A pre-feasibility study to assess the potential of Open Loop Ground Source Heat to heat and cool the proposed Earth Science Systems Building at the University of British Columbia

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LIST OF ACRONYMS

AERL	Aquatic Ecosystems Research Laboratory
BHE	Borehole Heat Exchanger
BVP	Boundary Value Problem
CCP	Comprehensive Community Plan
CIRS	Centre for Interactive Research on Sustainability
COP	Coefficient of Performance
EOS	Earth and Ocean Sciences
ESSB	Earth Systems Science Building
GHG	Greenhouse Gases
GSH(P)	Ground Source Heat (Pump)
GVRD	Greater Vancouver Regional District
LEED	Leadership in Energy and Environmental Design
LSC	Life Sciences Centre
OCP	Official Community Plan
UBC	University of British Columbia

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ABSTRACT

The predicted end of the oil era, along with increasing atmospheric carbon dioxide and pollution, and the resultant climate change have led to wider global acceptance of the urgent need for alternative renewable energy sources. Ground source heat presents such a viable alternative, having been hydrogeologically and economically refined through much research, design and development in the European Union and elsewhere over the past 20 years. This study investigated the hydrogeologic potential of using an open-loop ground source heat system to heat and cool the proposed Earth Systems Science Building (ESSB) at the University of British Columbia (UBC) campus. This was done by inserting existing data from previous hydrogeologic investigations at UBC into water and heat yield equations to finally identify a range of the total number of wells required to meet the heating and cooling demands of the ESSB. We found a best case scenario of 2 wells, a mean case of 5 and a worst case of 15 wells. The economic feasibility was assessed by comparing the capital and running costs for open-loop systems of the various well number scenarios to those for a steam-run heating system, i.e. the conventional method at UBC. We found the three well scenarios to have payback times of 5, 6 and 8 years respectively, after which they would offer a minimum annual cost savings of $50,500. Though a ground source heat system was found to be economically feasible, from a hydrogeologic point of view, installing more than one or maximum two wells is not realistic as it takes up a fairly large proportion of UBC's groundwater resources and the drawdown cone has a large land footprint. Hence using ground source heat and combination technologies is a better approach. Much further work would be needed before any such system could be implemented. A detailed hydrogeologic site investigation including the effects of pumping on the future utilization of groundwater resources at UBC, combined with finalized building specifications would be required in the next step of the assessment process. Furthermore, it was found that current British Columbia groundwater legislation is lacking in water withdrawal specifications, as are the Canadian ground source heat industry's level of information centralization and standardization of technique and design. Through its institutional development policies and practices, UBC has firmly demonstrated its commitment to sustainability in response to the threat of climate change. As a leading global academic institution, UBC has the potential to take its visionary development one step further by installing this new technology that makes much sense in the context of climate change and Canada's commitment to the Kyoto protocol.

1. INTRODUCTION

1.1. Introduction to Ground Source Heat

As early as 1956, it was predicted that our use of oil far exceeds a sustainable rate and that consequently the day will come when we will run out of oil (Deffeyes, 2004). This first assessment of the world's finite petroleum supply was carried out by M.K. Hubbert of Shell Oil Company, who believed that oil production would rise sharply to a maximum and then decline equally rapidly (Deffeyes, 2004). He predicted this maximum would be reached for US production in the early 1970's, and in hindsight we now know that the US peak oil production occurred in the year 1970 (Deffeyes, 2004). Since then the US has imported the majority of their oil from other countries. On a global level, most other countries are believed to be close to or just past the peak of their production potential with the exception of a handful of Middle Eastern countries that are still far from it (Duncan, 2003).

Since this early and rather notorious prediction of the end of the oil era, in combination with increasing atmospheric carbon dioxide and pollution, climate change and many other anthropogenic processes, there has been a slow global acceptance of the ever-more pressing need for alternative energy sources. Today we are obtaining a small, yet important fraction of our energy demand from a variety of alternative, "more sustainable" energy sources. This includes the use of solar power, wind power, nuclear energy, tidal energy and hydrogen fuel among many others. This is an innovative and rapidly growing field, and this study looks specifically at certain aspects of the use of ground source heat as an alternative energy source.

There are two main alternative sources of usable energy that we directly harness from beneath the earth's surface:

- Geothermal energy
- Ground source heat (GSH)

Geothermal energy is a widely used misnomer used to indiscriminately describe both of the above, yet they do refer to very separate, different processes.

A geothermal energy system, from the Greek words *geo*, meaning earth, and *therme*, meaning heat, uses heat directly from the earth's mantle that is emitted via natural sources, such as hot springs, geysers and volcanic hot spots. The steam or hot water originating from deep underground is used to heat buildings or power turbines for electricity generation (CanREN, 2006). It is thus a direct method of generating energy for our use. This is only possible in very few locations on earth (e.g. Iceland, Meager Mountain in British Columbia) and is not energetically effective when scaled down for use in single family houses (CanREN, 2006).

A ground source heat system, also known as earth energy or geoexchange, is not a method for generating energy. It uses electricity to move heat from one place to another. These systems run on the principle of a heat pump or reverse heat pump. They make use of the fact that at most locations in the world the earth's surface below a certain depth maintains a temperature of between 10 and 16°C all year round (BCHydro, 2005). In the parts of the world that require buildings to be heated and cooled, these soil temperatures are warmer than the average winter air temperatures, and cooler than the average summer air temperatures. Hence, a ground source heat system will transfer heat from the warmer earth and groundwater to the colder building in winter, and from the warmer building to the colder earth in summer. Thus, the ground and any groundwater it contains act preferentially as a heat source or sink depending on the season. While it still takes energy to operate such a system, it is much more efficient than electric furnaces or air conditioners. It can be used on both large and small scales, without significant decreases in efficiency or large energy losses. In addition, they offer large proven greenhouse gas reductions and cost savings (Hanova et al., 2007).

1.2. History of Ground Source Heat Pump Systems

The concept of ground source heat is in no way a new idea, but it has only recently gained popularity as the heating/cooling method of the future. As early as 1778, a French chemist/physicist realized that at a depth of 27 m below Paris' streets, the temperature remained constant throughout the year (B. Sanner, 2008). The first heat pump was developed by Lord Kelvin in 1852 (IGSHPA, 2006). The first ground source heat pump system was installed in Indianapolis, USA, by Robert Webber, an employee of the Indianapolis Power and Light Co. in the late 1940's (IGSHPA, 2006). He was experimenting with his deep freezer one day. When he lowered the temperature in the freezer significantly, he noticed that the outlet pipe became hotter. He realized that the heat being removed from inside the freezer was simply being lost. He decided to run pipes between his freezer outlet and his hot water boilers, and this set-up provided the family with more hot water than they could use. He took it one step further and used the remaining waste heat to heat his home and save coal. He ran the excess hot water through a coil of pipe and distributed the heat through his house with the help of a small fan. This set-up worked so well, he soon built a permanent larger scale ground source heat pump for his own house, using underground heat collected by Freon gas that was run through a long loop of copper tubing. The next year, Mr. Webber sold his old coal furnace, and so the ground source heat system was born (IGSHPA, 2006).

1.3. Components of Ground Source Heat Pump Systems

A typical ground source heat system can be used equally effectively for heating and cooling and is comprised of three main components (Natural Resources Canada, 2002b):

- **Earth connection** – extracts/discharges heat from/to the earth

- **Heat pump** – extracts heat from the groundwater/antifreeze and transfers it to the distribution system, or vice versa
- **Distribution system** – transports the extracted heat around the building to each of its spaces, or from the building to the heat pump when used as an air-conditioner

1.4. Types of Ground Source Heat Pump Systems

Ground source heat systems come in a variety of designs and orientations.

They can either use groundwater (**groundwater system**) or the soil (**ground source system**) as the sink or source of heat energy.

They can be **open loop** or **closed loop**. The first removes water from the soil via pumping wells, extracts its heat and then re-pumps it into the earth via a second well, or discharges it to a surface water body. The latter system collects heat by running antifreeze or some other suitable liquid or gas through a continuous loop of piping that is buried in the soil or within the aquifer.

They can be either **vertical** or **horizontal**. The horizontal set-up is generally easier to install but is less space efficient and more destructive to a wider area during its initial construction.

Below are the most common ground source heat pump set-ups that are in use today.

A. Groundwater Open Loop Vertical Systems

The groundwater, open loop, vertical system shown below (Figure 1) was the first to appear on the market and has subsequently been used successfully for many years (Natural Resources Canada, 2002a). It pumps up groundwater from a series of vertical wells, uses the water to heat the building and subsequently discharges the water back into the earth via another well or into a surface water body. It is limited by local environmental regulations that are concerned with the removal of large amounts of groundwater and its re-pumping back into the earth later on (Natural resources Canada, 2002a). These regulations are in place to prevent aquifer contamination and depletion. The exit and entry wells should be far enough apart so the colder and warmer water do not mingle, affecting the heat pump's thermal performance. They are also dependent on sufficient water availability and pumping power.

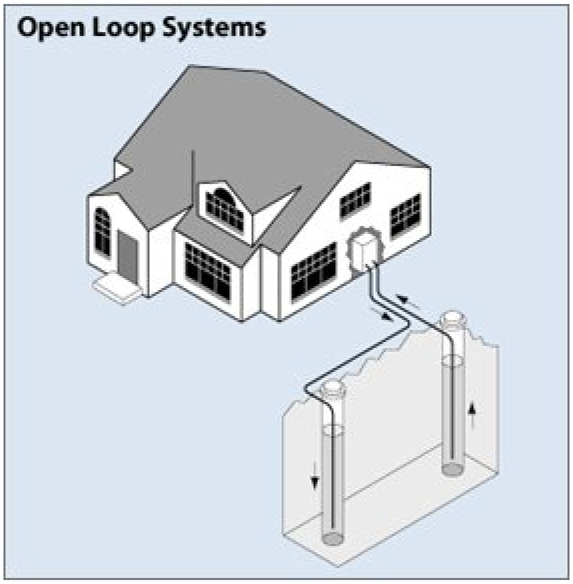
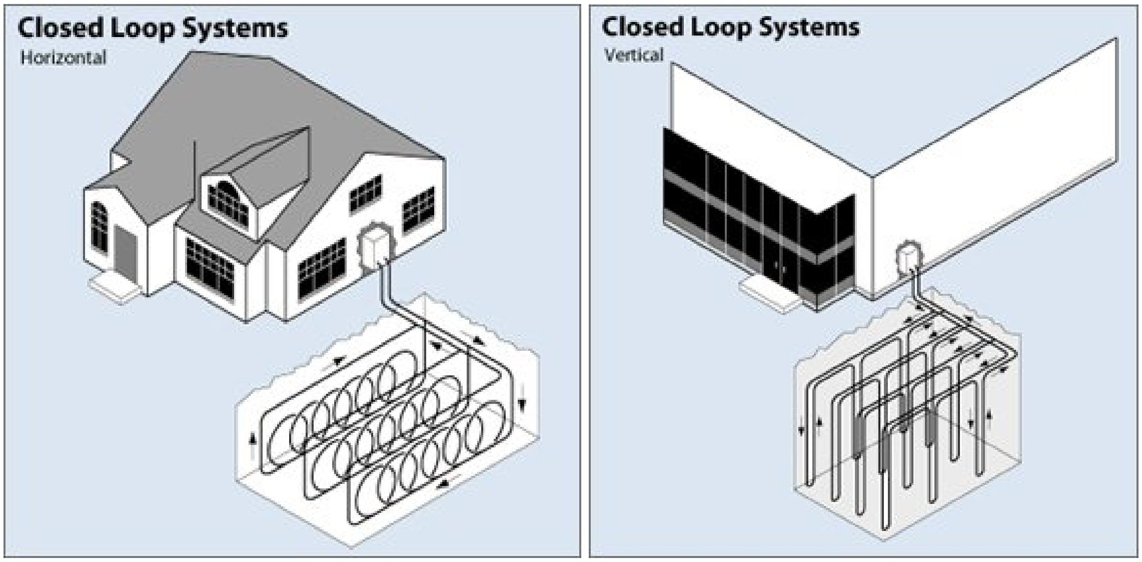


Figure 1: A typical groundwater, open loop, vertical system.

(Natural Resources Canada, 2002a.)

B. Ground Source Closed Loop Vertical and Horizontal Systems

Ground source, closed loop systems shown below (Figure 2) do not pump out any water, rather they run antifreeze or any other suitable chemical fluid in vertical or horizontal pipes through the ground. The vertical closed loop set-up is also known as a Borehole Heat Exchanger (BHE). It has a very small land footprint and can be successfully installed below other infrastructure. Both of these systems are well suited to most soil conditions, however the vertical set-up cannot be installed in bedrock. Vertical loops are understandably more expensive to install than horizontal ones as they require more drilling, but they need less piping length due to the more stable, narrower temperature range and thus better efficiency at greater depths (Natural Resources Canada, 2002a). Hence, horizontal systems are less robust to seasonal temperature variations as they are less deep within the soil. For instance, in winter, the air and thus the soil near the surface are cold. Ground source energy would be used for heating, and efficiencies would be greatest when the water has a high temperature. Deeper water will be warmer relative to the air than surface water.



a) b)

Figure 2: A typical ground source, closed loop,
a) horizontal and b) vertical system.

(Natural Resources Canada, 2002a.)

1.5. The Earth Systems Science Building

UBC as a university is very dedicated to sustainable development and sustainability in general. It is a signatory to a number declarations relating to sustainability and takes pride in the number and variety of green buildings on campus. This is discussed in greater detail in section 2.1 and 2.2. One such proposed green building, although still in the very early stages of planning, is the Earth Systems

Science Building (ESSB). The Department of Earth and Ocean Sciences (EOS) was created in 1996 by combining Geological Sciences, Geological Engineering, Geophysics, Oceanography, and Atmospheric and Environmental Sciences. Since then, growth in the department's researcher and student population has surpassed the capacity projected when the Earth and Ocean Sciences facilities were first built in 1974 (UBC Science, 2008). The Faculty of Science feels that UBC will not be able to effectively meet the growing industry demand for Earth Science professionals, as there is not enough space in the existing facilities to accommodate the learning needs of the more than 300 major and honors EOS students, 170 graduate students and more than 6,000 undergraduates that require the use of the EOS facilities (UBC Science, 2008). Thus, the proposed Earth Systems Science Building is tentatively slated to begin construction in 2009 and be completed in 2011 (Chadwick, 2008). It will accommodate the Department of Earth and Ocean Sciences, along with the Department of Statistics, the Pacific Institute of Mathematical Sciences, the administrative office of the Dean of Science and teaching laboratories and lecture theaters for science undergraduates (UBC Land and Building Services, 2007b).

Thus far, the Earth Systems Science Building has received approval from the UBC Board of Governors in concept and approximate location only. It is planned that the new building will be located near the corner of Stores Road and Main Mall, and have a gross area of 17,484 m^2, standing 5 stories high, with a basement underneath (D. Grigg, personal communication, November 2008) (Figure 3). Once the designers have developed a complete building program, a public review process will be initiated, followed by application for a development permit.

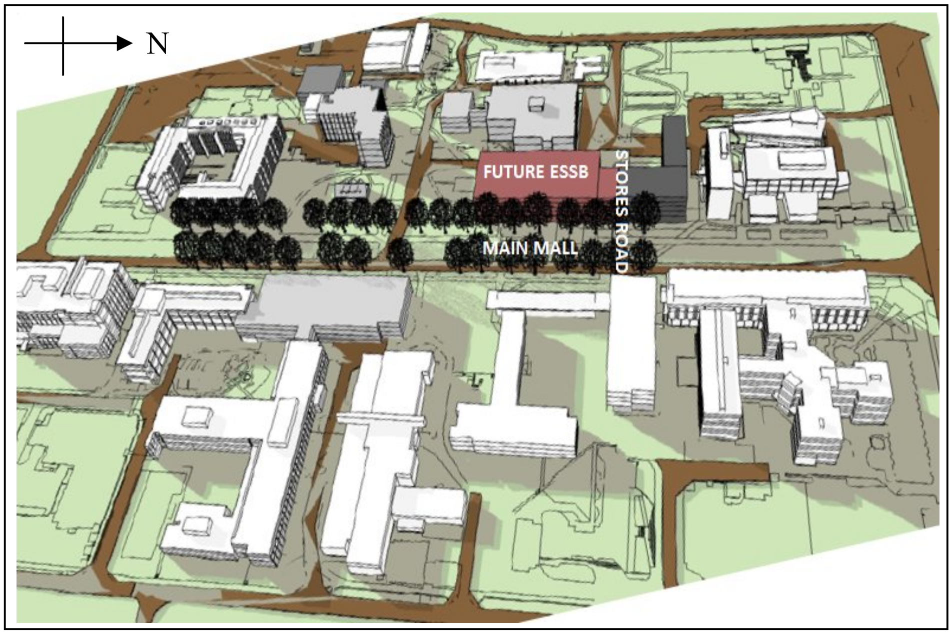


Figure 3: Preliminary structural model for the proposed Earth Systems Science Building (pink), to be located at the intersection of Main Mall and Stores Road. The dark grey attachment represents a future, connecting building site.

(Campus and Community Planning, 2008.)

1.6. Research Questions

This project will attempt to assess the hydrogeologic and economic feasibility of installing a ground source heat system in the proposed Earth Systems Science Building at the UBC Vancouver Campus. The original concept of this building was developed in the early 1990's, and while a basic design was created, the building is still in the early fundraising stages today. Hence, no feasibility studies for ground source heat or any other heating methods have yet been carried out.

In general, open loop ground source heat systems have been found to be more suitable for large scale applications than closed loop systems (Sanner, 2005). Groundwater wells are able to deliver a higher thermal capacity per borehole than closed loop set-ups. This is because the transport of heat to a well is done by hydraulic pressure, as opposed to heat transport in a closed loop system which requires a temperature gradient. As a result, larger applications typically use open loop systems (assuming the hydrogeologic conditions are favourable) because the greater costs involved in investigation, planning and maintenance are offset by the need for fewer boreholes than closed loop systems and hence lower cost (Sanner, 2005). In addition, the higher grade of heat obtained from open loop systems allows the ground source heat set-up to be used for additional purposes such as heating water for domestic use in buildings (J. Giffin, personal communication, March 2009). This would be an added benefit in any building at UBC as many contain showers for those who cycle to work. For these reasons, a feasibility study was carried out looking at an open loop ground source heat set-up. Had sufficient time been available, an analysis of a suitable closed loop system would have been performed for comparative purposes.

The specific research questions we will examine are:

a) Is it possible to extract enough heat for an open loop groundwater ground source heat system to be considered feasible for the proposed Earth Systems Science Building?

   This question can be broken down into a number of smaller component questions that must be answered:

   - What is the local geology and the hydraulic conductivity associated with it?
   - How much water can be extracted from this area?
   - How much heat can be extracted from this water?
   - How much heat is the Earth Systems Science Building likely to need?

b) Based on economic data and using set-up costs for other local systems as a rule of thumb, are the set-up and running costs, as well as payback time of an open loop ground source heat system for the proposed Earth Systems Science Building considered feasible?

Our approach to answering the above questions is to examine and compile existing data collected by a number of Vancouver-based consulting companies that have done exploratory work in the UBC area over the last few decades. We will look at a variety of hydrogeologic data in order to gain an all-round picture of the ground source heat possibilities in the vicinity of the future Earth Systems Science Building's location. Specifically, we will estimate the water and subsequent heat that can be supplied by the upper freshwater aquifer underlying UBC and compare this to the building's expected heat requirements, in this way determining whether ground source heat is a suitable, large enough heating/cooling method for this new building. Secondly, using values obtained from contractors who install ground source heat systems, in combination with other necessary economic data, we would like to give a broad price range for the installation, operation and maintenance of the system. In most cases, a ground source heat system is physically possible, but may not necessarily be cost efficient. By estimating costs for the installation of a ground source heat system for the Earth Systems Science Building, we aim to assist in the further planning and actual implementation of such an alternative energy system.

