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Open Loop Geothermal Resource Scoping Study

J.L.Richards
ENGINEERS · ARCHITECTS · PLANNERS

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1.0 Introduction

J.L. Richards & Associates Limited (JLR) was retained by the City of Ottawa (the City) to provide a preliminary study for assessment of the geo-exchange open loop resources within the City of Ottawa. The scope of this project is being executed under Standing Offer for Professional Engineering Services 30717-92500-S01 - Category 1 - Planning, Feasibility, Pre-Engineering, Environmental Studies and Assessments (the SOA).

Increasing the use of geothermal heat pumps by buildings across the City is one of the potential means of achieving the City's greenhouse gas (GHG) emission reduction targets. The City's intention for this study is to provide a survey of the open loop geothermal resources that can help the stakeholders with reducing the risk of decisions in developing the geothermal projects. This study will provide the City with a scan of the available well records and explaining how the obtained information from these records can help with establishing a methodology for the assessment of different locations for open loop geothermal technology. The well records have been analyzed, categorized, and incorporated into an ArcGIS user interface.

2.0 Background

The City of Ottawa Energy Evolution Program has set a goal for the City to achieve carbon neutrality by 2050, and for City corporate operations to achieve carbon neutrality by 2040. One key need within this plan is for buildings and infrastructure to move to zero carbon energy using a range of viable technologies including air source heat pumps, ground source heat pumps, district energy systems, waste heat recovery, and renewable natural gas.

Ground source heat pumps can be used in different configurations such as open loop, horizontal closed loop, and vertical closed loop. In open loop configuration, the groundwater is directly used as a heat carrier. When productive aquifers are accessible, this type of geothermal technology is technically feasible and has generally lower costs than closed-loop systems. The common practice is to drill two wells: the extraction well, and the injection well. The extraction well pumps the groundwater towards the building where its energy is used, then the injection well injects the water back to the same aquifer with the same rate but at a slightly different temperature.

The purpose of this study is to evaluate potential locations of the open-loop geothermal projects within the boundaries of the City of Ottawa by using existing well data and reviewing information on geology and the yield of the aquifers. Specifically, the objectives and deliverables of this report are as follows:

- Explain geothermal heat pumps systems
- Describe critical parameters from the well data for open-loop geothermal systems
- Assess the available well data
- Categorize the wells based on their suitability to open loop systems
- Compile the data in ArcGIS user interface
- Evaluate how geological information further explains likelihood

3.0 Geothermal Heat Pumps

Geothermal heat pumps are systems that use a fluid to exchange heat to and from the ground along with a heat pump to provide heating and cooling to a building. The stable temperature of the earth below a certain depth is used as an energy source and sink. While the air temperature varies between -40°C in winter to 35°C in summer, the temperature of earth and underground water stays in the range of 6 to 10°C all year long. This relatively stable temperature provides an attractive source for extraction of heat in the winter and injecting of heat in the summer; it is accessed by burying pipes (horizontally or in vertical bore holes) and circulating a liquid through them. Two different types of such systems are closed loop and open loop. In both cases, a heat pump is used to exchange the heat between the building and the outside loop.

In **closed loop geothermal systems**, a mixture of antifreeze and water passes through the closed loop pipes that are buried in the ground. This heat transfer fluid does not interact directly with the ground or ground water. This system requires a long length of buried loop to ensure that sufficient heat transfer occurs between the ground and the circulating fluid. Two main variations of closed loop systems are horizontal and vertical. In **horizontal closed loop systems,** the pipes are laid horizontally in the ground which requires accessibility to a large area of space. This makes the horizontal variation difficult to adopt in dense city areas. **Vertical closed loop systems**, on the other hand, involve pipes which run vertically in several boreholes 30 to 150 m deep, but which can be as deep as 300 m. The two pipes are placed inside each borehole and are connected by a U-bend at the bottom; these pipes are then grouted in place with thermally conductive grout. This reduces the need for the accessible land, but it can still be challenging to locate several boreholes in a small site. It should be noted that since the piping in these vertical bore holes are grouted in place, the ground loop involves little to no maintenance and can be placed below parking lots or even installed underneath a building foundation. The limiting factor in the feasibility of closed loop geothermal systems is the availability of space for the ground loop installation, as well as the high cost of drilling. Closed loop systems also must be properly designed to avoid overheating or overcooling the ground over time; this can occur when the annual heating and cooling energy loads of a building are not balanced. A closed loop system can be expected to cause a seasonal variation in ground temperature (which will affect system efficiency at the end of a season); however, if not properly designed, the temperature may not recover after a full year cycle. The result over time can be the degradation of the system performance or system failure.

Open loop geothermal systems, also referred to as groundwater heat pump systems (GWHPs), directly use the ground water as a heat carrier. A well-doublet scheme is the most common installation method in which an extraction (supply) well pumps the groundwater up and to the building, and after passing through a heat pump, an injection (diffusion) well injects the water back into the same aquifer at the same rate; a schematic of the open loop system installation is shown in Figure 1. It is common for ground water to flow in a given direction, so to avoid a short circuit between the two wells, the rejection well is ideally installed “downstream” of the source well. This configuration ensures that the rejected water is not recirculated through the system and that the *source* water ground have the same temperature as the ground temperature throughout the year. This system inherently avoids long term ground temperature variation which occur in closed loop systems over the course of a season, and which may even change year-over-year if there are unbalanced heating/cooling loads (as discussed above).

