Gartner Lee

Vanier School Ground Source Heat Pump Project: Site Setting & Conceptual Design

Prepared For:

Energy Solutions Centre

Prepared By:

Gartner Lee Limited

GLL 21-928

January, 2002

Distribution

8 Client

2 File

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January 3, 2002 GLL 21-928

Mr. Don Flinn, P.Eng.
Managing Director
Energy Solutions Centre Inc.
206A Lowe Street
1st Floor
Whitehorse, YT
Y1A 1W6

Dear Mr. Flinn:

Re: Site Setting and Conceptual Design for Vanier School Ground-Source Heat Pump, Final Report

Gartner Lee Limited is pleased to provide our Final report summarizing the conceptual design for three Ground Source Heat Pump options for the Vanier School site. Based on the simplest design concept and potentially lowest cost, the preferred option would be the development of a Groundwater Heat Pump that will utilize the Miles Canyon Basalt Aquifer.

Again, it should be stressed that the designs presented herein and associated costs are *conceptual* only and subject to further studies and design work.

Thank you for involving Gartner Lee Limited in this interesting project and we look forward to working with the Energy Solutions Centre in the future. Should you have any questions, or wish to discuss this project further, please do not hesitate to contact Forest Pearson at (905) 477-8400 extension 23.

Yours very truly,
GARTNER LEE LIMITED

Forest Pearson
Engineering Geologist

FKP:le
Attach.

2. dialog with the City of Whitehorse be initiate to gain the City's support of the proposed undertaking;

3. a 150 mm diameter (6 in.) test well be drilled to the base of the Miles Canyon Basalt aquifer adjacent to the Vanier School. This well is required to test the aquifer and the assumptions presented in the conceptual design prior to finalization of the GWHP design. Drilling and construction of the well should be conducted under the direction of a qualified hydrogeologist. At least one to two smaller diameter observation wells should be drilled adjacent to the test/production well to observe potential interaction with the overlying Selkirk Aquifer. Testing should include both step and longer-term constant rate pump tests to quantify well yield, aquifer properties, and to evaluate aquifer performance. Testing should also include continuous temperature and conductivity monitoring and synoptic water quality collection and analysis; and

4. a Water Licence application under the Yukon Waters Act be prepared for the proposed development.

It is interpreted that impacts to downgradient groundwater users (e.g., the City of Whitehorse) will be minor to undetectable. This is due to significant separation between the Vanier School site and the City's well field in addition to the very large thermal capacity present in the Selkirk Aquifer. However, it may be required that the Energy Solutions Centre demonstrate that the proposed GWHP system at Vanier School will not significantly impact the City's operation of the Selkirk Well Field. A numerical groundwater model of the Selkirk Aquifer was developed for the City of Whitehorse (Gartner Lee Limited 1998) which encompasses the Vanier School area. This model could be used to evaluate the degree of impact, if any, on the Selkirk Well field.

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1. Introduction

The Energy Solution Centre has initiated a Ground Source Heat Pump (GSHP) pilot project in Whitehorse, Yukon. Vanier Catholic Secondary School, located in the Riverdale subdivision (Figure 1) has been selected as the location for this project. The goal of this project is to demonstrate a sustainable energy resource technology to reduce overall energy consumption associated with heating the subject facility. Research conducted by the Energy Solutions Centre suggests that GSHP technology can be one of the most energy efficient heating options available to Yukoners. An economic comparison done by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) in 1995, suggested that a 4,200 m^2 (45,000 ft^2) school located in Winnipeg, would see a five year payback on the installation of a GSHP (Caneta Research Inc. 1995).

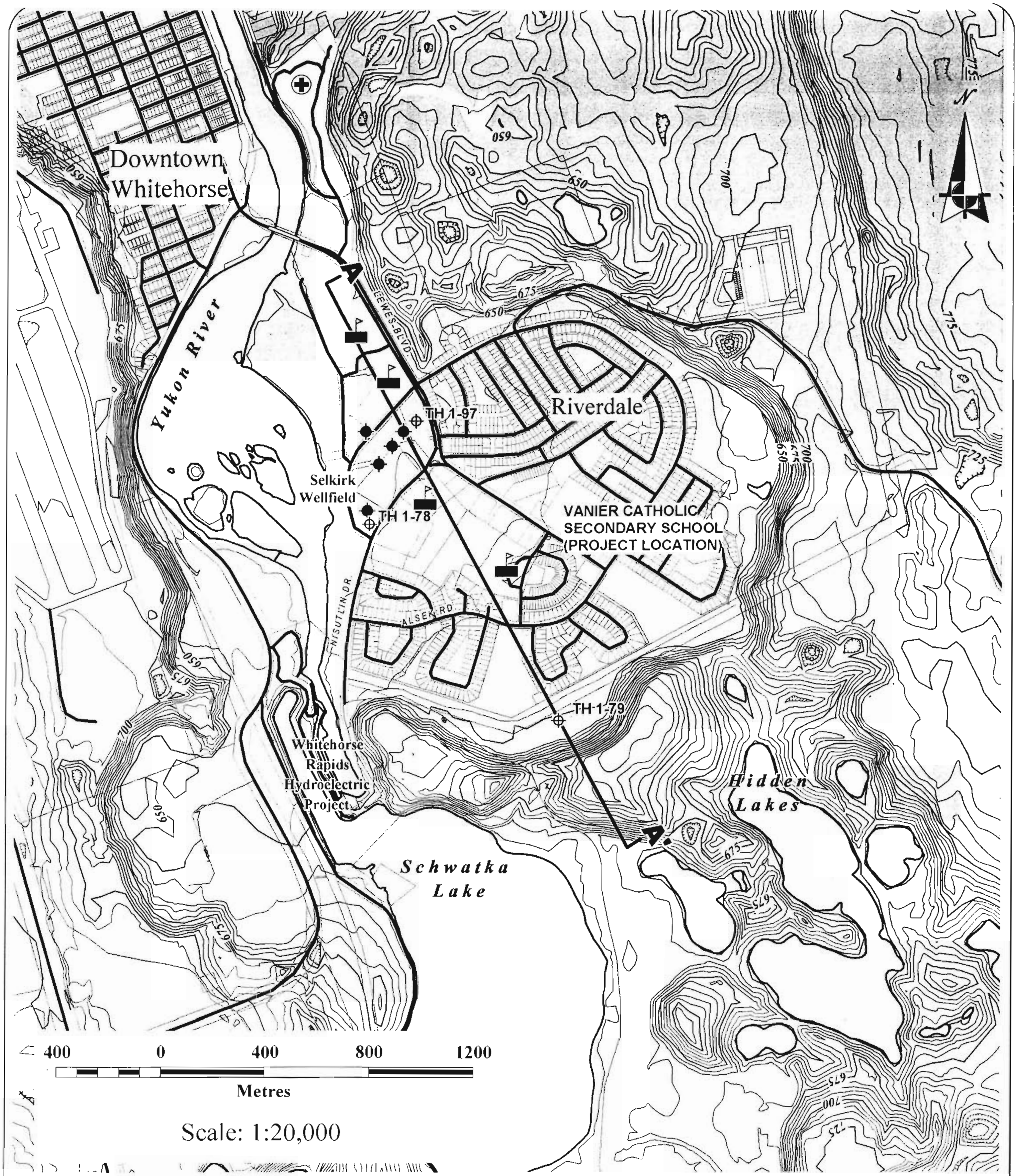
In its simplest form, GSHP technology can be described as the extraction of geothermal heat which is then transferred into a form which can be used to heat buildings. .

Two types of GSHP system have been considered for this project:

1. Groundwater Heat Pumps (GWHP) – commonly known as open-loop heat pumps. These systems pump groundwater from an aquifer, extract the heat energy from the water, and dispose of the chilled water to either surface or return it back into the aquifer; and
2. Ground Coupled Heat Pumps (GCHP) – commonly known as closed-loop heat pumps. These systems consist of a water or water-antifreeze solution which is passed through a network of small-diameter U-shaped tubes which are installed within vertical boreholes. Heat from the subsurface is passively conducted through the tubes into the liquid solution, which is then delivered to surface and extracted using a heat pump unit.

