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# The application of horizontal geothermal systems in Gillam (Manitoba): a case study

Marziyeh Fathalkhani, Hartmut Holländer, & Pooneh Maghoul
*Department of Civil Engineering – University of Manitoba, Winnipeg, Manitoba, Canada*
Rob Sinclair
*KGS Consultant Engineers, Winnipeg, Manitoba, Canada*

## ABSTRACT

The application of renewable energy resources can be proposed as a solution for addressing global warming caused by applying fossil fuels for energy supply. The application of the GSHP system, as an alternative of clean energy source, in cold regions may contribute to some potential problems such as the ground thermal imbalance. This study aims to investigate, by using a Thermo-Hydraulic (TH) analysis, the performance of a GSHP planned to be used in Gillam (Northern Manitoba), in which heat is extracted from the ground by means of a horizontal geothermal system. In this regard, the underground temperature profile was estimated using COMSOL Multiphysics. The research showed how energy from an external heat source such as rivers or lakes could be used to mitigate the underground thermal imbalance of traditional systems, and such a system is advantageous for cold climates. The efficiency of Gillam geothermal system was increased by 45 percent with utilizing Stephens Lake as a summer heat source.

## RESUME

L'utilisation de sources d'énergie renouvelable peut être proposée comme solution pour lutter contre le réchauffement climatique causé par l'utilisation de combustibles fossiles. Les pompes à chaleur géothermique font partie du mix de technologies pour utiliser les énergies renouvelables; il peut toutefois mener à certains problèmes potentiels tels que le déséquilibre thermique du sol dans les régions froides. Cette étude a pour but d'étudier, à l'aide d'une analyse thermo-hydraulique (TH), la performance d'un système géothermique dans laquelle la chaleur est extraite du sol au moyen d'un échangeur de chaleur horizontal. Les conclusions de cette étude seront utiles pour un système conçu à Gillam (Nord du Manitoba). À cet égard, le profil de température souterraine a été estimé à l'aide de COMSOL Multiphysics. La recherche a montré comment l'énergie des rivières et des lacs pouvait être utilisée pour atténuer le déséquilibre thermique souterrain des systèmes traditionnels. Une telle approche s'avère avantageuse dans les régions exposées à des climats froids. L'efficacité du système géothermique à Gillam augmenterait de 45% avec l'utilisation du lac Stephens lorsque sa chaleur stockée en été est utilisée.

## 1 INTRODUCTION

Geothermal is renewable and sustainable energy which comes from the earth interior and can provide 50,000 times the energy of oil and gas in the world (Younis et al. 2010). It is a promising alternative to fossil energy and its implications such as emission of carbon dioxide ($CO_2$), dioxide ($SO_2$) and nitrogen oxides ($NO_x$) (Mustafa Omer 2008).

The temperature of the subsurface is more stable than the air temperature and becomes constant below a certain depth. Thus, the soil temperature is warmer than air in winter and cooler in summer. In 1912 in Switzerland, a geothermal heat pump system is used for the first time as a heat source; however low efficiency of these heat pumps at that time was observed and the idea was not followed up (Rawlings and Sykulski 1999). Open loop systems pumping groundwater from a well were the most popular system in the past. Due to changing regulations concerning groundwater use, quality issues, and limitation of groundwater accessibility, the interests change towards closed-loop geothermal systems, although they are more expensive than open loop systems.

Ground source heat pumps (GSHPs) are an energy efficient method to provide heating and cooling for residential and commercial buildings. A heat transfer fluid is pumped through the GSHP to the heat pump installed in the building. An electricity heat pump operates a compressor to transfer the thermal energy to room temperature [5].

The GSHP can be as either a closed or open loop. The loop itself can be either horizontal or vertical (Mustafa Omer 2008, Younis et al. 2010). The fluid is circulated through buried pipes of closed-loop units, while open loop systems circulate well or surface water. In this study, a mixture of open and closed loop system was investigated.