When used in the larger systems (e.g., commercial buildings, universities, and hospitals), adequate control and monitoring measures are required. In such systems, water that is withdrawn from the extraction well, is pumped through several devices providing control and monitoring, as well as the heat exchanger and then returns to the aquifer through the injection well.

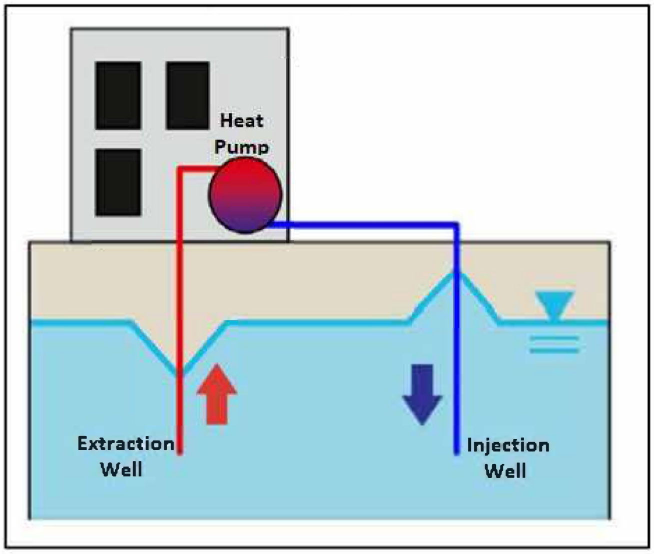


Figure 1: Schematic of an open loop geothermal installation

It should be noted the ground water piping loop runs from the source well through a closed heat exchanger, then to the rejection well with no exposure or interaction with the atmosphere or other water sources. This means that water quality is not affected and that there should be no environmental concerns. It also means that the pumping power is only required to overcome frictional losses in the pipes and heat exchanger, and is not affected by head loss (the inlet and outlet are at the same depth).

Due to the direct usage of underground water, which provides a constant temperature and high thermal conductivity, open loop systems offer a higher efficiency relative to closed loop systems. The system also requires fewer boreholes resulting in cost savings versus closed loop systems – often the open loop system can be half the capital expense of a closed loop system, though costs advantages do vary with ground conditions and system size. Hence, when there is enough groundwater, the feasibility study of an open loop geothermal system is highly recommended.

However, the design of the open loop geothermal system is dependent to the aquifer characteristics and the well yields. The limiting factor dictating the feasibility of an open loop geothermal system is the presence of sufficient ground water. In the absence of ground water, open loop systems cannot be relied upon and a closed loop system is a likely feasible alternative.

Implementation of a geothermal system is an iterative process that consists of pre-feasibility, feasibility, confirmation, design, and implementation steps. The feasibility stage starts when a client shows their desire for a geothermal system. In the feasibility stage, an initial evaluation from the site and geology will be undertaken, which may be followed by energy models on several geothermal options such as vertical closed loop, horizontal closed loop, and open loop.

Generally, conducting field tests by installing test wells is the most accurate method to obtain information about the aquifer such as porosity, conductivity, storage coefficient, and depth of water. However, performing these tests are expensive and could be economically infeasible in small geothermal projects. In the Ottawa area, drilling and pump testing a deep (180 m) test well for a commercial-sized open loop geothermal system can cost approximately $25,000.

Before incurring costs of this magnitude, a preliminary desktop study of published information and data about the local area and existing well records can be undertaken. The aim is to review if existing information indicates a likelihood of a suitable aquifer. If it looks sufficiently likely, then a test-well should be undertaken. Drilling a test well along with specific testing of the borehole (thermal conductivity test and/or water pump test) will show the detailed characteristics of the geology/hydrogeology and will help with a more detailed and accurate estimation of the costs of the project. Further explanations of these two steps are in the next section.

If an open-loop system is ruled out by either of these steps, then a closed loop system should be considered.

A common alternative heat pump solution to geothermal systems are air source heat pumps. These systems are considerably less expensive to install, but they have a lower efficiency due to their reliance on air as a heat source/sink. Seasonal variation of the air temperature hinders the performance of the heat pumps system. Hence, air source heat pumps often can’t heat sufficiently in the coldest hours of the year, requiring additional back-up heating equipment. Cold climate air source heat pumps technologies are emerging but are still limited in their ability to heat in the coldest days of the year in Ottawa, typically requiring a resistive back-up heater.

4.0 Well Record Data

4.1 Ontario Well Records

The government of Ontario has collected the well record data from 1899 to present. As prescribed by Regulation 903, the well information is submitted by the well contractors and this provides a dataset that is stored and made publicly available in the Water Well Information System (WWIS). The data contains the geology, material properties and groundwater information, which is important in geotechnical and groundwater site assessments. The well data used in this study was downloaded on November 2020 from the Ontario well record database; more than 15,000 well records were reviewed and categorized, as further explained herein.

Figure 2 indicates the main parameters related to construction and performance of a typical well. By drilling a well, different layers of the underground are identified. The topsoil and other unconsolidated materials such as gravel, sand, silt and clay, make the overburden. The solid rock underlying these materials is called bedrock.