The Groundwater Heat Pumps (GWHP) are typically considered the most cost effective GSHP system, but require both an adequate supply of groundwater and environmental acceptability. Conversely, the Ground Coupled Heat Pump (GCHP) does not require a groundwater resource and therefore, the GCHP could be applicable almost anywhere in the Yukon.

Surface water heat pumps have not been considered for this project due to very cold surface water temperatures typical of the Yukon during winter months (e.g., <0.5°C). Additionally, horizontal loop GCHP systems have not been considered as deep frost penetration occurs readily in the region (e.g., ≥ 3 metres), making depth of burial for horizontal loops prohibitively deep.



Site Name: WHITEHORSE File Name: 21928-D1_2.WOR Gartner Lee Limited Scale: 1: 20,000	ENERGY SOLUTIONS CENTRE VANIER CATHOLIC SECONDARY SCHOOL GROUND SOURCE HEAT PUMP PROJECT **Project Location Map**	Project No: 21928 Date Issued: JAN. 2002 **Figure 1**

For the purposes of this project, the American Society of Heating, Refrigeration and Air-Conditioning Engineer's publication "*Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*" (Kavanaugh and Rafferty, 1997) has been extensively used as a valuable resource for the development of the conceptual designs. Consequently, the calculations used during this work have been conducted using imperial units and subsequently many of the discussions used in this report follow this notation. For further information on GSHPs, the reader is referred to this design manual.

1.1 Scope of Work

The ultimate objective of this project is to design and construct a full scale GSHP for the Vanier School. As this is a pilot project, designed to demonstrate and study the applicability of this technology in the Yukon, a four Phase approach has been proposed:

Phase 1:	Develop a conceptual design and scope of work for further investigations and to develop the pilot scale GHSP system.
Phase 2:	Hydrogeological Field investigations.
Phase 3:	Detailed design and construction of the pilot installation.
Phase 4:	Expansion and completion of the full scale GSHP installation.

This report constitutes Phase 1 of the project. The pilot installation conceptually consists of converting a portion or all of the Vanier School heating requirements to GSHP technology. Following the installation, the system will be instrumented to provide monitoring and to evaluate system performance over the period of one year. Based on the data collected from the pilot installation, the GSHP system could be further optimized to include a larger proportion, or possibly all of the schools heating requirements.

2. Site Setting

The Vanier Catholic Secondary School is located at 16 Duke Street, Whitehorse, Yukon, in an area known as the Riverdale subdivision. The subdivision is generally quite flat, and lies on an abandoned floodplain of the Yukon River. The river is located approximately 650m west of the school (Figure 1). The school is at an elevation of 645m ASL, which is about 8m above river level. The areas located to the south and west of the school are occupied by private, single and duplex style residences (Figure 2). East of the site, along Lewes Boulevard, are three-story apartment buildings and the Leisure on Lewes strip-mall. The area north of the school is occupied by the school's playing fields and an undeveloped forested area.

Scale: 1:3,000

Site Name: WHITEHORSE	ENERGY SOLUTIONS CENTRE	Project No: 21928
File Name: 21928-D1_2.WOR		Date Issued: JAN. 2002
Gartner Lee Limited	VANIER CATHOLIC SECONDARY SCHOOL GROUND SOURCE HEAT PUMP PROJECT	
Scale: 1: 3,000	**Site Layout**	**Figure 2**

The school itself is one-story, 5,600 m^2 (60,344 ft^2) building which was originally built in 1970. Currently the school is heated by a series of oil-fired boilers and hot water circulation system. The school is serviced with electricity, telephone, and municipal sewer and water service. The nearest storm sewer is located approximately 250 m away near the intersection of Alsek and Blanchard Road and drains to the Yukon River (Figure 2).

Underground utility maps provided by the City of Whitehorse show that the school's water main approaches the school from the north (Figure 2). The location of the sanitary sewer connection is currently unknown.

It is assumed the subject property is titled to the Government of Yukon through the Whitehorse Block Land Transfer. Land disposition should be confirmed prior to initiating of the proposed on-site work.

The City of Whitehorse's Selkirk Well Field is located approximately 600 m north of the school. The Selkirk Well Field is used by the City during winter months to supplement the municipal water supply. The groundwater is used as a source of warm water that is mixed with colder surface water to help prevent the City's water distribution system from freezing. The well field supplies water from a series of four wells that are completed in an unconfined, sand and gravel aquifer. The wells range in depth from 12.7 m to 26.5 m. A calibrated numerical groundwater model was developed by Gartner Lee Limited in 1997 and suggests the well Selkirk Well field is capable of producing up to 190 L/s (2500 igpm) before cold water from the Yukon River is drawn into the system (Gartner Lee Limited, 1998).

The Whitehorse Rapids Fish Hatchery has a deep well adjacent to the Selkirk Well Field, which supplies "warm" groundwater to their operation. Their well is approximately 60 m deep and the hatchery reports pumping rates between 1999 and 2000 in the range of 2.5 to 13 L/s (33 to 171 igpm).

2.1 Building Energy Requirements

A building heat load analysis, based on the as-built drawings for Vanier school has been conducted by DFK Engineering of Calgary, Alberta. This analysis determined the following heat energy requirements

Peak block heating load	= 1,941,579 Btu/h
Peak block ventilation heating load	= 2,029,600 Btu/h

For the purposes of this project, only 50% of the heating load will be addressed, excluding the ventilation heating load. The rational for selecting 50% of the block heating load is that this value represents 70% of the annual heating energy requirements, which can potentially be satisfied by the proposed GSHP system (Flynn, pers. comm., 2001). Therefore, the design-heating load for this project is approximately 970,790 Btu/h.

2.2 Geology

Site stratigraphy is interpreted from surficial geology mapping (Mougeot GeoAnalysis and Agriculture and Agri-Food Canada, 1997) and groundwater exploration drilling conducted for the City of Whitehorse in 1978, 1979 and 1997 (Stanley Associates 1978 and 1980, and Gartner Lee Limited 1998). A generalized cross-section illustrating interpreted site stratigraphy is presented in Figure 3. The cross-section (shown in plan view in Figure 1) runs from north to south.

Based on the information collected from previous studies, the site is underlain by sands and gravel, likely of glaciofluvial outwash origin, deposited during the retreat of the last glaciation, approximately 10,000 years ago. In the Riverdale area, this unconsolidated material ranges in thickness from 40 m in the south to 50 m or more in the north.

