Vanier School Ground Source Heat Pump Project - Hydrogeological Assessment

prepared for:
Energy Solution Center Inc.

prepared by:
Gartner Lee Limited

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February 5, 2003

Ron Gee, Technical Advisor
Energy Solutions Centre Inc.
206A Lowe St. - 1st Floor
Whitehorse, Yukon, Y1A 1W6

Dear Mr. Gee:

Re: 22-292 – Vanier School Ground Source Heat Pump Project - Hydrogeological Assessment

We are pleased to provide the Final Report on the above noted project. This assessment included testing and characterization of both the overburden and bedrock aquifers at the subject site for the potential use as a groundwater source in Ground Source Heat Pump System.

Thank you for allowing Gartner Lee Limited this opportunity to work with you on this exciting and promising sustainable energy technology for the North.

We look forward to receiving your comments once you have had an opportunity to review this report. If you have any questions or comments please do not hesitate to call me at (867) 633-6474, extension 27.

Yours very truly,
GARTNER LEE LIMITED

Jonathan Kerr, M.Sc.
Hydrogeologist

JK:jk

Executive Summary

Gartner Lee Limited (GLL) on behalf of the Energy Solution Centre Inc. has completed hydrogeological services associated with the construction and testing of a test well, which for the purposes of this report has been formally identified as TH02-01. The study area is located within the subdivision of Riverdale, located within the City of Whitehorse, Yukon (Figure 1).

The objective of this hydrogeological assessment was to assess if the aquifers underlying the study site. The goal was to identify a groundwater supply capable of producing approximately 12.9 L/s (204 USgpm). Additionally the study assessed groundwater quality (i.e. temperature, chemical composition) from each of the aquifers encountered to help predict heat pump performance and potential problems associated with heat pump operations.

The project scope of work included:

1. Drilling of an auger borehole for an observation well (not completed).

2. Construction of a 150 mm diameter test well including:
   - Setting of temporary well screen in overburden aquifer.
   - Short term pumping test and groundwater quality assessment of the overburden aquifer.
   - Advancement of well through the basalt bedrock aquifer.
   - Pumping tests and groundwater quality assessment of bedrock aquifer.
   - Downhole geophysical survey of borehole.

3. Completion of assessment report.

Please note that the proceeding conclusions and recommendations are based on a design assumption of a heat pump system consisting of three 90 ton nominal capacity groundwater supplied heat pumps operating in parallel at 68 US gpm per unit (Waterfurnace 2002).

The principal conclusions of the project are summarized as follows:

1. The presence of two relatively warm water aquifers below Vanier School has been confirmed by the completion to test well TH02-01. These aquifer systems consist of:

   - The lower portion of the **Selkirk Aquifer**, composed of sand and gravel between depths of 54.9 m and 60.4 m below ground surface (5.5 m aquifer thickness at TH02-01).
   - **Miles Canyon Basalt Aquifer**, composed of fractured basalt bedrock between depths of 60.4 and 143.1 m below ground surface (82.7 m aquifer thickness at TH02-01).

2. The Selkirk Aquifer appears to have potential to meet the anticipated heat pump source water flow requirement of 12.9 L/s (204 USgpm). Furthermore, a properly sized well (i.e. 254 mm nominal

diameter) across the entire thickness of the Selkirk Aquifer at this location would likely produce maximum long-term yields in excess of 25 L/s (330 igpm).

3. Long-term maximum well capacity of TH02-01 as completed in the Miles Canyon Basalt Aquifer is estimated at 10.6 L/sec. Therefore, if this well were to be used, the target yield of 12.9 L/s (204 US gpm) will potentially lower water levels in the well below the safe available drawdown. To overcome this problem, two production wells would likely required to produce the desired flow rates.

4. Stabilized temperatures of pumped groundwater measured during the pumping tests were as follows:

   - 5.8^{o} C from the Selkirk Aquifer on July 28th, 2002; and
   - 6.9 to 7.1^{o} C from the Miles Canyon Basalt Aquifer on December 3rd to 6th, 2002.

Very little fluctuation in the pumped groundwater temperatures was observed throughout the pumping test.

5. Groundwater quality from both aquifer systems is relatively good and meets all of the tested health based Canadian Drinking Water Quality Guidelines and Yukon Contaminated Sites Regulations Aquatic Life standards. No significant scaling or corrosion of heat pump equipment is anticipated with respect to groundwater usage from either aquifer system. The average hardness (as $CaCO_3$) in groundwater from the overburden and basalt aquifer at TH02-01 is 87 mg/L and 113 mg/L respectively.

Based on the conclusions, the principal recommendations of the project are summarized as follows:

1. Although both aquifers are productive and appear to be capable of providing a viable water source for a groundwater heat pump system, it is recommended that the Selkirk Aquifer be selected as the preferred water source for the Vanier School Project. The rationale for this recommendation is as follows:

   - The groundwater temperature differential between the two aquifers is slightly more than 1º C, and therefore the Miles Canyon Basalt Aquifer does not appear to provide a significant thermal advantage.

   - It is likely that a single production well in the Miles Canyon Basalt Aquifer at this location, regardless of diameter, may not be adequate to deliver the required flow rates.

   - At the study location, drawdown levels in wells completed in the Miles Canyon Basalt Aquifer will be greater than drawdown levels in wells completed in the Selkirk Aquifer. Consequently, pumping costs associated with well operations in the Mile Canyon Basalt Aquifer will be higher.

- Water quality in the Selkirk Aquifer is marginally better than the Miles Canyon Basalt Aquifer, and therefore maintenance issues associated with water quality are anticipated to be reduced.

- Due to the relatively high estimated hydraulic conductivity identified in the Selkirk Aquifer, injection of the discharge water back into this aquifer system will require a lower injection pressure and therefore will be simpler to build operate and maintain.

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1. Introduction

1.1 Background

In 2001 the Energy Solutions Centre Inc. (ESC) began assessing the feasibility of using Ground Source Heat Pump technology in the Riverdale subdivision of Whitehorse. In January 2002 a site setting and conceptual design report was completed for the Vanier Catholic Secondary School in Riverdale (Gartner Lee Limited 2002). This report concluded that there was significant potential at this school for development of an Open-Loop Groundwater Heat Pump system. Based on this potential, ESC filed a Class-B Water License Application to the Yukon Territorial Water Board for this project. In parallel, ESC initiated a hydrogeological assessment to determine the groundwater conditions within the aquifers underlying the site. Gartner Lee Limited (GLL) was retained to conduct this work. This report provides the results of the project findings.

The study area is located within the subdivision of Riverdale, located within the City of Whitehorse, Yukon (Figure 1).

1.2 Scope of Work

Fieldwork conducted as part of this project was completed between July 3, 2002 and December 6, 2002. The project scope consisted of the following tasks:

1. Construction of an observation well (OB02-01):

   - Auger drilling of OB02-01 for completion of an observation well (not completed) to be used during the hydrogeological assessment of test well TH02-01.
   - OB02-01 was not completed as an observation well due to limitations of the drilling rig.

2. Construction of test well TH02-01, which included the following:

   - Advancement of the test well to bedrock;
   - completion of a temporary well screen, short term pumping test and water quality assessment within the overburden aquifer;
   - advancement of the test well into the underlying basalt aquifer;
   - completion of a bedrock well within the basalt aquifer;
   - completion of a down hole geophysical survey; and
   - completion of a short term and 72 hr pumping test and water quality assessment within the bedrock aquifer.

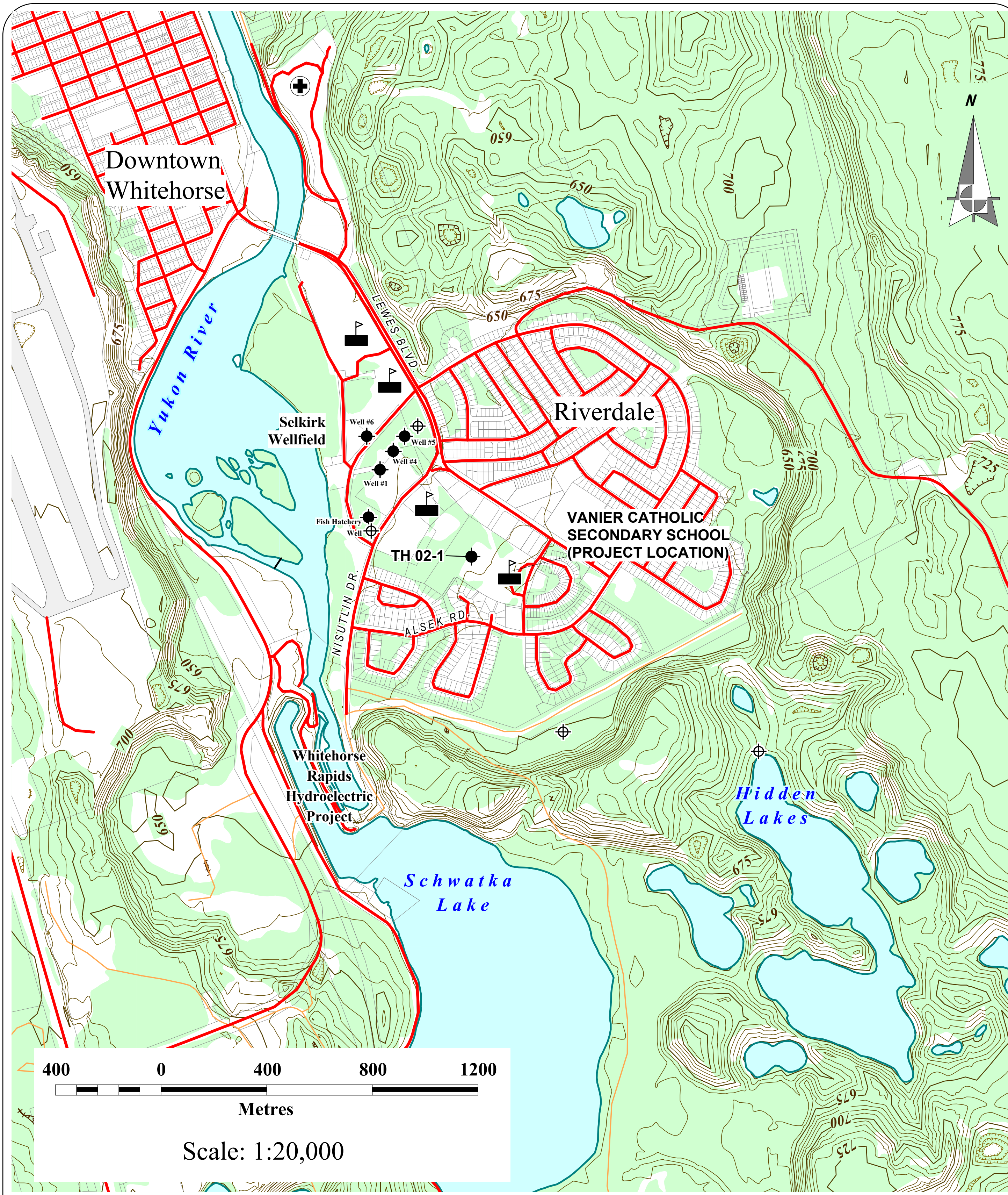
3. The completion of this report summarizing the results.

The project team consisted of the following parties:

1) Midnight Sun Drilling Co. Ltd. of Whitehorse, Yukon (drilling contractor);
2) Aurora Geosciences Ltd. of Whitehorse, Yukon (down hole geophysical consultant);
3) Aqua Tech Supplies and Services Ltd. of Whitehorse, Yukon (pumping test contractor);
4) Gartner Lee Limited of Whitehorse, Yukon (lead consultant).

1.3 Site Description

The study site is located approximately 250 m north of Vanier Catholic Secondary School, in Whitehorse, Yukon. The site is located on a parcel of land owned by the Yukon Territorial Government (YTG). The site is located near the edge of a forested area adjacent to the school's soccer field. Directly to the north of the drilling location, the ground surface drops in elevation slightly (approximately 3 m), onto a relatively flat forested area. Vegetation consists primarily of the pine-bearberry vegetation association. The forest floor consists of small depressions and swales (< 1 m deep). The location of TH02-01 and OB02-01 is presented in Figure 2.



Site Name: WHITEHORSE	**ENERGY SOLUTIONS CENTRE INC.**	Project No: 22-292
File Name: 22292-F1_2.WOR		Date Issued: DEC. 2002
Gartner Lee	**VANIER SCHOOL GSHP PROJECT HYDROGEOLOGICAL ASSESSMENT**	**Figure 1**
Scale: 1: 20,000	**Project Location Map**	

Scale: 1:3,000

Site Name: WHITEHORSE	ENERGY SOLUTIONS CENTRE INC.	Project No: 22-292
File Name: 22292-F1_2.WOR		Date Issued: DEC. 2002
Gartner Lee	VANIER SCHOOL GSHP PROJECT HYDROGEOLOGICAL ASSESSMENT **Test Well Location**	**Figure 2**
Scale: 1: 3,000		

2. Well Completion

2.1 Observation Borehole

On July 3, 2002, an observation borehole (OB02-01) was drilled using a CME 75 hollow stem auger drill rig provided and operated by Midnight Sun Drilling Co. Ltd of Whitehorse, Yukon. Split spoon samples and or grab samples were collected throughout the drilling operations at approximately 1.5 m intervals and were logged by Jonathan Kerr of GLL, according to standard geological methods. As the drilling depth increased, the soils became saturated and non-cohesive, making sample recovery difficult. The interpreted borehole log for OB02-01 is provided in Appendix A.

