**RESOURCE ASSESSMENT FOR HEAT POTENTIAL STUDY**

**VILLAGE OF HAINES JUNCTION, YT**

**Project No. 1240049**

**October 2003**

# RESOURCE ASSESSMENT FOR HEAT POTENTIAL STUDY

## HAINES JUNCTION, YT

Submitted To:

Lessoway Moir and Partners

Prepared by:

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Project No. 1240049

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**Executive Summary**

In the fall of 2002, a new water supply well was completed for the Village of Haines Junction (the Village) in a deep artesian aquifer bearing warm water. Recognizing the prospective economic and environmental benefit to the Village of Haines Junction, the Village has entered into a joint venture agreement with Energy Solutions Centre (ESC) to promote, study, and determine the feasibility of utilizing heat energy from groundwater for space heating in the Haines Junction as a means of reducing/displacing fossil fuel use.

The project team consisting of Lessoway Moir and Partners, EBA Engineering Consultants (EBA) and Quest Engineering Group were contracted by the Joint Venture to provide engineering and hydrogeology services to study and determine the feasibility of utilizing heat energy from this new water supply well (Well #5). EBA's role on the project team was to provide hydrogeological and geotechnical expertise for the resource assessment component of this project. Resource assessment work completed by EBA consisted of the following:

- **Data Collection and Review:** EBA collected and reviewed reports, maps, aerial and satellite photos and other relevant information to estimate the lithology and stratigraphy in the valley near Haines Junction.
- **Aquifer Testing:** EBA coordinated two short "step tests" followed by a long term pumping test. EBA also interpreted pertinent data collected by the Village of Haines Junction during the use of the supply well. The purpose of the aquifer testing was to provide information on:
    - the estimated long term capacity (sustainable pumping rate) of the well;
    - presence of aquifer boundaries (impermeable or recharge boundaries);
    - water temperature variation versus time (may be indicative of temperature gradient in the aquifer); and
    - variation in water quality versus time, if any.
- **Preliminary Aquifer Characterization:** EBA compiled the information collected during the previous tasks and built a conceptual model of the spatial distribution of both geologic structure and groundwater in the subsurface.
- **Preliminary Assessment of Subsurface Temperature:** EBA studied the vertical and spatial distribution of water temperature by using a field instrument to log water temperature at varying depths at several of the water wells in the area to obtain information on the geothermal gradient.
- **Identification of Operation and Maintenance Issues:** EBA gathered information to assess how the long-term use of Well # 5 may affect the observed artesian conditions. A preliminary conceptual hydrogeology and geothermal model was developed to estimate how the groundwater and energy conditions may vary due to the proposed extraction and

potential re-injection of groundwater. EBA also developed a program to monitor the risk associated with bacterial growth.

Based on the interpretation of the available information, the following can be concluded:

- Boundary conditions (either indicative of an impermeable barrier or of a recharge boundary) have not been identified;
- The aquifer behaves as a "leaky" aquifer with hydraulic conductivity in the order of $1 \times 10^{-5}$ m/s, assuming an aquifer thickness of 40 m. If Well #5 is pumped exclusively (no well interference), the estimated safe yield is 25.8 L/s.
- The various parameters monitored on the water flow, the water chemistry and the water temperature have indicated relatively constant conditions. The high flow rates used during the pumping test have not resulted in an apparent stress of the aquifer;
- The water chemistry and isotope analysis indicate that the water is low to moderately mineralized, of meteorological origin and has been resident in the subsurface for more than 50 years. It is probable that the groundwater originates from the Auriol range;
- Data are not available to stipulate on the size and lateral extent of this deep aquifer;
- The temperature observed in the deep aquifer has remained constant at 17°C over the period of extraction of the groundwater. The Dezadeash valley borders a series of major geologic faults and an area where the seismic activity is high. Therefore it is possible that "en route" to the deeper aquifer, the groundwater is heated as it comes in contact either with high temperature rock or thermal fluids. It appears that the heat transfer is well established, due to the constant temperature observed, and is not impacted by the change in groundwater flow generated both during the recent use of the well and the high discharge rate pump test.
- The topography of the rock substratum at the bottom of the valley, the geometry of the fracture network and faults, the contact between the deep aquifer and any warm rock or groundwater are not presently known. Therefore it is not possible to define the conceptual model that would describe the geothermal conditions in the valley.
- For the duration, and under the conditions used and tested, Well #5 has provided water of good quality and at a constant temperature of approximately 17°C. Therefore the deep aquifer in which Well #5 is completed should be considered as a source of both water and energy. However, the use of Well #5 as a geothermal source should proceed with caution to take into account the various parameters that are still unknown and that would be presently very costly to characterize. As such, EBA recommends design of mid-term and long term water and energy use should only consider using a portion of what the well has been estimated to yield. This will be done to reduce the risk of "mining" both the aquifer and the source of energy and to provide a margin of safety to adjust drinking water and energy supply management plans.

## 1.0 INTRODUCTION

In the fall of 2002, a new water supply well (Well #5) was completed for the Village of Haines Junction (the Village) in a deep artesian aquifer bearing warm water (17$^0$C). The potential to use this groundwater resource to the benefit of the community was recognized by the Village. The Village has entered into a joint venture agreement with Energy Solutions Centre (ESC) in order to promote, study, and determine the feasibility of utilizing heat energy from groundwater for space heating in the Haines Junction as a means of reducing/displacing fossil fuel use.

The project team, consisting of Lessoway Moir Partners, as lead consultant, Quest Engineering Group (Quest), and EBA Engineering Consultants Ltd. (EBA) was contracted by Energy Solutions Centre to complete the preliminary assessment and feasibility study. The components of the study undertaken by the project team include:

- A Resource Assessment
- A Demand Side Assessment, and
- A Business Case Study

As Well # 5 is the first well completed in the deep aquifer, little is known about the capacity of the aquifer to yield both water and energy. EBA's role on the project team was to provide hydrogeological and geotechnical expertise for the resource assessment component of this study.

In any subsurface investigation, the quality of the data, the more special the data, and the larger the data set, all result in a higher level of confidence in the data. In this study, however, the cost of additional wells completed within the deep aquifer in which Well #5 is completed would be significant. For this reason, the resource assessment was designed in a phased approach. The first phase consisted of reviewing existing information and collecting new information at a relatively low cost in order to build a business case and identify feasible options for using warm water for drinking, heating and cooling purposes. The second phase will consist of collecting the required information to complete a pre-design, after business decisions have retained selected options. The results of this first phase of the resource assessment are reported herein.

This report has been prepared in accordance with generally accepted hydrogeological practice and engineering judgement has been used in the development of conclusions and recommendations. For additional information and limitations regarding the use of this report, please refer to the attached General Conditions, which form a part of this report.