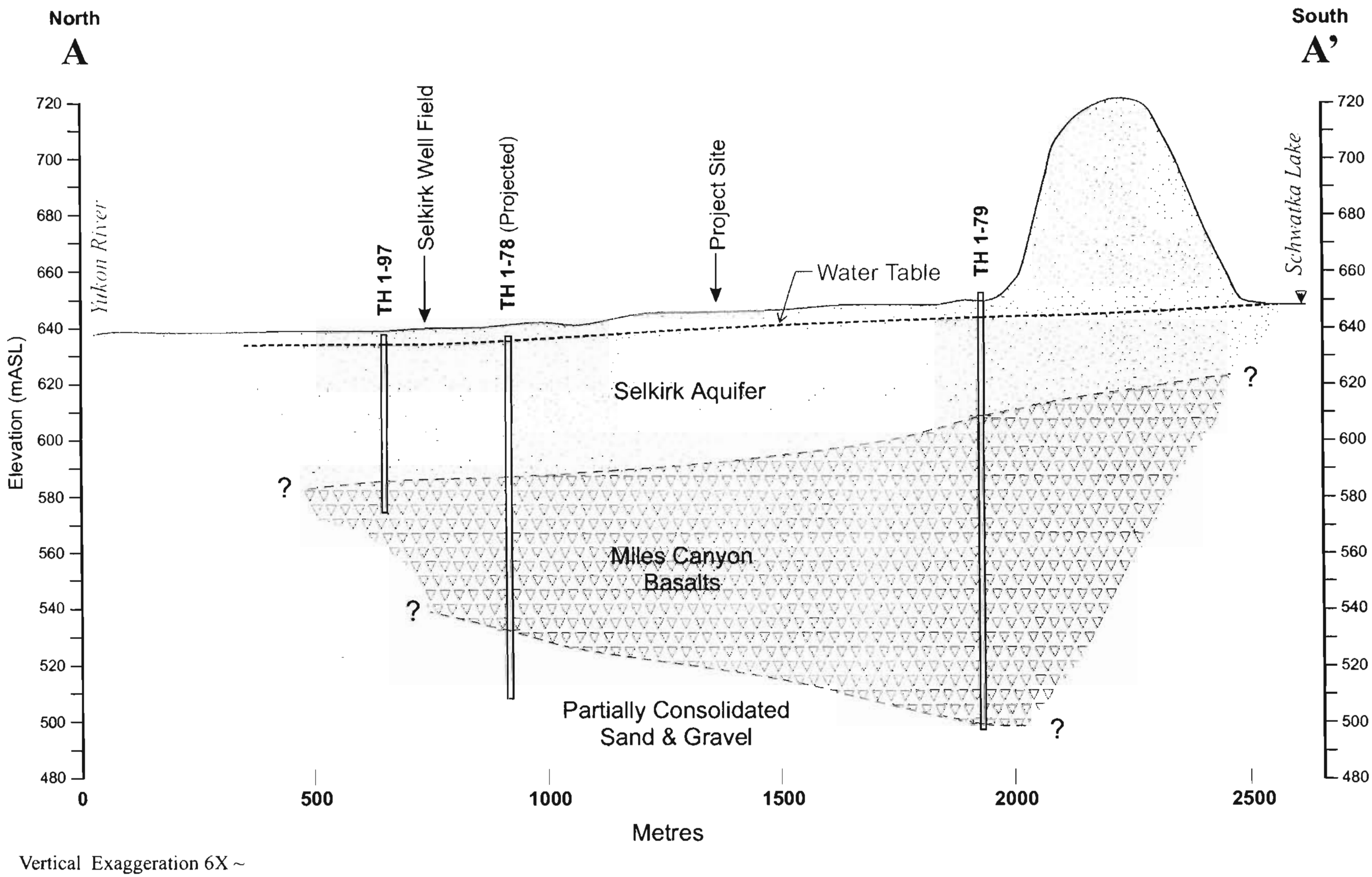
Underlying the sand and gravel are the Miles Canyon Basalts. These basalts are dominated by columnar-jointed, variably vesicular and amydaloidal flows and scoria, suggesting significant primary and high relative secondary porosity. This unit is thought to have a relatively lower hydraulic conductivity and the overlying soils. Individual flows are up to 20 m thick, but are thinner, down to 1 m , below the location of the hydro dam (Figure 1) (Pearson et al. 2001). In the Riverdale area the thickness of the basalts vary from 110m in the south to 40m in the north. The basalts outcrop to surface at the Whitehorse Rapids, however, within the Selkirk Well Field area, they are found approximately 50 to 60 m below ground surface.

Only two boreholes have penetrated the basalt flows in the Whitehorse area, these holes were completed for the City of Whitehorse in 1978 and 1979. The material underlying the basalt was described in TH 1-78 as "Sand and gravel, cemented, (mainly granodiorite); gravel, large number of rounded chert pebbles" while the second location, TH 1-79, is described simply a "sand" (Stanley Associates, 1978 and 1980). This material is interpreted to be either variably consolidated gravels probably of Neogene age or conglomerates of the Laberge Group.

2.3 Hydrogeology

Groundwater moves from the Hidden Lake and Schwatka Lake area, north and westward, under Riverdale, and discharges to the Yukon River. Groundwater gradients are approximately 0.008 and modelling suggest a ten year travel time from Hidden Lakes to the Selkirk Well Field.

Numerous pump tests have been conducted on the Selkirk Aquifer at the City's well field. These tests suggest aquifer transmissivities ranging from 115 m^2/day to 2,130 m^2/day (Gartner Lee Limited, 1998 and 2000). Using an aquifer thickness of 50 m, this results in a hydraulic conductivity ranging from 3×10^{-5} m/s to 5×10^{-4} m/s, consistent with published values for a sand and gravel aquifer (Freeze and Cherry, 1979). Aquifer specific yield is estimated at 0.1.



Vertical Exaggeration 6X ~

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GENERALIZED CROSS SECTION A-A'

Vanier Catholic Secondary School
Ground Source Heat Pump Project for Energy Solutions Centre

FIGURE
3

Project 21-928
(2001\928\X-Section.cdr)

No pump tests on wells completed in the Miles Canyon Basalts have been conducted in the Riverdale area, although a number of tests have been conducted within this unit elsewhere in the City of Whitehorse. These pump tests suggest a hydraulic conductivity range of 5.1×10^{-6} to 9.3×10^{-7} m/s with a median value of 1.7×10^{-6} m/s (Pearson et al. 2001). Aquifer storativity is assumed to be 2×10^{-4}.

No hydraulic testing of the underlying cemented gravel was conducted. Therefore, no hydraulic parameters for this unit are currently known.

Water level data collected while drilling a deep exploration hole in 1978 indicated an upward gradient between the shallow and deeper portion of the Selkirk Aquifer.

2.3.1 Groundwater Temperatures

The City of Whitehorse reports that during winter operations, their well field produces groundwater at 4°C. The City's wells are relatively shallow, ranging in depth from 12 to 25 m. The Whitehorse Rapids fish hatchery reports that their 60m deep well consistently produced groundwater at 5.5 ° C. Table 1 below summarizes ground temperatures measured by Stanley Associates in their deep drilling program:

Table 1. Reported Groundwater Temperatures*

Formation	TH 1-78 (Selkirk Well Field)	TH 1-79 (South of Firth Rd.)
Deep Selkirk Aquifer	6.0° C @ 63 m b.g.s.	5.5° C @ 39 m b.g.s.
Miles Canyon Basalt	8.8° C @ 91 m b.g.s.	8.9° C @ 99 m b.g.s.
Underlying Cemented Sand & Gravel	10.0° C @ 125 m b.g.s.	9.4° C @ 155 m b.g.s.

Notes: ** From Stanley Associates, 1978 and 1980.*

2.3.2 Groundwater Quality

Generally, groundwater quality from the Selkirk Aquifer is very good. Groundwater samples collected from the City's well field consistently meet all of the Canadian Drinking Water Quality Guidelines, however, the water hardness is classified as "Hard" (Driscoll 1986). No reliable groundwater samples have been collected from wells completed within the Miles Canyon Basalt from within the Riverdale area. However, for comparison, data has been collected from other wells outside the study area which are believed to be representative of the Miles Canyon formation water and are subsequently summarized in Table 2:

Table 2. ater Quality from Selkirk Aquifer and Miles Canyon Basalts.

Parameter	Selkirk Aquifer*	Miles Canyon Basalts**
PH	8.3	8.3
Hardness	131 mg/L $CaCO_3$ (Hard)	115 mg/L $CaCO_3$ (Hard)
Total Dissolved Solids	145 mg/L	158 mg/L
Alkalinity	116 mg/L $CaCO_3$	120 mg/L $CaCO_3$
Cl	1.25 mg/L	2.2 mg/L
SO_4	30 mg/L	24 mg/L
Ca	24 mg/L	30 mg/L
Fe	<0.03 mg/L	0.12 mg/L
Mn	0.001 mg/L	0.033 mg/L
Ryzner Index	8.12 (corrosive)	7.94 (corrosive)

Note: * *Average value of samples collected from wells WW1 and WW4, collected September, 1999 (Gartner Lee Limited 2000).*
** *Average value of two samples collected from domestic wells completed in Miles Canyon Basalt in the Wolf Creek Subdivision area, August, 2001 (Gartner Lee Limited 2001).*

Based on the data provided above, water quality from both aquifers appears similar and is considered very good, however, slightly "hard". Additionally, the water quality data suggests that the groundwater is not encrusting but slightly corrosive. Rehabilitation of wells in the Selkirk Well Field in 1997 and 1999 showed very little to no encrustation of the City's production wells (Gartner Lee Limited 1998 and 2000).

