MAXIMIZING GEOEXCHANGE PERFORMANCE WITH ABANDONED MINES

Stephen Tweedie, P.Eng., President, Tweedie & Associates Consulting Engineers Ltd., 33 Pine Glen Road, Riverview, NB, Canada E1B 1V3

Abstract:
The Town of Springhill, Nova Scotia has a rich history in energy production. For many years, Springhill was a major producer of coal in the region. Following a series of mining disasters, the third of which occurred in 1958, the coal mines were closed and Springhill's energy legacy was relegated to the history books. However, in recent years, the Town has found a new source of energy that has the potential to once again make Springhill an energy hub of sorts.

In 2004, the Town constructed a new recreational center that included an ice rink and activity rooms. A geothermal heat pump system was installed using water from the flooded mines as an energy source. Since this water remains at a near-constant temperature of 18ºC all year, the COP and EER of their heat pump system is much higher than that typically experienced with closed-loop vertical borehole and horizontal loop systems, or open-loop systems. This arrangement allows for a true thermal storage arrangement with huge potential.

Springhill's Town Engineer, a mining engineer by experience, completed a project to conduct GIS mapping of the old mine workings, which shows all the galleries and locations of pillars. Now, instead of guessing where to drill, well drillers can accurately locate a suitable access point for this energy source.

Key Words: geothermal, thermal storage, heat pumps, energy, mines.

1 INTRODUCTION

In recent years, there has been increased interest in exploring and developing alternate energy sources in Atlantic Canada, due to the high energy costs in the region. Although such efforts have focused on the production of electricity using renewable energy sources such as hydro, tidal, wind, solar and biomass, there is also a need to explore and develop resources that will reduce electrical consumption for the heating and cooling of buildings. Heating and cooling typically account for 60% of all the energy used for commercial, institutional and residential buildings (NR Can, 2006) and, therefore, is the major component of overall energy use.

In addition to storing heat from absorbed solar radiation, the Earth also generates heat internally due to the decay of radioactive isotopes within the earth. This internal heat production typically creates a temperature increase with depth, known as a geothermal gradient. Several investigations were carried out in the 1980's by Natural Resources Canada (formerly the Earth Physics Branch of Energy, Mines and Resources Canada), which identified the carboniferous sedimentary basins in Nova Scotia as having normal to above normal temperature gradients. Typically, this geothermal gradient is known to be in the order of 25ºC/km (Jessop 1976).

This paper will serve to discuss the potential for taking advantage of this phenomenon through the use of water from flooded abandoned mines as a natural thermal storage medium.

2 THE HISTORY OF A COAL MINING TOWN

Springhill is a former coal-mining town in northern Nova Scotia. Commercial coal mining operations were carried out there from 1825 with reserves leased to General Mining Association by the Duke of York. Operations continued under different company names until 1958 when the last of several seismic jolts or “rock bursts” resulted in the death of 75 miners and the closure of the mine. During those years, seven coal seams were mined, using various mining methods including “Room and Pillar”, “Room and Pillar with Pillar Recovery”, “Long Wall Advance” and “Long Wall Retreat”. Each of the series of seven overlying coal seams outcropped on the surface at the western point of the Town near what is today an industrial park, and continue parallel in a westerly direction at an angle of 30 degrees near the surface, to about 14 degrees at depth. All of the seams extend more than 4000 meters from their outcrop, to a depth of almost 1400 meters as demonstrated in Figure 1.

Each of the seams maintained a generally constant thickness of between 1.4 and 3 meters.

