Aquifer thermal monitoring of an open loop geoexchange system, UBC Okanagan, Kelowna, British Columbia, Canada

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ABSTRACT
By 2010, all existing and new buildings at the University of British Columbia, Okanagan will use open loop geoexchange technology for heating and cooling. Injection temperatures are expected to range down to 6.1°C (in heating mode) and up to 23.7°C (in cooling mode). A thermal monitoring system has been installed including multi-bead thermistor strings installed in boreholes and wells. The thermal monitoring system has been designed to provide a record of upgradient and downgradient temperatures from ground surface to a depth of 91 m. Data collected will be used to verify finite element heat transport modeling for the site.

RÉSUMÉ
D'ici 2010, tous les bâtiments, anciens et nouveaux, de l'Université de la Colombie Britannique qui sont situés dans la vallée de l'Okanagan seront chauffés et refroidis grâce à la technologie géothermique en boucle ouverte. Il est prévu que la température d'injection du fluide caloporteur se situera environ entre 6.1 °C (en mode « chauffage ») et 23.7 °C (en mode « refroidissement »). Un système de suivi de la température, articulé autour de chapelets de thermistors multi senseurs, a été implanté dans des trous forage et des puits. Ce système de surveillance de la température a été conçu pour enregistrer les gradients thermiques ascendants ou descendants, de la surface du sol jusqu'à une profondeur de 91 mètres. Les données recueillies serviront à vérifier la modélisation par éléments finis du transfert de chaleur pour le site.

1 INTRODUCTION

The use of closed and open loop geoexchange technology for building heating and cooling is rapidly increasing in Canada. The sustainability of both types of geoexchange systems ultimately depends on the earth's ability to both accept and supply heat. Unless designed and operated as a balanced system, there will always be either a net surplus or deficit of heat in the subsurface. The characterization of the thermal signature and the migration of thermal plumes from geoexchange systems is a largely unexplored field. However, with increasing use of the technology, there is a need for such monitoring due to the potential for thermal interaction between neighbouring systems and for thermal influence on downgradient receptors.

Anticipating the value of long term subsurface temperature data, the University of British Columbia Okanagan (UBC O) has installed a thermal monitoring system to observe subsurface temperatures around an open loop geoexchange system now being commissioned at the campus. The thermal monitoring system consists of up- and downgradient multi-bead thermistor strings installed in boreholes and wells around the well field. Data collected from the thermal monitoring system will be used in the future to verify and recalibrate finite element heat transport model we have developed for the site.

2 BACKGROUND ON UBC O OPEN LOOP GEOEXCHANGE SYSTEM

By 2010, all existing and new buildings at the UBC O campus will use open loop geoexchange technology for heating and cooling. Since 2004, ongoing hydrogeologic characterization at the site has involved drilling, monitoring, hydraulic aquifer testing, inorganic and microbial groundwater geochecmical analysis and numerical modelling of groundwater flow and heat transport. The system is currently being commissioned.

2.1 Aquifer Properties

The aquifer material at UBC O consists primarily of a fine-medium sand with some gravel and silt layers. On the UBC O campus, the aquifer is unconfined, and overlain in some places by a silt and clay (till) cap. The aquifer material generally displays a downward fining trend into a silty sand, and the entire sequence is underlain by a dense silt (till) at a depth of about 90 m. At the UBC O campus, the static water level ranges from 14 to 25 meters below ground level (mbgl) depending on the topographical position of the monitoring point. In places, the saturated thickness of the aquifer at UBC O is up to 61 m thick. Aquifer transmissivity interpreted from hydraulic testing is on the order of 10,000 m^2/day.

The full extent of the aquifer is not precisely defined. However, we infer (from domestic and surrounding drill logs) that the aquifer is bounded by bedrock or till to the east and west and by constant head (surface water) boundaries to the north and south.

In the vicinity of the UBC O campus, the direction of groundwater flow in the aquifer is from north to south, with a gradient of approximately 0.001. The seasonal fluctuation in groundwater levels in the aquifer is about 2.0 m. Significant seasonal variation in groundwater flow direction has not been observed.

The ambient temperature of the aquifer from supply well screen intervals (30 to 60 m depth) is about 12℃.

2.2 Well Field Configuration

The initial (Phase I) build out of the geoexchange system includes the new campus buildings which will be brought on line in 2008-2009. The expected diversified peak groundwater flow demand for this initial build out is on the order of 68 L/sec.