A water table describes the boundary between water-saturated ground and unsaturated ground. Below the water table, rocks and soil are full of water, but above the water table, water is unsaturated and is called the soil moisture.

Pockets of water existing below the water table are called aquifers. These aquifers exist in various layers of bedrock and are typically higher yield than the surface water or shallow aquifers in the upper water table (not shown in the schematic).

Parameters such as static water level and drawdown are explained later in this report.

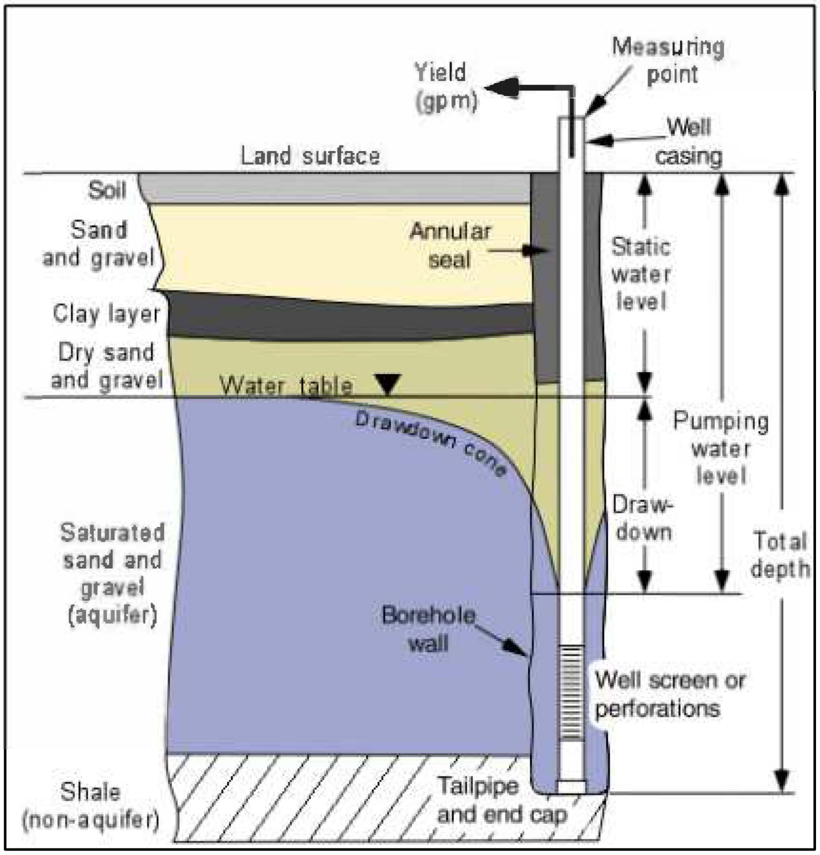
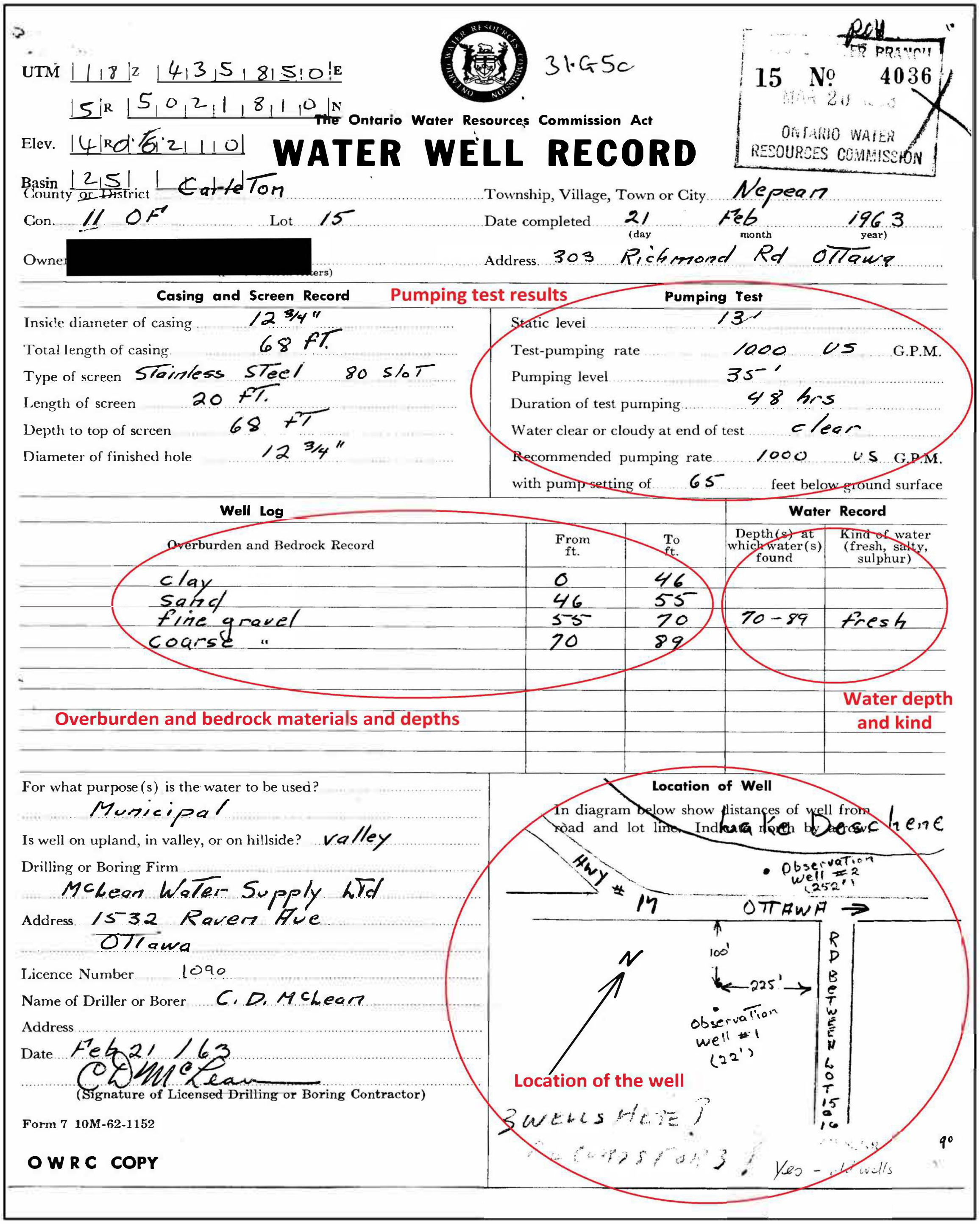


