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Milestone 3: Final Report

Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study

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This project is supported by the financial contribution of the Independent Electricity System Operator (IESO), through its Grid Innovation Fund. However, the views, opinions and learnings expressed in this report are solely those of York University.

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Task 3: Report 3.1 Final Report on the Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study

Report Overview

Three Milestone Reports have been issued as part of this IESO Grid Innovation Fund Project.

Milestone 1:

Report 1.1 Geophysics data collection for the York University ATES site investigation

Report 1.2 Cost comparison of two site investigation methods for ATES projects

Milestone 2:

Report 2.1: Preliminary design and technical and economic assessment of ATES, BTES, and PTES systems for York University

Report 2.2 Preliminary Analysis of ATES Implementation Potential across the Greater Toronto Area

Milestone 3:

Report 3.1 Final Report on the Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study

This document is submitted as deliverable for Milestone 3 of the project: *Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study*

The scope of Milestone 1 included the completion of a detailed non-intrusive, non-destructive seismic survey of the York University's Keele campus. The scope of the geophysical survey, and related report, was as a case study on the application and value of the geophysical techniques in reducing site selection uncertainty. For example improving the optimal location of boreholes. It was not completed to confirm the feasibility of a site, and the assessment of whether the site would be appropriate for the ATES system was outside the scope of Report 1.1. The assessment of the likelihood of the site conditions to support an ATES was done under the scope of Milestone 2, taking into account the scale of the system planned. Results from the site investigation did not conclusively identify the presence of a suitable aquifer to support the York U Keele campus heating and cooling demand, and therefore the subsequent technoeconomic analysis performed included alternative thermal energy storage technologies for consideration. The seismic survey included the neighboring TRCA (Toronto and Region Conservation Authority) property, which was at the time conducting a conventional aquifer borehole drilling survey approach independent of this Project. Report 1.2 compares the seismic approach to a conventional drilling site characterization approach to evaluate the non-invasive and lower cost seismic survey as a tool to yield “investment grade” results.

The scope of Milestone 2 included the completion of a techno-economic analysis to evaluate the incorporation of inter-seasonal thermal storage (using aquifers, boreholes or thermal pits) to the campus’ existing district heating and cooling system and the conversion of much of the heating and cooling loads from natural gas to electricity, while avoiding increased electricity demand during peak periods. Report 2.1 contains results of the techno-economic analysis, which included expanding an existing high accuracy TRNSYS simulation model of York’s Keele campus district cooling system and cooling equipment, by adding the heating equipment and heating loads into the model of the existing campus cooling system previously developed as part of a study completed by the project team and funded by the International Energy Agency District Heating and Cooling Technology Collaboration Programme (IEA DHC TCP). The techno-economic benefits for both heating and cooling loads were estimated for the first time for this university campus considering both ATES and alternative large-scale underground storage options such as pit and borehole thermal energy storage (PTES, BTES). Report 2.2 contains results of a preliminary analysis of ATES implementation potential across the Greater Toronto Area (GTA). The report includes publication of a map of high-yield suitable ATES areas in relation to medium and high density community loads.

The scope of Milestone 3 included results dissemination activities, including one forum discussion with policy stakeholders and one forum discussion with general stakeholders, held in the form of a two-session webinar featuring expert presentations from eight project participants and contributors. Other results dissemination activities were the presentation of project results at major Ontario conferences. Additionally, ***the report associated with Milestone 3 summarizes key findings from the previous project activities***, including the seismic survey conducted on the York U campus, the cost-comparison of seismic and traditional site characterization methods, the techno-economic analysis of ATES, BTES, and PTES integration scenarios, and the preliminary assessment of the potential for ATES scale up at the regional level.

Project Partners & Acknowledgements

Natural Resources Canada-CanmetENERGY-Ottawa (NRCan CE-O) is the project leader and manager. CE-O's mission is to lead the development of energy science and technology solutions for the environmental and economic benefit of Canadians. CE-O's Buildings and Renewables Group (BRG) is the lead federal group in Canada working on energy efficiency and sustainability in the building sector, including research and development activities on community district heating and cooling. By leading the development demonstration and implementation of novel energy systems for buildings in Canada, BRG supports the development of science-informed sustainability and energy efficiency policy for the building sector, including more stringent building codes and increased incentives for the utilization and integration of renewables.

York University is the third largest public university in Canada and operates one of the largest district heating and cooling system in the country. York University Keele Campus is the project lead applicant and a case study partner, and provided accesses to the university campus site and provide data and information on its district heating and cooling system design and operation. Natural Resources Canada would like to acknowledge the support of key personnel from the Facilities Services group at York University, including Bogdan Strafalogea and Steven Prince, for providing in-depth details on the design and operation of the University district cooling system and for all the support to complete successfully this study.

Natural Resources Canada-Geological Survey of Canada (NRCan GSC) has extensive experience and knowledge as Canada's national organization for geoscientific information and research. Its world-class expertise focuses on the sustainable development of Canada's mineral, energy and water resources. GSC lead the activities and reporting for the characterization of the hydrogeological properties of York University's Keele campus underground.

Toronto and Region Conservation Authority (TRCA) operates programs designed to monitor and evaluate clean water and low carbon technologies, assess implementation barriers and opportunities and to collaborate with academic and industry partners. TRCA's work with its municipalities on source water protection requires understanding of the hydrogeology in the Greater Toronto Area, employing many staff with local expertise. TRCA lead the efforts on the Preliminary Analysis of the ATES replicability potential at the regional scale and providing access to the TRCA campus onsite borehole test measurements data.

Industry partners include Brian Beatty of Salas O'Brien Inc. and Aart Snijders of UTES Consulting, both bringing extensive experience with ATES and other geothermal projects from within North America and Internationally. Jeff Thornton of Thermal Energy System Specialists contributed expertise in energy systems design and simulation, and Jarrett Carriere of J. L. Richards provided in-depth costing and economic analysis, with significant experience in Ontario energy systems.

Natural Resources Canada would like to acknowledge key personnel from the Facilities Services group at York University, including Bogdan Strafalogea and Steven Prince, for providing in-depth details on the design and operation of the University district cooling system and for all the support to complete successfully this study. Support and contributions from City of Toronto personnel Will Nixon and David McMillan, who provided contributions and informative discussions as well as participation in a webinar with policy stakeholders, was invaluable. Additionally, Natural Resources Canada acknowledges the contributions of Tennis Canada for facilitating access to Tennis Canada campus site allowing detailed seismic survey of the adjacent York University campus site.

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Figures and Tables

Abbreviations

ATES Aquifer Thermal Energy Storage
BTES Borehole Thermal Energy Storage
CE-O CanmetENERGY-Ottawa
CHP Combined Heat and Power
CHW Chilled Water
COM Commercial Land Use
COP Coefficient Of Performance
CUB Central Utilities Building
CWEC Canadian Weather Year for Energy Calculation
DE District Energy
DHC District Heating and Cooling
FSI Floor Space Index
GHG Greenhouse Gas
GIN Groundwater Information Network
GIS Geographic Information Systems
GSC Geological Survey of Canada
GTA Greater Toronto Area
GW Gigawatts
HDPE High Density Polyethylene
HDR High Density Residential Land Use
HVSR Horizontal-to-Vertical Spectral Ratio
IAM Incidence Angle Modifier
kW Kilowatt
LCA Life Cycle Analysis
LDC Local Distribution Company
MS Magnetic Susceptibility
MURB Multi Unit Residential Building
NMR Nuclear Magnetic Resonance
NRCan Natural Resources Canada
OGS Ontario Geological Survey
ORMGP Oak Ridges Moraine Groundwater Program
PTES Pit Thermal Energy Storage
RES Renewable Energy Sources
STHW Steam to Hot Water
S&T Science and Technology
TES Thermal Energy Storage
TRCA Toronto Region Conservation Authority

TWT Two-way Travel
USGPM United States Gallons per Minute

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Executive Summary

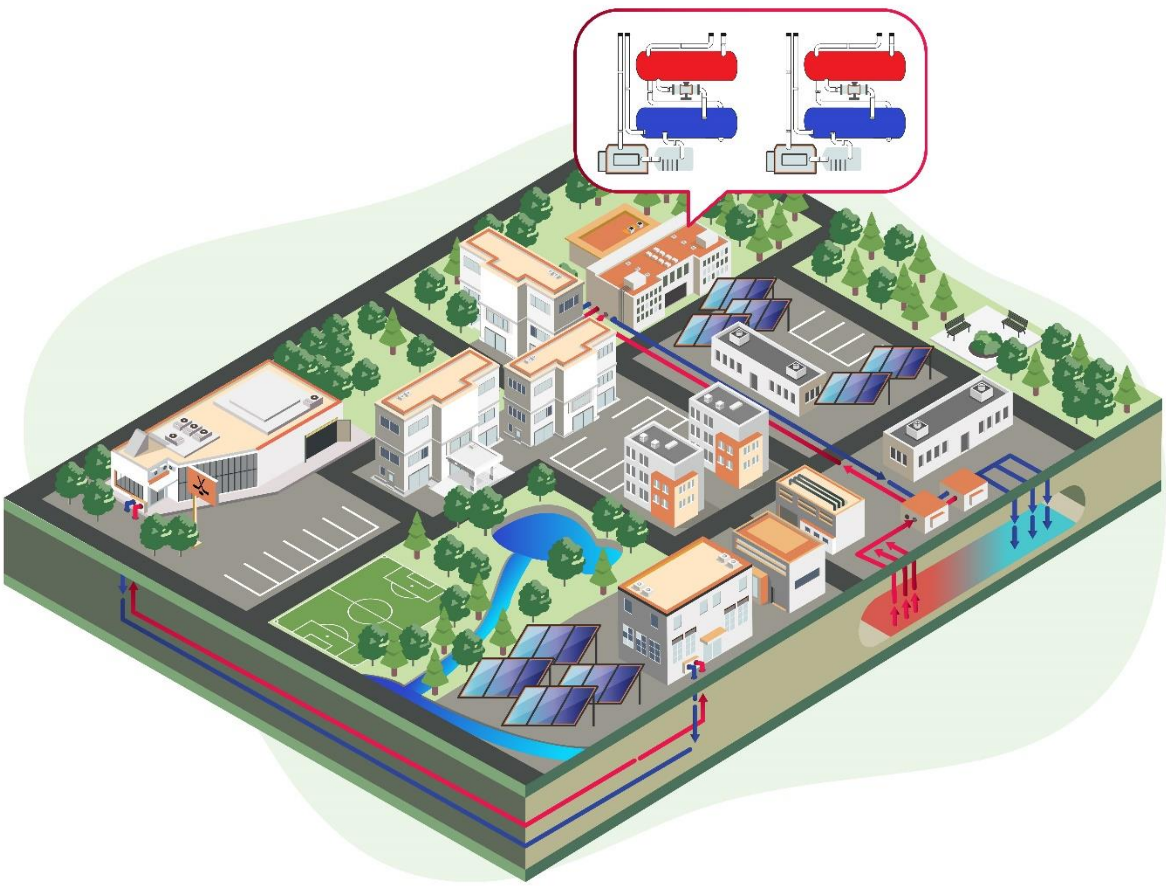
Project Overview

This document is submitted as deliverable for Milestone 3 of the project: Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study. This report summarizes key findings from each project activity. For additional information, the reader is directed to the complete reports for Milestone 1 and Milestone 2 as listed on page v.

Modern district heating and cooling (DHC) systems are a vital technology as we transition into a green economy. They enable the coupling of the heating and electricity sectors for increased flexibility of the overall energy system. Large-scale thermal energy storages (TES) allow for the integration of high shares of renewable energy sources (RES) with excess electricity from RES and have potential to reduce strain on the electricity grid associated with widespread electrification of building heating and cooling loads. Geo-exchange systems in general, and aquifer thermal energy storage (ATES) systems in particular, provide the opportunity to electrify heating in a highly efficient manner, avoiding any rapid growth in winter peaks. Perhaps more important for the long term, ATES systems are currently the most efficient cooling system available and can be instrumental in controlling summer peaks as well. ATES systems are significantly cheaper than traditional borehole-based, closed loop geo-exchange systems. However, ATES are highly dependent on the availability of a suitable aquifer, and the data gathering and analysis of the underground conditions can be costly and time consuming, which is a significant barrier.

Natural Resources Canada's CanmetENERGY-Ottawa (CE-O) mission is to lead the development of energy science and technology (S&T) solutions for the environmental and economic benefit of Canadians, and its strategic research agenda includes large-scale TES as central elements of DHC systems. The research in the NRCan-York University project 'Integration of Underground Seasonal Storage in Ontario's Large Electricity Consumers' District Heating and Cooling Systems – York University Keele Campus Case Study' contributes towards the development of knowledge and information to encourage the use of cost-effective large-scale underground thermal energy storage in DHC systems.

This project was aimed at evaluating the feasibility of large-scale seasonal thermal energy storage applications for major electricity consumers in Ontario, including a new approach for identifying suitable aquifers for large-scale seasonal TES applications and reducing the upfront risk of such projects. The project demonstrates the potential of: (i) using non-intrusive non-destructive seismic surveys for the cost-effective characterisation of large field areas to identify suitable aquifers for large-scale thermal storage applications, and (ii) integrating large-scale underground seasonal storage for GHG reductions, annual electricity use reduction, and electricity peak shaving of large electricity consumers. The final output of the project, (iii) is a preliminary analysis of the potential for scaling up ATES deployment in the greater Toronto region , resulting in publication of a preliminary map of high-yield suitable ATES in relation to medium and high-density community loads.



Characterization of York U Site

To support an Aquifer Thermal Energy Storage (ATES) system at York University three geophysical datasets were collected. To demonstrate the potential of horizontal-to-vertical spectral ratio technique (HVSR) as a low-cost approach to estimating depth to bedrock a reconnaissance survey of 18 stations was completed. A seismic reflection survey was completed to provide information on depth to bedrock, the stratigraphic architecture and seismic facies. This information can be used to better constrain understanding of the aquifer target location, geometry and heterogeneity. To demonstrate how downhole geophysical techniques can provide aquifer and stratigraphic characterization and parameterization a suite of logs were collected (gamma, conductivity, magnetic susceptibility, velocity, and temperature). Due to borehole constraints the nuclear magnetic resonance survey was completed in an appropriately cased (3 inch) diameter borehole to the north of Toronto Regional Conservation Authority borehole and York University.

The geophysical site investigation found that there are two small aquifers present on the York U site, but neither would be sufficient to support a full-scale ATES capable of meeting the majority of DHC loads. Though the site investigation contributed significant information regarding the geometry and location of possible drilling targets, including the two small aquifers indicated in Figure 1 below in blue, the geometry of the channel locations identified in the survey would likely be too small to support the number of wells required for the scale of the system considered for York University. Follow-up drilling would be a prerequisite to determining the aquifer yield.

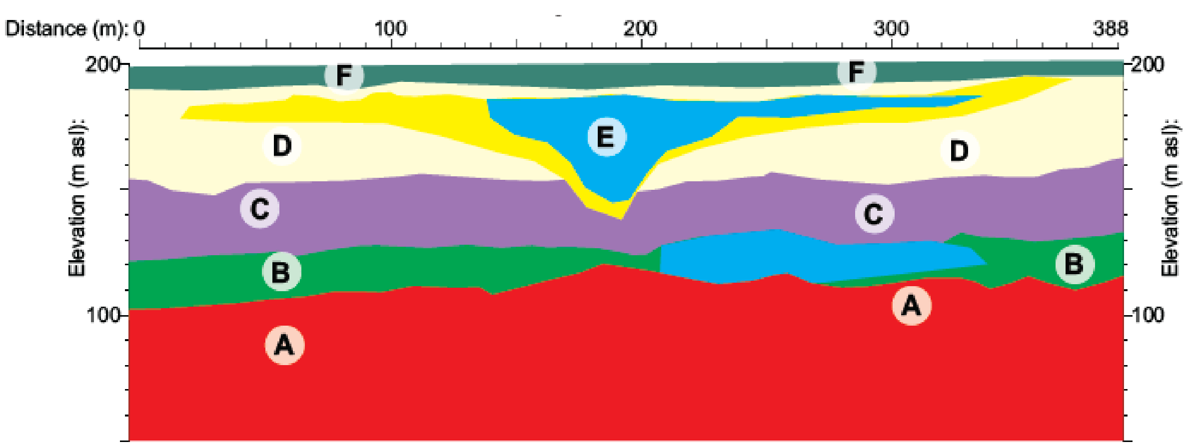


FIGURE 1: SIMPLIFIED VIEW OF CROSS SECTIONAL SITE CHARACTERIZATION AT YORK U CAMPUS

An analysis was performed to investigate whether geophysical site surveys are a cost effective way to characterize the underground for *larger sites* (areas) in order to reduce the geological risk for the application of larger scale ATES projects. For *small sites*, consisting of a single building or a group of houses with a zone of thermal influence in the aquifer of less than 10,000 m², the approach is more straightforward and standard test drilling approaches are sufficient. For large sites, the number of test boreholes required can be cost prohibitive, requiring approximately one borehole drilled for each 10,000 m^2 of site area. For York University, assuming 50% of available land area could be used for wells, 100 test boreholes would be required, and therefore alternative non-invasive geophysical approaches are suggested here.

The focus of the cost comparison is local sediment aquifers. So-called major aquifers are productive aquifers that extend over a large area. Examples are areas with limestone or sandstone bedrock aquifers (such as southwest Ontario and Ottawa). Major aquifers would have a different approach and are generally better mapped than sediment aquifers in populated areas. Major aquifers are generally relied upon for large ATES sites such as the York U campus.

The result of the cost comparison demonstrates that for large sites where there is a likely presence of a local aquifer that could support ATES development a seismic site investigation approach could significantly reduce exploration costs for ATES projects. Costs were estimated at $52,700 for the HVSR survey, which could be applied as a first screening, $748,630 for detailed seismic reflection survey which could either be applied standalone or as the second phase after an HVSR survey. The traditional drilling-based approach was estimated at $6,285,000 for a site the scale of the York University campus, requiring approximately 100 boreholes for testing.

Techno-economic Analysis

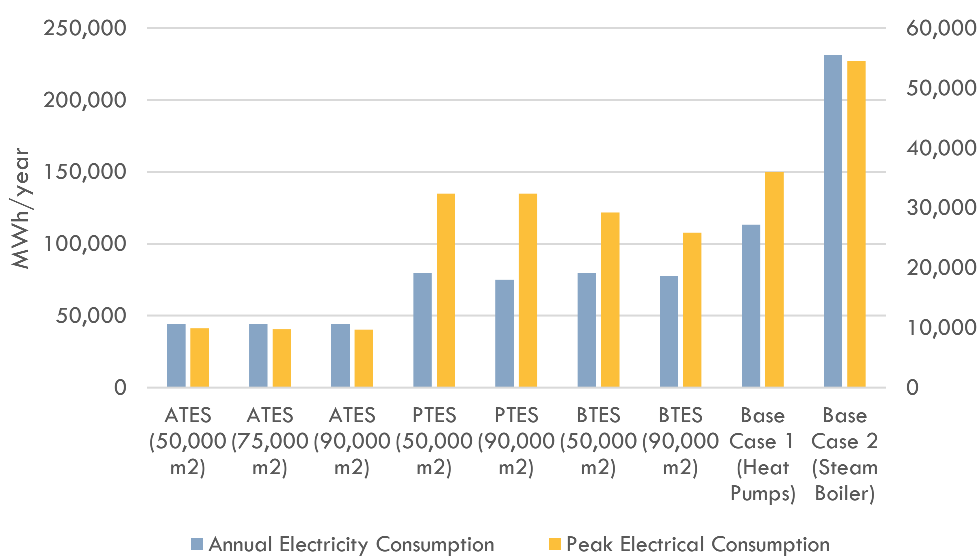
In Report 2.1, a case study to assess the techno-economic potential of integrating large-scale TES options, including aquifer, pit, and borehole thermal energy storage systems, into a built-up university campus is presented. The York University campus in Toronto, Ontario, Canada, has been used as the basis of this study. York University, the third largest university in Canada, is considered large enough to capture any benefit of economies of scale during the life cycle cost analysis of options.

A total of ten scenarios including two base cases were considered in the technical analysis. For each TES option, a number of scenarios were developed to analyze the impact of solar thermal collectors on balancing the thermal exchange with the subsurface using array sizes between 50 000 m^2 and 90 000 m^2. In addition to the eight ATES, PTES, and BTES scenarios, two base case scenarios were developed.

One base case scenario assumes the DHC remains using steam and replaces the CHP with an electric boiler. The second base case scenario assumes a steam to hot water conversion (which would also be required for all the TES scenarios) and heat pumps with a smaller electric boiler and cooling towers. This allows for an economic comparison between the TES scenarios and a base heat pump scenario without developing a cost estimate for the steam to hot water conversion, which is outside the scope of this study. In an electric steam boiler system would represent worse case for the electric grid, but would also be the lowest upfront cost.

TRNSYS simulations estimate that the ATES system could reduce peak electricity demands from 54.5 MW in the case of an electric steam boiler to 9.95 MW using ATES and heat pumps to meet the entire load. ***Given the presence of a suitable aquifer***, ATES would be the most affordable option compared to BTES and PTES, with a payback of approximately **3.2 years** when compared to a base case using air source heat pumps with an electric boiler and cooling tower. PTES and BTES scenarios indicate payback periods of 8 and 9 years respectively. These figures are well within an acceptable range for large scale infrastructure projects, and the PTES and BTES are less reliant on specific hydrogeologic conditions on the site. These technologies show good potential for decarbonizing the York U district energy system.

The ATES scenarios in this report represent a best case scenario with high capacity of 500 USGPM per well pair and an average case scenario with half the capacity per well, but they are unlikely to be achievable at the campus given that the results from the site investigation show that there is not likely to be a suitable aquifer to support the York U Keele campus heating and cooling demand.



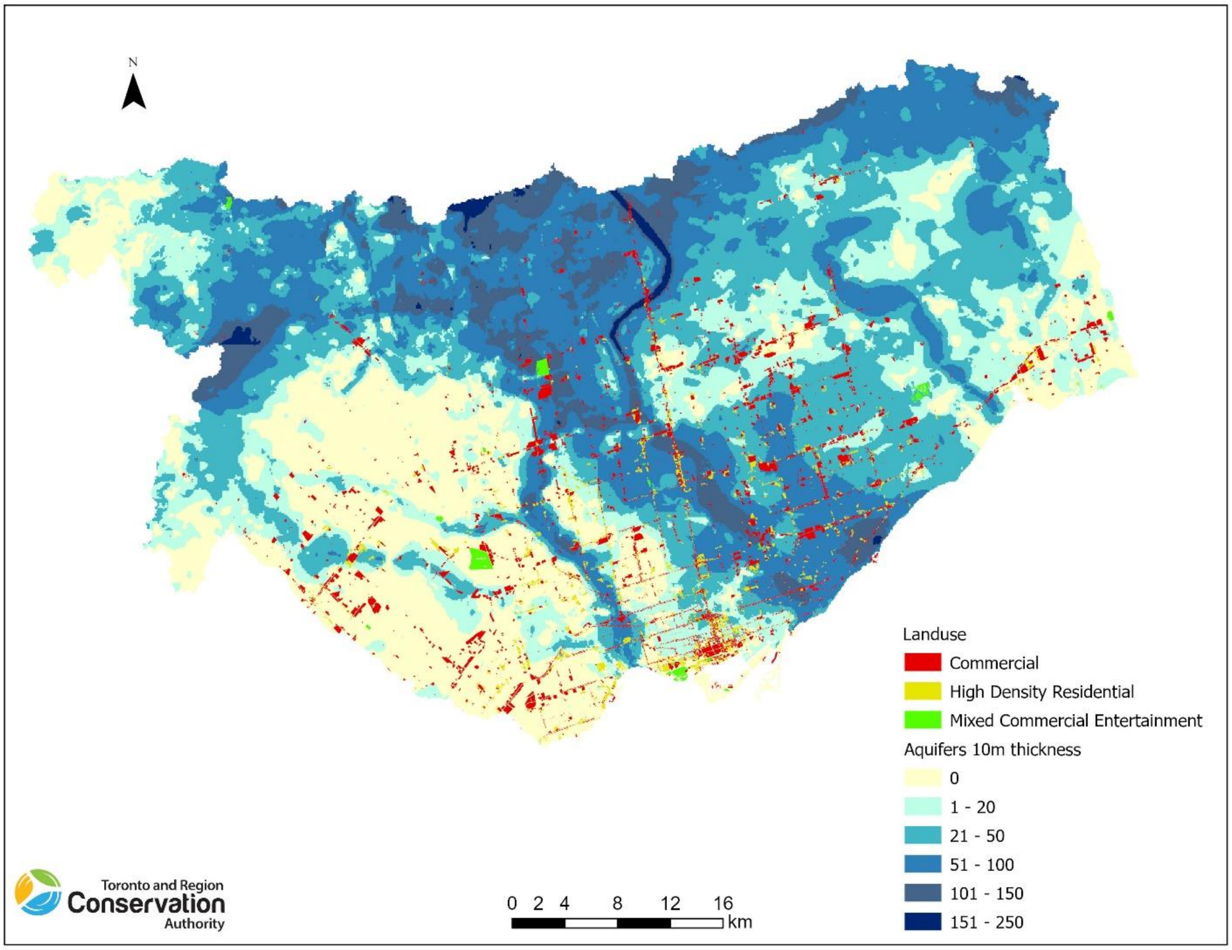
Preliminary Analysis of ATES Implementation Potential across the Greater Toronto Area

To provide a high-level estimate of the potential for implementing ATES across the Greater Toronto Area, a map of aquifer thickness was overlaid with land use information to identify areas where energy usage and heat demand corresponds with the likely presence of productive aquifers. This preliminary assessment of ATES scale-up should be used to influence policy development and guide allocation of resources for further evaluation of this technology at a neighbourhood and site scale.