The future build out of the geoexchange system will include the retrofitting of existing buildings on campus and may have a peak diversified groundwater flow demand up to 150 L/sec.

The Phase I well field configuration consists of three extraction wells (Well Nos. 4, 5 and 10) and two injection wells (Well Nos. 6 and 7). Phase I extraction and injection wells are located approximately 175 to 325 m apart from each other. The Phase II demands will be met with two new extraction wells (Well Nos. 11 and 12) which are located in the north portion of the campus approximately 500 m from the injection wells.

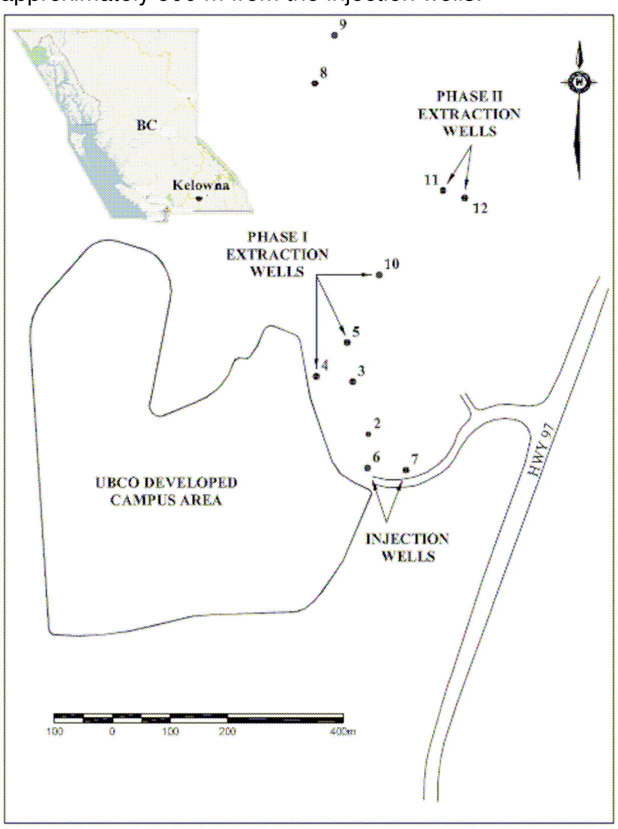

Figure 1. UBC O Open Loop Geoexchange Well Field Configuration

2.3 Energy Demands of the System

The heating and cooling load demand for the geoexchange system will be cooling-dominated. This means that over the course of each year there will be a net surplus of heat rejected to the subsurface. Net monthly heat rejection is predicted to occur in the cooling-dominated months of May to October when warmer than ambient groundwater will be injected into the aquifer. In the heating-dominated months of November to April, cooler than ambient water will be injected to the aquifer. This will result in alternating warm and cold pulses of groundwater injection into the aquifer seasonally. The result of this net heat rejection is that a warm groundwater zone or “thermal plume” is predicted to develop in the aquifer downstream of the injection wells. This plume is expected to expand until it reaches a size where the average annual surplus heat rejected to the ground balances the natural thermal dissipation into the surrounding soil and groundwater.

2.4 Predictive Heat Transport Modelling

Groundwater flow and heat transport was modelled using finite element modelling software (FEFLOW version 5.2). The aquifer area was represented by approximately 188,000 triangular elements and nine model layers. Constant head boundary conditions were applied to the up- and downgradient model extents. Estimated average monthly groundwater extraction and injection rates were applied to the extraction and injection wells. Monthly average re-injection temperatures were applied as a heat flux stressing function to the injection wells.

Model calibration for groundwater flow was performed for both steady state and transient (pumping) conditions. Predictive modeling was performed for up to 5 years of continuous operation at the Phase I demands. As UBC O plans to re-configure the well field as more buildings are brought online, 5 years was determined to be an appropriate duration for Phase I modelling. The leading edge of the thermal plume was defined as a groundwater temperature at 13℃, or 1℃ above the ambient aquifer temperature of 12℃.

Groundwater model results predict that after 5 years of continuous operation, the leading edge of the thermal plume will have migrated about 250 m downgradient from the injection wells.