## 1.1 Objectives and Methodology for Resource Assessment

The work program methodology consisted of the following:

**Task 1 - Project Start-up**

All the team members attended a kick-off meeting that was facilitated by Lessoway Moir Partners. The main purpose of the meeting was to ensure that there was an understanding of the "global picture" and of the potential interaction of the various elements of the projects, from source to tap and from extraction to re-injection. The proposed tasks and schedules were reviewed, and the project milestones and communication protocols confirmed.

**Task 2 - Data Collection and Review**

EBA collected and reviewed reports, maps, aerial and satellite photos and other relevant information to estimate the lithology and stratigraphy in the valley near Haines Junction. This task was conducted with the following objectives:

- to produce a map showing the estimated approximate extent of the deep aquifer;
- to identify if there are geological data indicative of thermal conduits (e.g. faults) to which the deep aquifer could be connected; and
- to complete a preliminary definition of the thermal gradient in the overburden, based on temperature information previously collected during the drilling and completion of boreholes (water wells or geotechnical boreholes) in the area of Haines Junction.

**Task 3 - Aquifer testing**

EBA coordinated two short “step tests” of 20 and 23.5 L/s followed by a long term pumping test at a constant pumping rate of approximately 27 L/s (360 Igpm) at Well #5 in July 2003. Well locations are indicated on Figure 1 (page 3).

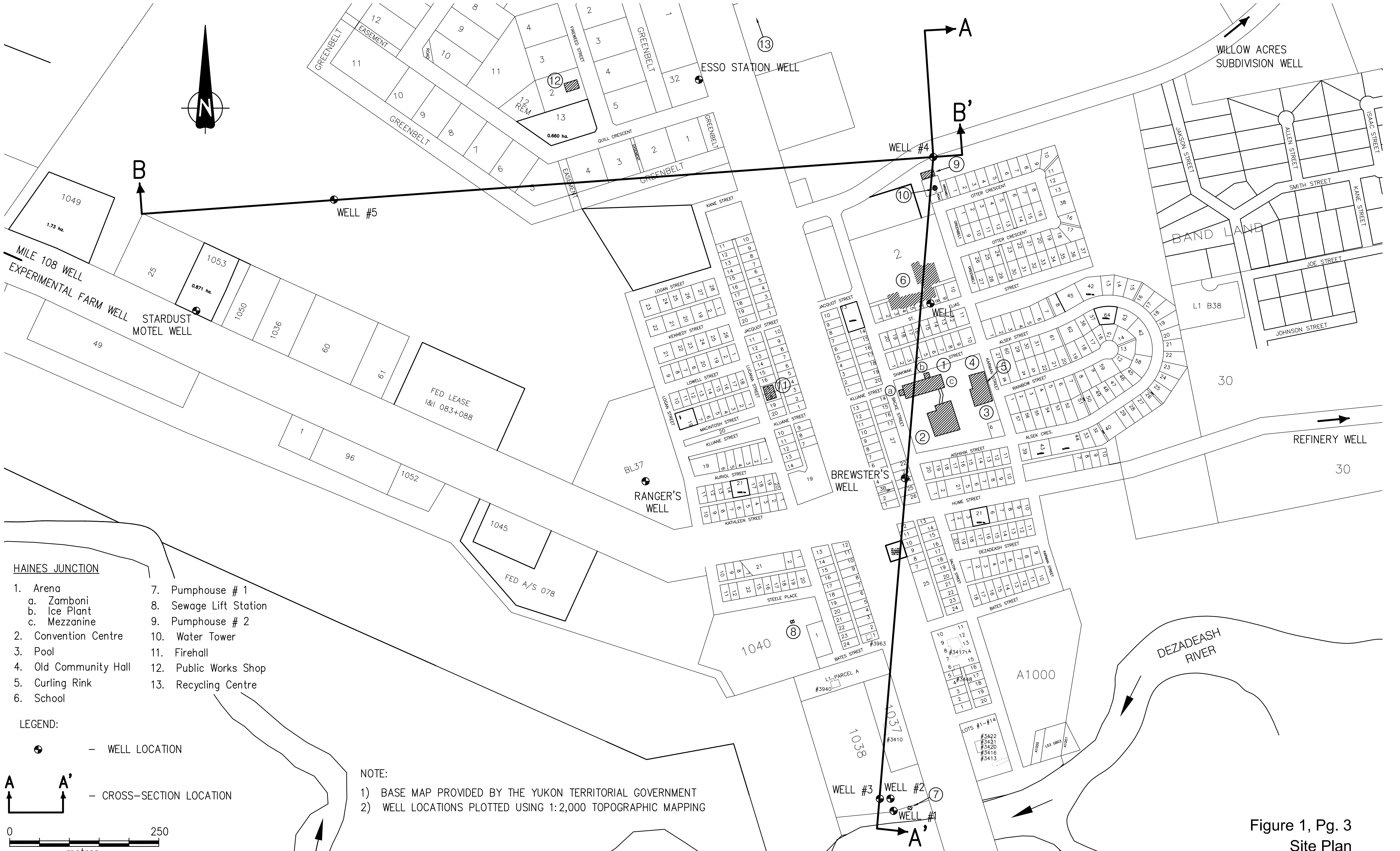


Figure 1, Pg. 3
Site Plan
Haines Junction

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Water level drawdown was monitored in the pumping well and at other locations to provide information on the impact of pumping on identified aquifers and aquitards. EBA installed electronic dataloggers in Wells #2, and #4 (the Village already has one in Well #3), and continuously monitored the variation of water levels for the whole duration of the pumping test. Water levels were also monitored manually and periodically for calibration purposes (quality control).

A water sample was collected and submitted for drinking water quality analyses (except coliforms) and also for bacteriological activity reaction tests (BART™). BART™ testing is conducted to assess the presence, size and level of aggression of common subsurface bacteria that can have a significant impact on the long-term operation and maintenance of water wells. A GPS survey to collect information on the location and elevation of the monitoring locations was also conducted.

Task 3 was completed to provide information on:

- the estimated long term capacity (sustainable pumping rate) of the well;
- aquifer parameters including transmissivity and storativity (if possible);
- presence of aquifer boundaries (impermeable or recharge boundaries);
- water temperature variation versus time (may be indicative of temperature gradient in the aquifer); and
- variation in water quality versus time, if any.

**Task 4 - Preliminary Aquifer Characterization**

Task 4 consisted of compiling the information collected during the previous tasks and building a conceptual model of the spatial distribution of both geologic structure and groundwater in the subsurface, and assessing potential links between the various identified aquifers and aquitards. If sufficient data had been available, groundwater flow direction and hydraulic gradients would have been estimated.

**Task 5 - Preliminary Assessment of Subsurface Temperature and Geothermal Analysis**

EBA studied the vertical and spatial distribution of water temperature by using a field instrument to log water temperature at varying depths at several of the water wells in the area to obtain information on the geothermal gradient. In addition, EBA reviewed climate and soil data to estimate the geothermal conditions of the soils at shallow depths (for future civil engineering or infrastructure upgrade work), and also to complement the assessment of groundwater temperature. EBA completed the following:

- gathered meteorological and soils data for Haines Junction area.
- calculated soil thermal properties based on grain size and moisture contents.
- generated a one dimensional soil temperature profile. Our team partners have used this information to calculate seasonal heat losses from the pipe distribution system to ground.