Figure 2: Main parameters related to construction and performance of a typical well

As shown in Figure 3, the Ontario water well records report the pumping test results, overburden and bedrock materials and depths, the depth at which the water is accessed and its quality, and the location of the well.

Generally, the important parameters that can be directly or indirectly extracted from the well records are: water flow rate, depth of water including static water level, pumping water level and drawdown level, depth of the well, and presence of sandstone, limestone, and granite (bedrock) and their depths.



UTM | 1 | 18 | Z | 4 | 3 | 5 | 8 | 5 | 0 | E

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Basin | 2 | 5 |

31G5c

The Ontario Water Resources Commission Act

WATER WELL RECORD

ROH... BRANCH
15 No 4036
MAR 20
ONTARIO WATER RESOURCES COMMISSION

County or District Carleton Township, Village, Town or City Nepean

Con. 11 OF Lot 15 Date completed 21 (day) Feb (month) 1963 (year)

Owner [redacted] Address 303 Richmond Rd Ottawa

Casing and Screen Record	
Inside diameter of casing	12 3/4"
Total length of casing	68 FT.
Type of screen	Stainless Steel 80 slot
Length of screen	20 FT.
Depth to top of screen	68 FT
Diameter of finished hole	12 3/4"

Pumping test results

Pumping Test	
Static level	13'
Test-pumping rate	1000 US G.P.M.
Pumping level	35'
Duration of test pumping	48 hrs
Water clear or cloudy at end of test	clear
Recommended pumping rate	1000 US G.P.M.
with pump setting of	65 feet below ground surface

Well Log

Overburden and Bedrock Record	From ft.	To ft.
clay	0	46
sand	46	55
fine gravel	55	70
coarse "	70	89

Overburden and bedrock materials and depths

Water Record

Depth(s) at which water(s) found	Kind of water (fresh, salty, sulphur)
70 - 89	fresh

Water depth and kind

For what purpose(s) is the water to be used? Municipal

Is well on upland, in valley, or on hillside? valley

Drilling or Boring Firm McLean Water Supply Ltd

Address 1532 Raven Ave Ottawa

Licence Number 1090

Name of Driller or Borer C. D. McLean

Address

Date Feb 21 /63

C D McLean
(Signature of Licensed Drilling or Boring Contractor)

Form 7 10M-62-1152

OWRC COPY

Location of Well

In diagram below show distances of well from road and lot line. Indicate north by arrow.

Lake Deschene

Location of the well

3 WELLS HERE ?

... ? Yes - ... wells

Figure 3: A sample of an Ontario water well record

4.2 Well record parameters of use to this study

As a rule of thumb, around one to two gallons per minute (GPM) of water flow rate is required for each cooling ton of heat pump capacity. The required capacity of the heat pump system depends on the heating and cooling loads of the specific building. Generally, the heat pump is sized to fully meet the heating and cooling loads without auxiliary heat sources. This, however, should be evaluated or optimized on a case-by-case basis. Our judgment is that flow rates above 50 GPM represent locations with the highest potential for commercial-sized open loop systems. Though it should be noted that single family residential buildings do not require such high flow rates.

Surface water (found at shallow depths) is not commonly high enough yield for commercial applications (though may be sufficient for standalone drinking water wells or single-family open loop systems). Thus, an open loop geothermal system will typically use deeper aquifers, which will typically be within the bedrock layers, and often dependent upon the type of bedrock. Aquifers are commonly found in sandstone layers (and to a lesser extent limestone) since this type of stone is water permeable; they often have fissures and cracks that fill with water over time. Granite, on the other hand, rarely contains high yield aquifers. Therefore, if a drilled well record is deep (such that it has passed through overburden, limestone and sandstone layers and has reached the granite bedrock) it can provide significant information on the presence or absence of deep aquifers. If the well record shows the existence of the sandstone, there is a high probability of a sufficient aquifer. Hence, such location could be considered as a potential location for open-loop systems (though not guaranteed) and further investigations (such as test drilling) are warranted.

