for heat pumps for heating and cooling of various facilities – Dr. Carson and Marion Murray Community Centre, Mauser Packaging, Surrette Battery, the new Fire Station, and the NSCC geothermal technician training lab.

The well log records from this substantial set of wells represent an invaluable data resource for further work on accessing geothermal energy in Springhill. The focus here will be on determining optimum locations to access the mine water resource for greenhouse heating and cooling.

2.4. Raw Temperature Data

The potential geothermal resource available for greenhouse heating and cooling was assessed using available raw temperature data compiled by municipal staff (T. Kelly, personal communication, 2024) from 17 geothermal wells that were drilled for past research and mine water extraction. Temperatures were measured in some cases simultaneously with drilling and in some cases 24, 40, or 72 hours or longer after drilling. The historical raw temperature data used in this study are summarized in Figure 2-8 below.

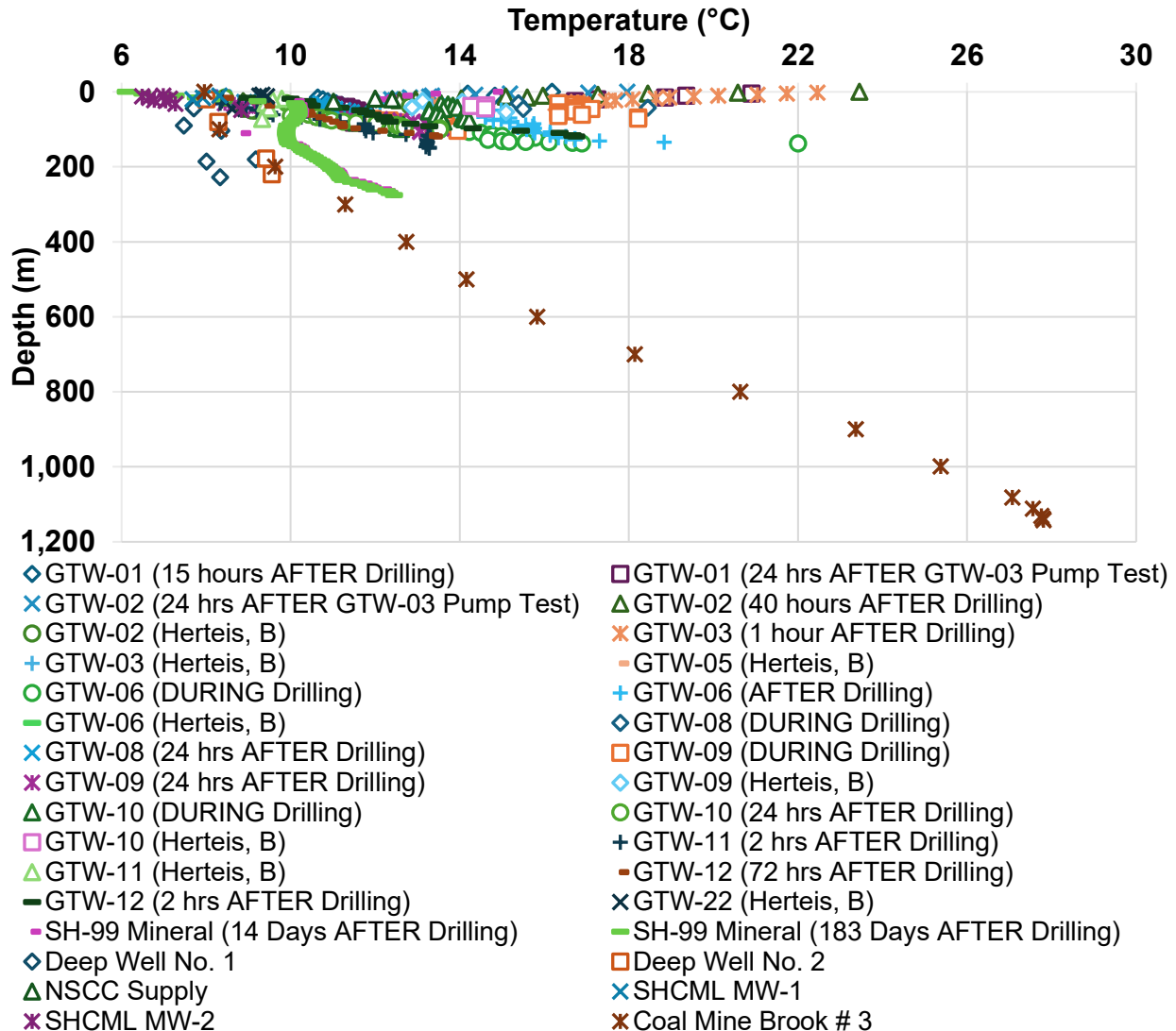


Figure 2-8: Raw temperature of groundwater as a function of depth for various geothermal wells in Springhill. The plot also shows the corrected temperature data from the Coal Mine Brook # 3 well.

The data confirm the findings that originally led to the interest in using mine water as a thermal reservoir. In one of the earliest studies, the temperature at the bottom of the mine was estimated to be at least 26°C (Jessop et al. 1995). Coal Mine Brook # 3, the deepest well for which we have corrected temperature data nearby, confirms this estimate. It shows a steady increase in temperature with depth, displaying the expected baseline thermal gradient and reaching a temperature of 28°C at the depth of the bottom of the mine. As discussed in Section 2.2, it should be noted that the Coal Mine Brook # 3

well was an exploratory well for coal bed methane. It was drilled into an area outside of the coal mine workings.

Several of the shallower wells show unusually high temperatures of up to 23°C at relatively shallow depths, and in some instances a decrease in temperature with increased depth. This is discussed in further detail in Section 2.5 below. It has been hypothesized that some of the unusually high temperatures at shallow depths are caused by the convection of warm water up the No. 2 Mine Slope. There is not yet enough evidence to either confirm or refute this hypothesis.

Herteis (2006) reported that pump tests of geothermal well no. 6 (GTW-06) yielded unusually warm temperatures of between 18°C and 22°C at a depth of 137 m in the No. 2 coal mine workings. This well is of particular interest because, due to its location, it reached the main haulage slope of the No. 2 Mine. GTW-06 was the original supply well for the Mauser Packaging and provided warm water for years until it ceased production due to well collapse.

Mauser Packaging drilled a new supply well nearby in the year 2000 (GTW-23.3), which based on its location and its reported depth of 41 m appears not to reach the main slope of the No. 2 Mine. Mauser Packaging still uses GTW-23.3 as a supply well for geothermal heating and cooling today, and preliminary data indicate that the supply temperature is now around 14°C, which is lower than the 18°C previously obtained in GTW-06. Due to the differences in depth and location between GTW-06 and GTW-23.3, a plausible hypothesis is that GTW-06 accessed warmer water due to connecting directly with water in the slope of the No. 2 Mine. A new set of comprehensive measurements of the supply temperature at Mauser Packaging and confirmation of the depth of GTW-23.3

are recommended as they would contribute to a greater understanding of the temperature distribution of the mine water.

It can be seen from the recorded well log data that the presence of unusually warm water at relatively shallow depth is specific to particular locations. Further analysis to gain insight into these locations and potential causes follows below. At very shallow depths, surface water and shallow groundwater infiltration may have an influence on the temperature readings, while at deeper depths the data can be considered to represent the temperature of mine water more consistently.

2.5. Warm Water at Shallower Depth

A close examination of the raw well temperature data reveals instances of anomalous temperatures at shallow depths. Four examples are shown in Figure 2-9 below. In GTW-01, GTW-02, and GTW-03, water temperatures as high as 23.5°C were found at surprisingly shallow depths of less than 10 m. In GTW-06, similarly high temperatures were found at 137 m depth. These wells were drilled with the goal of accessing warm mine water to supply geothermal energy for various projects, as described in Table 2-2.

Table 2-2: Four wells that showed elevated near-surface water temperatures.

Name	Year	Location / Purpose	Hole Depth (m)	Max T (°C)	Target Seam
GTW-01	1987	Mauser Packaging	82.3	16.2	# 2
GTW-02	1987	Community Arena	50.9	23.5	# 2
GTW-03	1987	Town loop district heating supply	44.2	22.5	# 2
GTW-06	1988	Mauser Packaging	137.5	22.0	# 2

The locations of these four selected wells are shown in Figure 2-9. All four of these wells entered the No. 2 coal seam, three of them in the main haulage zone and one in the workings, some distance away.

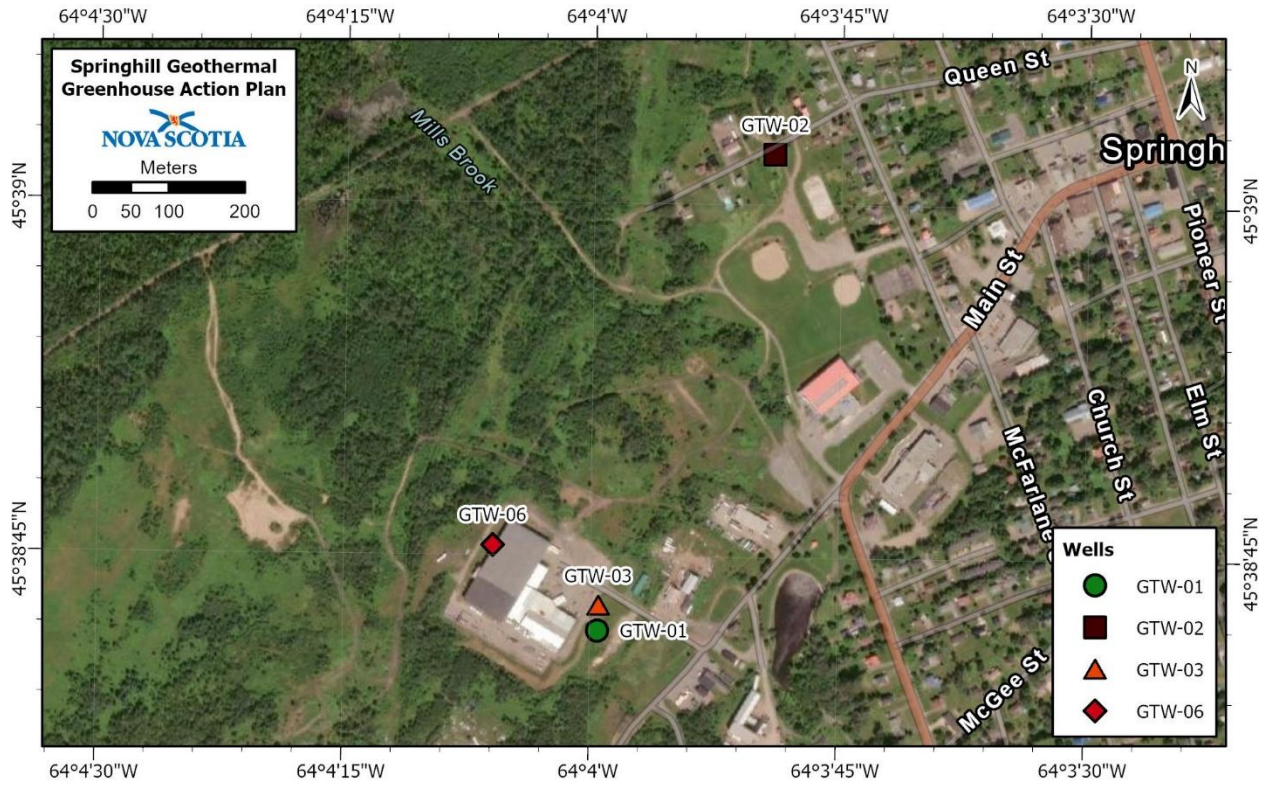


Figure 2-9: Locations of example wells GTW-01, 02, 03, and 06.

These wells are singled out here because their well log temperature data (Figure 2-10) shows remarkably high temperatures that are far above the normal surface ground temperature. The spatial and depth pattern of these unusual temperatures was investigated to gain a better understanding of how these warmer temperatures are generated and how to access them for additional thermal energy supply.

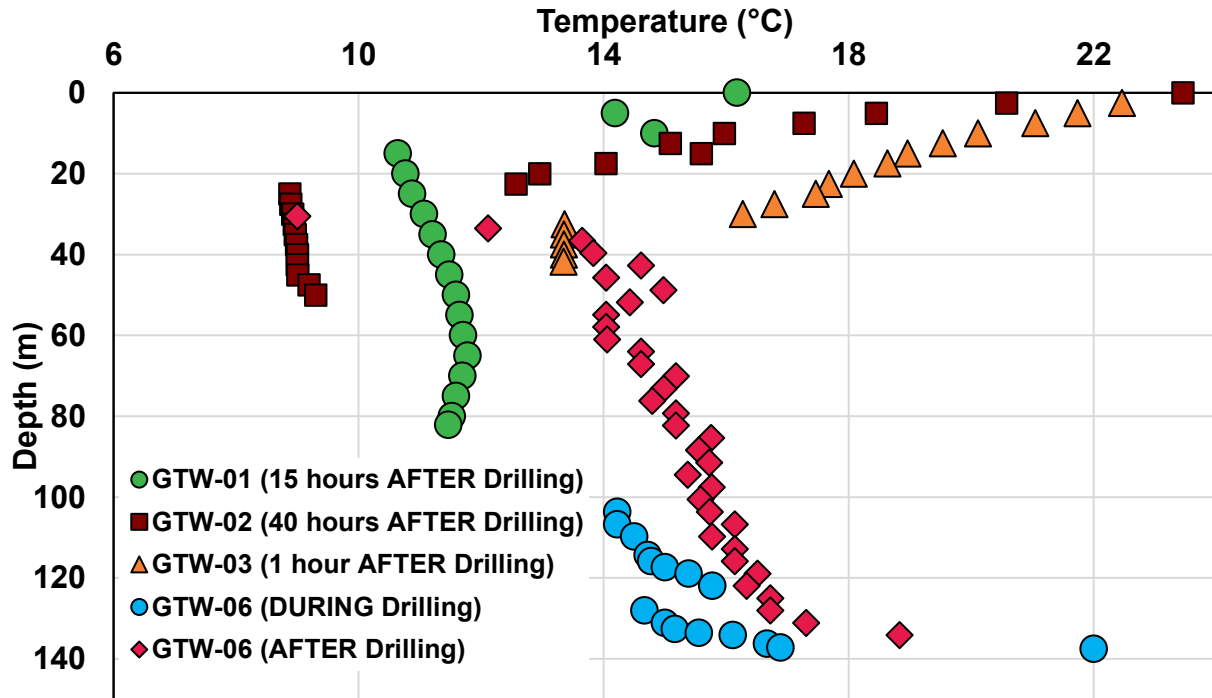


Figure 2-10: Temperature as a function of depth for selected wells to 150 m depth.

The shallowest well data, at depths less than 20 m, are probably unreliable. Some of these very shallow measurements are above the static water level and could be frequently affected by surface processes such as rainwater infiltration and mixing. Numerous factors related to the influence of drilling may also contribute higher temperatures at shallow depths. The following factors could have influenced the temperature measurements collected during and after drilling:

- **Frictional Heating:** The drilling process generates significant heat due to friction between the drill bit and the rock. This frictional heating can cause localized high temperatures near the drill bit (Kumar et al., 2024).
- **Circulating Drilling Fluid:** Drilling fluid is circulated through the borehole to cool the drill bit and remove cuttings. The temperature of the drilling fluid can affect the temperature measurements. If the fluid is warmer than the

surrounding rock, it can artificially raise the temperature readings (Schumacher and Moeck, 2020).

- **Heat Transfer:** As the drilling fluid circulates, it can transfer heat from deeper, hotter sections of the borehole to shallower, cooler sections. This can result in elevated temperature readings at shallower depths (Schumacher and Moeck, 2020).
- **Thermal Disturbance:** The process of drilling itself disturbs the natural thermal gradient of the rock. This disturbance can cause temporary high temperatures that do not accurately reflect the true formation temperature (Schumacher and Moeck, 2020).
- **Measurement Timing:** Temperature measurements taken during drilling or immediately after drilling are more likely to be influenced by the heat generated during drilling. Allowing time for the borehole to stabilize (equilibrate) can provide more accurate temperature readings (Schumacher and Moeck, 2020).

The temperature data are in raw form and were not corrected for these possible influences, therefore they have significant uncertainty. Aside from the potential influences of the drilling activity itself, the shallowest measurements are more likely to be influenced by processes involving near-surface groundwater and surface water infiltration. In addition, availability of water from very shallow depths for geothermal energy applications could be unreliable as groundwater levels fluctuate. Drawing water from a depth that is significantly deeper than the static water level (below 60 m) is recommended, to minimize the possibility of supply wells running dry.

Geothermal well GTW-06 demonstrates the most promising data, with water found at a depth of 137 m with a temperature of 18°C to 22°C, which is up to 13°C warmer than the expected baseline temperature at that depth. At this location and depth, GTW-06 is believed to have accessed the water in the main haulage slope of the No. 2 Mine, providing evidence that the main haulage slope of the No. 2 Mine could be a source of warm water.

GTW-06 itself may have been a good source for warm water to supply a greenhouse, but that well is no longer available. It was used by Mauser Packaging as a supply well for heating and cooling until the well collapsed in the year 2000. Re-drilling it is unlikely to be feasible as it is located immediately behind the Mauser Packaging building. Drilling into the main haulage slope of the No. 2 Mine further west on the municipal lands, where it is at a depth of approximately 240m to 270 m, would be an optimal approach to seeking advantageously warm water at a reasonable drilling cost.

In terms of a plausible mechanism for producing unusually warm at such a shallow depth, our working hypothesis, similar to that of Jessop et al. (1995), is that the main slope of the No. 2 Mine is serving as a conduit for convection of warmer water from the depths of the mine. Relatively warmer, lower-density water in a tunnel of sufficient dimension can rise along the top of the tunnel, to be displaced by cooler, denser water moving down along the bottom of the slope, resulting in a transfer of heat by convection from deeper to shallower depths via the main mine slope.

As Jessop et al. (1995) pointed out, convection can only effectively occur in a conduit of sufficient diameter. They concluded that convection could occur in conduits greater than 1 m diameter and with a slope greater than ten degrees. Assuming it is still

open to something like its original size, which is estimated from mine working plans to have been approximately 2.7 m high by 3.0 m wide, the main haulage slope of the No. 2 Mine is more than large enough to allow convection. As it accesses the warmest depths of the mine, the haulage slope itself is a possible conveyor of heat from the bottom of the mine to the top.

If this is the case, there could be a significant temperature advantage to drilling at locations that can access the main slope of the No. 2 Mine directly, where temperatures of 18°C to 22°C can possibly be accessed. As convection is driven by differences in density, warm water circulation will happen faster along the steep slope than in the side branches.

For these reasons, the area of land overtop of the main slope of the No. 2 Mine is preferential for tapping into mine water for greenhouses and other potential heating uses. An area prioritized for geothermal development is proposed here to maintain the access to the potentially warm water in the No. 2 Mine Slope. This area is outlined conceptually in Figure 2-11.

Deep Well No. 2, drilled in 2018, was originally drilled with the intention of accessing the slope of the No. 2 Mine (B. Herteis, personal communication, 2025). This well is believed to have nearly reached its target. A location near Deep Well No. 2, targeting direct access to the main haulage slope of the No. 2 Mine, would be a good starting point as a location for drilling a new geothermal well.