In the cold region, using a closed-loop geothermal system may cause the water inside the soil to freeze due to a thermal imbalance between energy demand and supply in the ground and excessive heat extraction from the ground. This has complicated implications for the GSHP such as damages in the pipes of the GSHP and may result in a malfunction of the whole geothermal system. Change phase releases a considerable amount of energy during the freezing of pore water. The thermal conductivity of ice is about four times larger than water, which results in stabilizing the soil temperature to a constant amount of 0°C until all porewater is frozen. However, the volumetric expansion of pore-water during freezing squeezes the cross-section of geothermal system pipes and affects adversely the structural integrity of such systems. There is an approach that injecting heat to the ground in summer can help to avoid the mentioned irrecoverable process by storing inter-seasonally energy. Using lakes, rivers or sea as a heat source to warm up the ground in the summertime was investigated as a solution for soil freezing problem in the geothermal unit. In this paper, the effectiveness of the thermal balancing of a potential geothermal system in the Town of Gillam (Northern Manitoba) was assessed due to injecting heat through lakes around. The main objective of this research is to evaluate the behavior of the soil and a geothermal plant due to the injection of energy in the summertime.

## 3 DESCRIPTION OF THE SITE AREA

Gillam in Northern Manitoba is a town at the Nelson River locating in the discontinuous permafrost zone. The surficial overburden material is mainly sand, gravel and silt and is typically free of ground ice; however, it could be problematic in the presence of thermal gradient changes.

Two series of the geotechnical and hydrological investigation were performed in this area (Fordyce 2016, David Flynn 2017). One at the recreational center in the Town of Gillam and the other was at the zone near the Stephon Lake which is shown by the caption Site 1 to 3 in Figure 1. The groundwater table is about 2-3 m below grade so that the GSHP is located in saturated clay.

Figure 1. The site location of Gillam town and Nelson river.

Eight Type T thermocouples with an accuracy of ±0.5°C were installed into two test holes in order to monitor the ground temperature. Using the average amount of the derived results from instrumentation in December, the temperature of the earth throughout the depth was assumed. The temperature reached from -32.5°C at the surface to +5°C at 20 m depth (Figure 2).

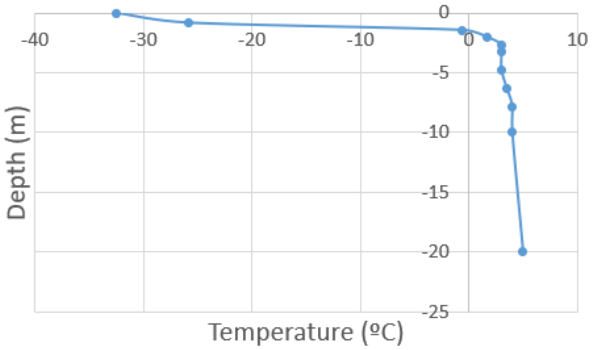

Figure 2. Temperature profile of the soil in Gillam in December

The data of the ground temperature instrumentation in Gillam was just for December (Figure 2). The seasonal temperature variations of the ground near the surface were unknown. Therefore, the surficial seasonal temperature profile was inspired by the seasonal measurement at Thompson in Northern Manitoba (Figure 3) (Batenipour 2012). A linear interpolation was utilized to estimate daily surface temperature in the project (Table 1) by having the surface the temperature in Gillam in December and the temperature profile of Thompson.

Table 1. Gillam daily ground temperature at the surface

| Date | Time (day) | Temperature (°C) |
|---|---|---|
| 1-Dec | 1 | -10 |
| 5-Dec | 5 | -10 |
| 19-Feb | 81 | -13 |
| 14-Apr | 135 | -8.5 |
| 15-Jun | 197 | 10 |
| 16-Jul | 228 | 7 |
| 16-Aug | 259 | 3 |
| 25-Sep | 299 | -2 |
| 2-Nov | 337 | -9 |
| 30-Nov | 365 | -9 |

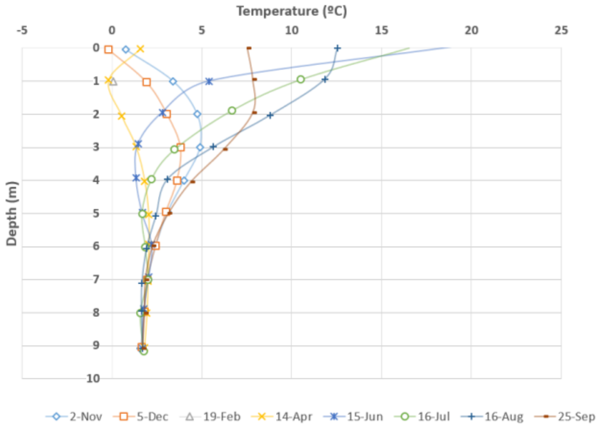

Figure 3. Thompson seasonal ground temperature measurements (Batenipour 2012).