The energy impacts of full-scale ATES deployment in the GTA are estimated to be equal to a 67% reduction in natural gas usage, 211% increase in electricity for space heating, and 36% reduction in electricity reduction for space cooling. The total emissions reduction expected would be 575,886 tCO2e per year (51% reduction).

The availability of groundwater varies considerably across the TRCA jurisdiction, with, on the low end, some wells reflecting no to very low quantities of groundwater available (i.e. < 6 USGPM) whereas on the high end, there are wells that can continuously provide over 240 USGPM. With such a large range in groundwater availability, a methodology was developed that can allow for a focus on those areas with greater groundwater potential. The location of high-capacity production wells is related to the geology of the area. To assist policymakers identify key areas for potential ATES development in the GTA, aquifer maps were constructed through a lengthy process of examining the geology associated with wells in numerous cross-sections across the area. To identify locations where more high capacity, productive wells might be successfully drilled in the future for open loop geothermal systems, these aquifer maps are key.

For this report the top two categories of aggregate aquifer thickness were considered to have high potential to support ATES (101-150 and 151-250m). Categories of aggregate aquifer thickness of 21-50m and 51-100 were considered to have medium potential to support ATES. The lowest two categories of aggregate aquifer thickness were considered to have low to no potential to support ATES systems. This assumption is very high-level and intended only to provide a general indication of the likelihood of suitability for an ATES system, which would require further analysis in the case of a real project or installation.



For an ATES installation to be economically feasible, the location of the wells should be nearby the end user. To identify where high potential aquifer correspond to heat demands, land-use mapping was utilized to indicate areas of High-Density Residential (HDR) and Commercial (COM) land areas. The total amount of HDR identified in the land use mapping was 2,878 hectares. Most of this land is in the City of Toronto (78%). 3% of all HDR land area is located on high potential ATES zones. Approximately 42% of all HDR land falls with medium potential ATES. 5% of all COM lands fall within the high potential ATES zones, and 42% of all COM lands fall within medium potential ATES zones.

The energy impacts of full-scale ATES deployment in the GTA are estimated to be equal to a 67% reduction in natural gas usage, 211% increase in electricity for space heating, and 36% reduction in electricity reduction for space cooling. The total emissions reduction expected would be 575,886 tCO_2e per year (51% reduction).

Switching to an ATES system for the areas of interest will require a shift from use of natural gas to electric space heating. As a result, the winter peak demands will increase. The impacts on the grid can be challenging to forecast as there are many factors that can impact peak demand. In general, ATES systems are more efficient than the typical ground source closed loop heat pumps, and air source heat pumps. They operate at a higher efficiency because the entering water temperatures into the heat pumps are generally more stable. Because of the higher efficiency levels, the demand is also reduced.

It is also important to note that sites that are not located on a suitable formation for ATES can also make use of alternative ground coupled thermal technologies such as borehole thermal energy storage or closed loop systems. Finally, ATES is a highly effective technology that has been proven internationally, and there is good potential for its deployment in the GTA in areas of high energy use. As Ontario's energy supply becomes electrified, annual electricity consumption will increase and peaks will grow. ATES and other ground coupled technologies can help offset these increases by providing options for space heating and cooling with very high efficiencies.

Project Objectives

Main activities

Geo-exchange systems in general, and ATES systems in particular, provide the opportunity to electrify heating in a highly efficient manner, avoiding any rapid growth in winter peaks. The main target market is district heating and cooling systems, but ATES and seasonal thermal storage can be applied to many markets where thermal loads are significant, including the greenhouse sector and many industrial applications. According to a study completed by CEEDC in 2023 for CanmetENERGY-Ottawa, there are over 60 district energy systems in Ontario, and of those 35 reported a total heating capacity of 1916 MW and cooling capacity of 617 MW. York University with 59,300 people on campus (students, faculty and staff) is the third largest university campus in Canada and the second largest in Ontario. Results of the proposed study were designed to inform York University management about potential next-phase investment decisions for significantly reducing the university campus carbon footprint, lowering the university utility bills and at the same time help with Ontario's electric grid peaks.

By using seismic methods, normal upfront costs of locating suitable aquifers could be reduced for ATES and thus reduce the risk of investing in infrastructure that may not achieve the desired ATES system performance.

Specifically, one of the principal objectives of the present study is to use a Canadian university campus with a significant heating and cooling load as a base case study in order to assess the benefit of economies of scale on the economic viability of seasonal storage. The goal would be delivering near 100% emission-free heating and cooling of buildings and communities with efficiencies significantly higher than those of ground source heat pumps. The results will determine the extent of electrical demand reduction that could be expected relative to the size and cost of the seasonal storage system. Similar such systems are popular in Europe, with over 2000 documented installations in the Netherlands alone, but not in Canada or North America more generally. There were about six ATES system installation attempts in Canada in the 1980s, however, none are believed to be currently operating. A combination of reasons for the limited popularity if any of ATES applications for cooling in North America might include relatively low energy costs, a lack of financial incentives to persuade implementation of such systems, and the very limited availability of experienced trades in North America needed to construct and operate such systems.

ATES systems are significantly cheaper than traditional borehole-based, closed loop geo-exchange systems. However, ATES are highly dependent on the availability of a suitable aquifer, and the data gathering and analysis of the underground conditions can be costly and time consuming. Clearly, the incorporation of thermal storage in larger heating and cooling systems also allows a certain amount of inherent nimbleness to lower peak electricity demands, by preferentially drawing on stored heat (or cold) during periods of peak load, whether local or provincial. It also increases the flexibility and resilience of the system. In addition, specific to York's Keele campus, for a long time the campus has been generating a significant portion of its own electricity through natural gas powered cogeneration.

This has allowed the campus to grow without being restricted by the amount of power available from the LDC, resulting in the current situation where increased use of grid electricity is a desirable path to lower GHG emissions, but is not possible because the LDC's local facilities cannot support the scale of required changes. By incorporating inter-seasonal thermal storage, especially for cooling, York could avoid adding to provincial grid peaks during hot weather. As part of this project, a detailed non-intrusive non-destructive seismic survey of the York's Keele campus was completed to identify if any locations on site would be suitable for ATES wells.

A cost comparison was conducted between the seismic survey approach and the current practice in North America of using borehole drilling survey approach for mainly BTES applications to provide insight on the most cost-effective method of locating suitable aquifers. The cost comparison shows that by using seismic methods, normal upfront costs of locating suitable aquifers could be reduced for ATES and thus reduce the risk of investing in infrastructure that may not achieve the desired ATES system performance.

The project expanded on an existing high accuracy TRNSYS simulation model of the York's Keele campus district cooling system and cooling equipment, by adding the heating equipment and heating loads into the model. Using the existing cooling-only model, the previous study estimated that the electric annual and peak loads could be greatly and cost-effectively reduced by integrating ATES into the York University DHC|CHP system. Using the expanded TRNSYS model developed within this project, the techno-economic benefits for both heating and cooling loads were estimated for the first time for this university campus. As the results of the seismic survey confirm that there is no suitable aquifer on the York

University campus, alternative large-scale underground storage options such as pit and borehole thermal energy storage (PTES, BTES) were considered in the techno-economic analysis.

As mentioned above, the current drive to reduce GHG emissions through electrification brings substantial challenges regarding the electrical system infrastructure. Geo-exchange systems with inter seasonal energy storage can provide significant energy and demand savings, and increase flexibility and resilience. This project addresses implementation barriers for ATES while also providing a comprehensive feasibility analysis that can be used to evaluate opportunities not only for York University, but also for similar applications. Beyond the proposed study, the data, information, design and analysis tools, and analysis methodology developed, as part of this project will continue to be used, further improved and adapted as part of NRCan's research program in this area. These tools and methods could be used to assess other large-scale underground seasonal storage systems, for projects in Ontario and in other Canadian provinces and territories.

To summarize, the Project had three main activities. The results of the following tasks are shared in this report:

1) Using York University's Keele campus as a test case, the project applied high-resolution seismic mapping techniques pioneered by NRCan's Geological Survey of Canada (GSC) to non-invasively characterize aquifers in sufficient detail to support investment decisions in geothermal systems. The GSC's seismic mapping techniques can characterize major aquifers programs at a potential cost lower than drilling test wells/boreholes;

2) Once ground information was obtained, a techno-economic analysis was completed. This analysis evaluated the incorporation of thermal energy storage (using aquifers, boreholes or thermal pits) to the campus' existing district heating and cooling system. The analysis also included the conversion of much of the heating and cooling loads from natural gas to electricity, while avoiding increased electricity demand during peak periods; and

3) Project results were disseminated, including a preliminary analysis of ATES implementation potential across the GTA, to policy makers, universities, colleges, commercial entities and government agencies that own and operate district energy systems in the GTA. Such users are better equipped to understand the potential of large geothermal systems, especially when coupled with thermal energy storage. In addition to district energy systems operators, other large users of thermal services such as industrial facilities and greenhouse operations can also benefit from the results of this Project.

Background & Methodology

DHC in Canada

Although Canada's power grid is over 80% non-emitting, heating is largely reliant on natural gas. In the commercial and institutional sector, over 50% of overall energy consumption is fueled by natural gas, and only 13% of space heating is met using electricity. Natural gas usage in this sector has largely remained constant since 2018 and meeting the energy needs of large end users like university campuses represents a challenge to cost-effective decarbonization. The imperative to rapidly reduce GHG emissions comes with a move to electrify heat. Widespread heat electrification could grow winter peak demand substantially, even beyond recent summer peaks, thus requiring additional investment in generation, transmission and distribution equipment. Geothermal systems in general, and ATES systems in particular, provide the opportunity to electrify heating in a highly efficient manner, avoiding any rapid growth in winter peaks.

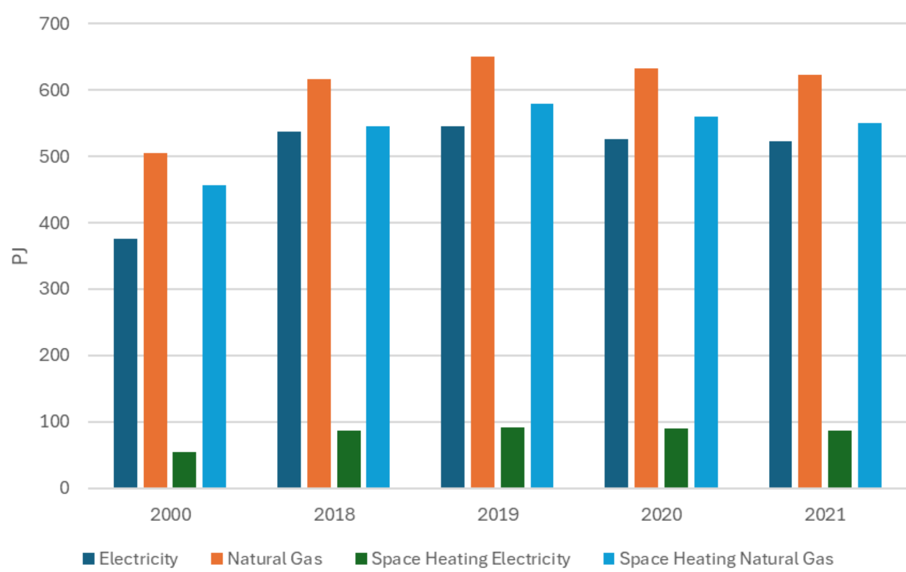


FIGURE 2: ENERGY USE IN THE CANADIAN COMMERCIAL/INSTITUTIONAL SECTOR

Since 2012, CanmetENERGY has supported the development and upkeep of a national District Energy (DE) systems inventory survey and database, which is administered and maintained by the Canadian Energy and Emissions Data Centre (CEEDC) of Simon Fraser University. An update to the inventory was completed in 2023, and identified 238 systems in operation in Canada. Although operational data has not been collected for all systems, a summary of some known system information is shown in Table 1 below.

TABLE 1: SUMMARY OF CANADIAN DISTRICT ENERGY SYSTEMS [1]

2023 DE Inventory Summary	District Cooling	District Heating			CHP Electric
		Steam	**Hot Water**	**Total**	
Installed Capacity (MW)	**981**	**3990**	**1024**	**5014**	**314**
Energy Supply (GWh)	**1439**	5135	**2038**	**7173**	**738**
Network Length (km)	**191**	**209**	**151**	**359**	**-**
Building Area (million m^2)	**20.8**	**28.1**	**13.3**	**41.0**	**-**

As indicated in Table 1, at least 41 million m^2 of buildings are connected to a DHC network in Canada. This is equivalent to approximately 280,000 households in terms of building area, or roughly 1.4% of the total Canadian building stock. If single-family dwellings are omitted from this comparison, given the primary application DE is with commercial, institutional, and multi-unit residential buildings, the connected area value equates to around 3.2% of that more targeted building stock.

Approximately two-thirds of the 238 DE systems identified in the national inventory are affiliated with campus installations, including university and college campuses, as well as healthcare facilities, military bases, corrections institutions, and other government campuses. The remaining systems are generally operated by municipal or private utilities, providing thermal energy services to both public and private building customers.

The distribution of DE systems by region is shown in Figure 3, with the greatest number of systems operating in Ontario and British Columbia. Over half of all systems in Canada have been commissioned since 2000. Many of the oldest systems, which are also some of the largest, have steam distribution. However, as shown in Figure 4, the relatively high number of new systems have trended to operate with lower temperature hot water networks. The latest inventory found that newer systems have integrated a larger proportion of renewable and low carbon energy technologies and sources, a key benefit of operating with lower temperature distribution.

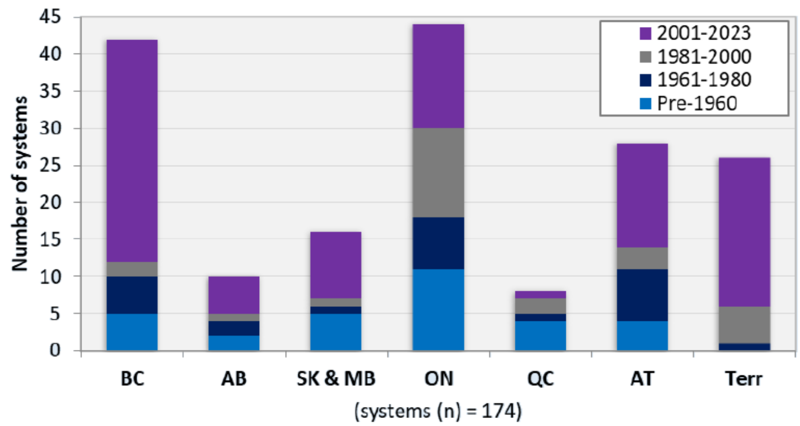


FIGURE 3: DISTRIBUTION OF CANADIAN DISTRICT ENERGY SYSTEMS BY REGION AND VINTAGE [1]

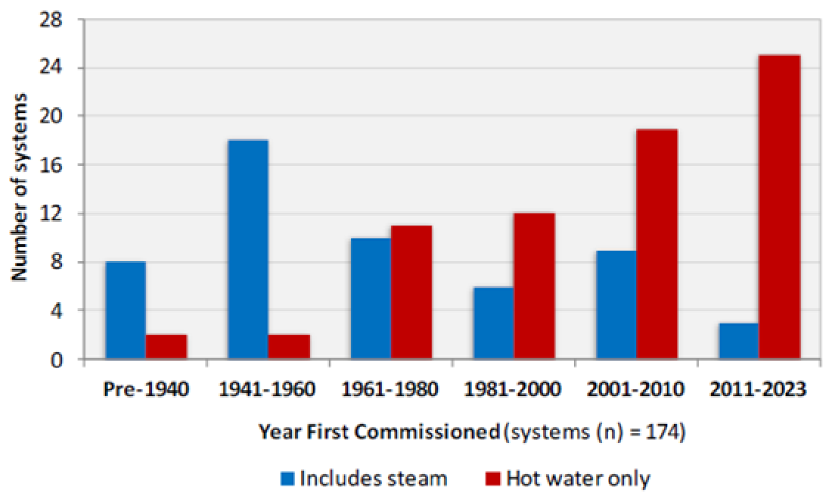


FIGURE 4: DISTRIBUTION OF CANADIAN DISTRICT HEATING SYSTEMS BY NETWORK TYPE AND VINTAGE [1]

From the CEEDC inventory, natural gas is the most heavily used energy source in Canadian DE systems. Over 80% of systems use at least one fossil fuel (natural gas or oil), while 37% of systems include at least one renewable or low carbon source (biomass, geo-exchange, or solar). As shown in Table 2, two-thirds of system operators who responded to the survey question on system decarbonization indicated some degree of consideration to integrate lower carbon technologies and sources in their systems, including heat pumps, electric boilers, energy storage, and geo-exchange. Thus, it is evident that reducing the carbon intensity of thermal energy delivered is a high priority for system operators.

TABLE 2: DECARBONIZATION OPTIONS BEING CONSIDERED IN THE NEXT FIVE YEARS BY CANADIAN DISTRICT ENERGY SYSTEM OPERATORS [1]

	Responses	
Heat Pump	18	67%
Heat Recovery (Industrial, sewage, etc.)	16	59%
Electric boiler	12	44%
Temperature reduction	10	37%
Energy Storage	8	30%
Geoexchange	7	26%
Biomass	6	22%
Steam to hot water conversion	6	22%
No option being considered	9	33%
Total systems (n)	27	

DHC system and Current energy and utility usage

Founded in 1959 and located in Toronto, Ontario, Canada, York University is the second largest University in Canada and includes three campuses all located in the City of Toronto, Ontario, Canada. York University's main "Keele" campus, which is considered in this study, covers 185 hectares and hosts a self-contained community of approximately 100 buildings (totaling 750,000 m² of floor space), 50,000 students, and 7,000 staff.

The majority of the buildings on the York University campus are heated by steam (1,700 kPa) and cooled by chilled water (~5°C) generated at the Central Utilities Building (CUB) at the northeast corner of the campus. The steam and chilled water are distributed throughout campus by a 3.6 km network of service tunnels. There are also two 5.2 MW gas-fired cogeneration (electricity and heat) units located adjacent to the CUB. Figure 5 is a map of the campus, highlighting the CUB. Figure 6 illustrates the location of the different main components of the central generation units in and around the CUB building.

The central plant currently has capacity for 14,100 tons (50 MW) of cooling (both steam and electrically driven chillers), ~75 MW of total steam, and ~10 MW of electricity. Additional electricity required to meet the 21 MW electric-peak load is sourced from the grid and purchased from local electric utility, Toronto Hydro. The cooling system utilizes six centrifugal chillers, one steam turbine centrifugal chiller, and one single-effect absorption chiller, all eight of which are water cooled and reject energy to the condenser cooling tower loop. More details on the existing system, including specifications for the chillers, cooling towers, and chilled water and condenser pumps can be found in [2]

On an annual basis as of 2019, the existing DHC system at York delivers approximately 220,000 MWh of heating, 55,000 MWh of cooling, and 66,000 MWh of electricity produced by the co-generation units. Annual electricity purchased from the grid amounts to approximately 30,000 MWh. The total annual university utility costs in 2019 were about $15 million (CAD). Approximately $5 million is attributed to electricity import during peak time, $7 million for natural gas use, and $2.5 million for water.

York University Keele Campus GHG emissions in 2019 reached a total of about 62,000 tons CO_2. Approximately 60% of these fossil fuel (natural gas) generated emissions, 37,000 tons CO_2, are attributed to the University Campus thermal consumption for heating and cooling. Two thirds, 25,000 tons CO_2, of thermal consumption is for heating and one third, 12,000 tons CO_2, is attributed to Campus cooling. The reminder 40% of the total Campus GHG emissions of about 25,000 tons CO_2 is attributed to the on-site co-gen electricity generation.

York University is developing a plan with milestones to reduce fossil fuel use, mainly natural gas, and to bring the Campus operations to carbon neutrality by 2050. In addition to the university carbon footprint, the university is also looking into reducing their increasing utility costs discussed above, be mindful of the ageing infrastructure and their timely replacement as well as planning for the anticipated University growth. A wide range of technologies and solutions are continuously explored by the university planners. Results of the present study, assessing the potential and limits of integrated ATES DHC|CHP system, will inform York University in their efforts in developing a suite of cost-effective solutions to achieve the medium and long-term GHG targets and university campus operational key performance indicators.

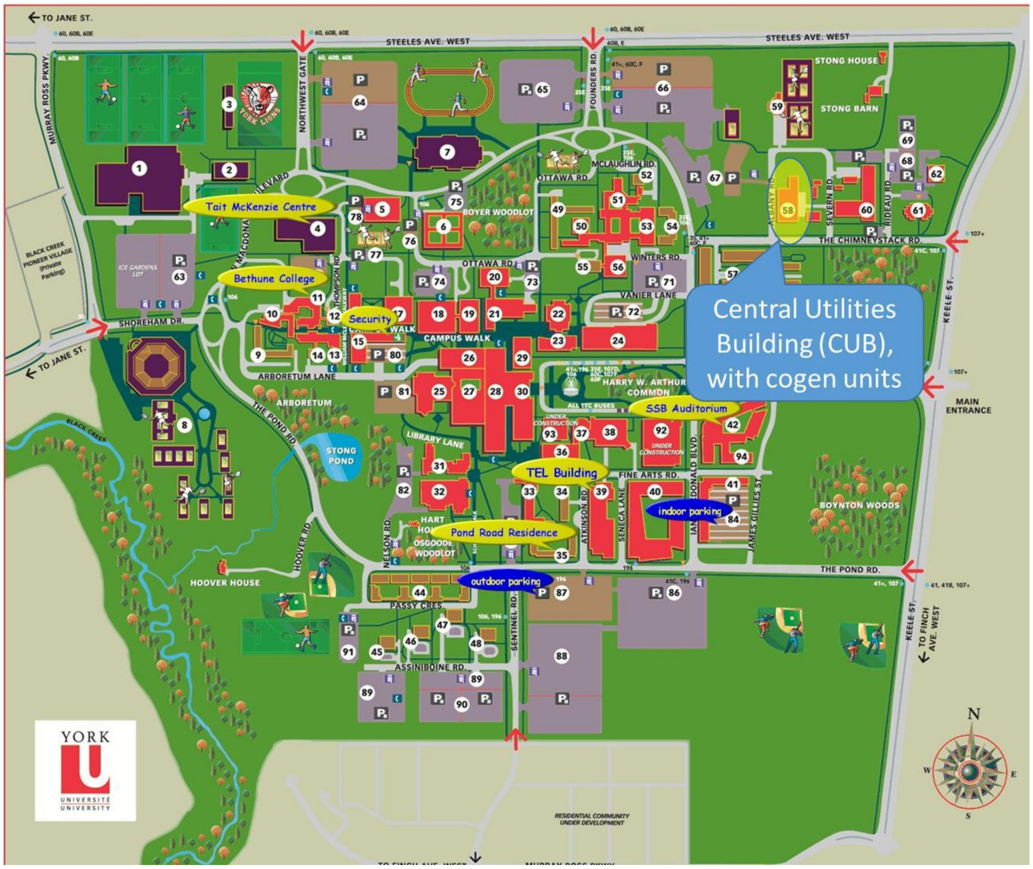


FIGURE 5: MAP OF YORK UNIVERSITY CAMPUS, INCLUDING CENTRAL UTILITIES BUILDING

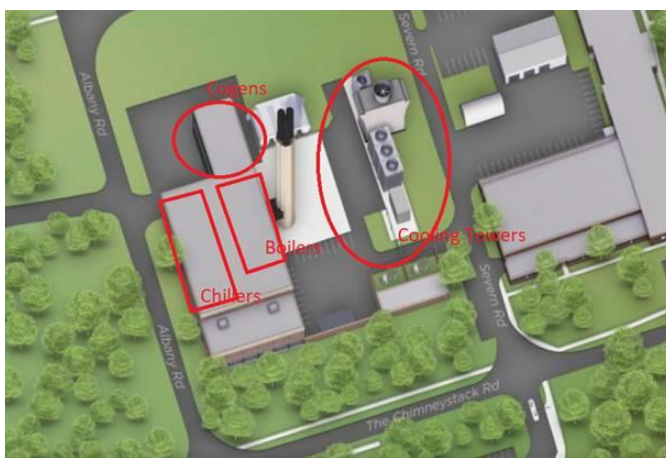


FIGURE 6: OVERHEAD VIEW OF EXISTING COMPONENTS OF YORK UNIVERSITY DHC CENTRAL UTILITIES BUILDING

Previous Studies

Site Conditions

A 1987 study conducted by Strata Engineering indicated a 50% chance of a suitable sand formation present below York University Keele Campus site at depths ranging from 35 to 60 m, with potential yield of 160 – 475 USGPM (10 – 30 L/s). A study commissioned by Environment and Climate Change Canada for their Downsview location approximately 2 km from the York site indicated a potential yield of up to 635 USGPM (40 L/s). Both studies estimated ground water natural temperatures of 9-10°C.

Two major aquifers, Oak Ridges and Thorncliffe are located within the vicinity of York University, though reviews of geological conditions indicate that neither are within the boundary of the campus. A recent literature review and desktop study conducted in 2018 reviewed wells within a 5 km radius of the Keele campus to determine the chance of locating a high capacity well, but found that most wells in the Thorncliffe aquifer could not sustain flows over 158.5 USGPM (10 L/s). One higher capacity well was found 4 km northwest of the university tested at 475.5 USGPM (30 L/s) [3]. The report recommends that lower capacity open loop geothermal or closed loop geothermal systems would be feasible, though the known aquifer conditions would likely not support a conventional open loop system.

Using a regional hydrogeological model to identify candidate areas for aquifer thermal energy storage in the GTA, Ford and Wong in 2010 indicated a significant areas with “favorable” and “acceptable” aquifers including in the vicinity of York University Keele Campus as shown on below Figure 7.