Falcon Engineering produced a technical memorandum (Quibell, 2020; Appendix D) with considerations for drilling supply wells for the proposed geothermal business park. This technical memorandum contains detailed information on how to increase the

probability of successfully accessing the water in the main slope of the No. 2 Mine, along with recommended locations for extraction and reinjection wells, and is an excellent resource to guide the next stage of planning for the geothermal greenhouse.

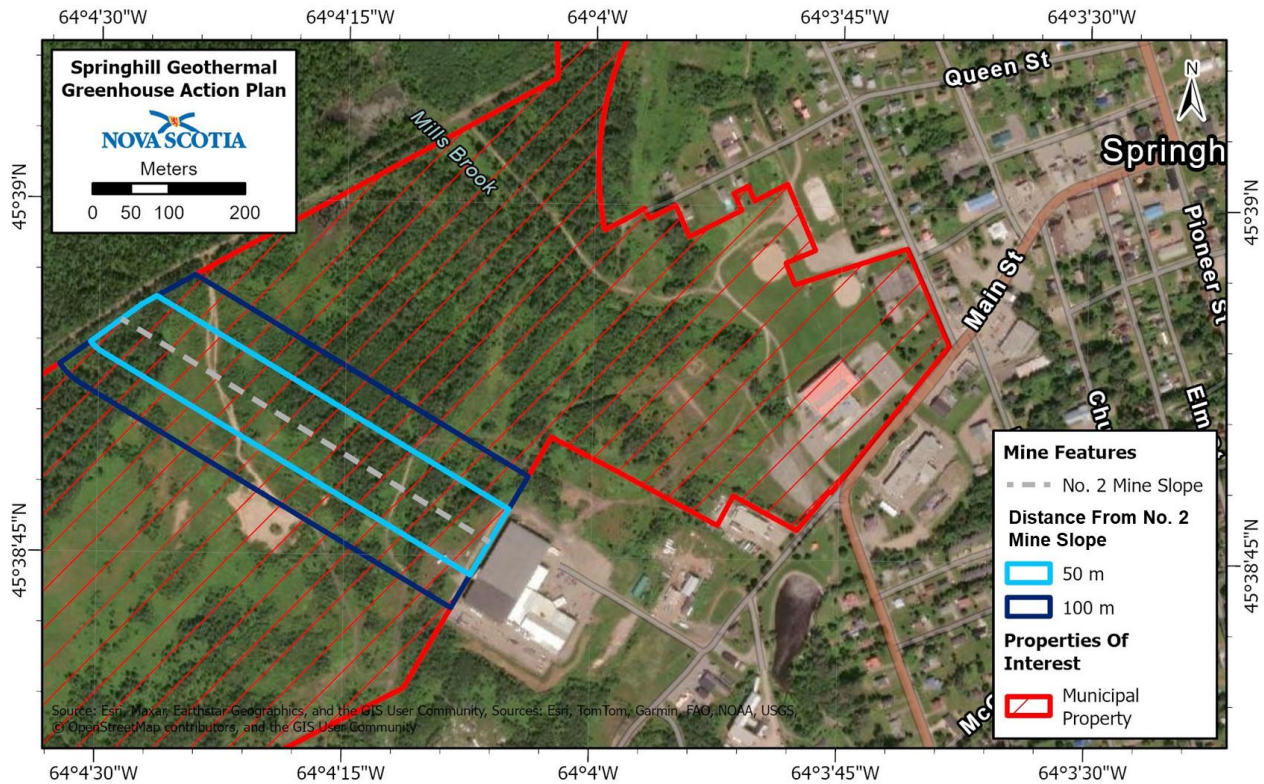


Figure 2-11: Area of surface land with preferential access to warm water in the No. 2 Mine Slope.

The area indicated within the blue border for potential access to the No. 2 Mine Slope is on municipal land. The municipal land in the area hosts a wastewater treatment facility and has potential to host additional industrial or community uses, as well as a proposed 9-MW community solar photovoltaic array (S. Ferguson, personal communication, 2024). Identifying areas that ensure future access to the land over the main slope of the No. 2 Mine can help guide future development.

2.6. Alternatives for Warm Water Access

2.6.1. *Near the top of No. 2 Mine*

An alternative for warm mine water access that could be considered is to drill near the top of the No. 2 Mine Slope with a wider-diameter borehole, near the site where the mine originally surfaced, in order to install pipes that would extend down the mine slope to access a consistent warm water supply. Remotely operated equipment may be able to guide pipe installations down the slope. This possibility is noted here for potential follow-up but has not been investigated within the scope of this study.

An advantage of this alternative would be to gain access to a large volume of water using the original mine infrastructure while minimizing drilling cost. It could also open up interesting possibilities for a more thorough exploration of the abandoned mine using remotely operated underwater vehicles that can record comprehensive video footage, which would add significant value in terms of research and education. The opening of the mine near where it surfaces would involve much shallower drilling that could be then enlarged to a larger diameter, thus offering a possibility of greater access.

This alternative could be considered at a location to the northwest of GTW-03 (the original Town Loop Well drilled in 1987, which reportedly ran dry under some conditions). From that point, if pipes could be installed along the top of the mine slope to a depth below the static water level, below approximately 60 m, it is possible that large volumes of warm water could be accessed directly from the mine slope.

2.6.2. *Alternative Drilling Scenarios*

Two potential drilling scenarios that could be applied to supply the warm water required for the mine water geothermal greenhouse are explored here. The first drilling

scenario assumes a shallow (less than 300 m) well on the municipal lands behind Mauser Packaging into the main slope of the No. 2 Mine. This is shown as Drill Scenario # 1 on Figure 2-12. The second drilling scenario assumes a deeper (approximately 1,200 m) well in the main slope of the No. 2 Mine near the toe of the mine and is also shown in Figure 2-12. A comparison of these two options in terms of various parameters and risks is shown in Table 2-3.

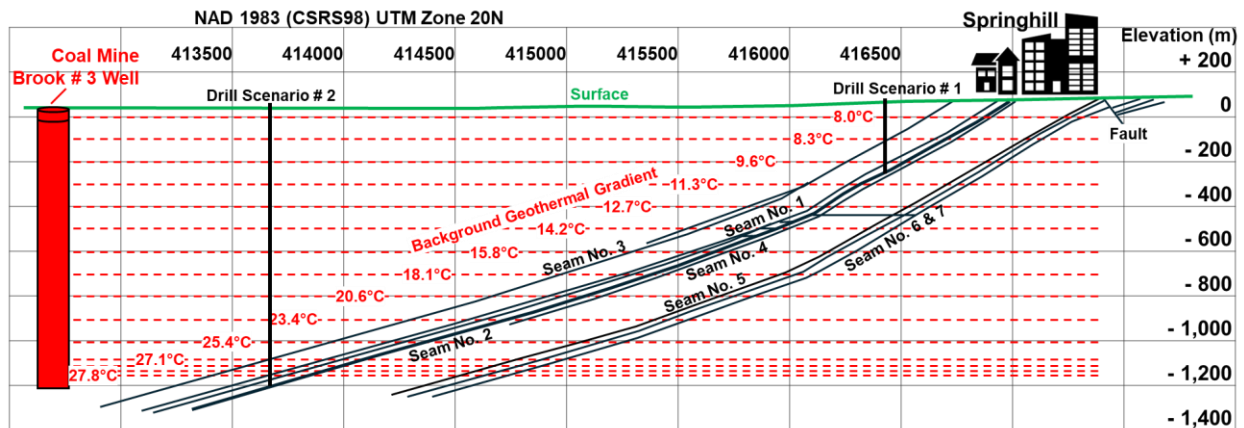


Figure 2-12: Cross-sectional view of the Springhill coal seams with the major seams labelled. On the left, the Coal Mine Brook # 3 well is shown with its respective corrected temperature readings shown in red. Two potential drilling scenarios are shown, a shallow well (less than 300 m) and a deeper well (approximately 1,200 m), both penetrating into the main slope of the No. 2 Mine.

The scope of this study did not extend to a more detailed investigation of the deep well (Drill Scenario # 2), or of the approach of making a larger opening near the top of the No. 2 Mine. Cost estimates for drilling were obtained only for Drill Scenario # 1 (drilling to a depth of 300 m or less), and these estimates are included in the cost estimate for greenhouse Scenario # 1 in Section 3.4.4.

Table 2-3: Comparison of Drill Scenario # 1 (shallow well) with Drill Scenario # 2 (deep well).

Parameter	Shallow Well (Scenario # 1)	Deep Well (Scenario # 2)
Depth	230 to 280 m; into the main slope within the municipal property boundary.	1,200 m; into the main slope at the terminus of the No. 2 Mine.
Cost	Lower cost; simpler drill rig.	Higher cost; requires a more robust drill rig to reach depth.
Resource risk	Low risk: resource is well known.	Low risk: resource is well known.
Temperature	Expect between 12°C and 22°C. Low estimate is geothermal gradient and high is based on theory of convection.	Expect approx. 28°C; temperature is more reliable than shallow.
Potential for gaining knowledge	With proper well construction can help resolve the question of whether water warmer than the background geothermal gradient can be obtained at relatively shallow depth (saving drilling and pumping \$).	Can demonstrate the ease or difficulty drilling into mine workings near the bottom of the mine, as well as the water quality and well capacity. Will not address the possible benefits of thermal convection up the Main Slope.
Formation stability	Shallow formations tend to be less consolidated; prone to instability and collapse.	Encounter varying geological formations; some more or less consolidated than others.
Environmental & groundwater risk	Requires casing and cementing to prevent water exchange with well bore.	Requires casing and cementing to prevent water exchange with well bore.
Equipment failures	Lower risk; less strain on equipment due to shallower depths.	Higher risk: more strain placed on equipment.
Logistical challenges	Less complicated; targets tend to be easier to intersect.	More complicated; targets become more difficult to intersect.
Hole deviation	Low because shallow.	Risk of missing target increases with depth due to uncertainty in records of exact locations and depths in the mine.

3. Greenhouse Scenarios

3.1. Summary

This Part delves into the potential of utilizing mine water geothermal resources in Springhill for greenhouse projects. It outlines the advantages of greenhouses, such as enabling year-round growing, providing educational opportunities, fostering social interaction, and promoting environmental sustainability. Additionally, greenhouses can generate economic benefits by creating jobs and generating income.

Three greenhouse scenarios are presented in this Part. The first scenario, and the one found to be the best fit with the objectives of this project, proposes a mid-size greenhouse. This scenario is large enough to demonstrate the capacity and suitability of the mine water resource for heating and cooling a greenhouse while supporting local food production, research, and education. The current estimated capital cost is CAD\$6.1 M, however it is hoped this can be reduced by refining the greenhouse design, size and construction costs. The second scenario envisions a large (5.16 ha) commercial geothermal greenhouse operation with sizable production and economic potential, at an estimated capital cost of CAD\$19.9 M. This capital cost is likely beyond the appetite of most investors, given the current uncertainties with such a project, and therefore is not recommended for further consideration at this time. The third scenario presented is a small greenhouse attached to the Dr. Carson and Marion Murray Community Centre. While this scenario has some attractive aspects, it would not advance current knowledge and understanding of the geothermal resource and therefore is also not recommended for further consideration at this time.

This Part also highlights the energy and cost savings associated with these scenarios. For example, the mid-size geothermal greenhouse (Scenario 1) could achieve energy savings of 67% compared to electric boilers if water at 18°C can be sustainably accessed (this is yet to be determined), which could result in annual cost savings of approximately CAD\$50,960 (calculated). The large commercial greenhouse (Scenario 2) would benefit from significant electricity savings due to geothermal heating and cooling, with potential additional savings from the use of a buffer tank for thermal energy storage.

Operational considerations are discussed for each scenario. Scenario 1 would require an investor and an operator for production and distribution, with potential partners including local farms, community organizations, and research institutions. Scenario 2 is suitable for large-scale commercial growers, with infrastructure supporting future expansion. Scenario 3 would require an owner/operator, and this was not investigated in any detail. Overall, this plan underlines the potential of geothermal greenhouses to enhance local food security, economic development, and environmental sustainability in Springhill.

3.2. Motivation

A greenhouse has been suggested as a possible user of the mine water geothermal resource in Springhill by numerous consultant reports prepared over the past several years, including Comeau et al. (2020), MacAskill and Power (2015), Brownell (2022), and Ryan (2023). The Municipality and community stakeholders have expressed interest in the community economic, social, and environmental benefits of increased local food production that greenhouses can facilitate. A community greenhouse offers numerous benefits, such as:

- ***Year-Round Growing:*** It allows for the possibility of plant cultivation throughout the year, regardless of external weather conditions, which is particularly favourable in cold climates.
- ***Educational Opportunities:*** Community greenhouses can serve as educational hubs where people can learn about sustainable agriculture, horticulture, and environmental stewardship. The Cumberland Campus of NSCC, across the street from the proposed greenhouse sites, offers possibilities for geothermal and horticultural education.
- ***Local Food Production:*** By growing fresh produce locally, community greenhouses can provide access to healthy, organic food.
- ***Social Interaction:*** They foster a sense of community by bringing people together to work on common projects, share knowledge, and build relationships.
- ***Environmental Benefits:*** Greenhouses can reduce the carbon footprint associated with transporting food over long distances, they promote sustainable practices like composting and water conservation, and the geothermal aspect reduces greenhouse gas emissions.
- ***Economic Benefits:*** The sale of surplus produce can generate income for the community, and the greenhouse can create job opportunities and support local economies.

The greenhouse would also serve as a modern pilot project to confirm the potential of the geothermal resource by applying a larger heating and cooling demand. The greenhouse would be closely monitored to collect data that supports the savings being

achieved using geothermal versus conventional oil, electric, or other heating methods. This study would promote the resource, demonstrating the potential economic benefits of using this resource efficiently to prospective commercial entities with the goal of being a catalyst for additional mine water geothermal development in the community and beyond. Nearby municipal and educational facilities would be prime candidates for this development.

In addition to demonstrating the use of geothermal energy, the Municipality and community stakeholders have expressed interest in the community economic, social, and environmental benefits of increased local food production that greenhouses can facilitate. Meetings with the Geothermal Research Advisory Committee, along with participation in a Food Security Summit in Springhill in the winter of 2024, supported the understanding that local food production is desired for food security, improved nutrition, work opportunities, and resiliency in the context of climate change and global political forces.

In that context, three greenhouse scenarios are considered here, covering three size scales:

1. Mid-size mine water geothermal greenhouse
2. Large geothermal commercial greenhouse
3. Small greenhouse using waste heat from the Community Centre

These scenarios offer a flexible range of possibilities, based on community goals, the desired scale of the outcomes, and the availability of funding and operating partners. All three scenarios are described here, however the goals of this project allowed only for detailed analysis for Scenario 1 – mid-sized mine water geothermal greenhouse.

3.3. Scenario 1 – Mid-Size Mine Water Geothermal Greenhouse

3.3.1. Description

This scenario describes a greenhouse at a scale that we believe would work well for a geothermal pilot project in Springhill, large enough to demonstrate use of the geothermal resource for food production and produce significant value for local benefit, while small enough to access capital funding opportunities and operating partners at the community level.

The greenhouse envisioned in this scenario is a 1,100 m² greenhouse, similar in concept to the model depicted in Figure 3-1. This example greenhouse includes four greenhouse modules, a shared corridor, and a headhouse for sorting, processing, and washing facilities. This type of greenhouse was chosen for illustration due to its suitable characteristics for winter production in the Springhill climate and its ability to use a lower temperature heating system. This greenhouse is considered only for illustration purposes and has not been chosen to be constructed. An open and competitive sourcing process for a greenhouse with similar capabilities and features will be required if a project of this kind is undertaken.

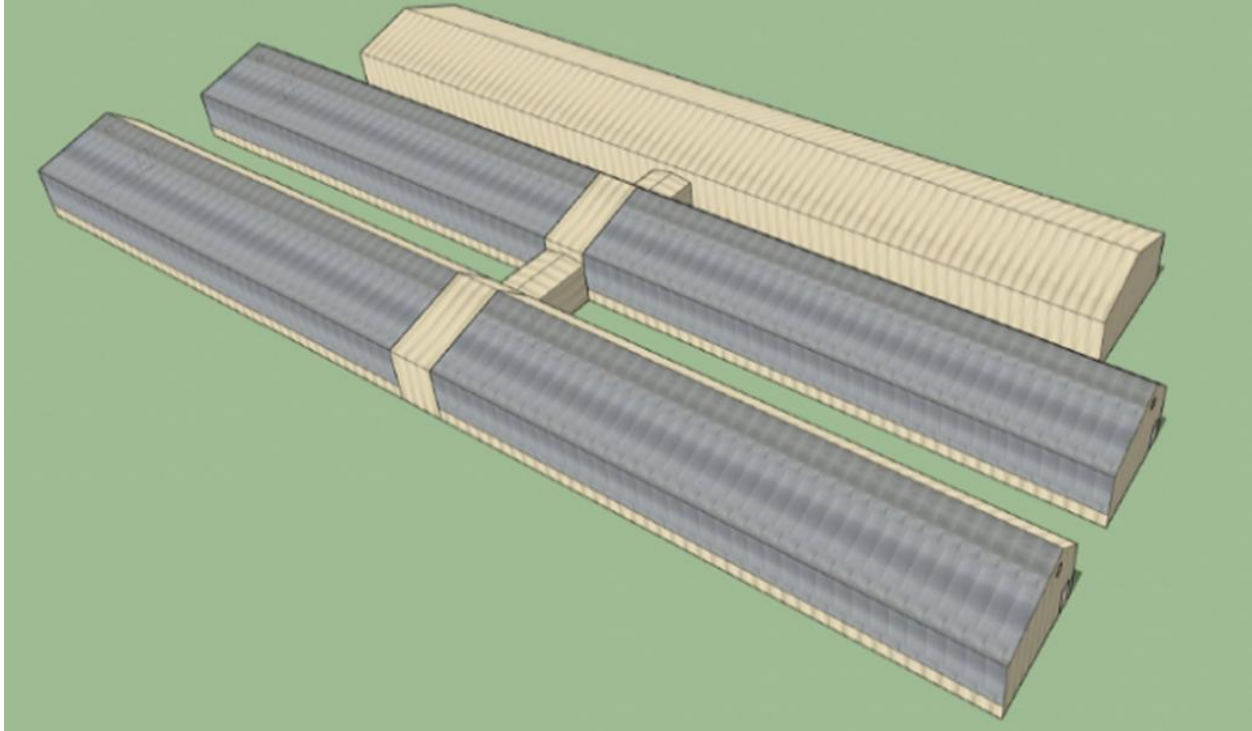


Figure 3-1: Conceptual design rendering of an 1,100 m² community greenhouse (Ceres Greenhouse Solutions, 2024).

The primary design characteristic suggested here is to choose a greenhouse designed for cold-climate operations, which has a relatively high level of insulation, and which can operate using a lower-temperature heating system that is well-suited to the geothermal resource in Springhill. By contrast, many large commercial greenhouses are designed with heating systems that use a working fluid as hot as 80°C flowing through heating pipes to provide heat to the plant growing area. However, a cold-climate greenhouse could operate with heating supply temperatures as low as 40°C, which will result in a greater energy savings.

Crops such as strawberries, greens, herbs, and flowers are grown in this type of greenhouse in climates at least as cold as Nova Scotia, including Alberta, Colorado, and Ontario. Energy efficiency is built into this greenhouse design through passive solar principles, insulating glazing materials, and under-floor and in-ground heating and cooling

systems. These characteristics make this type of greenhouse ideal for a geothermal resource application in Springhill.