### 3.1 Geology and hydrogeology of the site

Based on geotechnical and hydrological investigations performed by the KGS group in Gillam (Fordyce 2016, David Flynn 2017), the stratigraphy was determined as till being sandy silt. The ground elevation and groundwater level were reported as 142.00 m above mean sea level and 2.8 m below the ground level, respectively.

## 4 GOVERNING EQUATION

Heat transfer equation for a porous medium filled with fluid is governed from the equations below:

$$(\rho C_p)_{eff}\frac{\partial T}{\partial t} + \rho C_p\, \boldsymbol{u}\,.\nabla T + \nabla\,.\boldsymbol{q} = Q \qquad [1]$$

$$\boldsymbol{q} = -k_{eff}\nabla T \qquad [2]$$

Where $\rho\,[\frac{kg}{m3}]$ is fluid density, $C_p[\frac{J}{kg.K}]$ is the fluid heat capacity at constant pressure, $(\rho C_p)_{eff}[\frac{J}{m3.K}]$ is the effective volumetric heat capacity at constant pressure considering both effects of solid part and fluid, $\boldsymbol{q}$ is the conductive heat flux, $\boldsymbol{u}\,[\frac{m}{s}]$ refers to the fluid velocity, $k_{eff}$ is the effective thermal conductivity calculated by averaging the properties of both solid part and fluid, and $Q[\frac{W}{m3}]$ is the heat source or sink (Nield and Bejan 2013). The flow of fluid through the porous medium can be described using Darcy's law.

## 5 METHODOLOGY

The proposed geothermal plant in this project is a hybrid system that consists of a set of horizontal heat exchangers buried in the ground, a closed loop which is a connector of the ground exchangers, the residential or commercial building, a lake or pond, a closed loop, and some valves. The heat transfer fluid comprises of a mixture of an antifreeze and water.

The underground exchangers are 100 horizontal loops with 4.5 m spacing; each consists of three pipes at different depth having a vertical spacing of 4.5 m. The distance between inlet and outlet is about 90 m (Figure 4). These pipes are connected to collector pipes at each side. The pipes have a diameter of 37.5 mm and are made of High Density Polyethylene Pipe (HDPE).

The closed loop system circulates the heat transfer fluid from the building through the underground exchanger during the cold season. In the summertime, the water circulates the second circuit so that heat from the lake/river can be used to heat up the subsurface (Figure 4). The geothermal loop in the lake consists of pipe coils that are submerged at the bottom of the lake. It is assumed that the length is adequate to provide a thermal equilibrium condition so that the heat transfer fluid's temperature is the same as the lake water temperature. Only the underground heat exchangers were simulated in this work. Consequently, the other parts of this hybrid system are considered by means of the boundary conditions.

It was assumed that each pipe can be affected by its neighboring pipes only. For example, pipe "i" may be affected by "i+1" and "i-1" pipes (Figure 5). This follows that "i+2" and "i-2" pipes were not needed to be simulated. Therefore, three series of pipes were simulated in this study in the three-dimensional model using COMSOL software (COMSOL Multiphysics).

The modelling area was defined as a block of 130*50*20 m (Figure 6). The edges of the model are far enough from the pipes to mitigate boundary effect. The heat transfer in the pipe and porous media (soil) was simulated. The groundwater flow in the system was modelled using Darcy's law.

### 5.1 Material definitions

The water table level, which is 2.8 m below the ground surface, implies that a thin layer of the soil is dry. This could act as a kind of insulation due to its lower thermal conductivity installed at the beginning and the end of the pipes. The hydraulic conductivity of the dry soil was considerably lower compared to saturated soil. The hydraulic conductivity of saturated soil in Gillam was reported $8\times10^{-5}$ m/s utilizing Hazen method (Fordyce 2016).

The thermal conductivity and heat capacity of soil with a porosity of 0.3 was calculated to be 1.851 W/m.K and 1020 J/kg.K, respectively (Pavon 2018). The properties of the soil used in the simulation are presented in Table 2.