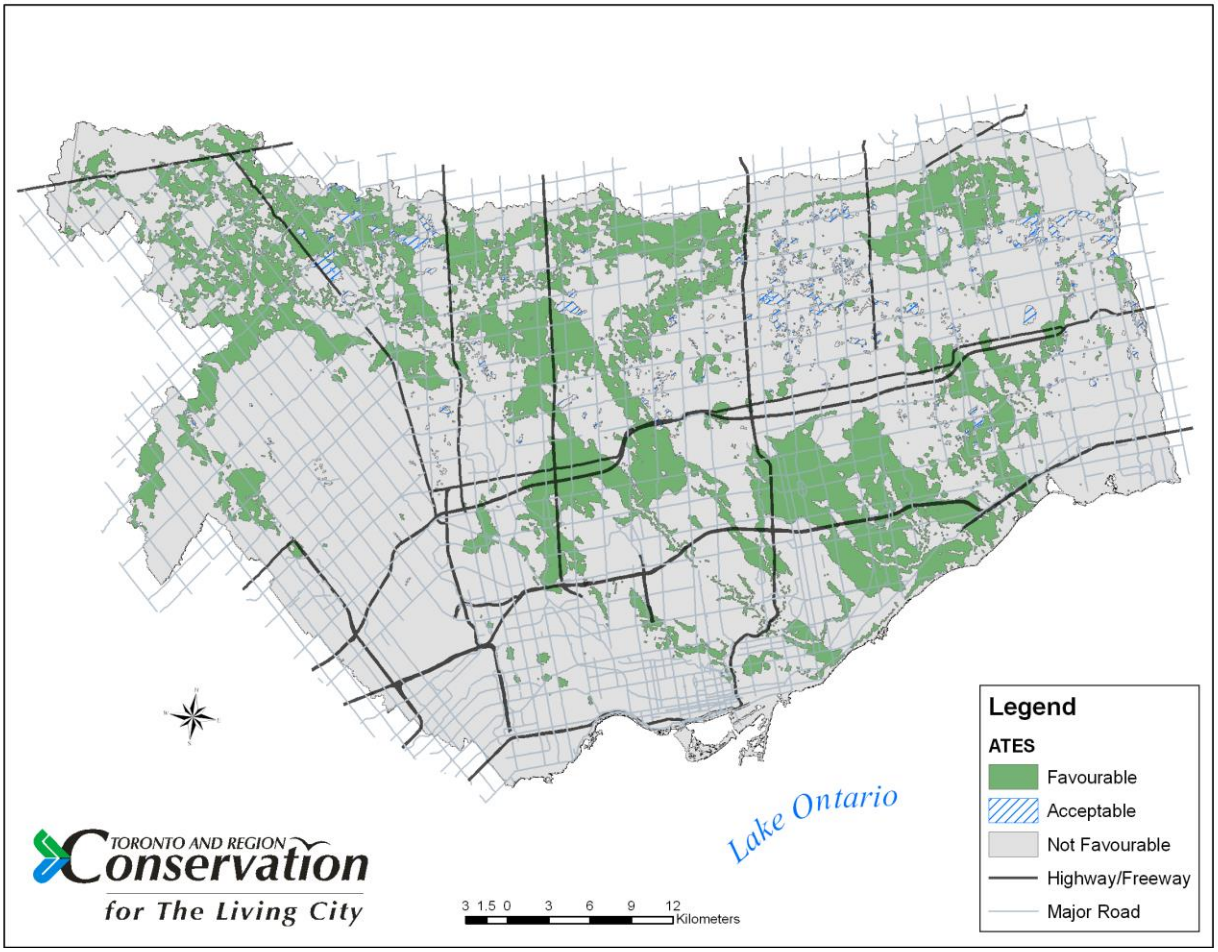


FIGURE 7: TRCA AQUIFER MAPPING

IEA DHC Annex XII: Integrated Cost-effective Large-scale Thermal Energy Storage for Smart District Heating and Cooling

Running from 2017 to 2020, the IEA DHC Annex XII Project *Integrated Cost-effective Large-scale Thermal Energy Storage for Smart District Heating and Cooling* investigated an aquifer based cooling system for York University. The proposed system deposited warmed water produced by the cooling system into the warm section of the aquifer and the cool section of the aquifer to store cooled water produced during the winter heating season. The cool section of the aquifer could then be used to supply cold water in the summer months. The system sought to add the aquifer storage to the existing system with minimal replacement of equipment. The study therefore focused on the wellfield design, underground and surface elements of the wells, including pumps, piping, and operational scenarios and controls. The study utilized TRNSYS software to conduct all performance modelling, including developing detailed models of the existing DHC system, cooling loads, and ATES scenarios. Measured data was used to perform a limited calibration of the model, which was then used to predict the plant performance with a variety of ATES integration configurations. A total of 11 different scenarios were developed to investigate integration of ATES for supplying the cooling. The scenarios included configurations that used the ATES to meet baseload cooling needs, considering designs with either 4, 9, or 20 well pairs, as well as designs which used the ATES to meet peak load with different well field sizes. Additionally, the study included scenarios which charged the ATES during low electricity price periods to try to minimize costs.

The study also included validation of the aquifer model, comparing a 3D hydrologic model from the United States Geological Survey to the TRNSYS-based component that uses a finite difference approach assuming no thermal interaction between each well doublet. The TRNSYS based component was found to produce excellent results with much faster simulation time and has been used in the current study.

The findings from that study indicate a positive, though generally modest, return on investment for all ATES designs considered. Two of the greatest factors influencing financial viability are whether the steam chillers (and cogeneration units) operate in base load or peak load mode, and at what cost the steam delivered to the steam chillers is valued. These are factors relevant to York's existing equipment, independent of whether or not an ATES system is added. The various concept designs were demonstrated to have excellent potential to reduce GHG emissions. The integration scenario with two times 20 ATES wells was found that it can substantially reduce cooling GHG emissions by up to 85% with a reasonable 25 year investment rate of return of over 10%. This is achieved by switching the steam chillers from serving the base load to serving the peak load, thus substantially reducing their operating hours each year, while increasing that the electric chillers. One major limitation to the economic viability of the scenarios considered in that work were the fact that they provided only cooling. Although the scenarios were designed to avoid costly and complex modifications to the existing DHC system, the addition of heating capabilities were noted as a potential pathway to greater economic viability.

Milestone 1.1: Characterization of the hydrogeological properties of York University's Keele campus underground - Geophysics data collection

To date, investigative techniques related to site characterization for the development of ATES systems have relied on geological knowledge of the area, water well analysis and geological models developed from water well records. Site investigations have involved drilling that has commonly employed either continuous coring or water well-style borehole development. Collection of continuous core to depths over one hundred meters can be expensive and result in minimal site characterization, given that subsurface properties and the presence of productive aquifers can vary greatly within relatively small distances. Geophysical techniques provide an opportunity to collect more data and provide an enhanced framework for subsequent drill site selection. The scope of this geophysical survey was as a case study on the application and value of the geophysical techniques in reducing site selection uncertainty, for example improving the optimal location of boreholes. It was not completed to confirm the feasibility of a site. The assessment of the likelihood of the site conditions to support an ATES was done under the scope of Milestone 2, taking into account the scale of the system planned.

To support an ATES system at York University three geophysical datasets were collected. Surface and downhole geophysical data was collected at the York University, Tennis Canada, and Toronto Regional Conservation Authority (TRCA) campuses, near the intersection of Highways 400 and 407 in Toronto, Ontario as shown in Figure 8. Three geophysical datasets are described: microtremor analysis (the horizontal-to-vertical spectral ratio technique, HVSR), seismic reflection, and downhole geophysical logging.

The potential of the HVSR technique as a low-cost approach to estimating depth to bedrock was demonstrated, and a reconnaissance survey of 18 stations was completed. A seismic reflection survey was completed to provide information on depth to bedrock, the stratigraphic architecture and seismic facies. This information can be used to better constrain understanding of the aquifer target location, geometry and heterogeneity. To demonstrate how downhole geophysical techniques can provide aquifer and stratigraphic characterization and parameterization a suite of logs were collected (gamma, conductivity, magnetic susceptibility, velocity, and temperature). Due to borehole constraints the nuclear magnetic resonance (NMR) survey was completed in an appropriately cased (3 inch) diameter borehole to the north of Toronto Regional Conservation Authority borehole and York University. Figure 8 shows Map of the York University campus study area with the three seismic reflection profiles (red lines) and 18 HVSR sites (light blue circles with crosses). Dark blue dots represent wells in the Groundwater Information Network (GIN) and Ontario Geological Survey (OGS) databases that provided material (mud, sand, gravel, till) information for the study area. The TRCA observation well used for seismic calibration is marked with a pink dot south of the Tennis Canada profile. Coordinates are shown in UTM NAD83 zone 17. An inset map of land surface topography between Georgian Bay and Lake Ontario with York University location indicated by red circle is also shown.

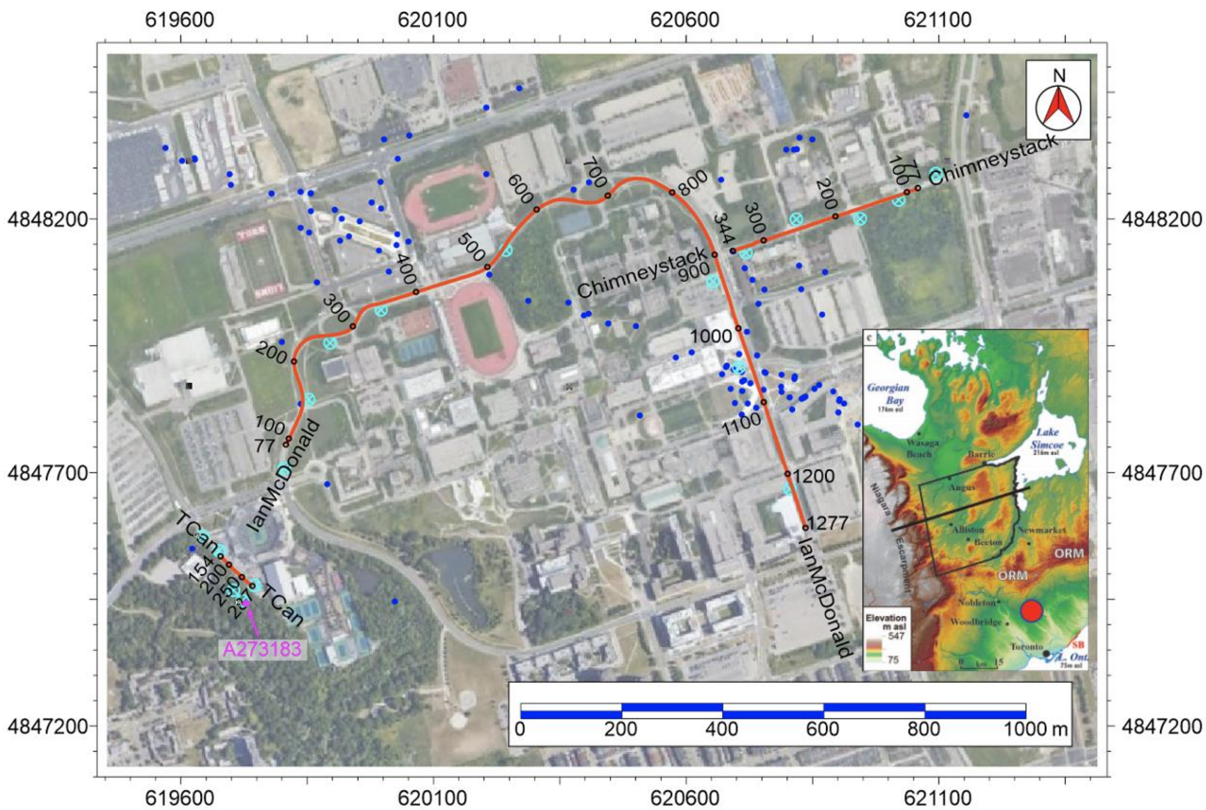


FIGURE 8: MAP OF THE YORK UNIVERSITY CAMPUS STUDY AREA WITH THE THREE SEISMIC REFLECTION PROFILES, 18 HVSR SITES

York University is located to the southwest of the intersection of Steeles Avenue and Keele Street in the city of North York (Figure 3). The campus is bounded to the west by Black Creek and covers an area of approximately 2 km^2 (~500 acres). The campus is situated 195 to 200 metres above sea level, and slopes gently to the west. The north edge of campus is located approximately 8 km south of the Maple Spur of the Oak Ridges Moraine and the old Keele landfill site. Golden Spike boreholes in the area include Earl Bales, approximately 6 km to the south-east, Kleinburg, ~16 km to the north-west, and King City ~18 km north.

Figure 9 (a) shows the area approximately 7 km north of the York University campus (YU, black arrow) on a digital elevation model (graded colours) with municipal supply well and monitoring well locations. The approximate boundaries of the Yonge Street Aquifer are outlined by the dashed corridor. Figure 9 (b) illustrates a west-east cross-section (along the X-Y axis) showing a historical depiction of the Bradford, Yonge Street, and Mount Albert aquifers, from International Water Consultants Ltd. 1991.

A continuously cored borehole at the TRCA property terminated at 125 m depth in sand without intercepting bedrock. The regional stratigraphic units intersected were Lower sediments Scarborough sands overlain by sand and diamicton from 110–45 m, succeeded by diamicton from 15-5 m (Newmarket Till) and surficial sand.

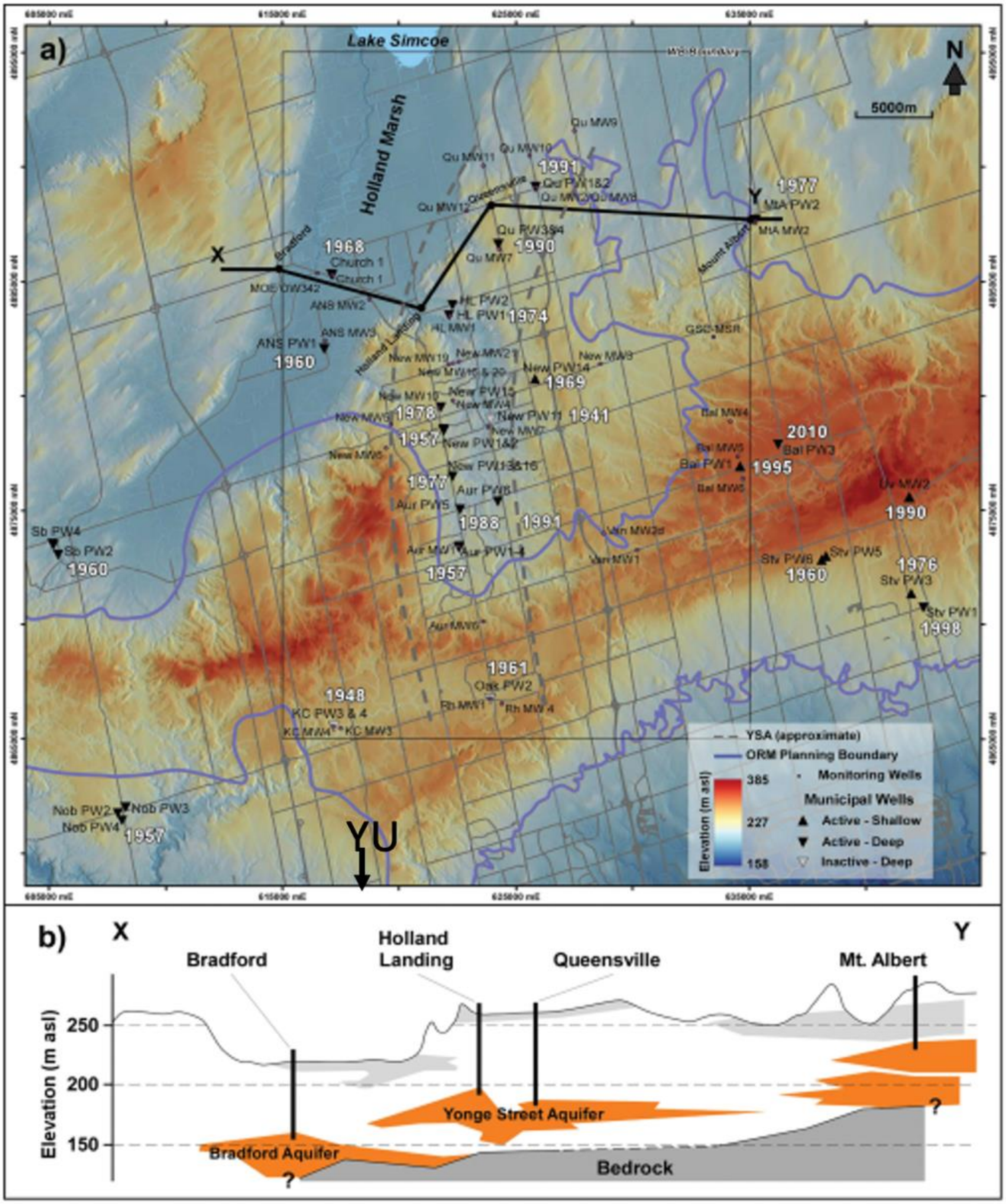


FIGURE 9: (A) MUNICIPAL WELL SUPPLY AND MONITORING LOCATIONS (B) CROSS-SECTION OF THE BRADFORD, YONGE STREET, AND MOUNT ALBERT AQUIFERS (ADAPTED FROM [4])

Data Collection

Passive seismic data were recorded at 18 stations along the seismic reflection alignments using a digital seismograph. The seismograph was placed on bare soil and recorded vibrations in three directions (N–S, E–W and vertical) for 30 minutes. A calibration HVSR station was located at the TRCA well (well tag A273183). Sediment descriptions and geophysical logs collected in this well during the project provided the lithological and shear-wave velocity information required to convert the HVSR curve amplitudes, measured in frequency, to depth. During the survey wind strength was high and gusty. The proximity and concentration of large buildings can therefore require further post processing to eliminate the effect of buildings in the current interpretation.

Reflection seismic data were acquired on the York University campus along three profiles ranging from 85 m to 1790 m in length for a total length of 2.26 km (Figure 1). The Tennis Canada (TCan) profile is 85 m long and was acquired in the parking lot next to the TRCA observation well thus providing the link between lithologies identified during the core logging and the seismic signatures. The Ian McDonald (IMCD) profile is 1790 m long and follows the winding road from west to north-east and southwards. The Chimneystack (CHIM) profile is 388 m long, and was acquired from east to west along Chimneystack Road. The western end of CHIM is 36 m east of CMP 902 of IMCD.

Borehole geophysical data were collected in the TRCA's 2.5" PVC-cased observation well using the GSC's borehole geophysical logging system [5], [6]. The following suite of instruments were run: high-resolution temperature, inductive bulk conductivity and magnetic susceptibility, natural gamma, and downhole triaxial geophones to calculate shear-wave velocities. The integration of new, industry-developed slim-hole nuclear magnetic resonance (NMR) technology into the suite of tools was the first known deployment in the glacial sediments of southern Ontario, and is an innovative aspect of this project. As the NMR tool diameter is too large for the 2.5" TRCA well, the NMR tool was run in a 3" PVC borehole located 25 km away in a comparable glacial sediment setting.

Horizontal-to-Vertical Spectral Ratio (HVSR)

The geophysical method known as microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) has evolved from earthquake site characterization [7] to more general subsurface characterization. The digital seismograph used to collect the data is portable and designed for one-person use. The technique is ideally suited to simple sedimentary settings such as found in the Ottawa area [8].

The highest amplitude (peak) occurs at the fundamental or resonance frequency which is related to the average shear-wave velocity and the overlying sediment thickness, which is usually assumed to equal the bedrock depth. In addition to depth, the HVSR data can be analyzed to provide directional estimations of subsurface structures. H/V amplitudes can vary in direction (azimuth) depending on the direction of subsurface structures such as steeply dipping layers or basins. The most common association of such dipping surfaces are the walls of buried bedrock valleys. The raw, three-component time series collected from the digital seismograph were processed to improve the signal-to-noise of the frequency spectra allowing the resonating layer depth (h, assumed to equal bedrock depth) to be estimated.

Seismic Reflection

High-resolution, near-surface seismic reflection surveys are optimized to illuminate subsurface structures down to the bedrock interface, providing detailed 2-D profiles of unconsolidated sedimentary sequences. This method is ideally suited for geotechnical and groundwater investigations [9], [10] as it can differentiate lithologies using seismic facies pattern and velocity analysis. The survey sites are required to be vehicle accessible (roads or gravel trails) and should be free of obstacles like tight curves or train tracks, where the acquisition would have to be interrupted.

Seismic surveys provide seismic reflection images from shear (S) and compressional (P) waves which can be interpreted in terms of lithological horizon interfaces where a contrast of density and/or velocity occurs in the sedimentary or rock column. Information on seismic velocities are computed during the processing of the survey data; subsurface materials can be inferred from these velocities as well as reflection strength and coherence (facies). Seismic downhole velocities from borehole logging are used for calibration purposes and significantly improve the depth conversion compared to using the travel times of reflection events.

Data collection was carried out by a crew of five people with the aid of a traffic control team (necessary because one traffic lane was occupied by the survey equipment). Data processing was required to improve the signal-to-noise ratio by frequency filtering and stacking of ~24 data traces. Conversion of recorded two-way-travel (TWT) time to depth was based on vertical seismic profiling of shear-wave velocities in the TRCA observation well and on the velocity analysis from the shear-wave reflection data processing.

Downhole Geophysics

Borehole geophysical logs provide a method of identifying and characterizing lithological units based on variations in their chemical and physical properties (conductivity, magnetic susceptibility, mineralogy, density) and the nature of the contacts between the units [11]. In the context of unconsolidated sediments, logs can also be used to interpret variation in hydrogeological parameters (porosity, estimates of hydraulic conductivity) [12] [13] [14]. High-resolution downhole fluid-temperature logs are also capable of identifying potential anomalies caused by fluid movement in aquifer sediments outside the borehole [15]. Velocity logs support the depth calibration of the seismic reflection survey using downhole compression (P) and shear (S) wave travel-time measurements, and provide information on variation in sediment consolidation/density. Interchangeable borehole geophysical tools are deployed on wireline logging systems. In unconsolidated sediment, the tools are run inside a 2.5 inch and ideally a 3 inch PVC-lined borehole, with data traveling up the wireline to be displayed and recorded on a laptop computer.

In southern Ontario, mineralogical composition can be similar between the fine and coarse grain fractions resulting in relatively little variation in the gamma or conductivity logs, although the presence of clay-size grains generally produces increases in both parameters [14]. The magnetic susceptibility (MS) log, which responds to changes in magnetic mineral content, is particularly useful in settings like southern Ontario where sediments are in part derived from the Canadian Shield and can contain magnetic mineralogy. The MS log response generally inversely mirrors the gamma and conductivity logs, as coarse-grained materials have retained a higher percentage of heavier magnetic minerals than fine-grained materials.

Geophysical Survey Results

The HVSR survey maps a number of resonant layers with the strongest contrast being between 1.44 and 1.78 Hz. Based on HVSR depth estimations, bedrock is between 87 to 118m below grade in the study area. Even though these estimates are based on a simplified lithology by using an average Vs, depths match the results from the seismic profiles as shown in Figure 10.

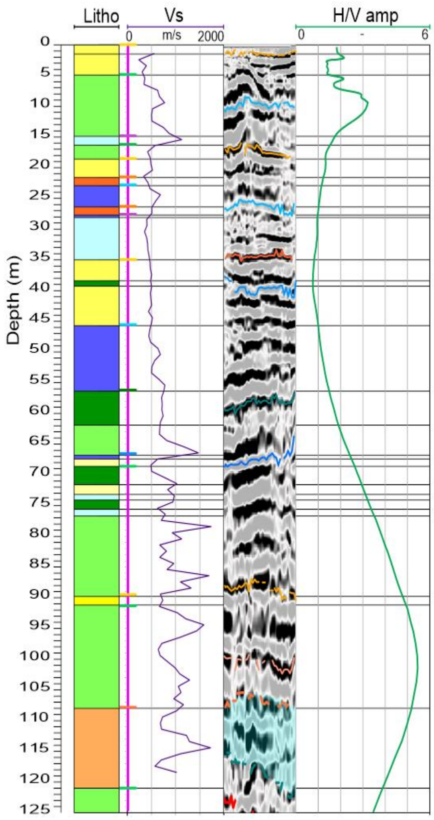


FIGURE 10: (FROM LEFT TO RIGHT) LITHOLOGY FROM THE TRCA OBSERVATION WELL, SHEAR-WAVE VELOCITY FROM VSP LOGGING, SHEAR-WAVE SEISMIC REFLECTIONS AND THE HVSR AMPLITUDE CURVE CONVERTED TO DEPTH.