3.3.2. Location

The proposed location for the mid-sized greenhouse (Figure 3-2) is on municipal land, near the Community Centre, on an area that currently hosts a gravel parking lot.

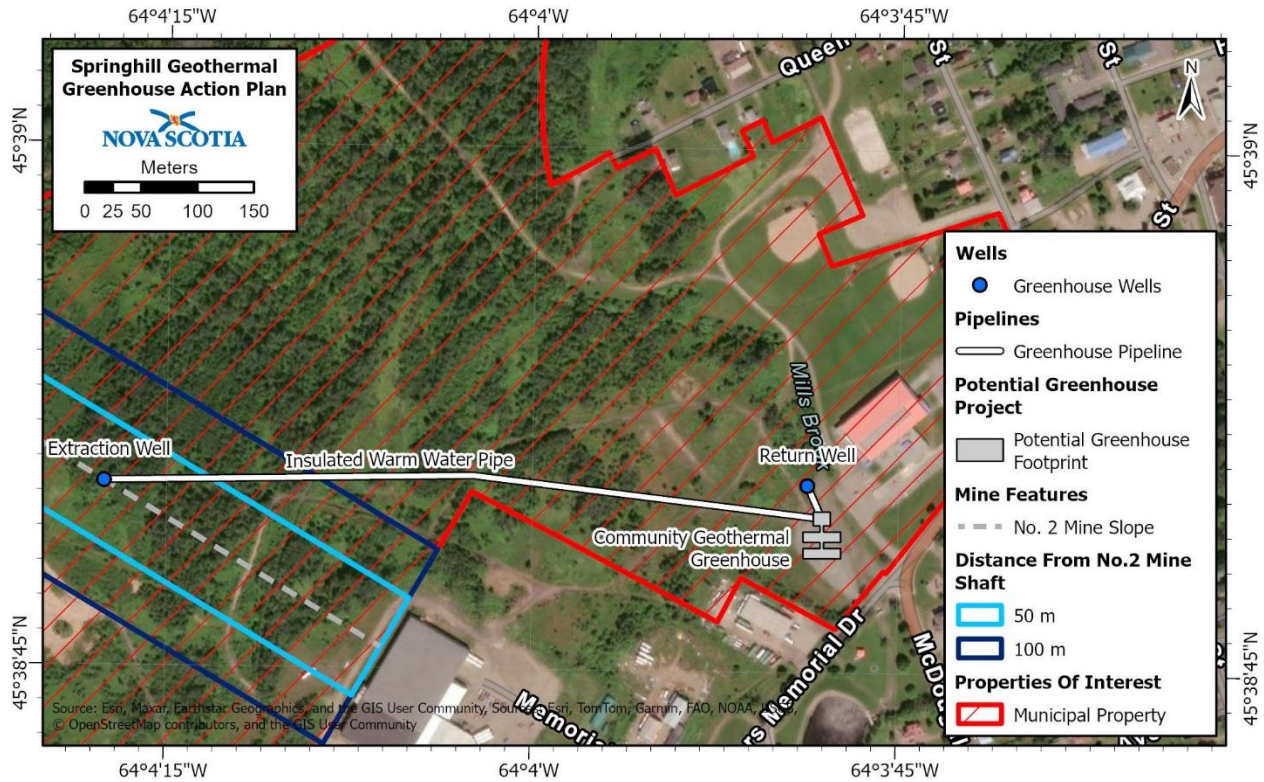


Figure 3-2: Proposed location for Scenario 1 community geothermal greenhouse.

This location is recommended for a pilot project because it is close to the necessary utility services such as water, electricity, and wastewater, while also being within a reasonable distance to access the water in the main slope of the No. 2 Mine through a proposed new extraction well. This proposed new well is in the same general areas as Deep Well No. 2, drilled in 2018, which was intended to access the main slope of the No. 2 Mine but failed to reach that depth (B. Herteis, personal communication, 2025). The technical memorandum from Falcon Engineering (Quibell, 2020; Appendix D),

recommends drilling to a depth of about 244 m near this location, with a 10-inch diameter well and improved well casing and sealing. There is a possibility, yet to be determined, of accessing water in the range of approximately 18°C in the main slope of the No. 2 Mine at this location.

Installing a pilot project here offers value in accessing geothermal heating and demonstrating its use, while also helping set the stage for future expansion. The well and the insulated water line to bring warm water can be designed and sized with future uses in mind, such as for larger greenhouses, nearby municipal and educational facilities (e.g. the Cumberland Administrative Office Building and the Springhill Campus of the NS Community College), or other industries in the industrial park.

3.3.3. Benefits

Cold climate greenhouses use passive solar design principles and insulated glazing. These characteristics allow it to operate effectively in winter using low-temperature heat provided by a geothermal heat pump while minimizing energy costs.

Year-round operation will have significant benefits in all seasons, supporting the production of warm-weather crops in the summertime in a protected environment, along with winter production of cooler-weather crops. Like any greenhouse, it will require cooling on sunny days in spring, summer, and fall. Cooling system options include open ventilation, controlled ventilation with evaporative cooling pads, or geothermal cooling in a closed greenhouse system.

The headhouse would provide space for sorting and processing. The organization(s) that would operate the greenhouse and distribute its produce could also use this space

to support logistics and training. The size of the headhouse can be chosen according to the uses, needs, and budget.

Another significant benefit of a greenhouse of this type and size is its potential to be used for research and education. Federal, provincial, and post-secondary research teams in agriculture, including universities and colleges, could use the greenhouse space to conduct research and support professional workforce development in protected agriculture and green energy technology. The data and research value to be gained from the geothermal heating and cooling system is also significant and would help facilitate further development of geothermal resources in Nova Scotia and elsewhere.

3.3.4. *Capital Cost Estimates*

The following budgetary estimate (Table 3-1) is based on a proposal from an established greenhouse supplier for a base greenhouse kit and options, along with estimates for civil works, construction, well drilling, insulated line, and geothermal heat pumps. Once detailed design for the project is undertaken, these estimates can be updated. This estimate can help define the scale of the project when seeking investment.

Table 3-1: Capital cost estimate for Scenario 1 (1,100 m²) geothermal greenhouse.

Item	Estimated Cost (CAD\$)
Greenhouse kit ¹	1,754,000
Optional headhouse kit ¹	277,000
Water-to-air heat pumps (4 @ 72,000 BTU/hr each) ²	96,000
Well drilling to 300 m at 12" diameter ³	330,000
Return well (opening, casing, repair or drilling) ³	23,000
Insulated pipe installed underground (700 m) ⁴	399,000
Greenhouse options (grow lighting, dehumidification) ¹	40,000
Civil works and construction of greenhouse ⁵	2,960,000
TOTAL	6,068,000

Sources:

¹ Sample pricing from an established greenhouse supplier (USA).

² Price for Nordic geothermal heat pump through Hydro Solar Energy (Canada).

³ Proposal from local drilling contractor.

⁴ Estimated using figures from the Danish Energy Agency (2022).

⁵ Class D budgetary estimate prepared by a local commercial construction contractor.

The capital cost is estimated at around \$6.1 M, with a range of uncertainty on the order of \$0.5 M. The cost of the greenhouse kit, well drilling, and construction are relatively well-known, based on quotes and Class-D estimates from suppliers. The cost of installing the insulated piping underground is approximated based on figures from outside of Canada. It should be noted that this estimate is based on sizing the well and pipes large enough to supply mine water heating and cooling for other future users, not only to meet the requirements of this greenhouse.

If the available investment is lower, several cost reduction measures are possible, including reducing the size of the greenhouse and headhouse, which alone would reduce the estimated cost to \$4M. The larger scale provides more benefits in terms of food production, agricultural research potential, and demonstration of expanded use of the mine water, but the key principles would still be demonstrated in a greenhouse half the size.

In any event, the current capital cost estimate is higher than anticipated, and further work will be required to reduce this cost without sacrificing the accuracy of the estimates.

3.3.5. Energy Savings Estimate

Warm water from the mine at 18°C (if this is, in fact, found) could result in substantial energy savings of approximately 67% on total energy consumption, in comparison with providing the same heat energy using electric boilers. The details are described in Table 3-2. The calculations associated with Table 3.2 can be found in Appendix B.

Table 3-2: Energy savings estimate for geothermal greenhouse in Scenario 1.

Parameter	Value
Estimated intensity of annual heating energy demand ¹	400 kWh/m ²
Estimated total annual heating energy (1,100 m ²)	440 MWh/year
Estimated COP of heat pump from 18°C water to 40°C heating supply ²	5.8
Heating energy savings due to using a geothermal heat pump (83%)	364 MWh/year
Electricity to run the heat pump	76 MWh/year
Non-heating annual energy intensity ³	90 kWh/m ²
Estimated annual non-heating energy	99 MWh/year
Total estimated annual energy consumption	175 MWh/year
Overall energy savings compared with baseline	67%
Cost savings at an electricity rate of \$0.14 / kWh ⁴	\$50,960/year
Estimated annual energy cost at a rate of \$0.14 / kWh ⁴	\$24,500/year

¹ Greenhouse energy analysis by Mijnhardt Geothermie for a large Venlo greenhouse at this location.

² Calculated from Mouzeviris and Papakostas (2021)

³ Adapted from Trépanier et al. (2024)

⁴ Approximate average tariff for Nova Scotia Power mid-sized commercial customers.

Energy, cost, and emission comparisons with other heating energy sources such as natural gas, propane or biomass have not been included in this work but can be estimated given prices and the estimated total annual heating energy of 440 MWh/year. Piped natural gas supply is not available at this location.

3.3.6. Operational Considerations

The greenhouse envisioned in Scenario 1 would require one or more investors and operators to own the project and manage production and distribution. The Municipality could seek an investor/operator and form an agreement in the form of a lease or sale. The kind of operator to be sought would depend on the desired outcomes of the operations and could include one or more of the following:

- A local farm seeking to expand production of protected crops for market.
- One or more local, provincial, or national organizations working in community support and food security, such as the United Way, Feed Nova Scotia, and similar organizations.
- Agricultural research organizations such as Perennia, universities, and/or NSCC.
- Food service providers who supply to the school lunch system in Nova Scotia.

By leasing or conveying the greenhouse to another party on mutually favourable terms, the Municipality and provincial government partners could realize most of the benefits of a mine water geothermal greenhouse while avoiding operating and maintenance responsibilities that they are not in a position to efficiently provide. One recommended next step would be to determine the day-to-day operational level of interest among farmers, community food organizations, and other potential investors. Part of this should be discussion regarding the parameters of a fair, open, and transparent process to select an Investor/Operator.

3.4. Scenario 2 – Large Commercial Geothermal Greenhouse

3.4.1. Description

Scenario 2 considers a 5.16 ha (12.75 ac) commercial greenhouse operation located on municipal lands, dependant upon access to warm water, from the main slope of the No. 2 Mine (yet to be demonstrated, and at a depth yet to be determined). This greenhouse scenario was developed by Mijnhardt Geothermie, an experienced geothermal greenhouse consultancy from the Netherlands.

This scenario describes a Venlo greenhouse of a type and scale that is common in large greenhouse production areas such as the Netherlands and southern Ontario. The most common crops grown in greenhouses of this kind are high value, warm climate vegetables and fruits, most often tomatoes, cucumbers and/or peppers. By comparison, the current largest commercial greenhouse in Nova Scotia, the den Haan greenhouse, is approximately 3.24 ha (8 ac) in size.

3.4.2. Location

A proposed location for a large commercial greenhouse is pictured below (Figure 3-3). This is on municipal land, north of the Mauser Packaging factory. This location would provide access to mine water from the No.2 Mine, possibly in parallel with the connection to the greenhouse from Scenario 1.

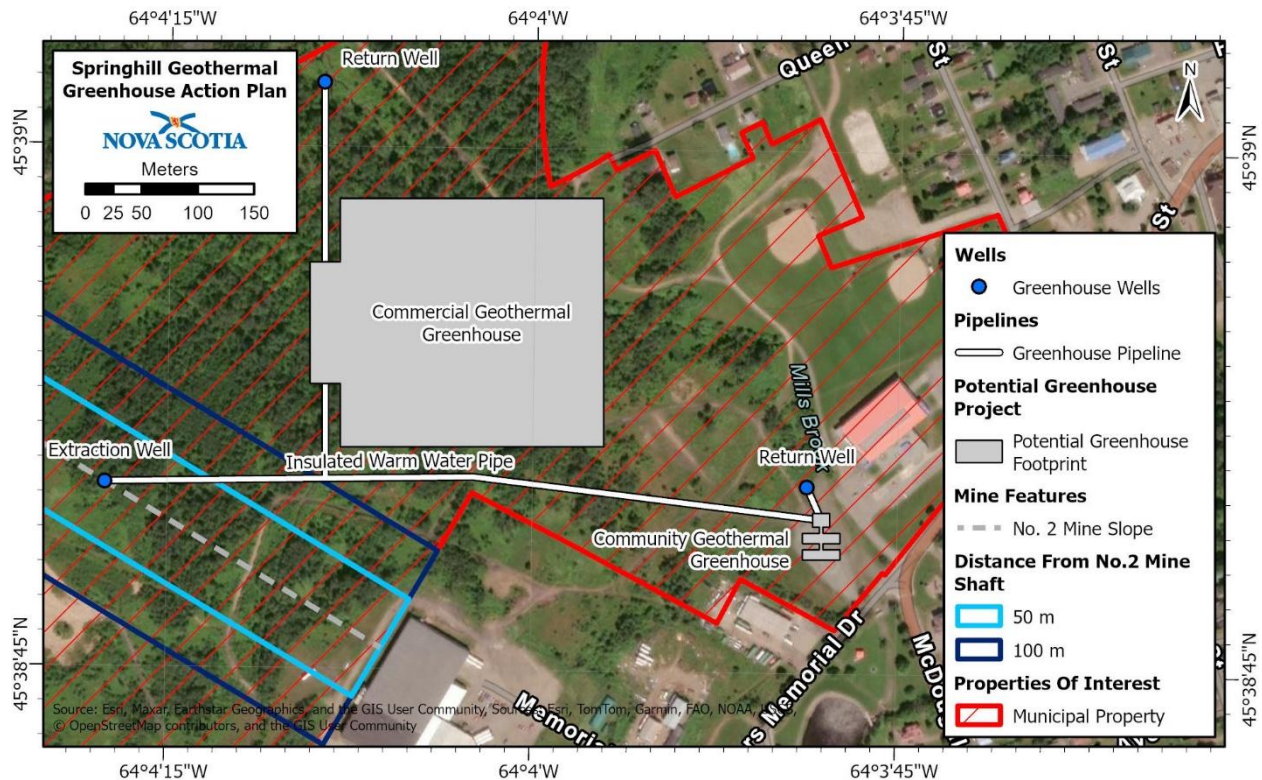


Figure 3-3: Location map of proposed large commercial greenhouse, including approximate locations, size, and key infrastructure. Scale of greenhouse is approximate.

3.4.3. Benefits

- Large scale production of fruits and/or vegetables. Considering tomatoes as an example, annual fruit production is estimated at 4,100 tonnes of saleable tomatoes, with an approximate wholesale value of CAD\$13.2 M per year at projected 2025 wholesale prices in Canada.
- Large employment opportunities in the operation of a greenhouse of this scale.
- Spinoff industries in food processing may be encouraged locally.
- With suitable agreements about the use of imperfect produce, the local community food security network could have a major source of freshly grown fruits and vegetables to add to their resources.
- Greenhouse production with reduced greenhouse gas emissions due to energy savings from using high efficiency heat pumps and geothermal energy.

3.4.4. Energy Consumption Estimates

Van der Hoeven Horticultural Projects, of the Netherlands, on behalf of Mijnhardt Geothermie, conducted a location-based energy analysis of the proposed 5.16 ha (12.75 ac) greenhouse, using climate data for Springhill. The heating requirement was estimated to be 400 kWh per square metre, for a total of 20,637 MWh of heat energy. This would be provided by a geothermal heat pump system with an estimated COP of 4.4, resulting in a significant electricity savings. The results of the energy analysis are summarized in Table 3-3.

Table 3-3: Energy analysis of large greenhouse operation.

Component	Annual Requirement	
	kWh/m ²	Total (MWh)
Electricity for heat pumps	90.9	4,690
Base Load (pumps and vents)	26.0	1,342
Fans	5.8	299
Grow lights	472.4	24,376
Total Annual Electricity	595.1	30,707

Note that with the efficiency of the geothermal system reducing the electricity consumption for heating, by far the largest component consuming electricity is the grow lighting. This lighting helps maximize the yield of produce, thereby adding significant value, but the lighting levels and timing could be studied to optimize the growing schedule and energy consumption. The case study considers tomato production, which is a heat- and light-intensive greenhouse crop.

At large industrial electricity rates in Nova Scotia in 2025, averaging \$140 per MWh, the annual electricity cost of the large commercial greenhouse is projected to be approximately \$4.5 M. In the absence of the geothermal heating system, heating this greenhouse with electric resistance boilers would add about \$2.2 M to the annual electricity cost, bringing it to \$6.7 M.

One related innovation proposed by Mijnhardt Geothermie is that a large buffer tank of water, which is often included in a greenhouse system of this kind, could provide additional cost savings by storing surplus energy from renewable electricity sources. Installing a large electric resistance heater of 1 to 10 MW power capacity could allow the buffer to be heated at times when surplus low-cost renewable electricity is available, either locally generated or on the wider grid. The extra heat in the buffer will increase the heat supply and the COP of the heat pumps. In some electricity markets with high percentages of wind and solar power, the price of electricity can go below zero when there is a surplus of renewable electricity. As Nova Scotia installs an increasing capacity of onshore and offshore wind power, this may become an opportunity for a greenhouse with thermal storage capacity.

Reports on conceptual design and sizing for the heat pumps have also been prepared by Mijnhardt Geothermie as part of this work. One key result from that work that should be noted here is that the performance of the large-scale geothermal greenhouse heat pump system is significantly improved if water at 28°C can be obtained, compared with using the water at the mid-depth source. This supports the notion of drilling further out and deeper, near the toe of the No. 2 Mine, to access these higher water temperatures.

3.4.5. *Estimated Capital Cost*

Van der Hoeven Horticultural Projects prepared a proposal that includes an estimate of the capital cost of the 5.16 ha greenhouse described in Scenario 2. The cost is estimated at EUR\$13.4 M (CAD\$19.9 M). This includes installation but does not include

site preparation, levelling, trenching, and foundation, which the greenhouse owner must provide prior to construction of the greenhouse.

A greenhouse of this scale could be successful if developed by a large-scale commercial greenhouse grower. It is considered beyond the scope of the Municipality to develop a greenhouse of this size, but with a site and the infrastructure in place to offer the energy and operational cost savings associated with geothermal energy, it may be attractive to a large private greenhouse grower from Nova Scotia, elsewhere in Canada, or internationally. The smaller Scenario 1 greenhouse represents a stepping stone to demonstrate the potential and strengthen the pitch for a large-scale grower.

3.5. Scenario 3 – Small Community Greenhouse Attached to Community Centre

Scenario 3 involves expanding the Dr. Carson and Marion Murray Community Centre to include a community greenhouse that would be built as an attached or semi-detached structure. This scenario would take advantage of the energy and utilities available at the community centre and provide a community greenhouse that would be highly accessible to community members.