2. LITERATURE REVIEW

2.1. UBC's Commitment to Sustainability

Sustainable development is the use of resources in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 2008). In 1990, UBC affirmed its commitment to sustainability by becoming a signatory to the Talloires Declaration, the first official statement made by university administrators from every continent to foster environmental sustainability in higher education (UBC Sustainability Office, 2008a). The Talloires Declaration recognizes that various environmental problems – air and water pollution, accumulation and mobilization of toxic wastes and resource depletion, among others – compromise the survival of humans and many other living species. These problems also jeopardize the security of nations and the basic livelihood of future generations. The Talloires Declaration calls on universities as institutions of research, education, policy formation and information exchange to address these issues and to work to reverse the trends by incorporating sustainability and environmental literacy within teaching, research, operations and outreach (University Leaders for a Sustainable Future, 1990).

In 1992, UBC also became a signatory to the Halifax Declaration, released in the aftermath of a conference between university leaders of 33 universities from 10 countries on 5 continents, who were also joined by representatives from the business community, banking institutions, governments and non-governmental organizations (International Institute for Sustainable Development, 1991). The conference centered around the role of universities in relation to the environment and development, and the resulting declaration, much like the Talloires Declaration, focuses on the role of universities in promoting and practicing sustainable development.

Since the Talloires and Halifax Declarations, UBC implemented its own policy framework for sustainable development in 1997, the Sustainable Development Policy, becoming the first Canadian university to adopt such a policy (UBC Sustainability Office, 2008a). It outlines UBC's motivations in pursuing sustainable development, acknowledging that just as UBC adds to a healthy society and economy through education to enhance society's social capital, it must also invest in preserving ecological services and resources, or “natural capital”, upon which society is also dependent. The Sustainable Development policy also describes how various players on the UBC campus will fulfill certain roles in order to advance UBC's sustainable development agenda in an economically viable manner (University Counsel, 2005).

UBC has also created a planning framework to address how sustainable development will be incorporated into campus and community planning: The Official Community Plan (OCP), and the Comprehensive Community Plan (CCP). The Official Community Plan is relevant to the whole of campus as well as two lots in Pacific Spirit Regional Park. It is an overall guide for the campus as it evolves into a “complete community” that balances the Greater Vancouver Regional District's (GVRD, now known as Metro Vancouver) Livable Region Strategic Plan for regional growth with UBC's own academic goals (UBC Campus and Community Planning, 2005). It focuses primarily on non-institutional growth, outlining specific objectives and targets for land use, green space, community services and transportation (Pottinger Gaherty Environmental Consultants Ltd., 2004). The use of ground source heat in the proposed Earth Systems Science Building and its associated energy and cost savings as well as greenhouse gas reductions relative to conventional technologies such as electric furnaces and air conditioners are consistent with these aims and directions (Hanova et al., 2007). The Comprehensive Community Plan is more focused on the 8 designated Neighborhood Plan areas that surround the academic core of UBC, and describes in more detail how the Official Community Plan's objectives and targets will be fulfilled in the Neighbourhood Plan areas in conjunction with its stated development capacity for the entire campus area (UBC Campus and Community Planning, 2005).

Thus, it is not directly relevant to the design and building of the Earth Systems Science Building, but will need to be considered if ground source heat is used in future developments in the Neighbourhood Plan areas surrounding the campus core.

2.2. Institutional Development at UBC

The development of institutional buildings at UBC can be initiated by faculties, departments, schools or third party groups affiliated with UBC's academic mission. The proposed projects are then reviewed by the University for compliance with UBC policies such as the Official Community Plan and Comprehensive Community Plan. A staff review and consultation process takes place, which includes posting a public notice, holding a public meeting and submitting the design plans to the University's Advisory Design Panel. During this stage of a proposed project, Metro Vancouver must also be made aware of the design plans. The project is then amended as necessary, and submitted to the UBC Board of Governors for final approval (GVRD & UBC, 2000).

Since the adoption of the Sustainable Development Policy, UBC has made significant progress in implementing programs at the institutional level that are reflective of the goals outlined in the Talloires and Halifax Declarations. It has undertaken initiatives that have made UBC the only Canadian recipient of the Green Campus Recognition from the U.S.-based National Wildlife Federation, a recognition it has garnered 3 times (UBC Sustainability Office, 2007). For example, the ECOTrek Energy and Water Reduction initiative reduced UBC's water use by over 20% and it's Greenhouse Gas Emissions by 15% (ECOTrek, 2006). ECOTrek was a 3-year, $35 million retrofitting project of over 300 buildings on campus, and saves UBC $2.6 million each year (ECOTrek, 2006). It included processes as simple as replacing inefficient lighting systems, installing low consumption plumbing fixtures and sealing drafty doors and windows. It also included more involved processes such as repairing and replacement of 5 kilometers of condensate pipe, modifications to the Central Steam Plant to reduce polluting nitrogen oxide emissions and centralizing the operation of heating, cooling and ventilation systems of 90% of campus buildings via the Building Management System, allowing for adjustment based on building occupancy (ECOTrek, 2006).

Recently, UBC has also opted to pursue certification via the internationally-recognized Leadership in Environmental Energy and Design Green Building Rating System (LEED) when renovating or developing some of its institutional buildings. LEED consists of 5 main categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources and Indoor Environmental Air Quality (Canada Green Building Council, 2008). It also has an Innovation and Design category to provide points for measures excluded from the 5 main categories. LEED is divided into 4 levels: Certified (26-32 points), Silver (33-38 points), Gold (39-51 points) and Platinum (51-69 points) (CaGBC, 2008).

Through its UBC Renew Program, UBC renovates aging academic buildings to meet minimum LEED Silver standards, resulting not only in reduction of each renovated building's impact on the environment, but also a 40-year extension of each building's lifetime. This has led to savings of $89 million to date and preservation of the history and culture reflected by each building's architecture (UBC Land and Building Services, 2007a).

Furthermore, newer buildings at UBC have achieved LEED certification at the Silver level and higher. The Aquatic Ecosystems Research Laboratory (AERL), opened in 2005, is certified LEED Silver. It features natural ventilation and less sheet metal ducting which reduce the use of both energy and materials. It also includes passive solar lighting and heating, natural materials and renewable wood sources (UBC Sustainability, 2008b). The Life Sciences Center (LSC), opened in 2004, is certified LEED Gold. It cost $125 million to build, and uses 28% less energy than a standard building (i.e. a building that complies with fixture performances of the 1992 Energy Policy Act), resulting in an annual savings of 6,400,000 kWh of energy, 1000 tons of greenhouse gas emissions and almost $180,000 at 2006 utility rates (Coady & Hasan, 2006). Coady and Hasan (2006) also describe the water use at the Life Sciences Centre as 50% less than standard buildings. They further describe the landscaping of 52% of the site's open space with soft-landscaping, 87.5% of which is native vegetation and requires no irrigation after 1 year of establishment. UBC is in the process of planning and building more green buildings, including the Centre for Interactive Research on Sustainability (CIRS), which is aiming for LEED Platinum certification through initiatives such as using waste heat from adjacent buildings for heating (J. Robinson, personal communication, October 2008). New provincial legislation mandates that the proposed Earth Systems Science Building must meet, at a minimum, LEED Gold standard (D. Grigg, personal communication, November 2008).

2.3. Ground Source Heat Pump Systems in Vancouver and at UBC

As of 2005, there were more than 70 documented commercial and multi-residential ground source heat pump projects completed in British Columbia (GeoExchange BC, 2005b). These include hotel resorts, schools, churches and recreation centers. Of these, at least 18 are located in Metro Vancouver, and most of these are closed-loop systems. The most well-known of these is the residential and commercial complex located at the intersection of West 4th Avenue and Vine Street in Kitsilano, which, in 1993, was the first Western Canadian complex to use a ground source heat pump system. The vertical, closed-loop system consists of piping in 46 bore holes that reach depths of up to 91 m and serve to heat and cool 2,300 m^2 of office space, 3,700 m^2 of retail space and heat the water used in the condos (US GHPC, 2008) .

There are also several elementary and secondary schools in Metro Vancouver that utilize some form of ground source heat for their heating and cooling needs (Table 1). Some, such as Bob McMath

Secondary School and Burnaby Mountain Secondary School, also use high efficiency condensing boilers to supplement their ground source heat systems on very cold winter days. The system at Bob McMath Secondary School, completed in 1997, is a horizontal, closed-loop field that is used for space heating and cooling 14,000 m^2, as well as water heating (GeoExchange BC, 2005b). The school building receives 80% of its heating requirements from a 108 ton earth energy unit located indoors, while a natural gas condensing boiler provides the remainder (EESC, 2008). This combined system saves the school approximately $11,000 in annual operating costs, relative to "conventional" heating and cooling systems (Natural Resources Canada, 2002). Burnaby Mountain Secondary School, completed in 2000, also has a closed-loop, horizontal ground source heat system that services 15,000 m^2 of space by extracting heat from and rejecting heat to the ground underneath a playing field via 24 km of pipe (Green Buildings BC, 2004). A case study published by Green Buildings BC (2004) also states that the school saves $15,000 annually due to its use of a ground source heat system.

Name of School	Location	Date Installed	Loop Orientation	Water heating?
Bob McMath Secondary	Richmond	1997	Horizontal	Yes
Burnaby Mountain Secondary	Burnaby	2000	Horizontal	No
Heritage Woods Secondary	Port Moody	2004	Horizontal	No
Nestor Elementary	Coquitlam	2000	Vertical	Yes
Seaview Elementary	Coquitlam	2000	Vertical	No
Westwood Elementary	Port Coquitlam	2002	Horizontal	No

Table 1: Elementary and secondary schools in Metro Vancouver that utilize Ground Source Heat Systems.

(Geoexchange BC, 2005.)

Similar to Bob McMath Secondary and Burnaby Mountain Secondary, some recreational buildings that use closed-loop ground source heat systems also combine their system with another form of energy supply or distribution to maximize energy use efficiency. The Gleneagles Community Centre, a 23,000 m^2 facility located in Vancouver, uses floor and concrete slab radiant cooling and heating along with 2 ground-source heat pumps to maintain an indoor temperature between 19 and 25 ºC (Earth Tech, 2003). A 10% propylene glycol solution is circulated through a 3,000 m horizontal loop field underlying the community centre's parking lot where heat is captured for the building or released from the building (i.e. the earth connection). A second system of 6,800 m of water-filled plastic piping set in the building's exposed concrete surfaces is the distribution system responsible for actually radiantly heating or cooling the interior or the building. (Earth Tech, 2003). During peak heating conditions, a small gas-fired boiler supplements the ground source heat pump system. The West Vancouver Community Complex uses a vertical loop field contained in more than 150 boreholes, to heat and cool three buildings – a pool, skating rink, and office complex (GeoExchange BC, 2005b). Unnecessary energy use is minimized via the use of waste heat from the ice rink cooling system, as well as an "advanced" management system based on the varying heating and cooling demands of the three buildings (Earth Source Energy, 2007).

The use of ground source heat at UBC campus is very limited compared to its use in Metro Vancouver. There is an existing system in place at the Marine Drive residence towers, though it is not yet fully connected due to the ongoing construction of one more building in the complex (A. Popple, personal communication, November 2008). It is also used at the Legacy housing complex in the South Campus area. Additionally, the faculty and staff-owned Clement's Green townhome complex in the Hawthorn Place neighborhood uses a ground source heat system to preheat water (A. Aloisio, personal communication, November 2008). Furthermore, Regent College, adjacent to UBC has used an open loop ground source heat system for several years now. The Regent College system will be examined in much greater detail later on.

Although ground source heat is currently not widely used on campus, it has been considered for use during recent development initiatives, such as the Sustainability Street project, and the Centre for Interactive Research on Sustainability. Sustainability Street is a multi-phase project located on Stores Road that attempts to the be the world's first closed-loop water recycling system, integrating stormwater management, wastewater treatment, and ground source heat (UBC Sustainability Office, 2006). During the first phase, developers of Sustainability Street had planned on using infiltrated wastewater that would be microbially remediated for ground source heating and cooling of the Earth and Ocean Sciences building. However, it was decided that replacing one of the existing natural gas heating and cooling units in the Earth and Ocean Sciences building with a ground source heat pump system would not be energy or cost-effective (R. Beckie, personal communication, October 2008). Furthermore, ground source heat was also considered for the Centre for the Interactive Research on Sustainability building, though it was later rejected for the use of waste heat from adjacent buildings (J. Robinson, personal communication, October 2008).

2.4. Ground Source Heat Pump Systems Around the World

In a review of worldwide geothermal and earth energy usage, Lund et al. (2005) found that 32% of the energy harnessed from the earth was through ground source heat pump systems, with most of these systems located in North America and Europe. They also found that compared to 2000, the installed capacity of these systems had doubled in 2005, reaching 491,962 TJ/yr (Lund et al., 2005).

In North America, most ground source heat pump use is concentrated in the United States of America. In the USA, their use accounts for 22,215 TJ/year of energy, and they are the fastest growing application of geothermal and earth energy, with an annual increase of 11% (Lund et al., 2005). In 2004, it was estimated that 50,000 ground source heat pump units were installed annually, of which

46% were vertical closed-loop systems, 38% were horizontal closed-loop systems and 15% were open-loop systems (Curtis et al., 2005).

Though ground source heat pump systems in Canada do not harness as much energy as those in the USA (a total of 33,000 units produced 891 TJ of energy in 2004), their use has also steadily increased (Lund et al., 2005). The ground source heat pump market has grown at a rate of 10-15% annually since 2000, while their operation has saved approximately 2160 TJ/year of energy and 200,000 tonnes/year in reduced greenhouse gas emissions (Lund et al., 2005).

Like Canada, most places in Europe do not have access to abundant geothermal resources that can be used as a direct energy source. However, in several countries in Central and Northern Europe, namely Germany, Sweden, and Switzerland, thermal resources from the shallow subsurface have been exploited primarily for space heating via ground source heat pumps. In these countries, most systems systems are vertical, closed-loop systems, and they have become very well-established in these regions due to over 20 years of research, design and development (Sanner, 2003).

Ground source heat pump systems have been established in Sweden since the early 80s, with installations numbering 50,000 by 1985 (Lund et al., 2005). Usage by the public increased greatly after 1995 due to strong support and subsidies from the Swedish government. They are now the most popular small-residential heating method in Sweden (Curtis et al., 2004) (Figure 4).

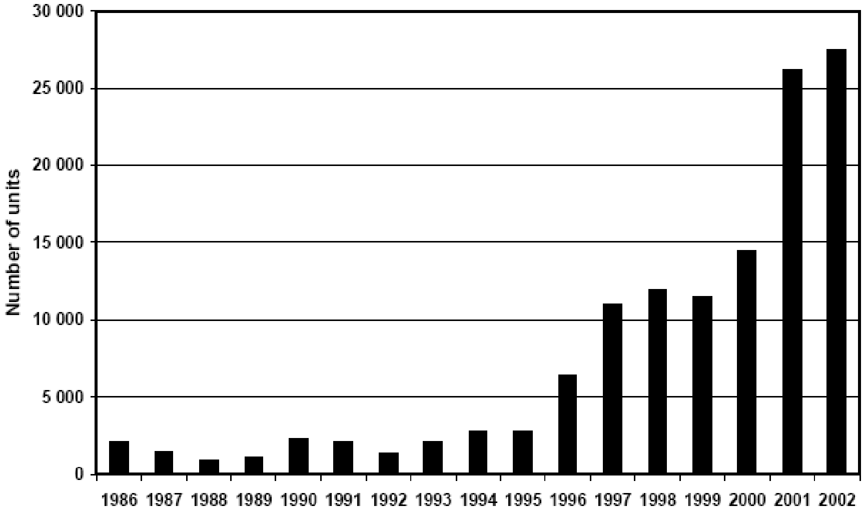


Figure 4: Heat pump units sold yearly in Sweden from 1986-2002, with a significant increase after 1995.

(Curtis et al., 2004.)

Additionally, an increased demand for cooling in the commercial sector has also opened a new market niche for ground source heat pumps (Lund et al. 2004). In 2004 alone, 47,000 units were installed in the country, and by 2005, there were a total of 275,000 residential heat pumps responsible for providing 28,440 TJ of energy each year (Lund et al., 2005). Ground source heat pumps in Sweden are recommended to provide for 60% of the heating load, while electric heaters included in heat pump cabinets cover the rest; however, there is a trend towards increasing the heat pump share to 80% (Lund et al., 2004). Concerns for the systems in Sweden include imbalanced annual heating and cooling loads leading to reduced heat pump efficiency and long-term thermal influence of neighboring boreholes (Lund et al., 2004). A ground source heat pump system under construction near Stockholm aims to mitigate these concerns by thermally recharging its boreholes with warm lake water (15-20ºC) during the summer (Lund et al., 2004).

In Germany about 30,000 ground source heat pump units supply 2200 TJ/year of ground source heat energy (Lund et al., 2005). Though the number of units is greater in the residential sector, installed capacity is greater in the commercial sector, which has many office buildings requiring heating and cooling (Curtis et al., 2005). Since predominant climatic conditions in Germany call for more heating than cooling during a given year, thermal imbalance issues must be addressed in the design of the systems. For small residential systems, most of which utilize ground source heat pumps for heating only, natural heat conduction and groundwater movement suffice in preventing thermal imbalance (Sanner, 2005). In the commercial sector, thermal imbalance issues are avoided by designing systems to meet cooling demand, and installing boilers or other additional heating mechanisms to meet peak heating loads (Sanner, 2005). In 2006, the German ground source heat pump market grew by over 100% (Eugster & Sanner, 2007) (Figure 5).

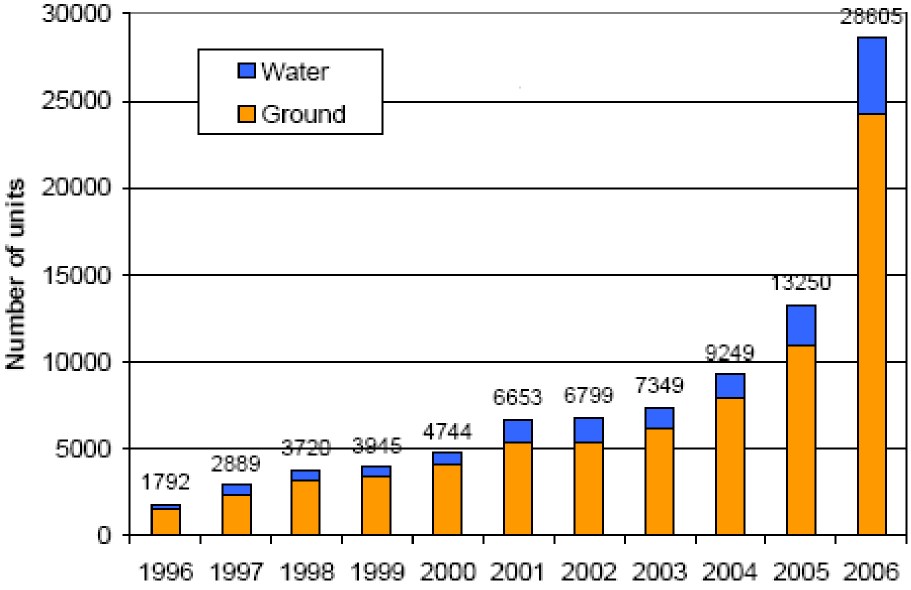


Figure 5: Number of Ground Source Heat Pump units Installed in Germany since 1996.

(Eugster & Sanner, 2007.)

Lund et al. (2004) assert that the research, design and development process has been left behind in Germany, with current efforts focusing on quality control via e.g. technical guidelines, certification of contractors and quality labels, so as to effectively protect industry and consumers against inadequate lifetimes of ground source heat pump systems.

