Geothermal Thermal Conductivity Report

Niagara Falls Exchange
Niagara Falls, ON

Prepared For:
City of Niagara

Prepared By:
Michael DeWeerd, EIT.
Geosource Energy Inc.

1508 Hwy 54
Caledonia, ON N3W 2G9
905 765-6950

July 16, 2019

EXECUTIVE SUMMARY

Geothermal heat exchanger installation was completed by Geosource Energy Inc. on under contract with City of Niagara for location at 5943 Sylvia Place in Niagara Falls, Ontario.

The depth of the borehole was 650’ (198.1m) with 105’ (32.0 m) of overburden soil containing Clay and sand, underlain by 195’ (59.4 m) of Limestone, followed by 350’ (106.7 m) of alternating red and grey Shale.

A 5 ½” (140 mm) casing was drilled to 115’ (35.1 m) using dual rotary rigs with air. Casing was sealed into bedrock using 20% solids bentonite grout. A 3 7/8” (98 mm) hole was drilled in the bedrock using a PDC rotary bit with air. Drilling was completed on MOECC multisite Environmental Compliance Approval Number 6747-8X9QZW dated August 21, 2012.

1 ¼” (32 mm) SDR11 4710 geothermal loop was installed to full depth in the borehole and grouted with thermally enhanced grout (K=1.2 btu/ft.hr.F). All temporary casing was removed while grouting the overburden portion of the hole. All materials comply with the applicable section of ANSI/CSA C448 Series 16.

Thermal conductivity testing was conducted from July 2, 2019 to July 4, 2019. Thermal conductivity testing was carried out in accordance with the latest version of ASHRAE HVAC Applications Handbook. Thermal conductivity results for the borehole are shown in the table below.

Parameter	Test BH
Thermal Conductivity	1.64 Btu/(hr*ft*°F) 2.84 W/(m*°K)
Borehole Resistance	0.23 (hr*ft*°F)/Btu 0.13 (m*°K)/W
Ambient Deep Earth Temperature	54.6 °F 12.56 °C
Estimated Thermal Diffusivity	1.17 ft^2/day 0.11 m^2/day

At no point during drilling did natural gas levels exceed 10% of LEL at a distance of 5 m from the drill discharge area or in the rig operator area. Continuous gas monitoring was conducted at both these locations. No natural gas was detected following completion of the borehole. While no gas was observed during drilling of the test boreholes, site conditions can be variable and presence of natural gas during drilling operations is always possible. Safety protocols as specified under Reg. 98/12 will be required to ensure safe installation of the geothermal system. Trace oil was not observed in discharge from drilling operations. Water production during drilling was not significant. Drilling and loop installation occurred without incident.

Table of Contents

Introduction

Geothermal heat exchangers were installed by Geosource Energy Inc. under contract with City of Niagara. The following items are covered in this report as the typical prerequisite for feasibility:

- Record the geological formation while drilling the test boreholes,
- Assess any geologic risks that might impact drilling or installation of geothermal loops,
- Measure the average Thermal Conductivity of geological formation,
- Estimate the Thermal Diffusivity of the geological formation
- Measure the ambient deep earth temperature of the geological formation

The results of the drilling logs and TC Tests can be used in the design of a geothermal heating and cooling system for the proposed residential / commercial development. The results, used in conjunction with a building energy model, has a significant impact on the physical dimensions of the ground heat exchanger (GHX) field as well as the cost of constructing the system.

Borehole Information

The boreholes were drilled to a depth of 650' (198.1m) using a dual rotary drill. Borehole construction with hole dimensions and drill log is shown in Figure 1.

A fusion welded U-tube, 1 ¼" (32 mm) in diameter, SDR11 4710 HDPE pipe was inserted to the bottom of the borehole on completion. A 1 ¼" (32mm) tremie line was inserted with the U-tube to facilitate grouting of the borehole. Installation of the loop proceeded as normal.

High-solids bentonite grout mixed with PowerTecX to improve the thermal conductivity of the grout was pumped through the tremie line to ensure complete filling of the test borehole. The thermal conductivity of the bentonite / PowerTecX grout was estimated at 1.2 Btu/hr*ft*°F or 2.1 W/(m*°K) based on manufacturer's mix recipes.