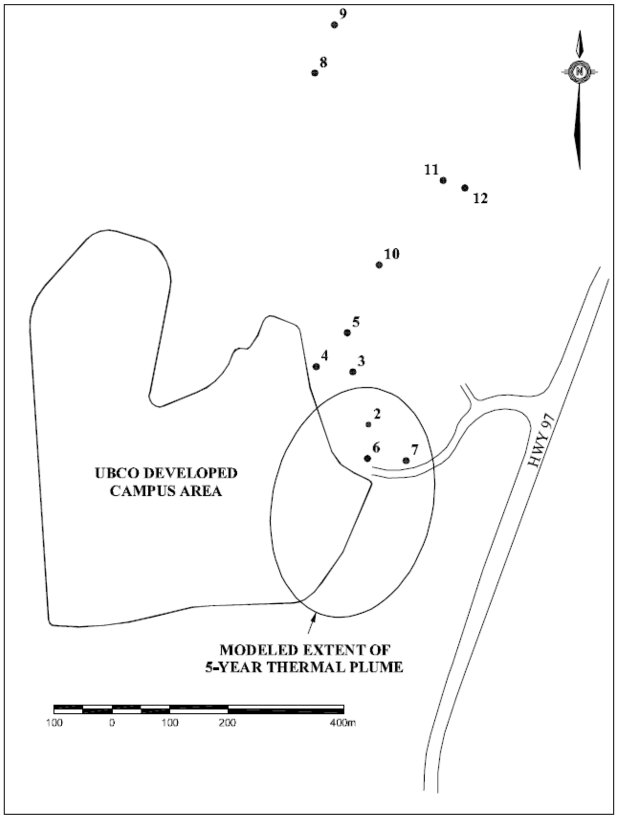

Figure 2. Five Year Thermal Modelling Output (13℃ Thermal Signature)

3 THERMAL MONITORING SYSTEM

To provide subsurface thermal monitoring, three thermal monitoring boreholes or wells were instrumented at the UBC O campus. This included Well No. 9 (upgradient), a thermal monitoring borehole (TMB-1) and an instrumented unused water well (University House Well), both downgradient. The thermal monitoring system installed at Well No. 9 and TMB-1 consisted of two multi-bead thermistor cables. Each thermistor cables consists of 16 thermistor beads attached to a central cable and above ground datalogger (Lakewood R-X Ultra-Logger). EBA designed and manufactured the thermistor cables to provide monitoring coverage above, below and throughout the depth of expected thermal impact.

3.1 Site Selection

The 5-year thermal modeling output was used as the basis for selecting the thermal monitoring locations

Well No. 9, an existing supply/ monitoring well was selected as the upgradient thermal monitoring point. This well is located approximately 375 m upgradient from the Phase I extraction wells and 625 m from the Phase I injection wells. Well No. 9 is constructed of 203 mm steel casing and completed at a depth of 83.5 m. Well No. 9 is constructed with 18.5 m of screen positioned between 65.0 and 83.5 mbgl.

The downgradient monitoring points were chosen to coincide with the predicted extent of the 5-year thermal plume. Upon inspection, EBA determined that at a depth of 25.9 m the University House Well was not deep enough to provide sufficient coverage at the expected depth of heat migration.

For this reason, TMB-1 (89.9 m deep) was installed to span the entire aquifer thickness. The location of TMB-1 was selected to coincide with the predicted leading edge of the 5-year thermal plume.

