CASE STUDY

Feasibility of Open Loop and Aquifer Thermal Energy Storage at the new TRCA head office

INTRODUCTION

TRCA's new head office is currently being constructed at 5 Shoreham drive and has incorporated an integrated design process with a strong focus on sustainability and reducing the environmental impacts of building operations. The new office building, has a gross floor area of 8,176 m^2,and has incorporated various passive design features to help reduce the building energy usage and to reduce the reliance on mechanical heating, cooling, and ventilation where possible. As part of the TRCA's goals and vision, the project is targeting as a minimum Leadership in Energy and Environmental Design (LEED®) rating of Platinum under the Canadian Green Building Council (CaGBC) New Construction category. Other aspirations include Low Carbon/ Reduced Green House Gas Emissions (CaGBC Zero Carbon Building Design) and Toronto Green Standard (TGS) Version 3 Tier 2. The intent is to create a building that can be used as a demonstration and engagement tool to illustrate and educate target groups on what new buildings can achieve.

In the design stage a closed loop geo-exchange system (CLGX) was incorporated into the HVAC design as it is one of the most energy efficient systems available today. In addition, geo-exchange systems provide a fully electric low-carbon system for the building, which supports the goal of achieving a zero-carbon building design.

During test drilling to design the CLGX, it was discovered that the new TRCA site sits on top of a deep bed rock valley called the Laurentian channel along with several other shallower aquifers. It was found that a deep aquifer is confined beneath thick glacial till deposits (at 122m). The presence of these aquifers indicated the potential for an open loop geothermal system (OLGX) or an Aquifer Thermal Energy Storage system (ATES). OLGX and ATES systems can be more energy efficient and can be less costly than the more common CLGX systems. This case study is necessary to determine which technology is economically and environmentally viable on the site and thus allow us to move forward with implementation.

The purpose of this case study is to evaluate the environmental, social, and economic costs and benefits of either an OLGX or ATES system relative to the planned business as usual (BAU) CLGX. The case study evaluates the options, makes a system recommendation, and identifies critical design parameters for the selected system. The context for this case study is unique as

In an Open Loop Geothermal System, groundwater is circulated through an indoor heat pump which delivers the heating and cooling to the building. Higher efficiencies can be achieved compared to conventional closed loop geothermal systems due to more favorable temperatures seen by the heat pump.

Aquifer Thermal energy Storage Systems are similar to Open Loop Geothermal System, with the added efficiency of thermal energy storage in the wells. The wells serve as thermal storage for heating and cooling and flow of groundwater is reversed in the system.

the study was undertaken after the building HVAC system had already been designed and the start of implementation was imminent. Despite this, TRCA decided to evaluate the additional options as there was enough evidence that the economic and environmental gains would add to what was planned to be an extraordinarily high efficiency, low carbon building.Two of our key partner municipalities have been very actively developing and implementing climate change mitigation plans, the City of Toronto, and the Regional Municipality of Peel. TRCA has been actively working with these municipalities during the development and implementation of their climate plans. TRCA is part of the Peel Climate Change Partnership lead by the Region of Peel. TRCA has developed strategic analysis of retrofit opportunities within 104 Region of Peel buildings to prioritize retrofits for GHG emissions reductions. TRCA continues to work with Peel to scope out low carbon retrofit scenarios for Peel buildings. The results of this feasibility study will be incorporated into our work with these municipalities to help them achieve their

SYSTEM DESCRIPTIONS

1. **Closed Loop Geothermal System (CLGX)**

A geo-exchange system utilizes the earth to exchange energy with the surface, typically a building heating and cooling system. A closed loop geo-exchange (CLGX) system uses a closed loop of pipe carrying a heat transfer fluid, typically an anti-freeze solution, to provide heating and cooling to a building. CLGX systems rely on heat transfer through conduction between the earth soil/rock in a pipe carrying the heat exchange fluid . The amount of the fluid in the closed system is constant and the fluid is pumped mechanically to recirculate between the ground loops and the heat exchanger in the building.

In a CLGX, heat is exchanged with the earth by a continuous loop of underground piping. A series of boreholes that act as heat exchangers are drilled either vertically or horizontally trenched based on the space constraints of the area around building. Vertical boreholes can reach depths of over 600 ft

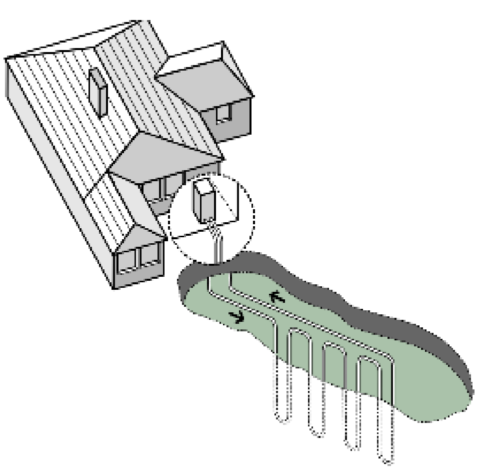

Figure 1. Closed Loop Geo-Exchange System(CLGS), Source: NRCan Heating and Cooling With a Heat Pump

below ground. Each of the boreholes has a U-shaped pipe placed in the hole. Typically backfill and grout are used to fill the space between the borehole walls and the U-shaped pipes (Figure 1). The thermal resistance of the pipe, grout and ground dictate the rate of energy exchange. Measuring the thermal resistance or conductivity of the ground during the feasibility stages is essential for proper sizing and system performance. The number of boreholes (and depth) or length of trench required will depend on the heating and cooling needs of the building and the thermal conductivity of the material surrounding the boreholes or trenches.

During the winter period, heat is extracted from the ground through the heat transfer fluid. Gradually, the temperature of the ground will decrease as more heat is extracted. During the cooling season, the system begins dumping heat rejected from the building from cooling applications back into the ground loops.

CLGX systems have been widely adopted in Canada. The operations of these systems in the long term present a significant opportunity to achieve low carbon building operations. But this is not without challenges as an energy balance in the ground needs to be maintained, otherwise the system performance can be compromised. The heating energy extracted for the heating season should equal the heat rejected during the cooling season. If this balance is not met, there will be a net heat loss and the ground temperature over time will lower, and the performance of the system will become less efficient.

In heating dominated climates, supplemental heating sources are typically required to help recharge the ground loop temperature. In Canadian climates, the heating load is the dominant load in the building compared to the cooling load as more heat is typically extracted then is put back into the ground. Therefore, careful monitoring of the ground temperatures over time is essential to ensure optimal performance of the system.

2. **Open Loop Geo-Exchange System (OLGX)**

An open loop system (OLGX) uses a series of water wells to extract and inject water to help cool and heat a building . A production well uses a submersible pump to take groundwater from an aquifer, a water-filled body below ground comprised of sand, gravel, sandstone, or limestone layers with high hydraulic conductivity, and uses it to heat and cool the building. The water is passed through a heat exchanger and immediately returned to the aquifer through the injection well. A heat exchanger and a heat pump are used to exchange the energy with the building systems and to upgrade the energy to meet the heating and cooling needs. The supply well and injection well should be a suitable distance apart to prevent any unintended heat transfer between the injection ground water with the extraction water. Interaction between the wells can warm or cool the supply water and reduce the efficiency of the system.