Following the thermal conductivity test, plugs were placed in each side of the loop 0.15 m below surface to prevent debris from entering the loop during further site activity.

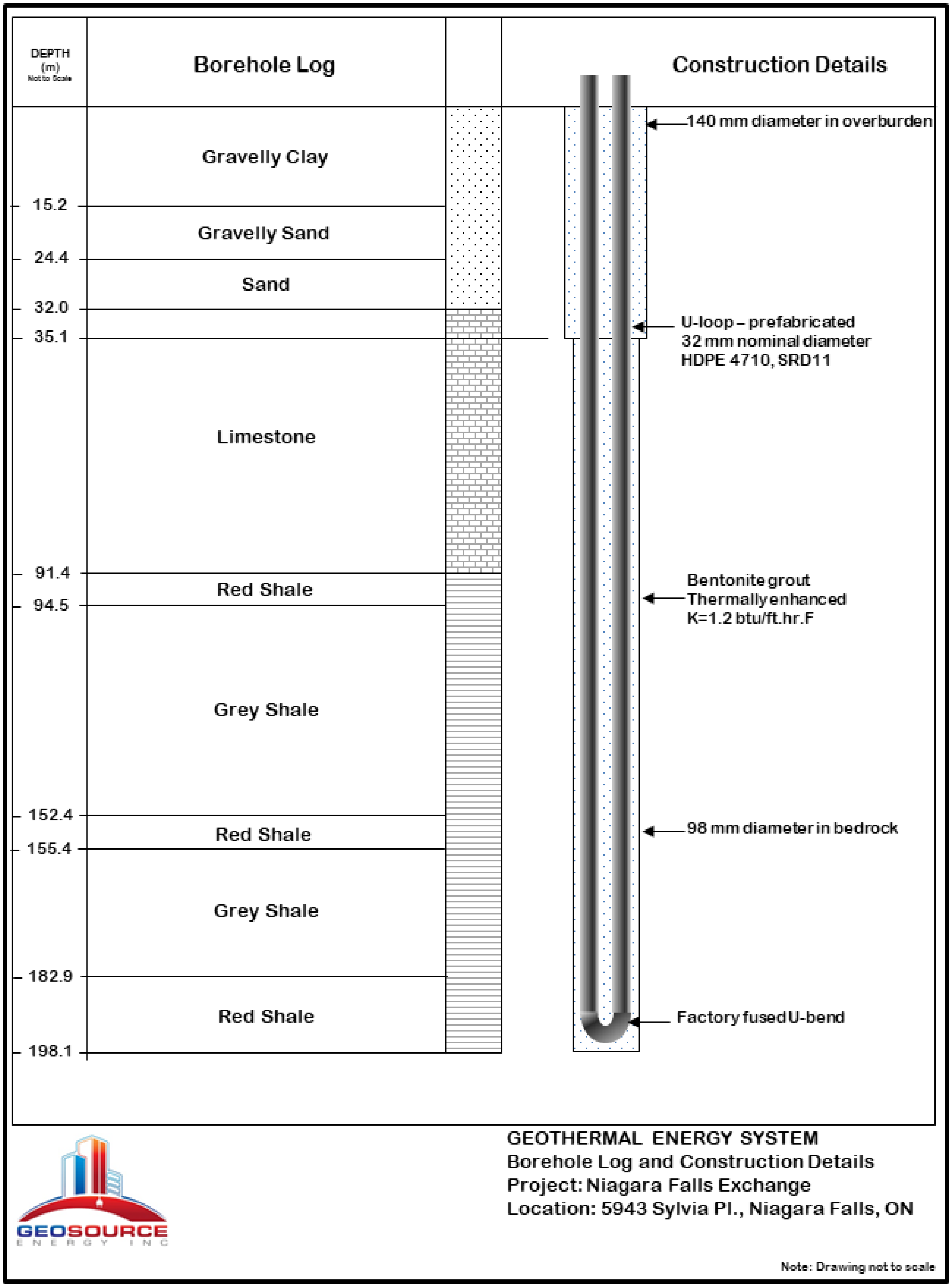


Figure 1. Borehole Log

At no point during drilling did natural gas levels exceed 10% of LEL at a distance of 5 m from the drill discharge area or in the rig operator area. Continuous gas monitoring was conducted at both these locations. No natural gas was detected following completion of the borehole. While no gas was observed during drilling of the test boreholes, site conditions can be variable and presence of natural gas during drilling operations is always possible. Safety protocols as specified under Reg. 98/12 will be required to ensure safe installation of the geothermal system. Trace oil was not observed in discharge from drilling operations. Water production during drilling was not significant. Drilling and loop installation occurred without incident.