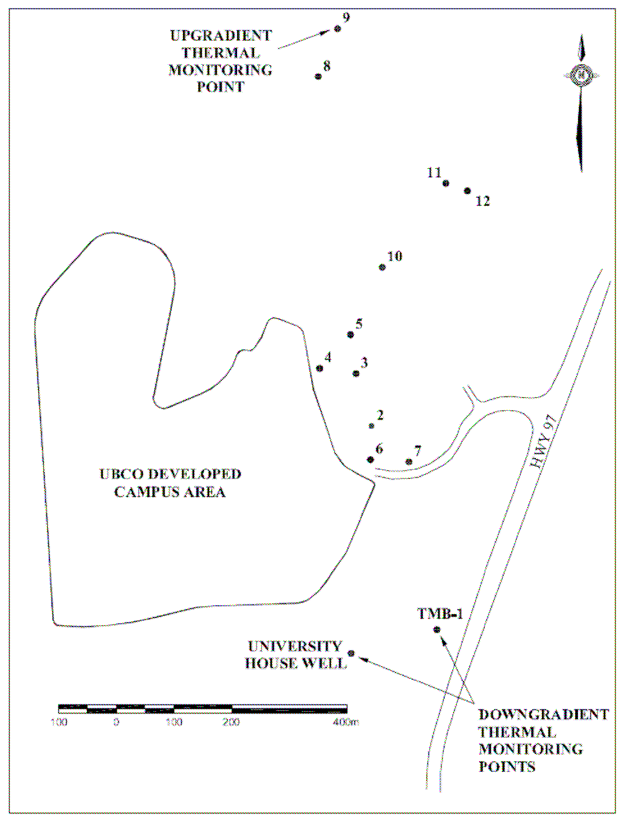

Figure 3. UBC O Thermal Monitoring Points

3.2 Thermistor Cable Design

Changes in the subsurface temperatures are not expected at the upgradient monitoring point, therefore, the upgradient thermistor cable was designed with equal thermistor spacing though the unsaturated zone and higher density spacing from the water table to the bottom of the well.

The thermistor cable at TMB-1 was designed with higher density thermistor spacing through the depth of expected thermal variations (40 to 65 mbgl), and lower density thermistor spacing above and below the expected depth of thermal variations.

Thermal monitoring depths for the upgradient and downgradient monitoring points are summarized in the following table.

Table 1. Thermistor Depths in Well No. 9 and TMB 1

Well No. 9 Thermistor Depth (mbgl)	TMB-1 Thermistor Depth (mbgl)
1.5	2.1
4.5	9.1
6.7	21.3
9.1	27.4
15.2	33.5
21.3	34.4
27.4	39.0
33.5	43.6
39.6	48.2
45.7	52.7
51.8	57.3
57.9	61.9
64.0	65.2
70.1	73.2
76.2	82.3
82.2	89.9

3.3 Upgradient (Well No. 9) Thermistor Cable Installation

Well No. 9 is a 203 mm diameter, 83.5 m deep water well. The static water level in Well No. 9 ranges from about 43 – 45 mbgl.

EBA installed the thermistor cable in Well No. 9 using two different installation methods. The purpose of the two installations was to determine whether potential convection within the saturated portion of the steel casing could significantly impact the temperature readings.

3.3.1 Suspension Installation in Well No. 9

EBA initially installed the thermistor cable in Well No. 9 as a simple suspension in the open water well casing. The thermistor cable was hung from a support bar positioned at the top of the water well casing. In this installation, there was nothing physically separating the measuring intervals between the thermistors.

3.3.2 Thermal Baffle Installation in Well No. 9

After five weeks of monitoring, EBA installed the thermistor cable in Well No. 9 a second time using a convection baffle system to isolate each thermistor bead. The convection baffle system involved attaching the thermistor cable to a central PVC stabilizer. Rubber gaskets (acting as convection baffles) were also attached to the central PVC to isolate a 2 m interval centred on each thermistor bead. The baffles consisted of 204 mm circular discs made of 3 mm neoprene gasket material, attached to the central PVC tube with the intent of preventing temperature-driven convection circulation in the well.

3.4 Downgradient (TMB-1) Thermistor Cable Installation

The downgradient thermal monitoring borehole (TMB-1) was installed by JR Drilling of Kamloops, BC using a Foremost DR-12 dual rotary drilling rig. The drilling and installation method for TMB-1 included advancing a 152 mm steel casing to a depth of 94.4 m. Once at depth, the thermistor cable was affixed to 38 mm diameter PVC. Holes were cut into the bottom 6.1 m of the PVC to allow for tremie grouting (from the bottom up) of the borehole. After positioning the PVC and thermistor cable assembly in the borehole, the borehole was grouted using 20% solids bentonite grout. The 152 mm steel casing was retracted at the same time as grouting to provide a continuous grout contact between the thermistor cable and the ground.

3.5 Downgradient Thermal Datalogger Installation

EBA installed a HOBO ® U-12 stainless steel thermal datalogger in the bottom of the University House well.

4 THERMAL PROFILE RESULTS AND DISCUSSION

The depth of seasonal influence is the depth at which outside air temperature influences the subsurface temperatures. This depth is dependant on many different factors such as climate, location, elevation, aspect, snow cover and soil conditions.

