Use of a Regional Hydrogeologic Model to Identify Candidate Areas for Borehole and Aquifer Thermal Energy Storage

Donald Ford, B.Sc., P.Geo.*
Manager, Geoenvironmental
Toronto and Region Conservation
5 Shoreham Drive, Downsview, Ontario, Canada M3N 1S4
dford@trca.on.ca

and

Bill Wong, P.Eng.
Program Manager, Renewable Energy and Climate Change
Science Applications International Corporation (SAIC Canada)
60 Queen Street, Suite 1516, Ottawa, Ontario, Canada K1P 5Y7
www.saic.com/canada

Summary

Borehole and aquifer thermal energy storage systems involve the seasonal storage of heat and cold energy for the purpose of heating and cooling buildings. These technologies have the potential to offer significant energy savings as compared to traditional earth energy systems, since the input temperatures from either the ground or groundwater are lower in the summer for cooling and higher in the winter for heating. However, determining the geologic and hydrogeologic conditions can be expensive and time consuming. However, regional models have the potential to screen for areas where these technologies may be effective. In Ontario, such models have been developed by many conservation authorities as part of their work under the *Clean Water Act, 2006*. This paper presents the findings of a study conducted within the Toronto and Region Conservation jurisdiction using both geological data and output from a three-dimensional groundwater flow model (MODFLOW, McDonald and Harbaugh, 1988).

Introduction

Providing the future energy needs of a growing Canadian population in a carbon constraint economy and achieving the federal government's commitment to reduce greenhouse gas emissions are major challenges that cannot be resolved entirely with conventional energy systems (Quest, 2008). Fortunately there are innovative technologies that utilize the earth as a source of renewable energy, thereby offering significant energy savings. One approach is to use the earth to store heat or cold in one season and then use this stored energy in the next season. Such energy can be stored in either the ground (borehole thermal energy storage – BTES) or in the groundwater (aquifer thermal energy storage – ATES).

It is possible to provide cooling in summer months from stored winter cold energy. This cold energy can be captured in the winter by using heat exchangers utilizing cold winter air or surface water. Conversely, space heating in the winter can utilize summer heat energy stored in subsurface. This inter-seasonal storage concept consists of three main components: the storage medium; the useful energy potential; and the energy flow mechanism (Wong, Snijders, and McClung, 2006).

The ATES technology is considered the lowest cost storage option, but in areas with inadequate groundwater resources, the BTES approach may be effective. From an energy management point of view, the efficiency of ATES or BTES systems depends on two major factors: capacity to retain the stored thermal energy potential in the underground for later use; and the rate at which thermal energy can be transferred to and from the storage medium. The hydrogeologic characteristics of a site determine which technology will be the most efficient.

Methodology

BTES Application

For ideal BTES sites, the soil and/or rock should have a high thermal capacitance and also a high thermal conductance. High thermal capacitance will provide a potentially higher thermal energy storage density thus reducing the required storage volume. This could lead to less impact on surface operations. High thermal conductance will provide a high heat transfer rate between the earth and the heat transfer fluid in the boreholes. A higher heat transfer rate will reduce the number of boreholes and the capital investment.

Once the thermal energy potential is stored in a borehole array, the thermal energy potential will drive heat flow along the subsurface thermal gradient. Natural heat flow will result in heat loss from the system and reduce the overall system efficiency. The design and the selection of a BTES site should attempt to minimize such heat loss. However, in the subsurface, heat loss from ground water flow through the borehole array could be extremely high and render the storage feature ineffective, wasting the capital investment. Although saturated conditions enhance soil thermal properties, groundwater movement will reduce the effectiveness of the energy storage. Using the above heat transfer principles and practical design considerations, thermal energy storage criteria for BTES applications have been compiled as shown in **Table 1**.

Table 1: BTES Evaluation Criteria

Assessment	Criteria	Model Application	Comment
Favourable	Rock and/or clay with ground water flow <0.05 m/day.	Any area with all aquifers >1 m in thickness.	Groundwater flow assumed to be <0.05 m/day in aquitards. Bedrock is low permeability shale.
Acceptable	Silt and/or silty sand with ground water flow <0.05 m/day.	Any area with any one aquifer >1 m thickness and ground water flow <0.05 m/day.	Geologic model used for aquifer thickness; numeric model used for flow velocity; porosity assumed to be 0.2.
Unacceptable	Any area not included based on the BTES favourable or acceptable criteria.		