The community centre has a heat sharing system that uses heat pumps to extract heat from the ice rink for icemaking and shares that extracted heat with the other heated areas of the building, including the offices, change rooms and spectator seating (not without some challenges). This system is supported by two geothermal wells that provide a buffer to balance the heating and cooling loads. Water from the supply well goes to a heat exchanger, where it supplies or absorbs heat before flowing to the return well. During much of the icemaking season, it appears that the icemaking system has surplus heat

available, that it is currently sending to the return well, that could be sufficient to heat an attached greenhouse.

3.5.1. Description

- A greenhouse attached to the Dr. Carson and Marion Murray Community Centre;
- Rectangular, approximately 16.7 m x 20.7 m, with a footprint of 346 m² (0.085 ac).

3.5.2. Benefits

- Connecting to the community centre is the most cost-effective place to build a community greenhouse, because the infrastructure for heating, water, and electricity is already available there.
- The greenhouse can be heated using the excess heat from the Kube heat pump system that makes ice for the skating rink.
- The location is close to NSCC and other organizations that can support volunteers working in the greenhouse. It is easy to reach on foot from central Springhill.

3.5.3. Further Considerations

A greenhouse at the community centre would have significant community benefits and could be considered an excellent project to pursue through funding opportunities that support local food security and community resiliency. It would also demonstrate a remarkable use of energy efficient technology because it would take advantage of the heat from icemaking that otherwise is being sent underground.

However, a primary goal of this Action Plan is to demonstrate the use of geothermal energy. Because the connected community centre greenhouse would be heated by the excess heat from the icemaking process, it is not substantially a geothermal greenhouse project and would not advance the demonstration of geothermal energy applications. While this greenhouse could be beneficial project, the detailed analysis in this report is focused on the other greenhouse scenarios that more closely involve an expansion of geothermal energy utilization.

3.6. Summary of Greenhouse Scenarios

The exploration of greenhouse scenarios utilizing the mine water geothermal resource in Springhill presents a promising opportunity for the community. The proposed greenhouses offer numerous benefits, including year-round growing, educational opportunities, local food production, social interaction, environmental benefits, and economic advantages.

The analysis of the mid-sized geothermal community greenhouse (Scenario 1) highlights its potential as a pilot project to demonstrate the viability of geothermal energy for food production. This scenario balances the scale of investment with significant local benefits, making it an ideal candidate for initial implementation. The project not only supports local food security and economic development but also serves as a model for future geothermal applications in the community (nearby educational and municipal buildings) as well the region at large.

The large commercial greenhouse (Scenario 2) represents a long-term vision for substantial economic impact and employment opportunities. While beyond the immediate scope of development in the short term, it underscores the potential for large-scale

geothermal greenhouse operations to attract private investment and drive regional growth.

The implementation of a geothermal greenhouse in Springhill aligns with community goals of sustainability, food security, and economic resilience. By leveraging the geothermal resource, Springhill can position itself as a leader in innovative, sustainable agriculture, preparing the way for future advancements and broader adoption of geothermal technology.

4. Crop Selection and Planning

Perennia's protected crops consulting team has studied crop selection and planning for the proposed community-scale greenhouse in Scenario 1, considering agricultural suitability, nutrition, marketing appeal, energy efficiency, and cost of production. Their results are summarized here, and their full report is included in Appendix C.

4.1. Suitable Crops

Food crops that perform well in protected agriculture in Nova Scotia include tomatoes, strawberries, cucumbers, and various leafy greens such as lettuce, kale, spinach, etc. These crops are highly desired by consumers and are quite versatile in their uses, making them a good fit for community-minded spaces.

In medium to large-scale greenhouse production, all of these crops are often produced hydroponically, meaning they rely on the water supplied to them for nutrients, as opposed to having access to a resource bank in soil. Hydroponic growing is recommended in this case, as this would facilitate easier long-term management (easier to clean up, easier to transport, easy to counter-act any issues with the fertilizer recipe) compared with a soil-based system, which is difficult to maintain indoors over long periods of time. Fruiting crops such as tomatoes, strawberries, and cucumbers are proposed to be grown in containers (pots or grow bags) and the greens would be grown using a nutrient film technique (NFT) setup.

4.2. Crop Production Scenarios

4.2.1. Scenario 1 – Strawberries and Greens

Greens have similar growing conditions as strawberries, although greens can be produced successfully with lower lighting levels and can survive lower temperature events. Recommended options for crops schedules include:

- With supplemental lighting, greens, and strawberries could be grown simultaneously year-round, each occupying half of the greenhouse area.
- Without supplemental lighting, the main growing season (March – October) can be 50% greens and 50% strawberries, and then only greens in the winter season (November – February).

4.2.2. Scenario 2 – Tomatoes and Greens

As a hot-weather crop, tomatoes are ideal in summer in a greenhouse in Nova Scotia. Greens are more suited to cooler temperatures, and running the greenhouse at a lower temperature in winter saves significantly on energy costs. Greens also have a reduced need for supplemental lighting, resulting in further energy savings, and they are a great nutritious product to offer locally in the winter. For this option, the proposed rotation would be:

- One batch of tomatoes (April – October).
- 100% greens production in winter (November – March).

4.2.3. Scenario 3 – Tomatoes and Cucumbers

Tomatoes and cucumbers have a 100% overlap of fertility needs and infrastructure, allowing for alternating production with no substantive changes in the setup between seasons:

- One batch of tomatoes in the summer.
- One batch of cucumbers through the winter (with supplemental lights).

4.2.4. Greenhouse Production Planning

Working in collaboration with the food security organizations in the community and with prospective greenhouse operators, the municipal and provincial government partners can use the crop planning scenarios in Perennia's report as a basis to plan for suitable crops and rotations that optimize local benefit while taking advantage of geothermal energy for the greenhouse. A substantial advantage of a greenhouse system of this kind is its flexibility. With an open floor concept, energy efficiency, and a set of separated greenhouse compartments, multiple uses can be served, including food production, research, and education.

5. Action Items

Based on the research and analysis conducted in this study and the data collected from past studies, it is believed that a mid-sized greenhouse (approximately 1,100 m²) will best fulfill the objectives of this project. The following action items will need to be addressed before agreements for capital funding, supply and construction, and operation of the greenhouse can be secured:

5.1. June to November 2025 – Improve Project Readiness

5.1.1. Share Action Plan and Gather Feedback

This Action Plan should be shared with the community, key project partners, and stakeholders to inform them of the results and gather feedback in support of next steps. Key stakeholders include the project partners, the Geothermal Research Advisory Committee, municipal and provincial government staff and representatives, federal government staff and representatives, agricultural organizations including the Nova Scotia Federation of Agriculture and Greenhouse Nova Scotia, and the Cumberland County Food Security Network, with its associated organizations. Support for moving forward will depend on active partnerships.

5.1.2. Estimate Energy Savings for a Range of Mine Water Temperatures

Although it has been hypothesized the mine water available from the proposed new extraction well in the main slope of No. 2 Mine at a depth of 244 m could be warmer than the background geothermal gradient, this is by no means assured, and it is also uncertain whatever temperature is available shortly after drilling will continue to be available with continuous pumping over the long term. It is therefore recommended the coefficient of performance (COP) be calculated for a range of temperatures from 10°C to 22°C and that

the energy savings and cost savings for the proposed 1,100 m² greenhouse be estimated from those calculations.

5.1.3. Refine Capital Cost Estimates

The Capital Cost estimates set out in Table 3-1 are significantly higher than hoped for. Consideration of different greenhouse suppliers, designs, and sizes, along with completion of Action Item 5.1.6 below could help reduce this figure to something more manageable.

5.1.4. Estimate Greenhouse Production and Conduct Market Study

To evaluate the economic sustainability of the proposed greenhouse, and identify ongoing financial support that may be required, the potential volume, market value, and market for the recommended crops needs to be determined. The Department of Agriculture, Perennia, and potential greenhouse operators should be approached to provide estimates of production on a voluntary basis. Resources will need to be found to prepare a market study based on those estimates.

5.1.5. Develop Relationships with Existing Greenhouse Operators

The Municipality is not envisioned as the owner or operator of the greenhouse. Working with existing greenhouse operators early in the design process can help ensure that the choices made during design and are suitable for eventual investor(s) and operators.

There are known operators and/or farmers with expertise operating successful greenhouses. Having informal “without prejudice” discussions with some of these operators would help develop the terms and conditions for a fair, open, and transparent

process to find an Investor (Section 5.3.2). That process would be undertaken when all the other Action Items in sections 5.1 and 5.2 are complete.

5.1.6. Refine Choice of Location of the Proposed Mid-Sized Greenhouse

It is recommended that existing resources (including provincial, municipal, and NSCC staff) be used to review and refine the proposed greenhouse location, including identification of potential risks, and creation of rough cost estimates of providing services and preparing the site for construction. The same process should be used for at least two other nearby locations (to be identified), and a comparison of relative pros and cons of the sites should be developed. Those pros and cons would include development and operational costs, ease of access, visibility, and potential for expansion. Previous assessments of the potential sites and nearby property, including geotechnical work prepared by the province or other bodies for other projects (e.g., the new elementary school and fire hall, and the proposed NSCC student housing), should be used as part of this process to the extent they are available. The foregoing work would ready the project for the professional pre-design and geotechnical work that will need to be conducted if and when an investor and capital funding for construction are secured.

5.2. June 2025 to June 2026 – Data Collection and Resource Management

5.2.1. Establish Consistent Data Collection for Water Temperatures

Despite all the use of, interest in, and research into, the use of the mine water in Springhill for geothermal heating and cooling, there is currently a lack of reliable temperature data available. One reason for this is likely that many of the current and past users of the mine water have been primarily interested in a reliable supply of water, and less interested in the temperature, due to the fact they use the resource for both heating

and cooling (e.g., buildings, manufacturing processes, ice-making). Whether the mine water used for their heat pumps arrives at 12°C or 18°C makes little difference in the long run. However, for a greenhouse or other operation that requires predominately heating, consistently warmer temperatures will make a large difference in the efficiency of their heat pumps and consequently in their energy consumption. Similarly, for a data centre or other operation that requires predominately cooling, consistently cooler temperatures would be more beneficial.

Repeated periodic temperature sampling of existing unused wells, as well as constant sampling of existing wells in use and new wells, coupled with consistent data collection and analysis, would greatly improve the understanding of the temperature gradient(s) to be found in the Springhill mines. This is an affordable undertaking that would have significant long-term value. It is therefore recommended that such a monitoring program be implemented as soon as resources permit.

As part of the current project, some temperature sensors have been procured and should be available to be put in use by June 2025. The deployment of this resource needs to be accompanied by a data collection and management plan.

The installation of wireless data collection devices to continuously record water temperature and flow rates at user facilities and transmit this information to a shared database would also enhance understanding of the resource. Such a monitoring program should be implemented for willing existing mine water users as resources become available and should be required for all new installations. The new geothermal extraction well described in Action Item 5.2.2 below would be a particularly important aspect of this effort to understand the resource.

5.2.2. Establish a New Extraction Well

According to the Technical Memorandum produced by Falcon Engineering (Quibell, 2020) for the purpose of establishing part of the warm mine water supply for a proposed, but not developed, geothermal business park, a good target for a new supply well would be into the main slope of No. 2 Mine at a depth of approximately 244 m. At this depth the effects of surface and ground water could be eliminated (with proper well construction) and the potential to obtain relatively warm water at a relatively shallow depth would be realised or discounted. Once established, this new well will need pump testing, temperature testing, and water quality testing to establish the parameters for using the water for geothermal heating and cooling systems.

The location and depth required is precise, with a goal not only of directly drawing water from the main slope, but specifically from the upper layer of the main slope, where the warmest water has been hypothesized to be flowing. If this theory is correct, it would matter whether water is drawn from the top of the slope or the bottom. Precise drilling, casing, and pump placement will be required to demonstrate whether water warmer than the baseline geothermal gradient can be sustainably obtained.

It is recommended this well be installed as soon as the required resources are available, as the temperatures found will bear directly on the viability of the greenhouse project. This will also help inform other ways to access and use the resource including both heating and cooling applications.

5.2.3. Limit Surface Development Above No. 2 Mine Main Haulage Slope

The main haulage slope of the No. 2 Mine may be the best source of relatively warm water. It may therefore be advantageous to use available policy tools to ensure future

growth does not conflict with maintaining surface access options to land above the No. 2 Mine Slope.

5.3. September 2025 to December 2026 – Seek Funding and Investment Partner

5.3.1. *Seek Funding Sources*

The greenhouse described in Scenario 1, a mid-sized geothermal greenhouse, is most likely to be able to attract funding support and an operator at the community level while demonstrating an expanded use of geothermal energy and providing substantial community benefit. The Municipality and the province have already begun identifying potential funding sources for this project and can continue and expand that search. Federal government funding support is the most likely source, with possibilities from Agriculture and Agri-Food Canada, Natural Resources Canada, and the Atlantic Canada Opportunities Agency. The Agricultural Clean Technology Program: Research and Innovation Stream from Agriculture and Agri-Food Canada represents one opportunity for this project.

5.3.2. *Seek Investment Partner*

The Municipality will not be the owner or operator of the Greenhouse, as that is outside the scope of normal municipal services. A private investor/operator, either for-profit or not-for-profit, will provide the drive to optimize the benefits delivered by this infrastructure, manage activities in the greenhouse for mutual benefit, and generate revenue to cover operating and maintenance costs.

As part of this process, the calculation of the projected value of crop production (Section 5.1.4. above) will assist potential investors when deciding whether to partner in the project.

6. Conclusion

This Springhill Geothermal Greenhouse Action Plan has been developed under a partnership between the Nova Scotia Community College, the Municipality of the County of Cumberland and the Nova Scotia Department of Energy. The overall goal of the plan is to provide a well supported and justified pathway leading to the creation of a community greenhouse to demonstrate the energy savings that can be realized by using the geothermal resource that the flooded coal mines in Springhill have to offer, while at the same time strengthening local food production and food security.

The main body of the plan provides context and historical background and then moves on to summarize what is currently known about the mine water resource. Next, three different sizes and types of greenhouses are described in some detail and evaluated for their ability to satisfy the overall goal of the plan. The report shows how a medium sized (approximately 1,100 m²) greenhouse designed for cold climate operations would be the best candidate to demonstrate the capacity of the mine water resource, and to contribute to local food production, at a cost and scale that could be achievable in the near future. The theoretical energy savings for this type of greenhouse (67%) are very significant.

This Action Plan describes next steps to actualize a community geothermal greenhouse in Cumberland County through sharing information to stimulate interest, developing partnerships, improving data collection from existing wells, installing a new extraction well at a previously recommended location and depth, identifying and pursuing funding opportunities, and beginning detailed site selection and planning.

The Springhill Geothermal Greenhouse Action Plan is a timely response to the growing need for sustainable agricultural practices and renewable energy solutions. Its development aligns with global trends toward environmental sustainability and local resilience, particularly in light of increasing climate change impacts. The initiative has the potential to create a model for the integration of geothermal technology in agricultural systems, underscoring the importance of innovative approaches in addressing contemporary societal challenges. A mine water geothermal greenhouse in the community of Springhill would represent a modern pilot project that has the potential for being a catalyst for additional mine water geothermal development in the community (nearby educational and municipal facilities), the region, and beyond.

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Appendix A: Summary of Geothermal Borehole Data

Well	Year	Well Location	Seam Target	Remarks	Hole Depth (m)
GTW-01	1987	Ropak Can Am (29 Memorial Crescent)	2	Target missed	82.3
GTW-02	1987	Community Arena (across from 16 Queen Street)	2	Target missed	50.9
GTW-03	1987	Industrial Park (Near Ropak); Town Loop	2	Town Loop supply; Dist. heating	44.2 (40.4) ¹
GTW-04	1987	NSPL Paved Yard (behind 10/12 Queen Street)	2,1	Return well for NSPL	79.9
GTW-05	1987	NSPL Storage Yard (behind 10/12 Queen Street)	2	Supply well for NSPL	82.3
GTW-05.1	1987	Springhill Tavern (25 Main Street)	Most likely 6	Supply for heat pump	99.1
GTW-06	1988	Ropak Can Am (29 Memorial Crescent)	2	Ropak supply well; collapsed in 2000	137.5 (136.3) ¹
GTW-07	1988	Ropak Can Am (29 Memorial Crescent)	3	Ropak return well	29.7
GTW-08	1989	Surrette Battery (58 Lisgar Street)	1	Surrette return well	63.4
GTW-09	1989	Surrette Battery (58 Lisgar Street)	2	Target missed	103.9
GTW-10	1989	Surrette Battery (58 Lisgar Street)	2	Surrette supply well	95.4
GTW-11	1990	Pizza Delight/JB's Bar and Grill (40 Main Street)	6 & 7	Pizza Delight return well	148.1 (150.3) ¹
GTW-12	1990	Pizza Delight/JB's Bar and Grill (40 Main Street)	7	Pizza Delight supply well	117.4 (119.2) ¹
GTW-13	1990	Industrial Park; Town Loop	2	Poor well; Town Loop return	114.3
GTW-14	1991	Industrial Park; Town Loop	4	Slope; diamond drilled	43.3 (49.0) ²
GTW-15	1991	Industrial Park; Town Loop	4	Air slope; diamond drilled	64.3 (68.0) ²
GTW-16	1991	Leckie Street? (coordinates near Herrett Road)	4	Mine; diamond drilled	Unknown
GTW-17	1993	Parkview Center (6 McFarlane Street)	6	Supply well; on property?	58.5
GTW-18	1993	Parkview Center (6 McFarlane Street)	6	Return well; on property?	73.8
GTW-19	1993	NSPL Site (off Queen Street)	6	New return; replaced GTW-04	50.3
GTW-20	1993	AH Brown Funeral Home (5 McFarlane Street)	6	Supply or return; on property?	61.0
GTW-21	1993	AH Brown Funeral Home (5 McFarlane Street)	7	Supply or return; on property?	64.0
GTW-21.1	1995	Behind Ropak (29 Memorial Crescent)	Most likely 2	Other Ropak wells target Seam 2	161.8
GTW-22	1996	Public Works (62 Lisgar Street)	6 or 7	Formerly Thermocell Recycling	73.2 (68.6) ³
GTW-23	1996	Public Works (62 Lisgar Street)	6 or 7	Formerly Thermocell Recycling	73.2 (68.6) ³
GTW-23.1	1998	Springhill Fire Department (5 Main Street)	Most likely 6	Supply or return	70.1
GTW-23.2	1998	Springhill Fire Department (5 Main Street)	Most likely 6	Supply or return	128.0

Well	Year	Well Location	Seam Target	Remarks	Hole Depth (m)
GTW-23.3	2000	New well; behind Ropak (29 Memorial Crescent)	Most likely 2	New supply well	41.1
Well-01	2003	Between Ropak & Community Centre	2	Community Centre observation (test) well	34.7
Well-02	2003	Between Ropak & Community Centre	1	Community Centre observation (test) well	32
Well-03	2003	Between Ropak & Community Centre	1	Community Centre supply well	64
Well-04	2003	Between Ropak & Community Centre	1	Community Centre return well; decommissioned	68.6
Well-05	2004	Between Ropak & Community Centre	1	Community Centre supply well	91.4
NSCC-01	2010	NSCC Cumberland Campus (1 Main Street)	6	Supply or return; front of NSCC	115.8
NSCC-02	2010	NSCC Cumberland Campus (1 Main Street)	6	Supply or return; behind NSCC	78.6
Well-06	2010	Between Ropak & Community Centre	3	Community Centre recharge well	114.3
Well-07	2011	Between Ropak & Community Centre	3	Replacement return well for Community Centre	125.0
GTW-24	2014	Surette Battery (58 Lisgar Street)	Most likely 1	New Surette return well	71.9
SHCML MW-1	2015	West of Highway 142/Highway 2 intersection	1	Monitoring well (bulk sample pit)	31.1
SHCML MW-1	2015	West of Highway 142/Highway 2 intersection	1 & 2	Monitoring well (bulk sample pit)	73.7
Deep Well No. 1	2018	West of Ropak	3	Test borehole (water flows and temperatures)	230.0
Deep Well No. 2	2018	West of Ropak	3, 1, 2	Test borehole (water flows and temperatures)	220.0
GTW-25	2024	New Fire Station	2, 7	Supply well	67.0

Appendix B: Calculations Supporting Table 3.2

Notes on the calculation of the energy savings for Table 3-2:

Estimated intensity of annual heating energy demand ¹	400 kWh/m ²
Estimated total annual heating energy (1,100 m ²)	440 MWh/year
Estimated COP of heat pump from 18 °C water to 40 °C heating supply	5.8
Heating energy savings due to using a geothermal heat pump (83%)	364 MWh/year
Electricity to run the heat pump	76 MWh/year
Non-heating annual energy intensity ²	90 kWh/m ²
Estimated annual non-heating energy	99 MWh/year
Total estimated annual energy consumption	175 MWh/year
Overall energy savings compared with baseline	67%
Cost savings at an electricity rate of \$0.14 / kWh ³	\$50,960 / year
Estimated annual energy cost at a rate of \$0.14 / kWh ³	\$24,500 / year

- (1) Savings with the heat pump are versus electric resistance heating (ground source heat pump versus electric boiler).
- (2) Energy consumption with the heat pump is calculated by estimating the total heating load required and dividing that by the Coefficient of Performance (COP). Therefore, the COP is a key factor in the energy savings estimate.
- (3) The COP is estimated here based on a peer-reviewed technical review paper published in the International Journal of Sustainable Energy (Mouzeviris and Papakostas, 2021). They used published performance data from 122 models of ground source (water-to-water or water-to-air) heat pumps available on the global market.
- (4) Mouzeviris and Papakostas found a strong relationship between COP and the temperature difference between the inlet and the outlet of the heat pump (ΔT) that was consistent and predictable across the range of different heat pumps studied. Their Figure 8 (Figure B1 on next page) shows this relationship and a best-fit equation that can be used to predict the COP, given ΔT .