The shear-wave seismic reflections along the Chimneystack Road (Figure 12) have high reflection strength and coherence allowing a detailed interpretation down to about 80 m depth. Below this depth, the reflected signal is weaker and more impacted by noise from the off-line echoes of building foundations. Reflections are therefore less coherent and bedrock is more difficult to interpret at around 100 m depth (red line in Figure 11). A trough structure is recognizable by the high-amplitude reflections of the fill and the terminated reflections on either side of the structure (outlined with yellow lines). The maximum 55 m depth of this trough structure is present at CMP 215. The structure truncates or cuts the underlying seismic reflectors supporting an interpretation of an erosion feature. This trough (channel) is overlain by the upper diamicton present in the near surface

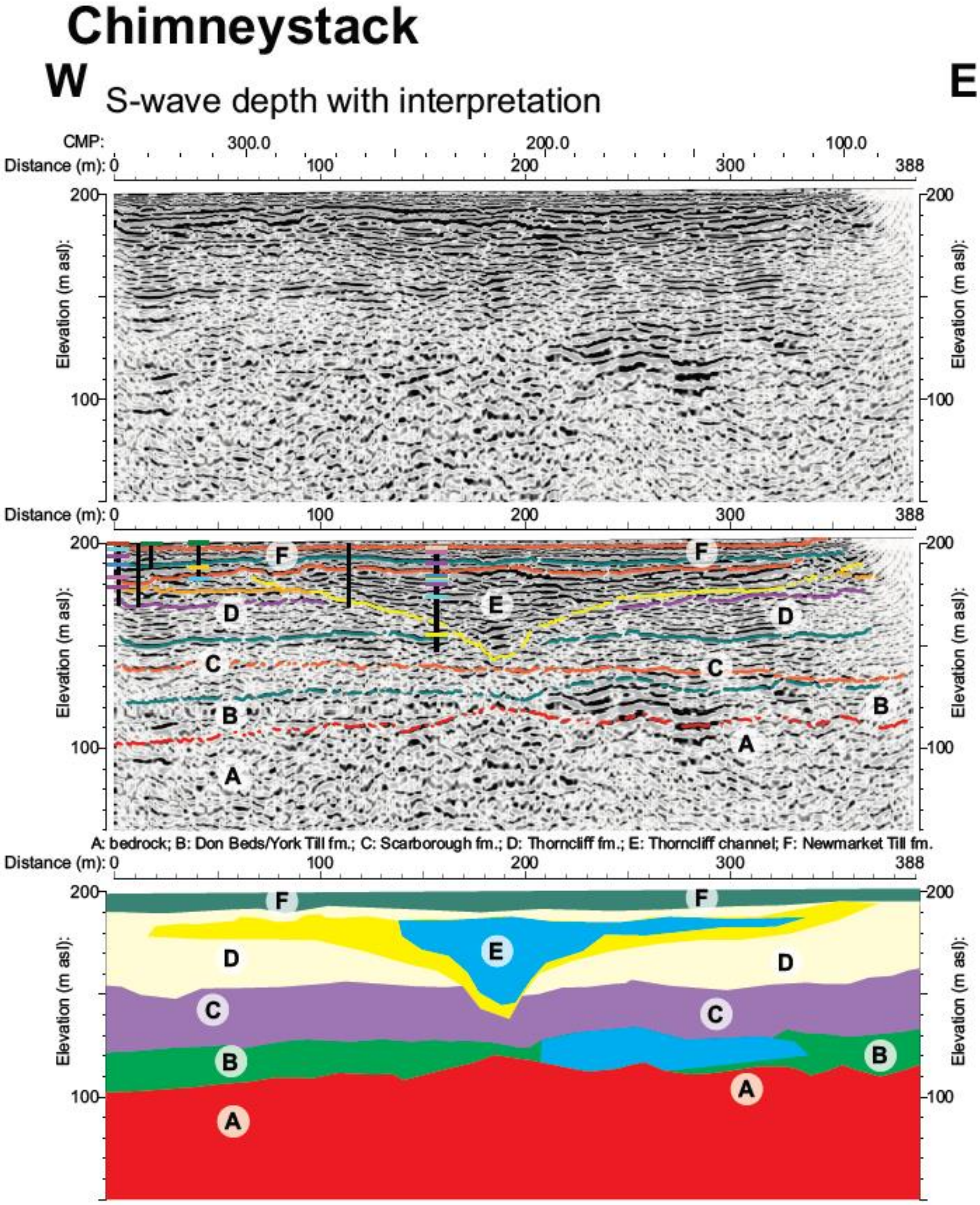


FIGURE 11: CROSS-SECTIONAL SITE CHARACTERIZATION SHEAR-WAVE SEISMIC REFLECTIONS ALONG THE CHIMNEYSTACK ROAD WITH INTERPRETATION SHOWING A FILLED-IN EROSION CHANNEL (YELLOW OUTLINE) WHICH IS 55M DEEP. THERE IS NO VERTICAL EXAGGERATION APPLIED.

The primary aim of the borehole geophysical logging was to identify variations in lithology and fluid response that would indicate the presence of favourable target zones for the ATES system (high yield aquifers). Additionally, the logging sought to allow for the conversion of travel times to depths for the seismic reflection profiles. NMR data collected from the GSC sediment borehole 25 km to the north provided clear indications of which intervals would be favourable targets for ATES systems, identifying the interval between 168 – 181 m as having predominantly mobile water in larger pores, while a shallower interval from 110 – 124 m has less free water and more capillary- and clay-bound water – making the deeper unit a better target.

The TRCA observational bore casing was too narrow for the NMR instrument, so this information was not collected on that site. Downhole geophysics from the TRCA observational bore show an interval that may be partially saturated between depths of 4.9 m and 11.4 m, and that the water table depth varies in this interval with changes in precipitation and season. Data from additional layers around 35 – 45 m (Figure 12, “ii”), and in the open screen at the base of the well (Figure 12, “iii”), suggest these are intervals where groundwater flow is occurring. When interpreted together with the lithological logs, these two lower intervals appear to be the main hydrostratigraphic features in the sediment sequence. The type of information that was gathered via NMR from the GSC borehole would have been particularly useful in the two sandy-gravelly zones identified with temperature increases in the TRCA observation well.

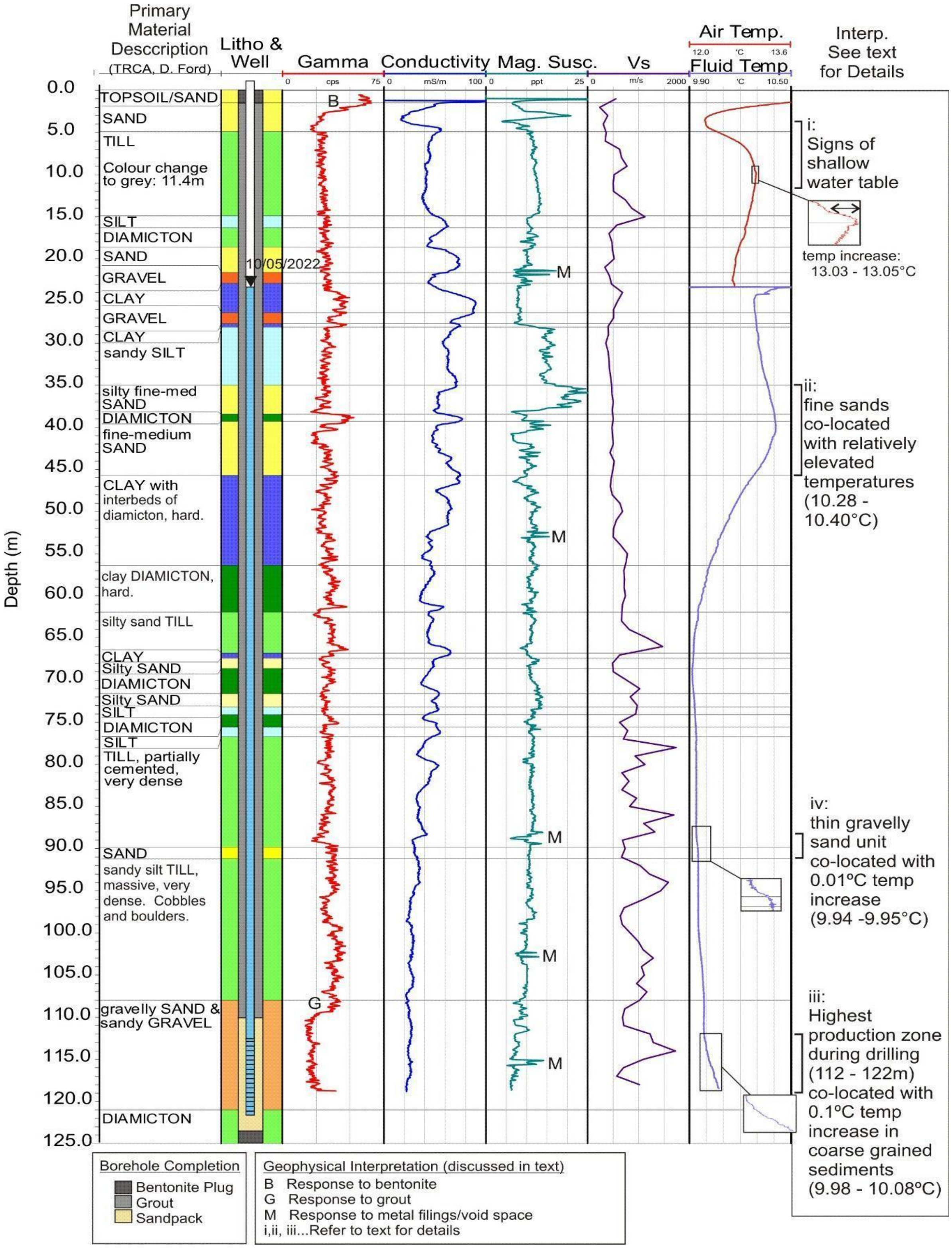


FIGURE 12: GEOPHYSICAL LOGS FROM TRCA OBSERVATION WELL ADJACENT TO SEISMIC PROFILE 'TENNIS CANADA' ON THE YORK U CAMPUS.

Summary

The collaborative study on the geological suitability of an Aquifer Thermal Energy Storage (ATES) system at York University provided an opportunity to address how geophysical surveys could enhance reconnaissance to support ATES site selection. The geophysical program demonstrated the rapidity of data collection, the breadth of 1- and 2-D information gained, and the effectiveness of geophysical techniques versus drilling alone.

The three geophysical techniques deployed for the study individually address specific issues that are critical to successful reconnaissance assessment and subsequent site consideration for an ATES development. The HVSR survey is a non-intrusive, rapidly deployed, low-cost technique capable of providing estimates of depth to bedrock. This technique can be particularly valuable in areas of thick sediment where there may be limited water well intercepts of bedrock. In addition to depth, the orientation of subsurface structures can be mapped to further refine understanding of subsurface geometry. In areas of thick and complex stratigraphic successions assignment of resonators with bedrock can be complicated, reducing confidence in depth estimates.

Seismic reflection surveying is a well-known non-intrusive, rapid technique used extensively in southern Ontario. In this study focus was on shear-wave data collection which is less sensitive to fluid contents and better images lithologies using various seismic interpretation tools related with seismic facies analysis. In this study the technique provided high-quality data on depth to bedrock and two-dimensional bedrock relief. The overlying surficial stratigraphy is dominated by sub-horizontally, and relatively continuous stratigraphic horizons. The value of continuous subsurface imaging was highlighted by identification of a previously unknown channel feature in the Lower Sediment. On the basis of TRCA borehole info and reflection amplitude, textural assignments were made to each of the respective seismic reflection horizons. The seismic data provides a complete stratigraphic architecture and seismic facies analysis that can provide a valuable source of information on aquifer target depths, geometry, and heterogeneity to support optimized selection of drilling targets. Integration of water well data along part of the Ian MacDonald road profile highlights the incomplete understanding provided by water well records due to interception of potable water at shallow depths. Analysis of the seismic reflection data is greatly enhanced if there is available borehole geophysics to constrain the velocity for conversion from time to depth.

The borehole geophysics, particularly gamma logs and NMR signal can provide useful information on the well completion. Signals of high mobile water from the MNR when compared with gamma / MS signal can provide information on fluid filled void spacing behind the casing. These points can help yield information that may be important to understanding the ATES performance and the degree of vertical isolation along the borehole casing.

When planning a site investigation geophysical data collection can provide valuable information that is much greater than one or multiple boreholes. Drilling involving continuous core provide a single point of information on the stratigraphic succession and heterogeneity. Individual or even multiple boreholes will not provide any information on the stratigraphic architecture where horizontal strata may be truncated by channels with completely different fill sediment textures. For reconnaissance the two seismic techniques provide complementary information that will greatly improve drilling site selection. Borehole geophysics can reduce the need for continuous core recovery, which is expensive, and provide a number of additional datasets on in situ aquifer characteristics. Integrated with the seismic reflection analysis, the data provide a means of verifying and calibrating the seismic facies analysis. The results of this survey contributed significant information regarding the geometry and location of possible drilling targets, including a filled-in channel erosion feature along Chimneystack road. A preliminary assessment of whether the possible targets would be suitable for an ATES system at York University was performed as part of Milestone 2, and it is noted that follow up drilling would be a prerequisite to determining the aquifer yield

Milestone 1.2: Cost comparison of two site investigation methods for ATES projects

Site investigations for ATES projects have very high upfront capital costs and risks associated. Traditional approaches involve drilling a large mesh of test wells to determine aquifer capacity before a project go/no-go decision can be made. Although main aquifers are well mapped in most of Canada, smaller aquifers that could support thermal projects like the one being investigated at York campus are not as well known and require extensive site exploration. Based on geophysical methods applied at the York campus, a cost comparison was performed related to non-invasive site investigation techniques with traditional test well drilling.

The investigations at York U were conducted over a more than 100 m thick layer in places of glacial and inter-glacial sediments that is run by channels and buried valleys of various ages in a rather complex geometry. An impermeable Silurian shale bedrock present under the entire city of Toronto excludes the possibility for an ATES project within the bedrock and forces the research for a shallower aquifer present in the Pleistocene aged sediments.

A small-scale ATES project is defined as an ATES project for a single building or a group of houses with a zone of thermal influence in the aquifer of less than 10,000 m^2. The groundwater system of a small-scale ATES project typically consists of 1-3 cold wells and 1-3 warm wells. The groundwater flow rate from the warm to the cold wells and vice verse is 100 m^3/h or less. The result of this cost comparison demonstrates that for large sites where there is a likely presence of a local aquifer that could support ATES development (depends on what is considered adequate information) a seismic site investigation approach could significantly reduce exploration costs for ATES projects.

The availability of equipment and knowledge can be a barrier to implementing seismic survey approaches. Though there are contractors with the required expertise, the availability of services is based on sector activities - for instance, seismic surveys are often performed in the context of mineral and petroleum exploration.

The flow chart below was developed to illustrate common approaches to large scale site investigations.

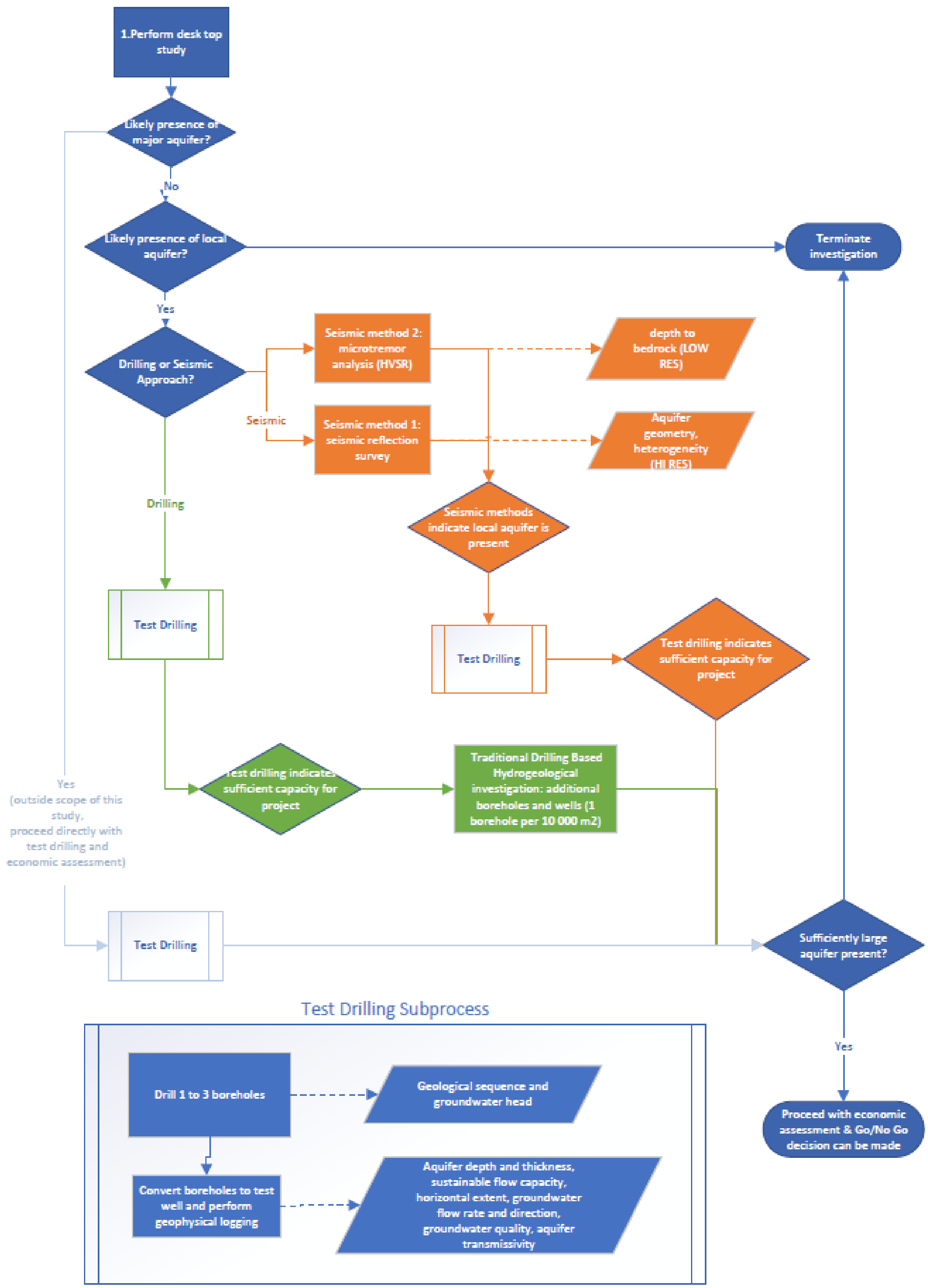


FIGURE 13: PROCESS FLOW CHART FOR SITE INVESTIGATION METHODS

The hydrogeological investigation applies additional investigation boreholes to assess the extent and homogeneity of the aquifer under the site. On average this will require one investigation borehole per 10,000 m². About 25% of the investigation boreholes will be converted to a monitoring well (equipped with PVC casing and screen) for geophysical logging. Also additional test wells will be drilled, to take water quality samples and to perform pumping tests (on average one test well per 250,000 m²). For the York University site, this would mean drilling about 200 investigation boreholes to bedrock (assume 80 m). In practice this number will be lower because significant parts of the site will not be available for future ATES wells due to the presence of buildings. It is assumed that 50% of the site will be available to locate future ATES wells (green areas, sporting areas, streets, parking lots, etc). This implies that as part of the hydrogeological investigation, four test wells and 100 investigation boreholes will have to be drilled and 25 of them will be converted into monitoring wells. The cost breakdown for the hydrogeological site investigation for a larger scale ATES project is given in Table 3.

TABLE 3: COST BREAKDOWN OF A HYDROGEOLOGICAL SITE INVESTIGATION FOR A LARGER SCALE ATES PROJECT

Activity	Cost
Step 1-3, see Table 1	$ 360,000
100 Investigation boreholes	$ 2,500,000
Additional cost conversion to 25 monitoring wells	$ 500,000
4 Standard geophysical borehole logs	$ 120,000
4 Test wells	$ 400,000
Pumping tests	$ 80,000
Water samples and analysis	$ 20,000
Data analysis and reporting of the results	$ 180,000
Total cost	**$ 4,160,000**

Seismic reflection data collection can provide enhanced information on the succession of surficial geological units, and aquifer geometry and heterogeneity and consequently provide greatly enhanced target information for follow-up drilling. It is advisable to get these insights before ATES wells are drilled. That method of data acquisition can be conducted on any types of roads and bike paths.

The already existing test well will serve to calibrate the data from a geophysical site survey.

With 30 line-km of P- and S-wave seismic reflections a dense grid of survey lines can be accomplished such that a pseudo 3D subsurface image can be created, see Figure 1. A detailed cost break-down for a 1 km² site is shown in Table 4.

TABLE 4: SEISMIC REFLECTION COSTING FOR A 1 KM2 SITE

Item No.	Description	Quantity	Unit	Total Price	Mob/Demob
1	Mobilization/demobilization			$ 25,500	
2	Air travel 3 additional workers including geophysicist			$ 2,400	
3	Onboarding - 4 workers if necessary	1	days	$ 1,400	
4	Survey/geohazard prior to crew arrival	10	fixed	$ 9,000	**$ 38,300**
5	Shallow reflection land-streamer crew including one operator, one landstreamer technician and helper	30	days	$ 343,500	**Acquisition**
6	Field geophysicist/data processor	30	days	$ 27,000	
7	Additional EWG truck for refraction including operator and radio link	30	days	$ 2,400	**$ 372,900**
8	Reflection processing - SH and P to final migrated stack	20000	points	$ 100,000	**Processing**
9	2D refraction processing - assuming every 6th VP	3334	points	$ 16,670	
10	Interpretation		20%	$ 115,170	
11	Depth conversion		10%	$ 57,590	
12	Field report/ deliverables	320	hours	$ 48,000	**$ 337,430**
	Total			**$ 748,630**	

In areas with thick overburden, depth to bedrock estimations often suffer from sparse ground truthing as drilling often is terminated before reaching bedrock. The HVSR technique is a nonintrusive, rapid approach to estimating depth to bedrock. At a fraction of drilling and seismic reflection cost, HVSR can be acquired anywhere from public parks to urban sidewalks.

As for the boreholes, one HVSR reading per 10,000 m² is assumed to properly cover the area of investigation. A detailed cost break-down for a 1 km² site is shown in Table 5.

TABLE 5: DETAILED HVSR COST BREAK-DOWN

ITEM	Unit Price	Units	Unit Type	STTL	NOTES
			HVSR Passive Seismic Survey:		
Mobilization.	$1 350	2	days	$2 700	Estimated two days' mobilization.
Standby.	$1 350	2	days	$2 700	Estimated two days' standby during the survey. Estimated for budgeting purposes only. Final invoicing will reflect actual standby.
Expenses – Consumables such as accommodations, fuel, food.	$450	13	days	$5 850	Estimated. Final amount charged at cost.
Data acquisition	$2 550	13	days	$33 150	Approximately 10 days to survey and 3 days dedicated to repeat readings. Assumes ground is easily accessible and traversable. If forested area, line cutting would be required to meet this production rate.
Calibration	$1 800	1	Calibration	$1 800	To provide a mean velocity estimate based on readings at up to 4 holes/trenches where bedrock depth is known (if holes/trenches are available)
QC/Processing	$20	200	Stations	$4 000	Note that the readings should be taken at least 25m away from the roads and ditches in 'undisturbed ground'. Earthworks impact the ground velocities and can result in poor data quality and inaccurate depth estimates
Acquisition Report	2500	1	Flat rate	$2 500	
Total:				**$52,700**	**CAD + GST**

The result of this cost comparison demonstrates that for large sites where there is a likely presence of a local aquifer that could support ATES development a seismic site investigation approach could significantly reduce exploration costs for ATES projects.

The specific approach is subject to site-specific conditions. For example, the two seismic methods could be performed sequentially, or only one or the other could be applied. Test well locations are crucial, especially in relatively small projects. Desktop studies do not account for all subsurface variability, especially in regions like Southern Ontario with a high degree of heterogeneity. Short seismic profiles could be obtained before the first test wells are drilled to ensure the optimal location is found.

The availability of equipment and knowledge can be a barrier to implementing seismic survey approaches. Though there are contractors with the required expertise, the availability of services is based on sector activities - for instance, seismic surveys are often performed in the context of mineral and petroleum exploration. Seismic surveys could be carried out by groups and organizations such as universities, municipalities, or different government organizations in order to provide data products that could be used to encourage consideration of ATES projects by developers.

Although exploration for individual sites is the responsibility of the developer, there are some instances internationally where test drilling is not required in ATES project development. For example, in international jurisdictions with a high adoption rate of ATES projects, such as the Netherlands, site investigations do not always require test drilling as there is significant knowledge at a fine resolution of (major) aquifers and their characteristics due to relatively homogenous geology and high population density. Southern Ontario, by contrast, is more sparsely populated and has highly variable geology (local aquifer) - if aquifer and other subsurface energy systems become more common, it will still likely be a site-by-site consideration of whether test drilling is required.

Milestone 2.1: Preliminary design and technical and economic assessment of ATES, BTES, and PTES systems for York University

The techno-economic analysis of integrating large-scale thermal energy storage into York University's DHC system used the TRNSYS model of the system developed in the previous study, expanded the model to include the heating load, and devised a number of technology scenarios that considered aquifer, pit, and borehole thermal energy storage. Using the energy performance outputs from the simulations, costing was developed for each scenario and a life cycle analysis was performed to determine the payback period for each technology configuration. The main steps taken in conducting the techno-economic analysis, presented in the following sections, are as follows:

- Developed a representative hot-water and chilled-water load profile for York university
- Devised low-carbon designs to meet the loads using aquifer, pit, and borehole thermal storage systems and model the three designs in TRNSYS and predict the performance over a 10-year window
- Developed costing information for three low carbon scenarios plus base case scenario and perform life cycle analysis to determine payback periods of all scenarios

Though the site investigation contributed significant information regarding the geometry and location of possible drilling targets, including a filled-in channel erosion feature along Chimneystack road, the geometry of the channel location identified in the survey would likely be too small to support the number of wells required for the scale of the system considered for York University. Given that the results from the site investigation did not conclusively identify the presence of a suitable aquifer to support the York U Keele campus heating and cooling demand, alternative inter-seasonal thermal storage technologies were included in the techno-economic assessment, and the presence of a productive aquifer was assumed for the modelling and simulation.