2.4 Ground Thermal Properties

Design of a Ground Coupled Heat Pump (GCHP) is particularly sensitive to the thermal properties of the ground. Specifically, the thermal conductivity (k), and thermal diffusivity (α), of the soil. Thermal conductivity is the rate of heat transfer, by conduction, through a unit thickness, across a unit area for a single unit difference in temperature. Estimates of these thermal properties for the geologic units underlying the project site are presented in Table 3 below:

Table 3. Estimates of Ground Thermal Properties for Riverdale Area

Geologic Unit	Thermal Conductivity, k (Btu/h °F ft)	Thermal Diffusivity, α (ft^2/day)
Saturated Sand & Gravel (assume dry density 1.7 tonne/m^3 (105 lb/ft^3), and moisture content = 27%)	1.31*	0.78*
Basalt	1.2-1.4** (assume 1.3)	0.7 – 0.9** (assume 0.8)

Note: * *Calculated using method developed by Kersten, Appendix D in Kavanaugh and Rafferty, 1997.*
** *From Kavanaugh and Rafferty, 1997.*

3. Conceptual Design of Ground Coupled Heat Pump

3.1 Conceptual Design

The conceptual design of a ground coupled heat pump (GWHP) consists of the follows and is illustrated on Figure 4:

1. An array of boreholes fitted with closed loop U-Bend tubing; and
2. a series of heat pumps to extract heat from the groundwater to the school heating loop.

Given the northern latitude of the study area, it is assumed that the school's heating load will dictate the sizing of the system. Furthermore, it should be noted that the system will be designed for 50% of the peak block heating load. This design assumption is reported to account for 90% of the buildings annual heating energy requirements (Flynn, pers. comm., 2001).

3.2 Heat Pump System Parameters

System sizing is controlled by the total length of borehole required to extract adequate heat from the ground. Calculation of the length of borehole required for the GCHP system based on the following heating length relationship:

$$L_h = (q_a R_{ga} + (g_{lh} - 3.41 W_h')(R_b + PLF_m R_{gm} + R_{gd} F_{sc}) / (t_g + ((t_{wi} + t_{wo})/2) - t_p)$$

(Kavanaugh and Rafferty 1997)

Table 4 provides a description of the variables and values used in the above equation.

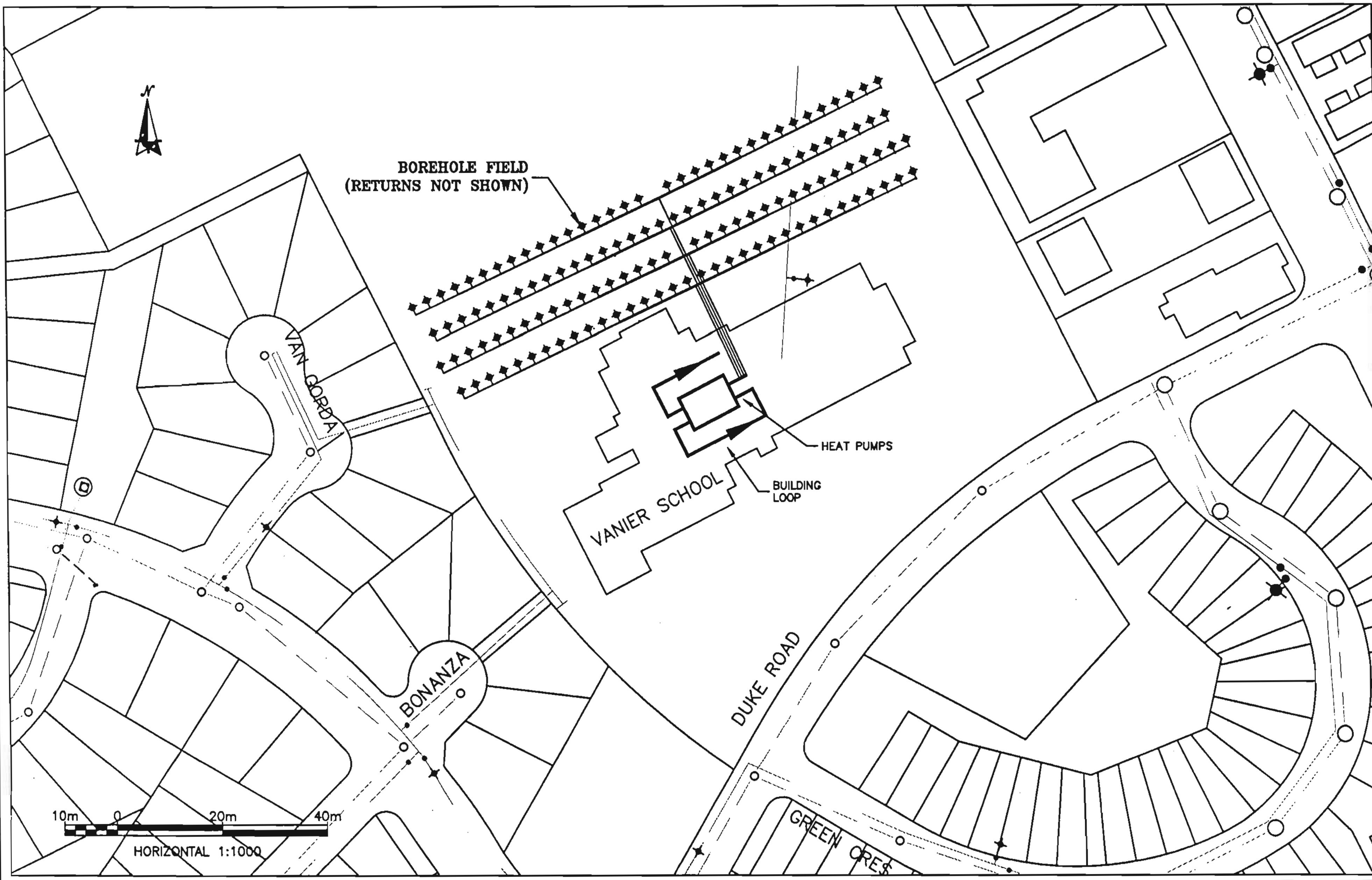
For the purposes of estimating borehole length, the following assumptions have been made:

a) U-bend tubes will be 1.5-inches in diameter and be installed within a 6-inch diameter borehole;

b) boreholes will be backfilled with a thermal grout material (k = 2.0 Btu/h ft °F);

c) the flow rate through individual loops should be approximately 3 gpm and consist of a methanol solution; and

d) heat pumps will consist of 3 Versatec VL360 heat pumps (DFK Engineering 2001).