Thermal Conductivity Test Methodology

The 1 ¼" (32 mm) SDR11 HDPE U-tube in the tested borehole was connected to a TC testing unit. A schematic of the test borehole with connections to the TC Testing unit and generator power supply is shown in Figure 2.

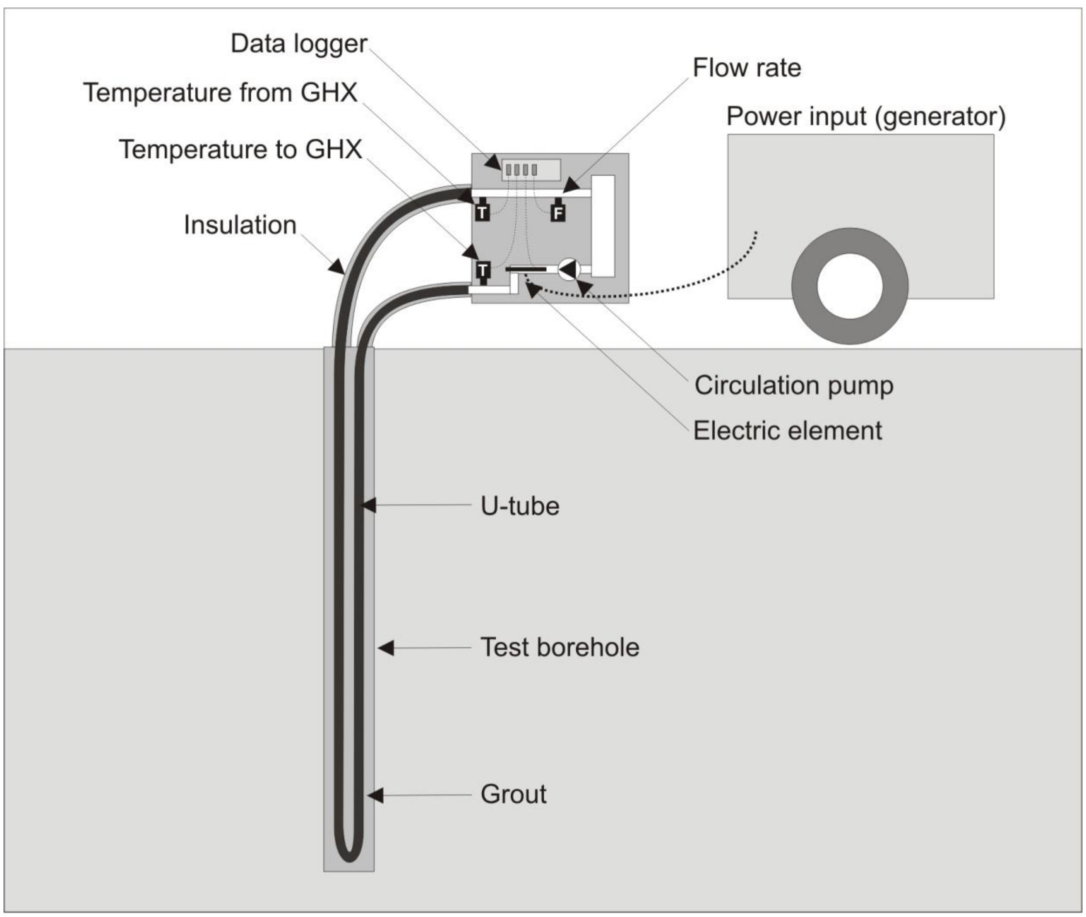


Figure 2 Schematic of T/C test equipment.