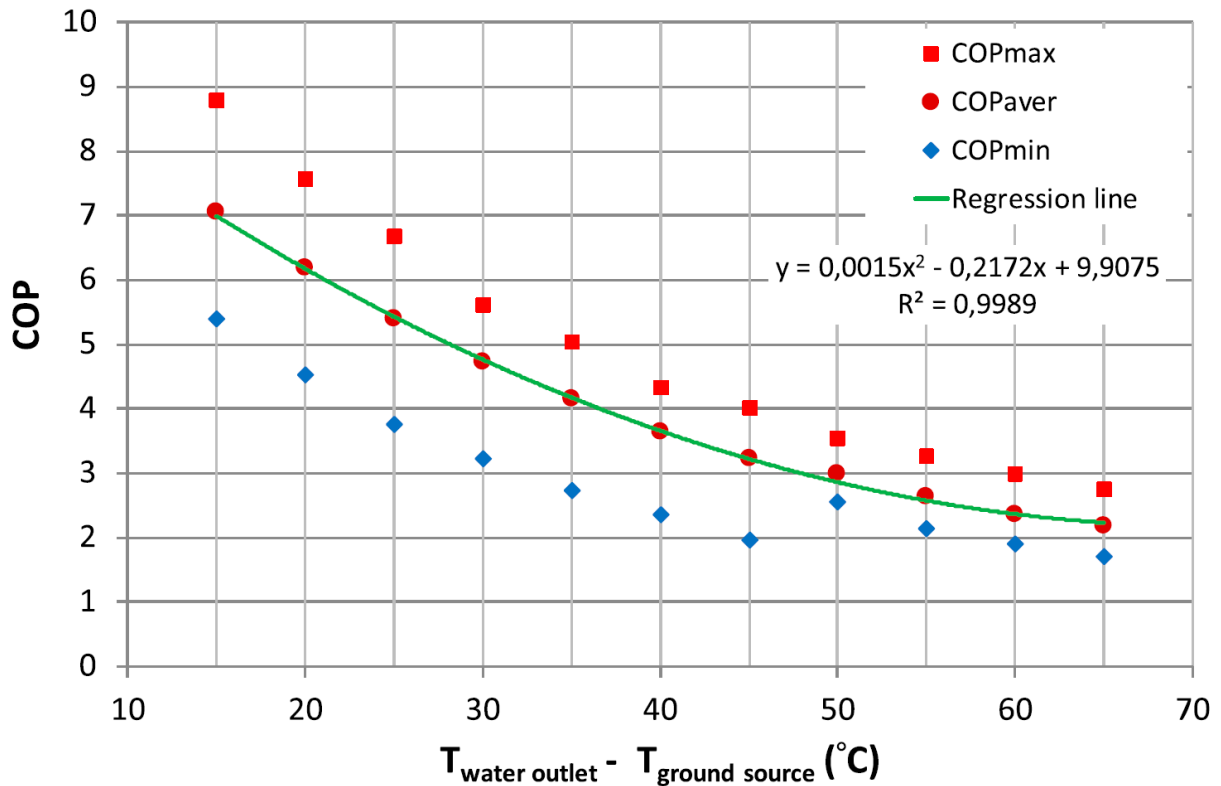


Figure B1: Correlation between COP and temperature rise ΔT across the GSHPs. The graph shows minimum, average, and maximum values for all models in sample with associated regression line.

Estimated intensity of annual heating energy demand

- Annual heating intensity estimated for a greenhouse in Springhill using local weather data (Jean-Pierre Schenkeveld and sub-consultant) = 400 kWh/m² (Row 1 of Table 3.2)

Estimated total annual heating energy (Greenhouse floor area = 1,100 m²)

- Estimated total annual heating energy = 400 kWh/m² x 1,100 m² = 440,000 kWh = 440 MWh (Row 2 of Table 3.2)
- 440 MWh / year heating energy needed
- This would equal the heating electricity if the heat were provided by a resistance heating electric boiler or electric coil heaters

Estimated COP of heat pump from 18°C water to 40°C heating supply

The amount of electricity required was calculated using the total heating load and the predicted COP, based on ΔT . The temperature difference chosen for this calculation was the difference between the expected temperature of the mine water (18°C) and the temperature needed on the outlet side to deliver sufficient heat to the greenhouse (the delivery temperature). This delivery temperature depends on the design of the greenhouse and its operating parameters. For this calculation, a delivery temperature of 40°C was chosen, based on discussions with a greenhouse supplier. The ΔT assumed here was therefore 40 °C - 18°C = 22°C.

Using ΔT and the equation from the chart above, the COP is estimated to be:

$$\begin{aligned} \text{COP} &= 0.0015 \times (\Delta T)^2 - 0.2172 \times (\Delta T) + 9.9075 \\ &= 0.0015 \times (22)^2 - 0.2172 \times (22) + 9.9075 \\ &= 5.855 \\ &= 5.8 \text{ (rounded down) (Row 3 of Table 3.2)} \end{aligned}$$

Electricity to run the heat pump

$$\begin{aligned} \text{Energy required annually by heat pump} &= \text{Total heat energy}/\text{COP} \\ &= 440 \text{ MWh}/5.8 \\ &= 75.9 \text{ MWh/year} = 76 \text{ MWh/year (Row 5 of Table 3.2)} \end{aligned}$$

- (5) Electricity saved by heat pump (compared with using an electric resistance heater):
 440 MWh/year – 76 MWh/year = 364 MWh/year
 Percentage savings: 364 MWh / 440 MWh = 0.827 x 100% = 82.7% of heating energy
 (though this percentage was left out of the table)
- (6) Estimated total electricity consumption:
 Electricity for heat pump + electricity for lighting, ventilation and accessory systems
 76 MWh/year + 99 MWh/year = 175 MWh/year
- (7) Estimate without heat pump:
 440 MWh/year + 99 MWh/year = 529 MWh/year
 Total energy savings: 529 MWh/year – 175 MWh/year = 364 MWh/year
 Energy savings as a percentage: 364 / 529 = 0.675 x 100% = 67.5% = 67%

Appendix C: Perennia Consultation on Crop Production

Geothermal Greenhouse Project

Consultation on Crop Production

2025-02-28

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Scope of Work

Outline of Services Required:

Nova Scotia Community College (NSCC) is conducting a project evaluating the feasibility of harnessing geothermal energy from an old mine and using it to fuel a greenhouse space in Springhill, NS. The Applied Energy Research team has evaluated the heating potential provided by the old mine, and the next phase of the project requires input into the logistics surrounding crop production in a community-driven greenhouse that would be harnessing this energy. There is potential for a more commercial/production-driven greenhouse as well. Perennia's Protected Crop Specialist can provide recommendations on what crops could work in the space they have proposed, as well as the growing parameters associated with those crops, and a list of basic hardware that would be needed for production. Keeping flexibility of use in mind, recommendations will include the 'ideal' hardware/setup, as well as similar versions that keep the space use adaptable to community needs.

Deliverables:

- Produce a document describing three recommended production scenarios for what crops could be grown in the community-minded, geothermal greenhouse located in Springhill NS. This document will include ideal growing conditions, target fertility requirements, and other considerations for the crop types listed.
- Basic list outlining the growing hardware required to implement the three potential growing scenarios, keeping flexibility in mind as much as possible when designing the spaces. The cost of the growing components are not necessary to be provided at this point in time.
- Basic diagrams outlining the look of the proposed scenarios will be included alongside the details for that particular production piece.

Based on the information provided by Nova Scotia Community College, this is what Perennia recommends for crops produced in the space. As greenhouse design and vision evolve with the project, this may need to be adjusted to better suit the end goal.

Types of Greenhouse Production Systems:

Greenhouse production typically falls into two categories: soil-based production, and hydroponic production. In soil-based systems fertility is applied to the soil. It acts as a reservoir for nutrients over time, and the majority of the fertilizer is applied before, during, or after a crop. Water that is applied to the plants is strictly for hydration: there is little or no added fertility in the irrigation water applied to the ground. Based on the description of the project and end goals for the facility, soil production would provide challenging. Managing soil nutrition, productivity and health in a protected space long term is incredibly difficult. Soil is heavy to transport and move around, and can serve as a reservoir for plant diseases and nutrients over time. Soil production can limit accessibility as well, with uneven walking and working surfaces, and the requirement to bend down and work on the ground with low-lying crops (ex. Strawberries, lettuce etc.).

Hydroponic production relies on water as a carrier for the main source of fertility to the crop. Water-soluble fertilizers are mixed in precise ratios, and carried to the crop via irrigation water. The substrate, or growing media, serves structural purposes (ex. Supporting the roots, holding moisture and air) but does not provide substantial fertility to the crop. It is meant as more of an annual/short-term production setup, which significantly reduces the buildup of viruses, diseases, insects and nutrients in the growing media over time. Without these barriers to production, hydroponics can translate to more uniform, reliable production patterns over time.

Hydroponic production can be further subdivided into two groups: containerized production, and nutrient film technique/deep water culture. Container production requires a sizable amount of growing media, typically a peat or coconut choir-based mix, to support the plant through the cropping cycle. Things like tomatoes, cucumbers, strawberries, peppers, and eggplant, are widely produced using this style of hydroponics. The second class of hydroponic production relies on very little growing media. Nutrient Film Technique (NFT) and Deep Water Culture (DWC) are the most recently evolved forms of production, that are primarily adopted to growing greens. These setups have very little growing substrate, and the roots are submerged in water for a period of time, multiple times a day, with the nutrient solution being recycled back to the crop a number of times.

With the parameters outlined by Nova Scotia Community College, hydroponic production would be a good fit for the greenhouse. Accessibility is better in hydroponic production systems compared to soil, providing solid, level surfaces for communittee members and employees to walk on. Hydroponics allows for plants/pots to be moved around throughout the growing season, and growing media is significantly lighter than soil making pots easier to move around. This type of production allows the plants to be raised up off the ground, facilitating work at ergonomic heights compared to working on the ground and in the soil. Produce that is grown in hydroponic systems is significantly cleaner compared to that grown in soil, and it can be designed in a way that allows for flexibility to produce a wide variety of crops as dictated by the community.

Considerations for Greenhouse Design:

Facility design has a significant impact on the success of a greenhouse. Where the focus of this report is on plant production, biosecurity is going to be the main driver for the items listed below. These do not necessarily consider the needs of employees, community members and workers in the greenhouse space, but there is overlap to functionality and more efficient work flows.

Biosecurity is very important for protected production. These spaces are designed to provide ideal growing conditions for plants and shelter them from weather that may be detrimental. Unfortunately these conditions are also conducive to support insect pests and disease as well. Once pests establish in a greenhouse space it can be very difficult to get rid of them. With that in mind, protocols can be implemented to reduce the risk of insect pests and disease getting into the greenhouse in the first place.

When discussing biosecurity for a greenhouse, the main goal is to limit the movement of insects and disease into the production space from the outdoors. For buildings that have multiple production areas that are connected through main areas, movement of insects and disease out of a greenhouse compartment is also important. It is entirely possible to limit the outbreak of a pest or disease in one greenhouse compartment, without it spreading to another one, with proper protocols and procedures adhered to by all staff. That is the ideal situation for a multi-tenant agreement, or where there is a mixed model of committed contracts to retailers and designated learning and training space.

Design considerations that support good biosecurity practices include:

-Washrooms

Ideally staff are not required to leave the greenhouse complex in order to use a washroom. Any entrance and exit to the greenhouse complex requires a series of steps (hand washing, shoe cleaning/sterilization, change of clothes) which are time consuming in nature and introduce additional risk to pest or disease introduction from the outside. Washrooms are ideally located within the greenhouse complex, but not in a growing compartment.

-Changing rooms

Having greenhouse-specific clothing for people who are regularly working in the greenhouse is imperative to limit the movement of diseases and pests into the growing compartments. The exclusion of street clothing from the main production areas is a large contributor to biosecurity. These should be located within the greenhouse complex, but not necessarily in a growing compartment.

-Storage

Storage of growing supplies and tools is important for greenhouse spaces. In addition to special storage for chemicals and fertilizers, things like pots, germination trays, cleaning supplies, growing media, packing supplies etc are going to need a place when they are not being used. This should not be housed in a production compartment, but in a general area away from plants and dirty equipment. This area should remain clean of plant material at all times, ideally away from outside access points and routes where garbage and waste may pass by.

-General area for cleaning and sterilization of growing equipment

Growing infrastructure (stainless steel carts, pots, germination trays, pruners, pallet jacks, ladders) can house disease and insect populations as much as clothing and personnel can. These permanent fixtures to the greenhouse space should be subject to routine cleaning to prevent/limit the spread of disease to other compartments, or young crops. Where these items will be quite dirty when they are brought around for cleaning, it should be done in a space that limits the spread into other areas within the complex, which includes storage of clean supplies, germination cabinets, production spaces, potting areas and general work spaces.

-Potting area (for containerized plant production)

Maintaining clean spaces is a huge component of biosecurity, and limiting opportunities for pests and disease to 'hide' among the mess is a great strategy. Growing media can be messy, and production spaces aren't necessarily set up to make for easy transplanting and efficient

work flows. Having a designated area for transplanting plant material can significantly reduce the risk of disease and insect infestation.

-Germination chambers for seeds and transplant raising space

Clean, healthy, strong plant material is crucial to any successful crop. Young plants are the most susceptible to pest and disease infestation compared to the other stages of plant growth. They also require different growing conditions compared to later stages of production. Ensuring that the plants have the adequate growing environment, away from older plants that may have started to show signs of disease is important. A germination cabinet, or make-shift germination chamber is recommended, in addition to an area for plants to transition from the seedling phase into plants that are ready for the production space.

-Washing/packing area for harvested produce

Plants at the end of their crop cycle are the most likely to house disease and insects. Keeping these plants away from more vulnerable plants, or plants who have yet to show signs and symptoms of infestation, is a good way to limit unnecessary spread. Having a dedicated space to wash/pack produce bodes well for compliance to food safety rules and regulations as well.

-Main office space

Ideally this would be housed outside of any growing compartments, to allow for the greenhouse manager to make adjustments to environmental conditions in the growing spaces without having to enter them. With the humidity, dust, water and debris that are typically present in the greenhouse, keeping technology hardware and general office space will preserve their integrity and prevent for accidental contamination of shared resources in the complex.

General Greenhouse Supplies:

The lists provided below are only a snapshot of the supplies that would be needed for a full production purchase. Once details on the project evolve, this can be refined as needed. The items listed below are limited to the production of the crops included in this brief and does not encompass everything that would be needed for successful food production.

Infrastructure

- Fertilizer Injectors
- Fertilizer Stock tanks
- Hoses for raw water
- Irrigation tubing
- Automatic timers
- Shelving for storage
- Troughs for plants
- Ladders
- Stainless steel carts
- Trellis infrastructure
- Fans
- Environmental sensors
- Chemical cabinet
- Pesticide sprayer
- Dumpsters
- Pallet jack
- Pressure washer
- Fork lift or tractor

Consumables:

- Pots
- Germination trays
- Growing media
- Fertilizer
- Pest control products

Individual Crop Growing Requirements:

Tomatoes

Growing Conditions

Ideal temperature for tomato production ranges from 17 – 24°C. A breakdown of the temperatures required for each plant stage can be found in Table 1.

Table 1. An outline of the ideal temperatures for tomato production, depending on plant stage.

Production Stage	Target Temperature
Plant Raising	19-21°C
Production	24°C
Full Harvest	20-22°C (Day temperature) 17-19°C (Night temperature)

Seasonality

Year-round commercial hydroponic production with supplemental lighting can support one or two full crops in a year. The main activities for both growing cycles are outlined in Table 2.

Table 2. An outline of the typical activities happening each month in order to produce one or two crops of hydroponic tomatoes under supplemental lights.

		Month of the Year												
		1	2	3	4	5	6	7	8	9	10	11	12	
One crop season	Planting													
	Production													
	Harvest													
Two crops per season	Planting													
	Production													
	Harvest													



Producing marketable tomatoes during the winter months (November – February) can be done with artificial lighting, but requires large capital investment. Tomatoes can be produced in a more season manner without supplemental lighting as well. This is the cycle that the majority of high tunnel growers in Nova Scotia adopt (Table 3).

Table 3. An outline of the typical activities happening each month of the year in order to produce one crop of tomatoes, without the use of supplemental lights.

		Month of the Year													
		1	2	3	4	5	6	7	8	9	10	11	12		
NS High Tunnels	Planting		■												
	Production			■	■	■									
	Harvest						■	■	■	■	■				

Plant Spacing

Arrange plants in a twin growing row 0.6-0.8m apart, with a 0.9-1.2m walkway separating the pair of growing rows. This translates to 2.4-2.7 plants/m².

Fertilizer Recipe

This is the recommended hydroponic tomato fertilizer recipe, prescribed in parts per million (ppm). The actual fertilizer quantities are going to depend on the growing medium used for the crop, as well as the source water on site. A proper purchase list/recipe can be put together once the growing media and source water have been properly analyzed.