Because of the simplicity of the system, less boreholes and less total piping, the capital costs for an OLGX are considerably lower than those seen in CLGX systems. However, individual water wells are more expensive to drill than an individual borehole and require screens and sand packing and depending on water quality, stainless steel casing. In addition, the water temperature in OLGX tend to be more stable and thus the heat pump tends to run more efficiently, reducing GHG emissions and operating costs.

OLGX systems (Figure 2) are highly dependent on the characteristics of the aquifer and these characteristics can vary significantly on an individual site. Depending on the heating and cooling requirements of the building not all sites will have an aquifer available with sufficient water supply. Thus, feasibility studies for OLGX can become sunk costs if insufficient supply is located.

In OLGX systems, water quality is a significant factor in the design stage of the system. Because ground water is being extracted, and heat is being injected and extracted using a heat exchanger, the precipitation of carbonates, iron, and manganese through oxidation can lead to clogging of components in an OLGX. Precipitates can clog the well screen where the water is being injected, or at the heat exchanger where the ground water heat is being extracted. Clogging of the heat exchanger and other components of the system can lead to poor system performance over time as heat transfer is reduced and the capacity to heat and cool could be compromised. Design requirements where poor water quality is an issue could include, stainless steel piping, fused HDPE pipe between the well and the heat exchanger to eliminate oxygen, and water filters to remove sediment.

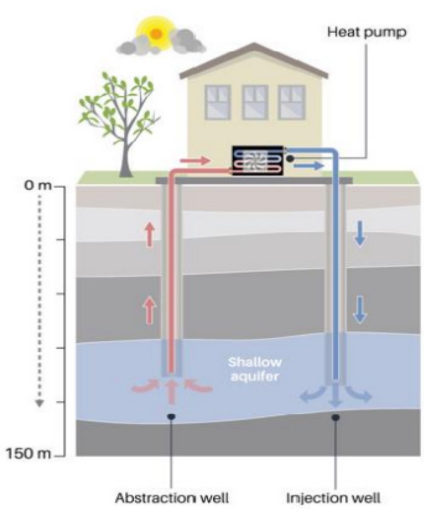

Figure 2. Open Loop Geo-exchange System (OLGX),Source: UK Parliament Post Geothermal Heating and Cooling With a Heat Pump

3. Aquifer Thermal Energy Storage Systems (ATES)

Like an OLGX system, Aquifer Thermal Energy Storage Systems (ATES) utilize aquifers to provide heating and cooling for the building. The main difference between the OLGX and an ATES system is that the Aquifers need to be suitable for thermal energy storage, where the wells can sustainably retain heat or cooling energy (Figure 3). The groundwater flow should be low enough to prohibit any significant heat transfer from the thermal storage to the surroundings. Heat loss through advection, the transfer of heat through the horizontal movement of fluid can be significant and impact the storage of energy and thus feasibility of this technology. The groundwater flow is dependent on the hydrogeology of the site and can vary significantly by location.

In an ATES system, like an OLGX system, a minimum of two wells are drilled into the aquifer, one well that extracts groundwater (known as the production well) and the other to inject the water back (known as the injection well). During the cooling season in a building, groundwater is extracted from the aquifer from one of the wells and used for cooling applications, the warmer return water is then reinjected into the second well. The second well serves as a storage for heat and is recharged through cooling processes in the building. During the heating season, the direction of flow is reversed, water from the warm well is extracted, and used for heating in the building, the cool return water is then injected back into the cold well. The ground water extracted from the aquifer typically goes through a heat exchanger that is connected to a heat pump which heats and cools the building. The use of the heat pump allows for moderate to low aquifer water temperatures to satisfy the heating and cooling load of the building. Because of the ability to store warm and cool water, very high levels of efficiency for heating and cooling can be achieved. ATES systems require very specific geological and hydro-geological ground conditions that can only be determined through test drilling during the early project stages. The hydraulic conductivity, a measure of how easily water can pass through soil or rock, is an important characteristic to evaluate when conducting the hydro-geological tests for ATES systems. The hydraulic conductivity can be estimated by measuring the grain size from sediment samples taken from the drilling process. The aquifer thickness must also be sufficient to allow enough area for the well to extract water from and for a well screen to be installed.

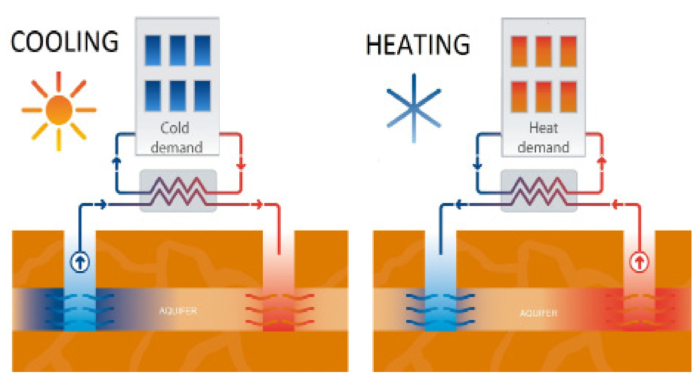

Figure 3. Aquifer Thermal Energy Storage Systems (ATES),

One major distinction between an ATES system and an OLGX system is that ATES systems have wells that serve as both the production and injection wells. Injection wells typically require longer well screens compared to the supply wells. The thickness of the aquifer is one of the parameters that dictates how many wells would be needed for a specific location. Less aquifer thickness on a site could mean more supply and injection wells are required, potentially increasing the total system costs. Since both wells operate as production and injection wells, well screens are larger than for just production wells. In addition, both wells require a submersible pump to operate through the heating and cooling season and typically water well diameter is larger for ATES wells, which also drives up capital costs. In an ATES system, the groundwater flowrate must be low enough to ensure that advective heat transfer, transfer due to the motion of the ground water fluid, is minimized. This ensures that the storage and retention of heat is possible. Like an OLGX system, the water quality in the aquifer is also important to evaluate for iron, manganese, and carbonate content, as precipitation can take place when air is introduced into the system. Oxidation of iron and manganese should be avoided by preventing air from entering the system. The oxidation of these elements can create scaling at the well screens where water is extracted from the aquifer and at the heat exchanger .

The main advantage of an ATES system is that less drilling is required than CLGX systems. In addition to this, ATES systems are typically more efficient than the traditional OLGX system because the heat pumps can operate at a higher point of efficiency or Coefficient of Performance (COP). This is because the stored heat can be utilized to bring a higher groundwater temperature to the heat pump, which raises the efficiency of the heat pump. In cooling mode, cooler groundwater temperatures can be seen at the heat pump when extracted from the cold well, once again raising the efficiency point that the heat pump will run at.

DRILLING PROGRAM AND WELL DEVELOPMENT

The TRCA site is located within the Black Creek watershed. The western boundary of the site is roughly aligned with the top of the creek valley. The valley at this location is approximately 10.5 m (35 ft) deep. The surface topography on the TRCA property slopes southward, from an elevation of 189 to 184 meters above sea level. Surface drainage from the site is directed to Black Creek via overland flow and a constructed runoff channel in the northwest corner of the parking lot. The quaternary geology in the study area was developed during several different episodes of glaciation. The Wisconsin glacier advanced and retreated several times between 10,000 and 30,000 years ago. Each advance deposited a layer of glacial till, and each recession deposited layers of sand and gravel in meltwater rivers and lakes.