**Task 6 - Identification of Operation and Maintenance Issues**

EBA gathered information to assess how the long-term use of Well # 5 may affect the observed artesian conditions. A preliminary conceptual hydrogeology and geothermal model was developed to estimate how the groundwater and energy conditions may vary due to the proposed extraction and potential re-injection of groundwater.

The extraction of water at these temperatures will enhance the development of subsurface bacteria, thus accelerating bio-fouling phenomena that are commonly observed in water supply wells. As such, a preliminary characterization of the native bacterial population was conducted using BART™ tests. Based upon these BART™ results, EBA developed a program to monitor the risk associated with bacterial growth and if necessary, EBA could develop an outline for maintenance and bio-fouling mitigation.

**Task 7 - Reporting and Project Management**

Results of the study are presented in this report, which is the result of several reviews of a previously submitted draft copy.

### 1.2 Authorization

EBA was authorized to complete the work program by Lessoway Moir Partners. The work program has been completed in a phased approach in conjunction with other phases of the overall project.

## 2.0 TECHNICAL BACKGROUND INFORMATION

The following sections provide some technical background for the remainder of this report.

### 2.1 Geothermal Energy, Gradients and Hydrodynamics

The Earth is a storehouse of geothermal energy that is produced internally by radiogenic heat production (heat produced by radioactive decay) and long-term cooling of the planet. While regionally variable, the ground temperature increases by about 15 to 30 degrees Celsius per 1000 metres depth into the Earth. This means that, on average, the temperature at a depth of around 500 metres is somewhere between 7 and 15 degrees Celsius higher than the temperatures at ground surface. In regions where geothermal gradients are higher (such as parts of British Columbia), temperature increases more rapidly with depth. Typically, these high gradient areas are associated with higher than normal heat flow resulting from geological causes such as recent volcanic or tectonic activity.

### 2.2 Aquifer Thermal Energy Storage (ATES) Systems – Applications and Aquifer Characterization

This section is intended to provide some background on the concept of aquifer thermal energy storage systems (ATES), which are referred to later in this report. Much of the information presented in this section was obtained from the review of a draft paper titled “Aquifer Thermal Energy Storage Systems” (Bridger and Allen, 2003).

The Earth's temperatures remains relatively constant over time except in the very near surface where seasonal fluctuations in ground temperature can extend to depths of several metres (such as in the Yukon where we experience ground freezing on a seasonal basis). This constancy of the temperature in the Earth’s surface makes it an ideal medium for energy storage. ATES refers to the storage of heated or chilled water in aquifers. This form of storage usually entails the injection of heated or chilled water during periods of low demand through a drilled well into an aquifer for storage. When the demand is again high, the stored water, which has usually retained an adequate amount of heat or chill, is pumped from the aquifer and converted into a useable form of energy. ATES systems include 1) cold storage systems, 2) heat storage systems, 3) and combined cold and heat storage systems.

Aquifers have proven to be a viable option for long-term storage of thermal energy. The critical design components of an aquifer thermal energy storage (ATES) system are:

- A production well or wells;
- A low cost source of thermal energy;
- A heat exchanger, and;
- A demand for stored thermal energy.

Assessing the suitability of the storage aquifer is a critical step in designing an ATES system. Suitable storage aquifers are typically deep confined or unconfined aquifers located below the maximum depth of annual cyclic temperature variation.

### 2.3 Long Term Sustainability Issues

In order to assess the feasibility and long-term viability of the warm groundwater that is produced by Well #5, it is important to understand the characteristics of the aquifer in which the groundwater exists. As well, it is important to understand the heat energy mechanism. Whether the aquifer can sustain the production of "good" water at a consistently warm temperature at the necessary quantities is critical to the success of a large-scale geothermal project. Ideally, the aquifer and well, which is the conduit to the aquifer, should produce consistently warm water that is suitable for deriving both heat energy and for use as potable water. Issues that need to be addressed within this phase, subsequent phases of the resource assessment, and long term monitoring are:

- What are the characteristics of the deep aquifer?
- What is the source of heat energy?
- Will continued use of this aquifer at high discharge rates deplete or "mine" the water from this aquifer?
- Will continued use of this aquifer alter the hydrodynamics of the system, thereby changing the geothermal regime?

## 2.4 Well Maintenance Issues

### 2.4.1 Biological Activity in Aquifers and Water Systems

Iron reducing bacteria (IRB), Sulphate reducing bacteria (SRB) and Slime forming Bacteria are non-health-related bacteria; however, they can cause bio-fouling, which can clog well screens, distribution piping, pumps and valves. Biofouling can cause clogging in most parts of a groundwater abstraction system including the distribution system.

The presence of these bacteria may also impinge on groundwater quality. Iron and manganese concentrations, and the presence of iron, manganese, and sulphate reducing bacteria in a well or water distribution system are interrelated. A rotten egg or sulphur odour is commonly generated by sulphate reducing bacteria (SRB) functioning in an oxygen-free environments and reducing either sulphates or sulphur to hydrogen sulphide.

Bio-corrosion is the inducement or enhancement of the electrochemical process of corrosion by the activity of sessile bacteria in forming biofilms. SRB bacteria are the key players in bio-corrosion. Bio-corrosion can also influence the quality of water in the system through:

- Increase in iron content generating red 'rust' water,
- Release of trace metals from corroded materials into the water.

The effects of mineral content in groundwater (in particular iron and manganese) and associated biochemical processes are complex and interrelated. These processes are also affected by temperature, dissolved oxygen content and water velocity within the well screens and distribution system. Consequently, minimizing or avoiding the factors that enhance these processes thorough proper well and distribution system design, installation, and operation and maintenance can assist in the prevention of biofouling problems and the associated aesthetic effects on water quality.

### 2.4.2 Testing Methods for Bacterial Aggressivity

Biological activity reactivity tests (BART™) are a water-testing tool for bacteria that are typically associated with groundwater systems. These tests detect the presence and degree of activity (aggressiveness) of these bacteria by time lag methods. There are bacteria specific tests including those that test for the aggressiveness of iron related bacteria (IRB-BART™) and Sulphate Reducing Bacteria (SRB-BART™).

### 2.4.3 Corrosivity and Encrustation

The chemical nature of groundwater can be corrosive to the well screen; pump, piping and distribution system, or it may clog the system by depositing scales (encrustation). Corrosion also causes enlargement of screen openings and can permit sediment to enter the well (Driscoll, 1986). It is important to use a well screen fabricated from corrosive-resistant material. The well screen for Well # 5 was constructed out of stainless steel and is resistant to corrosion.

Incrusting water will deposit minerals on the surface of the well screen and in the pores of the formation just outside the screen. These deposits plug both screen openings and the formation and are problematic to remove.