Finally, in Switzerland, SwissEnergy, a government initiative that aims to promote renewable forms of energy, has led the country to having the highest number of ground source heat pump systems per km^2 in the world, with a total energy usage of 2854 TJ/year by 30,000 units (Lund et al., 2005). Curtis et al. (2005) outline the reasons for such high areal density, including very ideal thermal and geologic conditions of the substratum, many years of theoretical and experimental measurements for monitoring, low operating costs relative to conventional oil-based, and other fossil fuel systems, and rebates provided by local electricity utilities.

Installations of ground source heat pump systems were also found to be increasing annually by 20% from 2002-2006 (Eugster & Sanner, 2007). Installed systems systems are typically vertical closed loop systems (65%), followed by groundwater open loop systems (30%) and horizontal closed loop systems (5%). Lund et al. (2004) also state that even though ground source heat pumps are used primarily for space heating in residential units, thermal imbalance of underlying soil is a non-issue in Switzerland, as the underlying geology allows for rapid thermal recharge during the non-use period in the summer. Theoretical and experimental measurements, as well as measurements taken over many heating seasons have consolidated the long-term viability of ground source heat pumps use in Switzerland (Eugster & Sanner, 2007). Modern innovations involving ground source heat pump systems include use for both heating and cooling and combined energy source systems (e.g. solar & ground source heat pumps) (Eugster & Sanner, 2007).

Similar to Canada, ground source heat pump systems in Central and Western Europe are used primarily for space heating rather than cooling, though an increasing number of commercial applications in both regions of the world are leading to emphasis on both heating and cooling. As new markets for ground source heat pumps develop in countries such as Japan, Turkey and Greece, Eugster and Sanner (2007) urge for further quality assurance and accompanying training and certification programs to prevent negative environmental impacts and subsequent damage to the public image of this promising technology. They assert that "well designed, installed and maintained ground source heat pumps systems work over many decades without any problems and do not pose any threat to the environment". This is especially important when considering the greenhouse gas reductions and energy and cost savings provided by ground source heat pump systems (Hanova et al., 2007).

2.5. Factors Limiting the Widespread Use of Ground Source Heat Pump Systems

Though ground source heat pump systems offer significant energy savings and have lower costs associated with them in the long-term relative to conventional technology in a particular country (Hanova et al., 2007), market penetration of these systems is still quite modest throughout the world, with the exception of the USA, Sweden, Germany and Switzerland (Curtis et al., 2005). This may be due to several factors. First, the higher capital cost due to installation may be a deterrent, despite the lower maintenance and operating costs (Hanova et al., 2007). Complicating factors, such as thermal imbalance, which may be mitigated through combination technologies or naturally due to underlying hydrogeologic conditions, may also be a further deterrent. In addition, all three common types of ground source heat pump systems – vertical and horizontal closed-loop and open-loop – present certain risks with regards to groundwater pollution.

Vertical closed loop set-ups may experience uncontrolled water flows into and along boreholes (Eugster & Sanner, 2007). Thus, in Europe, these installations are not allowed in groundwater protection areas, areas with several perched aquifers, or aquifers with heavily mineralized water, and groundwater authorities still impose special conditions upon ground source heat pump installers that pertain to dimensioning and installation (Eugster & Sanner, 2007). Ground source heat pump installers must take precautions regarding borehole fill material to ensure minimal contact between aquifer and surface water but still maintain thermal efficiency (Rafferty, 2003). This ensures maximum performance and minimal groundwater pollution risk. Horizontal closed-loop systems do not pose as big of a threat to aquifers if installed above the water table, though European authorities still require installers to follow specific regulations during design and installation such as optimizing leakage prevention (Eugster & Sanner, 2007).

Groundwater heat pump systems pose the largest risk to aquifers due to the direct contact between groundwater and the loop and exchange system. In Europe, this has led to the strong imposition of extensive guidelines dictating the assessment, design, and construction processes. For example, a preliminary hydrogeologic assessment is required, which includes evaluation of the natural thermal condition of the groundwater, estimation of thermal potential, construction of a hydrograph of yearly groundwater table and temperature variations, evaluation of groundwater chemistry, estimation of groundwater cooling impact, impact on other present or future installations and evaluation of compliance with existing laws (Eugster & Sanner, 2007).

Groundwater chemistry is especially important when assessing a site for an open-loop ground source heat pump. In areas with water hardness greater than 100 ppm (as $CaCO_3$) and a pH greater than 7.5, scaling is likely to occur in the heat pump heat exchanger (Rafferty, 2003). This is due to minerals such as $CaCO_3$ becoming supersaturated, and thus precipitating at higher temperatures, which may be the case on the surfaces of the heat exchanger, which heat up when the heat pump is in "cooling mode". If enough scaling occurs, performance of the heat pump diminishes. Furthermore, H_2S in concentrations exceeding 0.25 ppm can greatly reduce the lifetime of heat pumps with copper or cupro-nickel heat exchangers (Rafferty, 2003). Care must also be taken in screening outgoing water for particulates to prevent clogging of the injection well, and ensuring adequate spacing between production and injection wells such that there is no thermal interference. Eugster and Sanner (2007) argue that correctly dimensioned and built ground source heat pump systems that diligently comply with all regulations pose minimal risk to groundwater systems.

Despite the risks involved, high market penetration of ground source heat pump systems, especially in countries with a long history of ground source heat pump usage, such as Germany, Sweden, and Switzerland, show that “well designed, installed and maintained systems work over many decades without any problems and do not pose any threat to the environment” (Eugster & Sanner, 2007). The successes, failures and improvements in these systems over the years, particularly in Europe, can be very valuable for novice users of ground source heat. We can learn much from their mistakes, as well as their regulatory policies to ensure that future growth in the use of Canadian ground source heat resources does not endanger other natural capital. Thus the key, perhaps, to increasing use of ground source heat pump systems in countries such as Canada, is to standardize and strictly implement regulations overseeing design, installation, and maintenance, as has been done in Switzerland and Germany, so that performance of the systems does not fall short of expectations and damage the public image of ground source heat.

3. CASE STUDY – Regent College, Vancouver, Canada

Regent College is a theological school adjacent to, but not affiliated with UBC. It was founded in the mid-1960's by a group of business people whose vision was to make the study of God and religion available to all the many different members of God's church. Since then, the College has greatly grown in size and numbers, and much innovative design has been incorporated into the Regent College infrastructure. Notably, they installed one of the first ground source heat systems at UBC (C. Grout, personal communication, November 2008). This ground source heat system set-up, its construction, operation, drawbacks and successes will be examined in detail to provide a close look at the holistic geoexchange process and provide the necessary background for the rest of this project.

The original ground source heat system at Regent College was first installed in 1988. It is an open loop ground source heat system that pumps water using a lifting pump out of a single well located in a nearby outdoor garden (Figure 6). This water subsequently travels to an indoor heat exchanger, where it absorbs heat from the interior of the building, hence cooling the original 3-story Regent College building (Figure 6). Some degree of cooling is required both in summer and in winter. This warmer wastewater is then pumped back into the ground via the same well. This particular ground source heat set-up is thus used for cooling purposes only, while the main building was heated using an efficient electric boiler up until 2007 (K. Chen, personal communication, November 2008).

One important factor to take into account when designing ground source heat systems is their need to be thermally balanced to ensure continued long-term efficiency; that is, the amount of heat taken out of the soil in winter must be roughly balanced by the amount of heat put back in summer. In the case of Regent College, they are only using ground source heat for cooling, thus they are pumping more heat into the ground than they are taking up. This is resulting in a gradual, long term heating up of the ground since 1988, making it less and less effective at cooling the building (D. Grigg, personal communication, October 2008). This is confirmed by the increasing electricity usage in recent years, which runs the electrical system that augments any geoexchange cooling shortfalls (D. Grigg, personal communication, October 2008).

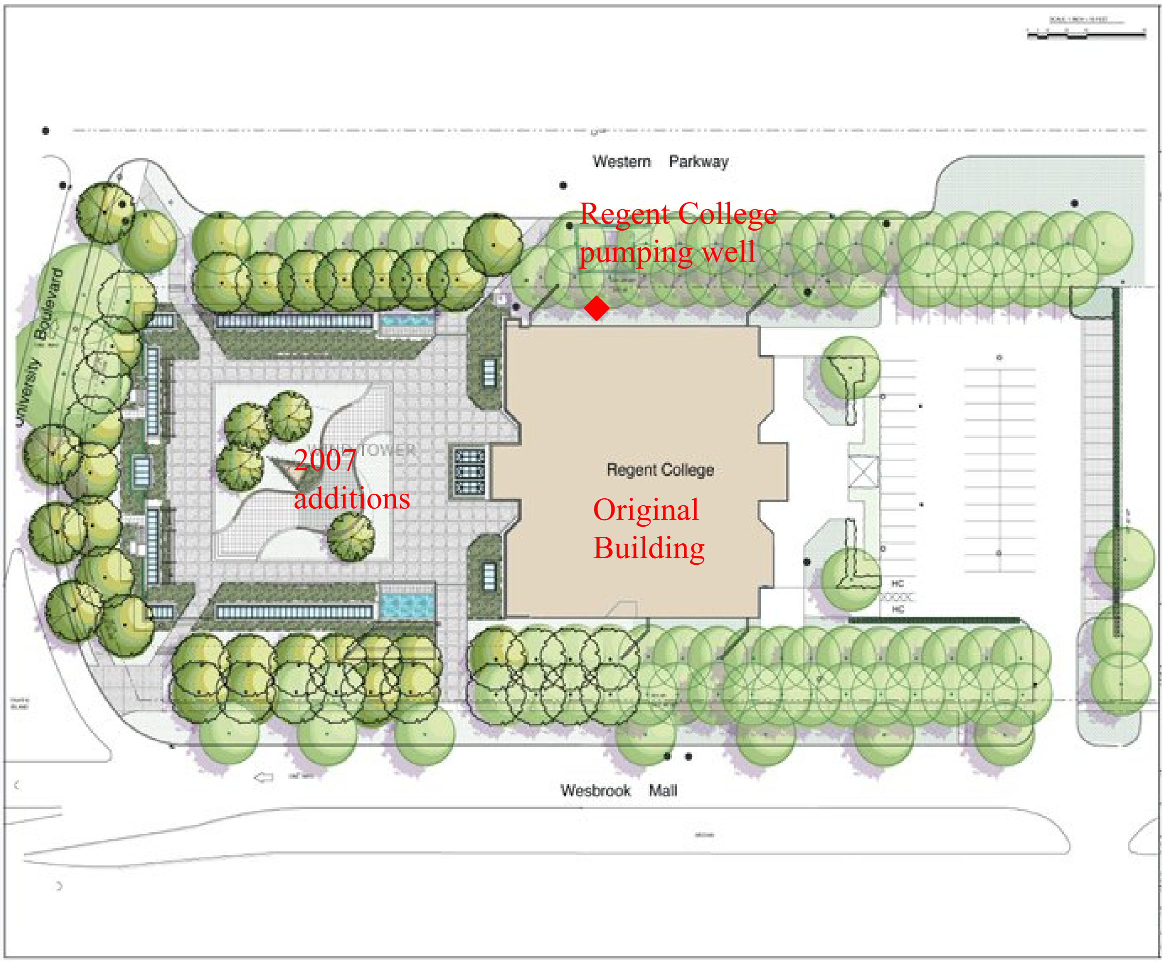
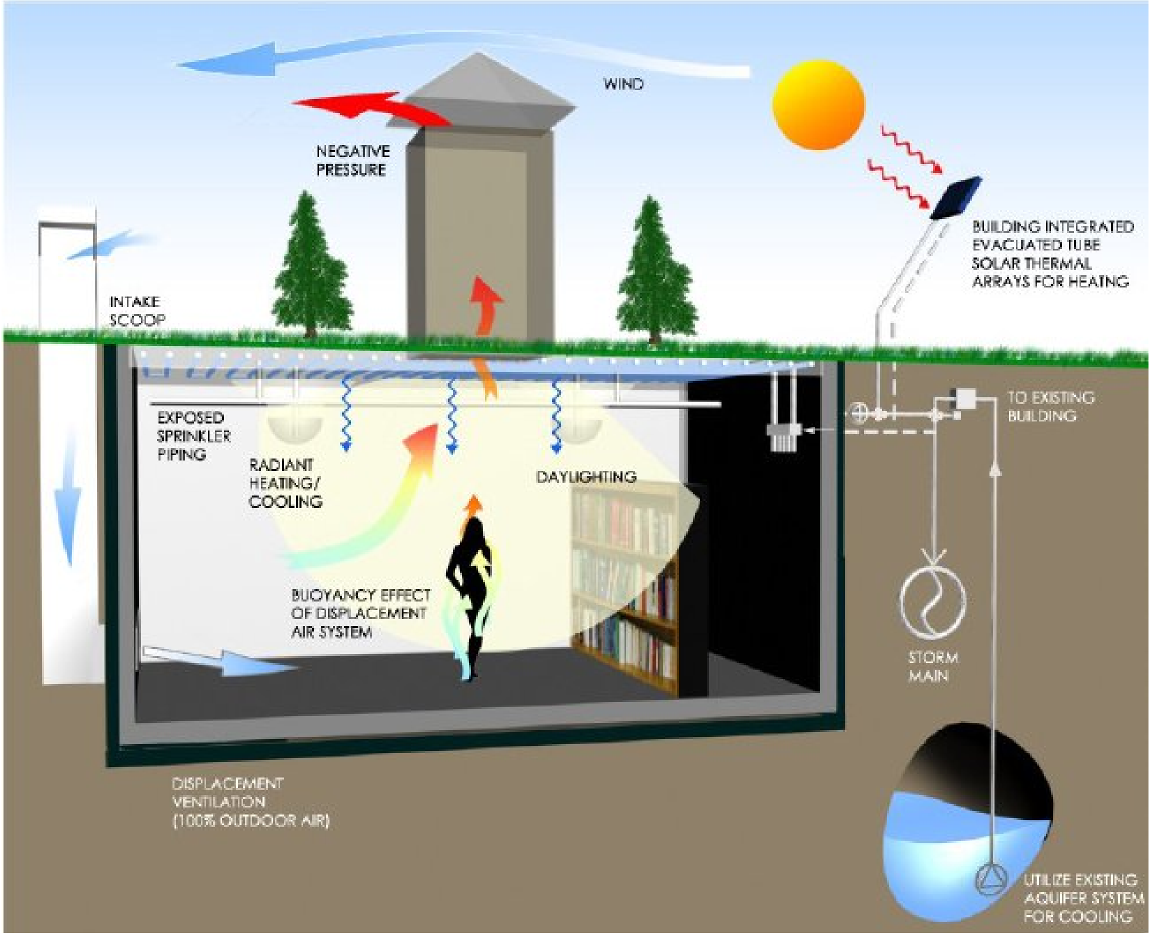


Figure 6: Plan of Regent College showing original and new buildings as well as pumping well.

(Sarah Hall Studio, 2008.)

In 2007, some new additions to the Regent College infrastructure were made (See Figure 6 above). A new, vastly expanded 220 m^2, $10-million (Anglican Journal, 2007) library was designed and built specifically to meet LEED Gold Certification (Cobalt Engineering, 2008). The building was believed to have the potential to utilize 0 purchased energy and produce no net carbon dioxide. At the time, this was the first building in North America to achieve this. During construction however, certain sustainable elements had to be eliminated due to cost considerations. For instance, it was initially proposed to locate solar panels on the roof of an adjacent existing building. These were never implemented however due to the budget impacts of upgrading the roof structure of this building. (Helen Goodland, 2006). Most of this recent construction was performed by Cobalt Engineering, based in Vancouver. A key design feature was to locate the high thermal mass new library building entirely underground in order to make use of the more stable ground temperatures, as compared to fluctuating air temperatures. It is powered using both solar and wind energy and utilizes Regent's previously installed ground source heat system for cooling. Other key concepts incorporated into this "green" building include natural and wind driven ventilation and radiant heating and cooling via the concrete slabs that form the library ceiling (VEL Engineering, 2008). An overview of all the processes occurring in the new library is shown in the diagram below (Figure 7).



<u>Figure 7: Heating, cooling and ventilation processes used in Regent College Library.</u>

(VEL Engineering, no date.)

As a result of the new construction completed in 2007, the ground source heat cooling system, as well as heating methods were updated and altered. While initially the Regent College ground source heat system was merely used to cool the original building, after 2007, the warmer wastewater is further utilized in the library. First, water is pumped out of the original well at a variable rate depending on the cooling load. This water has an approximately constant annual temperature of 10-11°C. It is then pumped to the heat pump and is cycled around the interior of the original Regent building. After cooling the building, the water has been heated up to an average of 15.5°C (K. Chen, personal communication, November 2008), roughly a 5 degree increase, which corresponds to an addition of approximately 21,000 J of heat energy to each kg of water. The original Regent building is still heated by an electric boiler. This warmer wastewater exiting the heat pump is then diverted to pipes in the concrete slabs in the new library ceiling. Here it is used to radiantly heat the library below, by warming the large thermal mass of the concrete slab which consequently warms the air in the library below it. A big advantage of radiant heating is its comfortable, ambient quality which results in it satisfying occupant's heating needs equally well using 30% less energy compared to more traditional space heaters (Miles Industries Ltd, 2009). As the ground source heat system is used to cool the original Regent building both during summer and winter, some radiant heating of the underground library will occur all year round. Even in summer, some heating of the library may be needed due to its contact with relatively cold soil all around. Hence, the library is kept at a constant comfortable temperature all year round by the combination of warm ground source heat wastewater, radiant heating from the library ceiling and the high surface area contact with the ground. Finally, the wastewater is pumped out of the concrete slabs and back into the ground.

The multiple consecutive uses of the water pumped out of the Regent College well are an illustration of the move towards a more holistic use of resources. While using ground source heat to heat or cool a building is already one step in a more sustainable direction, according to David Grigg of Campus and Community Planning (personal communication, October 2008) we are still largely under-utilizing our valuable, finite resources. He proposed that the most effective use of this water would involve many different processes, before it is finally pumped back into the ground. This concept was incorporated into the original design of the UBC Sustainability Street, which as mentioned previously, aimed to combine the use of ground source heat with stormwater and wastewater treatment. Regent College is hence a good example of this holistic, multistage use of groundwater: first it is used for cooling of the original building, then later for radiant heating/cooling of the new library before being pumped back into the ground so as to minimize aquifer depletion.

The newer, integrated ground source heat system has been in place for over a year at Regent College. Besides having encountered normal, general construction problems, the main challenge that has been faced since the project's completion is the stabilization of the concrete slab temperatures during the changing seasons. As the slabs are at the surface and concrete reacts strongly to heating and cooling, a very large temperature range is experienced throughout the year. This must be stabilized by an additional boiler to ensure consistent heating for the library below. Overall, no real assessments have been done of the system's workings, as it is still a fairly recent installation. The ground source heat system is still only used for cooling and while it is too early to evaluate the new system, thermal imbalance and continued heating of the soil is expected to continue. It has been found that the water pump needs regular maintenance, whereas the heat pump itself works optimally with a minimal amount of maintenance.

4. METHODS

4.1. Hydrogeologic Analysis

A. Evaluate the groundwater regime in the vicinity of the proposed Earth Systems Science Building

i. Determine the geology of the area and estimate a suitable range for the value of the hydraulic conductivity (K) for the water bearing soil layer below the Earth Systems Science Building:

The geology will be characterized based on the 2002 Piteau report by Alan Dakin (Piteau Associates Engineering Ltd., 2002), using a cross-section of the ground below UBC (Appendix C1) and borehole soil core data (Appendix C2). This report was conducted to assess the cliff stability of the North campus area; however it contains a compilation of previously collected data for the whole of UBC campus. The aforementioned cross-section runs across the centre of campus, from west to east (Appendix C1). The borehole soil core was taken from a well installed at the Biosciences building (Appendix C2), the closest soil core data available. The hydraulic conductivity (K) will be estimated from pumping test and test well data as described in the 2002 Piteau report. Hydraulic conductivity varies greatly even for one single soil type, and hence a representative range of values of K will be chosen to account for measurement uncertainty and local heterogeneities in geology, as determined in the previous step.

ii. Estimate the theoretical pumping rate for the area in question:

This will be estimated by setting up a simple boundary value problem (BVP), using the previously found range of values of K, a cross-section view of the area (Appendix C1), as well as hydraulic head contours (Appendix B), all from the 2002 Piteau report.