Figure 4 Drill Rig for the monitoring well

A drilling program was designed to determine the feasibility of using an Aquifer Thermal Energy Storage (ATES) or an Open-Loop geothermal system to heat and cool the new corporate head office building located at 5 Shoreham Drive. The drilling program included two wells with a contingency for a third well if there were water supply issues with any of the first two wells (Figure 4). In addition to developing the scope of work for the drilling program the hydrogeology consultant prepared a characterization of the aquifers and estimated potential pumping rates from the aquifer and flow requirements for the building heating and cooling systems. The Hydrogeology report includes details on the injection well which is beyond the scope of this feasibility study report. The implementation results and the costs of design and implementation have not been included in this Feasibility Study. A closed loop geothermal test borehole drilled on site determined that there are up to three sand and gravel aquifers in the overburden. This information contradicted a bore hole record nearby that found bedrock at 20 meters depth. In addition, historic depth to bed rock modelling had indicated a shallow overburden. Because of this discrepancy the team decided that the first well would be a continuous core to get an accurate picture of the overburden and associated aquifers.

Figure 5 Core Sediment Samples obtained through drilling at varing depths

A contractor was procured to construct a 4 "continuously cored borehole (Figure 5) and to install a monitoring well (MW 1-20). This well would be used to confirm the lithology and monitor groundwater long term on the site. PQ coring methods were used to drill the hole. The drilling found bedrock was at approx. 125m and intersected three sand deposits in the ORAC, Thorncliffe, and Scarborough Aquifers. A 63 mm (2.5") diameter monitoring well was installed in the sampling borehole and screened in the aquifer at 363 to 393 feet, a depth consisting primarily of coarse sand and gravel. Sediment samples were obtained from the core drilling to measure the grain size. A slotted PVC screen and sand pack were installed in the aquifer as determined by the driller and the hydrogeology consultant. The location of the borehole was in the southeast corner of the property (Figure 6).

Based on the initial findings from MW1-20, TRCA proceeded to drill a second well as a potential supply well for the ATES or OLGX system (MW2-20). The Driller collected sediment

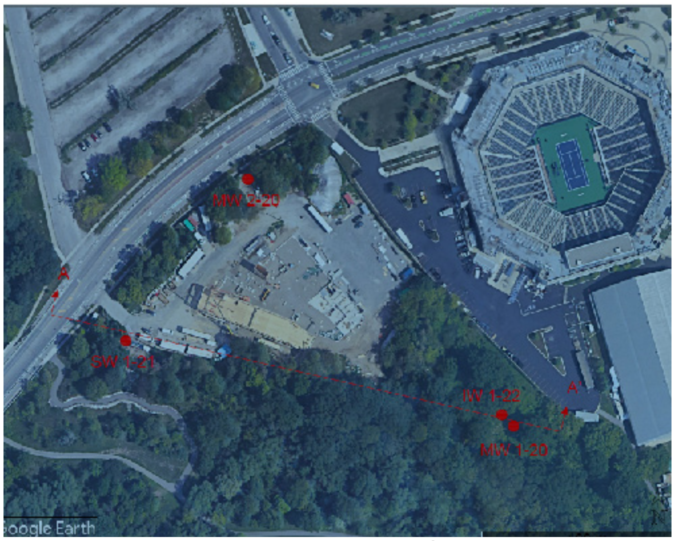

Figure 6.Well Locations TRCA new head office

samples from the deep aquifer at 0.75 m intervals. The contractor than conducted sieved analysis of sand samples and designed the well screens.

Well screens were installed on MW2-20 at similar depth as MW1-20 (Table 1). The well screen is "Johnson" type continuous slot stainless steel. These screens are designed for non-clogging, V-shaped slot openings, with the maximum possible open area. The unique well screen design minimizes the groundwater entrance and exit velocities to and from the wells and retards the deposition of encrusting minerals on the screen. The slot sizes in the screen were designed to retain about 50% of the sand sediments in the aquifer. This screen design criteria are appropriate for the deep aquifer, where there is alternating fine and course strata in the glacial outwash deposits.

The driller and the hydrogeology consultant recognized immediately that the sediments in MW2-20 at the depth of the deep aquifer in MW1-20 included much more fine sand than expected. Pump tests, discussed later, indicated a maximum pumping rate of 50gpm which is significantly lower than the 150-gpm required for the new building's building heating and cooling systems. Based on the very good results from the MW 1-20 well staff took the hydrogeology consultants advice to drill the contingency well at SW1-21. It was found that SW1-21 was able to provide the required flowrate and was suitable to become a supply well. To manage costs, the third well was done in two parts. For the first part, a 6" pilot hole was drilled directly to the target aquifer depth and then sediment samples were taken. If the sediment samples were fine indicating a poor production well, the pilot hole would have been grouted and abandoned and the feasibility study terminated. This would have kept the third holes costs to about 1 third of the full well cost. Fortunately, the sediment samples indicated a good thickness of coarse material, and the driller was given the go ahead to take step two and ream the pilot hole to 8" diameter and complete the test well as a supply water well. A fourth well was drilled to locate an injection well for the system (IW1-22).

Table 1. Summary of Geological Deposits at varying depths

Geological Deposit (in meters)	MW1-20	MW2-20	SW1-21	IW1-22
Halton till (sandy clay)	0 – 18.6	0-32.0	0 - 37.8	0-18.9
Oak Ridges Aquifer Complex (fine sand)	18.6 – 38.4	32.0 – 39.6	37.8 – 41.7	18.9-39.0
Newmarket till (silty clay)	38.4 – 52.8	39.6 – 61.6	41.7 – 58.8	39.0 – 52.7
Sunnybrook till (silty clay)	52.8 – 112.7	61.6 – 111.9	58.8 – 100.2	52.7 – 106.7
Bedrock Valley Aquifer (medium to coarse sand)	112.7 – 125.0	111.9 – 119.2	100.2 – 125.8	106.7 – 123.4
Shale Bedrock	125.0	119.2	125.8	123.4

An important step to the well development was the removal of finer sediments from the aquifer. The well development process increases the porosity and hydraulic conductivity of the aquifer deposits in the immediate vicinity of the well. A sand free condition is essential to prevent damage to the heat exchanger in the building and long-term plugging of the well screen in the injection well.

Well initiatives conducted a variety of well development procedures, including air surging, over pumping, high velocity jetting, backwashing, etc. The well development took place over several days, by slowly raising and lowering the development equipment throughout the full length of the screens. This additional investment in well development was to ensure that the test well could be used as a supply well for the implementation project. By using the feasibility study wells as part of the implementation system, the capital cost of the overall system was lowered.

PUMPING TEST

The step drawdown pumping test is a field experiment where a well is pumped at a controlled rate and the drawdown is measured in the pumped well and one or more surrounding monitoring wells. The drawdown of a well is the difference between the static groundwater level, the level attained by water at equilibrium in a well, when no water is being taken from the well, and the pumping level, the water level in a well when water is being taken.

The purpose of the pumping test is to determine the aquifer hydraulic properties, zones of influence and the well yield along with the impacts that drawing water from that well has on neighboring monitoring wells (Figure 7). The pumping test can help determine suitable production wells for an open loop and ATES system.