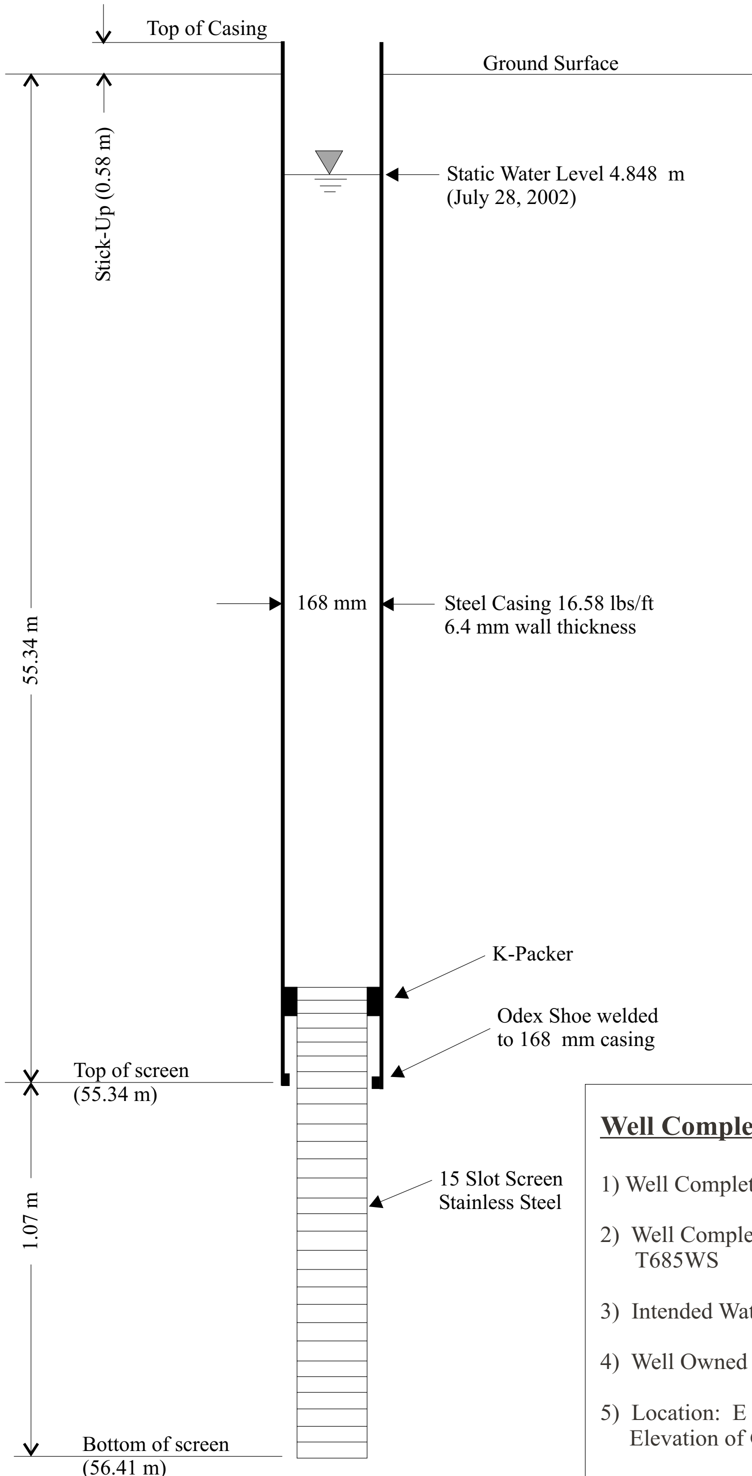
It was intended that borehole OB02-01 would be used to install an observation well that could be used during the hydrogeological assessment of the overburden aquifer. However, fine grain soils (fine sand and silt) were encountered which limited the auger depth to a maximum of 35.1 m below ground surface (bgs). An observation well completed in the material encountered would not likely yield meaningful data during the proposed aquifer test. Therefore, a decision was made to abandon the borehole. The borehole was filled with a mixture of drill cuttings (i.e. sandy silt) and bentonite to prevent the infiltration or short-circuiting of surface water.

2.2 Test Well TH02-01

Test well TH02-01 was constructed over a seven-day period from July 25, through July 31, 2002. TH02-01 was completed using a trailer-mounted air rotary Schramm T685 drill rig provided and operated by Midnight Sun Drilling Co. Ltd. The ODEX drilling method used a 168 mm outer diameter (6-inch) casing that was advanced into the ground as the borehole was drilled to a slightly larger diameter of 178 mm. Grab soil samples were collected from the cutting return cyclone at approximately 1.5 m depth intervals and logged by Jonathan Kerr of GLL. Logging of the recovered geological material followed standard geological methods. The borehole log for TH02-01 is provided in Appendix A.

2.2.1 Overburden Well Completion and Development

On July 27, 2002, upon drilling through the overburden to the top of the bedrock surface, a temporary well screen was telescoped through the casing and placed within the sand and gravel aquifer. This temporary screen was installed across a depth interval of 55.34 to 56.41 m bgs. A schematic diagram showing details of the temporary well completion is presented in Figure 3. A 4-inch (102 mm), 15 slot (0.38 mm) stainless steel well screen manufactured by Johnson Well Screens, was used for the completion of the temporary well.



Well Completion Notes:

1) Well Completed On: July 27, 2002.

2) Well Completed Using Air Rotary Drill Rig, 1998 Schramm T685WS

3) Intended Water Use: Testing of Overburden Aquifer

4) Well Owned by: Energy Solution Center

5) Location: E 0498236 N 6729702 (Nad 83) Zone 8
Elevation of Ground Surface: 805 masl

6) Well Drilling By: Midnight Sun Drilling of Whitehorse, Yukon

7) All elevations shown are relative to ground surface (Elevation: 0.00 m)

Not to Scale

Gartner Lee

TH02-01 - Temporary Well Completion Diagram in Selkirk Aquifer

Vanier School Heat Pump
Feasibility Study

FIGURE
3

Project 22-292
(22292\2002\Well Completion.cdr)

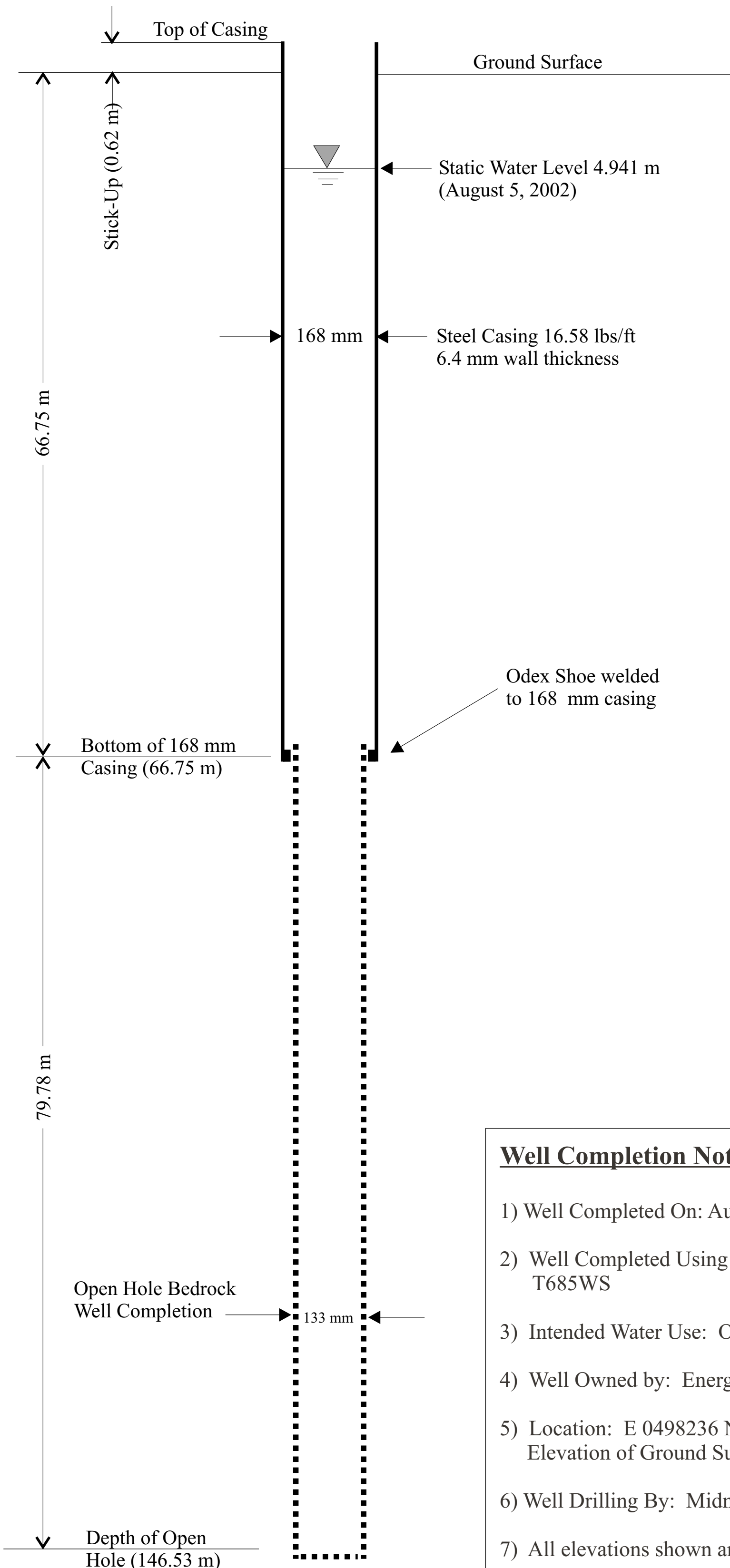
Once the well screen was within the overburden aquifer, the well was developed for approximately 2 hours using air surging. Throughout the development process an assessment of water quality (i.e. sand content and turbidity measurements) was not conducted as it was intended that the well be used for temporary hydrogeological testing purposes only. However, based on visual inspections, the groundwater appeared to reach a “sand free” condition.

Following the completion of the overburden well, a short-term pumping test and water quality assessment was conducted.

2.2.2 Bedrock Well Completion and Development

Following the completion of the pumping test in the overburden aquifer, the well screen was removed from the casing and the borehole was advanced into the underlying bedrock. To ensure adequate bedrock integrity within the “open-hole” portion of the borehole, the casing was toed approximately 6.4 m into the top of the bedrock surface (i.e. to a depth of 66.75 m bgs). A 133 mm (5 ¼ inch) diameter hole was then drilled out the bottom of the casing to a depth of 146.53 m bgs. Following the completion of the bedrock well, the top of the well casing was cut approximately 0.62 m above ground surface and a lockable steel lid was installed to reduce the potential for vandalism. A schematic diagram showing the final well completion details is presented in Figure 4.

On August 1, 2002, following the completion of TH02-01 within the bedrock aquifer, air surging development was conducted for approximately 4 hrs. Due to the nature of the bedrock, well development was achieved relatively quickly. Based on visual inspections, the groundwater appeared to reach a “sand free” condition.



Well Completion Notes:

1) Well Completed On: August 30, 2002.

2) Well Completed Using Air Rotary Drill Rig, 1998 Schramm T685WS

3) Intended Water Use: Open Loop Ground Source Heat Pump

4) Well Owned by: Energy Solution Center

5) Location: E 0498236 N 6729702 (Nad 83) Zone 8
Elevation of Ground Surface: 805 masl

6) Well Drilling By: Midnight Sun Drilling of Whitehorse, Yukon

7) All elevations shown are relative to ground surface (Elevation: 0.00 m)

Not to Scale

Gartner Lee

TH02-01 - Final Well Completion Diagram in Miles Canyon Basalt Aquifer

Vanier School Heat Pump
Feasibility Study

FIGURE
4

Project 22-292
(22292\2002\Well Completion.cdr)

2.3 Geophysical Survey

On August 29, 2002, approximately 28 days following final well construction, Aurora Geosciences, of Whitehorse, Yukon, conducted a downhole geophysical survey of TH02-01. The survey was conducted over a 4-hour period. The purpose of the survey was to assess in-situ groundwater temperatures and to measure thermal gradients within the bedrock aquifer. In addition to temperature measurements, other geophysical measurements were made to collect information on various ground properties (i.e. electrical resistivity). A downhole geophysical survey through the Miles Canyon Basalt Aquifer had never been conducted before thus making this data set unique. The geophysical log associated with this work is provided in Figure 5.