Several methods can be used to determine the corrosiveness or encrusting characteristic of groundwater. These methods include:

1) Langelier Saturation Index (LSI);
2) The Ryznar Stability Index (RSI); and
3) Measuring and comparing water quality indicators of pH, dissolved oxygen, hydrogen sulphide, total dissolved solids, carbon dioxide, chlorides, carbonate hardness, iron, and manganese.
    - **pH** Low pH, less than 7, indicates that the water is acidic and corrosive, while high pH, greater than 7.5, suggests that the water will be incrusting.
    - **Total dissolved solids** If exceeding 1,000 mg/L may conduct enough electricity to cause serious electrolytic corrosion.
    - **Chlorides** If exceeding 500 mg/L corrosive water can be expected.
    - **Carbonate hardness** If exceeding 300 mg/L incrustation of calcium is likely.
    - **Iron** If exceeding 0.5 mg/L precipitation of iron is likely, although some may precipitate at concentrations of 0.25 mg/L.
    - **Manganese** If exceeding 0.2 mg/L and the pH is high, precipitation of manganese is likely if oxygen is present.

Groundwater analytical results from Well #5 are compared with these indices (Section 6.3) in order to determine whether there is any long term potential for corrosion.

## 3.0 PREVIOUS HYDROGEOLOGICAL INVESTIGATIONS

Several previous investigations relating to hydrogeology, and groundwater supply issues within the Village of Haines Junction have been completed. Relevant information was compiled from each of these reports as part of the current study and is presented in chronological order in Appendix A. Well locations, where known, are indicated on Figure 1 (page 3).

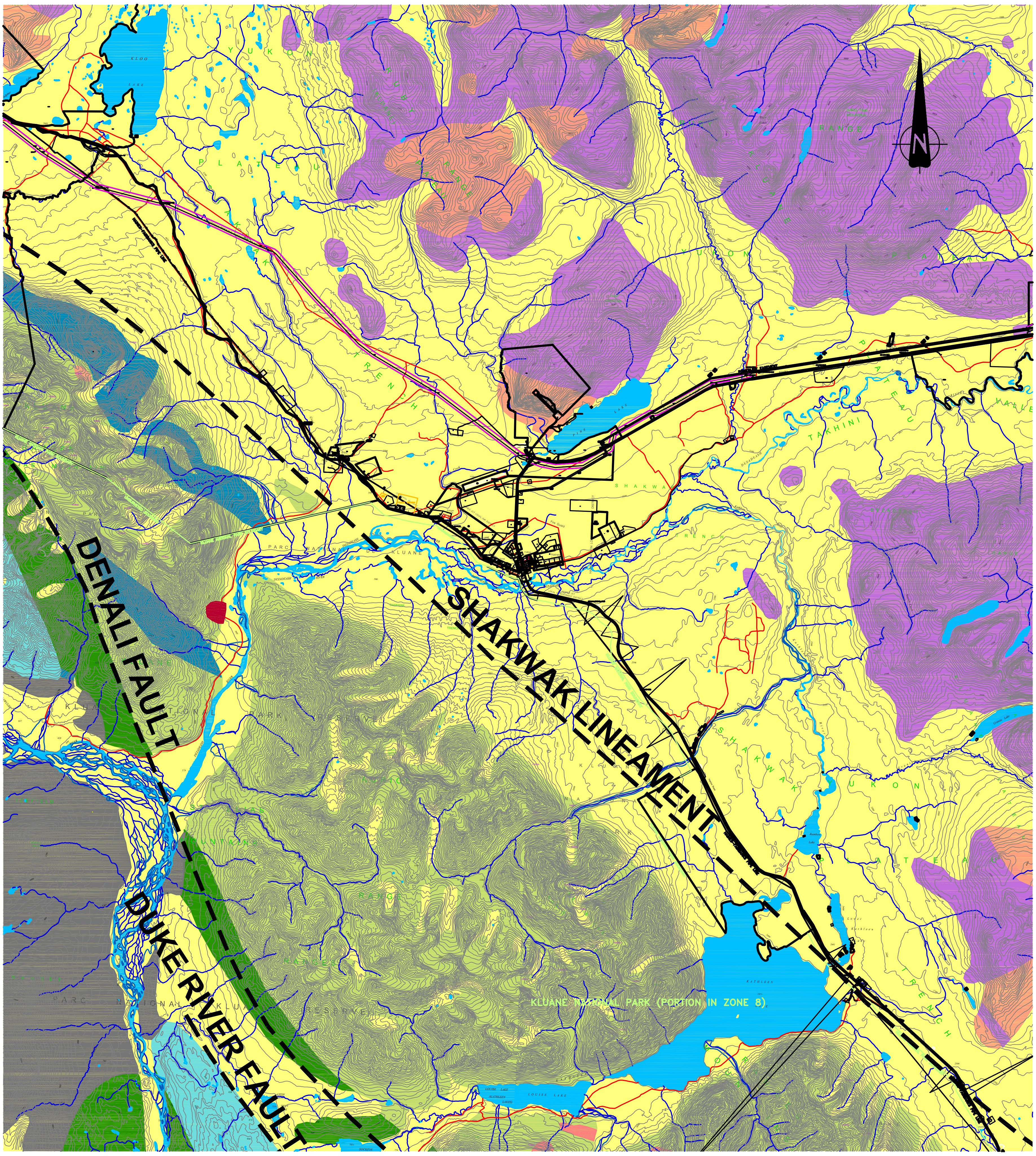
## 4.0 REGIONAL INFORMATION

### 4.1 Physiography/ Topography

The Village of Haines Junction is located 158 km west of Whitehorse, Yukon, Canada at the intersection of the Alaska Highway (Hwy #1) and Haines Road (Hwy #3). The Village is situated on the northern bank of the Dezadeash River with an approximate elevation of 600 metres above sea level (masl). Regional topography detail is indicated on Figure 2 (page 11) and Figure 3 (page 12).

Haines Junction is located within the physiographic region of the Shakwak Valley between the mountains of the Kluane Ranges, the Dezadeash Range, and the Ruby Range. Near the Village of Haines Junction the Shakwak Valley is about 13 km wide and extends from Pine Lake southwest to the Auriol Range. The topography gently increases from the Village to the foothills of the Auriol Range as indicated on Figure 2 (page 11). The Auriol Range is shown in Photograph 1 on page 13.

The Auriol Range of the Kluane Ranges is the closest range to Haines Junction and is approximately 5.5 km southwest of the Village. The Auriol Range rises steeply from the Shakwak Valley to a maximum elevation of about 2,310 masl. The Kluane Ranges are deeply dissected by V-shaped transverse valleys and are broken by major rivers such as the Dezadeash River. West of the Kluane Ranges is the Alsek River valley and the Icefield Ranges, which form the backbone of the Saint Elias Mountains and host a region of vast icefields, large valley glaciers, and high peaks such as Mount Logan at an elevation of 5959 masl.