Site Name:	RIVERDALE
File Name:	21928-F4.DWG

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VANIER CATHOLIC SECONDARY SCHOOL
GROUND SOURCE HEAT PUMP PROJECT

GROUND COUPLED HEAT PUMP CONCEPTUAL LAYOUT

Project No.	21-928
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Figure 4

Table 4. Ground Coupled Heat Pump Sizing Parameters

Parameter	Description	Value
q_a	Net annual average heat transfer to the ground (Btu/h)	5,500,000 MBT/yr x 70% = 439,200 Btu/h
R_{ga}	Effective thermal resistance of the ground, annual pulse (assuming ground thermal conductivity of 1.3 Btu/h ft °F and thermal diffusivity, α, of 0.8)	0.15 h ft °F F/Btu
g_{lh}	Building design heating block load (Btu/h)	1,941,579 Btu/h x 50% =970,789 Btu/h
Wh'	Power input at design heating load (W) (assuming 100% daily Partial Load Factor, PLF_d on design day and 3 Versatec VL360 heat pumps)	3 x 29.43 W x 100% = 88.3 W
Rb	Thermal resistance of bore (h ft °F/Btu) (assuming 0.16 bore resistance and -0.02 grout resistance)	0.14 h ft °F/Btu
PLF_m	Partial Load Factor during design month	Assume 70%
R_{gm}	Effective thermal resistance of the ground, monthly pulse (assuming ground thermal conductivity of 1.3 Btu/h ft °F and thermal diffusivity, α, of 0.8)	0.31 h ft °F/Btu
R_{gd}	Effective thermal resistance of the ground, daily pulse (assuming ground thermal conductivity of 1.3 Btu/h ft °F and thermal diffusivity, α, of 0.8)	0.2 h ft °F/Btu
F_{sc}	Short-circuit heat loss factor (one bore per parallel loop)	1.04
t_g	Undisturbed ground temperature (°F)	40.5 °F
t_{wi}	Liquid temperature at heat pump inlet (°F)	30 °F
t_{wo}	Liquid temperature at heat pump outlet (°F) (based on Versatec VL360 heat pumps)	26.7 °F
t_p	Temperature penalty for interference of adjacent bores (°F)	Assume 1 °F for high rates of groundwater movement
L_h	Required bore length for heating (ft)	**39,700 ft**

Based on the above required borehole length, it is proposed that the system would be laid out as four rows of 33 boreholes, each being 300 ft. deep. Minimum separation between adjacent boreholes should be 20 ft (6 m). It is recommended that the orientation of the borehole field be relatively perpendicular to the groundwater flow direction. Subsequently, this equates to a northeast-southwesterly orientation as illustrated on Figure 4. This configuration will provide maximum exposure to the groundwater flow field and will provide the best means to help reduce a build-up of cooled earth/groundwater within the borehole field.

3.2.1 Verification

A sizing estimate presented in *Commercial/Institutional Ground-Source Heat Pump Engineering Manual* (Caneta Research Inc. 1995) has been used to verify the estimated required drilling length. Caneta Research Inc. propose that the required borehole length for a GCHP system can be approximated by:

Borehole length = (343 x Energy Extracted/(T_{mean}-T_{min})) / 2

Where:

Energy extracted	Energy extracted from the loop per year (Million Btu) = 5,500,000 MBH x 50% = 2,750 Million Btu
T_{mean}	Mean annual ground temperature (°F) = 40.5 °F
T_{min}	Minimum entering liquid temperature (°F) =30 °F

Therefore, based on the above assumptions, the required borehole length would be approximately 45,000ft. Although the above methodology provided by Caneta Research Inc. does use a broad set of assumptions, it appears that conditions at the Vanier School site are similar enough to those used by Caneta Research Inc. and does confirm the general size of the proposed undertaking. Again, both methods are sized such that they provide 50% of the peak heating load.

3.3 Estimated System Costs

A construction cost estimated has been prepared for the proposed ground coupled heat pump (GCHP) system based on the conceptual design information presented. Details regarding the cost estimate of the Ground Coupled Heat Pump system are presented in Appendix A. These estimates are made based on the following information and considerations:

a) The most significant costs associated with this method include the completion of the boreholes and installation of the U-bend tubes. Local drillers in the Yukon suggest that drilling costs alone could be $40/ft or higher. However, there is potential that experienced drilling/contractors from out of the Territory could drill, install and backfill ground coupled heat loop boreholes for approximately $12/ft. Notably, in Alberta, it is reported that costs for completing these type of boreholes and installations can be as low as $6/ft (DFK Engineering, pers. comm. 2001).

b) Heat pump acquisition and installation costs have been provided by DFK Engineering Ltd.

c) The cost for installation and burial of the insulated distribution piping is an "order-of-magnitude" cost estimate only and is subject to variation upon detailed design and quotation. It is assumed all piping would need to be installed 2 to 3 m (6 to 9 ft) below ground surface to reduce/prevent susceptibly to frost penetration and freezing.

d) It is assumed that a suitable power supply (e.g., three-phase power) is available on-site.

e) It is also assumed that adequate space exists within the school's current mechanical room to house the proposed heat pumps and associated equipment.

f) A 15% Engineering and Supervision allowance and a 20% Contingency allowance have been added to all estimates.

Based on the above assumptions, Ground Coupled Heat Pump System construction costs have been estimated as follows:

With drilling and installation at $6/ft	= $960,000
With drilling and installation at $12/ft	= $1,280,000
With drilling and installation at $40/ft	= $2,770,000

It is assumed that $12/ft for drilling and installation of U-bend tubing maybe a reasonable value for comparison purposes with other alternatives.

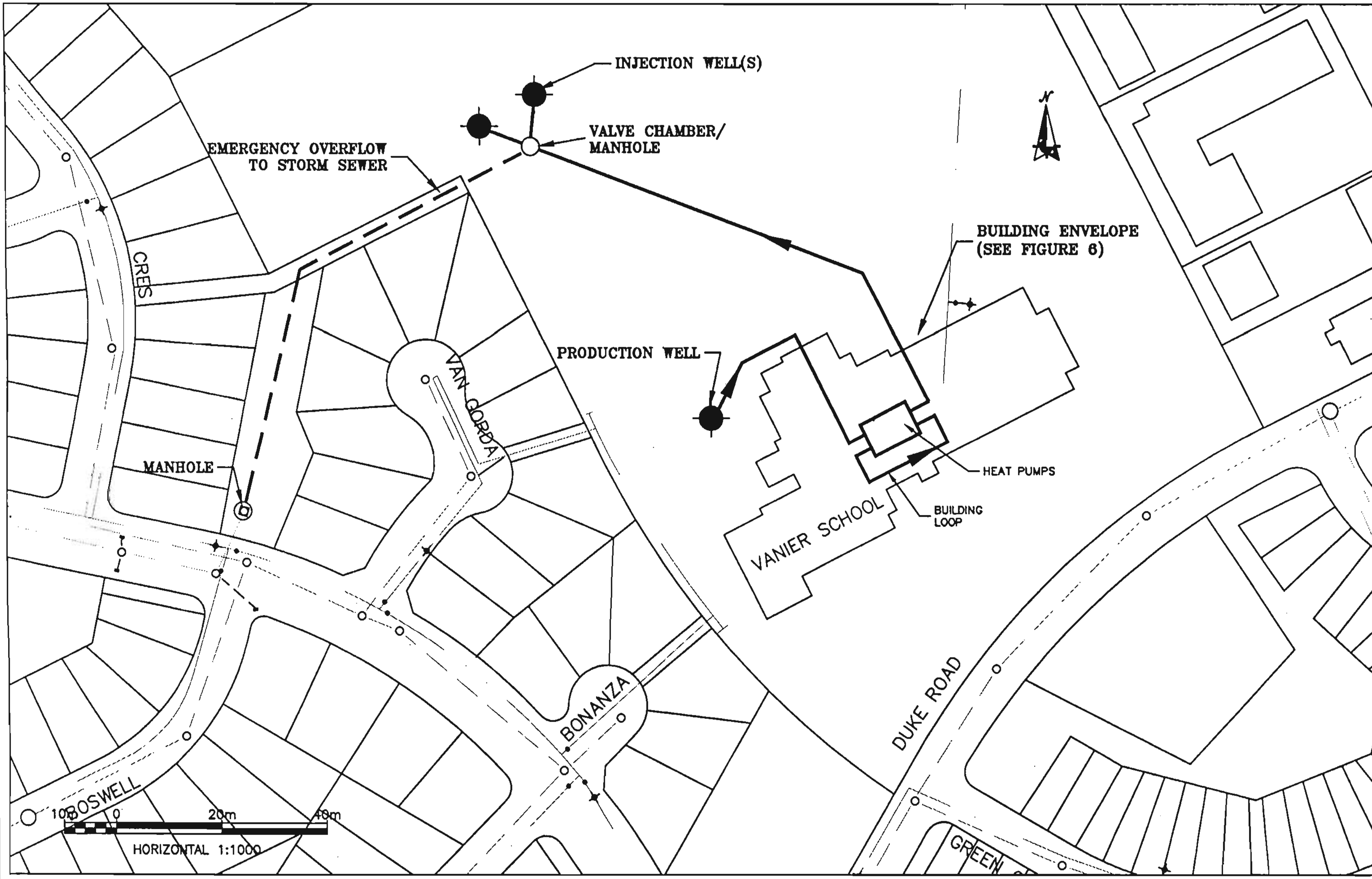
4. Conceptual Design of Groundwater Heat Pump