Loads

Measured data was available from York University based on monthly steam data and hand recorded daily steam logs. The measured monthly data was available for total steam supply between July 2015-July 2016 heating season, with ambient temperatures between -2 to 22 °C. The data indicated an uptick in steam consumption during the period of July 2016. The daily steam log data, however, and observations from the plant operators at very cold conditions, confirm that the relationship is nearly linear with decreasing temperature. The hand recorded daily steam logs were available for ambient temperatures ranging from approximately -19°C to 10 °C.

Curve-fits were created for steam flow as a function of temperature, with dual curve fits created for steam flow: for ambient temperatures less than 5 °C and for ambient temperatures greater than 5 °C. Using the steam profile curve fit (red points), assumed supply and return steam enthalpy, and 100% condensate return, the heating load was then generated for each hour of the year for the typical weather year being considered, using a rolling two-hour average air temperature. Figure 14 illustrates the hourly heating load based on curve fits and ambient temperatures, and the previously generated cooling load from the previous project.

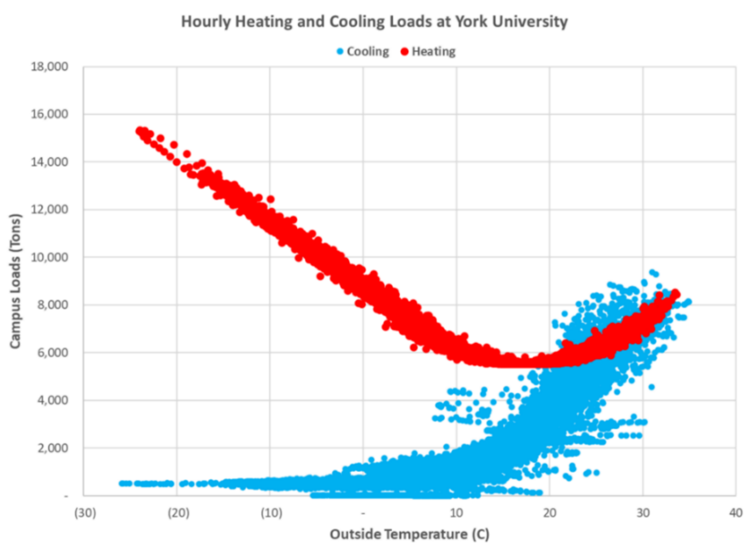


FIGURE 14: PRELIMINARY GENERATED HEATING AND COOLING LOAD CURVES

Several key assumptions were made to develop the final heating loads that were used in the modelling and simulation. Firstly, the increase in steam demand at higher temperatures was deemed to be a function of the curve fit and not representative of realistic operation. Measured steam data at higher ambient temperatures was not available to validate this assumption, and while outside the scope of this study, it is recommended that a more detailed study of the steam demand on the York campus be undertaken. Secondly, given the operating requirements for thermal energy storage systems including aquifer, pit, and borehole-based solutions, it was assumed that the district heating system would need to be converted from steam based to hot water based.

To convert the steam loads to hot water loads, a 30% reduction was applied to the heating load to represent savings from condensate return issues and excess steam line losses. As a result, the total heating load is 157 000 MWh, compared to the estimate of 220 000 MWh heating in the previous project report, attributable to both the steam to hot water savings and the flattening of the curve for higher ambient temperatures.

Based on these changes, a new hot water load profile created and then curve-fit against ambient temperature. It was assumed the hot water load could be met at 60 °C with a 35 °C return and the chilled water load could be met at 5 °C with a 13.33 °C return temperature. The final heating and cooling load is shown in Figure 16. The peak heating load is approximately 11,000 tons, or 38.7 MW at ambient temp of -25 °C and peak cooling approximately 9,500 tons, or 33.4 MW for ambient temperatures above 30 °C. Figure 15 shows the overall breakdown of total heating and cooling for the year, with over 75% of the total load being heating. This large imbalance between heating and cooling poses a challenge to the integration of large-scale thermal energy storage. Such systems generally require equal heating and cooling loads to ensure that the storage is not depleted of energy or oversaturated, which for example could result in a borehole field freezing and being unable to support heating far before the end of its predicted life. The scenarios developed in the following sections were designed to include additional heat input to the storages in order to overcome this imbalance.

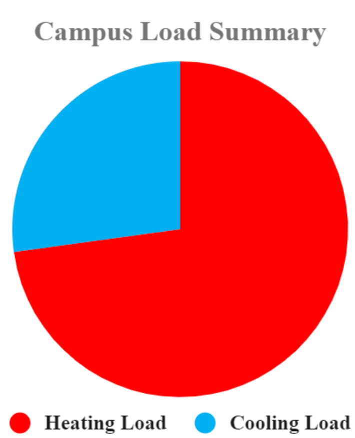


FIGURE 15: HEATING AND COOLING LOAD SUMMARY FOR YORK UNIVERSITY

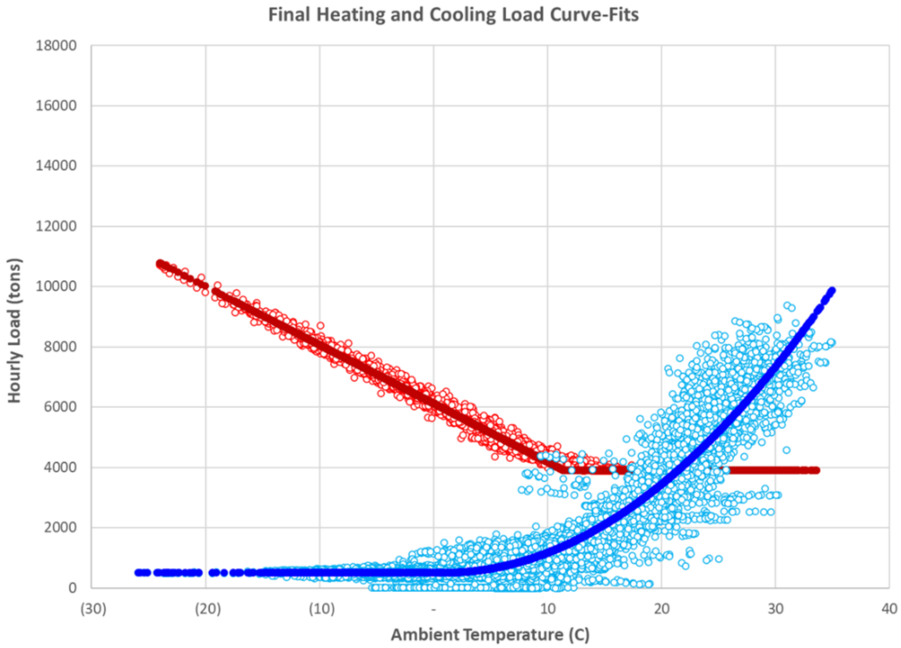
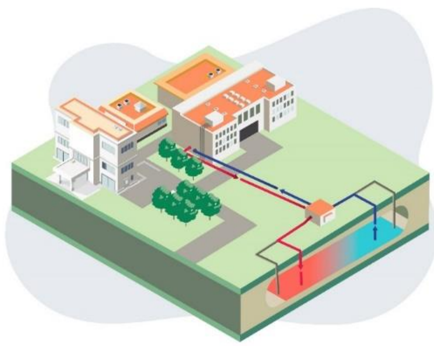


FIGURE 16: FINAL GENERATED HEATING AND COOLING LOAD CURVE

Technology Scenarios

Aquifer Thermal Energy Storage (ATES) Scenarios (1 - 4)



The goal of the ATES scenario was to study the feasibility of ATES for meeting the entirety of the York campus heating and cooling load, completely eliminating on-site combustion, while avoiding the extreme electrical peaks that result from an electrified scenario without storage. To that end, the ATES scenario was developed with the following assumptions:

- **Assume the presence of a productive aquifer:** Aquifer wells capable of producing 500 USGPM (31.54 L/s) per well in the high flow scenario and 250 USGPM (15.77 L/s) in the low flow scenario
- Undisturbed well temperatures of 9.5 °C
- An unglazed solar thermal collector array is available to help balance ATES heating and cooling loads

The wells were sized to match the maximum heating load requirements, for a total of 40 wells pairs capable of producing a combined flow rate of 20 000 USGPM (1261 L/s). One set of “warm” wells and one set of “cold” wells were modelled, each charged seasonally from heat pump operation. The single mode heat pumps act as a link between the warm and cold well fields. In the cooling season, water from the cold wells is directed to the heat pumps, warmed in the condensers, and pumped into the warm wells. In the heating season, water from the warm wells is directed to the heat pumps, cooled in the evaporators, and pumped into the cold wells. Over the course of the heating season, the temperature in the warm wells falls as energy is removed and directed through the heat pumps to upgrade the temperatures and provide hot water for the campus. At the same time, the temperature in the cold wells also decreases, which creates a cold energy source that can then be exploited for meeting chilled water needs in the summertime. Table 6 describes the configuration of scenarios 1 through 4.

TABLE 6: ATES SCENARIO DESCRIPTIONS (SCENARIOS 1 - 4)

	Size	Capacity	Operational temps
		Scenario 1	
Solar thermal collectors (unglazed, glycol)	50 000 m^2	-	Max ~60 °C*
Aquifer well pairs	40	-	-
Aquifer characteristics	-	500 GPM per well pair (20 000 GPM total)	9.5 °C undisturbed well temp
		Scenario 2	
Solar thermal collectors (unglazed, glycol)	50 000 m^2	-	Max ~60 °C*
Aquifer well pairs	80	-	-
Aquifer characteristics	-	250 GPM per well pair (20 000 GPM total)	9.5 °C undisturbed well temp
		Scenario 3	
Solar thermal collectors (unglazed, glycol)	75 000 m^2	-	Max ~60 °C*
Aquifer well pairs	80	-	-
Aquifer characteristics	-	250 GPM per well pair (20 000 GPM total)	9.5 °C undisturbed well temp
		Scenario 4	
Solar thermal collectors (unglazed, glycol)	90 000 m^2	-	Max ~60C*
Aquifer well pairs	80	-	-
Aquifer characteristics	-	250 GPM per well pair (20 000 GPM total)	9.5 °C undisturbed well temp
		All ATES Scenarios	
Simultaneous heat pumps	5 units	(3 900 tons/13.7 MW)	Heating at 60 °C / Leaving CHW °5 C
Single mode heat pumps	6 units	(10 000 tons/35.17 MW)	Heating at 60 °C / Leaving Source Temperature as Low as 5 °C

*note: Maximum temperatures listed in this table represent the upper temperature limit of the component or equipment, not necessarily the temperatures achieved in the system.

Because the simultaneous mode heat pumps operate to meet coincident heating and cooling loads, only the single mode heat pumps interact with the source loop and therefore the ATES. The coincident heating and cooling loads are substantial, and only the leftover heating and cooling loads are used to charge the ATES. The single mode heat pump stack has a total rated capacity of 10,000 tons (35.17 MW) of heating at 60 °C with a leaving source temperature as low as 5 °C at the end of winter, and the simultaneous heat pump stack has a total rated capacity of 3,900 tons (13.7 MW) of heating at 60 °C with a leaving CHW temperature of 5 °C. Figure 17 illustrates heating mode, including operational temperatures for meeting the heating and cooling loads. As described above, the simultaneous mode heat pumps recover heat from the cooling process to warm up the hot water that is sent to the heating loop.

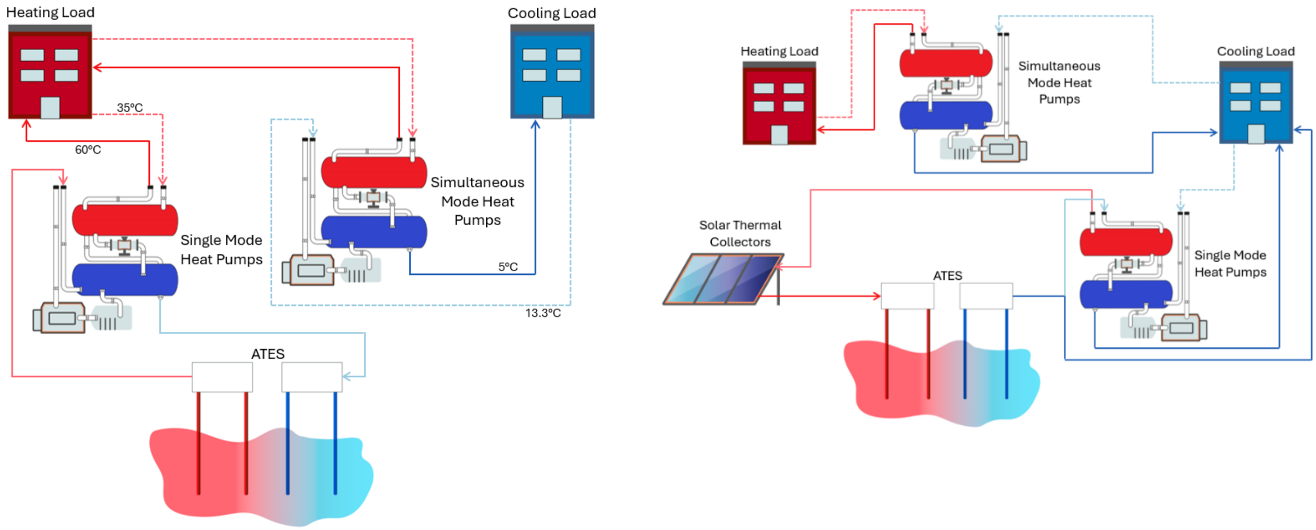


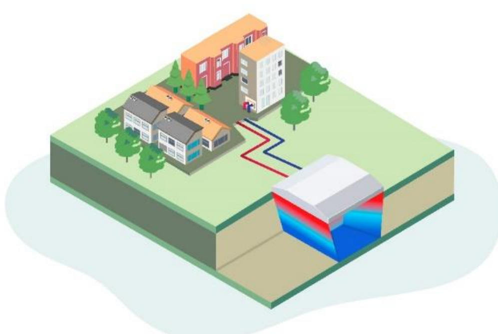
FIGURE 17: ATES SCENARIO SCHEMATICS. HEATING MODE (LEFT) AND COOLING MODE (RIGHT)

Figure 17 (right) illustrates the cooling mode of the ATES system. The system operates essentially in reverse, with cool water removed from the cold wells, warmed in the single mode heat pump condensers, and pumped into the warm wells. However, as depicted, when there is solar availability the water from the heat pump condensers is first warmed via the solar heat exchanger before being injected into the warm wells at higher temperature. Additionally, when the cold wells are at or below 5 °C, the water can be circulated through the direct cooling heat exchanger to provide chilled water directly to the load. The direct cooling heat exchanger is located upstream of the chiller condensers which creates a larger temperature rise for the water headed to the warm wells for use in the winter (boosted even further by the solar thermal collectors).

There are a number of design challenges for integrating an ATES into the York DHC system. The highly dominant heating load means that without additional heat input into the warm wells, the aquifer temperature would degrade over time. Additionally, the lower temperature in the ATES wells results in a lower heat pump COP, increasing the electricity required to operate the system especially at colder ambient temperatures. The minimum heat pump outlet temperature of 5 °C results in high pump flow rates when the warm wells cool down (9.5 °C undisturbed), which will increase the number of wells required to meet this flow rate.

Additional scenarios performed that use the ATES system consider a lower capacity aquifer formation that can only provide 250 GPM per well and therefore requires a total of 80 well pairs. Simulations were performed with 50 000 m^2, 75 000 m^2, and 90 000 m^2 of solar thermal collectors. The solar thermal collectors help balance the loads to reduce thermal interference of wells over time. Jurisdictions with policy and regulation related to ATES or other similar systems it is a common requirement to have a fully balanced heating input to the ground to prevent unwanted thermal effects upstream.

Pit Thermal Energy Storage (PTES) Scenarios (5, 6)



For the PTES integration scenarios, the same heat pump configuration is used as in the ATES system but in place of the aquifer, the system utilizes a large pit storage to provide the source energy for the single-mode heat pumps. A PTES was sized to be representative of large PTES systems being built in Europe: ~230 m x 230 m top surface with a 16 m depth. The pit is water-filled with an insulated cover and total volume of 500 000 m^3. The PTES relies on tank stratification to keep the top warm for heating mode and the bottom cold for cooling mode. A 30 MW electric boiler is also added to provide auxiliary heating when the PTES is not able to meet the demands, for example at the end of the heating season when the temperature of the pit has been depleted.

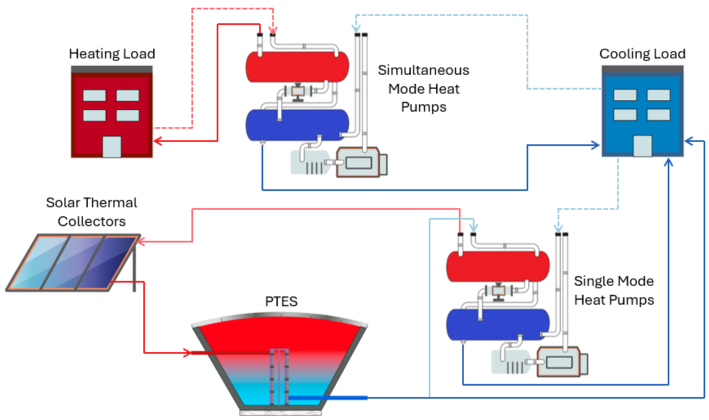


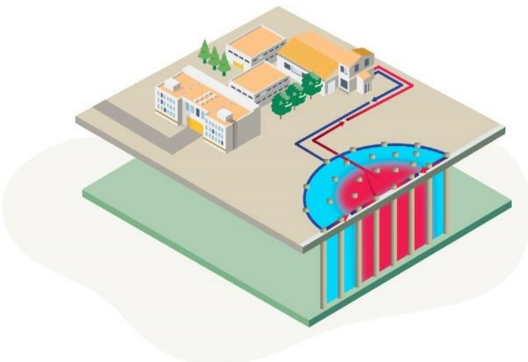
FIGURE 18: PTES SCENARIO SCHEMATIC

TABLE 7: PTES SCENARIO DESCRIPTIONS (SCENARIOS 5 – 6)

	Size	Capacity	Operational temps
	Scenario 5		
Solar thermal collectors (unglazed, glycol)	50 000 m²	-	Max ~60 °C*
	Scenario 6		
Solar thermal collectors (unglazed, glycol)	90 000 m²	-	Max ~60 °C*
	All PTES Scenarios		
PTES dimensions	230 m x 230 m x 16 m	500,000 m³	**Max ~80-90 °C***
Simultaneous heat pumps	5 units	(3 900 tons/13.7 MW)	Heating at 60 °C / Leaving CHW °5 C
Single mode heat pumps	6 units	(10 000 tons/35.17 MW)	Heating at 60 °C / Leaving Source Temperature as Low as 5 °C
Electric boiler	-	**30 MW**	

*note: Maximum temperatures listed in this table represent the upper temperature limit of the component or equipment, not necessarily the temperatures achieved in the system.

Borehole Thermal Energy Storage (BTES) Scenarios (7, 8)



In the BTES integration scenarios, the same heat pumps as the ATES system are used but in place of the aquifer the system utilizes a large ground heat exchanger to provide the source energy for the single-mode heat pumps. The BTES was sized with 4200 U-tube bores each at a depth of 200 m with 4 m spacing between each bore for a total surface area of 67 200 m2. The BTES uses water as the working fluid and each bore has a maximum flow capacity of 6 GPM at peak conditions. The BTES relies on stratification to keep the core warm for heating mode and the edges cold for cooling mode. The BTES scenarios use the same unglazed solar collectors to help balance the thermal inputs to the ground, with 50 000 m^2 and 90 000 m^2 scenarios.

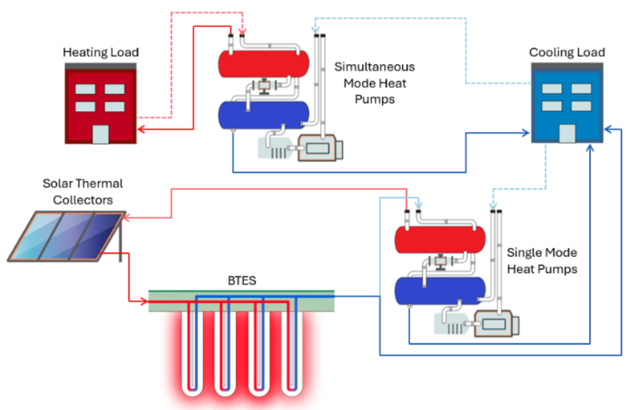


FIGURE 19: BTES SCENARIO COOLING MODE

TABLE 8: BTES SCENARIO DESCRIPTIONS (SCENARIOS 7, 8)

	Size	Capacity	Operational temps
Scenario 7			
Solar thermal collectors (unglazed, glycol)	50 000 m^2	-	Max ~60 °C*
Scenario 8			
Solar thermal collectors (unglazed, glycol)	90 000 m^2	-	Max ~60 °C*
All BTES Scenarios			

BTES size	**4200 bores (200 m depth, 4 m spacing, 67,200m² surface area)**	**6 GPM per bore (25,200 GPM total)**	**Max ~90 °C***
Simultaneous heat pumps	5 units	(3 900 tons/13.7 MW)	Heating at 60 °C / Leaving CHW °5 C
Single mode heat pumps	6 units	(10 000 tons/35.17 MW)	Heating at 60 °C / Leaving Source Temperature as Low as 5 °C
Electric boiler	**-**	**30 MW**	

*note: Maximum temperatures listed in this table represent the upper temperature limit of the component or equipment, not necessarily the temperatures achieved in the system.

Base Case #1 – Heat pumps (Scenario 9)

The first electrification scenario base case assumes the same steam to hot water conversion as the TES scenarios. Figure 20 illustrates the configuration, and Table 9 lists the parameters. The same heat pump configuration and sizing is used. To heat the source stream for the single mode heat pumps in place of a TES, a 30 MW electric boiler is used. Rather than bypassing the single mode heating pumps in heating mode, the electric boiler is used to heat the source stream with a COP of 1, then the heated water stream is further upgraded by the heat pumps with a more efficient COP. For cooling, cooling towers capable of providing 25,000 USGPM (1577 L/s) of water from 35 °C to 29.4 °C at a wet bulb temperature of 25.6 °C are used.

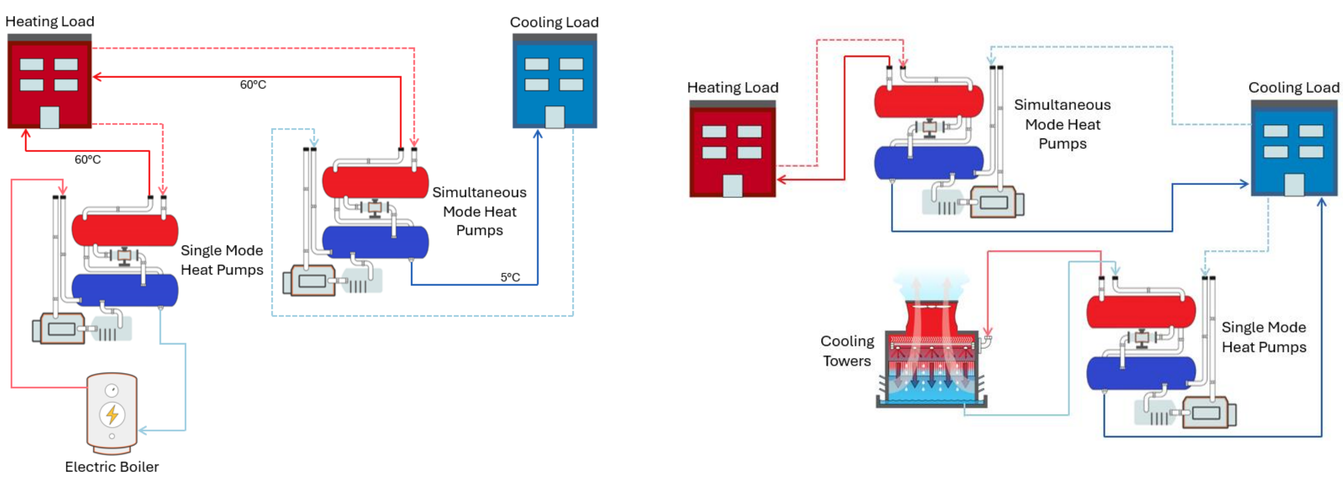


FIGURE 20: BASE CASE #1 (HEAT PUMP) SCENARIO SCHEMATICS. HEATING MODE (LEFT) AND COOLING MODE (RIGHT)

TABLE 9: BASE CASE #1 HEAT PUMP DESCRIPTION (SCENARIO 9)

	Size	Operational temps
Simultaneous heat pumps	5 (3 900 tons/13.7 MW)	Heating at 60 °C / Leaving CHW 5 °C
Single mode heat pumps	6 (10 000 tons/35.17 MW)	Heating at 60 °C / Leaving Source Temperature as Low as 5 °C
Electric boiler	30 MW	
Cooling towers	25 000 GPM (1577 L/s)	35 °C to 29.4 °C at a Wet Bulb of 25.6 °C

Base System #2 – Steam Boiler (Scenario 10)

For the second base case electrification scenario, the system uses steam as the heat distribution fluid and the system does not undergo a conversion. This scenario is representative of a case where the existing York University system is decarbonized by removing the cogeneration units and replacing them with an electric boiler capable of meeting the annual and peak loads. Table 10 lists the scenario parameters and the configuration is illustrated by Figure 21 This scenario uses a 60 MW electric steam boiler, water-cooled chillers, and cooling towers. The water-cooled chillers have a cooling capacity of 10,000 tons of cooling at 5 °C with an entering source temperature as high as 30 °C. As in the Base Case #1, the cooling towers capable of providing 25,000 USGPM of water from 35 °C to 29.4°C at a wet bulb of 25.6 °C.