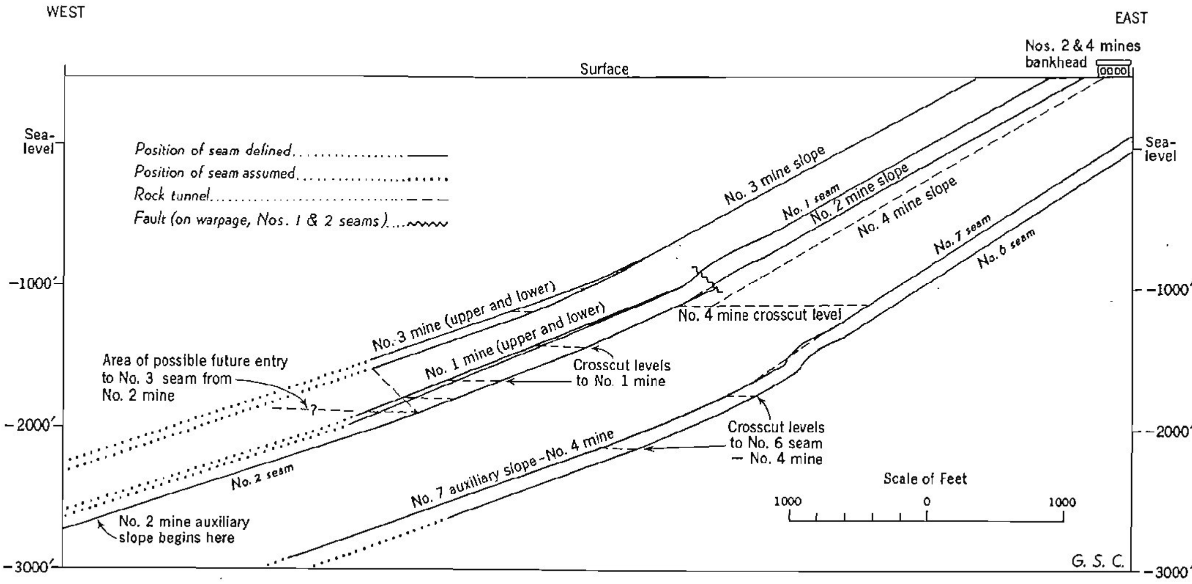

Figure 1 Schematic section of coal seams and working levels at Springhill (from M.J. Copeland, 1958, Figure 3, p.66)

Since the mines were closed, groundwater gradually flooded the mine workings. Although typical groundwater temperatures would be in the range of 7-8ºC, water temperatures of up to 20ºC have been observed at the surface of the mines, well above the typical range.

In 1989, Ropak Can-Am Ltd, a plastics manufacturing company, installed the first commercial heat pump system using water from the Springhill mines. This installation was featured in an IEA CADDET publication in 1992. Since that time, several other users, including the Town itself, have installed heat pump systems connected to this water source. However, efforts to transform this resource into an economic benefit for the Town have been slow to evolve. Only in late 2013 did the Town receive a lease from the Province of Nova Scotia, under the “Minerals Act”, which allows them to administer control over the rights to use the water from these mines.

Figure 2 contains a map that shows the abandoned underground mine workings for No.2 Mine (No. 2 seam) with the Town of Springhill municipal area overlain. This illustrates some of the challenge in accessing the mines at greater depths, since the Town boundary falls between the -400 to -600m level of the 1800m deep mines.