LEGEND:

QUATERNARY
MAINLY TILL AND STRATIFIED SILTS; GLACIAL OUTWASH; SAND AND GRAVEL; TERMINAL MORAINE; ALPINE MORAINE; FLUVIATILE GRAVEL, SAND, AND SILT

TERTIARY
VOLCANIC BRECCIA, TUFF, RHYOLITE, DACITE, ANDESITE, BASALT; SOME SANDSTONE

CRETACEOUS – COAST INTRUSIONS
MAINLY GRANODIORITE; GRANITE; PORPHYRITIC GRANITE; DIORITE; AUGEN-GNEISS

GABBRO

FAULT

PERIDOTITE, SERPENTINE; DUNITE

DEZADEASH GROUP
CONGLOMERATE, SHALE, SANDSTONE, TUFF, ARGILLITE, CHERT, GREYWACKE, COAL

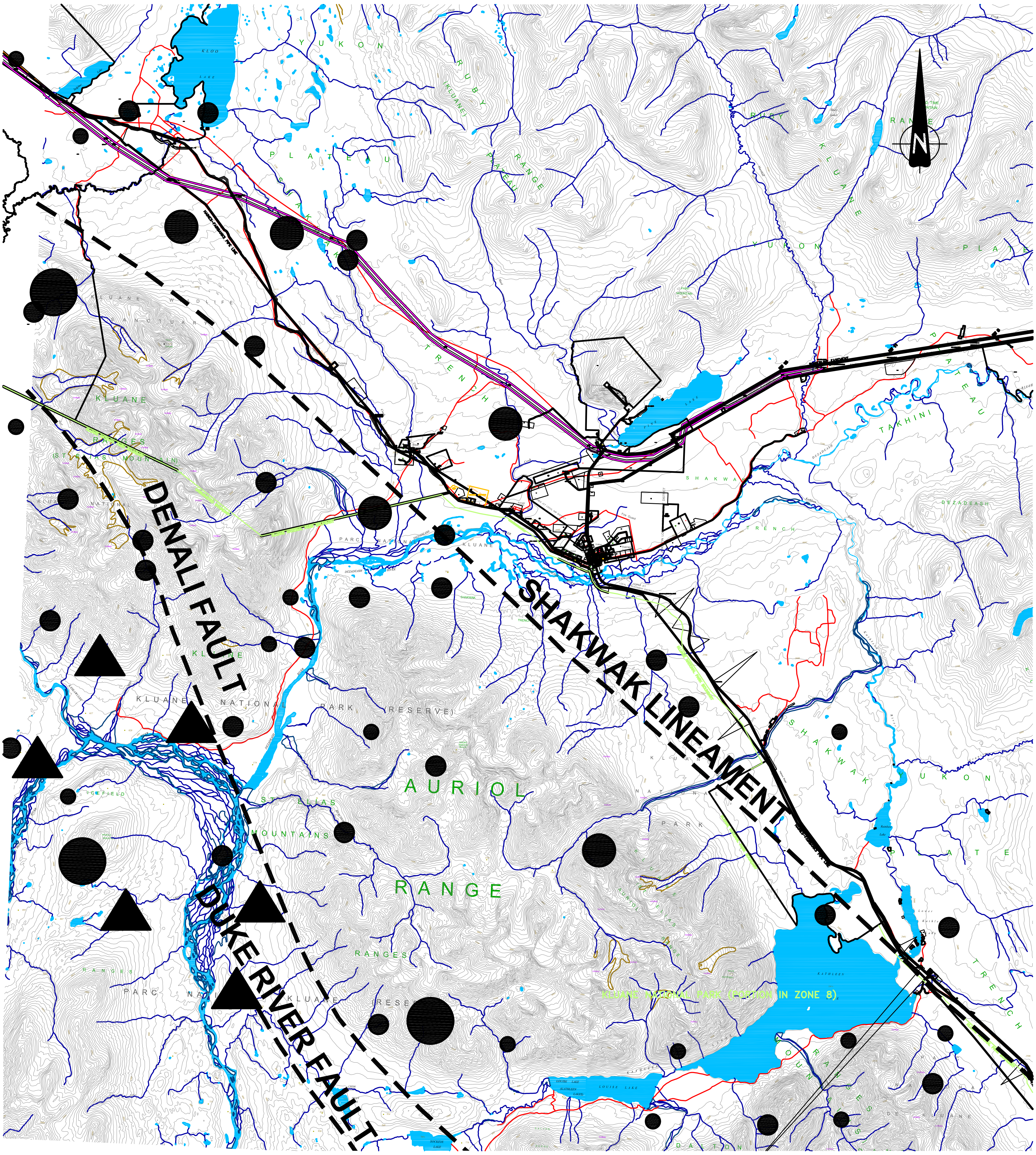
TRIASSIC AND JURASSIC – MUSH LAKE GROUP
ANDESITE, BASALT, RHYOLITE, VOLCANIC BRECCIA, TUFF, ARGILLITE, SLATE, LIMESTONE

PRECMBRIAN – YUKON GROUP
QUARTZ-MICA SCHISTS, GNEISS, SLATE, QUARTZITE, CRYSTALLINE LIMESTONE, GREENSTONE, CHLORITE AND GARNETIFEROUS SCHISTS

REFERENCES:
1) DEZADEASH, YUKON TERRITORY. GEOLOGICAL SERIES MAP 1019A, GEOLOGICAL SURVEY OF CANADA, DEPT. OF MIES AND TECHNICAL SERVICES.
2) DODDS, C.J. AND R.B. CAMBELL, 1992. GEOLOGY OF SW DEZADEASH MAP AREA (115A), YUKON TERRITORY, GEOLOGICAL SURVEY OF CANADA OPEN FILE 2190, 1:250,000 SCALE MAP.

0 10 000
metres

Figure 2
Regional Geology Map




LEGEND: SEISMIC ACTIVITY: 1971 – 2003

- MAGNITUDE < 1.1
- MAGNITUDE = 1.1 – 2.0
- MAGNITUDE = 2.1 – 3.0
- MAGNITUDE = 3.1 – 4.0
- FAULT
- RECENT VOLCANISM

REFERENCES:
1) SEISMIC ACTIVITY: 1971 – 2003, GEOLOGICAL SURVEY OF CANADA
2) MOUGEOT, C.M. AND L.A. WALTON, 1996. GEOLOGICAL PROCESSES INVENTORY MAP OF DEZEASH 115A, INDIAN AND NORTHERN AFFAIRS CANADA, OPEN FILE 1996.
3) BASE MAP ACQUIRED THROUGH THE YUKON TERRITORIAL GOVERNMENT

0 10 000
metres

Figure 3
Tectonic Activity Map

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**Photograph 1:** Looking south into Haines Junction. Auriol Range is in the background.

The Dezadeash Range and the Ruby Range form the western portion of the Yukon Plateau, which present a very different topography. The Yukon Plateau has a more subdued relief, with commonly rounded or flat mountaintops at elevations of 1,200 to 1,800 masl. Peaks up to 2,150 masl occur on some intrusive masses. The region is transected with an interconnecting network of valleys that drain into large river systems, such as the Dezadeash River. Except for the disappearance of the ice, the regional morphology has changed little since the last glaciation.