4.1 Conceptual Design

The conceptual design of a Groundwater Heat Pump (GWHP) consists of the follows and is illustrated in Figures 5 and 6:

1. A production well fitted with a variable speed pump which is controlled by building heating demands, developed to pump groundwater from one of two potential sources:
   a) the deep portion of the Selkirk Aquifer (@5.5° C); or from
   b) the Miles Canyon Basalt (@8.8° C).
2. to provide additional isolation/security in case of catastrophic heat pump failure a plate exchanger is recommended between the groundwater loop and the heat pumps for the Selkirk Aquifer option. This will provide additional isolation and security to the aquifer in case of a catastrophic heat pump failure, although results in a minor system inefficiency.
3. A set of three heat pumps to extract heat from the groundwater and deliver this energy to the school's heating loop.
   a) for the Selkirk Aquifer Option, the pumps are run in two parallel circuits; one circuit with two heat pumps in series and a second circuit with a single heat pump (see Figure 6); and
   b) for the Miles Canyon Basalt Option, the three pumps are run in series, each heat pump receiving the outlet source water from the previous unit.
4. One or two injection wells to return cooled groundwater back into the aquifer.
5. An emergency overflow for cooled groundwater to discharge to the storm sewer in the event there is a failure in operation of the injection well(s).

As mentioned previously, it is assumed that the school's heating load will dictate the sizing of the system. Furthermore, it should be noted that the system will be designed for 50% of the peak block heating load.



Site Name:	RIVERDALE
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VANIER CATHOLIC SECONDARY SCHOOL
GROUND SOURCE HEAT PUMP PROJECT

GROUNDWATER HEAT PUMP CONCEPTUAL LAYOUT

Project No.	21-928
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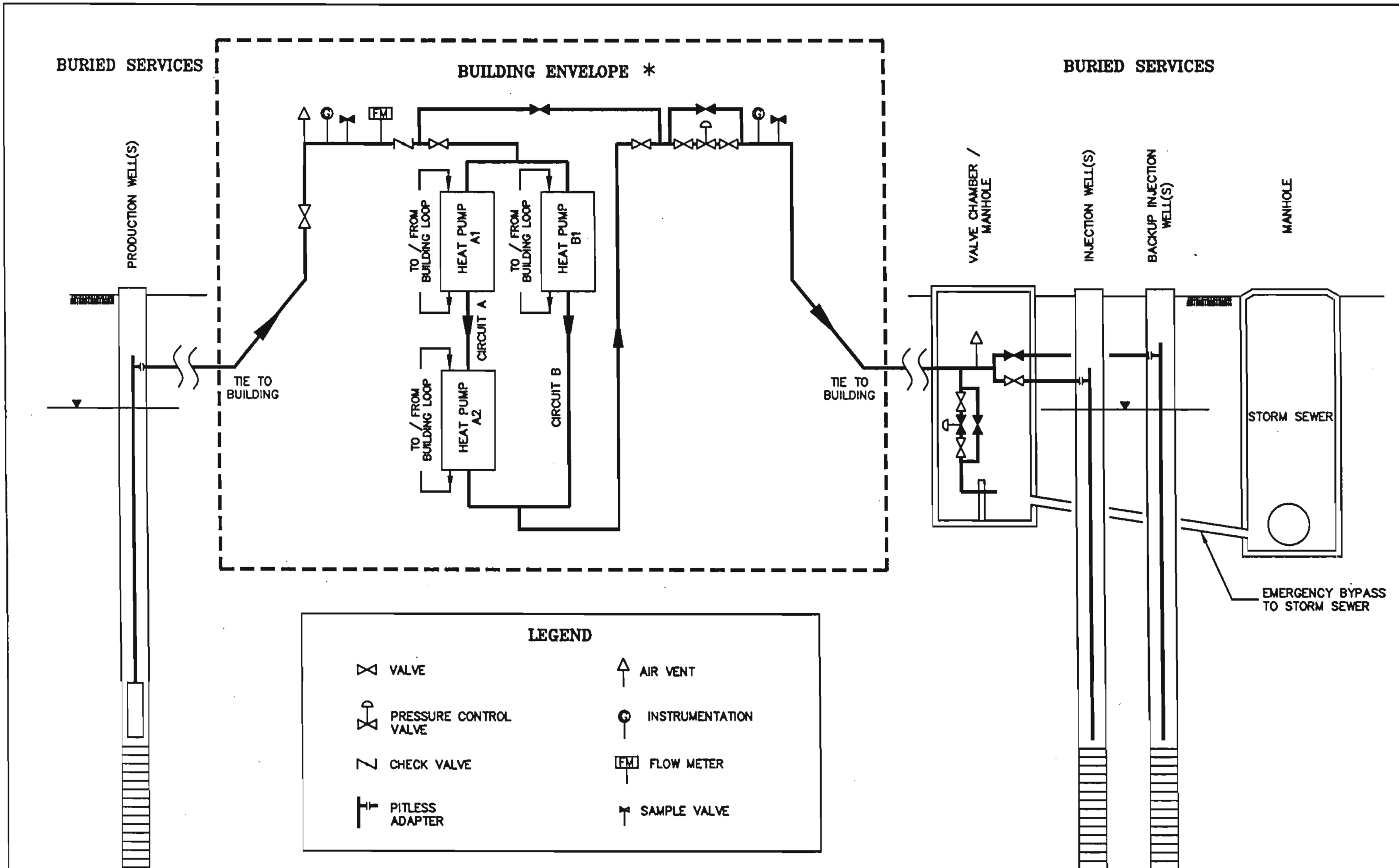
Figure 5



* NOTE: PLATE EXCHANGER IS RECOMMENDED FOR SELKIRK AQUIFER OPTION, BUT NOT SHOWN IN THIS DIAGRAM.

Site Name:	RIVERDALE
File Name:	21928-F6.DWG

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ENERGY SOLUTION CENTRE

VANIER CATHOLIC SECONDARY SCHOOL
GROUND SOURCE HEAT PUMP PROJECT

GWHP CONCEPTUAL LINE DIAGRAM

Project No.	21-928
Date Issued:	JAN. 2002

Figure 6

4.2 Heat Pump System Parameters

Design of groundwater flow requirements are based on the following heating relationships presented by Kavanaugh and Rafferty (1997):

$$gpm_{gw} = (q_h / 500 \text{ x } (t_{gwi} - t_{gwo})) \text{ x } (COP - 1 / COP)$$

Where:

gpm_{gw}	= required groundwater flow rate for heating, in U.S. gallons / minute.
q_h	= peak building heating requirement in Btu/h (for this project, 50% of peak requirement)
t_{gwi}	= groundwater temperature entering heat pump (°F)
t_{gwo}	= groundwater temperature leaving heat pump (°F)
CO	= heat pump coefficient of performance.

Both of the variables t_{gwo} and COP are dictated by the manufacture of the selected heat pump. For the purposes of this preliminary assessment, it is assumed that the heat pumps will consist of three Versatec VL360 heat pumps operating at 90gpm. (DFK Engineering 2001). It is also assumed there is 1°F approach temperature loss associated with the plate exchanger proposed for the Selkirk Aquifer option.