Preliminary design estimates indicate that the proposed geothermal system will require a peak flow of 9.5 L/s (150 gpm) to meet the heating and cooling loads in the TRCA new head office. The drawdown can be expected to increase as the pumping rate increases. The rate of local drawdown decreases over time and eventually stabilizes as the withdrawal is compensated for by inflow of groundwater from the surrounding area.

When the groundwater level stabilizes and has adjusted to the pumping, the resulting pattern of water table depression is sometimes referred to as steady-state drawdown.

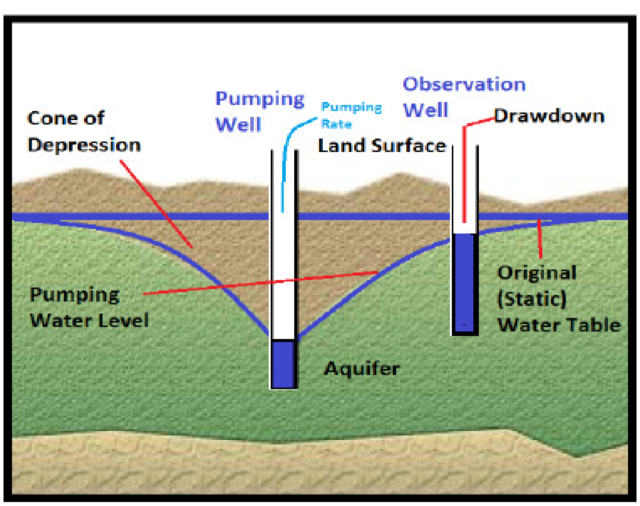

Figure 7. Impact of a pumping well on the water table and neighbouring well (Figure from B.C. Guide to Conducting Pumping Tests)

Figure 8 shows the Step Drawdown test results for test well MW 2-20 for the two flow rates 50 gpm (blue plot) and 100 gpm (orange plot). The results indicate that at 50 gpm flowrate, the drawdown for the well stabilizes at 30 meters. When the flowrate is increased to 100 gpm, the drawdown steadily increases over time and does not stabilize.

Ideally, the drawdown of the well stabilizes as water is pumped out of the well at a specified flowrate after a period of time. Based on the results ofthe pump test for MW 2-20, TRCA found that the well could not provide the desired flowrate for the new head office and did not proceed to the third step of the test. A second well (SW 1-21) was drilled and the pump test was repeated for this well (Figure 9). In the first step of the pumping test, the flow was set at 75 gpm, the drawdown in SW 1-21 was approximately 1.2 meter. The flow was increased in the next step up to 150 gpm, the drawdown in SW 1-21 increased to 2.5 meters. In the third step of the pumping test, the flow was increased up to 225 gpm. The drawdown from pumping at this flow rate was 3.7 meters.

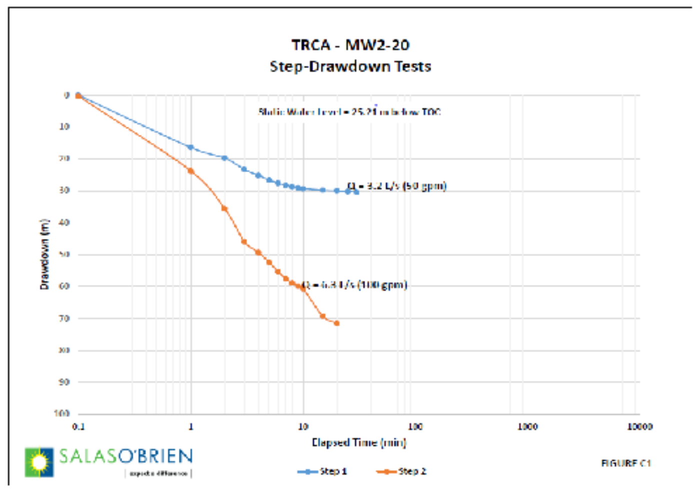

Figure 8. Pump Test Drawdown from MW 2-20

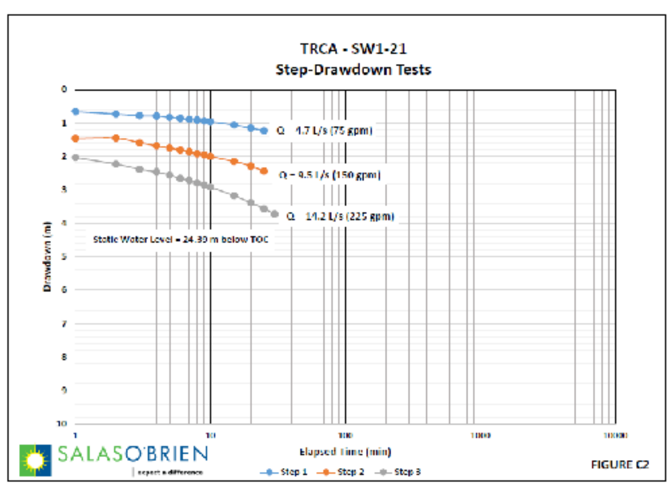

Figure 9. Pump Test Drawdown from SW 1-21

As shown in Table 2, we can see that the specific capacity (flow rate divided by drawdown) of SW 1-21 is nearly the same at each step. The average specific capacity is 3.9 L/s per meter drawdown across the different flowrates, which indicates that SWb1-21 is an efficient well and that the flowrate does not impact the specific capacity of the well.

The monitoring wells MW 1-20 and MW 2-20 were also measured for drawdown to measure the impacts of pumping water from SW 1-21 at step 3.

Table 3 shows the water level drawdown over the pumping period of 30 minutes for the 2 test wells and the monitoring well. Significant drawdown in adjacent wells can indicate potential problems with groundwater sources adjacent to the TRCA head office. In this case, drawdown in the adjacent wells were minimal .

Drawing water from the well impacts the static water level of oher adjacent wells . A graph of the drawdown cone from the Step 3 test after 30 minutes of pumping at 14.2 L/s (225 US gpm) is shown on Figure 10 . On a semi-logarithmic scale, the cone of depression becomes a straight line. The graph indicates that the drawdown cone will likely extend over 1000 m in radius, but the drawdown will be relatively small. The results of the pumping tests for SW 1-21 suggests that the well provides the sufficient flowrate required for heating and cooling the TRCA building and the impacts to adjacent wells is minimal.

AQUIFER CHARACTERIZATION

The bedrock valley aquifer is confined below the three overlying till sheets. The water levels in the three aquifer wells

Table 2. Results Pump Test Drawdown SW 1-21

STEP	Pumping Rate	Drawdown at t= 30 min	Specific Capacity at t=30min
	L/s	m	L/s per meter drawdown
1	4.73 (75 gpm)	1.2	3.94
2	9.46 (150 gpm)	2.5	3.94
3	14.20 (225 gpm)	3.7	3.84

Table 3. Results Pump Test Drawdown All wells

Well	Static Level (meter)	Drawdown at t=30 min (m)
SW 1-21	162.88	3.7
MW 2-20	162.95	1.3
MW 1-20	162.92	1.2