### 4.2 Geology

The geology in the region of the Village of Haines Junction consists of Quaternary sand, silt, clay and till deposits within the valleys, and partial to well exposed bedrock outcrops within the mountain ranges. The bedrock geology is described below, from oldest to youngest, followed by the Quaternary deposits.

### 4.2.1 Bedrock Geology

The Yukon Group is primarily located in the Yukon Plateau, Ruby and Dezadeash Ranges within the Haines Junction region, and generally consists of Precambrian quartz-mica schists, gneiss, slate, quartzite, crystalline limestone, greenstone, and chlorite and garnetiferous schists.

The Mush Lake Group, a thick assemblage of volcanic and sedimentary rocks, consists of fine-grained flows of green andesite, finely laminated light green tuffs, slates, and greywacke, basalt, rhyolite, volcanic breccia, argillite, and limestone. The Mush Lake Group is Triassic and/or Jurassic in age and underlies a large part of the Kluane front range, which includes the Auriol Range.

The Dezadeash Group forms most of the Auriol Range, is Lower Cretaceous in age, and consists mainly of a sequence of dull, dark grey to black, argillite and greywacke. The Dezadeash Group occurs in the axial zones of synclines, probably complicated by faults of the Kluane Range, and commonly exhibits strong internal folding. The respective ages of the Mush Lake Group and the Dezadeash Group illustrate that the geological contact is disconformable.

Coast Intrusions, consisting of mainly granodiorite, or peridotite and dunite exist within the mountain ranges and are from the Lower Cretaceous. The granodiorite intrusions of granite, porphyritic granite, diorite, and augen-gneiss are found intruded within the Yukon Group, while the peridotite and dunite intruded into the Dezadeash Group.

Tertiary volcanics are exposed west and southwest of the Auriol Range and are likely to be part of the St. Clare Group as defined within Muller (1967). The volcanics consist of volcanic breccia, tuff, rhyolite, dacite, andesite, basalt. Some sandstone has been associated with these volcanic deposits.

### 4.2.2 Surficial Geology

The most recent deposits in the Haines Junction region are the Quaternary unconsolidated and consolidated deposits. These deposits exist within river, mountain and glacial valleys, and depressions. According to Muller (1967), the Village of Haines Junction is situated within a lacustrine plain just north of fluvial floodplain of the Dezadeash River. Figure 2 (page 11) shows the regional geology and surficial geology information. Note that surrounding Haines Junction, northeast of Haines Junction along the Dezadeash River valley, and northwest and southeast of Haines Junction along the Shakwak Valley, the surficial deposits consist of glaviofluvial outwash gravels. Southwest of Haines Junction, towards the Auriol Range, the surficial deposits consist of diamicton ground moraine at the Auriol foothills, and a mixture of gravelly glacial kame deposits, till covered slopes, and gravelly glaciofluvial or fluvial fans on the slopes of the mountains.

At least three major glaciers have advanced through the Shakwak Valley and have covered the Village of Haines Junction (Muller, 1967). These glaciers deposited clay-rich tills and upon retreating, created the large pro-glacial lake, known as Glacial Lake Champagne (Day, 1962) that deposited thick sequences of clay and silt. During recent glacial surges of the late Holocene, the Lowell Glacier advanced across the Alsek Valley and blocked the south-flowing Alsek River. The resulting lake backed up into the Shakwak Valley in the vicinity of Haines Junction and created a lake, Lake Alsek, which was at least 110 km long and 200 m deep. Each lake phase may have consisted of many short-lived cyclic filling and draining events. Radiocarbon dating has indicated that there have been several phases of Lake Alsek in the last 500 years as well as one, or more, older Neoglacial episodes of ponding. The last and least extensive expansion of the lake into Haines Junction area occurred during the 19$^{th}$ century and was estimated about 1850 A.D. (Clague, 1982).

The geological materials encountered beneath the Village of Haines Junction during the drilling of Well # 5 correlate to the expected deposits from the geological history described above. These deposits consist of an alternating sequence of clayey tills and fine-grained glaciolacustrine deposits consisting of silt and clay with occasional sand and gravel lenses. A flowing artesian sand and gravel aquifer was intersected beneath this sequence from 329 to 369.2 metres below ground level (mbgl).

#### 4.2.3 Structural Geology

The Village of Haines Junction is located near two distinct major tectonic belts that may be traced far into Alaska and British Columbia. The north-eastern belt is a geoanticline that extents into Alaska, and is called the Tanana geoanticline. The south-western belt is a geosyncline that continues to the northwest as the Alaska Range geosyncline. The two regions are separated by the Shakwak lineament, which is southwest of Haines Junction.

Shakwak Lineament

The Shakwak Lineament exists within the Shakwak Valley, which separates the Yukon Group (Yukon Plateau, Ruby and Dezadeash Ranges) and the Kluane Ranges. The lineament is a major fault line that extends from beneath Dezadeash Lake into Alaska. The lineament can be identified on aerial and satellite photographs and is thought to be the hinge line for the Tanana geoanticline and the Alaska Range geosyncline, along which considerable vertical movement has occurred.

Duke River Fault

The Duke River Fault is situated west of the Auriol Range and is a structural contact between pre-Permian rocks and Permian to Tertiary rocks. The fault was active after eruption of the Tertiary lavas and suggests north-eastern thrust faulting.

Denali Fault System

The Denali fault system (DFS) extends for ~1200 km, from southeast to south-central Alaska. The DFS has been generally regarded as a right-lateral strike-slip fault, along which post late Mesozoic offsets of up to 400 km are inferred (Redfield and Fitzgerald, 1993). Some areas in the eastern segment of the DFS appear to be thrust faulting (Eck, 2003). The DFS consists of several faults, which include the Shakwak Lineament. South of the Shakwak lineament the DFS continues as the Dalton Fault, followed by the Chatham Strait Fault, which extends to the Pacific Ocean and terminates at the Fairweather Fault. The DFS continues north of the Shakwak Lineament with the McKinley, Farewell Fault, Holitna Fault, and the Togiak/Tikchik Fault (Redfield and Fitzgerald, 1993). St. Amand (1957) speculated that the DFS might be continuous with the Californian San Andreas fault system.

## 4.3 Air Photo and Satellite Photo Interpretation

Aerial photographs and satellite images of the region of Haines Junction were reviewed to help interpret the topography, physiography, geology and location of buildings. The aerial photographs were viewed under stereoscopes to identify elevation changes, geomorphology processes in the area, and surficial geology. The photographs were taken on August 28th, 1993 at the scale of 1:20,000. The satellite images showed the Shakwak Valley and Haines Junction from Kloo Lake to Dezadeash Lake and were used help delineate drainage patterns and outlying buildings within the valley.