2.4 Site Stratigraphy

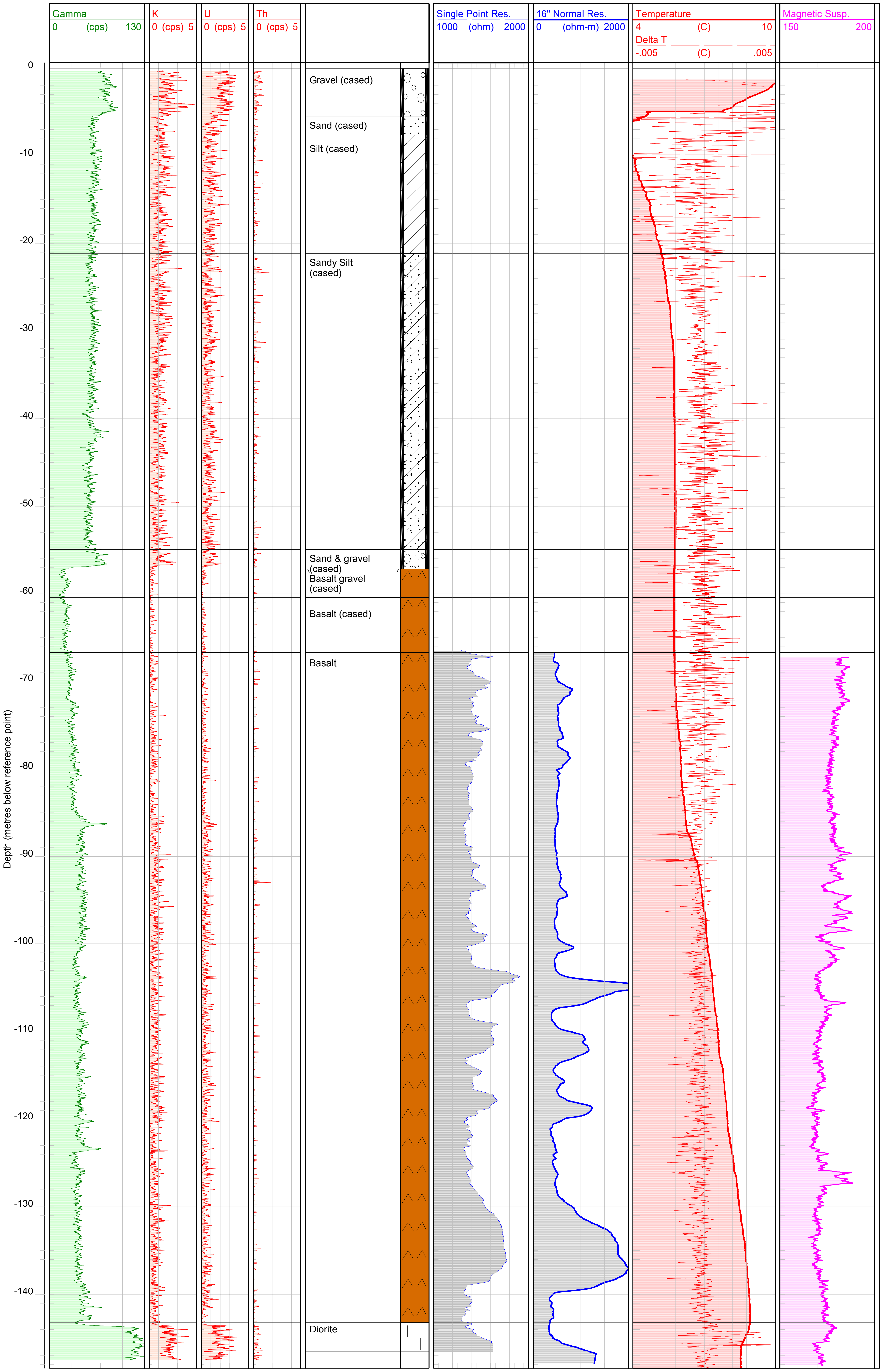
As discussed, borehole logs from each drilling operation (i.e. completion of OB02-01 and TH02-01) are provided in Appendix A. The principal geological materials encountered at each location are very similar and have been summarized in Table 1.

Table 1. Simplified Stratigraphy at OB02-01 and TH02-02

Depth (meters below ground surface)	Material Texture	Interpreted Stratigraphic Unit
0 - 5.8 m	SAND and GRAVEL with trace amounts of silt	Recent Alluvium
5.8 - 54.9 m	SILT and fine SAND	Glaciolacustrine
54.9 - 60.4 m	coarse SAND to GRAVEL	Lower Selkirk
60.4 - 143.1 m	Basalt	Miles Canyon Basalt
143.1 - 146.5 m	Granodiorite	Whitehorse Batholith

Figure 5. Geophysical Log of Test Well TH02-01
Location: Vanier Catholic Secondary School, Whitehorse, Yukon

Hole Logged By: Aurora Geosciences Ltd., August 16, 2002
Logging Tool: IFG Corp. BFG-06 Multiparameter Probe
Log Prepared By: Gartner Lee Limited, Project# 22-292
Well Location: 498233E 6729705N, Zone 8 (NAD83)
Reference Point: +0.63m Above Ground Surface



3. Hydrogeological Testing and Analyses

Hydrogeological testing included pumping tests of both the overburden (Selkirk) and bedrock (Miles Canyon Basalt) aquifers. Based on a reinterpretation of the Yukon Waters Act, DIAND Water Resources determined that a Class-B water license (i.e. production over 300 m^3/day) was required to conduct the necessary long-term (72-hr) pumping test of the Miles Canyon Basalt Aquifer. Accordingly, an application for such a license was submitted by Ron Gee of ESC and ultimately obtained (MS02-201) in November 2002.

The pumping tests conducted as part of this hydrogeological assessment are discussed in the following sections. Throughout the pumping tests, groundwater samples were collected and analyzed to assess the groundwater quality of each aquifer systems (i.e. Selkirk and Miles Canyon Basalt Aquifers).

The objective of this hydrogeological assessment is to produce flow rates of approximately 12.9 L/s (204 USgpm). This is assuming the operation of three WaterFurnace Versatec VL360 water-to-water heat pumps operating in parallel at 68 USgpm (4.3 L/s) per unit (Gartner Lee Limited 2002 and WaterFurnace 2002).

3.1 Overburden Aquifer

Following the installation of a temporary well screen within the Selkirk Aquifer at TH02-01, a short-term variable rate pumping test and water quality assessment was conducted on July 28th, 2002.

The variable rate (i.e step test) pumping test consisted of pumping the well at five different flow rates (i.e. steps) which occurred over a total pumping duration of 340 minutes. Each “step” lasted approximately 70 minutes, and consisted of an incremental increase in flow of approximately 0.8 L/sec. The minimum pumping rate was 2.88 L/sec (38 igpm), while the maximum pumping rate prior to the end of the pumping test was 4.17 L/sec (55 igpm). The maximum observed drawdown in TH02-01 at the end of the pumping test, was 1.63 m.

Throughout the pumping test, Jonathan Kerr of GLL completed a groundwater quality assessment. Groundwater sampling methodology and results are presented in Section 4 of this report.

3.1.1 Overburden Step Test Pumping Results

The drawdown of water levels in the pumped well over the duration of the step test, and the associated pumping rate during each step is illustrated in Figure 6. The raw data is presented in Appendix B.

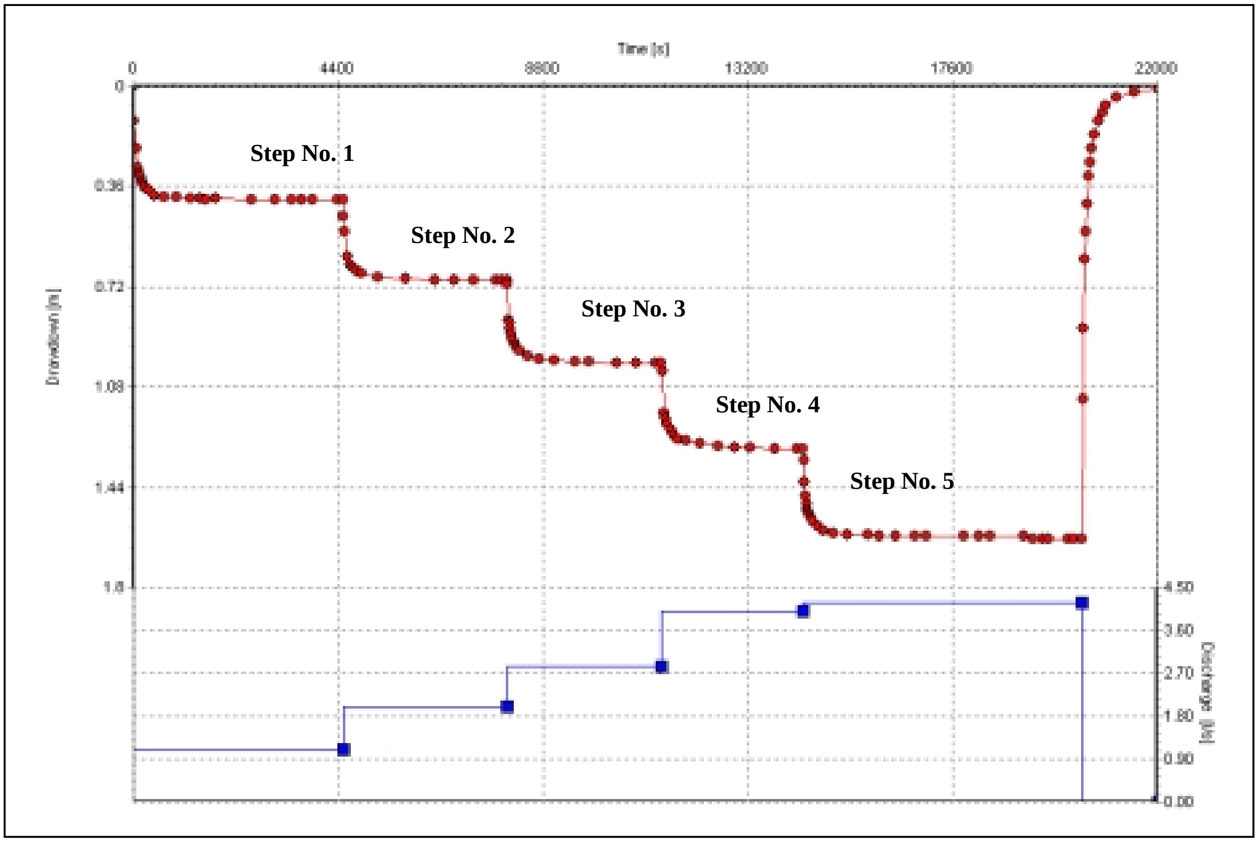


Figure 6. Overburden Aquifer - Short Duration Pumping Test Results

Analysis of the time-drawdown data obtained during the test shows that each increase in pumping rate produced an initial drawdown, however the magnitude of the drawdown appeared to stabilize relatively quickly. This type of hydraulic response (i.e. no additional change in drawdown with respect to time) is consistent with that of a "confined leaky aquifer" that is receiving recharge likely from overlying and or underlying, less permeable stratum. This interpretation is consistent with the aquifer materials identified in the borehole log (i.e. overlying silty fine sands).

Based on the character of the time-drawdown data collected during the first step, the hydraulic properties of the aquifer were estimated. The data suggests that early-time drawdown is likely to have been significantly affected by borehole storage. Consequently, only late-time data were analyzed and fit to the Hantush-Jacob Solution (1955, 1961a, 1961b).

The following assumptions apply to the use of the Hantush-Jacob Solution (1955, 1961a, 1961b):

- aquifer has infinite aerial extent;
- aquifer is homogeneous, isotropic and of uniform thickness;
- pumping well is fully or partially penetrating;
- flow to pumping well is horizontal when pumping well is fully penetrating;
- aquifer is leaky;
- flow is unsteady;
- water is released instantaneously from storage with decline of hydraulic head;
- diameter of pumping well is very small so that storage in the well can be neglected;
- confining bed(s) has infinite aerial extent, uniform vertical hydraulic conductivity and uniform thickness;
- confining bed(s) is overlain or underlain by an infinite constant-head plane source;
- flow in the aquitard(s) is vertical.

The results of the analyses indicate that the aquifer is moderately productive, having an interpreted transmissivity (T) of approximately 83 m^2/day. Transmissivity is defined as the hydraulic conductivity (K) multiplied by the thickness of the aquifer. Transmissivity is important for the prediction of long-term well yield and potential for drawdown influence on neighboring wells. Given the thickness of the aquifer at this location (5.5 m) the aquifer's interpreted hydraulic conductivity is estimated to be 1.75×10^{-4} m/s. This estimated hydraulic conductivity is consistent with results of previous pumping tests conducted in the Selkirk Well Field to the north (GLL 1999, GLL 2000). Aquifer storativity could not be estimated using the test results due to the absence of a nearby observation well. A summary of the pumping test data and analyses is provided in Appendix B.

3.1.2 Overburden Well Performance

The test results were used to estimate the maximum long-term well capacity based on a methodology provided by the B.C. Ministry of Environment, Lands and Parks 1999. The approach used for this estimate considers the aquifer type as "confined", based on the presence of the overlying sandy silts.

The total available drawdown (50.49 m) was calculated as the difference between the static water level (4.85m bgs) and the depth to the top of the well screen (55.34 m bgs). Safe available drawdown is defined as the "safe" or "allowable" drawdown in a pumped well. Based on the interpreted confined nature of the aquifer, the safe available drawdown was considered as the distance from the static water level (4.85 m bgs) to the to the top of the confined aquifer (54.90 m bgs). Given this assumption the safe available drawdown for the overburden well is 50.5 m (B.C. Ministry of Environment, Lands and Parks 1999).

To estimate the maximum long-term well capacity (i.e. a pumping rate that will induce the safe available drawdown), the observed drawdowns at the end of each "step" were plotted with the associated flow rate that induced that drawdown. During the overburden aquifer test, the size of the well screen was relatively small (length 1.07 m, dia 120 mm, slot size 0.38 mm). At low pumping rates it was observed that the steady state drawdown values plotted along a relatively straight line, however at higher flow rates (i.e. > than 4 L/sec) a disproportionate increase in drawdown occurred. This effect is likely the result of a decrease in well efficiency. Decreases in well efficiency associated with increases in pumping rate are often the direct result of head loss associated with groundwater entering the well screen at high velocities. To account for this observed decrease in well efficiency at high flow rates, a best-fit exponential line was placed through the data points and the equation of this line was calculated (Figure 7). The equation of the best-fit line was then used to estimate the flow that would induce the safe available drawdown (50.5 m). Given this methodology, the maximum long-term well capacity of the overburden well is estimated to be approximately 12.6 L/s.