Once heat exchanger fluid circulated in the pipes, it exchanges with the surrounding medium through the pipe walls called wall heat transfer in this work. The wall heat transfer for pipes was considered in this analysis. The thermal conductivity and the wall thickness of the pipes were assigned to 0.4 W/m.K and 4 mm, respectively, which represent the HDPE pipes in this project.

### 5.2 Initial and boundary condition

The flow in the geothermal system was assumed to be 4.5 L/min for each exchanger and was injected to the inlet which was determined by positive x-direction of the model. Also, the inlet temperature of the water was assumed to be 1.0°C during the heating season. For assessing the effectiveness of using the external heat source (lake water) in the geothermal system, the data of seasonal lake temperature of a nearby lake in Manitoba was used. The temperature instrumentation data of Stephens Lake (Figure 7), provided by the KGS group (KGS group Consulting Engineers) was utilized as the heat source in the summer since Gillam is located on the southeastern shore of this lake. The four-month duration from June 1st until the end of September was considered as lake water injection period.

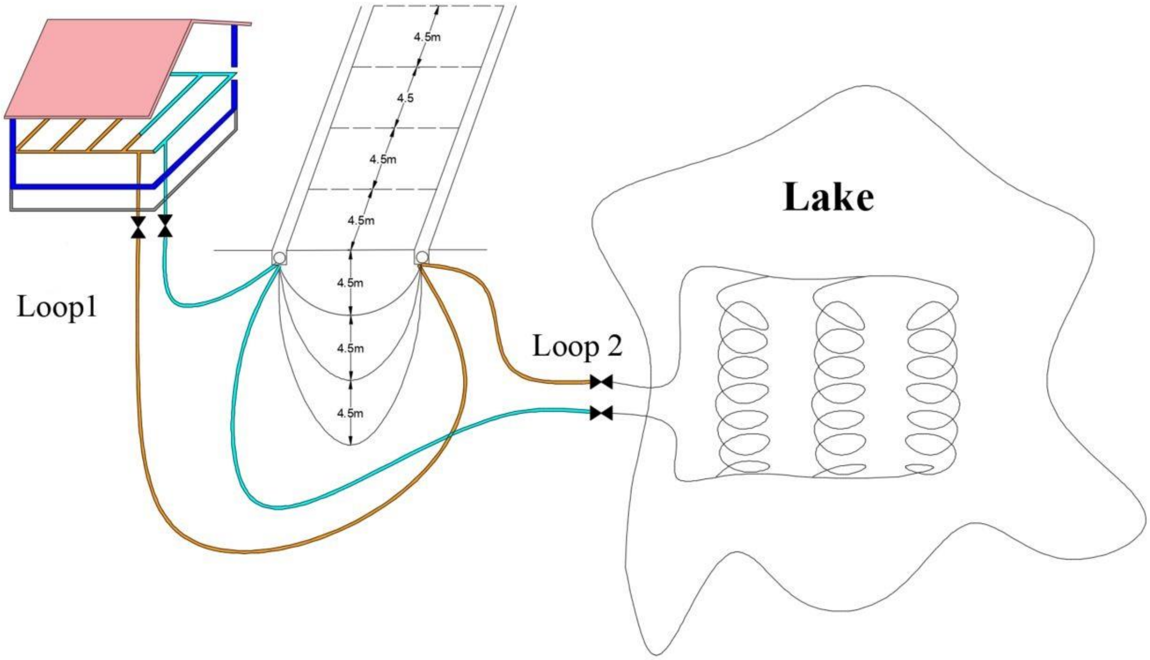

Figure 4. Schematic representation of Gillam hybrid geothermal system.

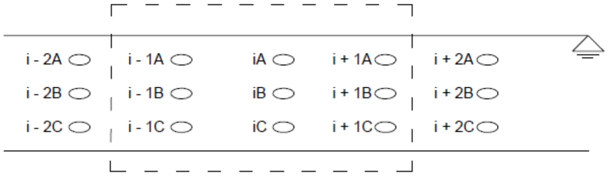

Figure 5. Cross section of geothermal heat exchangers.