Table 5. Summary of Groundwater Heat Pump Parameters

Source	Heat Pump Stage	q_h (Btu/h)	t_{gwi} (°F)	t_{gwo} (°F)	Plate Exchanger Approach (°F)	COP	gpm_{gw} (USgpm)
Selkirk Aquifer	Heat Pump A1	307,300	41.9	36.5	1	2.8	90
	Heat Pump A2	282,000	36.5	32.6	N/a	2.6	90 (from heat pump A1)
	Heat Pump B1	307,300	41.9	36.5	1	2.8	90
	Total System	*896,000*	*41.9*	*34.5*	*1*	-	*180*
Miles Canyon Basalt	Heat Pump A1	345,200	47.8	42.7	n/a	3.03	90
	Heat Pump A2	315,000	42.7	38.1	n/a	3.0	90 (from heat pump A1)
	Heat Pump A3	329,000	38.1	34.0	n/a	2.3	90 (from heat pump A2)
	Total System	*989,400*	*47.8*	*34.0*	*n/a*	-	*90*

Note that for the Selkirk Aquifer option, the leaving water temperature from the second heat pump in series (unit A2) is very cold and near freezing (32.6 °F). However, this water would be mixed with water leaving the B1 unit at 36.5 °F, producing a total system leaving temperature of 34.5 °F. Therefore, if the Selkirk Aquifer option is selected, testing and refinement of the system design and operation will be required to prevent freezing of the injection well during peak system operation.

4.3 Production Well

As discussed earlier, there are two possible groundwater supply sources within the study area; the cooler, sand and gravel Selkirk Aquifer (~5. 5°C) and the warmer, deeper Miles Canyon Basalt Aquifer (~8.8°C). Both of these supply sources have been investigated as part of this project. A summary of interpreted possible well yields and corresponding flow requirements for heating are presented in Table 6. It is assumed that the production wells will fully penetrate the aquifer.

Table 6. Estimated Groundwater Production Well Yields and Heating Flow Requirements

Parameter	Selkirk Aquifer (@5.5 °C)	Miles Canyon Basalt (@8.8 °C)
Estimated total well depth	50 m	125 m
Estimated Safe Available Drawdown (70% of total well depth)	31 m	84 m
Peak Hour Well Yield (1 hr)	> 75 L/s (>1000 US gpm) *	7.6 L/s (120 US gpm) **
Peak Day Well Yield (12 hr)	75 L/s (1000 US gpm) *	6.3 L/s (100 US gpm)**
Groundwater Flow Requirement (See Table 5, Section 4.2)	11.3 L/s (180 US gpm)	5.7 L/s (90 US gpm)

Note: * *Estimated from Theis Solution (Wexler, 2000), using T=200m2/day, S=0.1*

** *Estimated from Hantush (Leaky) Solution (Wexler, 2000), using T=11m2/day, S=0.00025, confining unit, K=0.147 m/d, confining unit thickness = 37.5 m.*

Based on the above estimates of well yields, both aquifers should be able to provide adequate yield from a single production well. However, hydraulic pump testing of the target aquifer is required to confirm the above assumed performance characteristics.

A preliminary assessment of potential change in water chemistry related to cooling of the injection water was conducted. Water quality data in presented in Table 2 (section 2.3.2) was input into a geochmical model called *Visual MINTEQ* (Gustafsson 2001) assuming an injection water temperature of 1 °C. The results of this geochemical modelling suggests that, based on the current data, no significant precipitation of ions are anticipated to be associated with cooling in the groundwater, which could result in fouling of the injection well.

4.4 Injection Well Requirements

It is proposed that chilled groundwater water leaving the heat pump will be returned to its source aquifer via an injection well. The use of an injection well as opposed to surface water disposal is proposed for the following reasons:

1. elimination of long-term water table drawdown caused by production well;

2. elimination of potential interference with the City of Whitehorse's water supply demands on the Selkirk Aquifer;
3. interpreted to be more environmentally sustainable; and
4. possible simplification of water licensing procedures (e.g., no disposal to surface water bodies).

It will be important for the injection well to return chill groundwater to the same aquifer from which it was extracted in order to prevent anthropogenic cross-contamination between the upper and lower aquifers. Therefore, a positive injection pressure will likely be required to return the cooled groundwater to the formation. Furthermore, the injection well must be located at a suitable distance down-gradient in order to prevent introducing a cold thermal plume to the production well. Table 7 provides a summary of the calculated injection pressures and the recommended extraction/injection well separation distances for the both of the considered aquifers. It is assumed the static water level is 4 m below ground surface.

Table 7. Injection Well Parameters

Parameter	Selkirk Aquifer (@5.5° C)	Miles Canyon Basalt (@8.8° C)
Estimated total injection well depth	50 m	125 m
Anticipated draw down in production well	7 m	61 m
Injection Well Pressure Requirement	3 m (4 psi)	57 m (77 psi)
Ideal Well Separation*	95 m	72 m

*Notes: * From Kazmann and Whitehead's estimates of well separation, presented in Driscoll, 1986.*

It is assumed that injection well pressures will be provided by the production well pump. The recommended working pressure for the selected heat pumps are 80 to 100 psi with a maximum pressure of 150 psi (DFK Engineering, pers. comm. 2001).

4.5 Estimated System Costs

Cost estimates of both groundwater heat pump systems have been produced using the conceptual design information presented above. Details of the estimate for the Groundwater Heat Pump system utilizing the Selkirk Aquifer or the Basalt Aquifer are presented in Appendix A. These estimates are made based on the following information and assumptions:

a) drilling costs are based on quotations by Midnight Sun Drilling Company Ltd. of Whitehorse, Yukon for drilling of a 6" diameter well(s);

b) well pump costs are based on estimates provided by Aqua Tech Service & Supplies of Whitehorse, Yukon;

c) heat pump acquisition and installation costs have been provided by DFK Engineering Ltd.;

d) it is assumed that pitless adapters will be used for both the production and injection wells and therefore well pump house(s) will not be required;

e) the cost for installation and burial of the insulated distribution piping is an order-of-magnitude estimate only and is subject to variation upon detailed design and quotation. It is assumed all piping will be installed 2 to 3 m (6 to 9 ft) below ground surface to reduce/prevent frost penetration or freezing;

f) provisions for an emergency bypass to the City's storm sewer is subject to City approval and potentially the Water License approval;

g) initially, it is assumed that only one injection well will be required, but due to an anticipated reduction in well efficiency related to injection, allowance for a second, back-up injection well has been made;

h) operation and maintenance costs have not been included, but will likely consist of electrical power for well pump(s), water quality, quantity and temperature monitoring of both supply and injection water, as well as the periodic rehabilitation of the injection well(s);

i) it is assumed that a suitable power supply (e.g., three-phase power) is available on-site;

j) it is also assumed that adequate space exists within the schools mechanical room to house the proposed heat pumps and associated equipment; and

k) a 15% Engineering and Supervision allowance and a 20% Contingency allowance has been added to all estimates.

Based on the above assumptions, system construction costs have been estimated as follows:

a) **Selkirk Aquifer** groundwater heat pump (approx. 180 US gpm) = $560,000

b) **Miles Canyon Basalt Aquifer** groundwater heat pump (approx. 90 US gpm) = $556,000

5. Options Assessment and Recommendations

5.1 Options Assessment Matrix

Based on the three options presented above, the following Options Assessment Matrix has been prepared to compare and select the recommended Ground Source Heat Pump technology for the Vanier School facility. Table 8 provides a brief description of each option, the main advantages and disadvantages and provides an "order-of-magnitude" construction cost estimate. A breakdown of the construction cost estimates for each option is presented in Appendix A.