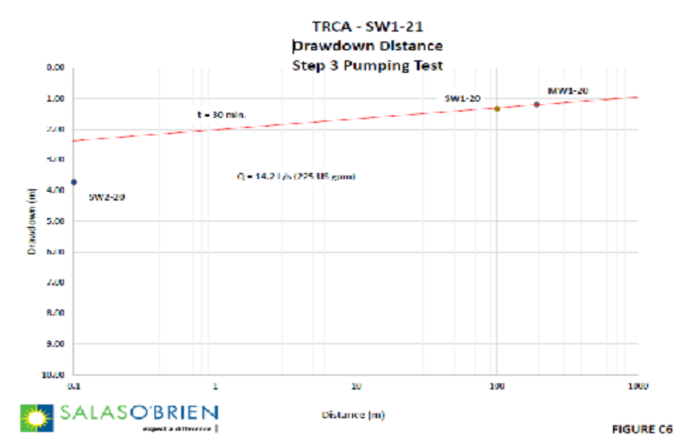

Figure 10. Drawdown Cone of depression Step 3 test at 225 gpm

averages about 33.8 m below ground surface. The actual water level elevations in the three wells at the time of the step-drawdown tests (October 5th, 2021) were within 7 cm of each other. MW1-20, MW 2-20, SW 1-21 and IW 1-22 are all screened in the bedrock valley aquifer, which is confined below the three overlying till sheets. The water levels in SW 1-21, MW 1-20 and MW 2-20 were measured on October 5th, 2021, at the time of the step drawdown tests at SW 1-21, and were as follows:

SW 1-21 = 23.19 m below ground (mbg) (162.88 masl);

MW 1-20 = 23.51 mbg (162.92 masl); and,

MW 2-20 = 24.83 mbg (162.95 masl).

*masl is meters above sea level, mbg is meters below ground, mbg is meters below ground

The water level readings indicate that groundwater migration in the aquifer is in a southwesterly direction. The hydraulic gradient is extremely low, measuring approximately 0.0004 in the vicinity of the TRCA property. From Figure 11, the calculated transmissivity is in the order of 125 m2/day and indicates a moderately productive aquifer. The aquifer transmissivity describes the ability of the aquifer to transmit groundwater throughout its entire saturated thickness. The aquifer water temperature was monitored during the step-drawdown tests on MW 2-20 and SW 1-21. The average temperature in the bed-

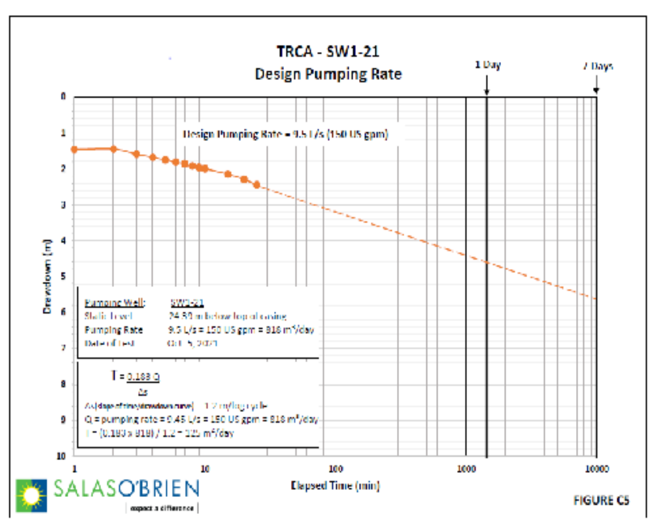

Figure 11. TRCA design pump rate for SW 1-21

rock valley aquifer is 10°C. Based on the results of the drilling program the hydrogeology assessment, and the building heating and cooling requirements, the consulting hydrogeologist recommended that an OLGX system would be feasible on site with two wells, a supply well (SW 1-21) and an injection well (IW 1-22). The Consulting Hydrogeologist indicated that an ATES system would require a third well be developed. The rationale is that the aquifer at SW 1-21 is nearly half the thickness of the aquifer at IW 1-22. Thus, for SW 1-21 to function as a supply well and an injection well it would require a second well to provide adequate well screen to meet water injection requirements. The two and three well requirements for OLGX and ATES, respectively were included in the capital and operating cost assessments.

GROUNDWATER QUALITY

The goal of assessing groundwater chemistry is to understand the water quality and determine what steps can be taken to maintain an efficient long-term OLGX or ATES system. Several key strategies are required to maintain optimum operating conditions and minimize the effects of scaling, corrosion, chemical, and biological impacts. To evaluate the groundwater quality, a groundwater sample was collected at MW 1-20 on Aug 26th, 2020, by TRCA staff. The sample was analyzed by ALS Environmental in Waterloo for several critical groundwater properties . The findings of the groundwater quality testing are summarized in Table 4. The groundwater testing revealed that the water is suitable for an open loop system or ATES.

Table 4. Groundwater quality test results

Tests	Description
Total Dissolved Solids	Dissolved Solids is the total quality of mineral constituents dissolved from rocks and soils in groundwater. The water sample obtained from the test well showed a TDS level of 386 mg/L. At this concentration, the water is not prone to potential scaling and corrosion.
Total Hardness	The hardness of water is representative of the amount of calcium and magnesium in the water. The most common form of scaling in groundwater systems is due to calcium carbonate. Calcium carbonate can form within heat exchange surfaces in an open loop or ATES system, reducing the efficiency of the system. Total hardness is primarily a measure of the calcium and magnesium salts in water. The hardness test for calcium carbonate indicated a hardness level of 217 mg/L. Hardness 180 mg/L can contribute to deposition of calcium carbonate on metal surfaces, however, the temperature variation in open loop systems is limited and this should not be a problem.
pH	The pH is a measure of the hydrogen ion concentration in the water. In general, the lower the pH, the greater the potential for corrosion to occur. The higher the pH levels, the greater potential for scaling. High acidity levels in the groundwater can lead to corrosion in the system components. The field pH of the groundwater is 6.98, which indicates the water is not prone to scaling or corrosion. A pH value of 7.0 is considered neutral and most groundwater is in the range of 6.5 to 8.5.
Turbidity	The turbidity level in the water sample is 1.05 NTW, a very low level. This indicates that suspended solids, such as silt and clay particles are not present in the deep aquifer.
Total Alkalinity	Total alkalinity measures the ability of the water to buffer acids and is linked to scale deposition. The concentration of total alkalinity in the aquifer water is 313 mg/L.
Carbonate and Bi carbonate	The carbonate in the well water is less than 2 mg/L. This low level is typica of groundwater with a pH less than about 8.5. The bicarbonate in the well water is 313 mg/L (i.e.- the same value as the alkalinity), which is typical of overburden aquifers in the Greater Toronto Area.
Chloride	Is the most common anions in uncontaminated groundwater. Most soils, rocks, and minerals contain some amount of chloride. High concentrations of chloride can impact the safety of the drinking water. The chloride levels were found to be 46.8 mg/ which is relatively low. This low level indicates that the aquifer is protected from road salt impacts by the overlying glacial till aquitard and the risk of metal corrosion due to chloride id negligible.
Nitrate/ Ammonia	Nitrate is the most common form of nitrogen in groundwater. Nitrite is a reduced form of nitrogen that is unstable in oxygenated environments and is much less common than nitrate in uncontaminated groundwater. Nitrogen compounds are indicators of fertilizer byproducts. High levels of nitrate levels in groundwater can indicate agricultural or residential contaminants such as pesticides or bacteria. The nitrate levels were found to be less than 0.02 mg/L. which is an insignificant concentration. The ammonia levels were found to be 4.9 mg/L, which is also an insignificant concentration.
Hydrogen Sulphide	Dissolved hydrogen sulphide in water can cause corrosion of some metals. However, both field and lab tests indicated there is no hydrogen sulphide in the water.
Calcium	Dissolved form solids and rocks, Calcium and magnesium are the primary cause of scaling in systems. Testing water for these metals in important in evaluating the scaling potential of the groundwater. The calcium levels in the groundwater samples were 49.2 mg/L. It is the dominant cation in the groundwater and is used to calculate the stability and saturation indices.
Iron	Extremely common and is dissolved from rocks and soils. On exposure to air, oxidizes and forms a reddish-brown precipitate. The precipitates can deposit on the well screens, pipes, and heat exchangers. The iron levels detected in the water sample were found to be 0.697 mg/L.
Manganese	Dissolved from some rocks and soils, manganese in groundwater can oxidize forming dark brown or black stains. Large quantities of manganese commonly are associated with high iron content and acid water. The manganese levels in the water sample were found to be 0.0399 mg/L.
Redox Potential	The redox potential is a measure of ease with which a molecule will accept electrons. The redox potential is used to describe a system's overall reducing (gaining electrons) and oxidizing (losing electrons) capacity. Dissolved oxygen is a strong oxidant meaning it strips other substances of their electrons. The Redox potential provides an indicator of how likely geogenic contaminants will be in an oxidated state. Generally, when dissolved oxygen is abundant, substances are more likely to be present in their more oxidized form. The redox potential was determined to be 289 mV and the level of DO in the groundwater was found to be 6.01 mg/L. The redox potential measurements indicates that the water tends to precipitate metals and cause corrosion of heat exchanger plates and pump impellers. Although this is not a constraint to the OLGX system, it is recommended that the system be managed as oxygen free as possible.