Once the conceptual model has been clearly defined by the boundary value problem, the Dupuit

Equation for unconfined aquifers (Misstear, Banks & Clark, 2006) will be used to estimate a range of possible groundwater flow rates to the proposed Earth Systems Science Building well. This equation assumes homogeneous, isotropic soil conditions, steady state, horizontal flow and an unconfined aquifer of infinite extent. While the soil underlying UBC is likely not entirely homogeneous, the range of values of K we will use captures any heterogeneity and gives a more accurate range of results. The upper aquifer underlying UBC is vast enough in its extent for it to be a realistic assumption that the boundary conditions can be placed far enough away so as not to have a significant impact at our proposed well location. The physical and hydraulic head gradients in most of the area are slight enough (Piteau, 2002) for flow to be considered horizontal. We assume any well installed would be completed across the entire saturated interval in order to maximize groundwater inflow, and flow. We perform a steady-state analysis, which is representative of conditions a few weeks after pumping has started. Hence, it is justifiable to use the Dupuit Equation for radial flow between two specified head boundaries in this case, which is usually expressed as follows

$$\mathbf{Q = \frac{\Pi\ K\ (H_0^2 - h_1^2)}{\ln\ (R_0 / r_1)}} \qquad \mathbf{(4.1)}$$

where Q = discharge in m^3/sec

K = hydraulic conductivity in m/s

R_0 = distance in m from the well, where the effects of pumping are no longer felt i.e. the outer edge of the drawdown cone

H_0 = hydraulic head in m at a distance R_0 from the well

h_1= hydraulic head at the well in m

r_1 = radius of well in m

Note that for the Dupuit analysis, the hydraulic head at a specified depth is measured from a datum at the base of the underlying confining layer and is therefore the same as the saturated thickness at that point. A simple schematic illustrating the Dupuit Equation and the drawdown cone resulting from pumping is shown below (Figure 8).

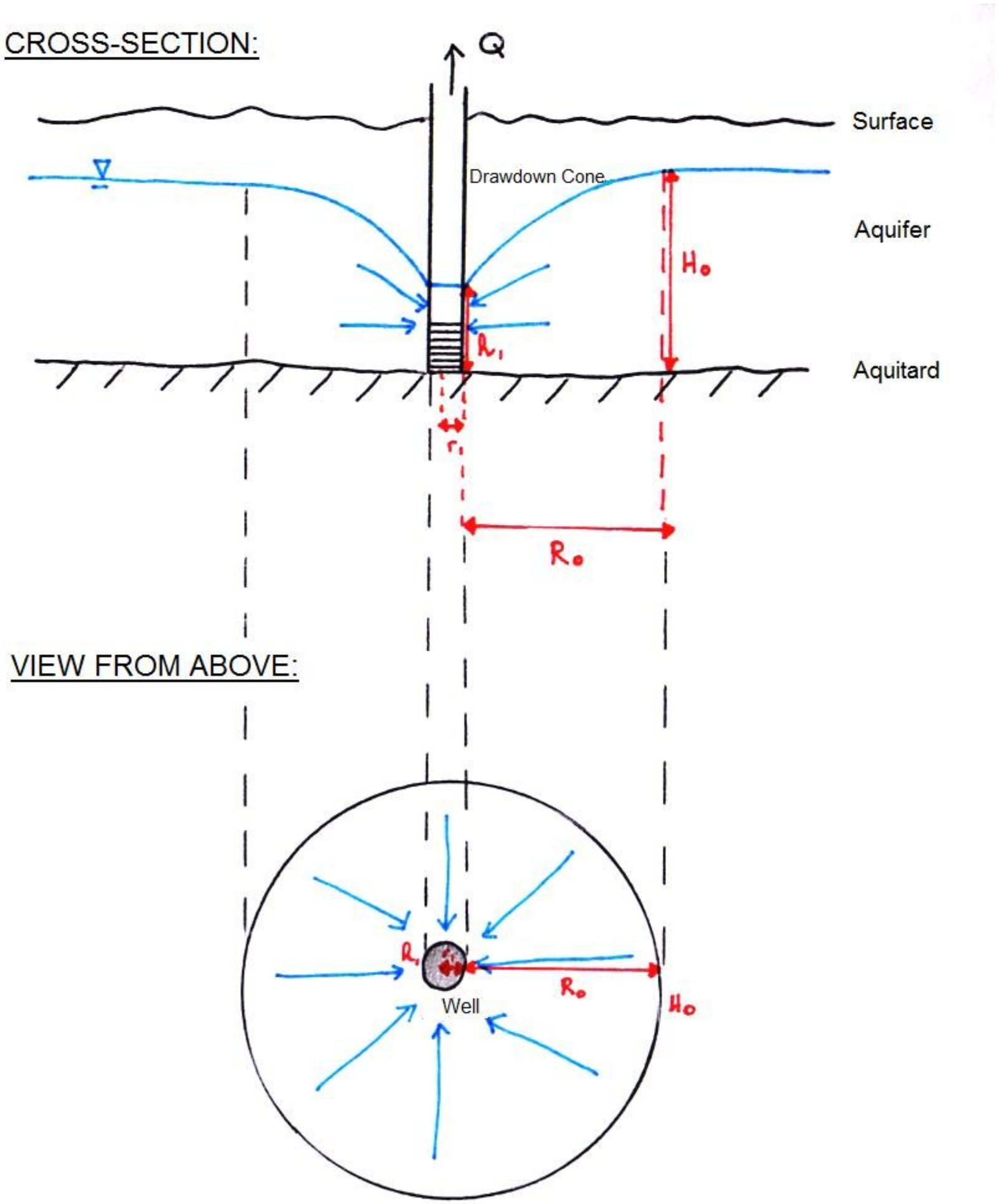


Figure 8: Illustration of the parameters required for the Dupuit Equation.

Note: Figure not to scale.

The values of H_0 and h_1 are known from the Boundary Value Problem and are obtained initially from the 2002 Piteau hydrogeological report. There has been no significant interannual variation in the watertable height since 1975 (Piteau, 2002) and seasonal fluctuations are minimal (R. Beckie, personal communication, January 2009), hence these values will remain largely fixed throughout the year. R_0 is obtained from the physical mass balance expression

$$\mathbf{Q = i\ A = i\ \ (\Pi\ R_0^2)} \qquad \mathbf{(4.2)}$$

where Q = discharge in m^3/sec

i = recharge in m/s

A = recharge area in m^2

R_0 = radius of the recharge area which we equate to the distance from the well where the effects of pumping are no longer felt i.e. the outer edge of the drawdown cone

where we assume that, the water available for pumping is equal to the recharge rate (usually expressed per unit area) times the area of the drawdown cone. The discharge will be taken from a pump test conducted by Hemmera in 2006 at the UBC Sustainability Street pumping well, the closest well to the proposed ESSB location (100 meters southwest) (Appendix B). The recharge rate is known from the 2002 Piteau report and hence an approximate suitable R_0 can be found. Furthermore, slight variations in R_0 will not greatly affect the calculated discharge due to the impact of the natural logarithm in the denominator of the equation. r_1 is set at 0.076 m (3 inches) , as the standard well casing used in industry today has a diameter of 6 or 8 inches (R. Beckie, personal communication, January 2009). K is known to be extremely variable due to pockets of heterogeneities, and hence a sensitivity analysis will be carried out using the estimated minimum and maximum values of K, to give a more realistic range and account for the large degree of uncertainty in such hydrological calculations. All other parameters needed for the Dupuit Equation that are described earlier are less variable than K, and hence are less likely to distort the results.

Typically, at a later stage in such a construction project, pumping rates are obtained by drilling a test well and subsequently pumping specified amounts of water out over a certain period of time until a new steady state is reached. This is an expensive process that must be undertaken by a consulting firm, hence we are not able to rely on this method. Drilling will likely be undertaken at a later stage, if the pre-feasibility study has concluded ground source heat is a feasible option.

B. Estimate the actual energy extractable and available to heat/cool the Earth Systems Science Building

i. Determine the temperature of the extracted water:

This is approximately constant for the whole of the UBC area and is known to be between 10 and 11ºC (D. Grigg, personal communication, January 2009; R. Arellano, personal communication, January 2009). This is a measure of how much heat per unit volume the groundwater contains, and hence could theoretically be extracted for heating purposes. It also indirectly gives an indication of how much heat could be added during the cooling process. In addition, the temperature of the water to be pumped back into the ground after heating or cooling must also be defined or identified. It was discovered at this stage in the investigation that no legislation exists in British Columbia that limits the maximum and minimum temperatures of water to be re-inserted into the ground after use for heating or cooling in a ground source heat system (D. Grigg, personal communication, January 2009)! There is a vague unwritten understanding that one should not negatively affect one's neighbours, and that harming fish-bearing waters is a punishable offence (D. Grigg, personal communication, January 2009). In addition, there should be essentially no impact on the subsurface due to the temperature changes, save some changes in mineral solubility and perhaps microbial ecology (R. Beckie, personal communication, February 2009). As no legal limits exist, local contractors were contacted in order to find typical rules of thumb for the minimum and maximum water temperature that they consider reasonable.

In Vancouver, heating demands for buildings are usually greater than the cooling demands. As air conditioning at UBC is only utilized to cool sensitive equipment and in inner, windowless areas of buildings where no natural ventilation can occur, the heating demand for institutional buildings is significantly larger than the cooling demand (D. Grigg, personal communication, January 2009). For this reason, the rest of the analysis is performed considering the use of the future ground source heat system for heating only. It is assumed that if the projected system is sized according to the heating load, then by default it will be sufficient to also meet the lower cooling load (Natural Resources Canada, 2004).

ii. Determine the heat contained in the extracted water:

This will be found by simply multiplying the specific heat capacity of water by the temperature difference of the water from when it is pumped out of the ground to when it is re-inserted back into the aquifer (ΔT). Combining this value with the pumping rate gives a rate of heat flow that is available to the building for heating.

$$\textbf{Rate of heat flow} = C\,\Delta T\,Q \qquad \textbf{(4.3)}$$

where C = specific heat capacity of water in J/kg/ºC = 4186 J/kg/ºC

ΔT = temperature difference between water coming out of ground and water going back into the ground in ºC

Q = pumping rate in m^3/s

C. Compare the heat available to the Earth Systems Science Buildings heating requirements

i. Determine the Earth Systems Science Building's Gross Heating Load:

When installing a ground source heat system, it is crucial to accurately assess the building's heating load. To calculate this, one must know the heat required to warm the building (net heating load) as well as the additional heat needed to make up for heat losses through windows, doors etc. These losses depend on a complex variety of factors including the type and size of windows, the number of occupants, the geographic location in Canada, the local soil type and many other factors (Dincer, 2003). Since we do not have access to this kind of detailed data during this very early stage of planning, we will research overall values of the gross heating load (net heating load + losses) of buildings in Vancouver. This will be calculated from its proposed square footage in conjunction with typical energy use values per unit area in this part of the world.

ii. Sizing of the Ground Source Heat System:

While ground source heat could be used to meet 100% of a buildings heating demand, this is in most cases economically unfeasible. Hence, it is typical to size a ground source heat system to 60-70% of the buildings peak heating requirements. By doing this, the costs are kept down, at least 95% of the annual demand is still met and the remainder of the heating needs can be supplied by a high efficiency gas boiler (Natural Resources Canada, 2004). The cost of this additional boiler must be included in any economics calculations. A further advantage of this is the presence of a back-up heating system. Should maintenance work be required on the ground source heat system, or in the unlikely event of system failure, there is an alternative source of heat available (R. Marier, personal communication, February 2009).

iii. Estimate the number of wells required:

By dividing the required energy previously calculated by the available energy calculated by Equation 4.3. in B. *ii.* we will get an estimate of how many wells we would need to install to satisfy the whole building's energy demands.

4.2. Economic Analysis

Given time and sufficient data available, we will attempt to perform a brief, economic feasibility study for the set-up of our proposed ground source heat system in the Earth Systems Science Building.

A. Estimate Installation Costs

The feasibility survey, drilling of well(s), piping, heat pump, heat pump installation, distribution system, distribution system installation, labour, engineering fees and other hardware costs will be estimated based on rules of thumb and installation company estimates. Typical values for all these costs are shown in Table 6.

B. Estimate Running Costs

Again, this will be estimated based on previously installed systems.

C. Estimate Payoff time

This will be done by comparing ground source heat system installation and annual running costs to the energy costs of the "usual" heating/cooling system according to the following equation:

$$\frac{\textbf{(Installation Costs GSHS – Installation Costs Usual System)}}{\textbf{(Annual Running Costs Usual System – Annual Running Costs of Ground Source Heat System)}} \tag{4.4}$$

The “usual” system at UBC and its costs will have to first be researched and identified. From this we will calculate an approximate “payback time” for the Earth System Science Building ground source heat system.

5. RESULTS

5.1. Hydrogeologic Analysis

A. Evaluating the groundwater regime in the vicinity of the proposed Earth Systems Science Building

i. Determine the geology of the area and estimate a suitable range for the value of the hydraulic conductivity (K) for the water bearing soil layer below the Earth Systems Science Building:

The underlying geology of UBC campus in the vicinity of the proposed Earth Systems Science Building is described as follows: a thin capping layer of about 1 meter comprised of glaciomarine silt to clay loam (Capilano Sediments), followed by 3 meters of sandy, loamy lodgment till (Vashon Drift), underlain by a relatively thick and permeable layer of fine to coarse sand with minor traces of silt and gravel (Quadra Sands 1), a thinner layer of interbedded silt, fine sand, and traces of peat (Quadra Sands 2), and finally a thin layer of Quadra Sands 1 down to sea level. Figure 9 shows an adaptation of a hydrogeologic profile taken from a well installed at the Biosciences building (Appendix C2), approximately 150 m North of the proposed location of the Earth Systems Science Building (Appendix B), which details the depths of these layers.

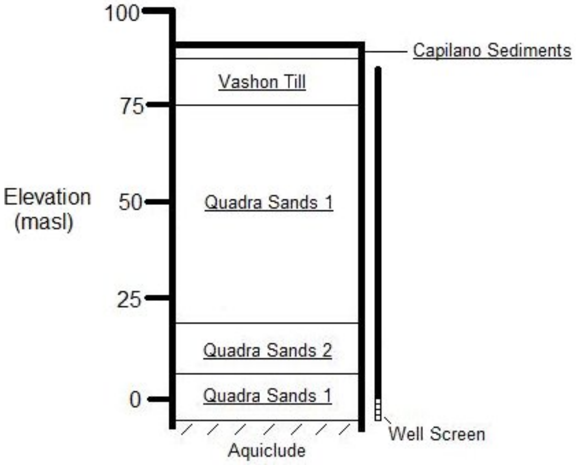


Figure 9: Soil profile taken from the Biosciences well 200 m north of the proposed Earth Systems Science Building.

(Adapted from Piteau Associates, 2002.)

Due to the relative permeabilities of the geologic units, the two Quadra Sands 1 layers both have basal portions that are saturated with water, and hence serve as aquifers, while the Quadra Sands 2 layer is an aquitard, and the layer underlying the lower Quadra Sands 1 unit is an aquiclude (Figure 10). The upper aquifer is fresh, while the water in the lower aquifer is salty, and is hence unsuitable for use in a ground source heat system as it would corrode the pipes. Precipitation falling over the area is either lost as evapotranspiration, runs off over the land surface, or infiltrates through the soil. Since the surface layer is relatively impermeable, much of the received water is lost through evapotranspiration or runoff. Using the Thornthwaite method, Piteau Associates estimated that only 9.6% of the average annual precipitation seeps into the ground as infiltration, at a rate of approximately 3.9 L/s/km^2. Thus, as seen in Figure 10, the two aquifers have relatively small thicknesses. Based on a cross-section provided in the Piteau Report (2002) (Appendix C1), we estimate the depth of the upper water table at the proposed Earth Systems Science Building to be approximately 68 meters below the ground surface.

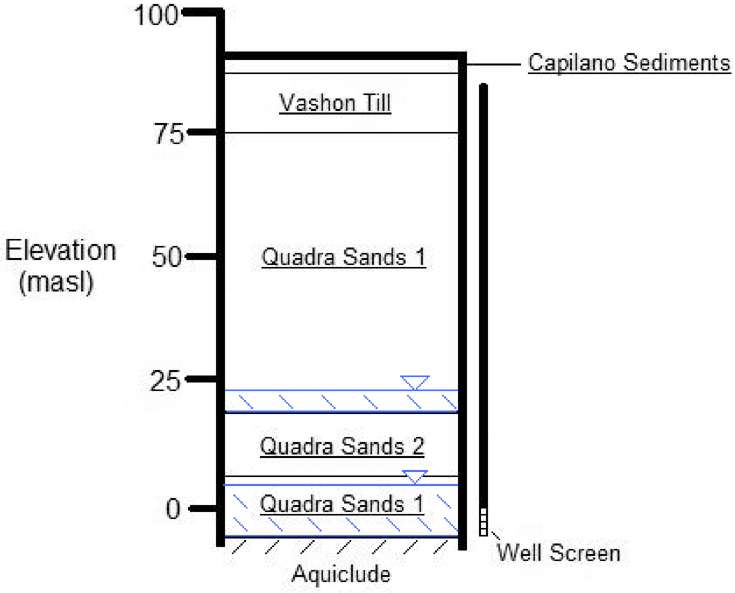


Figure 10: Approximate depths and thicknesses of the aquifers within the two Quadra Sands 1 units.

(Adapted from Piteau Associates, 2002.)

The heterogeneity underneath UBC campus is apparent in the range of K values cited in the Piteau Report (2002), whether based on the soil sample analyses and aquifer pump tests done by Piteau Associates or estimates from e.g. Smith (1981, in Piteau Associates, 2002). The minimum value we will use is 0.5×10^{-4} m/s found by Piteau Associates from back analyses of aquifer pump tests run on two production wells, while the maximum is 4.8×10^{-4} m/s, found by Smith when analyzing 12 soil samples from the North Campus Area (1981, in Piteau Associates, 2002). Our middle K value will be 1.9×10^{-4} m/s, based on the average found by Piteau Associates during grain size analyses of samples taken from a well (TH01-03) located at the intersection of University Boulevard and Main Mall (Appendix B).

ii. Estimate the theoretical pumping rate for the area in question:

A simple BVP was the basis of our conceptualization of the Dupuit equation, as applied to our own area of study (Figure 11).