The U-tube was connected to the TC Testing unit. Water was used to fill the unit and the U-tube and all air was purged from the system.

The TC Testing unit includes the following components:

- Circulation pump (Taco 2400-45-3P 240V): Circulates water through the unit and U-tube at approximately 10 USgpm (38 l/m)
- Five electric heaters (2 x 2.5 kW, 1 x 3.0 kW and 2 x 3.5 kW): Add heat energy to water circulating through TC Testing unit.
- Four temperature sensors: Monitor water temperature entering and leaving TC Testing unit with two sensors placed at the inlet and two sensors placed at the outlet.
- Flow meter: Monitors flow rate through TC Testing unit
- Data logger: Logs sensor collected data at regular time intervals for the duration of the test (4 x temperature, flow rate, current, voltage, time)

Test Statistics

A 20 kW diesel generator was used to provide power to operate the circulation pump and electric elements in the TC Testing unit. Four of the five electric elements totaling 11.5 kW (37,534 Btu/hr) were energized to heat water that was circulated through the U-tube by the circulation pump. The test for this project was run for approximately 48 hours and occurred from July 2, 2019 to July 4, 2019. The borehole location is shown on the site plan included in APPENDIX A – Borehole Location.

The following table shows the testing statistics for the borehole.

Parameter	Test BH	
Start date / time	2019-07-02 11:05	
Finish date / time	2019-07-04 10:51	
Duration of test	47 hours, 46 minutes	
Logging time interval (minutes)	2	
Average input voltage (V)	240.61	
Minimum input voltage (V)	240.01	
Maximum input voltage (V)	241.22	
Average input amperage (A)	48.84	
Minimum input amperage (A)	48.68	
Maximum input amperage (A)	49.06	
Average Power input (kW)	11.75	
Minimum Power input (kW)	11.72	
Maximum Power input (kW)	11.82	
Average flow rate (Usgpm,lpm)	10.3	38.9
Minimum flow rate (USgpm,lpm)	9.5	36.0
Maximum flow rate (USgpm,lpm)	10.5	39.7
Borehole depth (ft,m)	650	198.1
Power input per depth (W/ft,W/m)	18.1	59.3

Test Results

A TC Test measures the temperature of fluid entering and leaving the test borehole, the flow rate through the borehole and the power input into the borehole on a 2 minute time interval. Ground Loop Design 2016 was used to complete the analysis of the data.

From the data, the average thermal conductivity of the borehole can be calculated and the ambient deep earth temperature can be measured.

The thermal diffusivity of the formation is estimated based on the geological formation the borehole is drilled through. There is no method to determine the average diffusivity of a borehole other than to calculate a weighted average of the estimated diffusivity of each geological formation along the borehole.

Thermal Conductivity

Thermal conductivity is a measure of the quantity of heat that can be transferred through a material. It is measured in Btu/(hr*ft*°F) or W/(m*°K).

The data from the TC Test was analyzed by plotting the temperature data collected during the test and calculating the slope of the temperature trend line. This was calculated using the following formula:

$$k = q/4\pi Lm$$

where k is the thermal conductivity (BTU/(ft*hr*F), q is the rate of heat injection (BTU/hr), L is the length of the loop (ft), and m is the slope of the temperature (F) versus logarithmic time (-). The first 12 hours of the test are normally ignored for the calculation of slope.

Graphs showing the average temperature of the water entering and leaving the U-tube for the test is shown in Figure 3. The first 12 hours show a rapid increase in temperature of the water circulated through the U-tube. This indicates the time required for the thermal energy being added to the fluid to begin dissipating to the geological formation. The length of time this takes is attributed to the construction of the borehole.

Borehole construction affects the borehole resistance, or efficiency of the borehole. The factors that impact the borehole resistance include:

- U-tube pipe diameter
- U-tube pipe wall thickness
- U-tube material
- Position of the U-tube in the borehole
- Diameter of the borehole
- Thermal conductivity of the material (grout) between the pipe and the borehole wall

As the borehole resistance to heat transfer increases, the length of time required for the stability of the heat transfer to the ground increases. For this TC Test, stabilization of heat transfer occurs at approximately 12 hours. The test data used to calculate the thermal conductivity, or “k” of the formation was between 12.0 and 47.8 hours of testing.