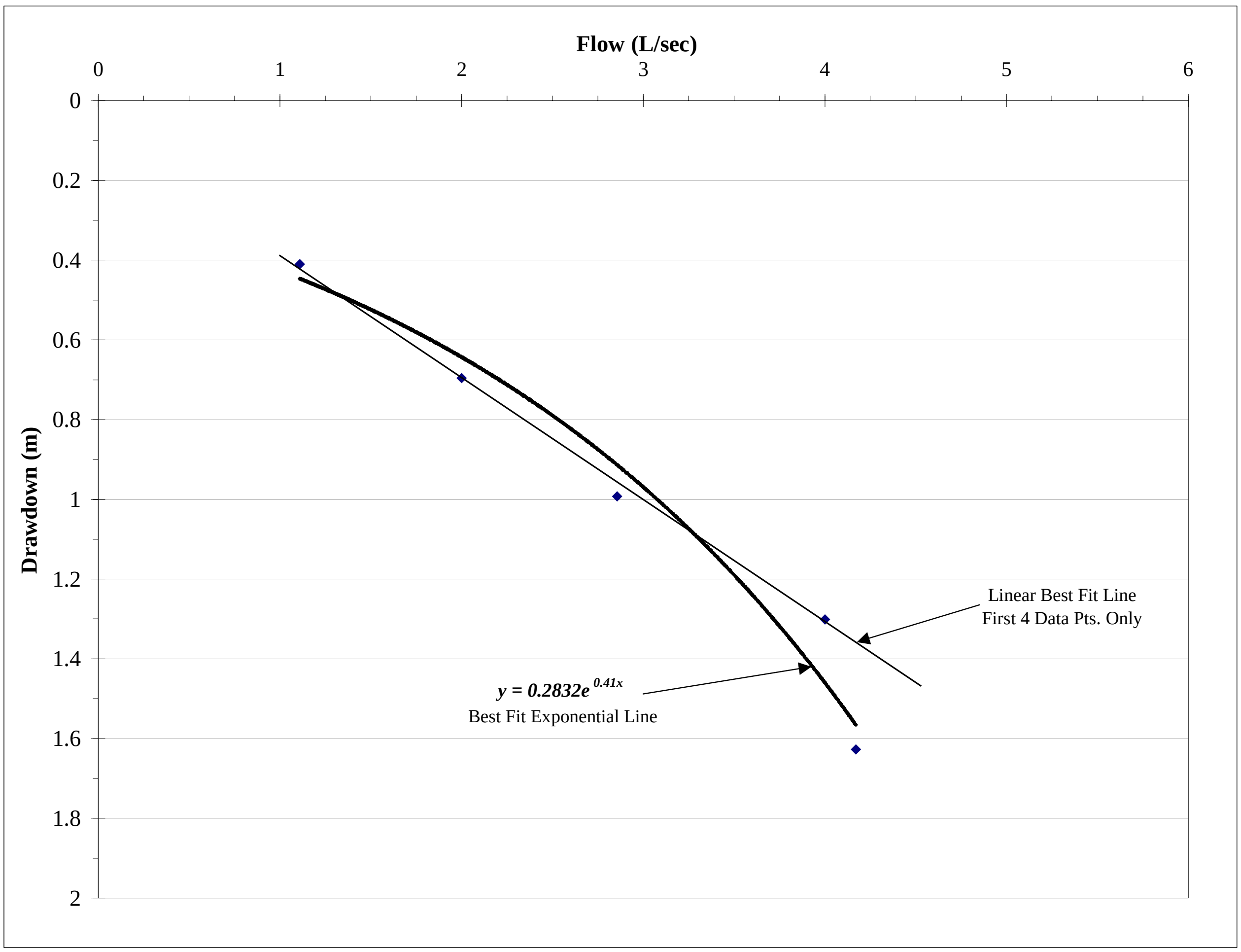


Figure 7. Overburden Aquifer - Flow Rate and Estimated Rate of Drawdown

It should be understood that the maximum long-term well capacity is valid only for a specific well construction in a given aquifer. Additionally, the methodology used to estimate the maximum long-term well capacity assumes an exponential decrease in well efficiency at higher flow rates. Significant improvements in well efficiency would likely be obtained with the installation of longer length, larger diameter/slot size well screen. As a design requirement in well construction, screens are typically selected to maintain entrance velocities of approximately 0.03 m/sec or less. If this condition is met, head losses can be assumed to be negligible and high well efficiencies can be obtained (Mabillot 1979).

Given the thickness of the sand and gravel aquifer (~5.5 m) observed at TH02-01, it would be reasonable to complete a well screen 3 m in length and with a diameter of 254 mm (10-inch). Excluding the properties of the aquifer and assuming a screen slot size of 100 (i.e. 2.54 mm), hydraulic well losses associated with high entrance velocities would likely not occur until flows of greater than 25 L/sec (330 igpm). To incorporate the aquifer properties into a prediction of potential flow rates, the first four data points in Figure 7 were considered. Based on the open area of the test screen and the associated flow rates used to obtain these first four data points, estimated hydraulic well losses associated with high entrance velocities are likely negligible (i.e. less than or equal to 0.03 m/sec). Therefore these data points were considered representative of a 100% efficient well, and were linearly extrapolated to estimate a flow rate that would induce the safe available drawdown (50.5 m) (Figure 7). Based on this analysis, it would be reasonable expect that the aquifer is capable of supplying as much as 170 L/sec (2244 igpm).

3.2 Bedrock Aquifer

Following the completion of TH01-02 within the Miles Canyon Basalt Aquifer, a short-term variable rate pumping test and water quality assessment were conducted on August 5, 2002. Pumping tests were also initiated on August 6 and 7, 2002, however electrical failures occurred and the tests were terminated shortly after they were started. Results from one incomplete tests conducted on August 6, 2002, did however provide a reasonable data set that was used to estimate aquifer properties. Additionally, on December 3 through Dec 6, 2003, a 72 hr constant rate pumping test was conducted on TH02-01.

3.2.1 Bedrock Step Pumping Test Results

The variable rate, pumping test (i.e. step test) consisted of pumping the well using three different pumping rates (i.e. steps) over a period of 360 minutes. Each step lasted approximately 120 minutes and consisted of a constant pumping rate with each consecutive step having an increase in pumping rate of approximately 5 L/sec. The flow rate of the third and final step however could not be increased significantly due to pump cavitation (i.e. aeration of the water). A discussion of this problem is provided in section 3.2.3. The maximum flow rate achieved at the end of the step test was 10.9 L/sec. Total drawdown of water in the well at the end of the test was 39.5 m.

Water levels (i.e. drawdown) in the well during the step test and the associated pumping rates are presented in Figure 8. Raw data is provided in Appendix B.

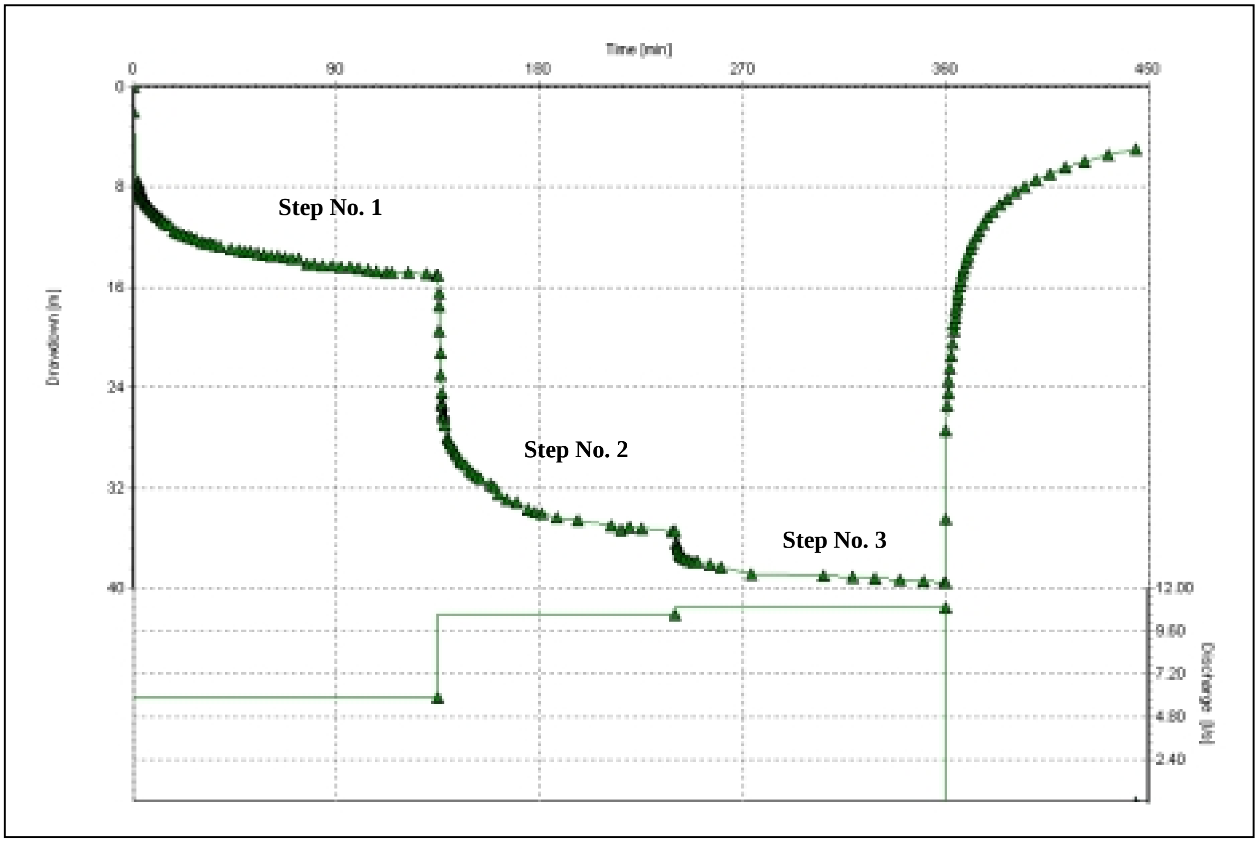


Figure 8. Bedrock Aquifer - Short Duration Pumping Test Results

Although groundwater entering TH02-01 during the bedrock aquifer test was likely derived primarily from fractures, the nature of the time drawdown curve (Figure 8) suggests the hydraulic behaviour of the bedrock aquifer is similar to that of a porous medium. Therefore, an equivalent porous media analytical approach and conventional porous media curve-matching techniques have been applied to the test results.

Based on an analysis of the time drawdown data, each increase in pumping rate produced an initial drawdown, however throughout the observation period, the magnitude of the drawdown did not appear to completely stabilize. This type of hydraulic response is consistent with that of a “confined aquifer” that is receiving water primarily from storage. Leakage from overlying or underlying stratum may be occurring however, based on the duration of this test, a “recharge” boundary effect is not apparent. The pumping data and analyses are presented in Appendix B.

Time drawdown data collected during one of the failed pumping tests provided a data set that was used to estimate the bedrock aquifer properties. This test consisted of a 143 minute constant rate (11.1 L/sec or 147 igpm) pumping test which was inadvertently terminated due to pump failure on Aug 7, 2002. The Theis (1935) aquifer solution was used to estimate the bedrock aquifer properties.

The time drawdown data was fit to the Theis (1935) solution, which assumes the following:

- The aquifer is confined and has an "apparent" infinite extent;
- The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by pumping;
- The piezometric surface was horizontal prior to pumping;
- The well is fully penetrating and pumped at a constant rate;
- Water removed from storage is discharged instantaneously with a decline in head;
- The well diameter is small, so well storage is negligible.

The early time data (less than 5 minutes) was excluded from the analyses as it suggested that over this interval there appeared to be significant borehole storage effects. The results of this analysis are presented in Appendix B. The aquifer transmissivity (T) is estimated at 14 m^2/day. Estimates of aquifer storativity provided by the analysis are not considered valid due to the absence of nearby observation well data. Given that the open portion of the well has been completed through the entire basalt aquifer (82.7 m), the hydraulic conductivity is estimated at 2.0×10^{-6} m/s. This hydraulic conductivity value is similar to other estimates obtained from pumping tests conducted elsewhere within the Miles Canyon Basalt (Pearson et al. 2001).

3.2.2 Bedrock 72 hr Constant Rate Pumping Test

A 72-hour constant rate pumping test of the bedrock aquifer (Miles Canyon Basalt Aquifer) was conducted from December 3rd to December 6th, 2002. As the pumping rates during the test were anticipated to exceed 300 m^3/day, this test was conducted under a Class-B water license (MS02-201) issued under the *Yukon Waters Act*.

A temporary submersible pump was installed in the test well (TH02-01) by Aqua Tech Supplies & Services of Whitehorse, Yukon. Depth to pump suction was 61.9 m below top of casing. A discharge line approximately 150 m long was used to convey pumped groundwater from the wellhead to the discharge site. The discharge site consisted of a relatively low-lying forested area to the northwest of the well. Water was pumped into a large plastic tub to dissipate its energy and prevent scouring of the ground. Discharge water was allowed to overflow from the tub and infiltrate back into the aquifer. During the pumping test, the discharged area was cordoned off with flagging tape to prevent access by the public.

The pumping test was conducted by Aqua Tech under guidance from Gartner Lee Limited. Operations were under 24-hr supervision by the pump contractor for the duration of the test. The discharge site was inspected at least four times per day to ensure that no flooding of private property occurred.

Pumping rates were recorded routinely using an in-line digital flow meter. Pumped groundwater temperatures were measured throughout the test using both an in-line mechanical thermometer mounted on the wellhead and a digital temperature probe (see section 4.3.3).

Water levels in the test well were measured routinely throughout the pumping test. To assess water level changes in other locations within the overburden Selkirk Aquifer, two observation wells (TH 1-78 and WW No. 5) located in the Selkirk Well Field were also monitored throughout the 72-hr pumping test. TH 1-78 is located adjacent to the Fish Hatchery Well and is completed in the lower portion of the Selkirk Aquifer. WW No. 5 is one of the City of Whitehorse's production wells and is located at the eastern end of the well field within the Upper Selkirk Aquifer. TH 1-97, another deep well adjacent to WW No.5, could not be used as an observation well due to vandalism. A continuous water level data logger was installed in WW No.5 during the pumping test. Manual water level measurements were made at both observation wells throughout the 72-hr pumping test. A location map showing the observation wells relative to TH02-01 is provided in Figure 2.