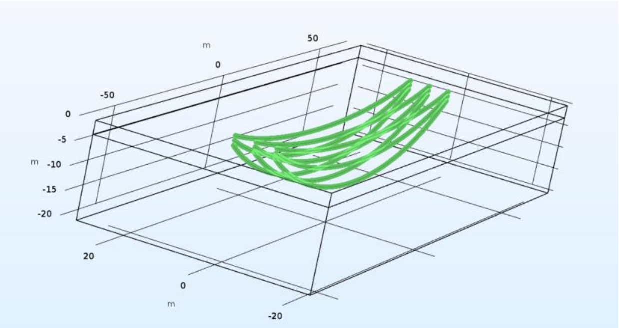

Figure 6. Three-dimensional representation of the Gillam horizontal geothermal heat exchangers.

Table 2. Properties of soil

| Property | Unit | Saturated Soil | Dry Soil |
|---|---|---|---|
| Thermal conductivity | W/m.K | 1.851 | 1.0 |
| Density | Kg/m3 | 2160 | 1860 |
| Heat capacity | J/kg.K | 1020 | 670 |

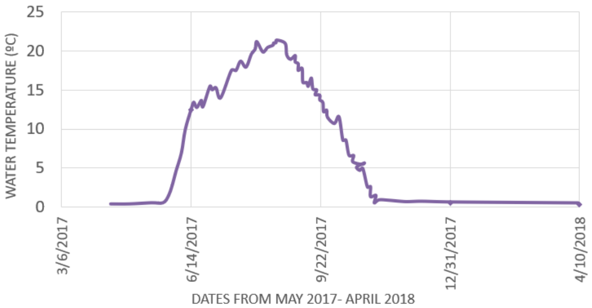

Figure 7. Water temperature during summer for Stephens Lake (data: KGS Group Consulting Engineers).

In order to investigate the effect of lake water injection on the thermal balancing of GSPHs, two various conditions of utilizing lake water loop in the warm season and injecting water with constant temperature were simulated. The simulation was carried out from the 1$^{st}$ of December and lasted for 18 months or right before next summer injection time. The target of the geothermal system is not to freeze the ground so that we do not consider phase change in this study. Therefore, the impact of latent heat is not considered in this model.

Three models with various inflow flux were made, to see the influence of exchanger water speed on thermal energy transmission in the unit.

The effect of using lake water during summertime to heat the ground and therefore, to prevent soil freezing in a GSHP system was evaluated. The temperature change at two points close to the pipe-soil interface were monitored (Figure 8). The central point of the observation is called Point A and the observation point at the left side is called point B. These two observational points are selected at the center and also near the outlet part of the middle pipe.

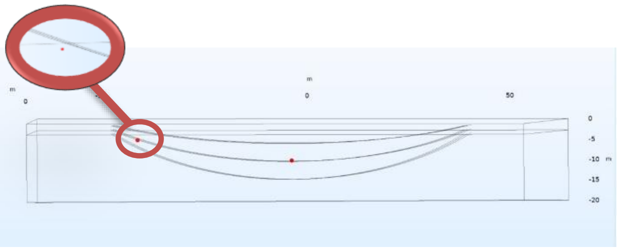

Figure 8. Selected observation points along the geothermal loop.

## 6 RESULTS AND DISCUSSION

Using the lake loop and injecting the energy of the lake water increases the temperature in Point A about 1.23°C and 1.37°C at Point B after an operational period of 540 days.

The temperature in the upper pipe reached 0°C at the end of the simulation period (Fig. 12). Nevertheless, utilizing the lake water loop in the summertime could help to prevent the pore water freezing, expansion of the soil close to the pipe, and potential implications such as pipe cross section squeezing.

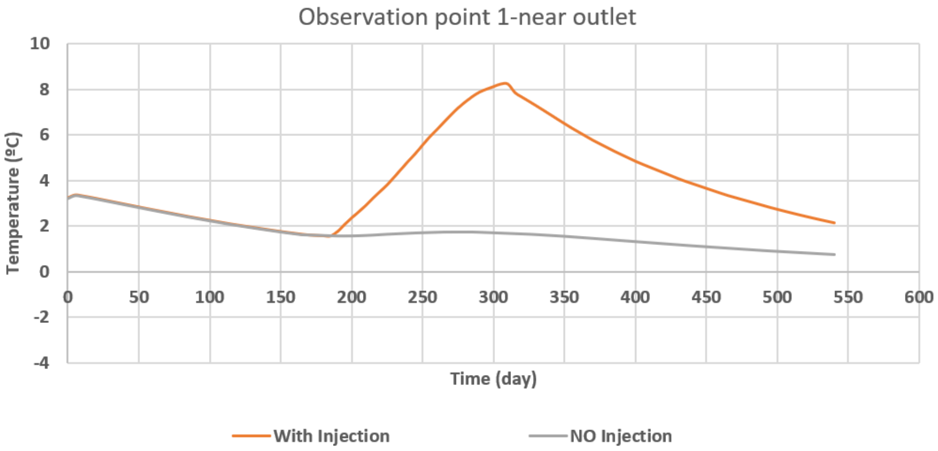

Figure 9. Temperature at Point B with and without injection of energy from the lake after 540 days of simulation.