## 4.4 Tectonic Activity

The Pacific and North American crustal plates are located west of the Village of Haines Junction, the Shakwak Valley and Kluane Ranges. The Fairweather Fault, which is only about 100 km to the southwest of the Shakwak Valley, is thought to be the present transform boundary between the two plates and is characterized by large earthquakes (Plafkar et al. 1978). Some segments of the Denali Fault System in Alaska are presently active and it is possible that the portion of the Shakwak Lineament that comprises the Denali Fault System must also be active (Clague, 1982).

Although the Denali Fault System in the region surrounding the Village of Haines Junction has been active to only a minor extent during the late Quaternary time, present-day seismicity in the region is high, as shown in Figure 3 (page 12). The seismic activity between 1971 and 2003, along with geologically recent volcanic eruptions, are plotted within this figure. Seismic activity have been monitored since 1899, but only since the establishment of the Whitehorse seismograph station in 1971 have the epicenters been more accurately detected and located. Most of the local earthquakes occur in the intensely faulted region between Shakwak, Denali and Duke River Faults in the Kluane Ranges. It has been estimated that ground accelerations of 0.1 g, the approximate threshold of accelerations capable of damaging ordinary structures on firm soil, have a return period of 30 to 100 years for the Shakwak Valley Area (Stevens and Milne, 1974). This demonstrates that there is potential for significant ground disruption in the region of Haines Junction.

## 4.5 Groundwater Usage and Water Well Details

### 4.5.1 Water Well Records

The Village of Haines Junction has had five municipal water wells developed for the community. Several private water wells also exist or have existed within the Village. These wells are shown within Figure 1 (page 3) and are summarized in Table 1 (page 19). Water well records were obtained from ESC who recently purchased these records from Midnight Sun Drilling. Well records are provided in Appendix B. As well, information was obtained through the review of historical reports. If available, information about the depth of the well, the static water level, existence of a well log, and water chemistry data are listed for each well in the table.

### 4.5.2 Village of Haines Junction

Currently, only Well # 3 and Well # 5 are used as groundwater supply wells. The other three water wells, Well # 1, Well # 2, and Well # 4, have not been abandoned and Well # 2 and Well # 4 were used as monitoring wells during the pump test at Well # 5. Well # 1 remains recognized, as a supply well within the water license in the event that this shallow cold well must be used for backup, however there is currently no pump installed within, nor piping to this well. The history of the groundwater wells in the Village of Haines Junction was documented earlier, a water well summary is provided in Table 1 (page 19), and the well logs are included in Appendix B.

#### Groundwater Usage

The municipal groundwater usage for the Village of Haines Junction in 2001 was reported to be 118,584 $m^3$. According to calculations provided by Quest Engineering (Quest, 2003), the average daily demand is 325 $m^3$/day or approximately 3.55 L/s. In 2001 and for most of 2002, only Well # 3 supplied the village's water supply and this demand was greater than the maximum allowable safe yield of 100,000 $m^3$/year for Well # 3. Well # 5 was connected to the Village's water distribution system beginning November 25, 2002. Both Well # 5 and Well # 3 supply the village with its municipal water. Between November 25, 2002 and July 7, 2003, Well # 5 and Well # 3 supplied the Village of Haines Junction with 22,216 $m^3$ and 39,776 $m^3$ of water with an average daily withdrawal of 98.7 $m^3$/day and 224 $m^3$/day, respectively. The water license which was amended in July 2003, allowed for only 100 $m^3$/day of use from Well #5. Since the water license was amended, and following the completion of the pump test and recovery, the Village has relied mostly on groundwater from Well #5 with some supplement from Well #3.

**TABLE 1: WATER WELL SUMMARY**

| Well Name | Approx. Elevation[A] (metres above sea level) | Depth[B] (metres below ground level - mbgl) | Static Water Level[B] (mbgl) | Aquifer Interval[B] (mbgl) | Pumping Rates[B] ($m^3$/day) | Well Logs (Yes/No) | Water Chemistry/ Water Characteristics[B] | Comments |
|---|---|---|---|---|---|---|---|---|
| **Well #1** | 582.5 | borehole: 7.6 screen: 7.0 - 7.6 | | 7.0 - 7.6 | 295 - 327 $m^3$/day | Yes | 19 Dec. 1973 (HCL 1974); 25 May 1988; 6 June 1974 Calcium Bicarbonate | Also known as: Testhole #2-74 |
| **Well # 2** | 583.0 | borehole: 134 screen: 76.5 - 78.3 | Artesian when drilled but currently not flowing | uncertain | 100 igpm during development, 45 ipgm in 1980 due to siltation (SAEL, 1980) | Yes | Medium hard, calcium-bicarbonate, 38 deg F; (HCL 1974b) Sodium Bicarbonate | Also known as: Warm Water Well #1 |
| **Well # 3** | 582.5 | borehole: 82.3 screen: 79.3 - 82.3 | -3 when drilled but currently not flowing | 78.4 - 83.2 | 690 $m^3$/day (105 igpm) during development, 298 $m^3$/day (UMA, 1988) | Yes | Both Aquifers in (HCL 1978); 25 May 1988; 3 samples in Stanley Assoc. 1980 Sodium Bicarbonate | Also known as: Warm Water Well #2 |
| **Well # 4** | 618.0 | borehole: 249.9 screen: 119.8 - 122.8 | 20 | 120.4 - 121.9 | 407 $m^3$/day but never reached due to sediment in water (UMA, 1988) | Yes | "Chemically acceptable" in David Nairne & Assoc. Ltd, 1996, but no data, Sulphate | Also known as: TW3-89 |
| **Well # 5** | 608.5 | borehole: 384.6 screen: 361.9 - 369.2 | -56.95 on July 2, 2002 | 329 - 369.2 | 2,333 $m^3$/day (GLL, 2002) | Yes | Table 3; GLL 2002 Sodium Bicarbonate | Aquifer interval from 329 mbgl to mbgl. |
| **Esso Station Well** | 613 | 60.0 | 24 | | 32.7 $m^3$/day | No | 5/25/1988 Sulphate | |
| **St. Elias School** | 612.5 | 34.0 | 26 | | 51.8 $m^3$/day | No | 6/20/1988 Sulphate | abandoned |
| **Brewster's Well** | 602 | 156.0 | Artesian | | Insufficient yield for community well | No | HCL 1974; 25 May 1988 Sodium Carbonate | NM |
| **Willow Acres Subdivision** | | 71.6 | 45.7 | | | No | High SO4 | Lot 13 |
| **Stardust Motel** | 605 | 79 (stated by owner) | 20 | | Tranmissivity = 4.8 $m^2$/day | No | Small print in HCL letter of March 13, 1997 Sodium Carbonate | |
| **Ranger's Well** | | 165.0 | 8.5 | 12.2 - 15.8 | | Yes | | Located at Park's Canada Kluane Visitor Center |
| **Sue Burton Well** | | 26.0 | | | | No | 5/25/1988 Magnesium Bicarbonate | |
| **Experimental Farm Well** | | 26 | Artesian | | | No | 5/25/1988 Sodium Bicarbonate | |
| **Refinery Well** | 590 | 6 to 9 | | | | No | Calcium Bicarbonate | obstruction in well water was hauled from well to supply the town |
| **Mile 1018 Well** | | | | | | No | Temp: 36 deg F Sulphate >800 mg/l iron: 1.7 mg/l very hard: 563 mg/l Sulphate | very poor water quality similar water quality to Pine Creek |

Note:
A) Elevations based on published reports or 2m contour mapping.
B) Well depths, static water levels, and water chemistry based on published reports or field measurement data.