Based on the parameters tested, the groundwater quality is typical of a confined aquifer in the area and will not be a constraint to an open loop geothermal system at this site. To prevent oxidation of the water, it is imperative that the open loop geothermal system be designed so that air does not enter the circulation piping.

Fouling or scaling of heat exchangers can severely impact system performance by increasing the pressure drop across the heat exchanger and wells screens and increasing wear of the submersible pumps.

SOCIAL ECONOMIC AND ENVIRONMENTAL IMPACTS

This section of the case study will take into consideration the social, environmental and economic impacts across the different system options.

1.Environmental Impacts

The environmental impacts between the different systems can vary based on the emissions produced over the life of the system, waste produce from drilling activities, and impacts to air quality in the community. The environmental impacts of each of the system types were evaluated and are summarized in the Table 5.

Table 5. Summary of Environmental Impacts

<table>
<tr><th>Impacts</th><th>CLGX</th><th>OLGX</th><th>ATES</th></tr>
<tr>
<td>Environmental</td>
<td>
•Larger land area is required for the number of boreholes (44 total) to satisfy the heating and cooling demand, land is cleared for well pad construction. Typically, topsoil is removed to reveal the subsoil.

•The disturbance of the soil in these areas can potentially release carbon content in the soil. The type of soil and the size of the excavation area are the key factors that can determine the carbon impacts of disturbing these lands.

•The removal of vegetation in the area can also have an impact on the natural systems. As trees and plants are removed in the area where the boreholes are drilled, the ability of the land to support wildlife habitats and absorb carbon emissions is reduced.

•The emissions impact of drilling for longer periods of time can be significant compared to the OLGX and ATES systems. (Estimated at 52 tCO2e)

•Higher criteria air contaminates (CACs)produced through increased drilling activity:
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>Non Methane Hydrocarbons (kg)</td><td>34.20</td></tr>
<tr><td>Nox (kg)</td><td>72.00</td></tr>
<tr><td>PM (kg)</td><td>3.60</td></tr>
<tr><td>CO (kg)</td><td>630.00</td></tr>
</table>
•Minimal Operating Emissions and CAC (Annual emissions of 3.27 tCO2e)
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>CO (kg)</td><td>9.76</td></tr>
<tr><td>Nox (kg)</td><td>10.30</td></tr>
<tr><td>SOx (kg)</td><td>2.12</td></tr>
<tr><td>PM10 (kg)</td><td>1.02</td></tr>
<tr><td>PM2.5 (kg)</td><td>0.95</td></tr>
<tr><td>VOC (kg)</td><td>0.33</td></tr>
</table>
•Drilling fluid contamination of the site is a risk

•Drill waste generated such as cuttings, soil, rock chips and other debris is more significant

•Improper grouting or sealing of boreholes can lead to groundwater contamination where surface water can find a pathway down to aquifers or inter-aquifer contamination
•Thermal pollution in ground from unbalanced heating and cooling of the borehole field can impact the ecosystem and biodiversity in the ground and soils.
•Risk of antifreeze leakage into the ground in the borehole loops
</td>
<td>
•Smaller land footprint needed compared to the CLGX (production and injection well only)

•Relatively less emissions intensive drilling process compared CLGX (Estimated at 8.3 tCO2e)

•Lowest criteria air contaminates produced through reduced drilling activity:
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>Non Methane Hydrocarbons (kg)</td><td>5.47</td></tr>
<tr><td>Nox (kg)</td><td>11.52</td></tr>
<tr><td>PM (kg)</td><td>0.58</td></tr>
<tr><td>CO (kg)</td><td>100.80</td></tr>
</table>
•Minimal Operating Emissions and Criteria Air Contaminates CACs (Annual emissions of 2.78 tCO2e)
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>CO (kg)</td><td>8.40</td></tr>
<tr><td>Nox (kg)</td><td>8.86</td></tr>
<tr><td>SOx (kg)</td><td>1.83</td></tr>
<tr><td>PM10 (kg)</td><td>0.88</td></tr>
<tr><td>PM2.5 (kg)</td><td>0.82</td></tr>
<tr><td>VOC (kg)</td><td>0.28</td></tr>
</table>
•Drilling fluid contamination of the site is a risk
•Less drill waste generated compared to a CLGX system

•Thermal pollution is less of concern compared to the CLGX and ATES systems because energy is not being stored at the wells

•The change in temperature of groundwater in the immediate vicinity of the injection well can change the hydrogeology and ecology of the area in the long term
</td>
<td>
•Smaller land footprint needed compared to CLGX (Pair of production and injection wells)

•Relatively less emissions intensive drilling process compared to CLGX. In the ATES system, both wells need to be able to serve as injection wells, so the diameter of the wells are larger compared to the OLGX systems. (15.6 tCO2e)

•Low criteria air contaminates produced through reduced drilling activity:
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>Non Methane Hydrocarbons (kg)</td><td>7.11</td></tr>
<tr><td>Nox (kg)</td><td>14.98</td></tr>
<tr><td>PM (kg)</td><td>0.75</td></tr>
<tr><td>CO (kg)</td><td>131.04</td></tr>
</table>
•Minimal Operating Emissions and Criteria Air Contaminates CACs (Annual emissions of 2.47 tCO2e)
<table>
<tr><th>CAC</th><th>kg</th></tr>
<tr><td>CO (kg)</td><td>7.42</td></tr>
<tr><td>Nox (kg)</td><td>7.83</td></tr>
<tr><td>SOx (kg)</td><td>1.61</td></tr>
<tr><td>PM10 (kg)</td><td>0.78</td></tr>
<tr><td>PM2.5 (kg)</td><td>0.73</td></tr>
<tr><td>VOC (kg)</td><td>0.25</td></tr>
</table>
•Drilling fluid contamination of the site is a risk

•Less drill waste generated compared to a CLGX system

•Thermal pollution in ground from unbalanced heating and cooling of the wells can impact the ecosystem and biodiversity in the ground and soils.