	N	NH4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S	Cl	HCo3
All Stages	190	22	50	400	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120-200	100-125	25

Additional Considerations

Water use:

A mature tomato crop uses 2L-3L of water per plant, per day when light levels are high. Irrigation and fertigation systems must be scaled appropriately to be able to meet crop demand.

Greenhouse setup:

Plants are contained in individual pots, each fed with their own supply of water and fertilizer solution. Pots are free to drain onto the supporting trough, where water is carried away from the roots and drain at the end of the row. The trough is typically placed close to the ground, so that once the fruit are mature, they are at a comfortable picking height. The troughs are all slightly angled in the same direction, allowing water that leaches from the pots to move away from the roots. Traditional high tunnel production of tomatoes has the support wire/trellis system set up about 1.8-2.5m above the plant row. This trellis must be able to support the weight of all of the plants, and all the fruit that a plant may bear throughout the season. The crop is continuously wound around support strings hanging from the overhead trellis infrastructure. Reference figures 1 and 2 for a schematic detailing a typical containerized tomato crop.

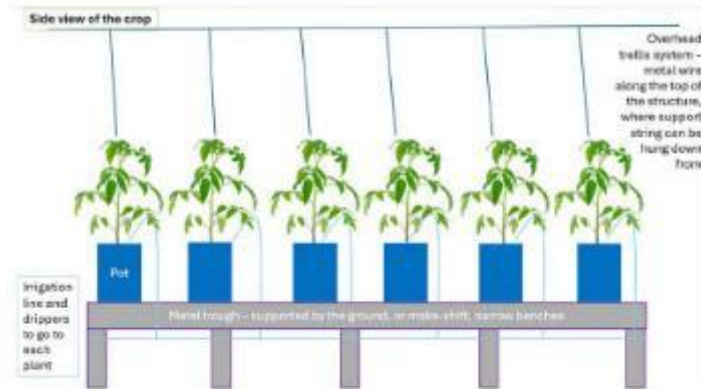


Figure 1. The side-view of a hydroponic tomato setup.

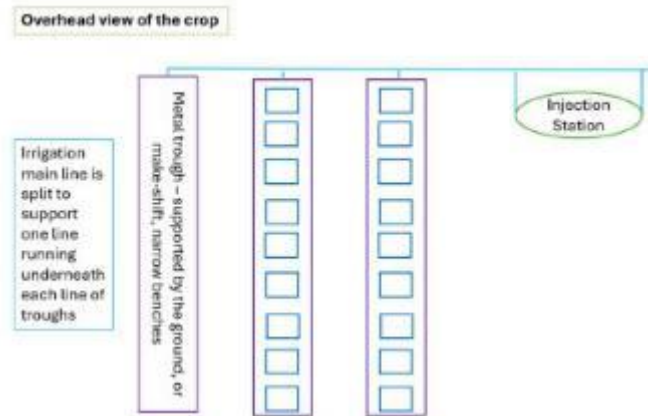


Figure 2. The birds-eye view of a hydroponic tomato setup.

Environmental Management:

Consider installing screens on vents/openings to the outside to reduce the influx of outdoor pests. Screens will limit the airflow coming in and out of the greenhouse space, and can cause issues with

temperature management during the summer time if they are not considered during the initial vent design phase.

Lettuce

Growing Conditions

Ideal temperature for lettuce production ranges from 15 – 22°C. A breakdown of the temperatures required for each plant stage can be found in Table 4.

Table 4. An outline of the ideal temperatures for lettuce production, depending on plant stage.

Production Stage	Target Temperature
Plant Raising	15-18°C
Production	18-19°C (Cloudy day temperature) 19-22°C (Sunny day temperature) 15-18°C (Night temperature)

Lettuce can be grown as a cool season crop in the winter when light is low, but this will extend the time to harvest (see seasonality for crop length).

Seasonality

Ontario sees 8-10 cycles of lettuce a year. During the summer, sowing to harvest can take 7-8 weeks. In winter time that same cycle is reduced down to 11-12 weeks.

Plant Spacing

Plants are grown close together in the early stages, with 10 cm x 10 cm of space around each plant plug. Once neighbouring leaves touch, plants are moved further apart (20 cm x 20 cm), and this spacing is maintained until harvest.

Fertilizer Recipe

This is the recommended hydroponic lettuce fertilizer recipe, prescribed in parts per million (ppm). The actual fertilizer quantities are going to depend on the growing medium used for the crop, as well as the source water on site. A proper purchase list/recipe can be put together once the growing media and source water have been analyzed.

	N	NH4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S	Cl	HCO3
All Stages	200	10	50	400	200	55	6	1	0.5	0.5	0.05	0.05	120	100	25

Additional Considerations

Greenhouse Setup

Lettuce can be set up in a few different ways – deep water culture (DWC) or nutrient film technique (NFT). NFT production has more resources and local expertise surrounding this method of growth, so that would be the recommended method of production of the two options presented.

Nutrient film technique (NFT) production sees multiple waterings a day, where plants are grown in small plugs, and placed into a small, narrow trough which suspends the plants to keep them from getting wet. Shallow, fast-flowing nutrient solution flows over the roots of the plants, and quickly drains out of the system into a covered collection tank. This nutrient solution is recycled, and used for many rounds of irrigation. A small pump is used to recirculate that solution. The mixing/reservoir tank should have a capacity of 1000-1500L/1000m². Figure 3 outlines a schematic for a basic NFT lettuce production system.

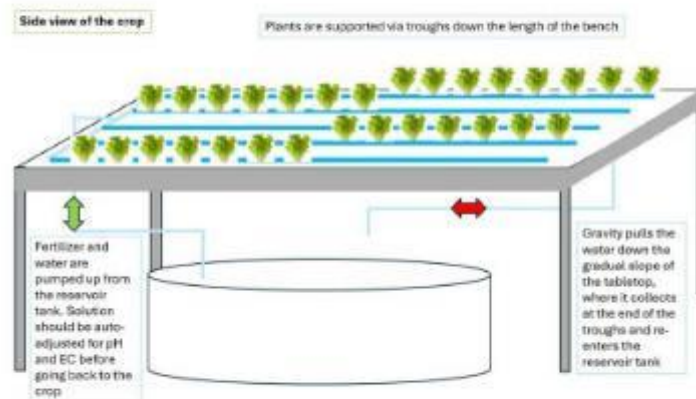


Figure 3. The side-view of a NFT lettuce setup.

Deep water culture (DWC) uses styrofoam sheets with holes drilled at specific plant densities, floating in pools of nutrient solution. Plants are inserted into the pre-drilled holes, which keep the plants upright and allowing for roots to grow in water. The production pools can take a few forms, ranging from more or less permanent

- Pressure-treated lumber used to create basic boxes, that are then lined with plastic
- Engineered concrete pools that run the length of the greenhouse

Nutrient solution is recirculated, aerated and amended with fertilizer to maintain the desired solution composition, EC and pH. Figure 4 shows a basic schematic for a DWC lettuce setup.

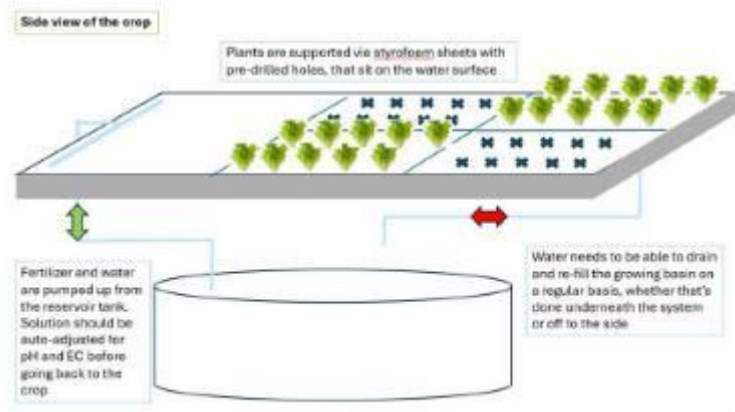


Figure 4. The side-view of a Deep Water Culture setup for hydroponic lettuce.

Environmental Management:

If year-round greens production is the goal, it is crucial to consider cooling strategies throughout the summer months to maintain ideal temperatures for crop production:

- o Ceiling vents in addition to side-wall vents
- o Energy curtains
- o High pressure fogging infrastructure
- o Whitewash and/or shade cloth applied to the outside of the structure

Consider installing screens on vents/openings to the outside to reduce the influx of outdoor pests. Screens will limit the airflow coming in and out of the greenhouse space, and can cause issues with temperature management during the summer time if they are not considered during the initial vent design phase.

Strawberries

Growing Conditions

Ideal temperature for strawberry production ranges from 15 – 24°C. A breakdown of the temperatures required can be found in Table 5.

Table 5. An outline of the ideal temperatures for strawberry production.

Production Stage	Target Temperature
All	21-24°C (day temperature) 15°C (night temperature)

Seasonality

Plant early to mid March, first fruits come out in May/June. Harvest continues until the end of October. If supplemental lighting is available, it is estimated that there could be two or three full crop cycles a year, reducing the gap between strawberries available for consumers.

Plant Spacing

Optimized spacing for strawberry production has 6 plants grown per linear meter.

Fertilizer Recipe

A proper purchase list/recipe can be put together once the growing media and source water have been properly analyzed.

	NO3	NH4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	SO4
Vegetative	150	6	40	150	150	35	2	1	0.5	0.1	0.1	0.05	40
Fruiting	145	5	40	250	120	30	2	1	0.5	0.2	0.1	0.05	45

Additional Considerations

Greenhouse setup:

Typical strawberry production sees two plants per pot, each fed with their own supply of water and fertilizer solution. Pots are free to drain onto the supporting trough, where water is carried away from the roots and drain at the end of the row. The troughs can be low to the ground, or higher up to optimize the ease of picking and plant maintenance. The distance between troughs should be wide enough to accommodate staff, as well as tools required throughout the production cycle (sprayer, harvesting carts etc.). Refer to figures 5 and 6 for two different views of a typical hydroponic strawberry setup.

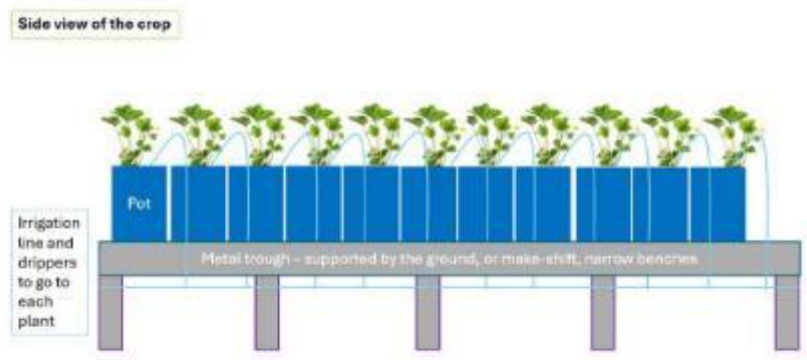


Figure 5. A side-view of a hydroponic strawberry setup.

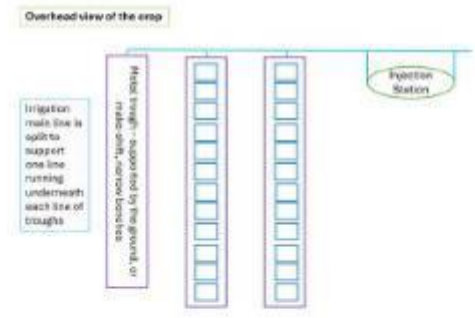


Figure 6. A birds-eye-view of a hydroponic strawberry setup.

Environmental Management:

If looking at strawberry production through the summer, we need strategies for lowering the greenhouse temperature

- o Ceiling vents in addition to side-wall vents
- o Two energy curtains
- o High pressure fogging infrastructure
- o Whitewash applied to the outside of the structure

Consider installing screens on vents/openings to the outside to reduce the influx of outdoor pests. Screens will limit the airflow coming in and out of the greenhouse space, and can cause issues with

temperature management during the summer time if they are not considered during the initial vent design phase.

Cucumber

Growing Conditions

Temperature range required for cucumber production is 17-25°C. A breakdown of the ideal temperatures depending on crop stage can be found in Table 6.

Table 6. An outline of the ideal temperatures for cucumber production, depending on plant stage.


Production Stage	Target Temperature
Growth to Wire	23-25°C (Day temperature) 21-23°C (Night temperature)
Until first harvest	23°C (Day temperature) 21°C (Day temperature)
Full Harvest	23°C (Day temperature) 17-21°C (Night temperature)

Seasonality


Year-round commercial hydroponic production with supplemental lighting can support two or three crops in a year. Details on these two scenarios are outlined in table 7 and 8.

Table 7. An overview of the typical activities done each month of the year in order to produce two or three crops of hydroponic cucumbers under supplemental lights.

		Month of the Year											
		1	2	3	4	5	6	7	8	9	10	11	12
Two crop season	Planting	█							█				
	Production		█						█				
	Harvest		█	█	█	█	█	█	█	█	█	█	█
Three crops per season	Planting					█							█
	Production	█	█				█						
	Harvest	█	█	█	█	█	█	█					



Crop 1
Crop 2



Crop 1
Crop 2
Crop 3

Producing marketable cucumbers during the winter months (November – February) can be done with artificial lighting, but requires large capital investment. Alternatively, cucumbers can be produced in a

more season manner without supplemental lighting. See table 8 for the outline of the cycle that high tunnel growers in Nova Scotia follow.

Table 8. An outline of the typical activities done each month of the year in order to produce two unit crops of hydroponic cucumbers.

		1	2	3	4	5	6	7	8	9	10	11	12
NS High Tunnels	Planting		■				■						
	Production			■	■	■	■	■					
	Harvest					■	■	■	■	■	■		

■ Crop 1
■ Crop 2

Plant Spacing

In general, plants are spaced at 1.4-1.8 plants/m². Larger spacing per plant improves fruit quality, length, and colour.

Fertilizer Recipe

A proper purchase list/recipe can be put together once the growing media and source water have been properly analyzed.

	N	NH4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S	Cl	HCo3
All Stages	190	22	50	370	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25

Additional Considerations

Greenhouse setup:

Plants are contained in individual pots, each fed with their own supply of water and fertilizer solution. Pots are free to drain onto the supporting trough, where water is carried away from the roots and drain at the end of the row. The trough is typically placed close to the ground, so that once the fruit are mature, they are at a comfortable picking height. The troughs are all slightly angled in the same direction, allowing water that leaches from the pots to move away from the roots. Traditional high tunnel production of cucumbers has the support wire/trellis system set up about 1.8-2.5m above the plant row. This trellis must be able to support the weight of all of the plants, and all the fruit that a plant may bear throughout the season. The crop is continuously wound around support strings hanging from the overhead trellis infrastructure. Reference figures 7 and 8 for a schematic detailing a typical containerized tomato crop.

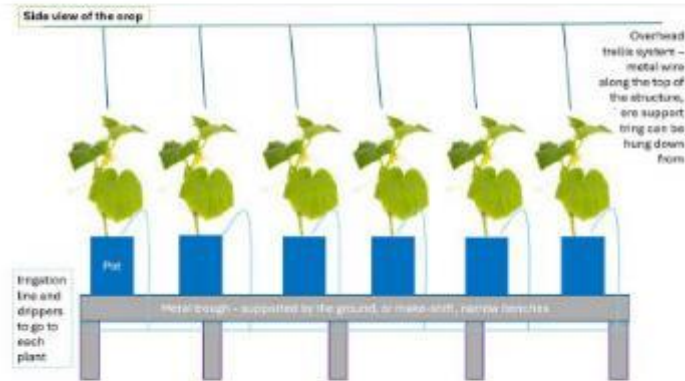


Figure 7. A side-view of a typical containerized cucumber crop.

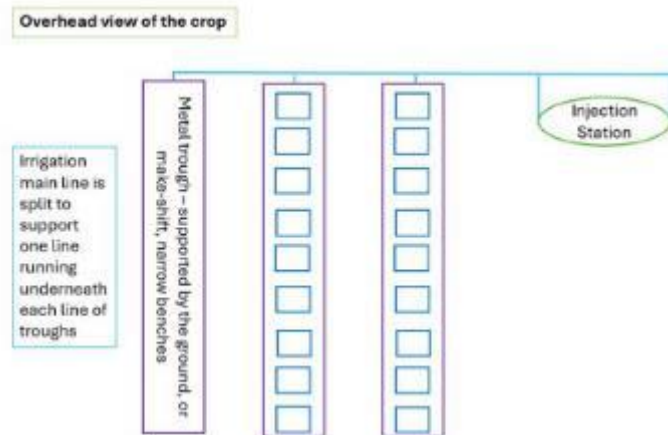


Figure 8. The birds-eye view of a hydroponic cucumber setup.

Environmental Management:

Consider installing screens on vents/openings to the outside to reduce the influx of outdoor pests. Screens will limit the airflow coming in and out of the greenhouse space, and can cause issues with

temperature management during the summer time if they are not considered during the initial vent design phase.

Potential Production Scenarios:

Strawberries and Greens

Scenario:

Strawberries and greens are two crops that are in high demand by consumers year round. One option for the community space would be to equip half of the greenhouse with infrastructure to support greens production, and the other half with strawberries. This configuration would remain for three out of four seasons of the year. The winter season wouldn't not have enough light to support a high yielding strawberry crop, so there is the option to fill the greenhouse with greens production throughout the winter. Year-round strawberry production would be possible with supplemental lights, in which case the greenhouse could support year-round production of both crops. These two crops have different fertilizer needs, so there would have to be two fertility stations in the compartment if both crops are intended to be grown year round. Following the recommendation for NFT lettuce, the stock tank would be placed underneath the tabletops used to grow the lettuce. If two separate fertility systems is an issue, the crops could be staggered to accommodate the growing conditions most suited for each crop (lettuce production in the winter, strawberry production in the summer). Refer to figure 9 for the proposed greenhouse layout to accommodate these two crops.

Rationale:

- Similar temperature requirements for both crops
- High-demand for these by consumers

Challenge:

- Would need supplemental lighting to maintain both crops year-round
- Different fertilizer needs require two fertility systems in one compartment

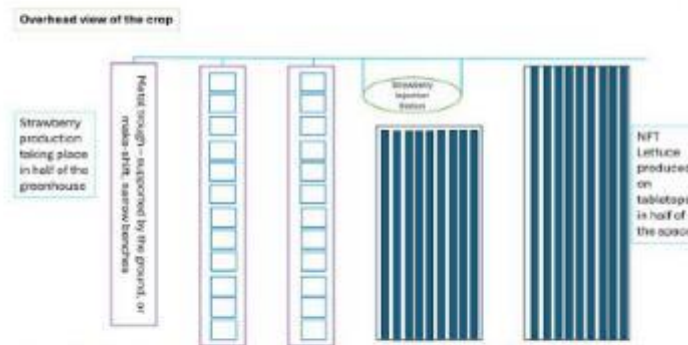


Figure 9. The birds-eye view of a hydroponic setup catered to strawberry and lettuce production.