Once below the depth of seasonal influence, ground temperatures will generally increase at the typical geothermal gradient of 2.5°C/ 100 m (Fetter 1994). Higher gradients may be observed due to the presence of recent plutonic activity, hydrothermal fluid migration, geothermal or seismically active zones.

4.1 Upgradient (Well No. 9) Thermal Profile

The thermal profile observed at Well No. 9 is shown in Figure 4.

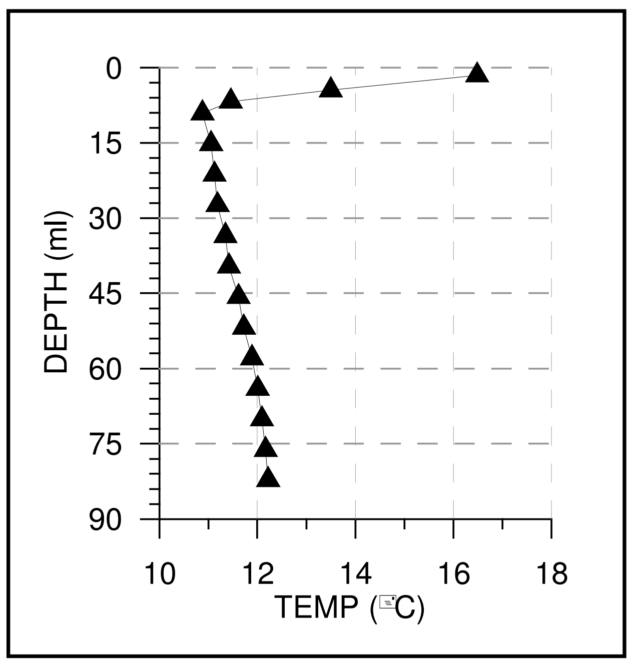

Figure 4. October 4, 2008 Thermal Profile at Well No. 9 (Installation with Convection Baffles)

To examine potential differences between the pre- and post-thermal baffle installation in Well No. 9, average thermal profiles were created for both thermistor installations. The data was average over a one-month period from June – July, 2007 (without baffles) and from July – August, 2007 (with baffles). The average thermal profiles for these two months are shown in Figure 5.

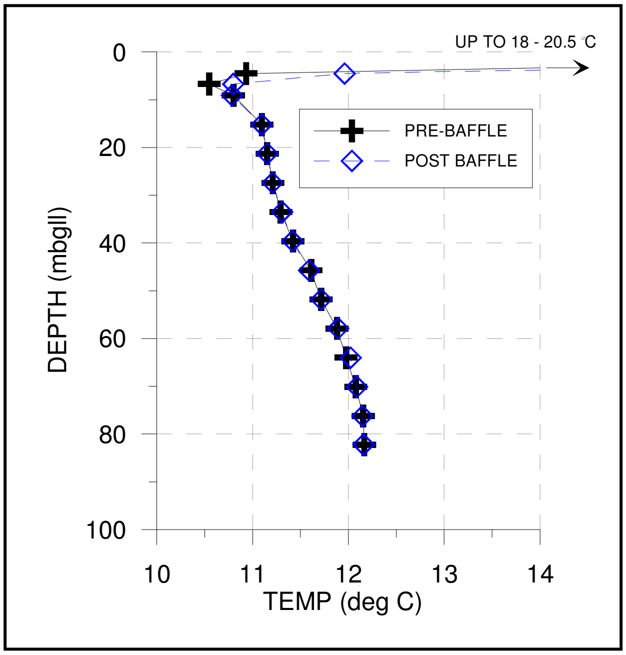

Figure 5. Comparison Between and Pre- and Post-Baffle Thermal Profiles in Well No. 9

At Well No. 9, the depth of seasonal influence is about 10 m; below this depth, the geothermal gradient is about 1.8℃/ 100 m. The same thermal profile was observed for the post-baffle installation in Well No. 9.

The upper three thermistor beads, which are located within the depth of seasonal influence, show a slight difference between average temperatures recorded with and without the baffles. We attribute this temperature difference to the difference in air temperature between the months of July and August.

Below the depth of seasonal influence, there is no meaningful difference between ground temperatures recorded with and without the thermal baffles.

4.2 Downgradient (TMB-1) Thermal Profile

The thermal profile at TMB-1 is shown in Figure 6.