Both the City of Whitehorse, Public Works Department and Yukon Energy Corporation (owners of the Whitehorse Rapids Fish Hatchery) were notified verbally of the pumping test prior to commencement and indicated no objections to the test. The City of Whitehorse provided access to their WW No. 5 and the Fish Hatchery offered flow data from their production well.

At the end of the test, all equipment was removed from site. Ponded water at the discharge site infiltrated completely into the ground within two hours, and there was no significant accumulation of ice.

The pumping test consisted of a 72-hr pumping period followed by a 2.5-hr recovery period. At the start of the test, the static water level in TH02-01 was 5.70 m below top of casing. Following 72 hours of continuous pumping, at an average rate of 8.98 L/s (118.5 igpm), the water level in TH02-01 was 44.98 m below the top of the well casing (i.e. a total drawdown of 39.28 m). Two and half hours following pump shut down, the water level in the well had recovered to 15.62 m below top of casing, a recovery of approximately 75%.

A graph showing the water levels (i.e. drawdown) in test well and the associated pumping rates is presented in Figure 9. Detailed pumping test data is provided in Appendix B.

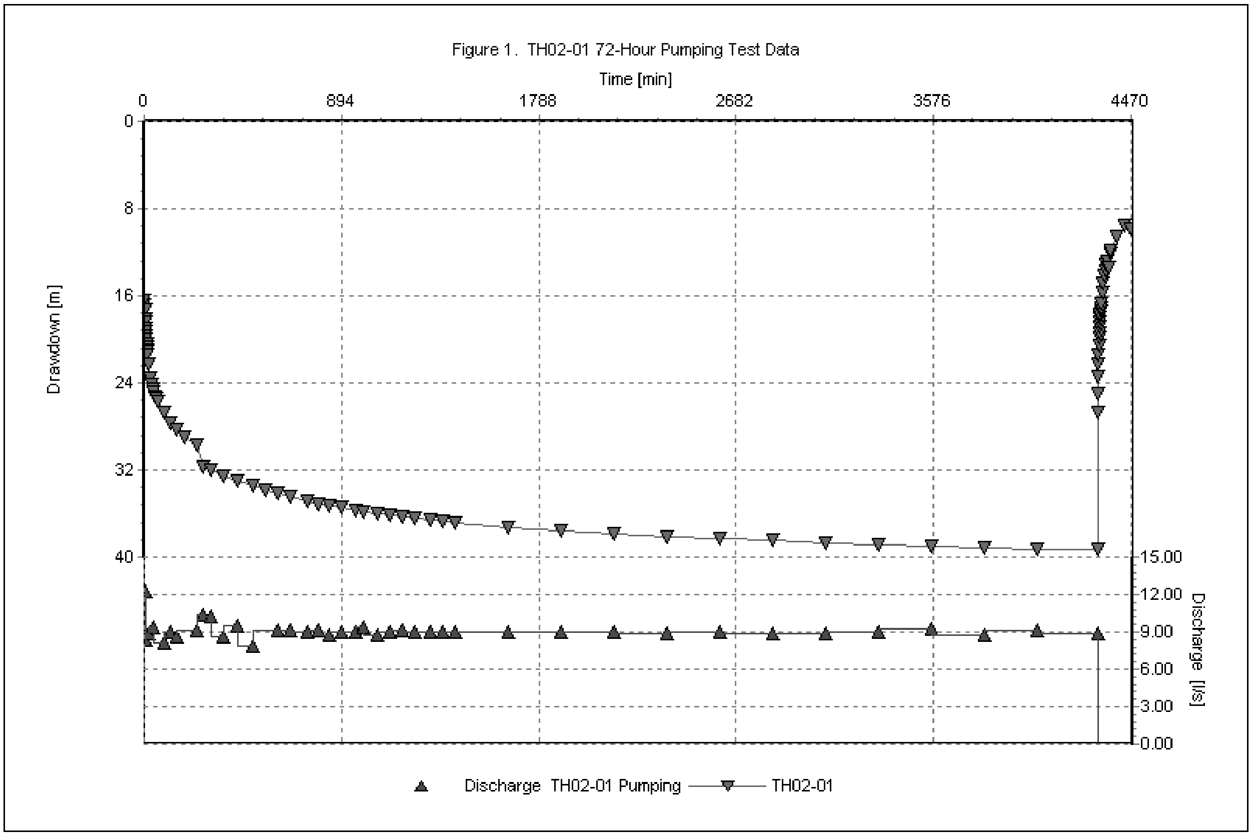


Figure 9. Bedrock Aquifer - 72 hr Pumping Test Results

Groundwater elevation data collected from the two observation wells (TH1-78 and WW No.5) is presented in Figure 10. These wells are 417 m northwest and 470 m north of the test well respectively. It is important to note that the City of Whitehorse could not cease operation of their well field for the duration of the pumping test. Therefore, water levels in the observation well are significantly influenced by the intermittent operation of WW No.6 and WW No.4. WW No.6 operated 79% of the time during the pumping test and at a pumping rate of approximately 130 L/s (1716 igpm). WW No.6 is 145 m west of WW No.5 and 272 m north of TH 1-78. The effect of the intermittent operation of WW No.6 is illustrated in the fluctuating water levels observed in both WW No.5 and TH 1-78 (Figure 10).

In addition, WW No.6, WW No.4 operated periodically for approximately 10 min every six hours to prevent freezing of the water lines. As part of this operation, a portion of the groundwater extracted from WW No. 4 is diverted back into WW No.5. Over the testing period, the Fish Hatchery Well was pumped continuously at a rate of 11.3 L/s (150 igpm). The Fish Hatchery well is located 16 m north of TH 1-78. Throughout the observation period, water levels in TH 1-78 and WW No.5 fluctuated 0.06 m and 0.12 m respectively. Based on the good correlation between City of Whitehorse production well operation and water levels in WW No. 5 and TH 1-78, it is likely that the fluctuations in these observation wells is attributable primarily to the operation of the production wells (WW No. 4 and 6).

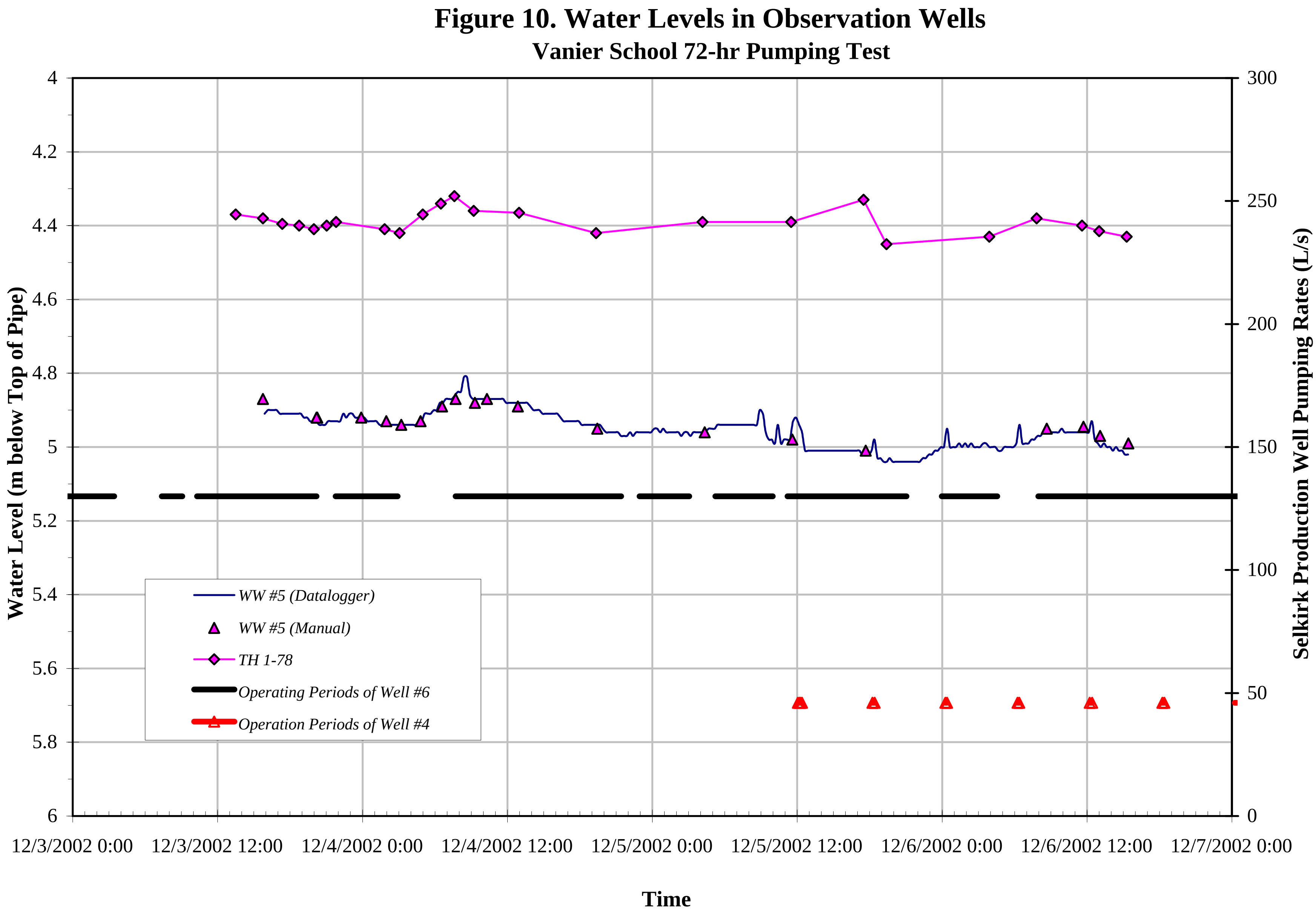


Figure 10. Water Levels in Observation Wells
Vanier School 72-hr Pumping Test
Water Level (m below Top of Pipe)
Selkirk Production Well Pumping Rates (L/s)
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
300
250
200
150
100
50
0
12/3/2002 0:00
12/3/2002 12:00
12/4/2002 0:00
12/4/2002 12:00
12/5/2002 0:00
12/5/2002 12:00
12/6/2002 0:00
12/6/2002 12:00
12/7/2002 0:00
Time
WW #5 (Datalogger)
WW #5 (Manual)
TH 1-78
Operating Periods of Well #6
Operation Periods of Well #4

Given the nature of the time drawdown data, the Theis Method and the Cooper-Jacob Method for confined aquifers were used to estimate the aquifer properties based on data obtained from the 72-hr constant rate pumping test. Recovery data was analyzed using the Theis-Jacob Recovery Method. Detailed pumping data and analyses are presented in Appendix B. A summary of the results is provided in Table 2.

Table 2. Summary of Miles Canyon Basalt Aquifer Parameters

Analysis Method	Transmissivity (T)	Hydraulic Conductivity (K)
Theis	19 m^2/day	2.7 x 10^{-6} m/sec
Cooper-Jacob	18 m^2/day	2.5 x 10^{-6} m/sec
Theis-Jacob Recovery	17 m^2/day	2.4 x 10^{-6} m/sec

The transmissivity and hydraulic conductivity estimates provided in Table 2, are similar to other estimates obtained from pumping tests conducted elsewhere within the Miles Canyon Basalt (Pearson et al. 2001). Additionally, the average transmissivity obtained during the 72-hr pumping test (18 m^2/day), is similar to the estimated transmissivity made during the failed pumping test (14 m^2/day) conducted on August 6, 2002 (section 3.2).

Although the hydraulic response of the time drawdown data is consistent with that of a "confined aquifer" it was observed that after approximately 1400 min (23hrs) the rate of drawdown in the well decreased slightly suggesting the presence of a recharge boundary (i.e. potential leakage from overlying or underlying stratum). This effect was not seen during the completion of the short term pumping test and can be seen on the log-log time-drawdown plot as a deflection (i.e. flattening) off the early time data, as shown in Figure 11.