Tomatoes and Greens

Tomatoes and greens are two crops that are in high demand by consumers year round. One option for the community space would be to equip a full greenhouse with infrastructure to support greens production, and then switch it out for the summer months to produce a full greenhouse of tomatoes. These two crops have different fertilizer needs and target temperatures, making it difficult to optimize production of both at the same time. In order to maximize the amount of each crop that would be grown, creating the opportunity to grow food for community spaces, there would have to be a change-over of infrastructure as well as a rotation of crops. The tomato troughs could be adjusted in density to support make-shift tabletops that would support NFT lettuce production, or swapped out entirely, depending on staff availability and ease of transitioning the production space. Similar to the setup described above for lettuce, the fertilizer reservoir would be placed underneath the benches, maximizing the amount of production space per square foot of the greenhouse. Figure 10 and 11 outline the two setups necessary to facilitate this proposed scenario.

Rationale:

- High-demand for these by consumers
- Producing one crop at a time is easier from a labour perspective, and will provide significant quantity of both crops, which could feed into community groups.

Challenge:

- Would need supplemental lighting to maintain tomatoes year round
- Different fertilizer needs require two fertility systems in one compartment
- Different target temperatures for the crops, so it would be difficult to maximize performance of one without sacrificing the other

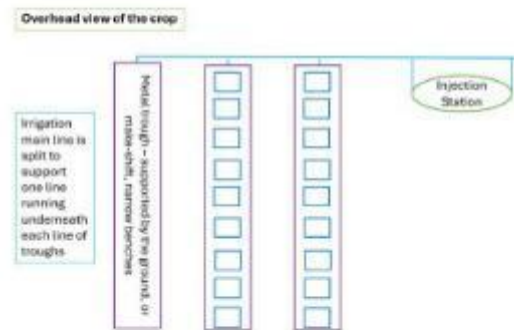


Figure 10. The birds-eye view of a hydroponic tomato setup for summer production of tomatoes.

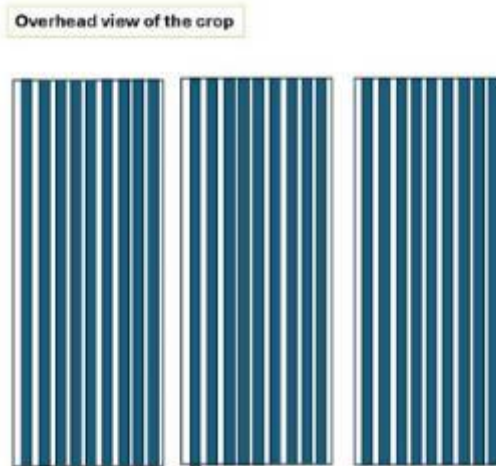


Figure 11. The birds-eye view of a NFT setup for winter production of lettuce.

Tomatoes and Cucumbers

Scenario:

In this case, the greenhouse would be filled with one crop at a time, rotating between two staple crops. One part of the year would be planted in cucumbers, and a second part of the year would be planted in tomatoes. Supplemental lighting would increase flexibility on those planting windows significantly, but it could be done without it. The greenhouse layout would stay the same throughout the whole year, with some adjustments to temperature targets, production timing, plant density and crop maintenance schedules. Overall this would be an easy pair of crops to grow interchangeably. See figure 12 for an birds-eye-view of the greenhouse layout.

Rationale:

- Greenhouse infrastructure would be very similar for the two crops, facilitating an easier transition between the two and reducing initial investment
- Staple crops to most communities
- Very similar fertilizer needs

Challenge:

- Different temperature requirements makes it difficult to grow both crops to maximum productivity at the same time

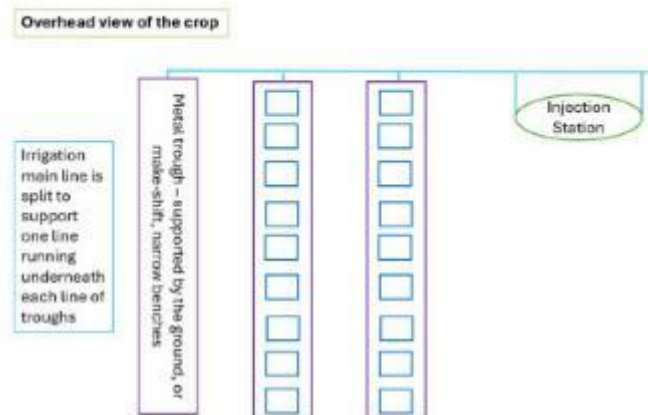


Figure 12. The birds-eye view of a hydroponic cucumber and tomato setup.

Appendix D: Falcon Engineering Study

TECHNICAL MEMORANDUM

TO: Neil Fougere, P.Eng.; DesignPoint Engineering & Surveying Ltd.
Andrew Byrnes, P.Eng.; Pinchin Ltd.

FROM: Jeff Quibell, P.Eng. Falcon Engineering Ltd.

DATE: 18 March 2020

SUBJECT: **GEOTHERMAL MINEWATER HARNESS EVALUATION**
SPRINGHILL BUSINESS PARK
SPRINGHILL, NOVA SCOTIA

PROJECT No.: 19148.001

1.0 INTRODUCTION

Large-scale mining in the Springhill Collieries began in the 1870s and extracted millions of tonnes of coal until 1958 when mining operations abruptly ceased following an enormous and deadly rock burst in the lower depths of the No. 2 mine on October 23, 1958.

With mining ceased, dewatering of the mineworkings was stopped and the workings filled with water. The water residing in the mineworkings (referred henceforth as *minewater*) can be harnessed for geothermal heat and cooling), and indeed small commercial-scale application of minewater geothermal was developed in the late 1980s in Springhill.

The mineworkings are extensive. Several different seams were worked through the mining era. The No. 2 Seam was the most extensively mined with the workings extending downslope over 4,000 m along the dip angle of the coal-bearing strata, with the deepest of the outer workings at approximately 1,200 m below the ground surface. These workings are unique in that they are some of the deepest coal workings in all of North America and among the deepest in the world at the time.

The condition of the workings is largely unknown. Over time, the underground workings inevitably collapse leading to the loss of some void openings and also leading to loss of connectivity of void openings.

2.0 OBJECTIVES

Objectives of the analysis:

- Review information relating to minewater temperature
- Consider amount of minewater extraction flow required to serve prescribed heating/cooling loads

- Identify suitable minewater extraction and injection well locations
- Consider needs for lateral and/or vertical separation of points of extraction and injection
- Consider construction configuration of extraction and injection wells
- Consider cost of minewater harness system

3.0 FUNDAMENTALS

There are a variety of different types of geothermal heat exchange systems. The most suitable type for minewater heat harnessing is the open-loop type well system.

3.1 Open-Loop Type Well Systems

Open-loop well systems adapted to a minewater application extract minewater from the subsurface workings by way of extraction wells, then pass the water through a heat exchanger at the surface (in the Energy Centre Building in this case) for transferring heat from the minewater in heating mode (or to the minewater in cooling mode) and then the minewater is returned back to the subsurface workings by way of injection wells.

In this manner the water is circulated through the system. If the volume of the water circulated in the system is very large and the mass of the host rock that the water is in encapsulated within is very large, then the heat exchange can be sustained on an ongoing basis.

3.2 Springhill Setting

Despite there being an enormous amount of water present in the Springhill mineworkings, only a very small fraction of the water is realistically available for reliable and cost-effective circulation through a geothermal heat exchange system.

If the mineworkings were flat-lying and present at a shallow depth throughout, then the minewater extraction could occur with wells placed at one end of the workings and the injection could occur at the other end of the mineworkings. In this manner, most, if not all, of the overall minewater volume and the entirety of the mass of the host rock that encapsulates the minewater would be available to exchange heat with the geothermal system and hence the system capacity would be enormous.

However, the Springhill mines are not flat-lying with most of the body of the mineworkings lying at considerable depth below the ground surface. The mineworkings dip to the northwest at dip angles varying from about 30 degrees in the upper 100 to 200 m and dipping more gently at a dip angle of less than 15 degrees at deeper depths. Thus, the depth to the workings becomes quite deep with outward lateral northwest distance (up to 1.2 km below ground surface at outer extent of the workings).

While wells could be drilled to the outer extent of the mine, several factors combine to discourage the need for positioning wells at the outer extent:

- Costs mount and risks increase to drill to depths greater than 500 m and certainly over 1,000 m (particularly since there is no certainty that a well drilled at any given location will encounter open and well-connected voids within the workings).

- The outermost extent of the mine exists well beyond the perimeter of the business park footprint. Thus, access arrangements, easements, and additional pipeline construction would be required to establish and serve such wells.
- The business park heating/cooling loads are expected to be satisfactorily served by harnessing minewater from a much smaller fraction of the available mineworkings. The enormous full extent of the mineworkings are not required for serving the scale of anticipated business park heating and cooling loads.

4.0 PERFORMANCE SUSTAINABILITY

Performance sustainability is considered in terms of *thermal stability* (the ability to operate within an acceptable envelope of source supply/return temperatures) and *hydraulic stability* (the ability to sustainably manage water production and water levels at extraction and injection wells).

4.1 Thermal Stability

The ability of the system to sustainably serve the heating and cooling demands placed upon it is a function of:

- The heating and cooling load profile placed upon the system:
 - The relative balance of heat removed from the mineworkings in winter heating relative to the amount of heat rejected to the mineworkings in summer cooling promotes better sustainability because the heat withdrawn in winter is replenished in summer.
- The volume of minewater in hydraulic circulation between the extraction and injection wells:
 - More volume provides greater thermal mass of minewater and greater thermal stability buffer.
- Tortuosity of the subsurface flow pathways through the mineworkings from injection wells back to the extraction wells:
 - The more tortuous the path, the longer the flow distance and the more mass of host rock that the circulating minewater is in thermal connection with.
 - The more tortuous the path, the more likely that water has opportunity for multiple different flowpaths on journey from injection wells back to extraction wells, leading again to more mass of host rock that the circulating minewater is in thermal connection with.

4.2 Hydraulic Stability

The ability of the system to maintain adequate water availability at extraction wells, while avoiding troublesome mounding of rejected water at the injection points. For most open-loop systems this usually requires that extraction wells are in direct hydraulic connection with the injections wells.

It is worthy of note that conditions that favour more certain hydraulic stability (such as close spacing between extraction wells and injection wells in the same saturated water zone) act to reduce the thermal stability. Open-loop design configurations typically aim to balance enough thermal sustainability without compromising hydraulic sustainability.

5.0 INFORMATION AVAILABLE FOR REVIEW

The following relevant information was provided by the project steering committee for review:

- **Report – Mine Workings Spatial Review and Deep Well Test Boreholes – Springhill, Nova Scotia**, CBCL Consulting Engineers, March, 2018; (CBCL, 2018)
- **Springhill Geothermal Energy Use Study**, Efficiency One Services, July 2017; (Efficiency, 2017)
- **Researching the Geothermal Potential of the Former Springhill Mine**, Post Doctoral Fellow Geophysical Mapping; Verschuren Centre for Sustainability in Energy and the Environment; (provided without appendices - request for appendices unmet); (Verschuren, 2015)
- **Springhill Geothermal Project – Preliminary Report**, Hy-Grade Geoscience, January 2004; (Hy-Grade, 2004)
- **Springhill Mine Water Geothermal**, Presentation Prepared by Brian Herteis for Presentation at CEA Symposium, undated file
- Geographic referenced information, including mine layouts of No. 2 and No. 3 mines superimposed on base-mapping, and structure contours of No. 2 and No. 3 seams; provided by DesignPoint Engineering and Surveying Ltd.
- Unbound charts showing water temperatures and water levels in various wells with descriptive contextual information or interpretation discussion.
- Unbound informal information regarding two deep wells installed in 2018, without lithology logs or well completion logs.
- General information about past and current plans for business park development.

In addition to this information, Falcon Engineering sought additional formal information, to provide additional contextual information regarding the mineworking setting and potential geothermal harnessing attributes:

- **Clean Energy from Abandoned Mines at Springhill, Nova Scotia**, ALAN M. JESSOP, JACK K. MACDONALD & HOWARD SPENCE (1995) *Energy Sources*, 17:1, 93-106, DOI: 10.1080/00908319508946072; (Jessop, 1995)
- **Rock Mechanics Analysis of Springhill Mine Disaster (October 23, 1958)**; K.R. Notley, Queen's University Mining Engineering Dept., Kingston, Ontario, July 1983 (Notley, 1983)
- **Geothermal Energy from Abandoned Mines: A Methodology for an Inventory, and Inventory Data for Abandoned Mines in Quebec and Nova Scotia**; Geological Survey of Canada; Open File 3825; K. Arkay, 2000 (Arkay, 2000)

Two reports were provided late in the information review process following request by Falcon for information relating to any prior pumping tests performed:

- **Town of Springhill Geothermal Demonstration Project; Report on Test Drilling and Pumping Test Results**; Project No. 4215; Jacques Whitford and Associates Ltd., Sept, 1987 (Jacques, 1987)

- *Town of Springhill Geothermal Demonstration Project (Phase 2); Report on Production Wells 8, 9, 10; Surette Battery Co. Ltd., Springhill, Nova Scotia*; Ralph Ross, Project Site Coordinator, Town of Springhill Geothermal Committee, March, 1989 (Town of Springhill, 1989)

6.0 ANALYSIS

6.1 Loads

Heating/cooling loads referenced as Energy Centre plant loads (heat exchanged from or to the minewater) was provided by Pinchin and is included below:

- **Heating (transferred from minewater)**
 - Peak Heating: 4638 kW
 - Annual Heating: 5759 MWh
- **Cooling (transferred to minewater)**
 - Peak Cooling: 3589 kW
 - Annual Cooling: 6655 MWh

6.2 Minewater Source Temperatures

The amount of minewater flow required to deliver prescribed heat at the Energy Centre is directly related to the temperature of the minewater. Previous work conducted by others (Jacques, 1987), (Town of Springhill, 1989), and (Jessop, 1995) suggest minewater at temperatures exceeding 14 to 15 °C is expected to be available.

A minewater temperature plot was provided to us for reference review (however, without interpretive discussion). It is included here as Figure A. The plot shows that two deep wells apparently constructed in 2018 appear to exhibit unusually cool temperatures (between 8 and 9 °C in both of the wells at a depth of 200 m. In discussion with Brian Herteis (representative of Cumberland Energy Authority), we understand there is a belief that the unusually cool minewater temperatures measured in these wells may be due to mixing with upper cooler groundwater that may be migrating down the well bore (pers. Comm Brian Herteis, August 14, 2019). We understand the upper, cased interval of the well was not securely sealed with an annular grout to prevent migration of the cooler groundwater on the outside of the casing.

From the balance of information available for review we infer that the minewater temperatures measured in the two new deep wells are perhaps not reflective of the temperature available with a more methodical well construction with adequately sealed casing to prevent mixing with the upper cooler water.

For purposes of this analysis we infer source minewater temperature of 12 °C is available.

6.3 Minewater Flow Demand

Calculations are based on the following parameters:

- Incoming minewater source temperature: 12 °C
- Minimum leaving temperature: 5 °C
{allowing minimum temperature on load side of heat

- exchanger to maintain 4°C to avoid antifreeze)
- Peak heating load: 4638 kW

At these parameters, a minewater flow of 159 L/sec (2513 USgpm) is required.

If it is assumed that 10-inch diameter extraction wells are to be installed and each of the wells intersects open well void with ample available water, then the diameter constraint of the submersible well pump will limit the available pumping capacity from each well to approximately 63 L/sec (1000 USgpm). Therefore, to produce 159 L/sec, at least 3 extraction wells are expected.

6.4 Minewater Harness Configurations

6.4.1 Extraction Wells

The dipping coal strata favoured the development of main “slope tunnel” access into the each of the mine seams as shown on the structure contour figures for the No. 2 Seam Mine in Figure B and the No. 3 Seam Mine in Figure C. These main slope tunnels likely accommodated twin mine haulage railway line access for transporting coal from the depths of the mine. These haulage slope tunnels are considered the most favourable location to extract minewater. Since the No. 2 mine was the deepest and most extensive of the mines, the No. 2 haulage slope tunnel is targeted for minewater extraction.

Since the tunnel is expected to be relatively large diameter (sufficient to accommodate a double tracked narrow gauge railway), and expected to be able to support significant flow relative to the capture flow of an intersecting well, the extraction wells are expected to be suitable for clustering in close proximity as shown in Figure D.

6.4.2 Injection Wells

The location of the injection wells is shown in Figure E and shown to penetrate into the shallower No. 3 mineworkings.

The rationale for penetrating the No. 3 workings for the injection wells is described in the context of *Performance Sustainability* as introduced in Section 4.0:

- *Thermal Stability* is more likely to be served by the separating the extraction from No.2 Seam and the injection to the No. 3 seam, because the vertical separation in addition to the lateral separation of the extraction and injection points will promote a longer and more tortuous pathway between injection and extraction positions.
- *Hydraulic Stability* is more likely to be compromised by injecting to a different seam than the extraction occurs. While there is some anecdotal suggestion of hydraulic connection between the No. 2 and No.3 seams, it does not seem assured. It is therefore possible that injection to the No. 3 zone could result in hydraulic separation which could cause unsustainable dewatering of the No. 2 Seam extraction wells to occur and/or could lead to unsustainable rise in water levels in the No. 3 Seam injection wells (leading to possibility of undesired performance or flooding concerns).

6.4.3 Thermal Stability Calculations

Calculations were carried out to determine the subsurface pathway distance required to support adequate minewater heat exchange to support the prescribed loads. A cylindrical source mathematical heat exchange model was developed as described in Attachment 2. For model simplification purposes, it is based on stated conservative assumptions. With these assumptions, if the heat exchange were to occur in a linear direct-path single channel (such as the main haulage slope tunnel), a subsurface separation pathway distance of over 11,000 m would be required between injection and extraction wells to maintain thermal stability. This calculated result leads initially to favour constructing the injection wells to penetrate into the No. 3 Seam.

However, if the path is sufficiently tortuous, or if the water has opportunity to travel by multiple separate pathways (in and around room and pillar arrangements, for example), then the effective pathway distance is much greater than the linear separation distance between injection and extraction wells. Considering that the calculations are based on conservative assumptions and recognizing that the effective pathway distance is likely many times greater than the linear separation distance, injection well penetration to the No. 2 Seam should not be discounted.

6.4.4 Option to Extend Injection Wells

The injection wells can be constructed so that they can be deepened if necessary at a future date. In this manner they can be constructed to penetrate only into the shallower No. 3 Seam initially. Then, if hydraulic stability concerns occur after testing, or in the future during use, the wells could be subsequently deepened to penetrate into the lower No. 2 Seam.

6.4.5 Staging Considerations

The buildout of the business park will likely occur over time and it is unlikely that the full minewater exchange capacity will be required immediately at system development. Accordingly, it is prudent to build out the system one pair at a time, with a single extraction/injection well pair at the first stage and then building out the remaining pairs as necessary with the design and configuration of the wells informed by the actual performance of the initial well pair.

7.0 WELL CONSTRUCTION CONSIDERATIONS

We currently interpret that future wells need to be constructed more carefully than the 2018 deep wells, with adequately sealed casing in critical zones to avoid mixing of cooler water into the well bores. Factors that warrant consideration:

- Casing and grouting:
 - The upper overburden zones (above the bedrock) and fractured zones or coal seams that occur in the upper bedrock zone require adequately sealed surface casing to preserve the grade of the geothermal resource.
 - Careful and methodical installation of the casing and grout sealing of the casing can add considerable cost.
 - Grout seals using bentonite or cementitious grout (neat cement) may be required to adequately seal the casing.
 - The grout seal may require installation by the "Halibuton displacement method" for adequate seal.