Drawdown is another important parameter to consider. As shown in Figure 2, this parameter is the difference between the pumping water level (i.e., the static level of the water inside the well after pumping) and the static water level (i.e., natural elevation of the water in the aquifer when no there is no pumping). Drawdown level is an indicator of the amount of available water in the vicinity of the well, and the smaller the drawdown, the higher the water yield and the reliability of good yield will be for that location.

It is important to note that the majority of the well records have a depth of less than 90 m. These records are not capable of providing relevant information for this study.

4.3 Evaluation of Potential for Open-loop Geothermal

A definitive evaluation of each well record was beyond the scope of the project and would need to be undertaken in the context of a known building heating and cooling load. The approach taken herein is to use the well record data to define the likelihood that a site would be a good candidate for open-loop geothermal system. Table 1 defines the categories of likelihood that were developed.

Table 1: Open loop geothermal suitability pick list

Likelihood Category	Description
Yes	Location with the highest potential
Potential	Likely to have a good potential, further investigation is warranted
Unlikely	Unlikely to be a promising location
No	Not suitable
N/A	Lack of information to decide

Based on the discussion in the previous section, technical criteria was developed to classify a given well to one of these categories, as detailed in Table 2. The analysis was undertaken on more than 15,000 wells.

Table 2: Technical criteria for selection from the picklist

Condition	Description	Likelihood Category
Flow ≥50 GPM	High capacity aquifer	Yes
Presence of granite in the materials without sandstone and limestone	Canadian shield	No
Presence of sandstone in the materials	Potential for high capacity aquifer after further investigation	Potential
Well depth ≥ 150 m and drawdown ≥ 60 m	Deep well and deep drawdown	No
Well depth ≥ 150 m and no presence of sandstone	Very low chance to access water	No
60 m ≤ Well depth ≤ 120 m and no presence of sandstone or limestone	Low chance to access water	Unlikely
depth ≤ 90 m	Not enough information	N/A

5.0 Presentation of the Results on ArcGIS

JLR analyzed the existing data in the Microsoft Access version of the Ontario Well database and extracted well locations and key parameters.This data was then transferred to the ArcGIS Online, which is a well-known geographic information system (GIS) for working with maps and geographic information developed by Esri. ArcGIS Online provides a user-friendly environment to filter potential locations and visualize relationships in the data. It gives access to all the data collected for each well including links to the well record detail sheets. The “shapefile” developed in this project show graphically the above mentioned data in a graphical format with access to underlying information. For example, by clicking on a well symbol, the information of the well record appears on the screen with a link to access the actual well record.

Figure 4 is a screenshot of the wells that show the highest potentials or “Yes” category. Similarly, the well records that show good potential, low potential, and no potential are shown by Figure 5.

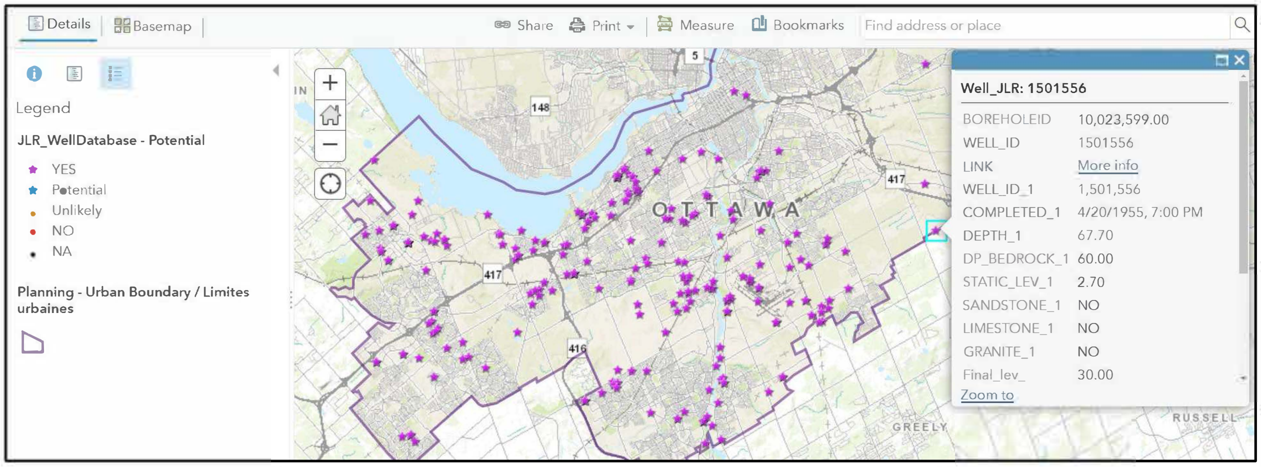
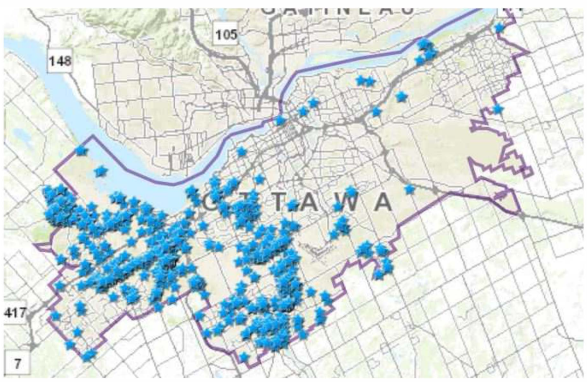
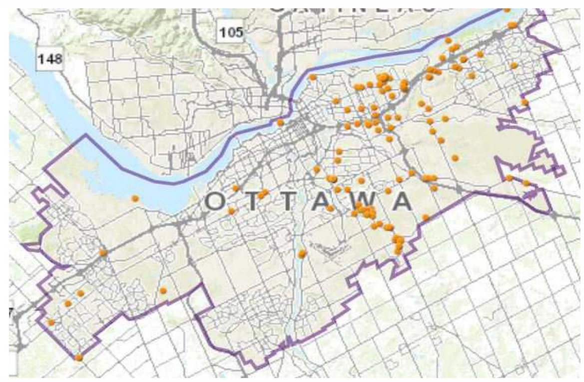