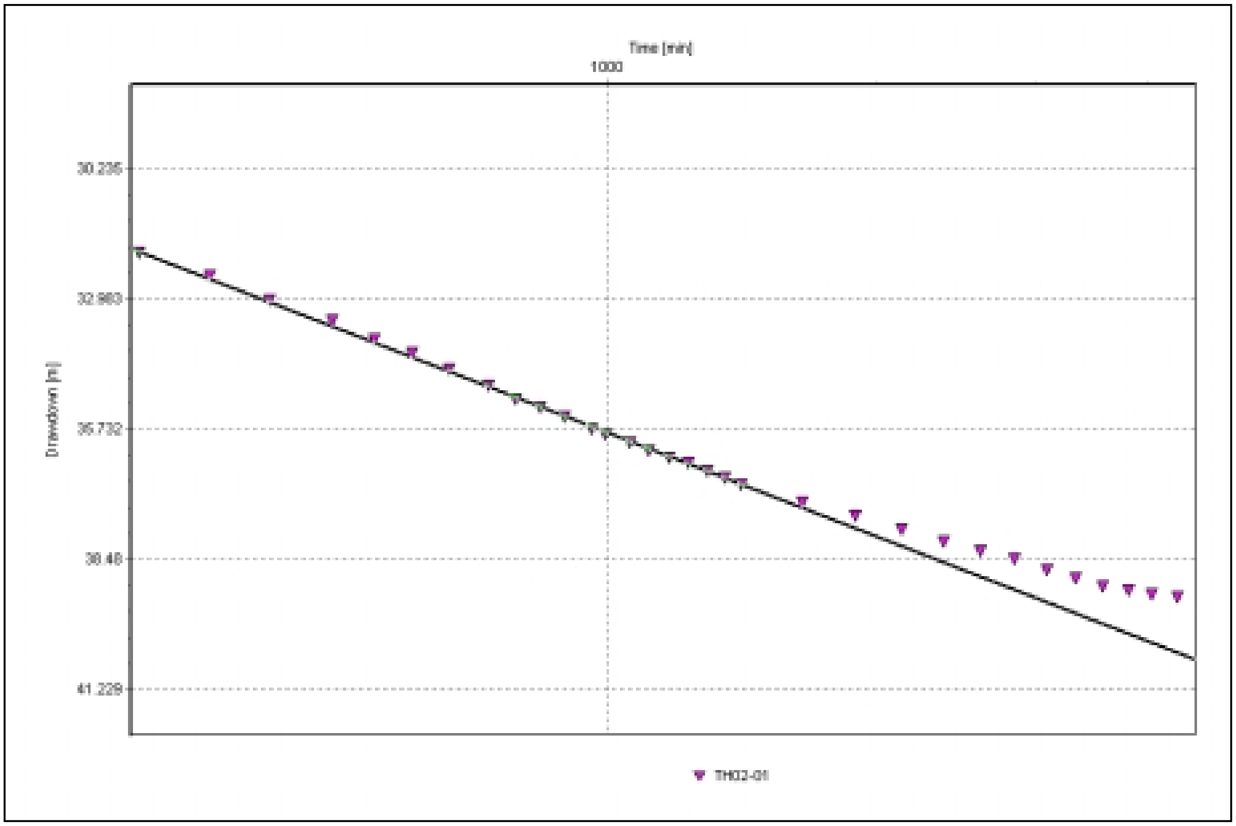


Figure 11. Bedrock Well 72 hr Pumping Test - Late Time Drawdown Data

3.2.3 Bedrock Well Performance

Data collected during the 72-hr pumping step test was used to estimate the maximum long-term well capacity for the well completed in the Miles Canyon Basalt Aquifer.

The total available drawdown in a bedrock aquifer is considered as the difference between the static water level and the uppermost major water bearing zone (B.C. Ministry of Environment, Lands and Parks 1999). For the purposes of this report, given the configuration of the test well, total available drawdown will be considered as the difference between the static water level (5.08 m bgs) and the top of the basalt aquifer (60.4 m bgs). Total available drawdown therefore is 55.3 m.

Safe available drawdown is "safe" or "allowable" drawdown in a pumped well. Given the large thickness of the basalt aquifer (82.7 m), it is anticipated that an adequate water column would be present for housing the submersible pump, seasonal water-level fluctuations, and potential decreases in well efficiency through time. Therefore, safe available drawdown is assumed to equal the total available drawdown (i.e. 55.3 m).

To estimate the long-term well capacity, (i.e. a pumping rate that will induce the safe available drawdown), the observed drawdown line shown in Figure 12 was projected forward in time to estimate the drawdown that would occur after 100 days of sustained pumping. Note that this projection is based on the late time-drawdown data, which incorporates the influence of the observed recharge boundary effect discussed previously. Using this methodology the drawdown value estimated at 100 days of sustained pumping is estimated at 47 m. This drawdown estimate was then divided by the pumping rate (8.98 L/sec) to determine the specific capacity. The specific capacity (1.94 x 10^{-4} m^2/sec) was then multiplied by the safe available drawdown (55.3 m) to produce and estimated long-term well capacity of approximately 10.6 L/sec.

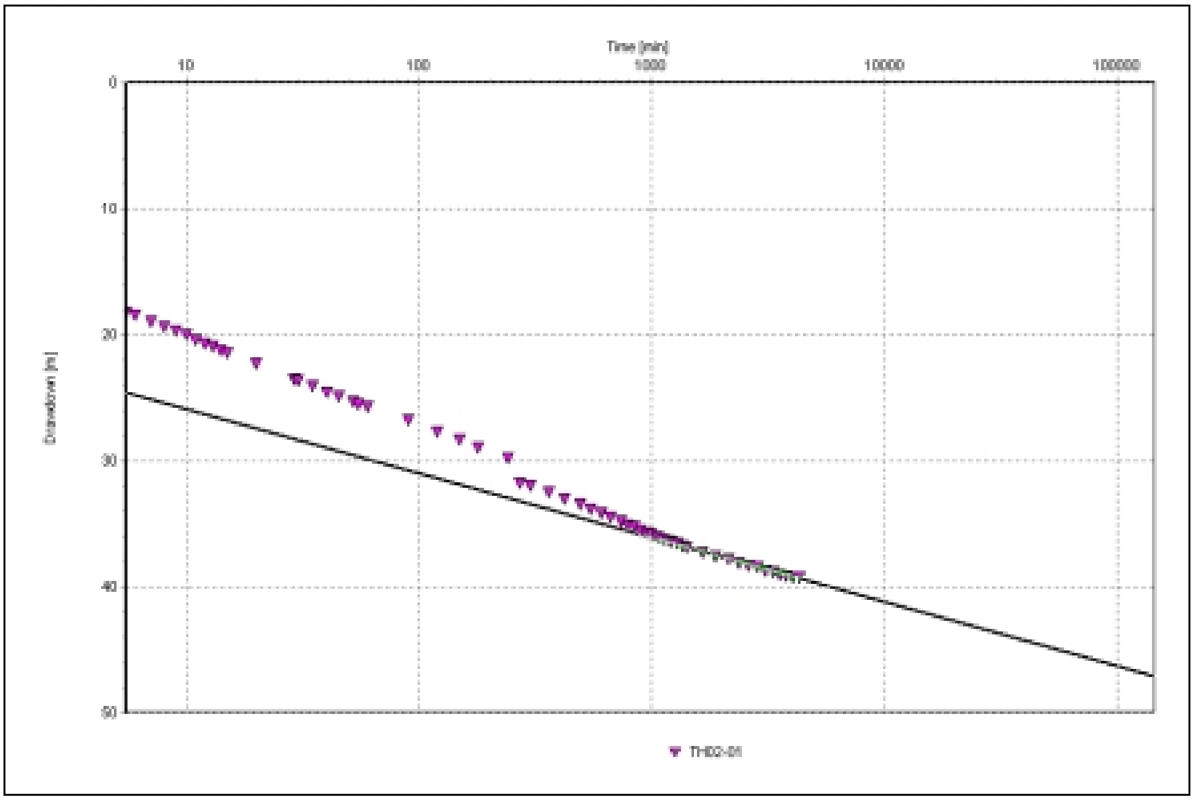


Figure 12. Predicted Drawdown After 100 Days of Sustained Pumping

As discussed briefly in section 3.2, it was observed during the last step of the short-term pumping test that the efficiency of the pump dropped significantly and the discharge water became quite aerated and "effervescent". This phenomenon commonly occurs, particularly in deep, slightly alkaline groundwaters, if the hydrostatic pressure in the groundwater entering the pump becomes significantly reduced. As drawdown in the well increases, the height of the water column above the pump intake decreases, causing a non-equilibrium of the carbonate system and the formation of gaseous carbon dioxide in the groundwater.

During the short term pumping test, the pump was set at a depth of approximately 44 m below the water table. It was observed that the formation of gaseous carbon dioxide did not occur significantly until the column of water above the pump intake was reduced to less than 10 m. If this well or a similar well were to be put into production it is likely that the pump would be set near the bottom of the well (i.e. 140 m bgs). This condition would effectively maintain an adequate water column above the pump intake and eliminate the formation of gaseous carbon dioxide.

4. Groundwater Quality

A significant component of this project included an assessment of groundwater quality from both the overburden and bedrock aquifers. Groundwater quality can have significant impact on the life span and efficiency of heat pump equipment. Specifically, groundwater conditions can cause either corrosion or encrustation of heat pump exchangers, auxiliary equipment and piping resulting in damage or reduced efficiency. Although the heat pumps only change water temperature and do not significantly alter the chemical quality of the water, characterizing the groundwater chemistr is required for assessing potential water disposal options. Disposal options may include re-injection of groundwater back into the aquifer, disposal to surface water bodies and/or use as potable water.

4.1 Sample Collection

All groundwater samples submitted for analyses were collected in pre-cleaned bottles supplied by the analytical laboratory. The following sampling and preservation methods were used:

- Samples submitted for total metal analysis were collected in 250 mL high density polyethylene (HDPE) bottles and were preserved in the field ($pH < 2$) using laboratory-supplied and measured aliquots of nitric acid.
- Samples submitted for general parameters (i.e. hardness) were placed into 1-L HDPE laboratory-supplied bottles and were not preserved.

Following sample collection, all samples were kept in a cool, dark environment and transported by courier to the laboratory within 24 hours. A total of five groundwater samples were collected and analyzed during the overburden short term pumping test. Three groundwater samples were collected and analyzed during the bedrock pumping test.

A specific notation was used to identify the groundwater samples. For example, the groundwater sample identified as “ST#1-S1” was the first sample (S1) collected at the end of the first step (ST#1), during the overburden pumping test. The notation “BR” was used to identify samples collected during the bedrock pumping test. The letter “R” in the sample ID was used to identify a sample taken in replicate.

4.2 Sample Analyses

ALS Environmental of Vancouver, BC (ALS), a member of the Canadian Association for Environmental Analytical Laboratories (CAEAL), conducted all water analyses.

4.2.1 Quality Assurance and Quality Control

Quality assurance/quality (QA/QC) measures implemented as part of this program consisted of the following:

- Collection, handling, storage and chemical analysis in accordance with "*Standard Methods for Examination of Water and Wastewater*" and *"Gartner Lee Limited Standard Field Protocols"* which are designed to minimize the potential for cross-contamination of samples;

- Documentation of sample field variability, consisting of the collection of two replicate samples that were analyzed for total metals and general parameters; and

- Internal laboratory QA/QC measures conducted by ALS.

4.3 Discussion of Results

The analytical results of the analyzed groundwater samples is presented in Table 3. Original laboratory reports for the laboratory analyses are presented in Appendix C.

4.3.1 Quality Control/Quality Assurance

To assess field sample variability, a set of field replicates were used to calculate the relative percent difference (RPD). RPD is defined as the following:

$$\%RPD = \frac{2(X_1 - X_2)}{(X_1 + X_2)} * 100$$

Where:
X_1 = The concentration of the first sample;
X_2 = The concentration of the second sample (i.e. the replicate).

Two replicate groundwater samples were collected from both the overburden and bedrock aquifers to assess the repeatability of data between the simultaneous grab samples. The repeatability of data with RPD values of 20% or less are considered to be acceptable if concentrations are more than 5 times the method detection limit (MDL). Additionally, acceptable RPD values of greater than 20% (i.e. up to 50%) can be observed when concentrations are near the MDL. All of the RPD values calculated from the field replicates were found to meet these criteria. Therefore it is concluded that the analytical data obtained during this water quality assessment was of acceptable quality.

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Table 3. Summary of Groundwater Quality TH02-01
Vanier School, Whitehorse, Yukon

Parameter		Canadian Drinking Water Quality Guidelines [a]	YCSR Aquatic Life Standard [b]	Detection Limits	Selkirk Aquifer TH02-01 Step #1	Selkirk Aquifer TH02-01 Step #2	Selkirk Aquifer TH02-01 Step #3	Selkirk Aquifer TH02-01 Step #4 [c]	Miles Canyon Basalt Aquifer TH02-01 Step #1	Miles Canyon Basalt Aquifer TH02-01 Step #3 [c]
Sample Collection Date		-	-	-	*28-Jul-02*	*28-Jul-02*	*28-Jul-02*	*28-Jul-02*	*5-Aug-02*	*5-Aug-02*
Sample ID		-	-	-	ST1-S1	ST2-S2	ST3-S3	ST5-S4R	BR-ST2-S1	BR-ST3-S2 (R)
ALS Sample ID		-	-	-	1	2	3	5	3	1,2
Physical Tests										
Colour	CU	15	-	5	<5	<5	<5	<5	<5	<5
Laboratory Conductivity	umhos/cm	-	-	2	186	183	182	181	804	819
Total Dissolved Solids		500	-	10	106	114	103	112.5	508	505
Hardness	CaCO3	-	-	0.7	85.4	87.3	86.5	87	113	113
pH		6.5 - 8.5	-	0.01	8.18	8.2	8.23	8.25	8.62	8.51
Laboratory Turbidity	NTU	1	-	0.1	***8.2***	***2.7***	***2***	***1.15***	***2.6***	***2.35***
Dissolved Anions (mg/L)										
Alkalinity-Total	CaCO3	-	-	1	85	84	87	84	128	130.5
Chloride	Cl	<=250	-	0.5	<0.5	<0.5	<0.5	<0.5	58.9	58.7
Fluoride	F	1.5	3 @ H => 50	0.02	0.22	0.22	0.22	0.22	0.36	0.38
Sulphate	SO4	<=500	1 000	1	12	12	12	12	187	188.5
Nutrients (mg/L)										
Nitrate Nitrogen	N	10	400	0.1	0.008	0.008	0.009	0.009	<0.005	0.009
Nitrite	N	1	0.2 @ Cl < 2mg/L or 2.0 @ Cl =>10mg/L	0.1	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
Total Metals (mg/L)										
Aluminum	T-Al	0.1	-	0.01	0.05	0.05	0.02	0.055	0.09	0.035
Antimony	T-Sb	0.006	0.2	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.001
Arsenic	T-As	0.025	0.05	0.001	0.006	0.006	0.006	0.006	<0.002	<0.002
Barium	T-Ba	1	10	0.02	<0.02	<0.02	<0.02	<0.02	<0.04	<0.04
Boron	T-B	5	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2
Cadmium	T-Cd	0.005	0.0003 @ H = 30 - <90 or 0.0005 @ H = 90 - < 150	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0004	<0.0004
Calcium	T-Ca	-	-	0.1	15.5	16.1	15.9	15.9	24.7	24.6
Chromium	T-Cr	-	0.01 for Cr^{+6} and 0.09 for Cr^{+3}	0.002	<0.002	<0.002	<0.002	<0.002	<0.004	<0.004
Copper	T-Cu	<=1.0	0.04 @ H = 75 - < 100 or 0.05 @ H = 100 - < 125	0.01	<0.001	0.001	<0.001	<0.001	<0.002	<0.002
Iron	T-Fe	<=0.3	-	0.03	**0.91**	**0.32**	0.26	0.145	0.2	0.16
Lead	T-Pb	0.01	0.050 @ H = 50 - < 100 or 0.060 @ H = 100 - < 200	0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
Magnesium	T-Mg	-	-	0.1	11.3	11.4	11.4	11.6	12.6	12.5
Manganese	T-Mn	<=0.05	-	0.002	0.011	0.006	0.006	0.0042	**0.185**	**0.105**
Mercury	T-Hg	0.001	0.001	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Potassium	T-K	-	-	0.1	1.5	1.5	1.5	1.6	2.1	2.1
Selenium	T-Se	0.01	0.01	0.001	0.008	0.007	0.006	0.004	<0.002	<0.002
Sodium	T-Na	<=200	-	2	5	5	4	4	133	134.5
Uranium	T-U	0.02	3	0.0001	0.0011	0.0011	0.0011	0.0011	0.0031	0.0025
Zinc	T-Zn	<=5.0	0.075 @ H = < 90 or 0.150 @ H = 90 - < 100	0.05	<0.05	<0.05	<0.05	<0.05	<0.1	<0.1