Test results are shown in the table below. The temperature, flow rate and power data is plotted in Figure 3. The average temperature versus the logarithm of time with the determined slope from 12.0 and 47.8 can be seen in Figure 4

Parameter	Test BH
Thermal Conductivity	1.64 Btu/(hr*ft*°F) 2.84 W/(m*°K)
Borehole Resistance	0.23 (hr*ft*°F)/Btu 0.13 (m*°K)/W
Ambient Deep Earth Temperature	54.6 °F 12.56 °C
Estimated Thermal Diffusivity	1.17 ft^2/day 0.11 m^2/day

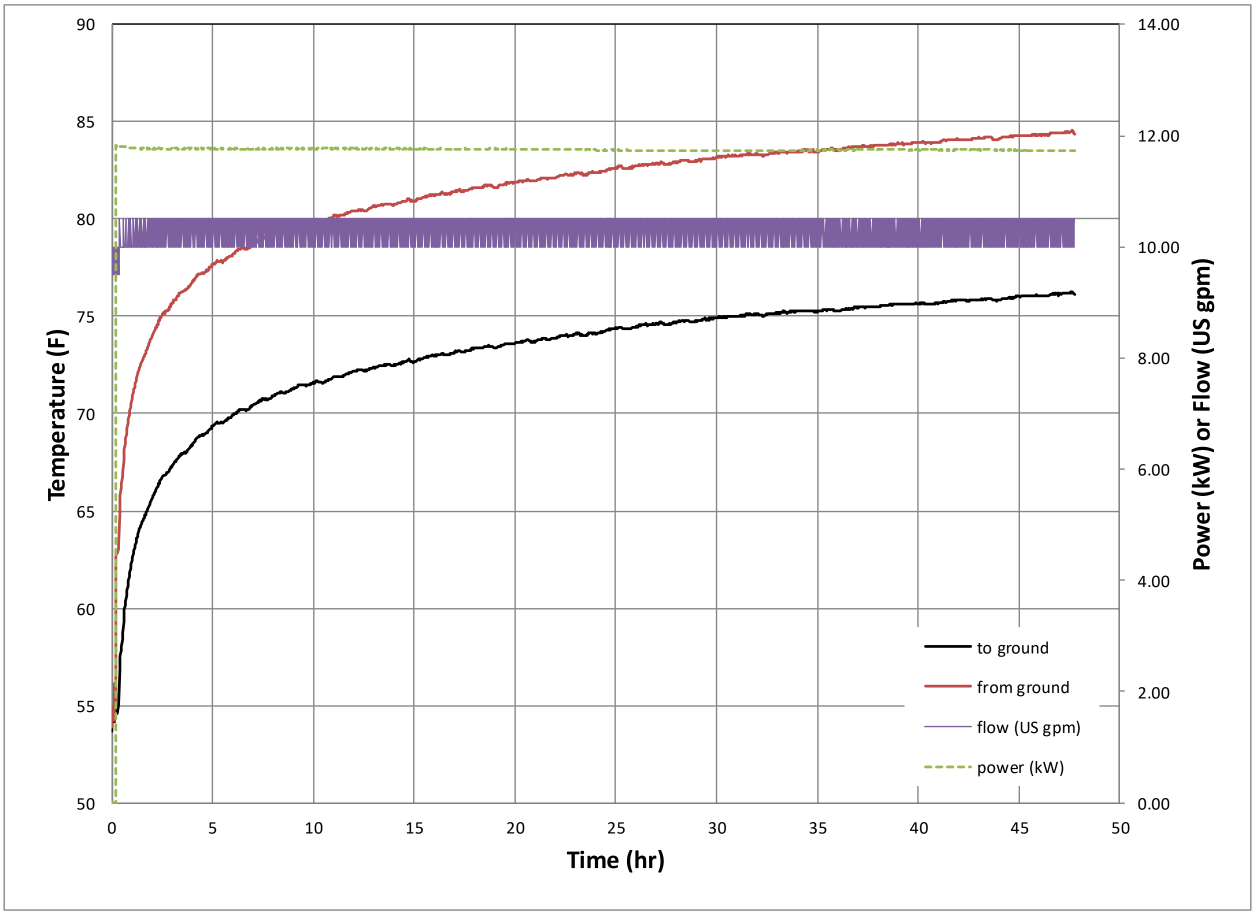


Figure 3 Temperature, power input, and flow rate versus time data from T/C test on borehole.