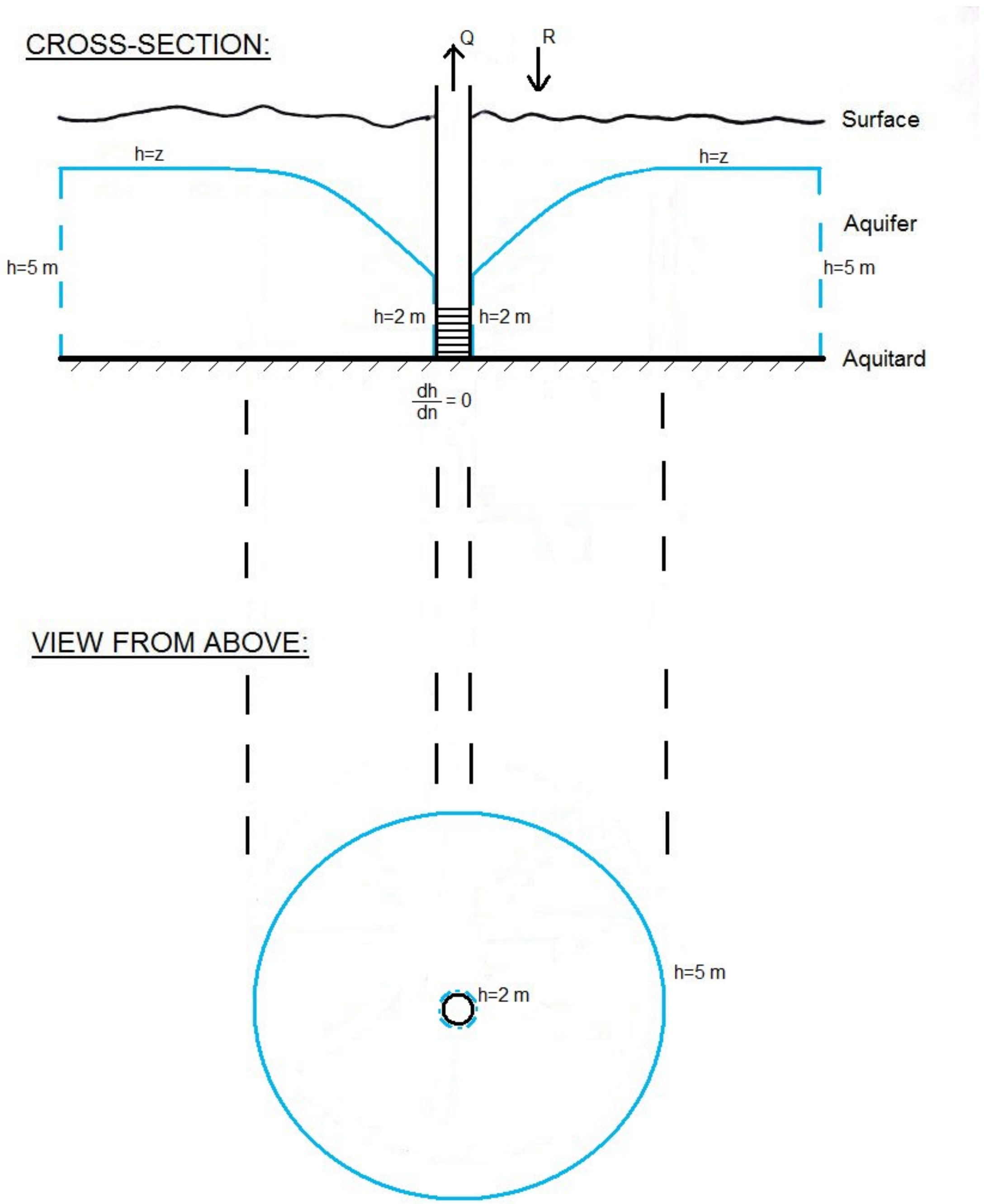


Figure 11: Boundary Value Problem visualizing the area around and beneath the imaginary pumping well at the proposed Earth Systems Science Building location. Water will move from areas of higher to lower hydraulic head. "h" represents hydraulic head, "dh/dn=0" signifies no change in hydraulic head in the direction normal to the boundary and h=z signifies that hydraulic head is equal to elevation along the boundary; in this case, the water table. Q denotes well extraction and R represents recharge to the aquifer.

Note: figure not to scale.

Subsequently, Equation 4.2 resulted in an R_0 of approximately 320 meters, when using the 20 gallon per minute (gpm) steady-state pumping rate found by Hemmera (2006).

Assuming a maximum drawdown of 3 meters to balance the need for water for the ground source heat system with keeping the aquifer saturated, we calculated theoretical pumping rates for the three hydraulic conductivity values, outlined in Table 2.

Hydraulic Conductivity (m/s)	Theoretical Pumping Rate (US gpm)
0.5×10^{-4}	11
1.9×10^{-4}	24
4.8×10^{-4}	60

Table 2: Theoretical pumping rates based on a range of hydraulic conductivity values to account for the heterogeneity of the subsurface beneath the proposed Earth System Science Building.

B. Estimate the actual energy extractable and available to heat/cool the Earth Systems Science Building

i. Determine the temperature of the extracted water:

We used a range of 10-11ºC for the initial groundwater temperature under UBC, as suggested by David Grigg of UBC Campus Planning and Ruben Arellano of Hemmera Inc., and set the minimum injection temperature of the water during heating mode to approximately 6ºC. The greater the difference in temperature, the less efficient the heat pump will be. Thus, while the heating water could be cooled in theory to 0ºC, 4-5 degrees of cooling is regarded as a good industry standard to ensure sufficient heat can be extracted without compromising efficiency.

ii. Determine the heat contained in the extracted water:

Using Equation 4.3, we calculated the heat extractable from the water for space heating of the Earth Systems Science Building (Table 3).

K (m/s)	Extractable heat flux (J/s), ΔT=4ºC	Extractable heat flux (J/s), ΔT=5ºC
0.5×10^{-4}	11,620	14,525
1.9×10^{-4}	25,350	31,688
4.8×10^{-4}	63,376	79,220

Table 3: Heat extractable, in J/s (=W), assuming an initial groundwater temperature of 10 and 11ºC respectively, and a final temperature after heat is extracted of 6ºC.

Best case (maximum heat extractable) = 79,220 J/s

Mean case (based on middle estimate of hydraulic conductivity) = 28,519 J/s

Worst case (minimum heat extractable) = 11,620 J/s

C. Compare the heat available to the Earth Systems Science Buildings heat requirements

i. Determine the Earth Systems Science Building's gross heating load:

Geoforce Energy Solutions and Dandelion Geothermal provided an estimate for peak load heating requirements of the Earth Systems Science Building based on typical values for the Lower Mainland: 12,000 BTU for 1000 square feet, or, 660,000 BTU (about 190,000 J/s) for the 55,000 square feet comprising the Earth Systems Science Building. Based on calculations that included parameters such as well condition space and UBC climatic conditions, C. R. Martin provided an estimate of 816,120 BTU (about 240,000 J/s) for the Earth Systems Science Building peak heating load.

ii. Sizing of the Ground Source Heat System:

We subsequently adjusted the peak heating load of the Earth Systems Science Building in order to size our system to 60-70% of the buildings peak heating requirements (Table 4), as is typically done. Remember that this still meets at least 95% of the annual demand (Natural Resources Canada, 2004).

Peak Heating Load (J/s):	60% of Peak Heating Load:	70% of Peak Heating Load
190,000	114,000	133,000
240,000	144,000	168,000

Table 4: Peak heating load adjusted based on either 60 or 70 % of peak heating load covered by the ground source heat system.

Best case 114,000 J/s

Mean case is 139,750 J/s

Worst case is 168,000 J/s.

iii. Estimate the number of wells required:

Using the range of adjusted peak heating loads, and the calculations of heat extractable from one well found in B.*ii*, we found that anywhere from two to fifteen wells will be required for an open-loop ground source heat system to meet the majority of the heating requirements of the proposed Earth Systems Science Building (Table 5).

	Heat Required (J/s) (from Table 4)		
Heat Available (J/s) (from Table 3)	Best Case: 114,000	Mean Case: 139,750	Worst Case: 168,000
Best Case: 79,220	**2**	**2**	**2**
Mean Case: 28,519	**4**	**5**	**6**
Worst Case: 11,620	**10**	**12**	**15**

Table 5: Bold numbers represent wells required based on best, worst and mean cases of both adjusted peak heating load of Earth Systems Science Building and heat flux from one well. Decimal values were rounded up to nearest whole number. Combining best case of both variables resulted in 2 wells required as a best case scenario. Using the same line of thought, the mean number of wells required is 5, and the worst case is 15.

5.2. Economic Analysis

A. Estimate Installation Costs

The two major types of ground source heat pump systems that could be installed are a central heat pump system or a distributed heat pump system. A central heat pump system consists of one large heat exchanger in a mechanical room, with pipes then running throughout the entire building. Every location in the building is serviced by four pipes, two for cooling, with one bringing water from the mechanical room and the other taking it back to the mechanical room, as well as two similar pipes for heating. This system is slightly more expensive to install due to the large amount of piping required. However, it can be used simultaneously for heating and cooling in different parts of the building if needed, which should occur 10% of the time in the Lower Mainland (R. Marier, personal communication, February 2009). In this way, groundwater and electricity use is decreased, as the heated cooling water from the hot portion of the building can then be used for heating another colder part of the building. A distributed heat pump system consists of multiple smaller heat exchangers; as many as one in each room. Though it has a lower capital cost, it requires more maintenance once exchangers need to be replaced some years later.

As described earlier, UBC cools its buildings selectively and hence cooling pipes are only needed in a few rooms per building. In this way, the cost of piping required is drastically cut down and hence a central heat pump system is thought to be the cheaper option. For the distributed heat pump system, heat exchangers would still be required in every room even if only for heating purposes, hence we have decided to do a cost-benefit analysis for a central heat pump system. The capital costs are outlined in Table 6. All costs shown in this report are in Canadian dollars, with values correct in 2009.

	Number of Wells Required		
Costs: (in Canadian $, value as of 2009)	Best Case: 2	Mean Case: 5	Worst Case: 15
Engineer	50,000	50,000	50,000
Well ($60/ft)	30,000	75,000	225,000
Indoor Materials – (heat pump, exchangers, controls, tanks, piping, additional gas boiler)	150,000	150,000	150,000
Outdoor Piping – ($5,000 per well)	10,000	25,000	75,000
Water pump, 50 gpm variable speed – ($8,000 per well)	16,000	40,000	120,000
Total	**$ 256,000**	**$ 340,000**	**$ 620,000**

Table 6: Estimates for capital cost based on best case, mean case and worst case of number of wells required. Depth of well casing is approximately 75m / 250 feet. Estimates of various costs provided by R. Marier of Terasen Energy Services (personal communication, February 2009).

B. Estimate Running Costs

Heat pumps, on average, have a coefficient of performance (COP) of 4, indicating that for every unit of electricity used, four units of heat are transported (Natural Resources Canada, 2004). Based on this COP and Terasen's current price of electricity per kWh, we estimated the annual running costs of our projected best case, mean case and worst case ground source heat systems (Table 7).

	Heat Requirement Met By Ground Source Heat System (GJ/yr) (from Table 4: scaling up of J/s to GJ/yr)		
Running Cost Parameters:	Best Case: 3,595	Mean Case: 4,407	Worst Case: 5,298
GSHS Electricity Need (GJ/yr) = heat requirement / COP	899	1,102	1,325
→Conversion to kWh	249,678	306,075	367,947
Final Cost of Electricity to power GSHS (=$.07/kWh), to the nearest $100	**$ 17,500**	**$ 21,400**	**$ 25,800**

Table 7: Estimates of running cost over one year for projected best, mean and worst case ground source heat system. Cost of electricity per kWh provided by R. Marier (personal communication, February 2009).

C. Estimate Payoff time

An estimation of payoff time attempts to compare the costs of a ground source heat system to a more traditional heating and cooling system. At UBC, heating of buildings is typically done using hot water loops that deliver heat into individual rooms. At present, the loop is heated using steam from the central steam plant. The general UBC operating fund pays for the purchase of natural gas, water and electricity, which are then used to generate steam energy that is supplied to core campus buildings free of charge. All residences and ancillary buildings at UBC do pay for steam at $21.63 per kilopound of steam (KLBS). In this study however we do not make the distinction as to who actually pays for the energy, merely that at some point in the energy cycle, costs will be incurred for energy usage. Overall $12 per KLBS of steam is a representative number for the total cost entailed in the production of 1000 pounds of steam energy for use in UBC buildings (J. Giffin, personal communication, February 2009). 1 GJ/yr of energy is approximately equivalent to 944 LBS of steam. Of the total steam generated, approximately 40% of the heat is lost during transport, leaving 60% available to finally heat buildings (J. Giffin, personal communication, March 2009). In other words, the efficiency of the heating process by steam is 0.6. Based on this efficiency and UBC's current price of steam per KLBS, we calculated an approximate payoff time for our projected best case, mean case, and worst case ground source heat systems relative to a steam driven heating system. First, we estimated the annual running costs for a steam powered system (Table 8).

	Heat Requirement Met By Steam Driven Heating System (GJ/yr) (from Table 4: scaling up of J/s to GJ/yr)		
Running Cost Parameters:	Best Case: 3,595	Mean Case: 4,407	Worst Case: 5,298
Required Energy (GJ/yr) = heat requirement/ efficiency	5,992	7,345	8,830
→Conversion to KLBS of steam	5,656	6,934	8,335
Final Cost of Steam (= $12/KLBS), to the nearest $100	**$ 68,000**	**$ 83,200**	**$ 100,000**

Table 8. Running costs for best, mean and worst case scenarios based on a steam driven heating system of efficiency 0.6. Steam price provided by J. Giffin (personal communication, February 2009).

With Equation 4.4, and rough estimates of installation costs for a traditional steam driven heating system at UBC, we then calculated payback times (Table 9).

	Best Case:	Mean Case:	Worst Case:
Ground Source Heat			
Capital Cost	256,000	340,000	620,000
Annual Running Cost	17,500	21,400	25,800
Steam Powered Heating System			
Capital Cost	30,000	30,000	30,000
Annual Running Cost	68,000	83,200	100,000
Payback Time (years):	**5**	**6**	**8**

Table 9: Payback times calculated for best, mean and worst case scenarios when comparing a ground source heat system and a steam powered heating system. Capital costs provided by R. Marier (personal communication, February 2009). Decimal values rounded up to the nearest year.

6. DISCUSSION

6.1. Sustainable Pumping Rates

Using the above described theoretical hydrogeologic method based on first principles to calculate the predicted water yield of a single well placed near the future Earth Systems Science Building, sustainable pumping rates were estimated to be anywhere between 11 and 60 gallons per minute. The large range is mainly due to uncertainties in the hydraulic conductivity. While an area may have a thick saturated layer with much water available, if the aquifer material transmits water very slowly, pumping rates will remain low despite much water being present. This was found to be the case for the Sustainability Street well, where groundwater was assessed for its potential to heat and cool the original Earth and Ocean Science building. While the saturated depth was approximately the same as that near the Earth Systems Science Building site, at depth a silt-clay lens in the Quadra Sands was found to greatly reduce the hydraulic conductivity and thus the water the well could produce (R. Beckie, personal communication, November 2008). The range of values of the hydraulic conductivity used attempts to address some of the heterogeneity that is likely present in the soil.

Where the true pumping rates lie within this range can only be conclusively known later on in the drilling phase of a further feasibility study. This installation of a pumping well would have to be done by an engineering firm. As with the Sustainability Street well, a pump test would be performed over a number of days to identify the maximum sustainable amount of water than can be removed from the well before it settles to a new steady state. This would need to be done at every future proposed well site and would identify any unexpected drawbacks such as large boulders underground or clay layers that do not transmit water rapidly. Combining the data from each well, a total pumping rate would be obtained and this would give an indication of how much water is available for use in a ground source heat system. Based on this concrete knowledge, one could chose to include optional benefits such as domestic water heating by ground source heat for use in the Earth Systems Science Building.

There appears to be an overall decreasing trend in the saturated depth and well yield as one moves from the eastern to western edge of UBC campus. Well discharge decreases from the most easterly Regent well which produces 100 gpm (6.3 l/s), to the Biosciences well which produces 51 gpm (3.2 l/s) and finally to the Fisheries well which produces 37 gpm (2.3 l/s) (Piteau Associates, 2002) (see Appendix B). The proposed Earth Systems Science Well is located approximately between the Biosciences and Fisheries wells, and the calculated discharge of between 11 and 60 gpm is consistent with the actual measured values obtained elsewhere on campus. The saturated depth decreases towards the west, as this is where discharge occurs at the boundary with the ocean.

The range of pumping rates from 11 to 60 gallons per minute are based on a drawdown cone of radius 320 m created as a result of pumping. Depending on the number of wells eventually installed, this has the potential to affect the groundwater availability and characteristics of a fairly large proportion of campus. If a large radius like 320 m is used when actually implementing the ground source heat system, plans for adjacent buildings must be taken into account as there may not be sufficient water left for them to utilize open loop ground source heat as well. A smaller radius could be used so as to lessen the ground source heat system's footprint, however less water would be extractable from each well and more wells would be needed in total. In this way, it is a trade off between a variety of factors including drawdown cone radius, number and cost of wells and area of campus affected. The radius of the drawdown cone can be changed in further calculations depending on the results of a pumping test and the need for water of adjacent buildings.

When installing multiple wells, as will likely be the case for the Earth Systems Science Building's ground source heat system, one factor to take into account is the Principle of Superposition. This hydrogeologic principle states that the drawdown at a point caused by pumping from many wells is equal to the sum of the drawdowns of the individual wells when treated as if in isolation. While this is only true for confined aquifers, it can be taken to be approximately true for unconfined aquifers if the drawdown is small relative to the saturated thickness of the aquifer. We are dealing with an unconfined aquifer, in which the drawdown is fairly large relative to the saturated thickness, and hence this principle does not necessarily apply. Nonetheless, any effects of superposition must be monitored to ensure that the wells are located a sufficient distance apart so as not to fully deplete the saturated layer due to multiple pumpings.

Finally, the uptake rate for return water into the aquifer for the proposed open loop system may also deplete the saturated layer if it is less than the rate of extraction. Care must be taken to ensure the aquifer remains at an overall steady state by returning the same amount of water to the aquifer as was initially pumped out otherwise well yield and heating capacity will diminish over time. Any rejection wells should have a large enough uptake capacity to dispose of all the water pumped out initially and used in the heat pump. According to Natural Resources Canada (2008), if an extra existing well is available, this could potentially be used as a rejection well. The Sustainability Street well is located close to the future Earth Systems Science Building and is currently not used for anything. Hence this well should be kept in mind for a possible future rejection well. Alternatively the single extraction and injection well set-up of Regent College could be applied here.

6.2. Building Heating and Cooling Loads

While typical rules of thumb for heating and cooling requirements of "archetype" institutional buildings in the Vancouver area are known and were used in this study to show the feasibility of a concept design, a more detailed analysis would be required before any ground source heat system is fully implemented. Ground source heat system design is known to be far more concerned with detailed heating and cooling load calculations and annual energy information than conventional heating and cooling systems (R. Arellano, personal communication, February 2009). This step can only be performed once a finalized and detailed plan for the building has been designed and the proportion of building space usage is known. This includes knowing the surface area of classrooms, offices, administration areas, museum space, as well as teaching and research laboratories. Each of these areas use and produce different amounts of heat and hence have different heating and cooling requirements. In addition the number of doors and windows, the window material, the wall types, the window orientation and the degree of insulation, among many other factors, all play a role in how much additional heating/cooling is required from a ground source heat system. Furthermore, diurnal, weekly and seasonal changes in the energy requirements would also have to be characterized in detail. For instance, during the day, internal heating required is higher due to people occupying the building needing a comfortable temperature to work in and to counteract the heat lost from the constant opening and closing of doors. However, this may be partially of entirely offset by the heat emitted from lights, people and computers. This detailed calculation of building heating and cooling loads is a complex, extremely involved process that requires specialized knowledge, detailed and varied data and in-depth methods (calculations or detailed modeling) to determine (R. Arellano, personal communication, February 2009).

6.3. Sizing of the Ground Source Heat System

In this study, the number of wells was computed from an estimate of groundwater extractable from a single well, combined with approximate building heat loads. In a later study, these results would be confirmed based on more detailed knowledge of the amount of water extractable from pump tests and the heating requirements of the building from complex modeling. This step has some overall flexibility.

Typical ground source heat systems are sized to meet 60-70% of the peak heating requirements (Natural Resources Canada, 2004), which results in 95% of the daily heating requirements being met. For this additional 5% and to serve as a back-up, some kind of high-efficiency boiler is installed in most cases. However, it is not unusual for systems to be sized to 50% of the peak heating requirements or even less (R. Marier, personal communication, February 2009). In this case, a higher capacity boiler is installed to meet the larger shortfall. Alternatively, the extra heat can be supplied by some other form of heating, using a combination method. Hence, in this way there are a variety of combinations that can be implemented to make the use of ground source heat both physically and economically feasible.