- Diameter:
 - Extraction and injection wells should be at least 10-inch service diameter or greater. The cost for each increment of diameter from 8 to 10 inch, and from 10 to 12 inch is significant but the larger diameter wells are more versatile for larger pumps and serviceability.
- Dry-hole gamble:
 - The reviewed reports including (Jacques, 1987) and (Town of Springhill, 1989) indicate that there is no certainty that a drilled well will encounter open void of the mineworkings. The room and pillar mining method inherently implies that some of the coal was left behind to act as “pillars” to keep the mineworks from collapsing. It is likely prudent to count on 1 in 3 drilled wells not encountering open mine void and to be unusable.

8.0 WELL INSTALLATION COST

The appropriate design for deep wells has not yet been proven. The needs for casing and seal installation and the dry-hole ratio will directly affect construction cost. Cost will vary by 20 to 50% or more based on what proves to be necessary for adequate construction.

For wells up to 800 feet deep we have provided guidance to Pinchin which is reflected in cost tables presented in the main body of their report. Following is a summary of information provided:

- Each 10-inch diameter well is expected to cost approximately \$ per well to depths up to 244 m (800 feet):
 - Cost will be largely determined based on length of casing required and the measures required to seal the annulus on the outside of the casing
 - Properly installed and sealed casing will be crucial to avoid mixing of shallow cool groundwater with warmer minewater
 - Pressure grouting the annular seal with cementitious grout will likely be required – no evidence this was done on any previous wells
 - Properly installed and sealed casing can be expensive and needs to adapt to conditions actually encountered
 - Thermal mixing due to poor casing seals is a documented problem that has occurred on previous wells
 - 2 out 3 wells may be useful (i.e., 1 out of 3 may encounter pillars or collapsed workings that may impair their usefulness)
 - There is documented information indicating previous wells have encountered conditions that have rendered them unusable
- Surface completions for each well: \$ per well including spooled pitless adaptor, and tubing and connection to pipeline
- Submersible Well Pump: \$ per pumping well
- VFD and power filter: \$ per pumping well

9.0 WELL TESTING

There is no information to suggest that the two deep wells installed in 2018 have been subjected to pumping tests. Pumping of both wells should be carried out separately at the maximum sustainable

rate that can be pumped from each well, while monitoring the response in the other deep well and the other shallower surrounding wells. Among the objectives, the pumping tests might indicate that the cool water column in these wells under static conditions might be overcome during dynamic pumping where new water is lifted into the well bore from depth.

Cost for this type of pumping test typically varies upward from \$ depending on the specific prescribed scope.

10.0 LIMITATIONS OF THE ANALYSIS

This analysis is limited in the refinement of its findings for three reasons:

- While there is a lot of relevant information and data available, much of it has not been digested nor integrated and interwoven with other information in a formal manner. Project outcomes would be well served with the preparation of a formal compendium of relevant information. We continued to discover critical information of various sorts through the execution period of this scope. There's likely additional information that would be beneficial for incorporation into this analysis that we've not identified.
- Carefully detailed documentation of the 2018 deep well construction, including detailed foot-by-foot lithologic log and detailed well completion logs showing precise well construction configuration, materials used, and quantities used in addition to any unusual observations or troublesome encounters was not available for review. This is critically important information that would have provided benefit to the outcome this analysis.
- The information about the mines and the related infrastructure that Mr. Brian Herteis obviously possesses is tremendously valuable. More of the information that he possesses should be formally recorded and integrated into a compendium of relevant information. Unfortunately, our request to travel to Springhill and spend two full days with Mr. Herteis including walking the sites, reviewing mine archives, and reviewing documents together was ungranted. While we appreciate the input we received from Mr. Herteis by telephone, the analysis and findings presented in this report would certainly have benefited from a closer and more direct association with Mr. Herteis.

ATTACHMENTS:

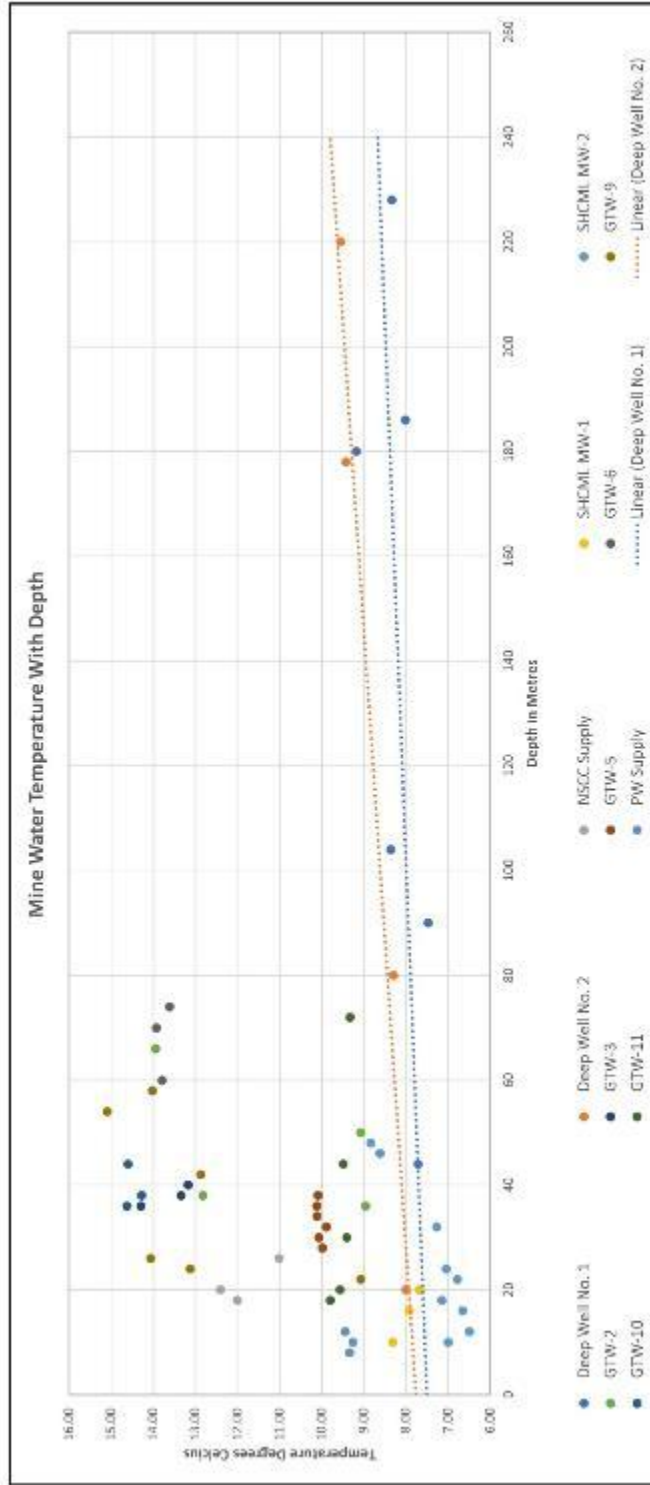
Attachment 1: Figures

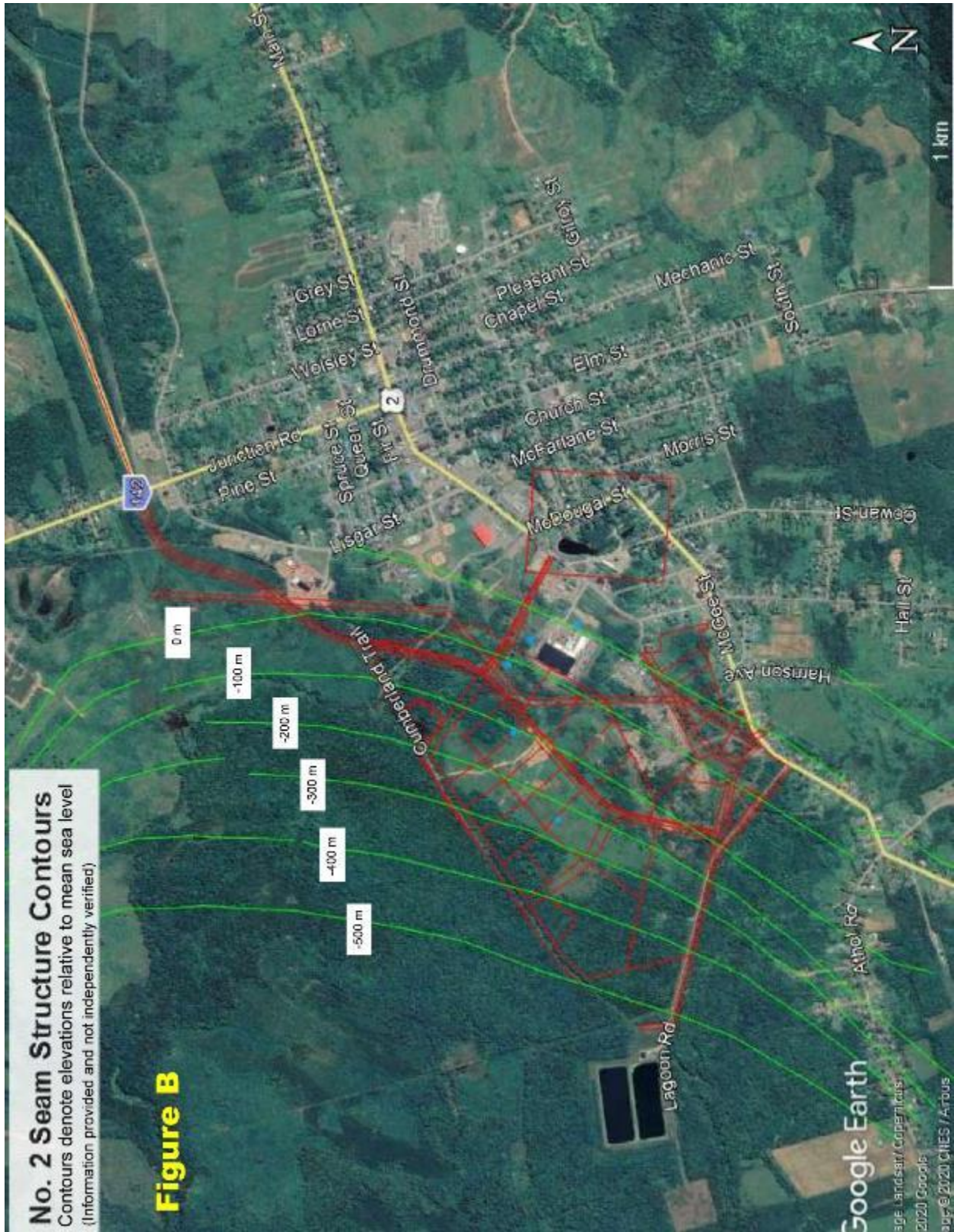
Attachment 2: Cylindrical Source Heat Transfer Mathematical Model

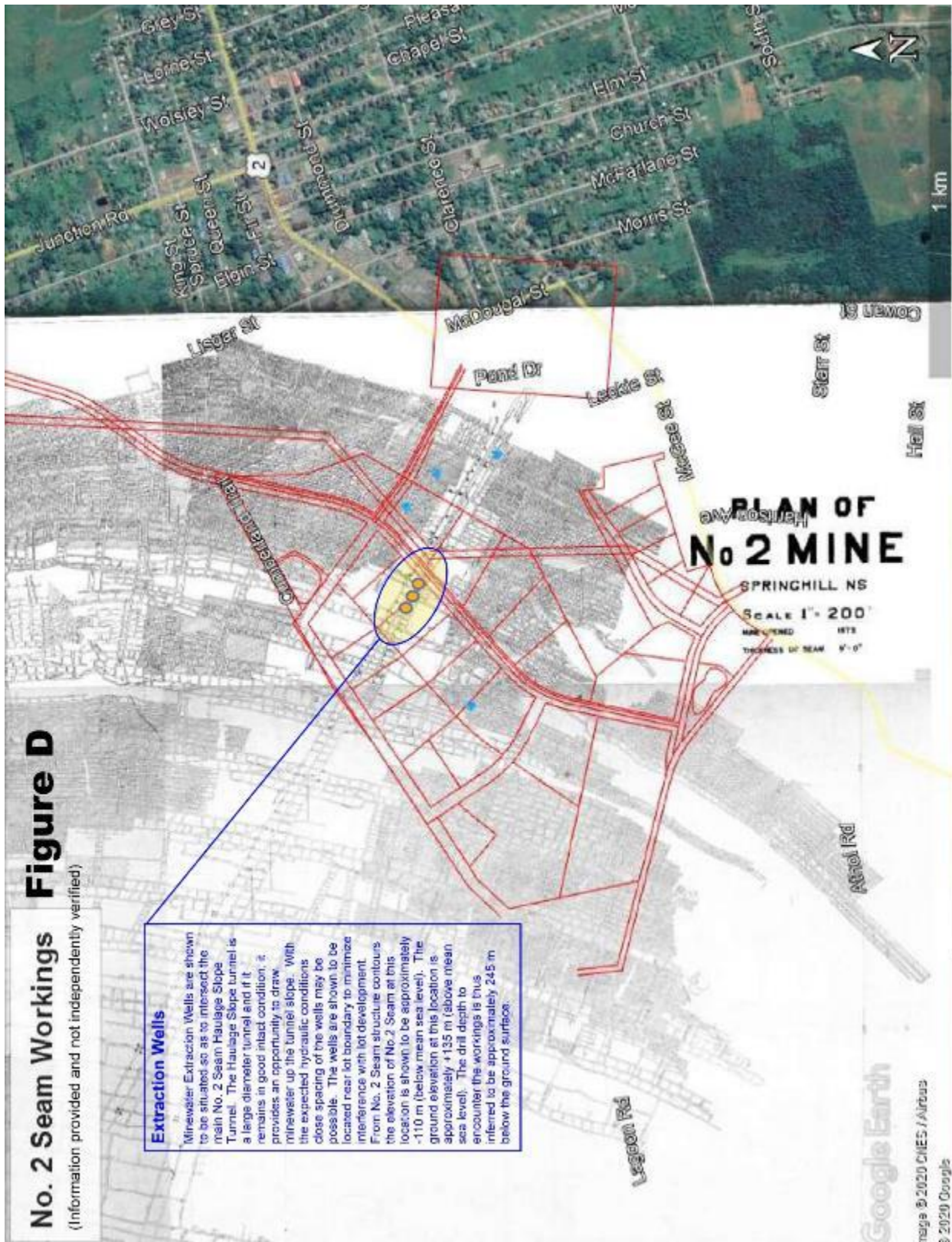
Attachment 1

Figures

Figure A







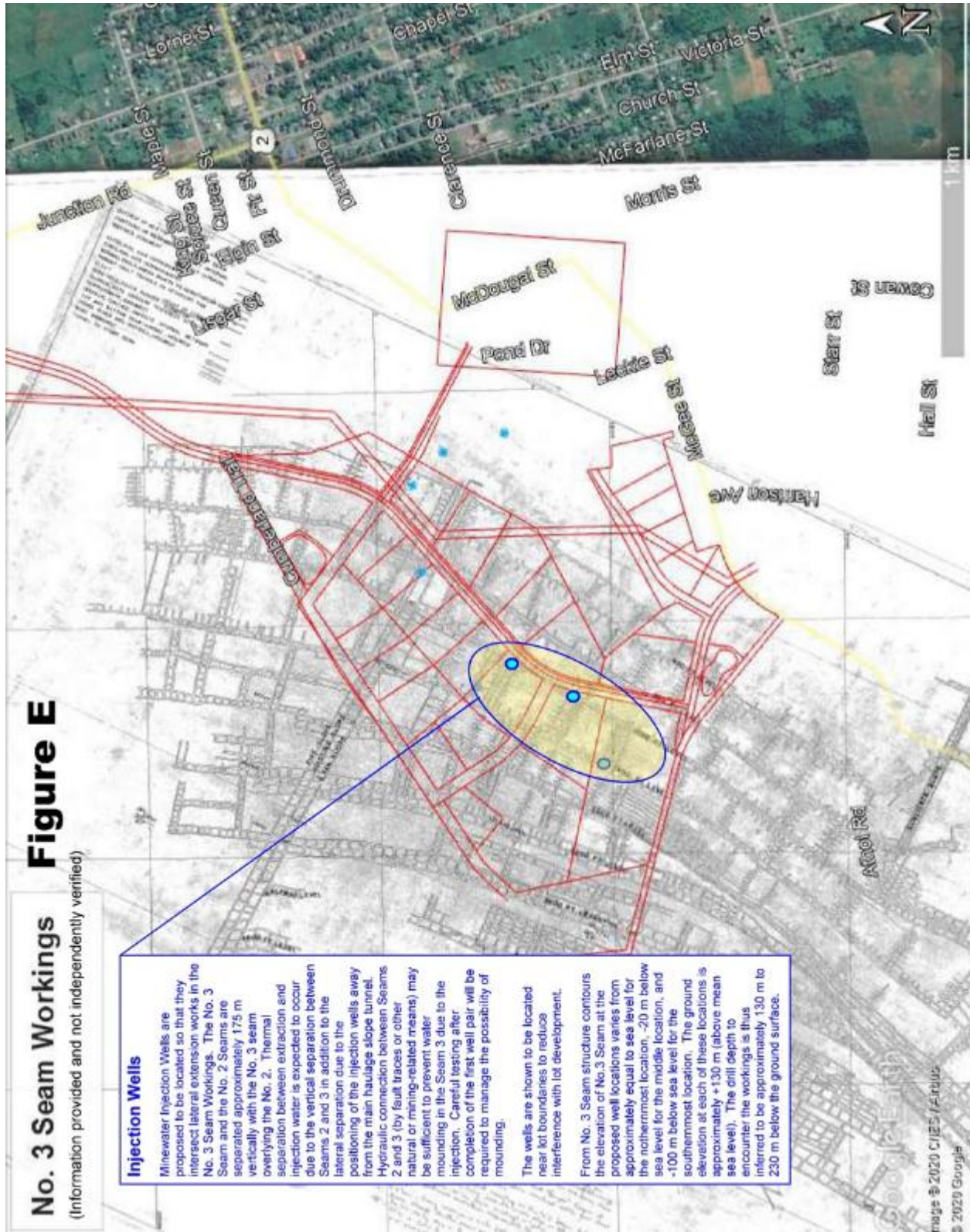
No. 3 Seam Workings Figure E

(Information provided and not independently verified)

Injection Wells

Minewater Injection Wells are proposed to be located so that they intersect lateral extension works in the No. 3 Seam Workings. The No. 3 Seam and the No. 2 Seams are separated approximately 175 m vertically with the No. 3 seam overlying the No. 2. Thermal separation between extraction and injection water is expected to occur due to the vertical separation between Seams 2 and 3 in addition to the lateral separation due to the positioning of the injection wells away from the main haulage slope tunnel. Hydraulic connection between Seams 2 and 3 (by fault traces or other natural or mining-related means) may be sufficient to prevent water mounding in the Seam 3 due to the injection. Careful testing after completion of the first well pair will be required to manage the possibility of mounding.

The wells are shown to be located near lot boundaries to reduce interference with lot development. From No. 3 Seam structure contours the elevation of No.3 Seam at the proposed well locations varies from approximately equal to sea level for the northernmost location, -20 m below sea level for the middle location, and -100 m below sea level for the southernmost location. The ground elevation at each of these locations is approximately +130 m (above mean sea level). The drill depth to encounter the workings is thus inferred to be approximately 130 m to 230 m below the ground surface.





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