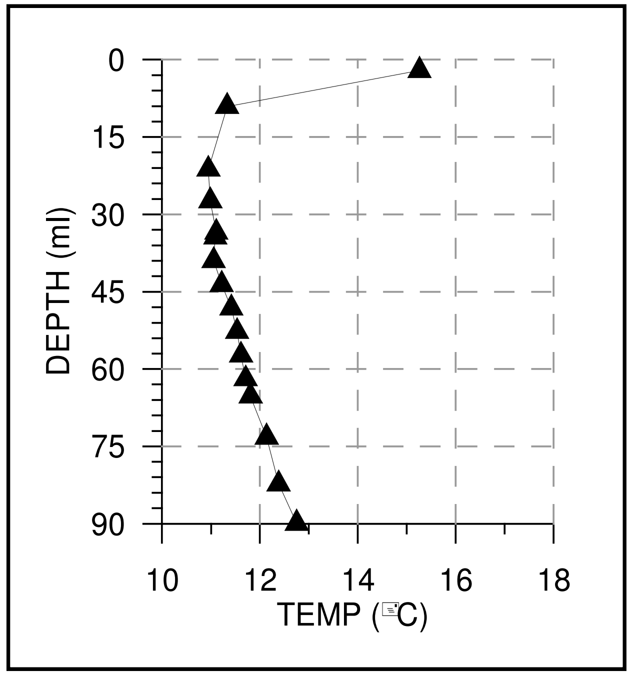

Figure 6. October 4, 2007 Thermal Profile at TMB-1

At TMB-1, the depth of seasonal variation is around 10 m, below this depth the geothermal gradient is about 2.5℃/ 100 m, which is slightly higher than the geothermal gradient recorded at Well No. 9. It is not clear why these ambient geothermal gradient values are different.

5 THERMOGRAPH RESULTS

Plots of ground temperature with time (thermographs) are presented below for the last half of 2007. Different temperature traces are shown for the various thermistor depths (meters below ground level, or mbgl).

5.1 Upgradient (Well No. 9) Thermograph

The thermograph for Well No. 9 is shown in Figure 7.

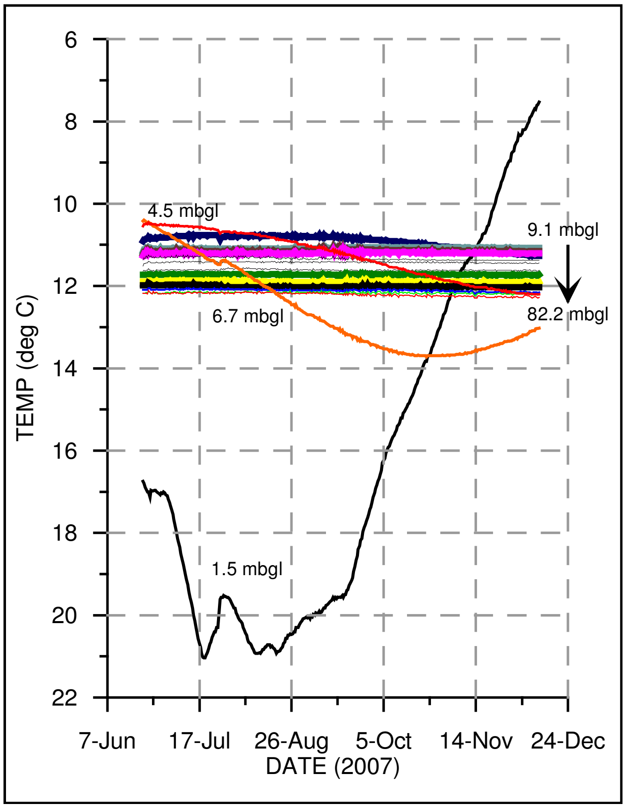

Figure 7. Well No. 9 Thermograph

Thermistor beads between the surface and 9.1 m depth are located within the depth of seasonal influence, with ground temperatures ranging from 8°C in December up to 22°C in August. Deeper thermistor beads display a consistent ground temperature for the period of record.

5.2 Downgradient (TMB-1) Thermograph

The thermograph for TMB-1 is shown in Figure 8.