•The change in temperature of groundwater in the immediate vicinity of the injection well can change the hydrogeology and ecology of the area in the long term
</td>
</tr>
</table>

2.Economic Impacts

Capital Costs

The economic impacts of the different geo-exchange systems are examined in this section. Two separate capital cost assessments are presented here. Table 6 provides a summary of capital costs based on our actual experience with the TRCA new head office project. The results in Tables 6 are used as part of this feasibility study in selecting the preferred system for the building. Because this feasibility project was undertaken within an active construction project, a second capital cost assessment was prepared to better reflect what the costs likely would be if the feasibility was assessed prior to the start of building construction (Table 7). The results in Table 7 are used to provide a more generic cost evaluation of the three systems to allow the results to be better utilized by other projects and to explore opportunities to further reduce capital costs. The summary of capital costs in Table 6 are derived from a few sources. The CLGX costs are based on the amount bid in response to a request to quote that was sent to the market. The ATES costs are estimated based on what would likely have been the costs had the TRCA project pursued that system type. Thus, the ATES costs include the same feasibility costs as the OLGX, additional costs for engineering and design and implementation due to the need for 3 wells (as per hydrogeology report recommendation). For CLGX, OLGX and ATES, project management costs were calculated as 10% of total project costs.

The OLGX costs are the actual costs incurred for the TRCA project and include costs associated with the redesign of mechanical systems to accommodate the OLGX. Because TRCA had already selected the CLGX systems initially in the project and the change in system selection was made while the construction of the building mechanical systems for the CLGX system was in progress,

Table 6.Capital Cost comparison of the three systems based on actual costs of OLGX , Bid Costs of CLGX, and a combined actual and estimated costs for ATES

Project Stage	CLGX	OLGX	ATES
Feasibility	$36,725	$391,036	$391,036
Engineering and Design	$45,850	$516,392	$523,473
Implementation	$1,122,500	$329,772	$564,543
Project Management (10%)	$120,508	$123,720	$147,905
Total	$1,325,583	$1,360,921	$1,626,957

additional engineering fees for mechanical and electrical design revisions were incurred which significantly increased the cost for the OLGX. The fees incurred were as high as $500,000 and are reflected in the OLGX costs in Table 6. Based on the results of the analysis, the capital costs of the CLGX and the OLGX are comparable with OLGX approximately 4% more expensive than CLGX. The capital cost for the ATES system would be 20% higher than the OLGX system.

The capital costs presented in Table 7 have been modified from Table 6 to reflect what would have been done had the feasibility not been assessed as part of an ongoing construction project. In Table 7, for the OLGX, the system redesign charges and additional design work as well as extra boreholes for feasibility testing have been excluded. Thus, for each system being evaluated the costs reflect the basic testing, and monitoring required to determine whether the project can move forward and that the requirements for each system type are met.

For a CLGX, this includes drilling a borehole for the purpose of conducting a thermal conductivity test to determine the suitability of the material and the depth required for a CLGX to meet the building heat and cooling requirements. For OLGX and ATES systems, this requires multiple test wells (mininum 2) to be drilled and pumping test to be conducted to ensure that the aquifer hydrogeological properties are suitable for these types of systems. The upfront costs to determine the feasibility of the OLGX and ATES systems are substantially greater than for a CLGX system. When drilling test wells for OLGX and ATES systems, it is not uncommon to intersect parts of aquifers with insufficient supply. In TRCA's study, the first well encountered a productive aquifer, the second well 150m away in the same aquifer encountered insufficient supply (50gpm) while the third wells (150m from the second) encountered more than enough supply (>225gpm). When the OLGX and ATES testing program encounters inappropriate water supply the feasibility study costs become sunk costs and a significant burden on future system development. For CLGX testing the

Table 7. Adjusted Capital Costs of the 3 Systems

Project Stage	CLGX	OLGX	ATES
Feasibility	$36,725.00	$243,613	$243,613
Engineering and Design	$45,850.00	$80,000	$564,543
Implementation	$1,122,500.00	$469,543	$704,315
Project Management (10%)	$120,508	$79,316	$133,177
Total	$1,325,583	$872,472	$1,196,721

feasibility study costs are far less significant and would not create a financial bourdon on future system development. In addition, with CLGX, when less than optimum conditions are encountered, the system developer generally has the option to drill more or deeper boreholes to meet thermal exchange requirements. Both wells in an ATES system are injection wells and supply wells and the requirements for these wells are more stringent than for just a supply well. Because OLGX and ATES systems are not as common in Ontario, additional specialized consulting and design expertise services were required to ensure that all relevant criteria were met to move forward with each system. This adds to the feasibility costing for the OLGX and ATES systems. The engineering and design of the systems includes costs of engineering fees to create design drawings and specifications for the systems. The costs of the design for the OLGX and ATES systems are higher than that seen in the CLGX systems.

The implementation costs for the three different systems vary, with the OLGX systems having the lowest overall capital costs followed by the CLGX and the ATES system. The CLGX system for TRCA head office would require 44 boreholes over 660 ft deep which presents as a significant cost. Significantly less drilling is required for both the OLGX and the ATES system which reduces the overall implementation costs (4 and 5 wells respectively, in aggregate for feasibility and system operation). However, in the ATES system, both wells serve as injection wells and supply wells which increases the costs. In addition, the added components in an ATES system increases the costs compared to an OLGX system which only requires one submersible pump and one injection well.

Table 8. Estimated Operations and Maintenance Costs

System Type	CLGX	OLGX	ATES
Typical Opera-tions and Maintenance Activities	Borehole field manifold inspections heat transfer fluid inspection (antifreeze), monitoring of system pressure (antifreeze leaking)	Monitoring of well specific capacity, Well rehabilitation if specific capacity below 15 to 20% of original, monitoring of pressure loss across heat exchanger, heat exchanger inspections (potential foul-ing) and cleaning as required, inspect and replace submersible pumps as required.	Similar to OLGX, however more components as there are additional submersible pumps
Typical Annual Maintenance Costs (based on 8,100m2 building) Note 1	$9,677	$19,354	$25,160
Annual Operating Costs (electricity)	$22,617	$19,460	$17,197
Examples of Specific Maintenance Actions and Associated Costs and Timing			
Heat Transfer Fluid Replacement (15 years)	$2,000		
Well Rehabilitation (10th year) Note 2		$49,450	$74,175
Heat Exchanger CleaningNote 3	$790	$1,580	$1,580
Submersible Pump Replacement (15 to 20 years) Note 4		$52,500	$157,500
Closed Loop Circulating Pump Replacement (25 years) (Note 5)	$35,000		

Note 1: ASHRAE Guidelines @ $0.11/sqft for closed loop, and $0.22/sqft for open loop. ATES assumed to be 30% more than OLGX due to extra well

Note 2: The cost of the well rehabilitation is approximately 10 to 33% of a new well. Assumed to be 21.5% of $115,000 per well

Note 3: 2 contractor hourly rate of $50/hr

Note 4: Based on preliminary costing analysis completed by JL Richards

Note 5: ASHRAE handbook indicates centrifugal pumps have typical life of 25 years.