Figures 4 shows the average temperature of the fluid circulating through the U-tube versus the logarithm of time for the test. The slope of this line is used to calculate the thermal conductivity (k) of the formation. It should be noted that groundwater movement does not appear to be a significant factor in this test since the slope does not vary significantly between the interval of 12.0 and 47.8 hours. If groundwater movement was significant, the slope would continuously decrease with increasing log(time).

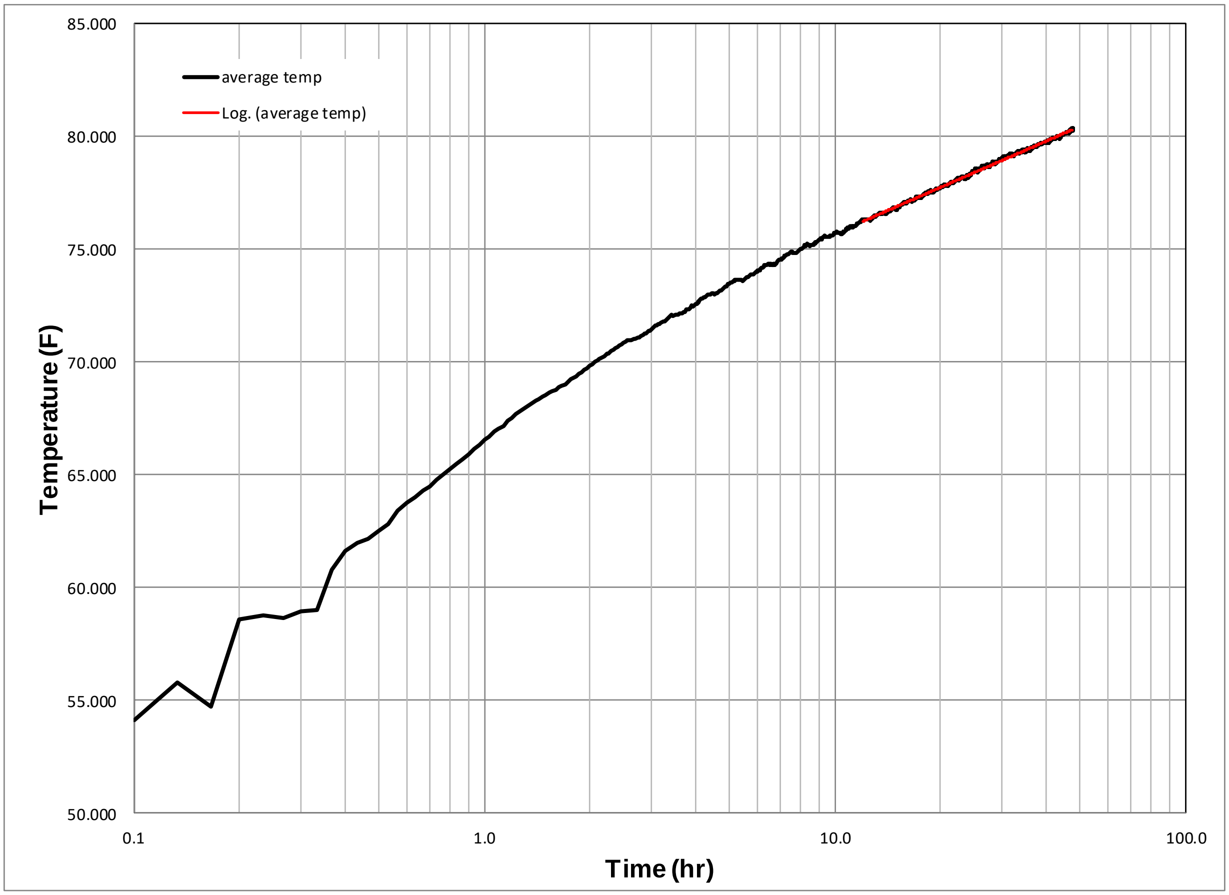


Figure 4 **Average temperature versus logarithm of time**

Thermal Diffusivity

The thermal diffusivity is a measure of the speed at which heat moves away from a borehole. It has units of ft^2/day, or m^2/day.