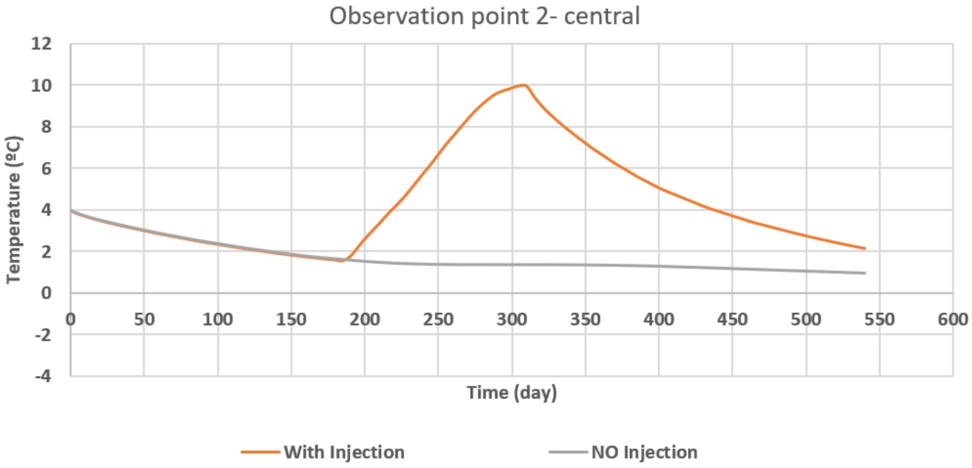

Figure 10. Temperature for Point A with and without injection of energy from the lake after 540 days of simulation.

The upper pipe does not help the system since the outlet temperature is lower than the input temperature (Figure 12). Although the inlet water temperature is higher than the soil temperature at the upper zone of the soil, the water in the upper exchanger loses its temperature to satisfy the equilibrium as the soil temperature is very low in near-ground surface parts. The two other exchangers work adequately in the GSHP system since the temperature of outlet points is higher than the input points, all the time.

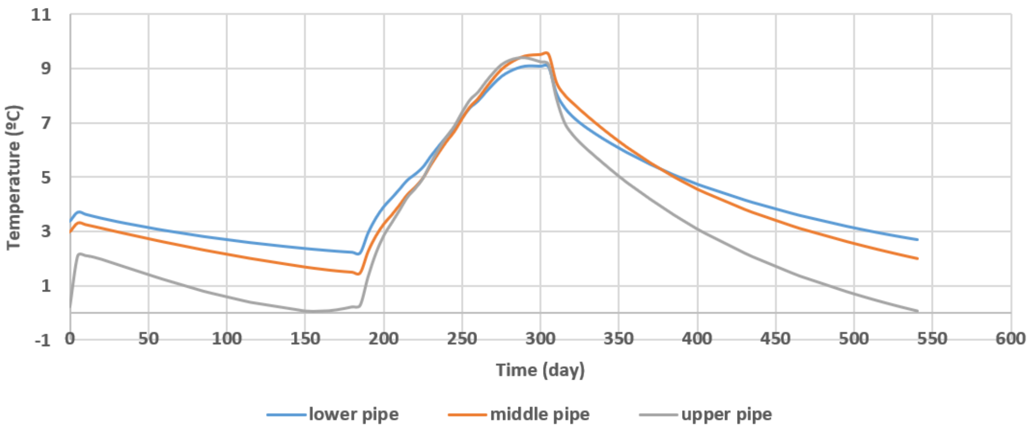

Figure 11. Outlet temperature for three exchanger levels after 540 days of simulation.