A further factor to take into account is the efficiency of the heat extraction process by the heat pump. The greater the temperature difference between the initial and final reservoirs of water, the greater the heat is in theory available to extract to subsequently heat the building. However, the greater this temperature difference, the lower the efficiency of the heat extraction process becomes (R. Marier, personal communication, February 2009). Hence, while it may seem advisable to work with a large temperature difference so as to have maximum heat available, the tradeoff between greater heat availability and lower extraction efficiency must be considered. There is at present no legislation that limits the temperature of water that is pumped back into the ground after use in a ground source heat system.

It was found in this study that anywhere between 2 and 15 wells would be required to satisfy 95% of the Earth Systems Science Building's heating and cooling requirements. While anything more than 2 wells of drawdown radius 320 meters will likely take up more of campus' groundwater and surface area than is available for this project, the final number of wells needed depends ultimately on the amount of water that can be pumped up and the proportion of the building that it is feasible to heat using ground source heat. If there is found to be little water (the lower end of the 11-60 gallon per minute range) then ground source heat could be used for a smaller portion of the building. If more water is found to be extractable, then the whole building could use ground source heat. Ground source heat is ultimately physically possible, if not for the whole building, than merely for a smaller portion of it, using other combination technologies to heat and cool the rest of the building. Here however, the economic feasibility of a ground source heat or combination system may become restrictive.

At a further stage in the feasibility study, water pumped out of the wells would have to be examined in detail. Poor water quality can cause severe problems in open loop systems as they can cause scaling or clogging of the heat pump system, making it malfunction in a very short period of time. The groundwater should be free of excessive particles and organic matter, and acidity, hardness and iron content should be tested. Different heat pumps are able to cope with water of different quality, hence it is important that the groundwater be tested, characterized and a suitable heat pump chosen (Natural Resources Canada, 2008).

In addition, later on in a further study, the exact distribution, location and type of wells will be have to be examined in more detail. These specifics were not covered within the scope of this project as it is too early in the design proceedings to be able to conclusively set such detailed engineering specifications.

A further consideration that must be taken into account when performing more detailed studies for the implementation of this ground source heat system is the effect of thermal imbalance. Thermal imbalance of the soil is something that needs to be considered for every ground source heat system, both open and closed loop. This is especially relevant as the systems proposed for the Earth Systems Science Building must meet a greater heating than cooling load, as only core areas and sensitive equipment is cooled at UBC (D.Grigg, personal communication, January 2009). There are several ground source heat systems in British Columbia which use their systems for cooling only and do not inject any heat at all from the building back into the soil. These ground source heat systems work well generally, but only if they are sized properly. When the ground source heat system is used more for heating or cooling, or only for one of the two, the system needs to be oversized to take into account the slow decay of efficiency over time due to the ground warming up or cooling down. This decrease in efficiency is considered normal for most buildings in the Lower Mainland, as generally their heating and cooling requirements do not fully match. A recent suggestion proposed to help address the issue of thermal imbalance is to install a few solar panels to inject some extra heat into the ground and help keep the soil temperature constant in a regime where ground source heat systems are mainly used for cooling. This is most effective in Vancouver during the summer months and a single glazed panel (4 by 8 inches) can inject approximately 13 GJ of heat into the ground per year if oriented and sloped properly (R. Marier, personal communication, February 2009). For our proposed system, we would theoretically need between 276 and 408 solar panels to thermally balance the aquifer provided the system is not used for any cooling. While this seems like a large amount, each panel is only 8 by 4 inches, so in total a panel area of between 5.7 and 8.4 square meters would suffice. A more obvious suggestion that may be feasible at UBC, is simply to increase the cooling load of the building, by not just providing cooling for core rooms but for the whole building. This would be pleasant for the building's occupants, while simultaneously ensuring the continued efficiency of the ground source heat system.

6.4. Economics of the Proposed Ground Source Heat System

Looking at the economic considerations, an approximate economic analysis was performed above to give a rough idea of the economic feasibility of this project, as cost often plays a large role in the (non-) implementation of a ground source heat project. A payback time between 5 and 8 years was obtained. This means that the additional cost of installing a ground source heat system is paid off within 5 to 8 years and from that point on, net savings are achieved. This payback time of approximately 5 to 8 years compares favourably to the average lifespan of a ground source heat system: the underground portion of the system typically has a warranty of 50 years (Corix Utilities, 2009), with the heat exchanger having a warranty of around 20 years, with a much longer lifetime if maintained properly (Unitary Products Group, 2006). Given its long lifetime, relatively short payback time and lower longterm running costs (typical monthly costs for ground source heat systems are approximately one third of more traditional electric or gas heating and cooling systems) (R. Marier, personal communication, February 2009), the installation of some sort of ground source heat system in the future Earth Systems Science Building is deemed to be very economically feasible.

In the future, if the decision is made to move forward with this project, a more detailed analysis will be possible based on the exact building design and suitable hardware. In addition, when performing more detailed and accurate payback time calculations, all prices and costs in the future must be consistently brought back to the value of money in the present. This degree of detail was not possible within the scope of this project, but must be taken into account in future calculations. Furthermore, the prices of gas and electricity are predicted to go up by at least 5% per year (R. Marier, personal communication, February 2009), a further factor which could be taken into account when performing more detailed payback calculations. 5% is an approximation based on current market conditions and projected changes and is likely to change much in the future. Hence this was not included in the payback analysis. This implies that as the running costs of more traditional heating methods which use electricity and gas increase, the payback time of alternative systems such as ground source heat systems will continue to decrease.

One issue that may be encountered is that at UBC, capital and running costs for university infrastructure come from separate budgets. Hence, while it may be advantageous to spend more initially in order to get greater savings in a few years, these two separate budgets do not allow for this kind of flexibility. More recently this has been addressed by initiatives such as Public Private Partnerships. This is discussed in more detail later on.

6.5. Further Steps to System Implementation

While this study has given a valuable first look at the background of ground source heat and the possibility of using it to heat and cool the Earth Systems Science Building, and in future perhaps other buildings on campus, much further work remains to be done. Should UBC Campus and Community Planning decide to look further into the use of ground source heat in the Earth Systems Science Building, many further stages of feasibility studies will need to be performed by a variety of experts, as described above. All things considered, a combination system, for instance an open loop ground source heat system in combination with a supplemental boiler, may be the best option when looking at the trade-off between groundwater footprint and depletion, realistic number of wells and cost.

Furthermore, this study has focused solely on the feasibility of using an open loop groundwater system to heat and cool the Earth Systems Science Building. While this set-up has been shown to be both physically and economically feasible, it may be helpful before proceeding to do a brief feasibility study of the other kinds of ground source heat systems. For instance, in a closed loop system, the cooling fluid can be cooled to as low as – 4ºC during peak load events (R. Arellano, personal communication, February 2009). This greater temperature change may result in the ability to meet a greater heating load, or may be canceled out by the lower heat capacity of the coolant or by the reduced efficiency of the heat pump at this higher temperature difference. Furthermore, a closed loop system may be limited by sub-surface conditions or lack of free space in which to install loops. In general however, as described earlier, open loop ground source heat have been found to be more suitable for large scale applications than closed loop systems, as they are able to deliver a higher thermal capacity per borehole

(Sanner, 2005). Another alternative would be to discharge the water after use in the Earth Systems Science Building directly into an open water body, such as the nearby ocean. This is known as surface water geoexchange. These options should be briefly examined to see if locally, they offer any overwhelming advantages over the proposed open loop groundwater system.

Ground source heat pumps have strong economies of scale. This means that both annual operating savings as well as greenhouse gas emission reductions increase proportionately as the building heating loads increase. As larger homes or institutional buildings typically have higher heating loads, ground source heat systems are most economically viable as well as environmentally beneficial for these larger installations (Hanova & Dowlatabadi, 2007). This would strongly support the decision to heat and cool the Earth Systems Science Building using ground source heat. Not only is this in line with UBC's sustainability policies and initiatives, it becomes more financially and environmentally effective when applied to a building of this size.

7. CONCLUSIONS AND POLICY IMPLICATIONS

Since the signing of the Talloires and Halifax Declarations in the early 90s, and becoming the first Canadian university to adopt a Sustainable Development Policy, UBC has demonstrated its commitment to sustainability through a variety of initiatives such as ECOTrek, UBC Renew and the design of several LEED certified institutional buildings. It has been enterprising in the realm of energy efficiency, utilizing waste heat, natural ventilation, and solar heating and lighting in more recent developments. Ground source heat technology, as a source of renewable energy, with its demonstrated cost and energy savings and the lowest greenhouse gas emissions of all conventional heating/cooling systems used today, can provide UBC with the opportunity to become a leader in the realm of new, energy and cost effective technologies.

7.1. An Alternative Financing Option for Ground Source Heat Systems in BC

Financing such a system for the Earth Systems Science Building may be made much easier by Public, Private Partnership (P3) opportunities, which were made mandatory for consideration by the BC Government Capital Standard in 2006. The Capital Standard requires that all BC Government and Agency projects over $20 million be assessed for P3 potential. Whereas the traditional route for project financing is individually optimizing budgets for various stages of the development process (i.e. Design, Build, Operate, Maintain and Finance), P3 attempts holistic optimization, and thus the potential for organizations such as UBC to reduce total project cost in the long-term. Such a scenario is proposed by Terasen Energy Services wherein it will take on the capital cost for the system, taking ownership of the pipes in the ground and the central mechanical equipment, while UBC returns the capital cost in monthly installments along with the electricity bill. During the period of Terasen ownership, operational risk is also eliminated as Terasen will operate the system to utility standards (Terasen Energy Services, 2009). As of 2007, UBC has been in the process of conducting a "High

Level Assessment" for the P3 potential of the Earth Systems Science Building (UBC Land and Building Services, 2007c).

7.2. Legislation Governing Ground Source Heat System Installations

If an open-loop ground source heat system is chosen to partially heat and cool the proposed Earth Systems Science Building, any relevant legislation governing groundwater usage and well installation must be considered. At the federal level, the government introduced the Federal Water Policy in 1987 which acknowledged the federal role in groundwater management, but has "taken little direct action to improve groundwater management" (Nowlan, 2005). Managing and protecting water quality in the provinces is primarily under the jurisdiction of the provincial government.

British Columbia is one of eight provinces that asserts its ownership over all water resources, including groundwater, which is defined as "water under the land" (Nowlan, 2005). It is the only province in which groundwater and surface water are part of separate licensing regimes, because permitting is currently not applicable to groundwater extractions of less than 75 litres per second (Geoexchange BC, 2005a). Furthermore, submission of well log records or groundwater reports is not mandatory, and there is no charge for extraction of groundwater. However, well identification plates are required in some cases, including that of the open-loop ground source heat system proposed for the Earth Systems Science Building, and must be obtained from the government.

In BC, use of water resources in general is regulated under the Water Act of 1996. In 2001, as part of a broader drive to protect drinking water supplies in the province, the legislature approved an amendment that became Part 5 of the Water Act entitled Wells and Groundwater Protection. The provincial government also introduced the separate BC Ground Water Protection Act, or Ground Water Protection Regulation in 2004, which builds upon and expands Part 5 of the Water Act and focuses on well construction standards and groundwater quality protection. There are no regulations pertaining to quantity of water allowed to be withdrawn, or limits to radii of influence of wells, though withdrawn water that has passed through the heat pump is required to be returned back to the source afterwards. There are no municipal bylaws that govern groundwater usage in Vancouver, likely because the drinking water, and other water supplies are taken from surface sources (A. Cohen, personal communication, February 2009). However, this ignores the large-scale hydrologic cycle and the consequent link between surface and groundwater. If ground source heat technology is to be more widely used in the future, municipal regulation that is holistic in nature is necessary. A new holistic approach should also be taken if provincial legislation concerning groundwater is ever to be edited or amended, as currently, the Water Act and Groundwater Protection Regulation seem to by and large treat surface water and groundwater as separate entities. This may make sense for organizational purposes, but is not very realistic in a physical sense.

The Government of British Columbia has acknowledged the “unregulated and uncontrolled” nature of groundwater use in BC, and is attempting to rectify the situation by developing the above-mentioned Groundwater Protection Regulation in three phases, and is aiming to complete the regulations by 2012. The third phase will include “requirements relating to aquifer protection, ground water quantity and use”, while the regulation itself will focus on larger-scale applications, including “open-loop water supply wells for geo-exchange purposes” (Province of British Columbia, 2007).

Such regulation in turn depends on more thorough characterization of the groundwater regime in the area of concern. A study commissioned by Natural Resources Canada and the Geological Survey of Canada in 2005 aimed to evaluate how well groundwater is understood in Canada. The study found that “the current state of government monitoring and assessment is deficient” and that “reporting groundwater use is not mandatory" (Rivera, 2005). As stated by the 2005 NRCanada report, “the limited current knowledge will be the main obstacle to improving groundwater regulation", or, that groundwater regimes must first be well characterized with concrete data and measurements for any groundwater legislation to be effective.

Vancouver could thus be dubbed energy-forward but groundwater-backwards with regards to policy. In 1991, Vancouver became the first Canadian city to incorporate energy efficiency measures into a by-law (Canadian Geoexchange Coalition, 2009). The bylaw applies to all new buildings and additions, with the exception of one-family and two-family dwellings. Bylaw 6871 was Vancouver's visionary attempt to decrease the environmental impact and operation costs of buildings in the Lower Mainland. Existing developments in the Lower Mainland that use ground source heat, though mostly of the closed-loop variety, are very good examples of optimizing energy efficiency, as they utilize hybrid heating and cooling systems that include waste heat redistribution as with the West Vancouver Community Complex or radiant slab heating and cooling as with Regent College and the Gleneagles Community Centre.

7.3. Improvements to Legislation and Standardization: The European Model

The lack of legislation regarding groundwater drawdown and quality of reinjection water may become problematic, especially if open-loop ground source heat systems are increasingly implemented on UBC campus and in Vancouver. Indeed, the use of ground source heat systems seems to be gaining popularity in Vancouver, as evidenced by the many billboards advertising new high rise developments that include ground source heat systems. Although many of the existing developments with ground source heat systems tend to be of the closed-loop variety, groundwater quality is still an important consideration in the design and implementation of such a system.

The European countries discussed earlier with widespread ground source heat system utilization have strict laws regarding groundwater usage, with some even having groundwater protection areas where ground source heat pump installation, regardless of type, is not allowed. They have also been monitoring and studying ground source heat pump installations since the early 80s (Eugster & Sanner, 2007). Their level of monitoring, as well as legislation regarding ground source heat pump installation are good models to look to as the ground source heat pump industry develops here in Vancouver, and in BC. In the EU, groundwater pollution is seen as a real threat, and policy has been shaped accordingly. Many authorities even provide maps and web-based GIS applications which delineate which type of ground source heat pump is allowed or recommended at a particular site. For example, the German state of Hessen provides maps that demarcate areas where small ground source heat pump systems of less than 30 kWh may be installed without special licensing, areas where an application for licensing is required, and areas where ground source heat pump installation is prohibited, such as groundwater protection areas, areas with several perched aquifers, or aquifers with heavily mineralized water (Sanner, 2005).

Furthermore, every ground source heat pump installation requires advance licensing from the relevant authority for groundwater protection, water management, or mining, regardless of location (Eugster & Sanner, 2007). Frequently, depending on the "risk potential" of the installation, the licensing authorities also impose special conditions for the construction and operation of the ground source heat pump, and site assessments also include determining the impact on present or future ground source heat pump installations. Within the countries discussed earlier, i.e. Germany, Sweden, and Switzerland, national or regional water management and/or groundwater protection authorities have published guidelines for the license proceedings, as well as for the construction and operation of ground source heat pump installations. Though they cannot be considered a "groundwater protection authority", Geoexchange BC has also published a 3-part guideline book regarding site assessment, design, construction and monitoring, intended to "promote appropriate and responsible designs, leading to successful, sustainable systems that will in turn meet owner's requirements and improve the reputation of the industry" in BC.

This leads to the need for more industry-wide standardization of technique in BC and Canada in order for ground source heat systems of all types to become more widespread. Canada has commenced with such attempts as is evidenced by GeoexchangeBC and the Canadian Geoexchange Coalition. Geoexchange BC is an attempt at BC-wide standardization, and provides a thorough guidebook detailing system design, potential shortfalls, hybrid systems and relevant environmental regulations. The Canadian Geoexchange Coalition is also an attempt at centralization on a country-wide scale, and seems to focus more on training and certification. The website offers few case studies from all the provinces (three in BC), and does not offer much in the realm of "technical reports" as many of the sections of the website, such as the Academic and Industry Technical Documents sections, do not have any documents in them.

Though the industry itself is moving towards standardization, there is still a lack of public awareness regarding this technology, highlighting the additional need for centralization of information in BC and Canada. It was discovered through the course of this research that while much is known in general about ground source heat, its uses and advantages, there is a distinct lack of detailed knowledge available regarding specific ground source heat systems. For example, though the GreenBuildings BC website contains a document listing all of the known ground source heat systems in BC, it is only current as of 2005 and contains only basic installation specifications such as type of system and date installed. Furthermore, the bulk of the knowledge about the Regent College ground source heat system, which we hoped would serve as an extensive case study upon which to build our pre-feasibility assessment, was held by one man, the former Facilities Manager who was present when the system was installed and who took an active interest in the details of the system. When he retired in early 2008, all knowledge beyond basic details of their ground source heat system was effectively lost (R. Smith, personal communication, November 2008). This caused our case study to be greatly limited in terms of post-installation assessment. Such lack of information not only makes future research near impossible, but it is also a great pity that those who use the facilities every day will never know the intricate details of a system so crucial to their comfort. An information consortium kept by each individual facility that uses ground source heat or all together by a central ground source heat bureau would ensure that this kind of information is not only available for future use, research and improvements, but also to ensure the optimum management of the existing systems.

The underdevelopment of standardization, information centralization and particularly public awareness is understandable as the ground source heat system industry in Canada is, as the Canadian Geoexchange Coalition states, “fragmented and relatively small”. Again, a region which has already reached a more advanced level of research, design, and development in the ground source heat sector, and is a good example to draw from, is the EU, especially since, like Canada, it is a big region with varying geographies, but has a much more established ground source heat pump industry. This can be in part attributed to the high level of regional industry-wide standardization and collaboration. In addition to national networks that provide information and technical support, there are technically-focused multi-national networks (e.g. DACH – Germany, Austria, and Switzerland), as well as a Europe-wide European Heat Pump Association that serves as a technical and marketing network, and the European Geothermal Energy Council which acts as an information provider. There are also many journal articles and conference proceedings that comprehensively cover the history, current state, and future outlook of the ground source heat pump industry in Europe on a country or regional basis, and though they can be helpful as a guide for the developing ground source heat industry in Canada, specific case studies of Canadian systems would be of greater relevance and help.

7.4. Climate Change and UBC's Role on the Global Stage

An important question that must be mentioned in the context of today's global changes, is how global warming and climate change are expected to affect the efficiency and potential of ground source heat systems. Soil temperature will likely change, but by only a few degrees as it maintains constant heating from below, and thus may affect installation of closed-loop ground source heat systems. For open-loop ground source heat systems, it is likely that changing precipitation regimes will have a much bigger impact on the installation of open-loop ground source heat systems such as that proposed for the Earth Systems Science Building on UBC campus. Changing precipitation regimes will alter groundwater recharge rates and thus may have significant potential to change the steady-state pumping rates of already established open-loop wells. This would be a good area for future research to be performed in as it will become an ever-more relevant issue in the future.

The academic community plays an important role on the global stage, uncovering the underlying causes and processes, and importantly mitigation methods, of many of the environmental and other issues we face today. UBC, as a leading global academic institution, thus has a key role in contributing to global awareness and shaping international policy when it comes to issues such as global climate change. We have reached the point where we do not have the time to simply converse about the underlying causes and processes of global climate change; there is an ever more pressing need to take action. As such, UBC has the potential to take its recent forward-thinking institutional development initiatives to the next level and serve as a role model to other institutions around the world by promoting this new technology that makes a lot of sense in the context of global warming and our commitment to the Kyoto protocol.