a *Heath Canada. Guidelines for Canadian Drinking Water Quality, 2002*
b *Yukon Environment. 2002. Contaminated Sites Regulations (YCSR). Generic Numerical Water Standards for Aquatic Life.*
c *Indicates an average result based on replicates samples*
H *Indicates water hardness in mg/L ($CaCO_3$)*
< *Indicates less than detection limit*
\- *Indicates no guideline or analysis for this parameter*
bold # *Indicates parameter exceeds Aesthetic Objective (taste, odour, appearance, etc.)*
bold, itallic # *Indicates parameter exceeds Maximum Acceptable Concentration (health related)*

4.3.2 Discussion of Drinking Water Quality Guidelines

The water quality assessment conducted for this report was primarily related to evaluating the potential for corrosion or fouling of heat pump equipment (section 4.3.8). However, water quality data has also been compared to the Canadian Drinking Water Quality Guidelines (CDWQG), (Health Canada 2002) and the Yukon Contaminated Site Regulation (YCSR) Aquatic Life Standards (Yukon Department of Environment 2002). These comparisons have been performed to help assess potential water disposal options. Specifically, the comparison of groundwater quality to the CDWQG was performed to assess the viability of re-injection to a water supply aquifer (i.e. back into the aquifer) and/or use of the groundwater for drinking water. Comparison of the groundwater quality results to the YCSR Aquatic Life Standard was also conducted to assess the potential disposal of the cooled groundwater to nearby surface water bodies (i.e. the Yukon River).

4.3.3 Physical Tests

Physical water tests conducted as part of this study included measurements of turbidity, colour, total dissolved solids, pH and hardness. The results of these parameters are discussed in the following paragraphs.

Hardness
Hardness is a key parameter used to assess scaling potential. Scaling has a potential to decrease the efficiency of groundwater heat pump systems (Rafferty 2000). Water hardness is classified based on a range of calcium carbonate concentrations that commonly varies slightly from reference to reference. Table 4 provides a common interpretation.

Table 4. Classification of Hardness in Groundwater

Hardness ($CaCO_3$) mg/L	Classification	Comments
< 50	Soft	-
50 – 100	Medium Hard	May deposit in kettles and hot water heaters.
100 – 200	Hard	Scale build up or staining is likely quite noticeable.
> 200	Very Hard	Recommended that water be softened for household uses.

Notes: Table from Carrier (1965)

Based on the water quality results conducted during this assessment, the groundwater samples tested from both the overburden and bedrock aquifers would be classified as "medium hard" to "hard". The groundwater from the bedrock aquifer, however, was found to be slightly harder (average hardness of 113 mg/L as $CaCO_3$) than the groundwater from the overburden aquifer (average hardness of 87 mg/L as $CaCO_3$). A discussion of the scale and/or corrosion potential of the analyzed groundwater is presented in section 4.3.8 of this report.

Groundwater Temperature

Groundwater temperatures were continuously monitored throughout the short-term and long term pumping test using a digital temperature probe (YSI Model 30/10 FT Salinity Conductivity Temperature Probe). The instrument measurements are considered to be accurate to 0.1 degrees Celsius.

Temperature monitoring of pumping groundwater throughout the short-term pumping test in the overburden aquifer indicate the groundwater temperature was initially approximately 6.4º C, however after approximately 300 min of pumping the temperature appeared to declined slightly to a stabilized temperature of approximately 5.8º C.

Similar temperature monitoring was conducted throughout the short term pumping test of the bedrock aquifer. The results indicated that during early time, the pumped groundwater temperature was approximately 7.4º C however after approximately 240 min of pumping the temperature appeared to decline slightly to a stabilized temperature of approximately 7.1º C. Similarly, over the duration of the 72-hr pumping test, pumped groundwater temperatures remained constant between 6.9 and 7.1^{o} C with no indication of significant fluctuations or trends.

Following well completion, the borehole was allowed to stabilize for approximately 3 weeks prior to conducting the down hole survey. The results of this survey are presented in Figure 5. The in-situ groundwater temperatures in the uncased portion of the well (i.e. the Miles Canyon Basalt Aquifer) ranged from 5.8^{o} C to a maximum of 8.9^{o} C. The temperatures appeared to increase relatively linearly with depth. It was also observed that an inflection point in the groundwater temperature profile occurred at a depth of approximately 84 m bgs.

It should be noted that various groundwaters derived from different fractures may vary in temperature. Additionally, groundwater entering the well bore through these fractures is likely mixing as a result of the open nature of the bore hole column. Consequently, the groundwater temperature profile obtained during the down hole geophysical survey (Figure 5) is representative of a stabilized or “mixed” condition. As a result, representative groundwater temperature signatures from discrete fractures within the borehole could not be assessed during this investigation.

Turbidity

All of the groundwater samples submitted to the laboratory were analyzed for turbidity. Canadian Drinking Water Quality Guidelines (CDWQG) have both a Maximum Acceptable Concentration (MAC) for turbidy (1 NTU) applicable to water entering a distribution system and an Aesthetic Objective (AO) for turbidity of 5 NTU. All groundwater samples exceeded the 1 NTU threshold. It is suspected this result may be caused by insufficient well development and/or, in the case of samples containing elevated iron and or manganese concentrations, the result of inorganic compounds (i.e. metal oxides and hydroxides) precipitating out of the groundwater after sample collection. It is anticipated that acceptable turbidity levels would be obtained with prolonged pumping and adequate well development.

4.3.4 Major Ions in Groundwater

A Trilinear Diagram showing the relative concentrations of major ions in the analyzed groundwater samples is presented in Figure 13. The diagram illustrates the nature and difference between the groundwater analyzed from the two aquifer systems (i.e. bedrock groundwater and overburden groundwater). The diagram presented is useful for visually assessing differences in major-ion chemistry in groundwater flow system. There is also a need to be able to refer in a convenient manner to water compositions by identifiable groups or categories (Freeze and Cherry 1979). Such diagrams provided a means of meeting such needs.

Information shown in the Trilinear Diagram (Figure 13) suggests a notable distinction between the two groundwaters. Groundwater from the bedrock aquifer is considerably more mineralized (i.e. higher total dissolved solids) and is characterized as “Sodium Type” while the groundwater in the overburden is characterized as “Calcium/Bicarbonate Type” (Morgan et al. 1962). Based on this finding, there appears to be a significant difference with respect to the degree and type of dissolved mineralization in the groundwater between the overburden and bedrock aquifers.

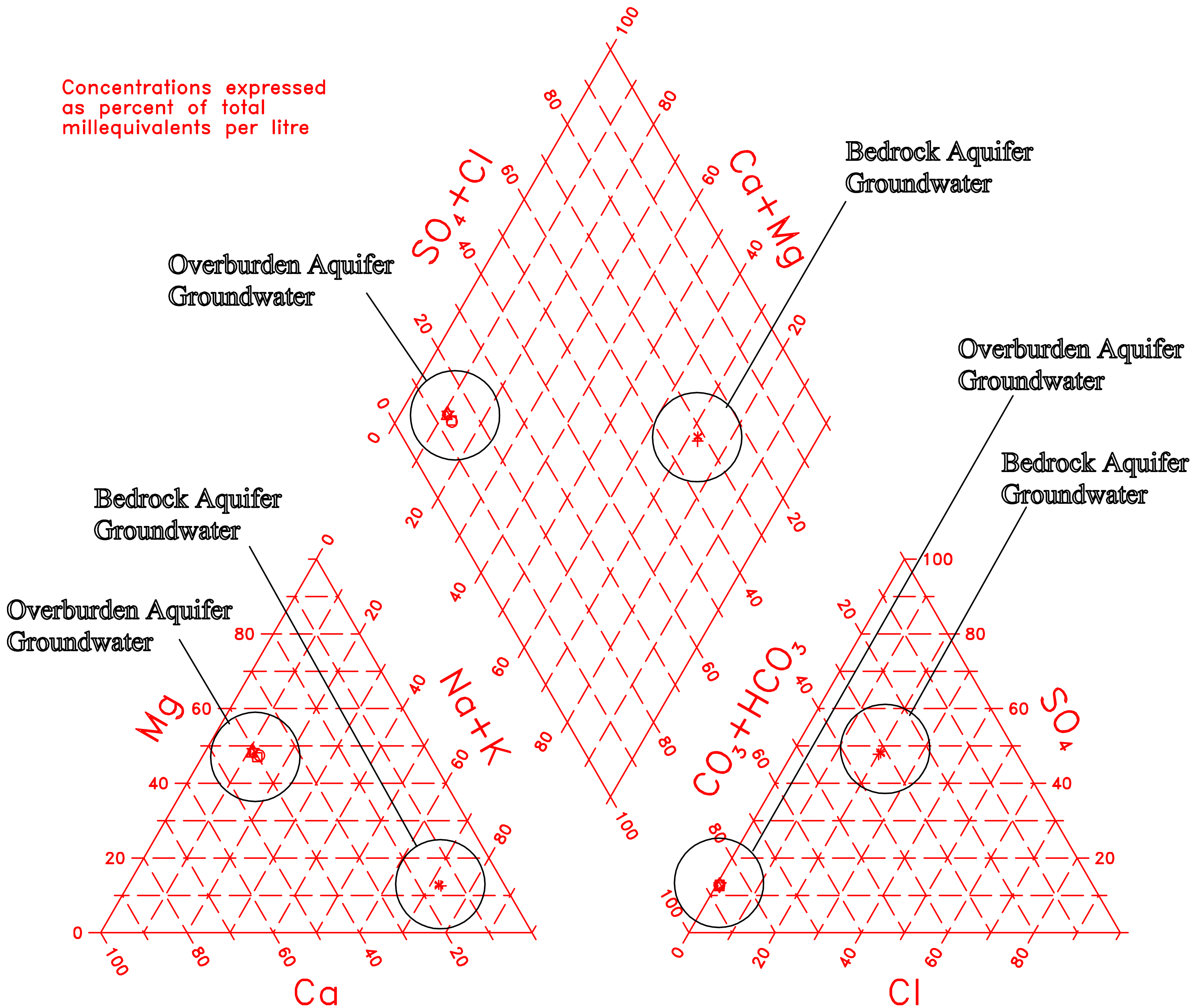
4.3.5 Dissolved Anions

Dissolved anion concentrations were measured in all analyzed groundwater samples. Concentrations of dissolved anions in the groundwater samples were found to meet both the Canadian Drinking Water Quality Guidelines (2002) (CDWQG), and the Yukon Environment, Contaminated Sites Regulations (2002) (YCSR), Generic Numerical Water Standards for Aquatic Life.

The groundwater analyzed from the bedrock aquifer however was found to contain higher concentrations of dissolved sulphate (average concentration of 188 mg/L) than the groundwater analyzed from the overburden aquifer (average concentration of 12 mg/L).

The low concentrations of sulphate in the analyzed groundwater suggest that poor tasting water associated with the presence of this anion is unlikely. The aesthetic (AO) CDWQG for dissolved sulphate is 500 mg/L.

Additionally, groundwater from the bedrock aquifer contains considerably higher concentrations of dissolved chloride (average concentration of 58.8 mg/L) than the groundwater from the overburden aquifer (< 0.05 mg/L). It is suspected that this is the result of the differences in mineralization between of the bedrock aquifer material and the overburden aquifer material. The AO CDWQG for dissolved chloride is 250 mg/L.



LEGEND

Overburden Groundwater Sample IDs

- ○ ST1–S1
- □ ST2–S2
- △ ST3–S3
- ◇ ST5–S4
- ☆ ST5–S4R

Bedrock Groundwater Sample IDs

- + BR–ST3–S2R
- × BR–ST3–S2
- * BR–ST2–S1

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Trilinear Plot

Groundwater from TH02-01

GLL 22-292 Dec 2002

Figure 13

4.3.6 Nutrients

Nutrients (i.e. nitrate) were measured in all analyzed groundwater samples. Concentrations of all tested nutrient related parameters in the analyzed samples met both the CDWQG and the YCSR, Generic Numerical Water Standards for Aquatic Life. All of the samples tested for nitrate were found to be only slightly above or below the method detection limit of 0.005 mg/L. The maximum allowable concentration (MAC) for nitrate under the CDWQG is 10 mg/L.