The average heat transfer over the length of the pipes was calculated for a duration of 18 months with and without the injection of heat transfer fluid from the lake source in the summertime for “iB" pipe (defined in Figure 5) and is represented in Figure 12. The region below the x-axis represents the transferred energy from the pipe into the ground and the positive area expresses the transported energy from the ground into the heat transfer fluid. The overall thermal energy extracted from the system during one year for the system with and without lake water loop usage is about 1960 W/m and 1060 W/m, respectively. The difference between these two models is due to 4216 W/m yearly energy storage in the soil when the pipes are connected to the lake in the summer (Figure 12). The system with heat injection allowed to extract nearly 2640 W/m thermal energy while the system with no injection of lake water could take around 120 W/m.

This analysis proves the potential of the soil for seasonally storing energy decreases without any energy replacement. Using Stephens Lake as the heat source of energy in summer to balance the geothermal system of Gillam inserts 2250 W/m extra energy in the simulated year into the ground. However, the data from Thompson and the short simulation period do not allow making conclusions for the life-span of such a system. Nonetheless, this study shows that under the given assumptions, the system could be used for about 10.5 months of the year and rested from the beginning of December till the 15th of January to compensate the emerged thermal energy from the ground. It is recommended to use Stephens Lake’s heat source in the Gillam GSHP system for shorter duration (e.g. two months) instead of four months to keep the ground balanced thermally. The optimal time can be determined using a longer time period for the simulation.

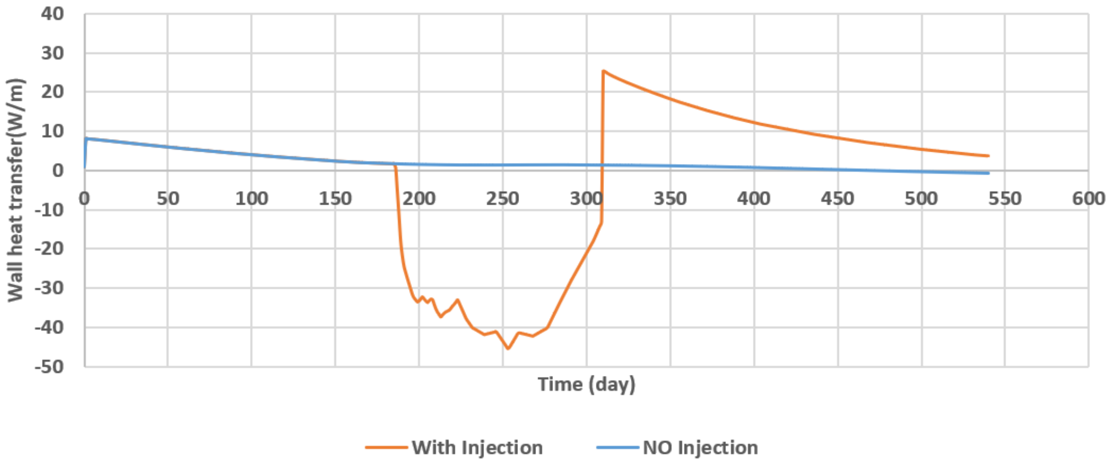

Figure 12. Average heat transfer per length for middle pipe with and without injection of water as heat source.

## 7 CONCLUSIONS

In the current study, the feasibility of using the geothermal system for the Town of Gillam located in Northern Manitoba was assessed. An abstracted model was analyzed by a finite element based program named COMSOL. The geological data was lumped to simplify the calculations.

The effect of heat injection by using lake water in summer period on ground temperature profile was investigated. This was performed by simulating two geothermal system modelling under the constant temperature inflow and adding the close to project lake temperature profile in the summer season, respectively. According to the performed analysis, the presence of lake water injection in the summertime could remediate the production of ice lenses in the pipe-soil interaction area due to dropping below the freezing temperature in the soil.

It is recommended to use the Stephon's Lake water as a summer heat source in the Gillam GSHP unit for a shorter period than 4 months to compensate the energy harvested from the ground and maintain the thermal balance of the soil and preventing environmental consequences.

A parametric study was performed to assess the effect of water speed in exchanger on the ground thermal gradient and transmission of energy. Based on the heat exchange analysis for different inflow fluxes, it is concluded that lower inlet flux causes higher temperature changes in the geothermal system.

Such a system is advantageous for cold climates and can increase the efficiency by 21 times than the GSHP unit with the constant temperature water inflow case.

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