The thermal diffusivity of a borehole cannot be measured. The thermal diffusivity of materials can be measured. Published values of the diffusivity of various soil and rock materials are available which makes it possible to estimate the average thermal diffusivity of the borehole. An estimate of the average thermal diffusivity of a borehole can be determined by calculating the weighted average of the diffusivity of each geological formation the borehole is drilled through. To estimate thermal diffusivity, the thermal conductivity and heat capacity of each individual stratigraphic layer must be chosen. Values are chosen such that they are typical in the material type and that the weighted average of the chosen thermal conductivities equals the thermal conductivity that was determined from the TC test. Thermal conductivities were chosen for each layer which resulted in a weighted average thermal conductivity of 1.64 Btu/(hr*ft*F).

The average thermal diffusivity was calculated to be 1.17 ft^2/day. The summary of the calculation is shown in the Table below.

Borehole information				Estimated Specific Heat (Btu/lb-F)	Estimated Density (lb/ft^3)	Estimated K (btu/ft.hr.F)	Weighted K	Calculated Diffusivity ft^2/day
Start Depth	End Depth	Thickness	Description					
0	50	50	Gravelly Clay	0.22	119	1.1	55	1.01
50	80	30	Gravelly Sand	0.22	119	1.1	33	1.01
80	105	25	Sand	0.22	119	1.1	27.5	1.01
105	300	195	Limestone	0.21	162	2.0	390	1.41
300	310	10	Red Shale	0.21	169	1.6	16	1.08
310	500	190	Grey Shale	0.21	169	1.6	304	1.08
500	510	10	Red Shale	0.21	169	1.6	16	1.08
510	600	90	Grey Shale	0.21	169	1.6	144	1.08
600	650	50	Red Shale	0.21	169	1.6	80	1.08
						weighted average:	1.64	1.17

Conclusions

The thermal conductivity measured and the thermal diffusivity calculated are within the expected range for the geology encountered at this site. Drilling and loop installation occurred without incident. It is expected that construction of a geothermal field at this site to a depth of 650’ (198.1m) is achievable.

No significant amount of natural gas was evident during drilling, although precautions as specified in Reg. 98/12 remain necessary for future drilling. Water production from the borehole during drilling was insignificant, and there was no trace oil produced during drilling of the borehole.

Closure and Limitations

This report was prepared for the exclusive use of City of Niagara or its designated designers. The report is based on data and information collected by Geosource Energy Inc. and is based solely on the conditions of the property at the time of the work.

Site conditions may vary beyond this sampled location. It is important to note that the thermal conductivity of the geological medium as obtained through the thermal response test integrates three parameters, which are the thermal conductivity of the geological formations; the thermal conductivity of groundwater present within the formations and the effect of groundwater movement. Therefore, the thermal conductivity could vary on the site based on the heterogeneity of these parameters.

The services performed, as described in this report, were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions.

Any use which a third party makes of this report, or any reliance on, or decisions to be made based on the report, are the responsibilities of such third parties. Geosource Energy Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

The results presented in this report are to be used for the design of a vertical closed-loop geoexchange cooling and heating system. The results cannot be used for other applications. Geosource Energy Inc. will not accept any liability associated with the use of the information collected by Geosource Energy Inc. in a design by others.