4.3.7 Total Metals

All of the samples tested for total metal concentrations met both the health related CDWQG and the YCSR, Generic Numerical Water Standards for Aquatic Life.

4.3.7.1 Total Iron Concentrations

Total iron concentrations from two groundwater samples collected at the end of Step #1 and Step #2 of the overburden short term pumping test, exceeded the AO CDWQG of 0.3 mg/L (i.e. 0.91 mg/L and 0.32 mg/L respectively). This exceedance may be an effect of incomplete well development as iron from suspended particulate matter in the groundwater could have dissolved into the sample after acid preservation and transport to the laboratory. This hypothesis is supported by the slightly elevated turbidity measurements, believed to be the result of incomplete well development. Groundwater samples from other wells in the Selkirk Aquifer typically have total iron concentrations less than 0.3 mg/L. It is unlikely that a fully developed production well in the overburden would produce similar elevated total iron concentrations. Total iron concentrations from all samples collected during the short term bedrock pumping test were found to meet the AO CDWQG and had an average concentration from all four samples of 0.16 mg/L.

High concentrations of total iron commonly contribute to secondary hardness issues as it may precipitate out of solution (i.e. forming iron oxides and the accumulation of microbial growths) following entry into the well or pump assembly or exposure to air. This effect can lead to aesthetic problems such as staining of household toilets or clogging of distribution pipes through time. Such effects have not been observed with operation wells from the Selkirk Well Field.

4.3.7.2 Total Manganese Concentrations

The AO CDWQG for total manganese concentrations in drinking water is 0.05 mg/L. Similar to secondary hardness issues associated with elevated iron concentrations, elevated manganese concentrations (greater than 0.15 mg/L) could also be problematic. Additionally, elevated manganese has been known to produce undesirable tastes in beverages.

Exceedances of the AO CDWQG with respect to total manganese concentrations have been detected in groundwater samples collected from the bedrock aquifer (i.e. Miles Canyon Basalt). Total manganese concentrations from groundwater samples collected during the bedrock short-term pumping test were found to be approximately 2.6 times higher than the AO CDWQG of 0.05 mg/L, with an average concentration from 3 samples of 0.13 mg/L.

Other wells completed within the Miles Canyon Basalt have been sampled and found to have manganese concentrations below the AO CDWQG. Specifically, the Wolf Creek North Subdivision test well had a manganese concentration of 0.098 mg/L (Gartner Lee Ltd. 2001) and the Wolf Creek Observation Well had a total manganese concentration of 0.085 (Gartner Lee Ltd. 2003b).

Groundwater samples from 11 domestic water wells completed in Miles Canyon Basalt in the Wolf Creek Subdivision were found to contain total manganese concentrations averaging 0.014 mg/L with a maximum detected concentration of 0.058 mg/L. (Gartner Lee Ltd. 2003a). This observation suggests that the elevated manganese concentrations detected in TH02-01 may be related to incomplete development and that with routine usage, the total manganese concentrations may be lowered.

Total manganese concentrations from groundwater sampled during the overburden short term pumping test were found to meet the AO CDWQG of 0.05 mg/L with an average concentration from 5 samples of 0.0062 mg/L.

4.3.8 Stability Indices and pH

The Ryznar Stability Index (RSI) and the Langelier Saturation Index (LSI) are used for predicting the potential reaction of metal objects in saturated subsurface environments. Specifically, these indices help predict the potential of water to corrode and or deposit scales (encrustation). Depending on its specific chemistry, water can promote scaling, corrosion or both. Scaling, according to the Water Quality Association, is the number one water quality issue in the United States (Rafferty 2000). Scale can be formed from a variety of dissolved chemical species but two reliable indicators are hardness and alkalinity. Calcium carbonate is the most common form of scale deposition attributable to groundwater used in Ground Source Heat Pump systems (Rafferty 2000).

Both the RSI and LSI are based upon a calculated pH of saturation for calcium carbonate (pHs). The calculated pHs value is then used in conjunction with the groundwater's actual pH, and other water chemistry, to calculate the index values as follows:

- RSI - 2pHs - pH
- LSI = pH - pHs

Table 5 and Table 6 presents the interpretation of both the RSI and LSI indices.

Table 5. Interpretation of the Langelier Saturation Index

LSI Index Value	Indication
2.0	Scale forming but non corrosive
0.5	Slightly scale forming and corrosive
0.02	Balanced but pitting corrosion possible
-0.5	Slightly corrosive but non-scale forming
-2.0	Serious corrosion

Notes: Table from Carrier (1965)

Table 6. Interpretation of the Ryznar Stability Index

RSI Index Value	Indication
4.0 - 5.0	Heavy scale
5.0 - 6.0	Light scale
6.0 - 7.0	Little scale or corrosion
7.0 - 7.5	Corrosion significant
7.5 - 9.0	Heavy corrosion
> 9.0	Corrosion intolerable

Notes: Table from Carrier (1965)

Table 7 presents the results of the calculated LSI and RSI based on the groundwater quality data collected during the assessment. It should be noted however, that the RSI and LSI indices are most useful as predictors of scaling potential rather than of corrosion potential.

Table 7. Results fo Stability Indices

Stability Index	Overburden Aquifer *(Calculated Index Value)*	Bedrock Aquifer *(Calculated Index Value)*
Langelier Saturation Index (LSI)	-0.183	0.404
Ryznar Stability Index (RSI)	8.588	7.735

These indices suggest that water from both aquifers are near balanced and that significant scaling should not occur. The groundwater may be mildly corrosive, but not sufficiently corrosive to warrant use of special alloys in the heat pump equipment (i.e. cupronickel heat exchangers). By way of comparison, the RSI for water from the City of Whitehorse's WW No. 6, is 8.2. This well has been operating since 1974 and a down hole video inspection of the well conducted in 2000 indicated no evidence of encrustation or significant corrosion (Gartner Lee Ltd. 2001)

5. Conclusions and Recommendations

The objective of this hydrogeological assessment was to assess if the aquifers underlying the study site are capable of sustaining a design flow rate of approximately 12.9 L/s (204 USgpm). This is assuming the operation of three WaterFurnace Versatec VL360 water-to-water heat pumps operating in parallel at 68 USgpm (4.3 L/s) per unit (Gartner Lee Limited 2002, WaterFurnace 2002). Additionally the study assessed groundwater quality from each of the aquifers to help predict potential problems associated with heat pump systems and or operations.

Photographs of the project work are presented in Appendix D.

5.1 Conclusions

The principal conclusions of the project are summarized as follows:

Please note that the proceeding conclusions are based on a design assumption of a heat pump system consisting of three 90 ton nominal capacity groundwater supplied heat pumps operating in parallel at 68 US gpm per unit (Waterfurnace 2002).

1. The presence of two relatively warm water aquifers below Vanier School has been confirmed by the completion to test well TH02-01. These aquifer systems consist of:

   - The lower portion of the **Selkirk Aquifer**, composed of sand and gravel between depths of 54.9 m and 60.4 m below ground surface (5.5 m aquifer thickness at TH02-01).
   - **Miles Canyon Basalt Aquifer**, composed of fractured basalt bedrock between depths of 60.4 and 143.1 m below ground surface (82.7 m aquifer thickness at TH02-01).

2. The Selkirk Aquifer appears to have potential to meet the anticipated heat pump source water flow requirement of 12.9 L/s (204 USgpm). Furthermore, a properly sized well (i.e. 254 mm nominal diameter) across the entire thickness of the Selkirk Aquifer at this location would likely produce maximum long-term yields in excess of 25 L/s (330 igpm).

3. Long-term maximum well capacity of TH02-01 as completed in the Miles Canyon Basalt Aquifer is estimated at 10.6 L/sec. Therefore, if this well were to be used, the target yield of 12.9 L/s (204 US gpm) will potentially lower water levels in the well below the safe available drawdown. To overcome this problem, two production wells would likely required to produce the desired flow rates.

4. Stabilized temperatures of pumped groundwater measured during the pumping tests were as follows:

- 5.8^{o} C from the Selkirk Aquifer on July 28th, 2002; and

- 6.9 to 7.1^{o} C from the Miles Canyon Basalt Aquifer on December 3rd to 6th, 2002.

Very little fluctuation in the pumped groundwater temperatures was observed throughout the pumping test.

5. In-situ groundwater temperatures within the Miles Canyon Basalt Aquifer ranged between 5.8^{o} C to a maximum of 8.9^{o} C with a relatively linear temperature increase with depth.

6. Groundwater quality from both aquifer systems is relatively good and meets all of the tested health based Canadian Drinking Water Quality Guidelines and Yukon Contaminated Sites Regulations Aquatic Life standards. No significant scaling or corrosion of heat pump equipment is anticipated with respect to groundwater usage from either aquifer system. The average hardness (as $CaCO_3$) in groundwater from the overburden and basalt aquifer at TH02-01 is 87 mg/L and 113 mg/L respectively.

7. Quality of groundwater from samples collected during the short term pumping test in the Selkirk Aquifer met the health related Canadian Drinking Water Quality Guidelines (2002) (CDWQG) for the parameters tested, with the exception of turbidity. The tested parameters from samples collected from the Selkirk Aquifer were also found to meet the Yukon Contaminated Site Regulations (YCSR) Aquatic Life Standards (Yukon Department of Environment 2002). It is anticipated that with additional well development, a production well completed within this aquifer could produce acceptable turbidity levels. The water quality results from the Selkirk Aquifer also indicate an exceedance of the CDWQG Aesthetic Objective (AO) for total iron concentrations. It is suspected that elevated total iron concentrations may be related to the presence of elevated turbidity and with adequate well development acceptable iron concentrations will be achieved. Groundwater from the City of Whitehorse's well field, completed within the Selkirk Aquifer, typically produces groundwater that meets the CDWQG for both turbidity (1 NTU) and total iron (0.3 mg/L).

8. Groundwater samples collected during the short term pumping test in the Miles Canyon Basalt Aquifer were found to meet all of the tested health related CDWQG (2002). Concentrations from all tested parameters in groundwater samples collected from the Miles Canyon Basalt Aquifer were also found to meet the YCSR Aquatic Life Standards (Yukon Department of Environment 2002). However, the average manganese concentration in analyzed groundwater from the Miles Canyon Basalt Aquifer was 0.13 mg/L, which exceeds the CDWQG AO for manganese (0.05 mg/L). Based on other wells completed with the Miles Canyon Basalt Aquifer however, it is suspected this marginal exceedance may also be related to slightly elevated turbidity and may decrease in time with additional well development and/or future well usage.

9. A summary of well construction details and estimated aquifer properties is presented in Table 8 below. The data presented from the Selkirk Aquifer was collected during the short-term pumping test described in this report. The data presented from the Miles Canyon Basalt Aquifer was collected during the 72-hr long-term pumping test described in Appendix B.

Table 8. Summary of Results from TH02-01

Parameter	Selkirk Aquifer Step Test July 28, 2002	Miles Canyon Basalt Aquifer 72-hr Pumping Test Dec 3 - Dec 6, 2002
Total Well Depth (m bgs)	56.41	146.53
Screen/Production Interval (m bgs)	55.34 – 56.41	60.4 – 143.1
Static Water Level (m bgs)	4.85	5.08
Pumping Test Rate	L/sec (minimum) 4.17 L/sec (maximum)	8.98 L/sec (constant rate)
Pumping Test Duration	340 min.	72 hours
Maximum Observed Pumped Drawdown	1.63 m	39.28 m
Safe Available Drawdown	54.9 m	60.4 m
Estimated Average Aquifer Transmissivity	83 m^2/day	18 m^2/day (Dec, 2002)
Observed Aquifer Thickness	5.5 m	82.7 m
Estimated Hydraulic Conductivity	1.75×10^{-4} m/s	2.5×10^{-6} m/s
Estimated Long-Term Well Capacity	> 25 L/sec	10.6 L/sec
Pumped Groundwater Temperatures	5.8 º C	7.1 º C

5.2 Recommendations

Based on the conclusions, the principal recommendations of the project are:

1. Although both aquifers are productive and appear to be capable of providing a viable water source for a groundwater heat pump system, it is recommended that the Selkirk Aquifer be selected as the preferred water source for the Vanier School Project. The rationale for this recommendation is as follows:

    - The groundwater temperature differential between the two aquifers is slightly more than 1º C, and therefore the Miles Canyon Basalt Aquifer does not appear to provide a significant thermal advantage.

    - It is likely that a single production well in the Miles Canyon Basalt Aquifer at this location, regardless of diameter, may not be adequate to deliver the required flow rates.

    - At the study location, drawdown levels in wells completed in the Miles Canyon Basalt Aquifer will be greater than drawdown levels in wells completed in the Selkirk Aquifer. Consequently, pumping costs associated with well operations in the Mile Canyon Basalt Aquifer will be higher.

    - Water quality in the Selkirk Aquifer is marginally better than the Miles Canyon Basalt Aquifer, and therefore maintenance issues associated with water quality are anticipated to be reduced.

    - Due to the relatively high estimated hydraulic conductivity identified in the Selkirk Aquifer, injection of the discharge water back into this aquifer system will require a lower injection pressure and therefore will be simpler to build operate and maintain.

2. Production well(s) for this project should be completed to a nominal diameter of at least 200 mm (8-inch) to accommodate submersible pumps capable of producing the required flow rates. Additionally, the pump should be set to a depth whereby a minimum 10 m water column will be maintained above the pump at all times to reduce the potential for degassing of the groundwater (i.e. aeration) which can lead to a significant reduction in pump efficiency.

Report Prepared By:

Jonathan Kerr, M.Sc.
Hydrogeologist

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Appendices Provided in Report Hardcopy