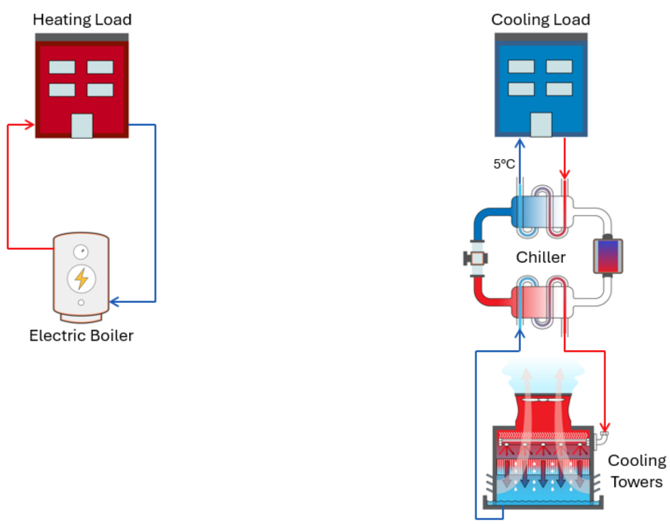


FIGURE 21: BASE CASE #2 (STEAM BOILER) SCENARIO SCHEMATICS. HEATING MODE (LEFT) AND COOLING MODE (RIGHT)

For the second base case electrification scenario, the system uses steam as the heat distribution fluid and the system does not undergo a conversion. This scenario is representative of a case where the existing York University system is decarbonized by removing the cogeneration units and replacing them with an electric boiler capable of meeting the annual and peak loads. This scenario uses a 60 MW electric steam boiler, water-cooled chillers, and cooling towers. The water-cooled chillers have a cooling capacity of 10,000 tons of cooling at 5 °C with an entering source temperature as high as 30 °C. As in the Base Case #1, the cooling towers capable of providing 25,000 USGPM of water from 35 °C to 29.4°C at a wet bulb of 25.6 °C.

TABLE 10: BASE CASE #2 STEAM BOILER DESCRIPTION (SCENARIO 10)

	Size	Operational temps
Water-cooled chillers	10 000 tons (35.17 MW)	5 °C with entering source temp up to 30 °C
Electric steam boiler	60 MW	
Cooling towers	25 000 GPM (1577 L/s)	35 °C to 29.4 °C at a Wet Bulb of 25.6 °C

Techno-economic results

Energy Results

The energy results of the scenarios are discussed in this section, with the overall results summarized in Table 11 below. The table lists the annual electricity consumption, peak electrical consumption, as well as energy loop flows including the electricity consumed by the heat pumps, the boilers, energy input and output of TES where applicable, energy production from the solar collectors. This section will review the performance of the thermal energy storage scenarios.

Figure 22 shows the annual electricity consumption and peak loads of each scenario. Base case #2, using a steam boiler, results in a peak load of 54,546 kW and annual electricity consumption of 231,257 MWh. Base case #1, using heat pumps, reduces the peak load to 35,932 kW and annual consumption to 113,339 MWh, a reduction of 34.1% and 50.9% respectively. Base Case #2 is the only scenario considered in the current work that uses the existing steam distribution network – all other cases assume a steam to hot water conversion to reduce the temperature of the heat transfer fluid and enable the use of conventional heat pumps and large-scale sensible thermal storage, technologies which are not feasible for steam systems.

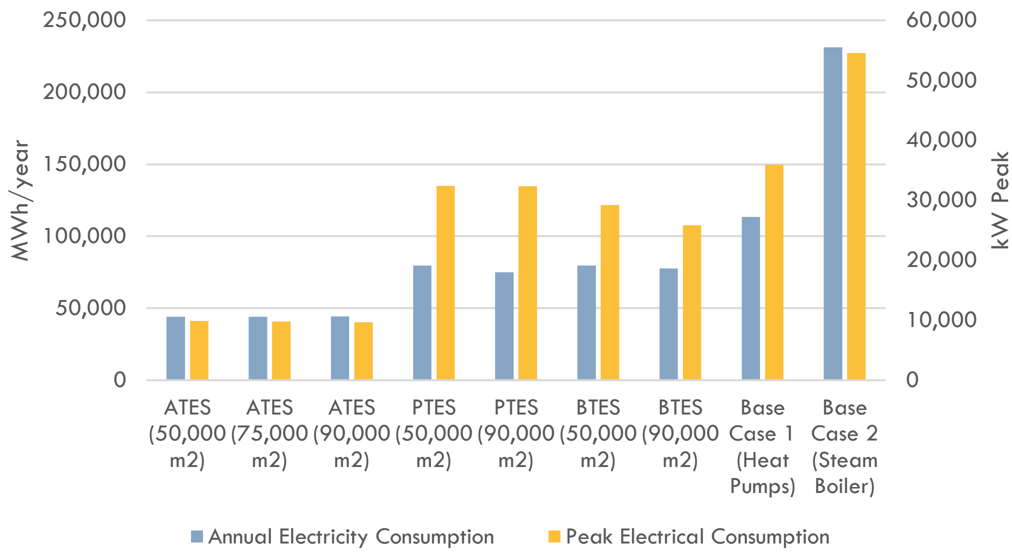


FIGURE 22: ANNUAL ELECTRICITY CONSUMPTION AND PEAK DEMAND OF ALL SCENARIOS

Scenarios 1 and 2, using ATES wells with 50 000 m^2 solar collectors, reduce the peak even further to 9,957 kW and annual electricity consumption to 44,146 MWh, a savings of 72% (peak) and 61% (annual) compared to the heat pump base case and 81% (peak) and 80.9% (annual) compared to the steam boiler base case. However, scenarios 1 and 2 do not have balanced energy flows into and out of the aquifer. Therefore, the system would not be sustainable and would cause degraded temperatures in the ground. A total of 90 000 m^2 unglazed solar thermal collectors are required to balance the ground. Scenario 5 uses an array area of 90 000 m^2 to fully balance the aquifer. There is an increase in parasitic loads due to increased collector flows, from 892 MWh/year to 2602 MWh/year for scenario 4, but the overall energy performance is similar, with a peak of 9,680 kW and annual consumption of 45,441 MWh. The PTES configuration using 90 000 m^2 solar thermal, Scenario 6, resulted in an annual consumption 75,063 MWh, with peak of 32,354 kW. Scenario 8 with a BTES system and 90 000 m^2 solar thermal resulted in an annual consumption 69,062 MWh and peak of 25,834 kW.

TABLE 11: ENERGY RESULTS OF SCENARIOS 1 - 10

ID	Thermal Storage	Area solar collectors	Annual Electricity Consumption	Peak Electrical Consumption	Single mode Heat pump electricity (heating/cooling)	Solar contribution	Boiler electricity	Source loop transfer – cooling mode	Source loop transfer – heating mode
		m^2	MWh/year	kW	MWh/year	MWh/year	MWh/year	MWh/year	MWh/year
1	ATES (40 wells)	50 000	44,046	9,890	21,501/418	37,548	5	4,892	(68,208)
2	ATES (80 wells)	50 000	44,046	9,890	21,501/418	37,548	5	4,892	(68,208)
3	ATES (40 wells)	75 000	44169	9,756	21,320/ 472	49,190	2	5,609	(68,392)
4	ATES (40 wells)	90 000	44,324	9,680	21,197/ 523	64,145	-	6,185	(68,517)
5	PTES	50 000	79,690	32,385	9,672/ 2,465	20,471	44,625	14,574	(35,408)
6	PTES	90 000	75,063	32,354	11,045/ 2,812	26,953	37,916	15,845	(40,745)
7	BTES	50 000	79,606	29,222	12,045/ 932	15,477	40,658	9,280	(36,973)
8	BTES	90 000	77,560	28,605	14,822/ 1,444	17,583	38,095	13,042	(47,317)
9	None *(Base Case #1)*	-	113,339	35,932	21,897/2,462	-	67,470	-	-
10	None *(Base Case #2)*	-	231,257	54,546	-	-	220,807	-	-

Economic results

The economic analysis conducted for the present work uses Base Case #1 (Heat Pumps) as a reference scenario. The scenarios with large-scale thermal storage integration are compared to this reference case. Base Case #2 (Steam Boiler) is excluded from the analysis, as a full accounting of the costs of a steam to hot water conversion are outside the scope of the current study. Table 12 lists the capital costs for each of the considered scenarios, with the difference in capital costs between the thermal storage scenario and the reference Base Case #1 scenario given in the rightmost column. The costing performed here includes costs related to equipment and installation of major system components, including heat pumps, ATES wells, the BTES borefield, PTES pit, and auxiliary boilers. The resulting Delta CAPEX represents the cost differences between the thermal storage scenarios and the reference case (that is, all equipment that is common to all scenarios including heat pumps, heat exchangers, etc). Costing for the ATES includes the well drilling, well housing, mechanical and electrical components, based off of contractor quotes and previous costing performed under the 2020 IEA DHC report [16]. The thermal storage scenarios include an estimate of soft costs like engineering, overhead, and insurance for the thermal storage, but exclude costs related to site investigation and environmental assessment. This costing exercise focused on the ATES scenarios that assume lower flow capacity and therefore use 80 well pairs. Additionally, since the energy savings were minor for the BTES and PTES scenarios that considered larger solar arrays, only the scenarios assuming 50 000 m^2 solar arrays are presented here. ATES with 90 000 m^2 solar thermal to balance the system, and BTES and PTES with 50 000 m^2 solar thermal and electric boiler backup. Estimation of the cost associated with a full-scale steam to hot water conversion is outside the scope of the current study. As such, Base Case #2 (Steam Boiler) is not considered in the economic analysis. As a general example, the University of British Columbia estimates $2000 per meter of piping to convert from steam to hot water, which would be necessary for any of the thermal storage scenarios. The York site was initially investigated for the use of ATES to supply cooling loads which would not require conversion of any steam-based equipment or network infrastructure. This follow on work was intended to build upon that study and explore the options for fully decarbonizing York's DE system. There is a trend towards lowering DE network temperatures, both in new and existing systems like the University of British Columbia which has undergone a steam to hot water conversion, replacing 14 kilometres of 90-year-old steam piping. Whether a STHW is feasible for the York University campus depends on many factors, but it is important to consider the entire lifespan of the system when making investment decisions. A life cycle cost analysis of a STHW conversion is outside the scope of the current study, but it is possible to say that although a STHW conversion may have high upfront expenditures, long-term operating costs associated with decarbonizing and electrifying a steam-based network may make conversion more appealing.

TABLE 12: CAPEX FOR KEY SCENARIOS

ID	Scenario Description	Capital Cost	Delta CAPEX
4	ATES (80 wells, 90 000 m^2 solar)	$111,833,571.69	$36,048,602.94
3	ATES (80 wells, 75 000m^2 solar)	$106,993,964.53	$31,208,995.78
7	BTES (50 000 m^2 solar)	$130,802,611.69	$55,017,642.94
6	PTES (50 000 m^2 solar)	$123,822,611.69	$48,037,642.94
9	Base case #1 – heat pumps	$75,784,968.75	Reference scenario
10	Base case #2 - steam	N/A	N/A

A life cycle cost analysis was performed using the parameters in Table 13 as inputs, with values in line with estimates from previous work [16]. A timeline of 50 years was used to perform the analysis. Operational costs consist of electricity and water purchases, with electricity purchases subject to a unit price of $150.00 per MWh, or $0.15 per kWh. Given the recent changes to carbon pricing in Canada and the removal of consumer carbon charges, no analysis is done of the cost associated with GHG emissions for these scenarios. Alternatively, estimates are provided for the avoided emissions, based on emissions factor projections for the Ontario electricity grid.

TABLE 13: LCA INPUT PARAMETERS

Parameter	Value
Annual escalation rate of electricity	3.5%
Inflation rate	2%
Discount rate	5%
Electricity price ($/kWh)	0.1500
Price of water ($/$m^3$)	4.10
2024 Carbon intensity of electricity (gCO2/kWh)	0.0360
Lifetime of systems (years)	50

Annual operational and maintenance costs are presented below in Table 14 for the ATES, PTES, and BTES cases, compared to Base Case #1 (Heat Pumps) as a reference scenario. Base Case #1 (Heat Pumps) requires 113,339 MWh to meet the heating and cooling needs of the campus, with ATES, PTES, and BTES using 44,324 MWh, 79,695 MWh, and 79,606 MWh respectively, equal to 61%, 29.7%, and 29.8% reductions. Using an electricity price of $0.15/kWh, annual electricity savings are $10.3 million for the ATES scenario, and $5.0 million each for BTES and PTES scenarios. The annual cost for electricity used by the DHC system in Base Case #1 would be $17 million, over three times the total electricity costs currently paid by the university.

As mentioned earlier, on an annual basis as of 2019, the existing DHC system at York delivers approximately 220,000 MWh of heating, 55,000 MWh of cooling, and 66,000 MWh of electricity produced by the co-generation units. Annual electricity purchased from the grid amounts to approximately 30,000 MWh. The total annual university utility costs in 2019 were about $15 million. Approximately $5 million is attributed to electricity import during peak time, $7 million for natural gas use, and $2.5 million for water. This results in an average electricity price of $151 per MWh, essentially equivalent to the value of $150 per MWh calculated for the current work. The annual electricity that would be required to operate a heat pump and cooling tower system is **113,339 MWh** – more than triple the total existing electricity import, plus this represents only the heating and cooling electricity loads, not accounting for electrical end uses. The decommissioning of the co-gen would result in a further 66,000 MWh annual electricity purchases from the grid. This additional electricity is not accounted for in the current work, and a full analysis would be required to estimate the impacts on the campus' utility costs. An additional analysis was performed using a low-cost electricity scenario, assuming prices of $0.05 per kWh to illustrate the sensitivity of the outcomes to electricity prices. The annual savings for the ATES scenario drop from $10.3 million to $3.45 million, which, as discussed in the following section, results in a significantly longer payback period.

The 2030 carbon cost savings illustrates the potential cost reductions associated with the TES scenarios given a carbon price increase to $170 per tonne by 2030. These values are not used in the LCA results, given the recent ceasing of consumer carbon pricing at the federal level in Canada and associated uncertainty around future carbon costs. However, the costs are substantial, with the ATES scenario having $1.66 million savings assuming $170 per tCO_2 pricing.

The water savings for each of the TES scenarios compared to the base case is equal to a Year 1 value of $52,713. This figure is calculated assuming savings of 12,857 cubic meters of water related to the cooling towers that are used in the base case.

TABLE 14: ANNUAL OPERATING COSTS FOR ATES, BTES, AND PTES SCENARIOS AGAINST BASE CASE #1 AS A REFERENCE SCENARIO

Scenario	ATES	PTES	BTES
Total CAPEX	$111,833,571	$123,822,611.69	$130,802,611.69
Total MWh	44,324	79,695	79,606
MWh Savings	69,015	33,643	33,733
Energy cost savings ($0.15/kWh)	$10,352,263.42	$5,046,593.17	$5,060,010.60
Energy cost savings ($0.05/kWh)	$3,450,754.47	$1,682,197.72	$1,686,670.20
Water cost savings ($4.10/m^3)	$52,713	$52,713	$52,713
GHG cost savings ($170/ t$CO_2$)	$1,662,090	$823,480	$825,690
Average annual GHG savings (tCO_2)	9,777	4,844	4,857

Table 22 lists the results of the LCA for ATES, BTES, and PTES scenarios assuming an electricity price of $0.15/kWh. Figure 35 shows the cashflows for the scenarios compared to Base Case #1, with the ATES having the shortest payback periods. All show a positive return on investment, with 20 year IRR ranging from 10.52% for the BTES scenario to 33.17% for the ATES scenario. These attractive returns are in reference to a reference scenario considering a fully electrified heat pump system with no thermal storage. The results do not include the cost of the steam to hot water conversion, or the cost of the heat pumps and associated equipment, which is estimated to be $75.8 million. Nonetheless, these results demonstrate that thermal storage can play a role in decarbonizing and avoiding strain on the grid economically compared to electrified DHC systems that do not integrate storage. The ATES scenario, for example, has a very short payback period of 3.22 years. It is also important to note that though these figures represent an ATES system that assumes a capacity of 250 USGPM, the results of the on-site study at York University do not indicate the presence of an aquifer with a level of capacity approaching that figure. These findings could be applicable to nearby sites with similar loads but that are located on productive aquifers, but it is highly unlikely that an ATES system is technically viable at the York University campus. However, the PTES and BTES scenarios, while having lower overall returns, still achieve payback within 10 years and are less dependant on the subsurface conditions present at the site.

TABLE 15: LCA RESULTS FOR ATES, PTES, AND BTES SCENARIOS COMPARED TO BASE CASE #1 AS A REFERENCE SCENARIO

Scenario	Capital cost (M$)	20 year NPV (M$)	50 year NPV (M$)	20 year IRR	Lifetime GHG reductions (tCO2)	Year to zero cashflow
ATES	111.83	143.36	331.74	33.17%	496,909	3.22
PTES	123.82	39.83	131.96	12.35%	242,236	8.04
BTES	128.70	33.08	125.45	10.52%	242,881	9.03

FIGURE 23: CASHFLOW OF ATES, BTES, AND PTES SCENARIOS COMPARED TO BASE CASE #1 AS A REFERENCE SCENARIO

Table 16 lists the results of the LCA for ATES, BTES, and PTES scenarios assuming an electricity price of $0.05/kWh. The annual cashflows for these scenarios are shown in Figure 24. The ATES scenario payback increases from 3.22 years to 8.68 years with the 66% reduction in electricity prices from $0.15 per kWh to $0.5 per kWh. The rates of return are also much less attractive, with PTES and BTES scenarios having a year 20 IRR of 0.4% and -0.7% respectively. They both have payback periods within the lifetime of the major system components, however, at 19.2 and 21.2 years. The cost of carbon could also play a significant role in the results, but it is unclear what costs will be applied at the provincial or federal level in the future. The additional approximately $825,000 in annual savings for the PTES and BTES scenarios assuming a carbon price of $170 per tCO_2 would increase return on investment substantially.

The ATES scenario with 75 000 m^2 solar thermal collectors is included on the plots to illustrate the relatively small impact of the additional solar collectors – the payback period changes from 2.8 to 3.22 between the 75 000 m^2 scenario and the 90 000 m^2 scenario, approximately 5 months. For an ATES scenario, the solar thermal collectors, or another heat source, are critical in the long term sustainability of the system. Given the large imbalance of York's heating and cooling loads, the ATES would need the entire 90,000 m^2 to avoid degrading the temperatures of the aquifer. The lifetime of the various components is not reflected in the analysis, such as replacement of heat pumps, the pit liner, and so on. The useful life of 25 years can be assumed for most of the components, including control electronics and wiring, piping, heat exchangers, and so on, with limited maintenance costs. Each of the scenarios considered achieves payback before 25 years. The PTES and BTES scenarios have similar payback periods of 8.04 and 9.03 years respectively.

TABLE 16: SUMMARY OF LCA RESULTS FOR THREE KEY SCENARIOS ASSUMING $0.05/KWH

Scenario	Capital cost (M$)	20 year NPV (M$)	50 year NPV (M$)	20 year IRR	Lifetime GHG reductions (tCO2)	Year to zero cashflow
ATES	111.83	24.28	87.46	11.11%	496,908	8.68
PTES	123.82	(18.22)	12.87	0.44%	242,236	19.27
BTES	128.70	(25.12)	6.05	-0.70%	242,880	21.21

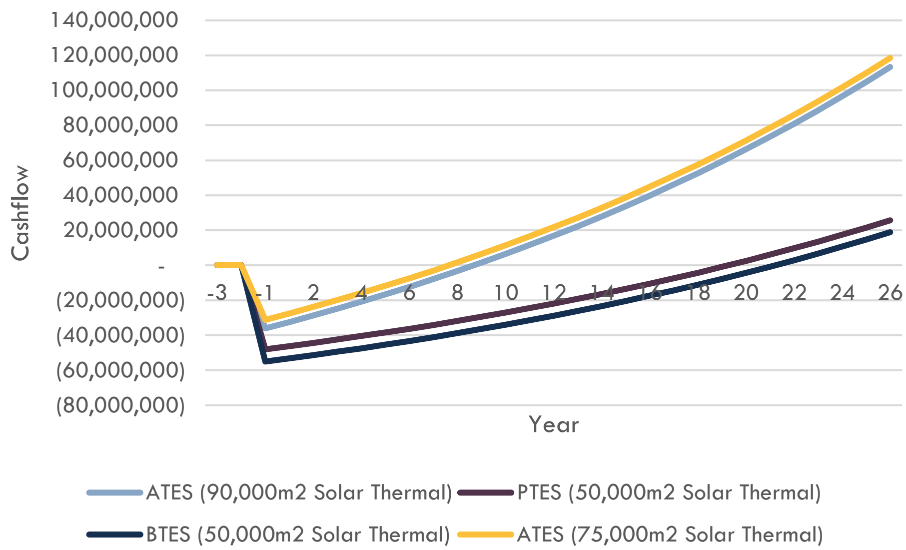


FIGURE 24: ANNUAL CASHFLOW OF ATES, BTES, AND PTES SCENARIOS COMPARED TO HEAT PUMP BASE CASE ASSUMING $0.05/KWH

Milestone 2.2: Preliminary Analysis of ATES Implementation Potential across the Greater Toronto Area

To better understand the effects that widespread adoption of ATES would have on the energy system within the Greater Toronto Area, a study was undertaken to provide a high-level estimate of the opportunity of ATES for meeting the energy needs of consumers in the GTA and impacts that this would have on the existing energy system. The results of the York University study and this preliminary assessment of ATES scale up should be used to influence policy development and guide allocation of resources for further evaluation of this technology at a neighbourhood and site scale.

The objectives of this study were:

1. Identify and map zones of high, medium and low potential for deployment of ATES technology in the GTA.
2. Identify and map areas of high-density development and estimate existing energy usage.
3. Evaluate the impact on energy use, of deploying ATES technology in high-density land use zones.

Mapping ATES Potential

To operate, open loop geothermal systems, including ATES systems, require a consistent source of groundwater. Groundwater reflects the average annual temperature of the region, which in the Toronto area is around 10 °C. Geothermal energy systems take advantage of that consistency in temperature to extract heat from the groundwater when atmospheric temperatures are lower than 10°C, and to extract cold from the groundwater when atmospheric temperatures are below 10°C.

The availability of groundwater varies considerably across the TRCA jurisdiction, with, on the low end, some wells reflecting no to very low quantities of groundwater available (i.e. < 6 USGPM), whereas on the high end, there are wells that can continuously provide over 240 USGPM. With such a large range in groundwater availability, TRCA needs a methodology to that can allow for a focus on those areas with greater groundwater potential. The location of high-capacity production wells is related to the geology of the area.

To the east of the Niagara Escarpment, across most of the TRCA jurisdiction, the bedrock in the area is comprised of low permeability shales which in general, yield low quantities of groundwater. So, for higher capacity wells that can support open loop geothermal systems, one must look in the overlying Quaternary glacial sediments. The deposition of these sediments in the Toronto area is complicated, owing to the glacial processes that laid down sediment during and prior to the last glaciation, which reached its maximum extent some 20,000 years ago. The most important characterization of the glacial sediments in the Toronto area has come from examination of sediment exposures along Toronto's riverbanks and, perhaps most importantly, along the Scarborough Bluffs on the Lake Ontario shoreline. These sediment exposures have allowed geologists to group the glacial sediments into aquifers, those sediments that consist mostly of course, water bearing sands and gravels, and aquitards, the remaining sediments that consist primarily of lower permeability silts and clays that yield only poor quantities of water. Using subsurface well data, three primary aquifer units have been extended inwards from the riverbank and bluff exposures, such that there are now maps of these three aquifer systems (lowermost is the Scarborough, middle is the Thorncliffe, and the shallowest is the Oak Ridges Moraine) that extend across the entire TRCA jurisdiction.

Through the Oak Ridges Moraine Groundwater Program (ORMGP), many subsurface data sets have been assembled to help decision makers. Raw data such as the recorded sand/gravel thickness, driller recommended pumping rates, specific capacity, etc. can all be used to look for areas where aquifers might be coarser or thicker or more productive in general. In addition to these data sets, the ORMGP has also prepared maps showing the thickness of each of the three main aquifers the Scarborough, Thorncliffe and Oak Ridges aquifers.

The aquifer maps were constructed through a lengthy process of examining the geology associated with wells in numerous cross-sections across the area. Both E-W and N-S sections were drawn along roadways and the top of each geological unit was 'picked' at the wells. As each pick is made, the x/y/z information from the pick is saved into the ORMGP database. From this data, the top of each subsurface geological unit was then interpolated to construct each geological unit. By examining the difference in the elevations of successive geological units the thickness or isopach of each geological unit could then be determined. To identify locations where more high capacity, productive wells might be successfully drilled in the future for open loop geothermal systems, these aquifer maps are key.

Figure 25 shows the combined thickness of the three aquifers across the TRCA Jurisdiction. The trend of thicker aquifer materials is generally linear in the south part of the map. Aquifers in this area tend to align with deeper bedrock valleys, where ancient rivers have scoured channels into the bedrock surface. These valleys were subsequently infilled with glacial sediment. In the north parts of the TRCA jurisdiction, coincident with the Oak Ridges Moraine, the glacial sediment is generally thicker and there tends to be more areas of thicker aquifer material. In Figure 1, areas that are light green or yellow, have thicker aquifer materials (e.g. sand and gravel) and would tend to have a greater chance of having a higher productivity aquifer in the subsurface. Wells drilled into these areas might yield high volumes of groundwater for geothermal energy. These areas should be the focus of additional subsurface investigations should they look promising for geothermal development from other perspectives (e.g. energy needs, development density, proponent land holdings, etc.).