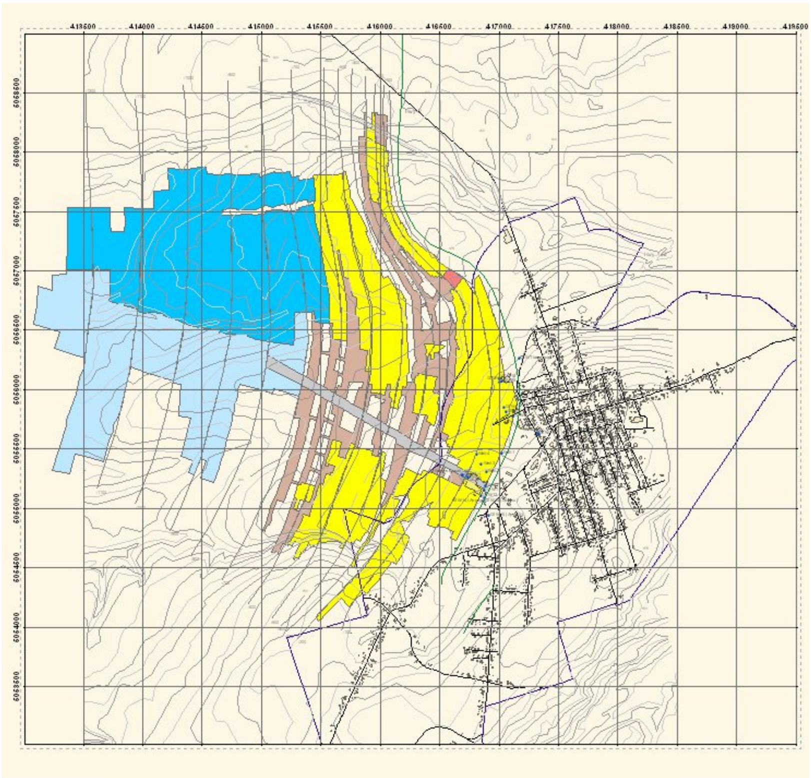

Figure 2 – Abandoned underground mine workings for No. 2 Mine (No. 2 Seam) with Town of Springhill municipal area overlain (from Herteis, B. 2006. Geothermal Resources Assessment, No.2 Seam, Springhill, Nova Scotia)

Figure 3 illustrates the locations where current geoexchange wells have been drilled. The available well data from these wells is contained in Table 1. As seen from this data, the missing information illustrates the lack of consistency and level of documentation maintained on much of the drilling carried out to date. This further highlights the need for a coordinated effort in managing and transforming this resource.

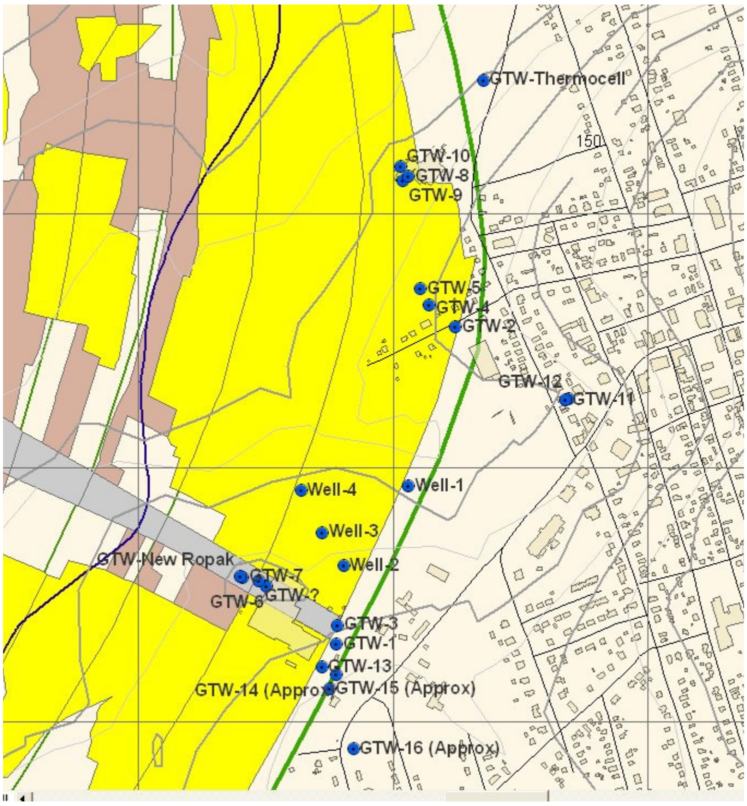

Figure 3 – Springhill Geothermal Wells (from Herteis, B.2006. Geothermal Resources Assessment, No. 2 Seam, Springhill, Nova Scotia)

Table 1-Geothermal Well Data (from Herteis, B. 2006. Geothermal Assessment, No.2 Seam, Springhill, Nova Scotia)