ATES Application

In an ATES system, the beneficial thermal energy potential is carried by the groundwater into the aquifer and later retrieved via groundwater flow back to the surface through water wells, piping, heat exchangers and pumps. Heat transfer of the stored thermal energy potential is by the available heat in the groundwater and some convective heat transfer between the groundwater and the aquifer itself. Generally, heat transfer is much more efficient with ATES as compared to BTES.

In assessing a site for ATES potential, aquifer characteristics such as transmissivity, aquifer depth, ground water flow velocity are important factors in determine the usefulness of the aquifer as a thermal potential storage medium. For obvious reasons, the well locations and the pumping regime will impact the amount of heat (or cold) that can be stored and retrieved. The potential impact from groundwater flow must also be considered. If the groundwater flow velocity is too high, the system design will be challenging and the piping complexity will increase the capital cost. Therefore, a site having an aquifer with a high permeability and low groundwater flow velocity has the potential to be a good ATES candidate site.

Based on the results from an ATES system field test in Canada (SAIC Canada, 2007), ATES site criteria discussed by the international energy management community (Roth and Brodrick, 2009; A. Snijders, pers. comm.) and the required thermal system capacity for a potential application in Toronto, ATES site filtering criteria have been compiled for discussion (**Table 2**). Although other criteria could have been considered, those selected are associated with data from either the regional geologic or hydrogeologic models available, as discussed below.

Table 2: ATES Evaluation Criteria

Assessment	Criteria	Model Application	Comment
Favourable	Aquifer >15 m thickness.	Any area with aquifer >15 m thickness.	Geologic model used for aquifer thickness.
	Aquifer depth between 5-80 m.	Any area where any aquifer is present within 5 to 80 m of grade.	Geologic model used for top of aquifers, TRCA Digital Elevation model used for ground surface.
	Ground water flow <0.2 m/day.	All areas with estimated flow velocities less than <0.2 m/day.	Numeric model used for flow velocity; porosity assumed to be 0.2.
	Static head between 5 and 20 m below grade	Any area where the static head in one of the aquifers is between 5 and 20 m of grade.	High heads can cause make well installation challenging; low heads involve high energy inputs.
Acceptable	Aquifer thickness is 2-15 m.	Any area with an aquifer 2-15 m in thickness.	Geologic model used for aquifer thickness.
	Aquifer depth is 80-150 m.	Any area where at least one aquifer is present within 80 to 150 m of ground surface	Geologic model used for top of aquifers, TRCA Digital Elevation model used for ground surface.
	Ground water flow is 0.2-0.3 m/day.	All areas with estimated flow velocities between 0.2 to 0.3 m/day.	Numeric model used for flow velocity; porosity assumed to be 0.2.
	Static head is 20-50 m, or between 5 m and 5 m above grade	Areas where the static head in one of the aquifers is within the stated criteria.	High heads can cause make well installation challenging; low heads involve high energy inputs.
Unacceptable	Any area not included based on the ATES favourable or acceptable criteria.		

Geologic/Hydrogeologic Data

In 2006, the Conservation Authorities Moraine Coalition (CAMC) in partnership with the York-Peel-Durham-Toronto (YPDT) Groundwater Management Study released a comprehensive hydrogeologic analysis of large area stretching from Lake Simcoe to Lake Ontario (Kassenaar and Wexler, 2006). This work included the generation of a conceptual geologic model and an eight-layer, three-dimensional numerical groundwater flow model (MODFLOW). The models were then updated and refined on behalf of Toronto and Region Conservation (TRCA) for both watershed planning and source water protection technical studies (TRCA, 2008; TRCA, 2009). The data from these models was then applied in conjunction with the BTES/ATES criteria, as per **Tables 1 and 2**, respectively, to identify potential candidate areas. Although hydraulic conductivity would have been a good screening criterion, the model contains average values for the entire aquifer thickness, which are not easily compared to a criterion for a particular well.

Results

The output of this study is summarized on **Figure 1** (BTES) and **Figure 2** (ATES). Potential candidate areas have been identified for both BTES and ATES systems. These areas fit with the overall geologic understanding, with the till and bedrock dominated systems in the southwest being more favourable for BTES, and the known aquifer locations in the remainder of the jurisdiction being more favourable for ATES. The major aquifer systems are either associated with the Oak Ridges Moraine that extends along the northern boundary, or deep sediments in bedrock valleys.