For this report the top two categories of aggregate aquifer thickness were considered to have high potential to support ATES (101-150 and 151-250m). Categories of aggregate aquifer thickness of 21-50m and 51-100 were considered to have medium potential to support ATES. The lowest two categories of aggregate aquifer thickness were considered to have low to no potential to support ATES systems. The authors recognize that this categorization is relatively arbitrary and the ability of the aquifers to support ATES will depend on many other aquifer characteristics as well as the energy profile and other characteristics of the individual developments within each targeted land use category. Although this is a significant limitation of the analysis, given the intent of this paper is only to provide the audience with a feel for the potential impact of ATES in the GTA, the limitation is acceptable.

It should be noted that the map has been produced at a regional scale using whatever well data was available at the time of aquifer interpretation. As such, the map certainly does not guarantee that wells drilled in these areas would necessarily be successful high-capacity wells. It should also be noted that since the map combines the thickness of all three of the main aquifers in the area, it would be recommended that wells be advanced right to the bedrock surface such that they would intersect all potential aquifer materials in the glacial sediment package that overlies bedrock.

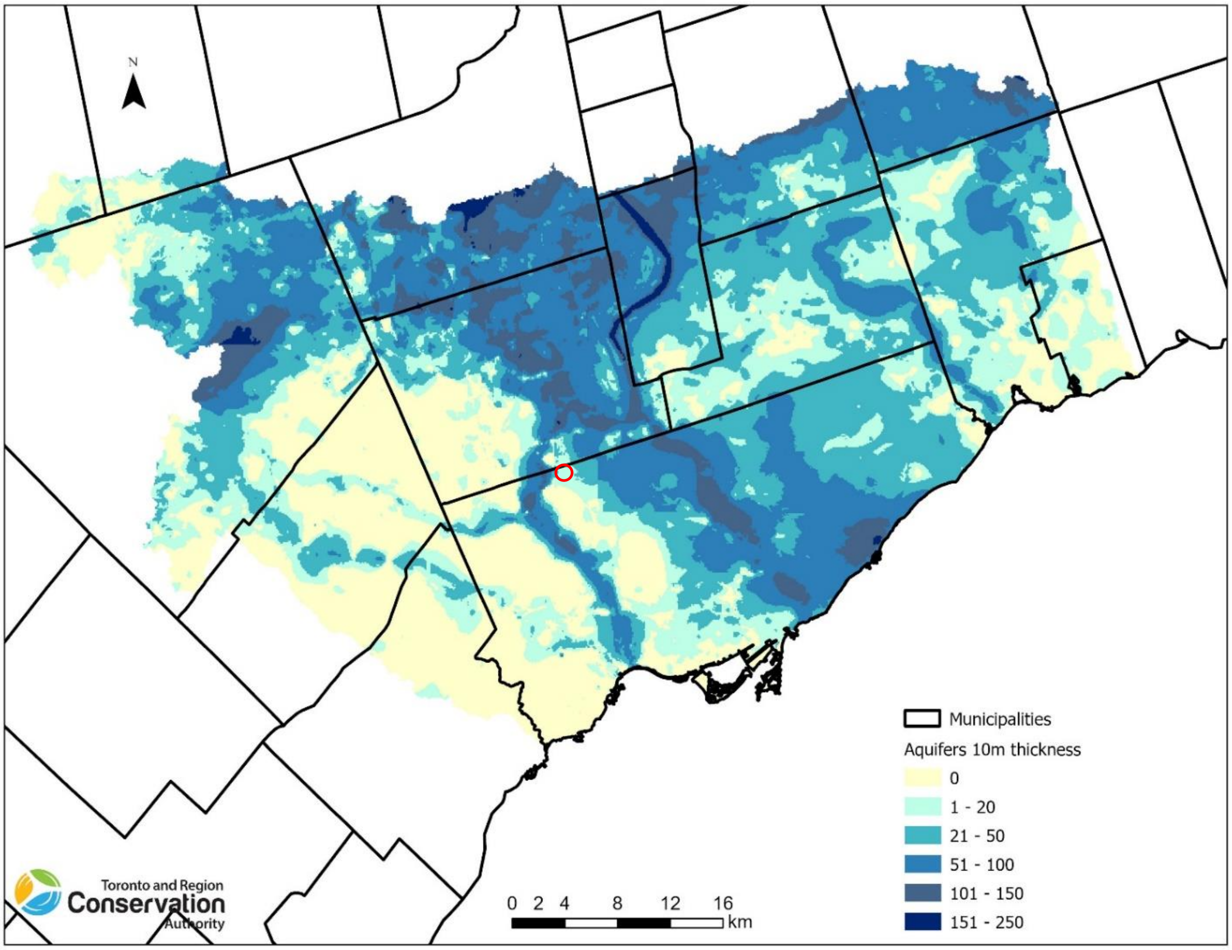


FIGURE 25: AQUIFER THICKNESS MAPPING OF TRCA REGION

Mapping Land use and Existing Energy Usage

As a surrogate for the GTA, land use mapping for the Toronto and Region Conservation Authority's (TRCA) jurisdiction was utilized. The land use mapping was readily available to staff and was based on recent aerial photography (2017). In addition, TRCA's jurisdiction encompasses 3,400 square kilometers which is nearly 50% of the GTA and includes a significant amount of the high-density residential land use and commercial development. TRCA's jurisdiction includes the city of Toronto and parts of the Regional Municipalities of Peel, York and Durham.

The land use layer was derived from 2017 aerial photography and was conducted by on-screen digitizing of land imagery and classified according to 25 different land use classes. The classifications were achieved through qualitative characteristics of the lands based on the 2017 imagery.

TRCA examined two land use classes for evaluating the energy use impacts of potential ATES deployment. High Density Residential (HDR) and Commercial (COM) classes were included in the analysis, as there is data available for predicting the space heating and cooling energy use of these types of facilities. HDR land use consists of high-rise apartment buildings and high-density town house complexes in isolated subdivisions/contained development units with minimal to no existence of manicured lots visible, apartment and large condominium complexes. The COM class incorporates a wide variety of building types including box-store complexes, variety stores, restaurants, grocery stores, malls, plazas and office towers. Visual indicators for commercial areas included small to large parking lots, small to large buildings, flat paved roofs, proximity to street, level of road (arterial roads vs. residential or minor streets), shipping/receiving entryway, alleyways, rear parking, and a lack of manicured areas.

The GIS mapping layer of the land use survey data was overlayed with the aquifer thickness layer to identify where the target land use types fall within the areas of high aquifer potential for ATES deployment. Figure 26 shows the resulting map. The intersect of these two layers was then summed to identify the total hectares for each targeted land use category combined with each category of aquifer ATES potential. Two thresholds of aquifer thickness were categorized, 21 to 100 meters were considered medium potential aquifers and 101 to 250 meters were considered high potential aquifers.

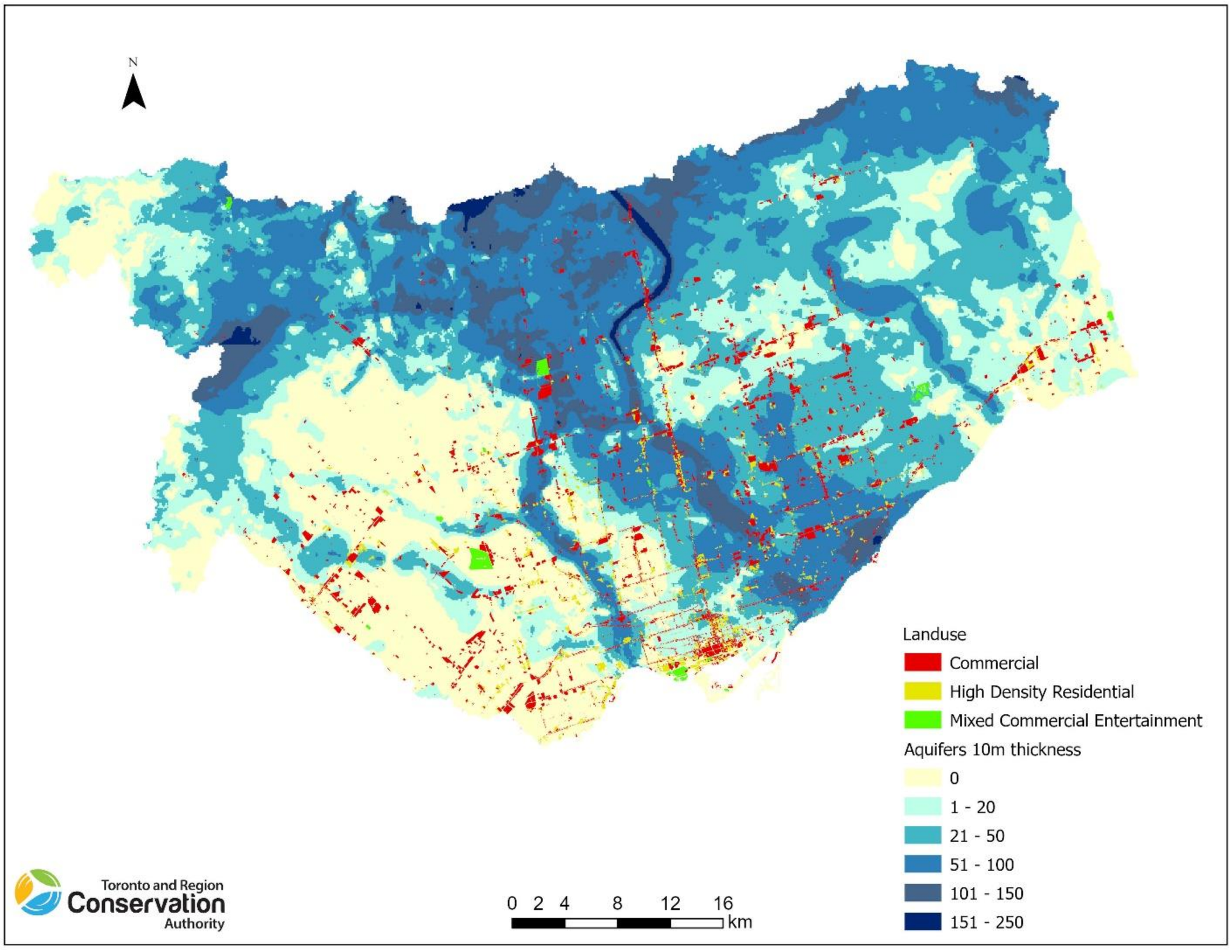


FIGURE 26: MAPPING LAYERS AQUIFER THICKNESS AND LAND USE SURVEY OVERLAPPED.

Estimating the Impact of ATES Deployment

To quantify the impact on the existing energy system that widespread adoption of ATES would have in the GTA, the total energy use of the HDR and COM buildings was estimated by determining the total building gross floor area for each municipality for each land use type, then applying values for annual energy use per unit floor area. Total floor area was calculated using values for HRD and COM land use types' floor space index (FSI), the ratio of total constructed building floor area to the total area of the plot of land. Existing energy sources of the MURB buildings in HDR land use locations are primarily natural gas, electricity, or a mix of both. To estimate the energy usage by fuel type for the HDR areas, the percentage of building gross floor area heated by natural gas and electricity as the primary heat source was estimated. The split of MURBS for fuel source for heating was determined to be 66% natural gas and 34% electricity respectively. The percentage of MURBs cooled was found to be 41%. Using the resulting figures, the space heating and cooling energy consumption for the areas of interest split by the fuel type of natural gas and electricity was calculated. A similar methodology was used for COM land use areas. Nearly 55% of commercial and institutional building floor area is heated by natural gas, the remaining 45% represents primarily electric heated buildings, and 77% of the commercial and institutional buildings in Canada are cooled.

The energy impacts of full-scale ATES deployment in the GTA are estimated to be equal to a 67% reduction in natural gas usage, 211% increase in electricity for space heating, and 36% reduction in electricity reduction for space cooling. The total emissions reduction expected would be 575,886 tCO2e per year (51% reduction).

The impact of ATES on the areas of high potential aquifer thickness and areas of high space heating and cooling energy use can be predicted by applying a seasonal efficiency of an ATES type system to the estimated space heating and cooling energy consumption. To estimate the impacts of ATES on energy use and emissions, it was assumed a seasonal heating SCOP of 3.5 and a seasonal cooling SCOP of 5 for the ATES system to calculate the potential reductions in energy use and emissions. It was also assumed that the existing heating systems for both COM and HDR areas were 75% for boilers/furnaces. The existing cooling efficiency of the areas was assumed to have a SEER cooling efficiency of 11. To ensure that heating loads are met, natural gas would still be used in some capacity to provide secondary heating during the peak winter heating period, 75% of the total heating energy could be satisfied by the ATES system while the remaining 25% would be natural gas sourced heating. The thermal balance of ATES systems is important to maintain. The amount of energy injected and withdrawn from a well should be similar and any imbalance can have impact on performance long term.

The total amount of High-Density Residential (HDR) Land Use identified in the land use mapping was 2,878 hectares (Table 17). Most of this land is in the City of Toronto (78%). The next largest areas include Brampton (5%), Markham (3%), and Mississauga (3%) (Table 17). A total of 81.9 ha or 3% of all HDR land area is located on high potential ATES zones (101-150, and 151-250 meters aquifer thickness). Approximately 1,216.3 ha or 42% of all HDR land falls with medium potential ATES (21-50- and 51-100-meters aquifer thickness).

TABLE 17 HDR AND AQUIFER THICKNESS LAND AREA INTERSECT DATA.

High Density Residential Land Use HDR (hectares of land)	Aquifer Thickness m thickness						
Municipality	0	1-20	21-50	51-100	101-150	151-250	Grand Total
Ajax	22.48	8.27					30.76
Brampton	77.94	50.29	24.35	0.01			152.60
Caledon	0.06		0.35	4.63			5.04
King				3.13			3.13
Markham	21.01	48.35	24.47	3.30			97.14
Mississauga	93.59	0.67	0.31				94.57
Pickering	56.25	4.88	0.41				61.54
Richmond Hill	10.22	5.54	37.54	4.94	2.62	1.47	62.33
Toronto	693.67	454.42	486.47	578.87	53.55		2,266.98
Vaughan	17.67	10.75	12.87	25.65	24.25		91.19
Whitchurch-Stouffville		3.73	9.02				12.75
Grand Total	992.89	586.92	595.79	620.54	80.43	1.47	2,878.03

The total amount of Commercial (COM) Land use identified in the land use mapping was 8,333 hectares (Table 18). Key municipalities that had the highest COM land areas were Toronto, Vaughan, Markham, Brampton, and Mississauga. 433.2 ha or 5% of all COM lands fall within the high potential ATES zones. Approximately 3,540.64 ha or 42% of all COM lands fall within medium potential ATES zones.

TABLE 18 COM AND AQUIFER THICKNESS LAND AREA INTERSECT DATA.

Commercial Land Use COM (hectares of land)	Aquifer Thickness m thickness						
Municipality	0	1-20	21-50	51-100	101-150	151-250	Grand Total
Adjala - Tosorontio		0.12	1.90	0.01			2.0
Ajax	88.66	144.43	8.67				241.8
Aurora				0.19		0.00	0.2
Brampton	618.14	96.75	41.62	0.94			757.5
Caledon	11.43	60.14	47.76	20.22	1.79		141.3
King			0.41	42.11	7.35		49.9
Markham	127.88	260.86	335.63	47.36			771.7
Mississauga	383.75	40.71	46.08				470.5
Mono		2.57	0.19				2.8
Pickering	139.30	64.41	24.69	12.08			240.5
Richmond Hill	51.54	36.69	158.73	107.39	28.79	31.59	414.7

Toronto	1203.33	736.19	1114.24	1024.43	133.01		4211.2
Uxbridge			0.00	1.04			1.0
Vaughan	130.14	121.00	143.66	297.20	229.14	0.72	921.9
Whitchurch-Stouffville		41.72	55.86	8.23	0.85		106.7
Grand Total	2,754.18	1,605.58	1,979.45	1,561.19	400.92	32.32	8,333.6

The space heating and cooling energy usage was estimated for a base case and an ATES case using the land areas, intersect areas of HDR and COM land use and medium and high potential aquifer areas. Energy estimates included natural gas space heating (m^3), electric space heating (kWh) and electric space cooling (kWh). The base case represents a scenario where no changes are made (business as usual) and this would be the expected consumption from the HDR and COM land. The ATES scenario shows the estimated consumption if ATES were utilized to space heat and cool the HDR and COM land.

The total emissions were also calculated for each case using the National Inventory Report emissions factor from the 2023 report.

For the HDR land areas, the energy estimates are summarized in Table 19 and Table 20 and for medium potential ATES zones and high potential ATES zones respectively. The total annual energy consumption in the base case for medium and high potential ATES zones includes a total of 542 million cubic meters of natural gas, 1.97 TWh for space heating, and 1.71 TWh for space cooling. In the ATES case, the consumption levels include a total of 181 million cubic meters of natural gas (67% reduction), 6.139 TWh for space heating (211% increase) and 1.1 TWh for space cooling (36% reduction). The total emissions reduction expected would be 575,886 tCO2e per year (51% reduction). For the COM land areas, the energy estimates are summarized in Table 21 and Table 22 high potential and medium potential ATES zones respectively. The total annual energy consumption in the base case includes a total of 56 million cubic meters of natural gas, 330 million kWh for space heating, and 399 million kWh for space cooling. In the ATES case, the consumption levels include a total of 18.7 million cubic meters of natural gas (67% reduction),671 million kWh for space heating (103% increase) and 257 million kWh for space cooling (36% reduction). The total emissions reduction expected would be 32,000 tCO2e per year (51% reduction).

TABLE 19: HIGH DENSITY RESIDENTIAL LAND USE ENERGY USE AND EMISSIONS SUMMARY EXISTING VS ATES, HIGH POTENTIAL ATES ZONES

High Potential ATES zones

High Density Residential Land Use HDR High Potential Aquifer Thickness	Base Case (Existing)				ATES Case			
Municipality	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)
Ajax	-	-	-	-	-	-	-	-
Brampton	-	-	-	-	-	-	-	-
Caledon	-	-	-	-	-	-	-	-
King	-	-	-	-	-	-	-	-
Markham	-	-	-	-	-	-	-	-
Mississauga	-	-	-	-	-	-	-	-
Pickering	-	-	-	-	-	-	-	-
Richmond Hill	1,052,893	3,831,059	3,316,428	2,202	350,964	11,918,333	2,137,770	1,084
Toronto	23,501,625	85,513,035	74,025,968	49,157	7,833,875	266,028,999	47,717,139	24,203
Vaughan	8,257,863	30,047,067	26,010,809	17,273	2,752,621	93,475,704	16,766,567	8,504
Whitchurch-Stouffville	-	-	-	-	-	-	-	-
Grand Total	32,812,381	119,391,161	103,353,205	68,632	10,937,460	371,423,037	66,621,476	33,791

TABLE 20 HIGH DENSITY RESIDENTIAL LAND USE ENERGY USE AND EMISSIONS SUMMARY EXISTING VS ATES, MEDIUM POTENTIAL ATES ZONE

Medium Potential ATES zone

High Density Residential Land Use HDR High Potential Aquifer Thickness	Base Case (Existing)				ATES Case			
Municipality	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)
Ajax	-	-	-	-	-	-	-	-
Brampton	3,686,982	13,415,456	11,613,342	7,712	1,228,994	41,735,160	7,485,960	3,797
Caledon	1,176,542	4,280,969	3,705,901	2,461	392,181	13,317,991	2,388,824	1,212
King	260,195	946,746	819,569	544	86,732	2,945,304	528,294	268
Markham	9,876,947	35,938,270	31,110,640	20,659	3,292,316	111,803,097	20,053,919	10,172
Mississauga	68,120	247,863	214,567	142	22,707	771,095	138,310	70
Pickering	83,337	303,230	262,497	174	27,779	943,341	169,205	86
Richmond Hill	10,929,189	39,766,956	34,425,014	22,860	3,643,063	123,714,046	22,190,364	11,255
Toronto	467,548,509	1,701,222,460	1,472,695,238	977,949	155,849,503	5,292,462,237	949,299,350	481,497
Vaughan	13,116,453	47,725,538	41,314,510	27,435	4,372,151	148,473,003	26,631,333	13,508
Whitchurch-Stouffville	2,799,198	10,185,165	8,816,980	5,855	933,066	31,685,804	5,683,425	2,883
Grand Total	509,545,473	1,854,032,652	1,604,978,257	1,065,792	169,848,491	5,767,851,078	1,034,568,984	524,747

TABLE 21: COM LAND USE ENERGY USE AND EMISSIONS SUMMARY EXISTING VS ATES, HIGH POTENTIAL ATES ZONE

High Potential ATES zone

Commercial Land Use COM High Potential Aquifer Thickness	Base Case (Existing)				ATES Case			
Municipality	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)
Adjala - Tosorontio	-	-	-	-	-	-	-	-
Ajax	-	-	-	-	-	-	-	-
Aurora	48.0	282.3	341.9	0.1	16.0	574.1	220.4	0.1
Brampton	-	-	-	-	-	-	-	-
Caledon	25,313.0	148,890.4	180,270.9	57.7	8,437.7	302,757.9	116,202.6	28.5
King	103,665.3	609,755.8	738,269.4	236.2	34,555.1	1,239,894.8	475,888.4	116.7
Markham	-	-	-	-	-	-	-	-
Mississauga	-	-	-	-	-	-	-	-
Mono	-	-	-	-	-	-	-	-
Pickering	-	-	-	-	-	-	-	-
Richmond Hill	851,974.6	5,011,287.9	6,067,478.5	1,940.9	283,991.5	10,190,095.1	3,911,096.6	959.2
Toronto	1,876,697.2	11,038,674.7	13,365,211.3	4,275.3	625,565.7	22,446,354.6	8,615,215.2	2,112.9
Uxbridge	-	-	-	-	-	-	-	-
Vaughan	3,243,261.8	19,076,765.3	23,097,428.4	7,388.5	1,081,087.3	38,791,236.2	14,888,602.3	3,651.5
Whitchurch-Stouffville	11,938.7	70,223.0	85,023.3	27.2	3,979.6	142,793.4	54,806.0	13.4
Grand Total	6,112,898.6	35,955,879.4	43,534,023.5	13,925.8	2,037,632.87	73,113,706.00	28,062,031.55	6,882.32

TABLE 22: COM LAND USE ENERGY USE AND EMISSIONS SUMMARY EXISTING VS ATES, MEDIUM POTENTIAL ATES ZONE

Medium Potential ATES zone

Commercial Land Use COM High Potential Aquifer Thickness	Base Case (Existing)				ATES Case			
Municipality	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)	Estimated Annual Space Heating Natural Gas Usage (m3) natural gas	Estimated Annual Space Heating Electricity (kWh)	Estimated Annual Space Cooling Electricity Usage (kWh)	Total Annual GHG Emissions (tCO2e)
Adjala - Tosorontio	26,920.0	158,342.5	191,715.2	61.3	8,973.3	321,978.2	123,579.6	30.3
Ajax	122,318.2	719,471.7	871,109.2	278.7	40,772.7	1,462,994.2	561,517.0	137.7
Aurora	2,743.5	16,137.1	19,538.2	6.2	914.5	32,813.7	12,594.3	3.1
Brampton	600,478.4	3,531,995.5	4,276,407.1	1,368.0	200,159.5	7,182,060.0	2,756,572.0	676.1
Caledon	959,232.1	5,642,173.1	6,831,330.5	2,185.2	319,744.0	11,472,955.0	4,403,475.7	1,080.0
King	600,027.1	3,529,340.6	4,273,192.6	1,366.9	200,009.0	7,176,661.4	2,754,500.0	675.6
Markham	5,403,866.6	31,785,375.2	38,484,534.3	12,310.6	1,801,288.9	64,633,284.5	24,807,130.8	6,084.0
Mississauga	650,140.9	3,824,108.4	4,630,086.3	1,481.1	216,713.6	7,776,050.6	2,984,553.7	732.0

Mono	2,674.1	15,728.8	19,043.8	6.1	891.4	31,983.4	12,275.7	3.0
Pickering	518,853.7	3,051,881.5	3,695,103.1	1,182.0	172,951.2	6,205,782.5	2,381,863.4	584.2
Richmond Hill	3,754,838.8	22,085,845.2	26,740,708.9	8,553.9	1,251,612.9	44,909,984.6	17,237,060.9	4,227.5
Toronto	30,176,016.9	177,494,392.4	214,903,520.2	68,744.3	10,058,672.3	360,922,137.0	138,526,809.1	33,974.2
Uxbridge	14,689.6	86,403.7	104,614.3	33.5	4,896.5	175,695.7	67,434.4	16.5
Vaughan	6,220,387.5	36,588,125.6	44,299,523.3	14,170.7	2,073,462.5	74,399,333.3	28,555,472.7	7,003.3
Whitchurch-Stouffville	904,364.0	5,319,440.7	6,440,578.3	2,060.2	301,454.7	10,816,701.8	4,151,596.8	1,018.2
Grand Total	49,957,551.2	293,848,762.0	355,781,005.3	113,808.7	16,652,517.08	597,520,415.85	229,336,436.05	56,245.66

The results of this report are preliminary in nature and are meant to provide a high-level estimate of potential for ATES technology to impact the amount and characteristics of energy use in the GTA. The results of the York University study and this preliminary assessment of ATES scale up should be used to influence policy development and guide allocation of resources for further evaluation of this technology at a neighbourhood and site scale. According to the 2023 Survey of District Energy in Canada, there are 18 active DE systems within the Toronto region [1], with a total thermal capacity of 992 MW. This mapping exercise could be used by energy planners and system operators to investigate the potential for ATES at DE sites within the study area, in addition to individual commercial, institutional, or residential buildings.

Switching to an ATES system for the areas of interest will require a shift from use of natural gas to electric space heating. As a result, the winter peak demands will increase. The impacts on the grid can be challenging to forecast as there are many factors that can impact peak demand. In general, ATES systems are more efficient than the typical ground source closed loop heat pumps, and air source heat pumps. They operate at a higher efficiency because the entering water temperatures into the heat pumps are generally more stable. Because of the higher efficiency levels, the demand is also reduced.