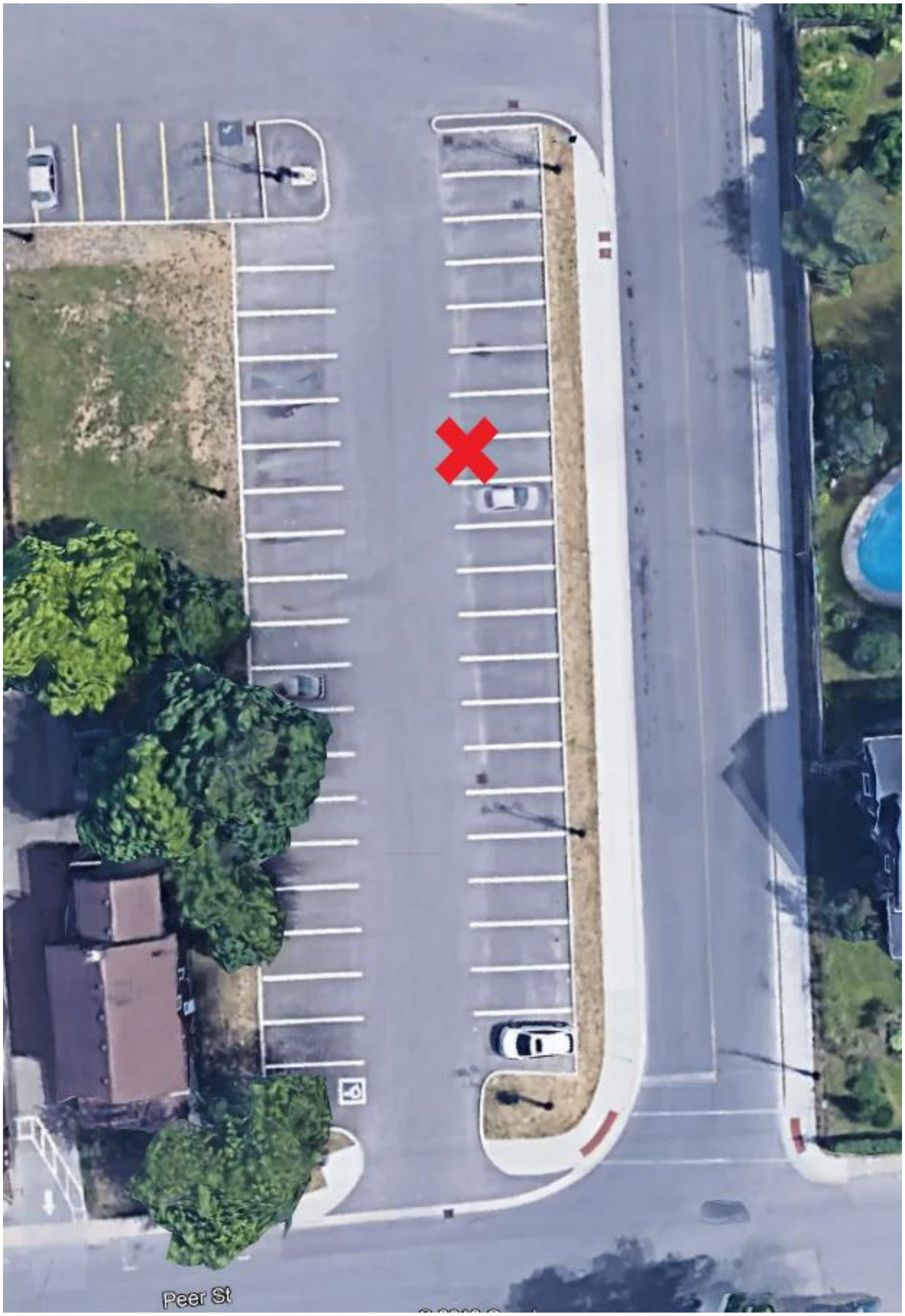
The findings and conclusions of this report are valid only as of the date of this report. If new information is discovered in future work, Geosource Energy Inc. should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

Please do not hesitate to contact the undersigned if you have questions or require clarification on any aspect of this report.

Regards,

Stanley Reitsma, P. Eng.

APPENDIX A – Borehole Location



Approximate Borehole location (Indicated by X): 4772367 m N, 655368 m E

APPENDIX B – Field Notes and Drill Log

Borehole information			
Start Depth	**End Depth**	**Thickness**	**Description**
0	50	50	Gravelly Clay
50	80	30	Gravelly Sand
80	105	25	Sand
105	300	195	Limestone
300	310	10	Red Shale
310	500	190	Grey Shale
500	510	10	Red Shale
510	600	90	Grey Shale
600	650	50	Red Shale

Casing set at 115 ft