Borehole Name	Easting	Northing	Coal Seam Target	Hole Depth (m)
GTW-1	416888.83	5055153.44	N/A Target Missed	82.3
GTW-2	417123.30	5055777.64	2	50.9
GTW-3	416890.54	5055188.67	2	44.2
GTW-4	417070.75	5055819.55	2,1	79.9
GTW-5	417054.14	5055851.40	2	Unknown
GTW-6	416751.77	5055266.39	2	137.5
GTW-7	416705.02	5055284.67	3	Unknown
GTW-8	417031.10	5056072.77	1	63.4
GTW-9	417018.68	5056064.63	2	103.9
GTW-10	417015.82	5056092.78	2	Unknown
GTW-11	417338.45	5055632.68	7	Unknown
GTW-12	417345.28	5055635.42	6	Unknown
GTW-13	416860.49	5055107.86	2	Unknown
GTW-14	416888.81	5055094.36	4	Unknown
GTW-15	416876.04	5055065.41	4	Unknown
GTW-16	416922.86	5054947.95	4	Unknown
GTW-New Ropak	416700.34	5055287.01	Unknown	Unknown
GTW-Thermocell	417177.17	5056262.45	Unknown	Unknown
GTW-?	416735.68	5055276.82	Unknown	Unknown
GWT-17	Unknown	Unknown	Unknown	Unknown
GTW-18	Unknown	Unknown	Unknown	Unknown
GTW-19	Unknown	Unknown	Unknown	Unknown
GTW-20	Unknown	Unknown	Unknown	Unknown
GTW-21	Unknown	Unknown	Unknown	Unknown
Well-1	417030.74	5055464.01	2	34.7
Well-2	416903.42	5055307.94	1	32
Well-3	416861.43	5055372.74	1	64
Well-4	416819.45	5055454.43	Unclear	68.6

Notes:

1. Projected Coordinate System: NAD 1983 (CSRS98) UTM Zone20N

3 THERMAL CAPACITY OF THE MINES

3.1 Water Volume

Over the years, there have been several estimates of water volume in the mines. These estimates have been prepared using various calculation methods and assumptions. As a result, volumes were estimated to be between 3.73 and 4.19 million cubic meters of water (Jessop, et.al. 1993).

However, more recent studies of the No. 2 Seam (Herteis, 2006) using GIS methods indicate that this seam alone contains a total of 5,582,588 cubic meters of water. It is known that the No.2 Seam was the most extensively mined seam of the seven. However, if one were to extrapolate from the production figures (Nova Scotia Department of Mines, 1978), this would translate to a potential of 10,308,442 cubic meters or $10.3x10^9$ liters of water.

The ability of the mine to produce water with a relatively consistent temperature, depends upon its ability to circulate freely from its most extreme depths. This ability to circulate is directly related to the presence of connecting channels, and the influence created by the flow of water being extracted and re-injected into the mine.

The various levels of the mines were known to have been interconnected. However, the current state of ventilation control doors and other potential obstructions is not known for sure. Nevertheless, despite the substantial roof falls that would have taken place, the resulting voids combined with tunnels and mined areas would provide ample channels for water movement.

In addition to forced flow of water due to active usage, the convective overturn of water in the mines would also serve to cause water heated at depth to rise to the surface. The fact that these warmer temperatures are being observed near the surface are a good indication that this thermal mixing is indeed taking place as a result of adequate flow from the deeper reaches of the mine.

3.2 Thermal Energy

Given the estimates of water contained in the mine, the useable thermal energy contained therein would be in the order of 644,400/GJ or 179,000 MWh. This assumes an average supply water temperature of 18ºC, having heat extracted so as to return the water to the mine at 3ºC. It represents the instantaneous total amount of heat reasonably accessible to geoexchange heat pumps. The result also does not take into account the heat exchange that takes place over time from the rock to the water. In order to have a full understanding of the recovery capabilities, pumping tests would be required. This would help to establish what the maximum extraction rate would be, and would provide further insight into the total potential value of the resource. The transfer of heat from the rock walls of the mine is a process that takes place slowly, and has the potential of maintaining the heat content of the water over an undetermined period of time, depending upon the rate of extraction. It also does not consider the matter of heat being discharged to the mine water from any cooling taking place in buildings to which this water source is connected. Although in this climate many buildings may have a net annual heating requirement, larger commercial buildings and buildings with industrial processes often have a cooling-dominant load due to large internal heat sources. A combination of building types using this resource would tend to ensure a somewhat stable water temperature throughout the year, if properly managed. This would be further enhanced by managing not only the quantity of flow, but also the logistics of where water is extracted and returned. By keeping hot and cold bodies of water physically separated from one another, such as drawing warm water from a higher level mine and returning cold water to a lower level (or reversed for cooling), one could maximize the thermal value of the resource.