The operational and maintenance costs differ significantly between the three systems with CLGX having the lowest costs and the ATES system the highest (Table 8). However, OLGX and ATES systems theoretically are more efficient than a CLGX. More stable groundwater temperatures from the aquifer typically translates to better efficiency at the heat pump which heats and cools the building. ATES systems can operate at higher efficiency levels than OLGX systems because of the storage component of the system where heating and cooling energy is stored in the wells. This can further increase the performance of the heat pump. Table 8 shows that ATES systems can achieve a 24% reduction in electricity costs relative to a CLGX and a 12% reduction in electricity costs relative to an OLGX system.

3. Social Impacts

The social impacts of each of the system types vary and are often difficult to quantify. There were originally several open-loop geo-exchange and ATES systems operating in Canada, however, some of these systems are no longer in operation. The lack of expertise and familiarity of the technology brings challenges in servicing and maintaining system performance. In addition to this, the hydrogeological requirements and quality of the groundwater must be suitable to install a system. This needs to be determined early in the design process. OLGX and ATES systems are often overlooked in the design process because there is minimal resources and success stories in Canada to promote and change the optics that the systems can carry operational risks. An example of this would be groundwater quality issues causing scale formation and clogging a heat exchanger. The knowledge and design of these systems are very specialized and wider adoption of such technologies are only possiblethrough education and providing real life examples of successfully running systems. The wider adoption of these systems can generate new employment, income and improve living conditions of the local community. It can also foster a change in how our buildings are designed and how systems are selected in the design process by building owners and design consultants.

CONCLUSIONS AND LESSONS LEARNED

Conclusion

Based on the results of the environmental and economic impact assessment, along with TRCA's desire to identify and share knowledge of sustainable, low carbon technologies, the OLGX system was selected for implementation. The capital costs of the OLGX were comparable with the CLGX only because the project was undertaken in the middle of an active construction project (Figure 20).

Annual operating and maintenance costs are expected to be 20% higher for OLGX despite lower electricity consumption. This is due in large part to the need for periodic maintenance of the wells and submersible pumps. GHG emissions from system implementation and operation for the OLGX over a 25-year period are expected to be 40% lower than the emissions from the CLGX system.

Both the OLGX and the CLGX provide exceptional results from an operational efficiency and GHG emissions perspective. Although there are many low carbon ATES systems in Sweden, Denmark and Belgium, they are uncommon in the rest of the world. In Ontario there are no known operating ATES systems at this

Lessons Learned

There were a number of important lessons that were learned working through this project and they are summarized below:

1. The key lesson learned is that TRCA should have undertaken a hydrogeology study as soon as the decision was made to go with a geothermal system. The initial test borehole for the closed loop geothermal assessment could have been drilled as a well to assess the viability of both OLGX and CLGX systems. Such a study would have provided us with a more comprehensive understanding of the underlying hydrogeology for only a small added cost.

Although the cost for the first well would have been a sunk cost (other than its use as a monitoring well) the study would have identified the potential for a OLGX during the design stage and thus would have saved the project many hundreds of thousands of dollars in implementation costs. This is where good collaboration and communication between different disciplines early in the project can help reduce implementation costs.

2. In our specific situation, incorporating the feasibility of OLGX and ATES earlier, as part of the design stage would have significantly reduced the total capital costs compared to the CLGX. TRCA incurred significant redesign costs in this project because it had initially selected a CLGX system for the head office and procurement and construction had already begun. The mechanical and electrical design revisions effectively eliminated the capital cost savings that TRCA expected by pursuing OLGX. If TRCA had initially decided to explore the OLGX option at the design stage, it would have reduced the actual implementation costs by 40% or more.

3. When assessing the feasibility or implementing the supply and injection wells for an open loop system, the variability of the underlying geology can result in non-performing or under-performing wells. In our specific situation the second well drilled intersected a fine sand deposit at the depth of the deep aquifer and could only provide a sustained production of 50 gpm. The cost of this well became a sunk cost as it could not be used as part of the building HVAC system. We moved forward with the third well because we were confident, based on the results of the first well and the experience of the hydrogeologist and well driller, that we had a high production aquifer under the site.

4. This feasibility study was undertaken in the middle of an active construction project, as such, we had to accept more risk than if we were undertaking this project prior to implementation. Based on the results from the first well and historic knowledge of the production potential of the deep aquifer in other locations, there was a high probability that we had located a high production aquifer. When the pilot hole for the third well confirmed that we had intersected a thick layer of coarse sediments, the decision was made to develop this well as a supply well for the new building. There was inherent risk with this decision because we did not yet have pumping tests to confirm the well's potential. However, the experience of the well driller and the participating hydrogeologists gave us confidence to invest the additional funds in a larger diameter well, stainless steel casing and extra well development. By utilizing one of the test wells as a production well the project reduced the overall capital cost of the OLGX system.

5. Once constructed, monitoring of OLGX system performance is crucial to ensure the longevity of the system. Monitoring changes in specific capacity of the aquifer and pressure drop across the heat exchanger can help to identify system issues and schedule maintenance as appropriate. It is also critical, where the aquifer has high levels of iron and other minerals, to ensure that the system is oxygen

free. Otherwise, the well and heat exchange will have a higher risk of clogging and scaling, a common issue seen in many of the systems.

6. To minimize the issues identified in point 5 above, engineering consultants may advocate for additional redundant wells (supply and injection), a redundant heat exchanger, and a supply side water filtration system. These additions would have significantly increased the capital costs of the project and are likely only a requirement for buildings that cannot schedule down times for maintenance (i.e., hospitals). Our Hydrogeology consultant recommended the monitoring identified in 5 above and regular maintenance of the heat exchanger and regular rehabilitation of the wells as well as HDPE welded pipe and positive pressure on the supply to ensure no oxygen infiltration. Based on the Hydrogeologist's recommendation we did not include the redundant systems. Well rehabilitation is a significant operating cost but the lack of oxygen in the system coupled with significant well development, should increase the time before we need to undertake this maintenance.

7. There are areas in the GTA and the rest of Ontario that have high production aquifers like the Laurentian Channel, that could support extensive OLGX systems. Given the variability of the underlying surficial geology at the local site scale and associated risk of encountering low production aquifer conditions, it may be worth-while undertaking a project to delineate the high production zones in these aquifers. The starting point might be to look at where these high production aquifers underly existing or proposed medium and high-density developments. Various geophysical assessment techniques such as gravity surveys, 2D electrical resistivity imaging, vertical electrical sounding, very low frequency, and seismic refraction, could be used for geological structure investigation, locating the aquifers and assessing the hydrogeological conditions and groundwater potential. These types of assessments could be used to better define the high production zones in strategic areas and increase the probability that a drilling program would intersect enough water to create a viable OLGX system and thus, minimize sunk costs.

This communication has been prepared by the Community Transformation Group. This project was carried out with assistance from the Federation of Canadian Municipalities' Green Municipal Fund, an endowment created by the Government of Canada.

If you are interested in getting involved through any of our engagement opportunities, please contact us at:

info@trca.ca

Published June 2022.

GREEN MUNICIPAL FUND | FONDS MUNICIPAL VERT

a program of/ Un programme de la FCM

funded by/ Financé par Canada

Toronto and Region Conservation Authority