It is also important to note that sites that are not located on a suitable formation for ATES can also make use of alternative ground coupled thermal technologies such as borehole thermal energy storage or closed loop systems. Finally, ATES is a highly effective technology that has been proven internationally, and there is good potential for its deployment in the GTA in areas of high energy use. As Ontario's energy supply becomes electrified, annual electricity consumption will increase and peaks will grow. ATES and other ground coupled technologies can help offset these increases by providing options for space heating and cooling with very high efficiencies.

Milestone 3: Results dissemination activities

To ensure knowledge and insights from the Project are shared with relevant stakeholders, a number of results dissemination activities were undertaken, ranging from meetings and webinars to major Ontario conferences. A summary of the main publications and activities are listed here, with full links to presentations, publications, and reports in the appendices.

Conference Presentations

Geophysical data interpretation for the York University ATES site investigation, Ontario. Ontario Geoscience Forum, 2024. B. Dietiker, A.J.-M. Pugin, H. Crow, K. Brewer, and H.A.J. Russell

About the conference

The 2024 Ontario Geological Survey (OGS), Geological Survey of Canada (GSC) and Conservation Ontario (CO) groundwater geoscience open house represented the 9th annual event. The open houses focus on sharing the results of a collaborative OGS and GSC groundwater mapping and research and is an important opportunity to keep the groundwater community apprised of new mapping, research and publications.

In 2024, attendees numbered over 400, consisting of stakeholders and clients from the consulting industry (34%), municipal, provincial and federal governments (33%), academic institutions (19%), Conservation Authorities (7%), non-governmental organizations (2%), Indigenous communities (<1%) and 4% who remained anonymous.

The program offered presentations on a wide variety of topics grouped into themes. Our speakers represent the OGS, GSC, Environment Canada, Ontario Ministry of the Environment, Conservation and Parks, Conservation Authorities, the Ontario Oil, Gas and Salt Resources Library, Indigenous communities, consultants and academia.

Abstract:

Aquifer Thermal Energy Storage (ATES) systems have the potential of reducing heating and cooling energy consumption at institutional and commercial scales. ATES systems are popular in Europe, particularly in areas of extensive glacial and post glacial unconsolidated sediment. Southern Ontario shares numerous similarities with such settings. To support an ATES study at York University, Toronto, Ontario, three geophysical datasets were collected i) Microtremor analysis (the horizontal-to-vertical spectral ratio technique, HVSR), ii) seismic reflection, and iii) borehole geophysics. The three techniques provide different scales and resolution of subsurface investigation and form a complementary suite of tools. In areas with thick sediment cover, depth to bedrock estimations often suffer from sparse data. The HVSR technique is a low cost, nonintrusive, rapid approach to estimating depth to bedrock. ATES systems commonly require enhanced information on the succession of surficial geological units, and aquifer geometry and heterogeneity. Seismic reflection data collection can provide insights into all these characteristics and consequently provide greatly enhanced target information for follow-up drilling. The confidence in seismic interpretation can be improved through collection of subsurface information from drilling, either through the combination of drill core logging (sedimentology), core testing, and downhole geophysics. Multiple downhole geophysical data were collected to support i) lithological characterisation (gamma, conductivity, magnetic susceptibility), ii) seismic velocity analysis (p and s-wave), and iii) hydrogeological characteristics (temperature, and porosity using nuclear magnetic resonance). Collectively, the geophysical data can be framed in a basin analysis methodology. This study shows that these surveys can reduce uncertainty - and potentially the cost - of mitigating a poorly understood geological context that could compromise the full potential of an ATES development.

Aquifer Thermal Energy Storage in Ontario: Climate-Resilient Energy Solutions for Decarbonization Pathways LatornellConservation Symposium October 9, 2024. Presented by Don Ford, Senior Manager, Hydrogeology, TRCA.

About the conference

The Latornell Conservation Symposium is an annual event that provides a forum for practitioners, students, academics, government, and non-government organizations to discuss issues, challenges, and opportunities in the conservation movement in Ontario and learn about new tools, techniques, and strategies for natural resources management. 512 delegates attended the 2024 Latornell Conservation Symposium.

Abstract

Ontario's groundwater resource offers an innovative opportunity to reduce GHG emissions in the path towards decarbonizing our energy system. CanmetEnergy-Ottawa (CE-O) of Natural Resources Canada is investigating building decarbonization pathways that make use of underground thermal energy storage, with partners including the Geological Survey of Canada (GSC) and the Toronto Region Conservation Authority (TRCA). We are seeking to develop cross-disciplinary, climate-resilient solutions that address two key issues: resource and land use planning, including developing methodologies to make exploration easier for developers, and impacts to the grid associated with large winter peaks from the electrification of heating.

This presentation shared a background on low temperature geothermal energy technologies, common barriers to their implementation in Ontario, and initial results of both the York University study including the geophysical site survey using innovative seismic sensing techniques and a techno-economic analysis of aquifer and other underground thermal storage systems, as well as current projects being undertaken at the TRCA campus. Additionally, to investigate the potential for replicating such systems throughout Ontario, the presentation reported on methodology and results of an analysis of scale-up potential for the Toronto region, and considerations for future implications of ATES systems, learning from the international community, such as the Netherlands, where ATES is common in urban areas. The results of this work will help guide land use planners and policy makers, and we seek to build collaboration with municipalities and others who can benefit from the inclusion of underground thermal energy storage.

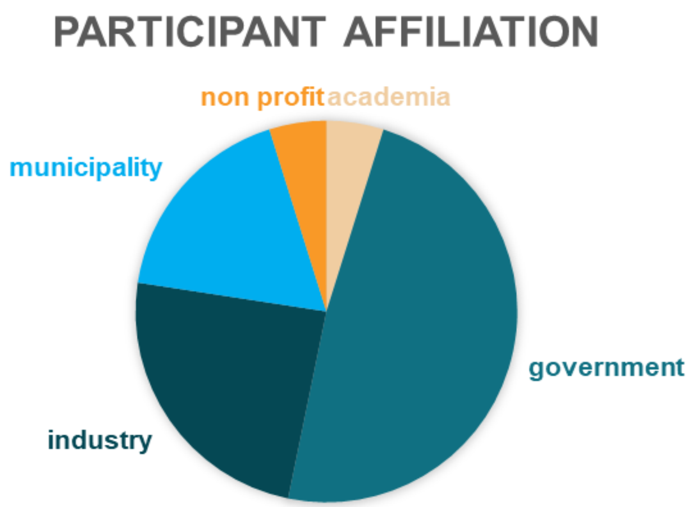
Webinar Presentations

CanmetENERGY-Ottawa's Renewable Heat and Power team held this virtual event on November 12, 2024, focused on decarbonizing large-scale heating and cooling systems. This webinar featured leaders from the Geological Survey of Canada, the Toronto Region Conservation Authority, the City of Toronto, and other key stakeholders.

This event featured **two sessions to allow for forum discussions between general stakeholders and policy stakeholders.** The webinar brought together researchers, industry professionals, and policymakers to share challenges and opportunities for enabling electrification and decarbonizing building heating and cooling loads using large scale thermal projects. Expert presentations included Aart Snijders' (Underground Thermal Energy Storage Consulting) report on the widespread success of Aquifer Thermal Energy Storage (ATES) in Netherlands, with over 2200 installed systems, Will Nixon's (City of Toronto Project Lead, Environment & Climate Division) status update on the City of Toronto's sustainability initiatives including the wastewater heat project at Toronto Western Hospital Campus which will service 90% of the campus' heat needs, and Don Ford, (Senior Manager, Hydrogeology, Toronto Region Conservation Authority) who shared results of a scale-up analysis of ATES for the Toronto Region which estimated potential GHG savings from buildings could reach 34-40% with the integration of ground coupled thermal energy systems. The full webinar presentations can be found in Appendix .

Session 1: York University Project Results	
Raymond Boulter – CE-O	District Energy in Canada & CE-O activities
Isabelle Kosteniuk – CE-O	York University Project: Results of techno-economic analysis
Hazen Russel – Geological Survey of Canada	Geophysical application in site characterization and selection - York University Resource Characterization
Don Ford – Toronto Region Conservation Authority	Scale up potential of Aquifer and Open Loop systems in the Greater Toronto Area
Session 2: Applications in Ontario and Internationally	
Aart Snijders – UTES Consulting	ATES in Netherlands including policy &political context
Brian Beatty – Salas O'Brien	Ontario UTES Projects - Aquifer Thermal Storage and Open Loop Systems
Jarrett Carriere – JL Richards	Wastewater Energy Transfer: Thermal projects for municipalities
Will Nixon - City of Toronto	City of Toronto: Decarbonizing Buildings with Underground Thermal Energy Storage

The webinar attracted 63 participants from a range of government bodies, academia, nonprofit organizations, industry including energy project developers and engineering consultants, and municipalities.



Conclusions & Next Steps

To assess the viability of integrating large scale thermal energy storage into York University's DHC system, including the impact that such technology deployment would have on the electricity system, this Project conducted three main activities:

1) Using York University's Keele campus as a test case, the project applied high-resolution seismic mapping techniques pioneered by NRCan's Geological Survey of Canada (GSC) to non-invasively characterize aquifers in sufficient detail to support investment decisions in geothermal systems. The GSC's seismic mapping techniques can characterize major aquifers programs at a potential cost lower than drilling test wells/boreholes. The survey provided information on potential drilling targets that was used in Milestone 2 to assess the potential for an ATES system on the York U campus.

2) A techno-economic analysis was completed that evaluated the incorporation of thermal energy storage (using aquifers, boreholes or thermal pits) to the campus' existing district heating and cooling system. As no suitable aquifer was identified from the geophysical survey, the simulations used assumed parameters for aquifer characteristics and included alternative PTES and BTES systems that could be more viable given on-site conditions. The analysis also included the conversion of much of the heating and cooling loads from natural gas to electricity, while avoiding increased electricity demand during peak periods; and

3) Project results were disseminated, including a preliminary analysis of ATES implementation potential across the GTA, to policy makers, universities, colleges, commercial entities and government agencies that own and operate district energy systems in the GTA. Such users are better equipped to understand the potential of large geothermal systems, especially when coupled with thermal energy storage. In addition to district energy systems operators, other large users of thermal services such as industrial facilities and greenhouse operations can also benefit from the results of this Project.

The collaborative study on the geological suitability of an Aquifer Thermal Energy Storage (ATES) system at York University provided an opportunity to address how geophysical surveys could enhance reconnaissance to support ATES site selection. The geophysical program demonstrated the rapidity of data collection, the breadth of 1- and 2-D information gained, and the effectiveness of geophysical techniques versus drilling alone.

The three geophysical techniques deployed for the study individually address specific issues that are critical to successful reconnaissance assessment and subsequent site consideration for an ATES development. The HVSR survey is a non-intrusive, rapidly deployed, low-cost technique capable of providing estimates of depth to bedrock. This technique can be particularly valuable in areas of thick sediment where there may be limited water well intercepts of bedrock. In addition to depth, the orientation of subsurface structures can be mapped to further refine understanding of subsurface geometry. In areas of thick and complex stratigraphic successions assignment of resonators with bedrock can be complicated, reducing confidence in depth estimates.

The seismic data provides a complete stratigraphic architecture and […] information on aquifer target depths, geometry, and heterogeneity to support optimized selection of drilling targets.

Seismic reflection surveying is a well-known non-intrusive, rapid technique used extensively in southern Ontario. In this study focus was on shear-wave data collection which is less sensitive to fluid contents and better images lithologies using various seismic interpretation tools related with seismic facies analysis. In this study the technique provided high-quality data on depth to bedrock and two-dimensional bedrock relief. The overlying surficial stratigraphy is dominated by sub-horizontally, and relatively continuous stratigraphic horizons. The value of continuous subsurface imaging was highlighted by identification of a previously unknown channel feature in the Lower Sediment. On the basis of TRCA borehole info and reflection amplitude, textural assignments were made to each of the respective seismic reflection horizons. The seismic data provides a complete stratigraphic architecture and seismic facies analysis that can provide a valuable source of information on aquifer target depths, geometry, and heterogeneity to support optimized selection of drilling targets. Integration of water well data along part of the Ian MacDonald road profile highlights the incomplete understanding provided by water well records due to interception of potable water at shallow depths. Analysis of the seismic reflection data is greatly enhanced if there is available borehole geophysics to constrain the velocity for conversion from time to depth.

The borehole geophysics, particularly gamma logs and NMR signal can provide useful information on the well completion. Signals of high mobile water from the MNR when compared with gamma / MS signal can provide information on fluid filled void spacing behind the casing. These points can help yield information that may be important to understanding the ATES performance and the degree of vertical isolation along the borehole casing.

When planning a site investigation geophysical data collection can provide valuable information that is much greater than one or multiple boreholes. Drilling involving continuous core provide a single point of information on the stratigraphic succession and heterogeneity. Individual or even multiple boreholes will not provide any information on the stratigraphic architecture where horizontal strata may be truncated by channels with completely different fill sediment textures. For reconnaissance the two seismic techniques provide complementary information that will greatly improve drilling site selection. Borehole geophysics can reduce the need for continuous core recovery, which is expensive, and provide a number of additional datasets on in situ aquifer characteristics. Integrated with the seismic reflection analysis, the data provide a means of verifying and calibrating the seismic facies analysis. ***It is critical to note that while the seismic techniques explored in this study can support site characterization activities, follow-up with drilling is a prerequisite to making a statement on aquifer characteristics and yield.*** The geometry of the channel location identified in the survey would likely be too small to support the number of wells required for the scale of the system considered for York University.

The result of the cost comparison between traditional drilling-based site exploration methods and the seismic techniques demonstrated as part of this project concluded that for large sites where there is a likely presence of a local aquifer that could support ATES development a seismic site investigation approach could significantly reduce exploration costs for ATES projects. The specific approach is subject to site-specific conditions. For example, the two seismic methods could be performed sequentially, or only one or the other could be applied. Test well locations are crucial, especially in relatively small projects. Desktop studies do not account for all subsurface variability, especially in regions like Southern Ontario with a high degree of heterogeneity. Short seismic profiles could be obtained before the first test wells are drilled to ensure the optimal location is found.

The availability of equipment and knowledge can be a barrier to implementing seismic survey approaches. Though there are contractors with the required expertise, the availability of services is based on sector activities - for instance, seismic surveys are often performed in the context of mineral and petroleum exploration. Seismic surveys could be carried out by groups and organizations such as universities, municipalities, or different government organizations in order to provide data products that could be used to encourage consideration of ATES projects by developers.

Although exploration for individual sites is the responsibility of the developer, there are some instances internationally where test drilling is not required in ATES project development. For example, in international jurisdictions with a high adoption rate of ATES projects, such as the Netherlands, site investigations do not always require test drilling as there is significant knowledge at a fine resolution of (major) aquifers and their characteristics due to relatively homogenous geology and high population density. Southern Ontario, by contrast, is more sparsely populated and has highly variable geology (local aquifer) - if aquifer and other subsurface energy systems become more common, it will still likely be a site-by-site consideration of whether test drilling is required.

The techno-economic analysis of large scale thermal storage integration on the campus expanded on an existing high accuracy TRNSYS simulation model of the York University's Keele campus district cooling system and cooling equipment, by adding the heating equipment and heating loads into the model. Using this Project's TRNSYS modeling, the techno-economic benefits for both heating and cooling loads were estimated. Given that the seismic survey confirmed that there is no suitable aquifer on York University's campus, and therefore the present study includes alternative large-scale underground storage options including PTES and BTES as part of the techno-economic analysis. In addition to the three TES technologies considered here, two electrified base case scenarios were developed to allow for direct comparison of electrical usage.

Several key assumptions were made to develop the final heating loads that were used in the modelling and simulation, given that limited information was available on the steam consumption during periods of high ambient temperatures, and that the system would require a steam to hot water conversion to allow for the integration of large-scale thermal energy storage, which operates at temperatures well under 100 °C. The TRNSYS model of the existing plant at York University to include heating using hot water in place of steam, and low-carbon scenarios were designed, integrating aquifer, pit, and borehole thermal storage. The various scenarios were run using the TRNSYS simulation engine for multi-year periods to characterize the energy flows and power consumption, which were then used to inform the CAPEX and OPEX costs and run a life cycle cost analysis. The primary objective of each scenario was to meet the entire campus heating and cooling load over the course of the year without the use of fossil fuels – to that end, each scenario is fully electrified, using either thermal energy storage or, for the base cases, heat pumps or a steam boiler in combination with cooling towers.

A total of ten scenarios, including the two base cases, were devised for the current work. The scenarios were configured using two stacks of heat pumps: one simultaneous stack to meet the coincident heating and cooling loads, and one single-mode stack to meet the remaining demand, either heating or cooling depending on the time of year. The single-mode stack has a capacity of 10,000 tons (35.17 MW) of heating at 60 °C with a leaving source temperature as low as 5 °C, and the simultaneous heat pump stack has a total rated capacity of 3,900 tons (13.7 MW) of heating at 60 °C with a leaving CHW temperature of 5 °C. The ATES scenarios were designed based on the subsurface information gathered as part of the previous project, with simulations performed for both high flow and low flow scenarios with the well field capable of producing a combined flow rate of 20 000 USGPM (1261 L/s). The aquifer wells were assumed to be capable of producing 500 GPM (31.54 L/s) per well in the high flow scenario and 250 USGPM (15.77 L/s) in the low flow scenario, with both configurations assuming an undisturbed well temperature of 9.5 °C. The BTES scenarios use a borefield consisting of 4,200 bores each with a depth of 200 m and 4 m spacing for a total surface area of 67,200m2 surface area. Flow is assumed to be 6 GPM per bore for a total of 25,200 GPM. The PTES has was sized to be comparable to the largest pits currently being installed globally with a total volume of 500,000 m^3. Each of the thermal storage scenarios uses an unglazed solar thermal collector array to help balance heating and cooling loads. The scenarios are also equipped with an auxiliary electric boiler to meet any demand not covered by the heat pumps and thermal storages.

Base case #2, using a steam boiler, results in a peak load of 54,546 kW and annual electricity consumption of 231,257 MWh. Base case #1, using heat pumps, reduces the peak load to 35,932 kW and annual consumption to 113,339 MWh, a reduction of 34.1% and 50.9% respectively. Base Case #2 is the only scenario considered in the current work that uses the existing steam distribution network.
The ATES scenarios reduce the peak even further. Scenario 5 uses an ATES and solar thermal array area of 90 000 m^2 to fully balance the aquifer. This scenario achieves a peak of 9,680 kW and annual consumption of 45,441 MWh, equivalent to 73% reduction in peak load, 61% reduction in annual electricity consumption compared to Base Case #1, and 82% and 81% reduction to peak and annual consumption compared to Base Case #2. The PTES and BTES scenarios had lower impact from the size of the solar thermal array due to the controls and low operating temperatures of the collectors. The PTES configuration using 90 000 m^2 solar thermal, Scenario 6, resulted in an annual consumption 75,063 MWh, with peak of 32,354 kW, compared to 79,690 MWh and 32,385 kW peak using 50,000 m^2. This is because the system is not designed to add heat to the pit year over year, and only uses the collectors

during periods when the heat pumps are calling for heat, leaving a large amount of energy uncollected. Similarly, Scenario 8 with a BTES system and 90 000 m^2 solar thermal resulted in an annual consumption 69,062 MWh and peak of 25,834 kW, compared to Scenario 7 with 50,000 m^2 only increases the annual consumption by 2%, and peak by 11.6%. The PTES and BTES scenarios equipped with 50,000 m^2 solar arrays reduce peak compared to Base Case #1 by 10% and 19% respectively, and annual consumption by 30% and 32% respectively. Compared to Base Case #2, using steam boilers, they reduce peak demand by 41% and 46%, and annual consumption by 66% each. The thermal storage scenarios all result in GHG savings compared to Base Case #1, with average annual reductions of 9,777 tCO_2 for the ATES (90,000 m^2) scenario, 4,844 tCO_2 for the PTES (50,000 m^2) scenario, 4,857 tCO_2 for the BTES (50,000 m^2) scenario. These figures would be much larger compared to Base Case #2 (steam boiler), and compared to the existing natural gas co-gen system. Overall, the scenarios show good potential to reduce annual electricity, peak consumption, and GHG emissions compared to fully electric DHC systems that do not make use of large-scale thermal storage.

The overall energy results found that the large heating load causes issues with all the systems, even with large collector arrays. The PTES and BTES are not sufficiently warm to supply the single mode heat pumps with a heated source stream through the heating season, causing over-reliance on the auxiliary boiler to heat the input to the heat pumps. Changing to glazed collectors would produce more heat for the source loops but could impact the cooling that the systems can provide. A more in-depth assessment of energy use at the campus, including electricity for non-heating and cooling needs, and the impact of decommissioning the co-gen would be needed to more fully understand the requirements of the DHC system in the case of a steam to hot water conversion, taking into account considerations like orphaned steam loads.

The sheer volume and size of the collector arrays, boreholes, aquifer wells, and pit, would be challenging to integrate into the highly built-up urban campus. The York University campus is already built up, making piping and cabling runs more costly to install. Costs for other system components, including the ATES, PTES, and BTES systems are impacted by a lack of experience in Canada. Such systems are uncommon in Canada and North America, and a lack of experienced designers, engineers, and installers, would impact the complexity and time scale of such a project, and cause uncertainty in costing. Engineering and permitting costs would likely be higher than similar systems installed in Europe.

The results of the life cycle analysis indicate that given the current electricity prices paid by the university, all of the thermal storage scenarios show good return on investment compared to a fully electrified heat pump system without thermal storage. The ATES, PTES, and BTES scenarios resulted in payback periods of 3.22, 8.04, and 9.03 years respectively, compared to the reference Base Case #1. Given the complexity of estimating the costs of a full steam to hot water conversion, no analysis was done for the total costs of Base Case #2 (steam boiler). The University of British Columbia estimates $2000 per meter of piping to convert from steam to hot water, which would be necessary for any of the thermal storage scenarios.
To provide a high-level estimate of potential for ATES technology to impact the amount and characteristics of energy use in the GTA. The results of the York University study and this preliminary assessment of ATES scale up should be used to influence policy development and guide allocation of resources for further evaluation of this technology at a neighbourhood and site scale.

To better understand the effects that widespread adoption of ATES would have on the energy system within the Greater Toronto Area, a study was undertaken to provide a high-level estimate of the opportunity of ATES for meeting the energy needs of consumers in the GTA and impacts that this would have on the existing energy system. The study identified and mapped zones of high, medium and low potential for deployment of ATES technology in the GTA and overlaid this information with areas of high-density development and estimate existing energy usage. The impact of deploying ATES technology in high-density land use zones was then estimated.

For the HDR land areas, the total annual energy consumption in the base case for medium and high potential ATES zones includes a total of 542 million cubic meters of natural gas, 1.97 TWh for space heating, and 1.71 TWh for space cooling. In the ATES case, the consumption levels include a total of 181 million cubic meters of natural gas (67% reduction), 6.139 TWh for space heating (211% increase) and 1.1 TWh for space cooling (36% reduction). The total emissions reduction expected would be 575,886 tCO2e per year (51% reduction). For the COM land areas, the total annual energy consumption in the base case includes a total of 56million cubic meters of natural gas, 330 million kWh for space heating, and 399 million kWh for space cooling. In the ATES case, the consumption levels include a total of 18.7 million cubic meters of natural gas (67% reduction), 671 million kWh for space heating (103% increase) and 257 million kWh for space cooling (36% reduction). The total emissions reduction expected would be 32,000 tCO2e per year (51% reduction).

Switching to an ATES system for the areas of interest will require a shift from use of natural gas to electric space heating. As a result, the winter peak demands will increase. The impacts on the grid can be challenging to forecast as there are many factors that can impact peak demand. In general, ATES systems are more efficient than the typical ground source closed loop heat pumps, and air source heat pumps. They operate at a higher efficiency because the entering water temperatures into the heat pumps are generally more stable. Because of the higher efficiency levels, the demand is also reduced.

It is also important to note that sites that are not located on a suitable formation for ATES can also make use of alternative ground coupled thermal technologies such as borehole thermal energy storage or closed loop systems. Finally, ATES is a highly effective technology that has been proven internationally, and there is good potential for its deployment in the GTA in areas of high energy use. As Ontario's energy supply becomes electrified, annual electricity consumption will increase and peaks will grow. ATES and other ground coupled technologies can help offset these increases by providing options for space heating and cooling with very high efficiencies.

Given the findings of the activities undertaken as part of this project and shared in this report, it is recommended that for any institutional, existing DHC like the one in operation at York University, a fully electrified heating and cooling system would require detailed analysis of many factors, including:

- The existing heating and cooling loads, including steam loads used in laboratories, kitchens, for sterilization
- Utility expenditures and the cost of upgrading electrical capacity to the campus
- Demand side management to help balance heating and cooling loads
- Available heat sources including industrial waste heat, wastewater, waste heat from facilities, metro stations, supermarkets, etc.

It is clear that electrifying heating and cooling systems of major facilities and campuses represents a great challenge to electricity systems operators, and the use of steam based heating systems with electric boilers could lead to extreme stress on local grids. The integration of large-scale thermal storage, including aquifer systems where local site conditions allow, could enable decarbonisation of existing or new systems while avoiding the spike in peak demand associated with electric boiler or heat pump systems alone.

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Appendices

All appendices are attached as pdfs

1.1 Major Ontario Conference 1 - Ontario Groundwater Geoscience Open House 2024

1.2 Major Ontario Conference 2 - Latornell Conservation Symposium Oct 2024

1.3 Webinar Forum Discussions

1.3.1 Webinar Forum Discussions – Presentations

1.3.2 Webinar Forum Discussions - Summary Report