8. FINAL RECOMMENDATIONS

Using first principles to estimate the amount of extractable groundwater in the soil below the proposed Earth Systems Science Building, it has been found that in the best case, 2 wells will be needed to provide 95% of the building's heating demand. In the mean case, 5 wells will be needed and in the worst case, 15 wells would be required, based on lower quantities of groundwater available to the ground source heat system. Economically, these systems would take 5, 6 and 8 years respectively until their capital costs are paid off and they result in net savings. While economically this compares very favourably to the 50 year lifespan of a typical ground source heat system, physically the possibilities are fairly limited. 2 wells of drawdown radius 320 m could possibly be installed around the Earth Systems Science Building without taking up unrealistically high proportions of groundwater. However, this is the best case only and the wells would be far removed from the building thus requiring much energy to transport the groundwater to the building site. The mean and worst cases of 5 and 15 wells are entirely unrealistic and practically unfeasible due to their large ground footprint and the high proportion of UBC campus' groundwater resources they would utilize. Thus, a tentative further feasibility study may be commissioned to perform a single pumping test adjacent to the proposed Earth Systems Science Building. Even in the best case, one well will not produce sufficient water to fully meet the heating requirement of the Earth Systems Science Building, and hence combination technologies should be further explored. These specific combination systems should be studied in much greater detail to optimize energy and cost effectiveness.

BIBLIOGRAPHY

BCHydro. (2005). *Geoexchange Systems.* Retrieved October 5, 2008, from http://www.bchydro.com/powersmart/technology_tips/geoexchange_systems.html.

Canada Green Building Council. (2008). *What is LEED and Why Certify?* Retrieved October 5, 2008, from http://www.cagbc.org/leed/what/index.php.

Canadian Geoexchange Coalition. (2009). *Kitsilano – 2211 West Fourth.* Retrieved February 16, 2009, from http://www.geo-exchange.ca/en/british_columbia_arc8.php.

Capital Well Drillers. (no date). *Geothermal.* Retrieved October 29, 2008, from http://www.capitalwell.ca/Geo_Thermal.htm.

Chadwick, J. (2008, January 15). Mining community invests C$20 million to create new UBC building. *International Mining.* Retrieved November 5, 2008, from http://internationalmining.mining.com/2008/01/15/mining-community-invests-c20-million-to-create-new-ubc-building/

Coady, T., and Hasan, A. (2006). UBC Life Sciences Centre. *Journal of Green Building.* 1 (3): 26-45.

Cobalt Engineering. (2008). *Regent College Library.* Retrieved November 1, 2008, from http://www.cobaltengineering.com/projects/academic/regent-college-library/.

Corix Utilities. (2009). *Geoexchange Q and A.* Retrieved February 17, 2009 from http://www.corix.com/utilities/sustainable_energy/geoexchange-qa.htm.

Curtis, R., Lund, J., Sanner, B., Rybach, L., and Hellstrom, G. (2005). *Ground Source Heat Pumps – Geothermal Energy for Anyone, Anywhere: Current Worldwide Activity.* Retrieved October 31, 2008, from http://www.sanner-geo.de/media/1437.pdf.

Curtis, R., Lund, J., Sanner, B., Rybach, L., and Hellstrom, G. (2005). *Ground Source Heat Pumps – Geothermal Energy for Anyone, Anywhere: Current Worldwide Activity.* Retrieved October 31, 2008, from http://www.sanner-geo.de/media/1437.pdf.

Deffeyes, K.S. (2004). Hubbert's Peak: The Impending World Oil Shortage. *American Journal of Physics.* 72 (1): 126–127.

Dincer, Ibrahim. (2003). *Refrigeration Systems and Applications.* Retrieved January 13, 2008 from http://books.google.ca/books?id=g4E0Op3w87YC&pg=PA303&lpg=PA303&dq=heat+loss+calculations+for+GSHP&source=web&ots=NHOwLtjsLq&sig=qbVZb4_dO7XvQ6PcJ4uXvodAE-c&hl=en&sa=X&oi=book_result&resnum=10&ct=result#PPP1,M1.

Duncan, R.C. (2003). Three World Oil Forecasts Predict Peak Oil Production. *Oil and Gas Journal.* 101 (21):18.

Earth Energy Society of Canada (EESC). (no date). *Lower Capital and Operating Costs: McMath Gets it Both.* Retrieved October 17, 2008, from http://www.earthenergy.ca/richmond.html.

Earth Source Energy (2007). *Earth Source Energy Inc.* Retrieved November 8, 2008, from http://www.investorideas.com/CO/ESIV/EarthsourceEnergyProjectPortfolio.pdf.

Earth Tech. (2003). *Gleneagles Community Centre*. Retrieved November 1, 2008, from http://www.metrovancouver.org/buildsmart/resources/CaseStudies/gleneaglescasestudy.pdf.

ECOTrek. (2006). *ECOTrek Success*. Retrieved October 25, 2008, from http://www.ecotrek.ubc.ca/success.htm.

Eugster, W.J., and Sanner, B. (2007). Technological Status of Shallow Geothermal Energy in Europe. *European Geothermal Congress Proceedings*. Retrieved November 15, 2008, from http://www.egec.org/target/final%20paper%20ShallowGeothermal.pdf.

Geoexchange BC. (2005a). *Geoexchange Energy Systems Professional Design Guidelines*. Retrieved February 16, 2009, from http://www.geoexchangebc.ca/pdf/ahsrae_april292005.pdf.

GeoExchange BC. (2005b). *Inventory of GeoExchange Systems in BC*. Retrieved November 1, 2008, from http://www.geoexchangebc.ca/resourcedir/InstallationsBC.pdf.

Goodland, H. (2006). *Carbon Trust Information Exchange and Green Building Tour*. Retrieve November 18, 2008, from http://www.sustainablebuildingcentre.com/blog/helen_goodland_7

Green Buildings BC. (2004). *Burnaby Mountain Secondary School*. Retrieved November 1, 2008, from http://www.greenbuildingsbc.com/Portals/0/docs/case_studies/Burnaby_Mountain.pdf.

GVRD & UBC. (2000). *Memorandum of Understanding*. Retrieved October 25, 2008, from http://www.planning.ubc.ca/pdfs/New_Final_MOU.pdf

Hall, S. (2008). *Sarah Hall Studio*. Retrieved November 18, 2008, from http://www.sarahhallstudio.com/regent

Hanova, J. and Dowlatabadi, H. (2007). *Strategic GHG reduction through the use of ground source heat pump technology*. Retrieved February 17, 2009 from http://www.iop.org/EJ/article/1748-9326/2/4/044001/erl7_4_044001.html.

Hanova, J., Dowlatabadi, H., and Mueller, L. (2007). *Ground Source Heat Pump Systems in Canada: Economics and Greenhouse Gas Reduction Potential*. Retrieved October 28, 2008, from http://www.rff.org/Documents/RFF-DP-07-18.pdf.

Hemmera. (2006). *Well Log for Sustainability Street at UBC*.

HydroHeat. (2006). *High Efficiency Geothermal Heat Pump Systems*. Retrieved October 29, 2008, from http://www.hydrodelta.com/commercial.htm.

International Ground Source Heat Pump Association (IGSHPA). (2006). *What is IGSHPA, Mission and History*. Retrieved November 1, 2008, from http://www.igshpa.okstate.edu/about/about_us.htm.

International Institute for Sustainable Development. (1991). *The Halifax Declaration.* Retrieved October 24, 2008, from http://www.iisd.org/educate/declarat/halifax.htm.

Lund, J. W., Sanner, B., Rybach, L., Curtis, R., and Hellström, G. (2004). *Geothermal (Ground-Source) Heat Pumps: A World Overview*. Retrieved October 31, 2008, from http://geoheat.oit.edu/bulletin/bull25-3/art1.pdf.

Lund, J. W., Freeston, D. H., and Boyd, T. L. (2005). Direct application of geothermal energy: 2005 worldwide review. *Geothermics.* 34: 691–727.

Miles Industries Ltd. (2009). *Advantages of Radiant Heat.* Retrieved February 5, 2009, from http://www.milesfireplaces.com/education/advantages.php

Misstear, B., Banks, D. and Clarke, L. (2006). *Water Wells and Boreholes.* UK: John Wiley and Sons Ltd.

Natural Resources Canada. (2002a). *Commercial Earth Energy Systems: A Buyer's Guide.* Retrieved October 29, 2008, from http://www.canren.gc.ca/app/filerepository/EARTH-BuyersGuide-CommercialEarthEnergySystems.pdf.

Natural Resources Canada. (2002b). *Earth Energy: No Matter the Name, the Choice is the Same.* Retrieved October 17, 2008, from http://www.canren.gc.ca/prod_serv/index.asp?CaId=152&PgId=776.

Natural Resources Canada. (2004). *Heating and Cooling With a Heat Pump.* Retrieved January 25, 2009, from http://oee.nrcan.gc.ca/publications/infosource/pub/home/heating-heat-pump/booklet.pdf.

Natural Resources Canada (CanREN). (2006). *Technologies and Applications: About Earth and Geothermal Energy.* Retrieved October 5, 2008, from http://www.canren.gc.ca/tech_appl/index.asp?CaID=3.

Natural Resources Canada. (2008). *Heating and Cooling With a Heat Pump.* Retrieved February 17, 2009 from http://oee.nrcan.gc.ca/publications/infosource/pub/home/Heating_and_Cooling_with_a_Heat_Pump_Section4.cfm.

Nowlan, L. (2005). *Buried Treasure: Groundwater Permitting and Pricing in Canada*. Retrieved February 16, 2009, from http://www.buriedtreasurecanada.ca/Buried_Treasure.pdf

Piteau Associates Engineering Ltd. (2002). *Hydrogeological and Geotechnical Assessment of Northwest Area UBC Campus, Vancouver.*

Pottinger Gaherty Environmental Consultants Ltd. (2004). *Environmental Assessment: UBC South Campus Neighborhood.* Retrieved October 5, 2008, from http://www.planning.ubc.ca/corebus/pdfs/pdf-landuse/SC_EA_Final_Nov04.pdf.

Province of British Columbia. (2007). *Doing Business Differently – Protecting our Groundwater.* Retrieved February 18, 2009, from http://www.livingwatersmart.ca/business/groundwater.html.

Rafferty, R. (2003). Groundwater issues in geothermal heat pump systems. *Groundwater*. 41 (4): 408–410.

Regent College. (2006). *Art, Architecture and Design: Environmental Components*. Retrieved November 1, 2008, from http://www.regent-college.edu/about_regent/architecture/index.html.

Rivera, A. (2005). *How Well Do We Understand Groundwater in Canada?* Retrieved February 16, 2009, from http://ess.nrcan.gc.ca/2002_2006/gwp/pdf/rivera_case_study_final_e.pdf.

Sanner, B. (no date). *Description of Ground Source Heat Types for the Heat Pump*. Retrieved November 1, 2008, from http://www.geothermie.de/oberflaechennahe/description_of_ground_source_typ.htm.

Sanner, B. (2003). Current Status of Ground Source Heat Pumps in Europe. *Futurestock 2003 Conference, Warsaw, Poland.* Retrieved November 15, 2008, from http://www.buildingphysics.com/Futurestock%201.pdf.

Sanner, B. (2005). *Examples of GSHP and UTES Systems in Germany.* Retrieved October 31, 2008, from http://www.sanner-geo.de/media/1441.pdf.

Terasen Energy Services. (2009). *Geoexchange Systems.* Retrieved February 16, 2009, from http://www.terasen.com/EnergyServices/GeoexchangeSystems/default.htm.

The Anglican Church of Canada. (Nov 2007). Art Installation Provides window on energy conservation. *Anglican Journal*. Retrieved November 18, 2008, from http://www.anglicanjournal.com/100/article/art-installation-provides-a-window-on-energy-conservation-1/

UBC Campus and Community Planning. (2005). *UBC Official Community Plan.* Retrieved October 25, 2008, from http://www.planning.ubc.ca/corebus/ccp.html.

UBC Land and Building Services. (2007a). *UBC Renew.* Retrieved October 31, 2008, from http://www.lbs.ubc.ca/renew/UBC_Renew_HC_06.pdf.

UBC Land and Building Services. (2007b). *Request for Decision.* Retrieved November 12, 2008, from http://pdf.lbs.ubc.ca/lbs/boardreports/2007/may/5.2-earth_systems_science_building.pdf.

UBC Land and Building Services. (2007c). *BC Government Public Private Partnership Policy.* Retrieved February 16, 2009, from http://pdf.lbs.ubc.ca/lbs/boardreports/2007/september/4.10-BC_government_public_private_partnership_policy.pdf.

UBC Science. (2008). *Earth Systems Science Building.* Retrieved November 5, 2008, from http://www.science.ubc.ca/essb.

UBC Sustainability Office. (2006). *UBC Sustainability Street.* Retrieved November 15, 2008, from http://www.sustain.ubc.ca/sustainabilitystreet/news.html.

UBC Sustainability Office. (2007). *UBC Sustainability Strategy.* Retrieved October 25, from http://www.sustain.ubc.ca/pdfs/ia/UBC_Sustainability_Strategy_2007.pdf.

UBC Sustainability Office. (2008a). *Get Sustainable.* Retrieved October 24, 2008, from http://www.sustain.ubc.ca.

UBC Sustainability Office. (2008b). *Green Buildings.* Retrieved October 25, 2008, from http://www.sustain.ubc.ca/greenbuilding.html.

University Counsel. (2005). *Sustainable Development.* Retrieved October 24, 2008, from http://www.universitycounsel.ubc.ca/policies/policy5.pdf.

University Leaders for a Sustainable Future. (1990). *The Talloires Declaration – 10 Point Action Plan.* Retrieved October 24, 2008, from http://www.ulsf.org/pdf/TD.pdf.

United Nations Division for Sustainable Development. (2008). *About the United Nations Division for Sustainable Development.* Retrieved November 7, 2008 from http://www.un.org/esa/sustdev/.

Unitary Products Group. (2006). *Heat Exchanger Warranty.* Retrieved February 17, 2009 from http://www.yorkupg.com/PDFFiles/66207-UWA-B-0506.pdf.

US Geothermal Heat Pump Consortium (USGHPC). (no date). *Geothermal Comfort Goes Low-Rise in Kitsilano, British Columbia.* Retrieved October 17, 2008, from http://www.eitechcorp.com/Case%20Studies/Kitsilano%20BC%20_%202211%20West%20Fourth.pdf.

VEL Engineering. (no date). *Climate Change and Buildings*. Received from Kai Chen, November 18, 2008.

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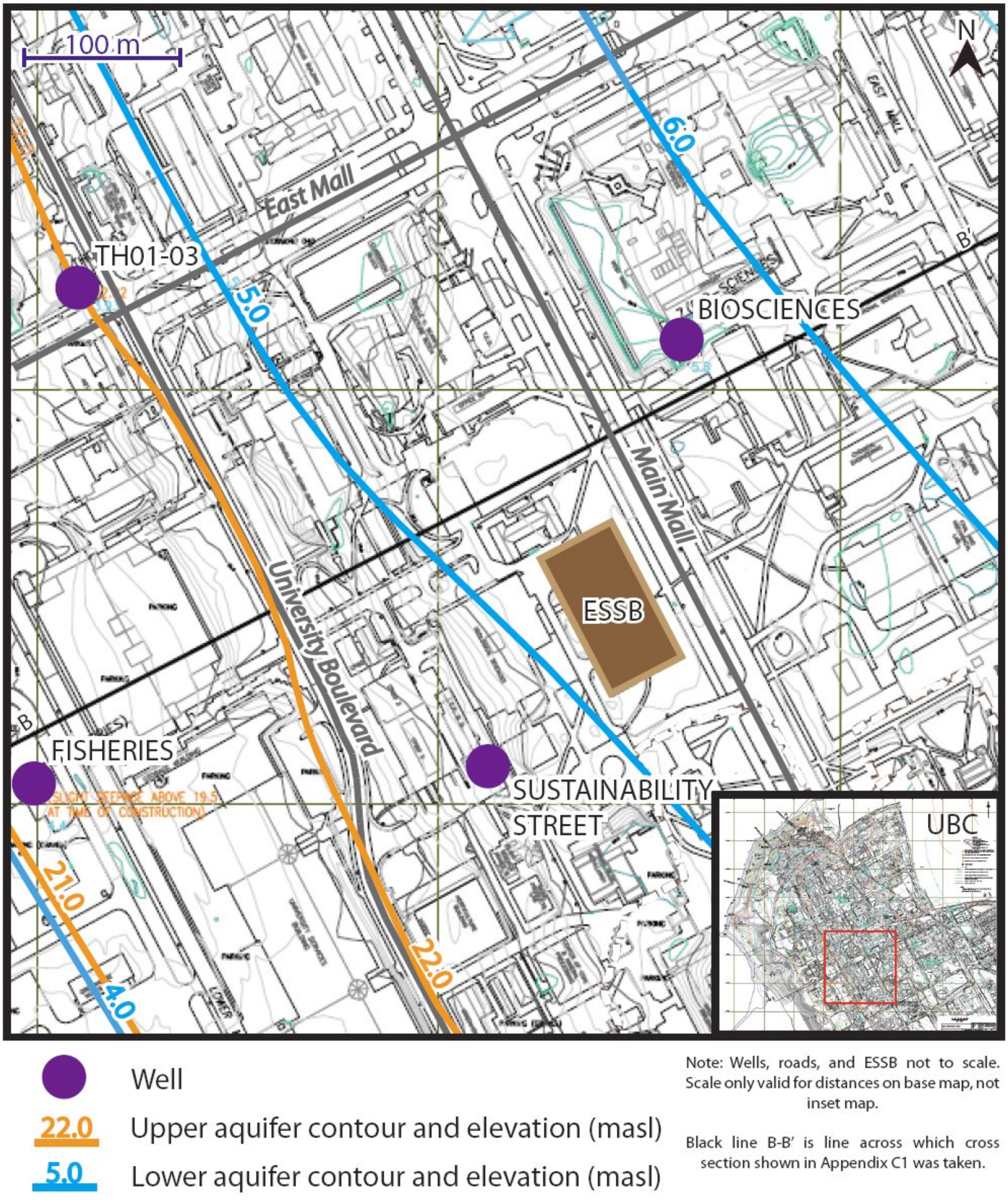
<u>Appendix B: Relevant Well Locations (Zoom-in of Page 45 of Piteau Report)</u>

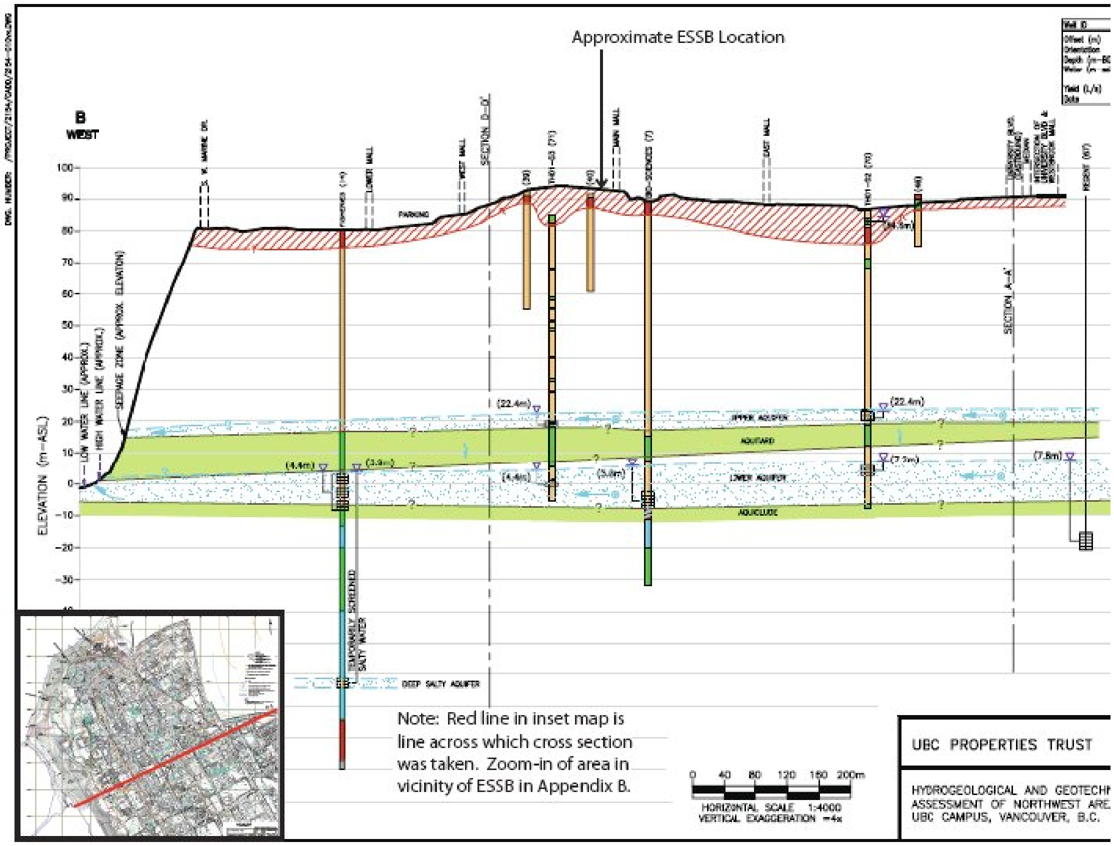
Vicinity of the Earth Systems Science Building
Demarcating Relevant Wells and Hydraulic Head Contours



Note: Wells, roads, and ESSB not to scale. Scale only valid for distances on base map, not inset map.