Conclusions

It is possible to use regional geologic models to screen areas for potential application of BTES and ATES technologies. However, the mapping from this type of exercise is for initial application **screening** only. A more detailed review should always be conducted before any investment decisions are made. In addition, comprehensive site specific environmental impact studies must be conducted for all BTES and ATES projects to collect the necessary geologic, hydrogeologic, and natural environment data and ensure that the technology can be applied without impacting neighbouring landowners and/or the natural environment.

Figure 1: BTES Screening Map

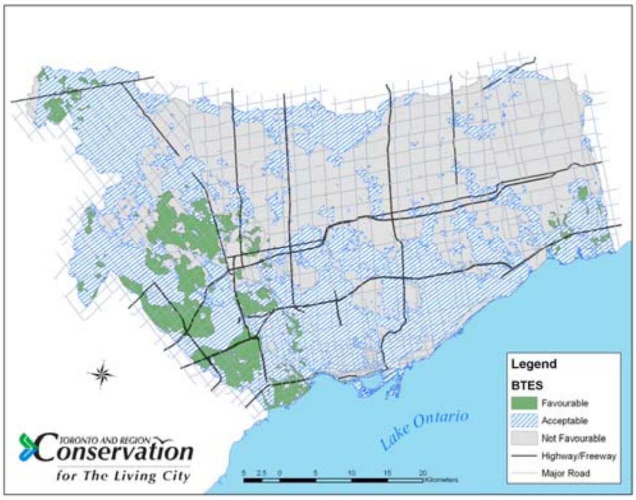
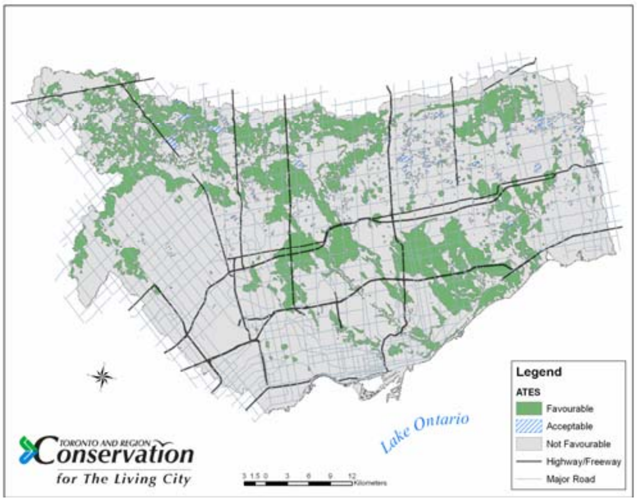


Figure 2: ATES Screening Map



Next Steps

It is not possible to assess the effectiveness of the screening process until a variety of projects have been successfully implemented. Therefore, TRCA and SAIC will share the candidate area mapping with potential implementers such as BILD (Building Industry and Land Development Association) and monitor the market to identify planned BTES and ATES projects. Also, it will be important to refine the mapping based on other screening criteria, such as hydraulic conductivity estimates, known well yields, and groundwater chemistry. It will also be important to consider such factors as proximity to municipal water supply wells and/or sensitive ecosystems such as cool and coldwater streams.

Acknowledgements

TRCA and SAIC would like to thank the City of Toronto for providing financial assistance to undertake this project. The authors would also like to thank all of the YPDT-CAMC technical and funding partners for having the foresight to create the geologic and hydrogeologic models upon which this assessment was based.

References

Kassenaar, J.D.C. and Wexler, E.J., 2006. *Groundwater Modelling of the Oak Ridges Moraine Area.* CAMC-YPDT Technical Report #01-06.

McDonald and Harbaugh. 1988. A Modular Three-Dimensional Finite Difference Ground-Water Flow Model, Techniques of Water Resource Investigations of the US Geological Survey, USA.

Roth, Kurt and J. Brodrick, 2009. *Seasonal Energy Storage*, ASHRAE Journal, January 2009, page 41-43.

SAIC Canada, 2007. *Integrated Solar and ATES system Field Test and Feasibility Study for a Condominium Complex in Medicine Hat, AB.* Report issued to the City of Medicine Hat, August 2007.

Snijders, A., 2009. *Personal Communication* IF Technology, The Netherland, September 2009.

TRCA, 2009. Draft Accepted Tier 1 Water Budget, TRCA Watersheds.

TRCA, 2008. *Humber River State of the Watershed Report – Geology and Groundwater Resources*.

Wong, B, A. Snijders and L. McClung. Recent Inter-seasonal Underground Thermal Energy Storage Applications in Canada. Climate Change Technology Conference (Ottawa, ON), November 2006.

Quality Urban Energy Systems of Tomorrow (QUEST), March 2008.