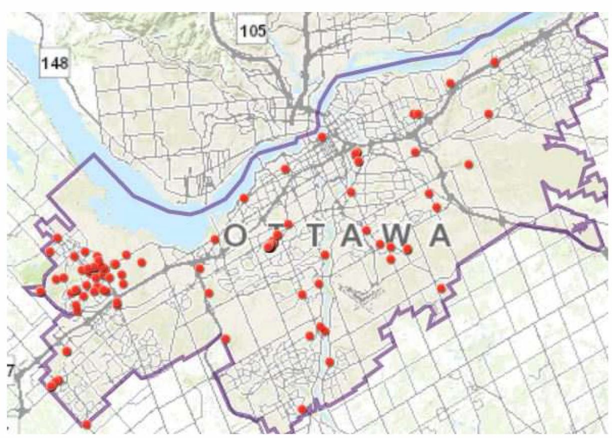
Figure 4: Map of the well records with the highest potential on ArcGIS



(a)



(b)



(c)

Figure 5: Map of the well records categorized as (a) "Potential", (b) "Unlikely", and (c) "No"

6.0 Evaluation of Geological Information

It should be noted that well records do not universally cover the City. There are areas in the City where there are few well records (such as downtown), since drinking water wells are not required in that area. There is a higher occurrence wells on the outer areas of the City (e.g. Kanata and Barrhaven); the magnitude of wells in these areas is/was due to the need of drinking water wells. The presence or lack of well records is in itself not an indication of groundwater, but merely an indication of available information.

As can be seen in Figure 4, the viable wells (classified as “Yes”) are concentrated in the western area of the City. This is further demonstrated when comparing the concentration of “potential” wells in the west side and “unlikely” wells in the east side as shown in Figure 5 (a) and Figure 5 (b) respectively.

To further investigate the geology of the region, a layer was added to the ArcGIS that can describe the surficial geology which is shown in Figure 6. The formations are categorized into different names including Billings, Bobcaygeon, Carlsbad, Covey Hill, Gull River, Lindsay, March, Nepean, Oxford, Queenston, Rockcliffe, and Verulam. The detailed description of these formations is out of the scope of this study but could be found in the documents of Ministry of Energy, Northern Development and Mines.