Black line B-B' is line across which cross section shown in Appendix C1 was taken.

Appendix C1: Cross Section Running West to East Across UBC Campus (Page 44 of Piteau Report)

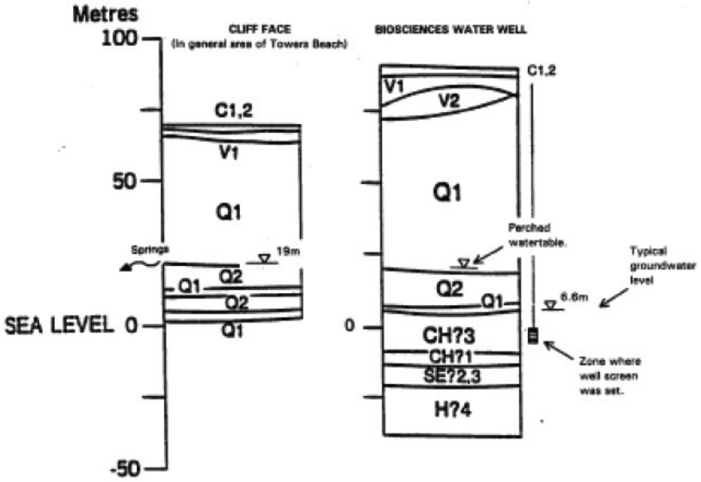


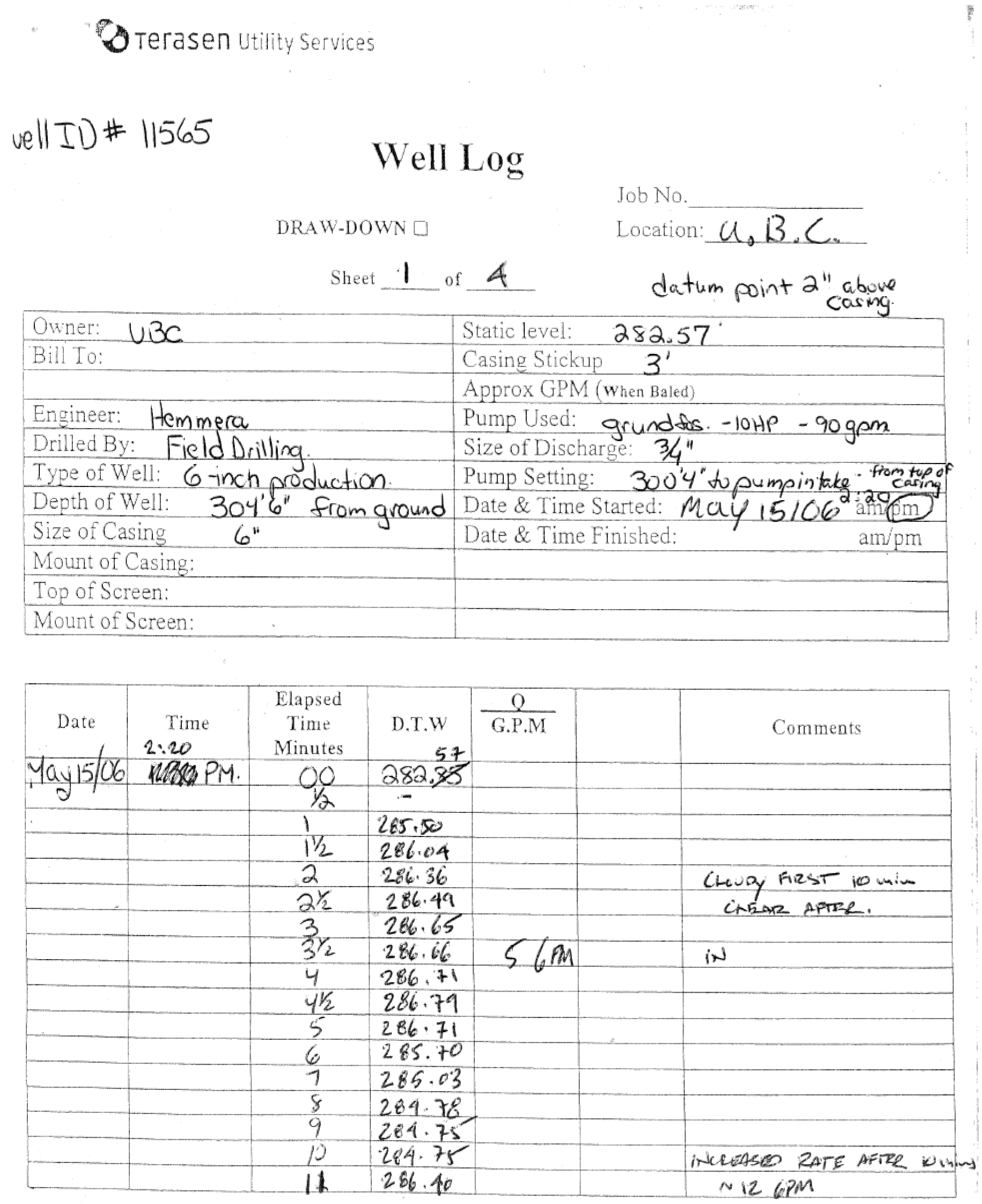
Note: Red line in inset map is line across which cross section was taken. Zoom-in of area in vicinity of ESSB in Appendix B.

Appendix C2: Soil Profiles Under UBC (Page 38 of Piteau Report)

TYPICAL PROFILE OF UNCONSOLIDATED SEDIMENTS EXPOSED IN UBC CLIFFS

CAPILANO SEDIMENTS (C)	
C1	Beach gravel
C2	Glaciomarine stony silt to clay loam
VASHON DRIFT (V)	
V1	Sandy, loamy lodgment till; a,b,c, youngest to oldest
V2	Glaciofluvial pebble to boulder gravel and sand; a,b,c, youngest to oldest
QUADRA SAND (Q)	
Q1	Fine to coarse sand; minor silt and gravel
Q2	Interbedded silt, fine sand, and minor peat
Q4	Silt, sand, and silty clay, minor gravel; probably of marine origin
COWICHAN HEAD FORMATION (CH)	
CH2	Silt, silty clay, and sand; peat beds in places
CH3	Sandy gravel and gravelly sand
CH4	Organic colluvium and peat
CH5	Marine silt, silty clay, and sand; lenses of gravel
SEMIAHMOO DRIFT (SE)	
SE1	Loamy lodgment till, minor lenses of sand and gravel; a,b,c, youngest to oldest
SE2	Glaciomarine and marine stony silt loam, clayey silt, and silty clay
SE3	Silty sand to sandy gravel; in places pumice rich
SE4	Glaciolacustrine silt, silty clay, and fine sand
HIGHBURY SEDIMENTS (H)	
H1	Silt, silty sand, minor gravel; lenses of gravelly sand
H4	Marine fine sand, silty sand, silt, clay, and minor gravel





Terasen Utility Services

well ID # 11565

Well Log

Job No.

DRAW-DOWN ☐

Location: U. B. C.

Sheet 1 of 4

datum point 2" above casing.

Owner: UBC	Static level: 282.57'
Bill To:	Casing Stickup 3'
	Approx GPM (When Baled)
Engineer: Hemmera	Pump Used: grundfos. -10HP - 90gpm
Drilled By: Field Drilling.	Size of Discharge: 3/4"
Type of Well: 6-inch production.	Pump Setting: 300'4" to pump intake · from top of casing
Depth of Well: 304'6" from ground	Date & Time Started: May 15/06 2:20 am/[✓ pm]
Size of Casing 6"	Date & Time Finished: am/pm
Mount of Casing:	
Top of Screen:	
Mount of Screen:	

Date	Time	Elapsed Time Minutes	D.T.W	Q / G.P.M		Comments
May 15/06	2:20 PM.	00	282.~~85~~57			
		½	-			
		1	285.50			
		1½	286.04			
		2	286.36			CLOUDY FIRST 10 min
		2½	286.49			CLEAR AFTER.
		3	286.65			
		3½	286.66	5 GPM		IN
		4	286.71			
		4½	286.79			
		5	286.71			
		6	285.70			
		7	285.03			
		8	284.78			
		9	284.75			
		10	284.75			INCREASED RATE AFTER 10 min
		11	286.40			~12 GPM

Terasen
Utility Services

Well Log

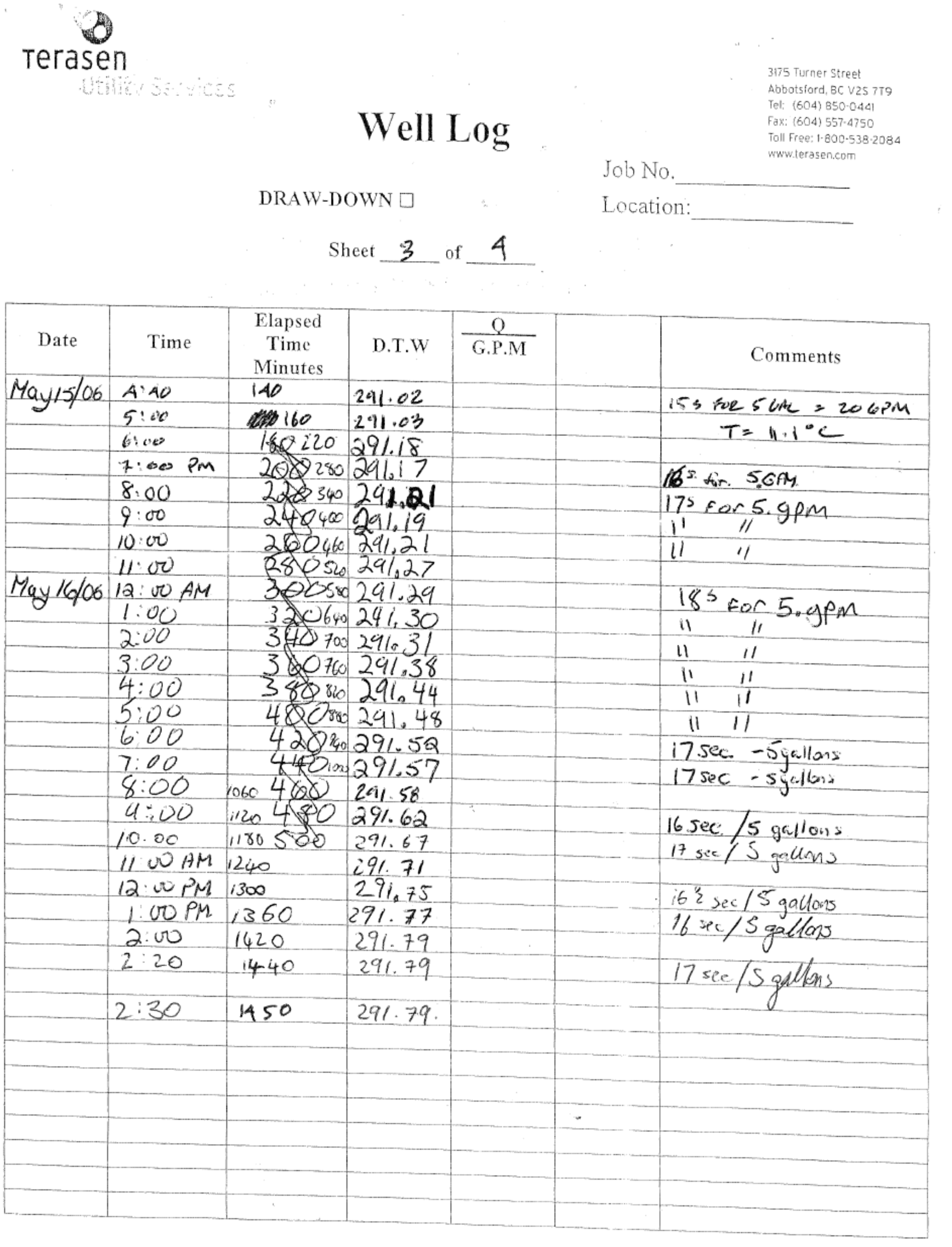
Job No.

Location

Draw-down

Sheet 2 of 4

Date	Time	Elapsed Time (Minutes)	D.T.W.	Q / G.P.M.	S	Comments
		12	286.89			
		13	287.07			
		14	287.21			
		15	287.15			
		16	286.95			
		18	286.90			
		20	286.88			INCREASED RATE TO: 22s FOR 5 GAL
		21	288.38			~ 13.5 GPM
		22	288.75			
		23	288.96			
		25	289.09			
		27	289.07			21s FOR 5 GAL
		30	289.03		STEP→	INCREASED RATE TO: 17.9 GPM
		31	290.03			17s FOR 5 GAL
		32	290.61			
		33	290.65			
		34	290.68			
		35	290.72			
		37	290.78			16s FOR 5 GAL = 18.5 GPM
		40	290.84			11°C CLEAR
		45	290.91			16s FOR 5 GAL = 18.5 GPM.
		50	290.96			
	1 HR	60	291.01		8.9'	16 s FOR 5 GAL = 18.5 GPM
		70	291.05			15s = 20 GPM (11.2°C)
	[illegible] HRS.	80	290.98			15s = 20 GPM.
	3:50 PM	90	290.98		8.41	Sc = 2.4 GPM/ft.
	4:00 PM	100	290.98			
	4:20	120	291.01			



Terasen
Utility Services

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Fax: (604) 557-4750
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www.terasen.com

Well Log

Job No.____________

Location:____________

DRAW-DOWN ☐

Sheet 3 of 4

Date	Time	Elapsed Time Minutes	D.T.W	Q G.P.M		Comments
May15/06	4:40	140	291.02			15s for 5 GAL = 20GPM
	5:00	160	291.03			T= 11.1°C
	6:00	~~160~~ 220	291.18			
	7:00 PM	~~200~~ 280	291.17			16s. for. 5GPM
	8:00	~~220~~ 340	291.21			17s for 5.gpm
	9:00	~~240~~ 400	291.19			" "
	10:00	~~260~~ 460	291.21			" "
	11:00	~~280~~ 520	291.27			
May 16/06	12:00 AM	~~300~~ 580	291.29			18s for 5.gpm
	1:00	~~320~~ 640	291.30			" "
	2:00	~~340~~ 700	291.31			" "
	3:00	~~360~~ 760	291.38			" "
	4:00	~~380~~ 820	291.44			" "
	5:00	~~400~~ 880	291.48			" "
	6:00	~~420~~ 940	291.52			17sec. -5gallons
	7:00	~~440~~ 1000	291.57			17sec -5gallons
	8:00	1060 ~~460~~	291.58			
	9:00	1120 ~~480~~	291.62			16sec. /5 gallons
	10.00	1180 ~~500~~	291.67			17 sec/ 5 gallons
	11:00 AM	1240	291.71			
	12:00 PM	1300	291.75			16½ sec/5 gallons
	1:00 PM	1360	291.77			16 sec/5 gallons
	2:00	1420	291.79			
	2:20	1440	291.79			17 sec/5 gallons
	2:30	1450	291.79.			

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Well Log

Job No._______________

Location:_______________

DRAW-DOWN ☐

Recovery

Sheet 4 of 4

Date	Time	Elapsed Time Minutes	D.T.W	Q / G.P.M		Comments
May 16/06	2:30 PM	00	291.79			
		½	287.01			
		1	285.43			
		1½	284.60			
		2	284.21			
		2½	283.90			
		3	283.81			
		3½	283.63			
		4	283.54			
		4½	283.50			
		5	283.42			
		6	283.36			
		7	283.29			
		8	283.21			
		9	283.17			
		10	283.15			
		12	283.09			
		14	283.04	283.03 ∘	95%	Recovery.
		16	283.00			
		18	282.97			
		20	282.96			
		25	282.90			
		30	282.87			
		40	282.82			
		50	282.79			
		60	282.73			
		80	282.75			
		100	282.71			
		120	282.73			
		140	282.74			
		160	282.72			
		180	282.71			
		200	282.72			
		220	282.69			

May 17/6 8:30 AM 282.60

Appendix D: Obtaining Best Case of 2 Wells – Sample Calculation

1) Estimate a suitable range for the value of hydraulic conductivity (K) for the water bearing soil layer below the Earth Systems Science Building:

"Best case" value for K (from Piteau Associates, 2002) = **4.8×10^{-4} m/s**

2) Estimate the theoretical pumping rate for the area in question:

Use the Dupuit Equation for radial flow between two specified head boundaries:

$$Q = \frac{\Pi \times K \times (H_0^2 - h_1^2)}{\ln (R_0 / r_1)}$$

Need R_0, therefore use:

Discharge = (Recharge) x (Recharge area)

$$Q = i \times A = i \times (\Pi \times R_0^2)$$

where we subsititute $Q = 20$ gpm $= 1.262 \times 10^{-3}\ \mathrm{m^3/s}$ found by Hemmera (2006), and

$i = 3.9\ \mathrm{L/s/km^2} = 3.9 \times 10^{-9}\ \mathrm{m^3/s/m^2}$ found by Piteau Associates to find R_0:

$$R_0 = [\ (1.262 \times 10^{-3}\ \mathrm{m^3/s}) / (\Pi \times 3.9 \times 10^{-9}\ \mathrm{m^3/s/m^2})\ ]^{1/2}$$

$$R_0 \approx 320\ \mathrm{m}$$

Back to Dupuit:

$$Q = \frac{\Pi \times (4.8 \times 10^{-4}\ \mathrm{m/s}) \times [(5\mathrm{m})^2 - (2\mathrm{m})^2]}{\ln(320\ \mathrm{m} / .076\ \mathrm{m})}$$

$$= \mathbf{3.79 \times 10^{-3}\ m^3/s = 60\ gpm = 3.785\ kg/s}$$

3) Estimate the energy extractable from the water given this flow rate:

Rate of heat flow = specific heat capacity x temperature difference x pumping rate

$$= C \times \Delta T \times Q$$

Use “best case” temperature difference of 5ºC, and C = 4186 J/kg/K

= 4186 J/kg/ ºC × 5ºC × 3.785 kg/s

= 79,220 J/s

4) *Compare extractable energy to ESSB heating requirements to obtain final well number:*

Number of wells = (ESSB heating requirements / Energy extractable from one well)

Best case consultant estimate of peak heating load of the ESSB: 190,000 J/s

→Size system to 60 percent of peak heating load: 114,000 J/s required

Finally,

Number of wells = (114,000 J/s / 79,220 J/s) = **2 wells**