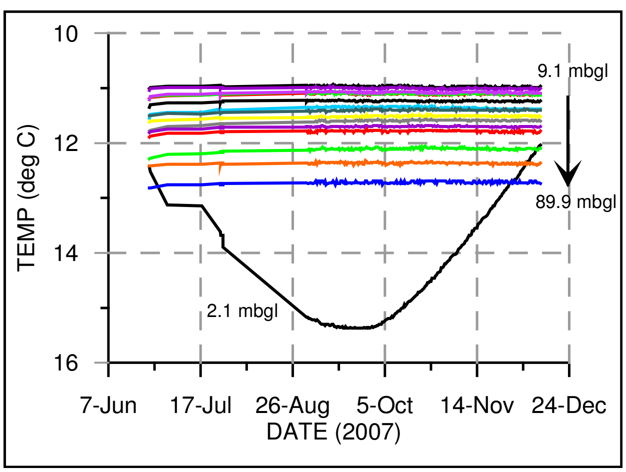

Figure 8. TMB-1 Thermograph

The upper most thermistor bead (2.1 m depth) shows the seasonal trends in ground temperatures ranging from 12°C in December up to 15°C in August. All other thermistor beads display a consistent ground temperature for the period of record.

5.3 Downgradient (University House Well) Thermograph

The thermograph for the University House well is shown in Figure 9.

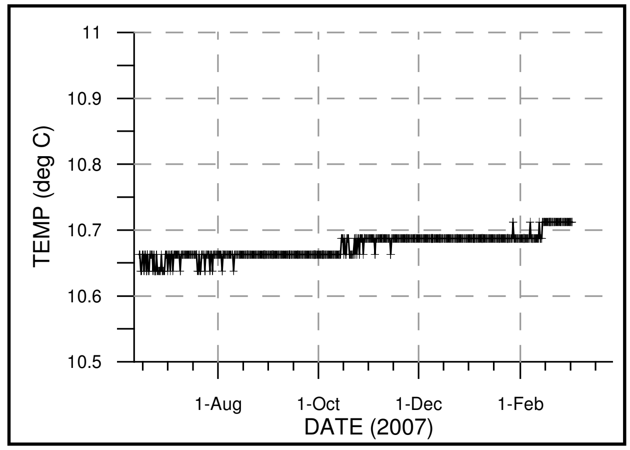

Figure 9. University House Thermograph

The thermograph for the University House well shows a temperature of about 10.65°C at a depth of 25.9 m with a slight increase (0.05°C) in temperature from June 2007 to March 2008. The temperature increase is within the precision of the instrument (0.025°C), we are unsure if this rise is real or related to the datalogger installation. This temperature is consistent with the temperature at the same depth recorded at nearby TMB-1.

6 SUMMARY AND CONCLUSIONS

Unless designed and operated as a perfectly balanced system, the operation of ground heat exchangers will always results in either a net rejection or extraction of heat to or from the subsurface. This will result in an associated subsurface thermal signature and plume from the geoexchange system. Such plumes are expected to expand until the heat added (or removed) balances the natural dissipation or transfer with surrounding earth materials.

At UBC O, a thermal monitoring system has been installed to provide a long term temperature record of subsurface ground temperatures. This thermal monitoring system includes an upgradient thermistor cable installed in an unused water supply well, a similar thermistor cable installed in a downgradient thermal monitoring borehole and a downgradient thermal datalogger in an unused domestic water well.

Thermal data collected so far from the UBC O thermal monitoring system shows that:

1) The depth of seasonal influence at UBC O is about 10 m.
2) Once below the depth of seasonal influence, the thermal gradient at UBC O is 1.8 to 2.5°C/ 100m depth.

3) Below 10 m, subsurface temperatures for the period of record are constant at a given depth.

To evaluate potential effects of thermal convection at the upgradient monitoring point, the thermistor cable in Well No. 9 was installed twice; with and without thermal baffles.

Comparison of the two different thermistor installations suggests one of three things:

1) Convection effects within the steel well casing were negligible.
2) The thermal baffles were ineffective.
3) There was not a strong enough temperature gradient to cause convection in the well casing.

Long term subsurface thermal data collected at UBC O will be useful for calibrating the finite element heat transport model for the site when thermal anomalies are detected in the subsurface after the system is operational.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the contribution of Oleg Ivanov, P.Geo and Skye Thompson, B.Sc. in carrying out field work and numerical modeling used in this paper.

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