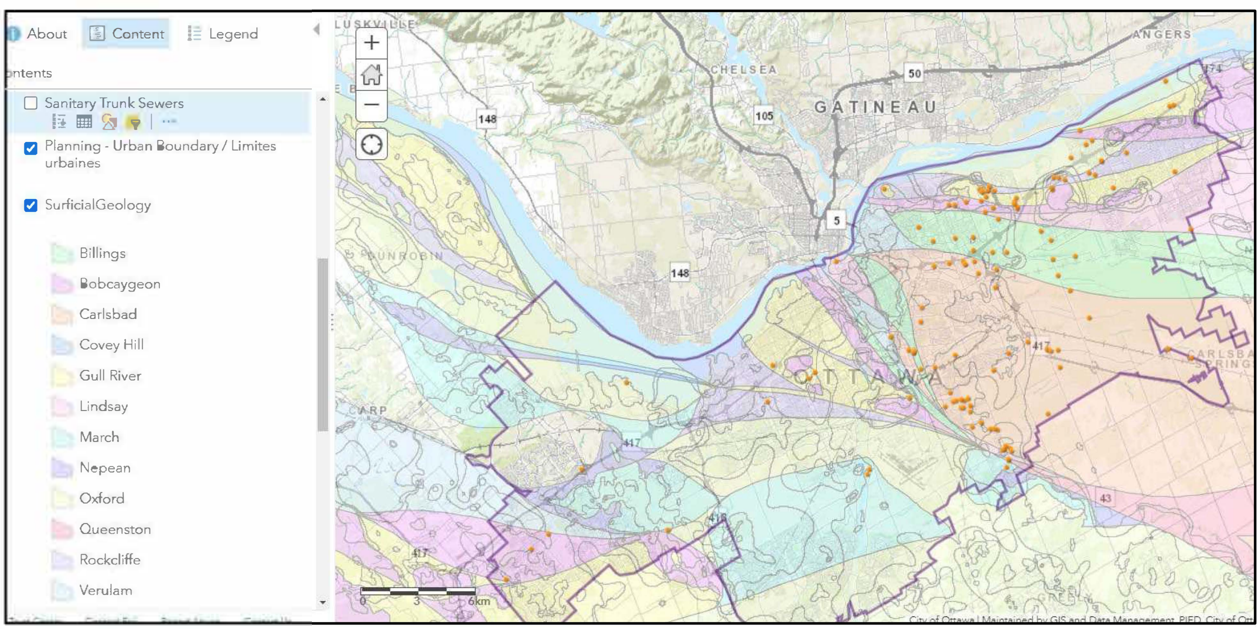


Figure 6: Layer of the surficial geology of the City of Ottawa

An interesting observation from Figure 5 (a) and Figure 5 (c) is the very close proximity between locations that do not show any potential (“No”, orange dots) and locations that do show a good potential (Yes”, purple dots). This is due to the occurrence of a complicated geology phenomenon of granite outcrops and fault lines.

The Nepean formation for example, which is located along the western margins of the Ottawa and St. Lawrence Basin, is sandstone bedrock; it has good potential for high yield aquifers and open loop geothermal projects. However, this formation lies directly over the Precambrian granite bedrock which has little to no potential for high yield aquifers. The granite layer can be variable with outcrops that can reach surface level. An example of such close proximity of “Yes” and “No” is observable in Figure 5 (a) and Figure 5 (c) in the northern area of Kanata where significant granite outcrops exist.

In addition, Figure 6 shows an extension of the Rockcliffe formation from the neighbourhood known as Rockliffe (west of downtown, near the Ottawa River) towards the West. Rockcliffe formation is mainly shale (with no potential for open loop systems), with lenses of sandstone (with high potential for open loop systems); these lenses explain the presence of the locations with no potential and high potential beside each other in this area.

There are also numerous fault lines in Ottawa. While one side of a fault line could contain a high yield aquifer in sandstone, the other side of the fault line may contain shale which is unsuitable for high yield aquifers. This is evident in Figure 6 where the Carlsbad and Billings formations of shale border the Nepean sandstone formation.

As shown in Figure 6, many of the locations that are unlikely to have a good potential, are in the Billings formation. The Billings formation outcrops east of Ottawa in a narrow band extending across Carleton and Russell Counties. The formation consists of brown shale that passes upwards into black fissile shale. This formation is known to contain brackish water and an underlying limestone formation that produces low rates of water that is not suitable for a geothermal system. It is also known to contain pockets of methane gas which can be hazardous when drilling. Another area in Figure 6 that indicates low potential is the area associated with the Carlsbad formation. These formations are mainly composed of grey shale that conformably overlies the Billings Shale and outcrops east of Ottawa in Carleton and Russell Counties.

Figure 7 contains all categories of well records as well as the geological information. An “unlikely zone” is shown with a hand-drawn red dashed line – this roughly aligns with the Billings and Carlsbad formations discussed above and where the majority of the “No” sites are located. The possibility of open-loop geothermal in this area is unlikely, though cannot be fully ruled out. Two zones with high variability - one in Kanata and one in Orleans - are also delineated with a hand-drawn yellow dashed line. These areas have particularly highly local variations in geology and intermingled both “YES” and “NO” sites.