4 ECONOMIC POTENTIAL

4.1 Resource

There is a tremendous economic value to the geothermal resource contained within the Springhill mines. There are a variety of methods by which to evaluate the energy stored at this site. Based upon the 179 GWh contained within the body of water, one can compare this with the value of various heating energy sources.

Many home owners and commercial building operators install electric heating, as it generally has the lowest capital cost for installation. When considered in equivalence to electricity at an average cost of $0.10/kWh, the “static” value of the water would be approximately $17,900,000. This does not take into account the heat added to the water continuously either by the earth, or by heat that may be rejected through cooling processes in buildings.

In comparison, burning #2 fuel oil in a boiler or furnace at 80% combustion efficiency, this quantity of energy would equate to 20,415,430 liters of oil. At current prices of $1.00/liter (average), this would have a value in excess of $20,400,000.

Although it is not currently available in Springhill, considering the resource in comparison with natural gas, at $25/GJ (including distribution costs) and 90% combustion efficiency, the value is equivalent to that of electricity, or $17,900,000.

In order to take full economic advantage of the resource, now that they have a lease from the Province of Nova Scotia, regulations require that the Town forms a utility to manage the distribution and sale of the energy.

4.2 End Use

While there is a huge potential value in the energy contained within the mine water, potential end-users must consider what the value would be to them. Outside this “geothermal resource area”, any individual could potentially drill wells to obtain water for their geoexchange system. Even if limitations existed with regard to available quantities of water, or even municipal drilling restrictions, closed-loop systems could still be installed that would allow the building owner to operate a geoexchange system. However, the difference is that “conventional” geoexchange systems operate with an average groundwater temperature of about 7^0C. Consider a liquid-to-liquid heat pump of nominal 5-ton (17.5kW) capacity as represented in Table 2.

Table 2 Heat Pump Capacity Ratings

Nominal 5 ton											
Source Data (Outdoor Loop)					Power Consumption					Load Data	
ELT	Flow	LLT	Delta T	HAB	Compressor		Fan*	Effective	**COPh**	Delta T	**Net Output**
°F	USGPM	°F	°F	BTU/Hr	Watts	Amps	Watts	Watts	**W/W**	°F	**BTU/Hr**
°C	L/s	°C	°C	Watts						°C	**Watts**
26.0	14.4	21.4	4.6	31,644	3,290	14.9	300	3,573	**3.56**	22.6	**43,391**
-3.3	0.908	-5.9	2.6	9,272						12.6	**12,713**
32.0	14.4	26.9	5.1	34,798	3,384	15.3	300	3,667	**3.74**	24.4	**46,866**
0.0	0.908	-2.8	2.8	10,196						13.6	**13,732**
38.0	14.4	32.5	5.5	37,954	3,522	15.9	300	3,806	**3.89**	26.3	**50,495**
3.3	0.908	0.3	3.1	11,120						14.6	**14,795**
44.0	14.4	37.8	6.2	42,566	3,620	16.3	300	3,903	**4.16**	28.9	**55,440**
6.7	0.908	3.2	3.5	12,472						16.1	**16,244**
49.0	14.4	42.4	6.6	47,314	3,765	16.9	300	4,045	**4.40**	31.0	**60,717**
9.4	0.908	5.8	3.7	13,863						17.2	**17,790**
55.0	14.4	47.8	7.2	51,599	3,865	17.4	300	4,144	**4.62**	33.4	**65,344**
12.8	0.908	8.8	4.0	15,118						18.5	**19,146**
61.0	14.4	53.2	7.8	56,159	3,968	17.8	300	4,247	**4.85**	35.9	**70,253**
16.1	0.908	11.8	4.3	16,455						19.9	**20,584**
67.0	14.4	58.5	8.5	61,001	4,074	18.3	300	4,353	**5.08**	38.6	**75,456**
19.4	0.908	14.7	4.7	17,873						21.4	**22,108**

Operating on an entering liquid temperature of 6.7^{0}C, the heat pump has a coefficient of performance (C.O.P.) of 4.16. This means that for each unit of energy input work there are 4.16 units of energy output. COP= Energy out ÷ work.