Table 8. Ground Source Heat Pump Options Assessment Matrix

System	Description	Pros	Cons	Estimated Construction Costs [1]
Groundwater Heat Pump (GWHP)—Selkirk Aquifer	• 50m production well producing up to 250 gpm from sand & gravel unconfined Selkirk Aquifer • Three 30 Ton Heat Pumps (two in series, one in parallel), with plate exchanger. • Injection well(s) for return of cooled water to Selkirk Aquifer • Emergency bypass to storm sewer.	• Shallow drilling depths • Single well could be upgraded to produce increased flows. • Relatively simple design and construction—currently available technology in the Yukon.	• Perception of potential impacts to Selkirk Aquifer and potential for resistance from City of Whitehorse • Water Licence required and City approval for hook-up to storm sewer • Plate heat exchanger recommended to provide additional separation between heat pumps and groundwater • Single well failure could cause system downtime	$560,000
Groundwater Heat Pump (GWHP)—Basalt Aquifer	• One to two 125 m deep production well(s) producing up to 180 gpm from Miles Canyon Basalt Aquifer • Three 30 Ton Heat Pumps operating at 90gpm (three in series) • 2 injection wells for return of cooled water to Basalt Aquifer • Emergency bypass to storm sewer.	• Relatively simple design and construction—currently available technology in the Yukon. • Development of lower aquifer and potential for increased acceptability to City of Whitehorse (reduced interaction with Selkirk Aquifer) • Lower pumping rates and power demand (potentially lower operations costs)	• Deeper drilling and pumping depth • Increased potential difficulties associated with injection into basalt • Deep production and injection depths require higher pressures and moderately increased complexity. • Water Licence required and City approval for hook-up to storm sewer • Single well failure could cause system downtime	$556,000
Ground Coupled Heat Pump (GCHP)	• Array of 132, 91.5 m (300 ft.) boreholes with U-bend tubing • Three 30 Ton Heat Pumps operating at 90 gpm	• No extraction of water from aquifer, may be perceived as more sustainable. • Applicable in all environments, high yield aquifer not required. • Water Licence may not be required	• Most complex system • More uncertainty in sizing of ground loops. • Highest cost option due to significant drilling. • No existing experienced contractors in Yukon.	≥ $1,280,000 [2]

Note: 1. Details and assumptions of cost estimates are presented in Appendix A. It is noted that no allowance has been made for ongoing operations, maintenance and monitoring costs for any of these options.
2. Assuming drilling & installation costs of $12/ft.

5.2 Recommendations

Based on the options assessment matrix presented in Table 8, it is recommended that:

1. a Groundwater Heat Pump system utilizing the Miles Canyon Basalt Aquifer be selected as the preferred option. This option is recommended due to the following reasons (in order of significance):
   a) reduced potential conflict with the City's operation at the Selkirk Wellfield; and
   b) reduced operation costs associated with pumping (only 90 US gpm versus 180 US gpm for the Selkirk Aquifer Option);

2. dialog with the City of Whitehorse be initiate to gain the City's support of the proposed undertaking;

3. a 150 mm diameter (6 in.) test well be drilled to the base of the Miles Canyon Basalt aquifer adjacent to the Vanier School. This well is required to test the aquifer and the assumptions presented in the conceptual design prior to finalization of the GWHP design. Drilling and construction of the well should be conducted under the direction of a qualified hydrogeologist. At least one to two smaller diameter observation wells should be drilled adjacent to the test/production well to observe potential interaction with the overlying Selkirk Aquifer. Testing should include both step and longer-term constant rate pump tests to quantify well yield, and to evaluate the aquifer performance. Testing should also include continuous temperature and conductivity monitoring and synoptic water quality collection and analysis;

4. a Water Licence application under the Yukon Waters Act be prepared for the proposed development.

It may be required that the Energy Solutions Centre demonstrate that the proposed GWHP system at Vanier School will not significantly impact the City's operation of the Selkirk Well Field. As mentioned previously, a numerical groundwater model of the Selkirk Aquifer was developed for the City of Whitehorse (Gartner Lee Limited 1998) which encompasses the Vanier School area. This model could be used to evaluate the degree of impact, if any, on the Selkirk Well field.

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Appendices

Appendix A

Construction Cost Estimates

Appendix A1. Ground Coupled Heat Pump Conceptual Construction Cost Estimates

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132, 91m Deep Boreholes

Item	#	Units	Unit Cost	Total
Hydrogeological Assessment & Permitting	1	LS	$ 15,000	$ 15,000
Drilling & Installation of Tubing	39600	ft	$ 12	$ 475,200
Variable Speed Pump Controller*	1	LS	$ 10,000	$ 10,000
Assocaited Instrumentation	1	LS	$ 20,000	$ 20,000
Piping to buildings	900	m	$ 300	$ 270,000
Building Tie-in	1	LS	$ 6,000	$ 6,000
Heat Pumps	3	LS	$ 25,000	$ 75,000
Plumbing & Install of Heat Pumps	3	LS	$ 25,000	$ 75,000
Total				$ 946,200
Engineering & Construction Supervision (15%)				141,930
Contigency (20%)				189,240
GRAND TOTAL				**$ 1,277,370**
SAY				$ 1,280,000

Notes

** Assumed that suitable power is avaible on-site*

*** applicable taxes not included*

Gartner Lee

Appendix A2. Groundwater Heat Pump Conceptual Construction Cost Estimates

Selkirk Aquifer (50m production well)

Item	#	Units	Unit Cost	Total
Hydrogeological Assessment & Permitting	1	LS	$ 25,000	$ 25,000
Production & Injection Wells (Overburden)	3	LS	$ 15,514	$ 46,541
Production Pump (180 Usgpm)*	1	LS	$ 2,500	$ 2,500
Variable Speed Pump Controller	1	LS	$ 10,000	$ 10,000
Assocaited Instrumentation	1	LS	$ 20,000	$ 20,000
Riser & Pump Install	1	LS	$ 2,000	$ 2,000
Pitless Adapter (Installed)	3	LS	$ 12,000	$ 36,000
Piping to buildings	30	m	$ 400	$ 12,000
Building Tie-in	1	LS	$ 6,000	$ 6,000
Piping to injection well	130	m	$ 350	$ 45,500
Overflow Line to Storm Sewer	170	m	$ 250	$ 42,500
Manhole/Valve Chamber	2	LS	$ 6,000	$ 12,000
Plate Exchanger	1	LS	$ 5,000	$ 5,000
Heat Pumps	3	LS	$ 25,000	$ 75,000
Plumbing & Install of Heat Pumps	3	LS	$ 25,000	$ 75,000

Total	$ 415,041
Engineering & Construction Supervision (15%)	62,256
Contigency (20%)	83,008
GRAND TOTAL	**$ 560,305**
SAY	$ 560,000

Notes

** Assumed that suitable power is avaible on-site*

*** applicable taxes not included*

Appendix A3. Groundwater Heat Pump Conceptual Construction Cost Estimates

Gartner Lee

Miles Canyon Basalt Aquifer (125m production well)

Item	#	Units	Unit Cost	Total
Hydrogeological Assessment & Permitting	1	LS	$ 20,000	$ 20,000
Production & Injection Wells (Deep)	3	LS	$ 21,895	$ 65,684
Production Pump (90 gpm)*	1	LS	$ 2,500	$ 2,500
Variable Speed Pump Controller	1	LS	$ 10,000	$ 10,000
Associated Instruementation	1	LS	$ 20,000	$ 20,000
Riser & Pump Install	1	LS	$ 1,000	$ 1,000
Pitless Adapter	3	LS	$ 6,000	$ 18,000
Piping to buildings	30	m	$ 400	$ 12,000
Building Tie-in	1	LS	$ 6,000	$ 6,000
Piping to injection well	150	m	$ 350	$ 52,500
Overflow Line to Storm Sewer	170	m	$ 250	$ 42,500
Manhole/Valve Chamber	2	LS	$ 6,000	$ 12,000
Heat Pumps	3	LS	$ 25,000	$ 75,000
Plumbing & Install	3	LS	$ 25,000	$ 75,000
Total				$ 412,184
Engineering & Construction Supervision (15%)				61,828
Contigency (20%)				82,437
GRAND TOTAL				**$ 556,449**
SAY				$ 556,000

Notes

** Assumed that suitable power is avaible on-site*

*** applicable taxes not included*