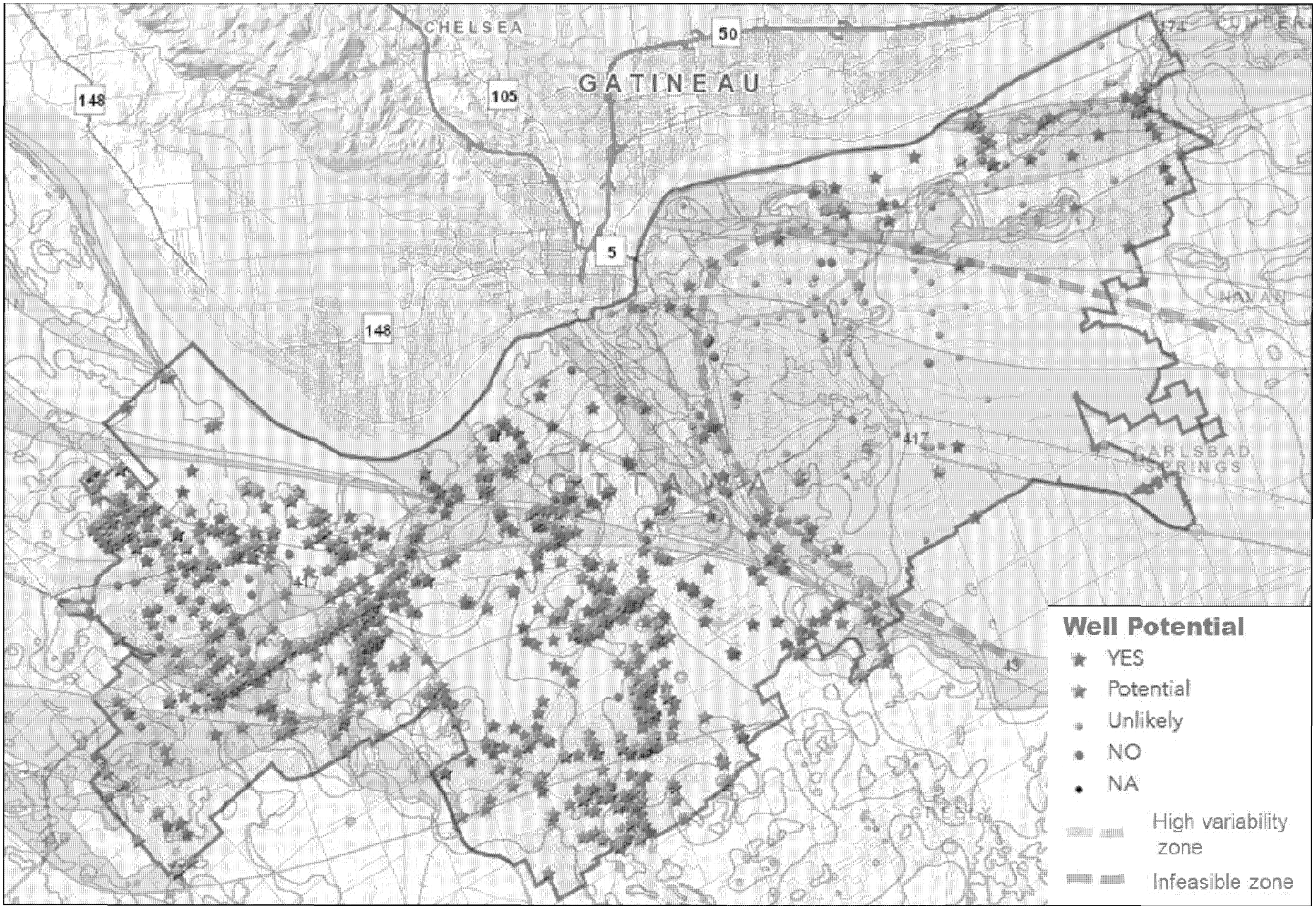


Figure 7: Map summarizing all well and geological information

7.0 Conclusions

The public well records were used to develop a map of the potential presence of deep aquifers for use in open-loop geothermal systems. Well records with depths of less than 90 m were ignored as not providing sufficient information on deep aquifers. For deeper wells, a range of categories were developed to describe the likelihood of there being a deep aquifer. For wells that recorded water flow rates, there were two categories: (i) high flow rates (categorized as “YES” sites), and (ii) where the well was ≥150 m and found only low flow capacities (“No” sites). Where flow measurements were not recorded, the underground geology provided in the well records was further used to predict the likelihood of an underground aquifer – these were labeled “Potential” when sandstone was found and “Unlikely” or “No” if no sandstone was found by 120 m or 150 m, respectively. In addition, if granite was encountered, the site was labeled as a “No”.

These well records provide a sufficient distribution across the City to enable a rough sense of the probability of open-loop geothermal across the City. Well records categorizations were superimposed onto geological information to further complement the findings. The analysis identified: (i) one zone that will be infeasible for open-loop due to its geology, and which also had a large number of poor likelihood well records, and (ii) two zones that have high variability due to particularly mixed and locally-dependent geology. However, these finding must be clearly understood as only indicative of the probably that open-loop geothermal can be supported - geology can vary dramatically over short distances and there will be good and bad sites scattered throughout the City.

Further investigations are required for a developer to proceed. This is often a two-step process: pre-feasibilty would typically involve having a hydrogeologist undertake site-specific evaluation using similar process as herein but with added information and rigour (including consideration of the full three dimensional geological volume, aquifer shape and flow direction). Feasibility would involve engaging a geothermal consultant to develop drilling and testing specifications with which a driller can be contracted to drill a well and perform the testing. The findings presented in this study may influence a developer’s interest in undertaking the pre-feasibility analysis, especially if other low carbon thermal energy supplies are available. Closed-loop geothermal can nearly always be developed if the open-loop option does not materialize.

8.0 Other Considerations

While this data is useful with providing information about the pumping test and geology of each location, several other factors such as hydraulic properties, water chemistry, and aquifer geometry should also be assessed. Some of the important factors are explained in this section:

- In addition to the well capacity and pumping costs, chemistry of the water needs further assessment. With an increase in the water temperature, smaller ranges of acceptable pH are expected as alkaline and acidic can dissolve the heat exchanger faster. A pH in the range of 6-8 is deemed to be reliable. Moreover, water hardness, and iron content should be tested and considered in any system design.

- A well can be used for both drinking water and open-loop geothermal systems. Dual use wells can aid the financial viability if a location required a drinking water well. The well however must have the capacity to meet both needs.
- Generally, it is more challenging to inject the water back into the aquifer than to extract it. If the material in which an open system is installed has higher percentage of void spaces (higher porosity), the reliability of the water injection to the aquifer increases. This is because materials with higher porosity can accept more water flow.
- In addition to high porosity, formations with high hydraulic conductivity (i.e., an indicator of aquifer's ability to transmit water), are more suitable for open loop systems.
- In many cases, if a test drill shows insufficient aquifer yields for providing the heating and cooling demands, the same well could be converted into a closed loop borehole.

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