From Table 2, the effective power consumption (work) is 3,903 watts while the net output (energy out) is 16,244 watts.

COP = 16,244 ÷ 3903 = 4.16

This means that for 3903 watts of electricity input, the heat pump is able to transfer an additional 12,472 watts of heat energy from a water flow of 0.908 liters/second. In this climate, this would represent an annual heating cost of $726 versus $3020 for an electric resistance heating system.

If this is compared with an entering water temperature of 18^{0}C, by extrapolation the COP increases to 4.98, representing an increase of 20% in the heat pump performance. Using these figures, for every hour of operating a heat pump with this water flow (3269 liters/hour), the benefit of the mine water to the user over a conventional ground-loop system would be 4.8kWh or $0.48/hour.

This may not sound like a significant saving on an hourly basis. However, compared with the annual cost of the conventional ground-loop system, this represents an annual heating cost of $606 for an additional saving of $120 per year. Since the installation cost for the building owner would be approximately the same for either geoexchange system, this additional energy saving represents the maximum that the Town could expect to recover from a client using a system of this size. Obviously, there needs to be some sharing of this amount between the utility (Town) and the building owner to serve as an incentive to buy into this system.

When considering the value of the geothermal resource in this perspective, one must consider the incremental value of the heated water from 7^0C to 18^0C as the actual marketable value of the resource. This reduces the potential "static" value for this quantity of water to approximately $1,514,000. Again, one must consider that the continuous replenishing of the heat in the water at lower depths will potentially increase this number, depending upon the extent to which the resource is utilized.

4.3 Other Locations

This potential energy source is not unique to Springhill. There are many abandoned mines throughout the country and around the world that could be utilized in a similar fashion. The economics will vary depending upon a number of factors including proximity of the mine to a town, the depth of the mine, the geothermal gradient, and the relative cost of energy in that locality.

While Springhill may have been one of the first communities to make use of such an energy source, others have attempted to follow their lead. Examples of similar applications can be found in Pennsylvania and Missouri in the USA, in Shettleston and Lumphinnans in Scotland, and in the town of Heerlen in the Netherlands. If proper planning were to be carried out, mines that are nearing the end of their life could be easily assessed and prepared for such use prior to their abandonment. Temperature profiling could be carried out, cross connections could be prepared for adequate flow between seams, and piping could be installed to prepare for pumping the water to the surface. The savings from such preparations could be significant in the overall development costs for such a project.

5 ENVIRONMENTAL ADVANTAGES

The use of energy from mine water has no direct environmental impacts. It produces no combustion gases, it generates no harmful chemical residues, and requires only the electrical energy required to transfer the energy from the mine water to the energy user. Although the generation of electricity itself may create some emissions, this depends entirely upon the generating mix. Historically, a large portion of Nova Scotia's electricity was generated through the burning of coal and, to a lesser extent, oil. However, there is a greater move toward the use of natural gas for electricity generation, and away from the higher polluting fossil fuels. Included in the mix is the use of hydro-electric generation and an increase in the use of wind power. Regardless of the electricity generation source, the use of geoexchange heat pumps to produce heating and cooling from an energy source such as this generates far less pollutants than heat produced from "conventional" fossil fuel sources. Although the hardness of the water and the presence of hydrogen sulfide and ammonia may require a premium type of heat exchanger materials, this added cost would be mitigated through the overall savings offered by the heat pump system.

6 CONCLUSIONS

The energy available from waters of flooded abandoned mines is capable of providing a significant source of heating and cooling for buildings of all sizes and types. Due to the convection circulation in the mines, warmer water is obtained at relatively shallow depths as compared with groundwater at similar depths.

The use of geoexchange systems, in applications such as this, represents a significant reduction in emissions which makes the technology environmentally beneficial. However, it is important to ensure that, in considering individual mines for this application, a market for the energy must be in close proximity.

Across Canada and around the world, there are potential locations where such an application may be replicated. It is necessary that the particular jurisdiction has proper legislation in place in order to define and regulate such a resource.

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