### 4.5.3 Private Groundwater Wells

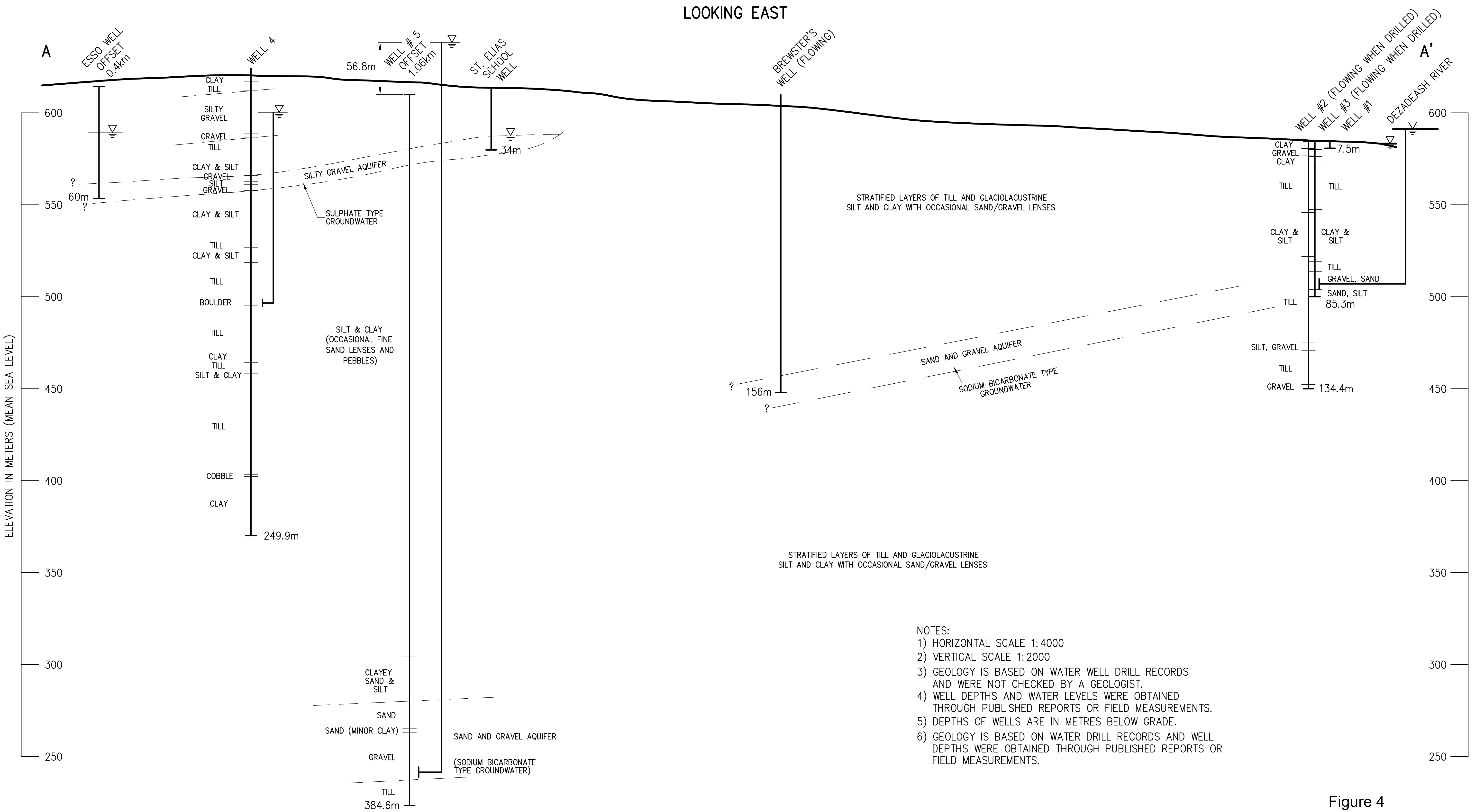
Ten private groundwater wells are known to be located within the vicinity and Village of Haines Junction. These private wells are known as the Esso Station Well, also referenced as the Hotte well (now a Fas Gas Station), St. Elias School Well, Brewster's Well, Willow Acres Subdivision Well, Stardust Motel Well, Ranger's Well, Burton Well (location unknown), Experimental Farm Well, Refinery Well, and the Mile 108 Well. The details on each well vary and are listed in the water well summary table of Table 1. Typically these are low yielding wells suitable for domestic or limited community needs, such as a school or motel. The water quality also varies from good quality to very poor water quality. Some of these wells had high sulphate readings. Where possible, these wells are located on Figure 1 (page 3).

## 4.6 Inferred Lithology and Local Hydrogeology

Based on a review of water well records, surficial geology maps, and consultants reports, cross sections were developed to illustrate the lithology at the known locations, and where possible, the inferred lithology between the well locations was interpreted. Cross section A-A (Figure 4, page 21) is a north-south transect through the Village, while section B-B' (Figure 5, page 22) is an east west-transect. As indicated on the cross sections, all water wells in Haines Junction have been completed within overburden materials. No bedrock wells are known to exist in the Village.

As mentioned previously, Well #5, the deepest well completed in the area was screened within a sand and gravel aquifer that was encountered between the depths of 343 and 370 m below ground surface. There is no obvious evidence that Well #5 is completed within the same aquifer as any of the other wells in the area (based on borehole log lithology, static water levels or artesian pressures and groundwater chemistry).

Based on lithology and groundwater chemistry, it appears that the Brewster well, and Village Wells #2 and #3 are likely completed within the same sand and gravel aquifer bearing sodium bicarbonate type groundwater. This aquifer appears to have a component of dip (not likely the steepest gradient) from south to north at a grade of approximately 13%. Well # 4, bearing sulphate type groundwater is not likely completed within this same aquifer. The Esso (Hotte) well, Well #4, and the St. Elias School well are likely completed within the same silty gravel aquifer bearing sulphate type groundwater. This aquifer ranges in depth from 30 to 60 m below grade and appears to have a component of dip from south to north at an approximate grade of 5%.




NOTES:
1) HORIZONTAL SCALE 1:4000
2) VERTICAL SCALE 1:2000
3) GEOLOGY IS BASED ON WATER WELL DRILL RECORDS AND WERE NOT CHECKED BY A GEOLOGIST.
4) WELL DEPTHS AND WATER LEVELS WERE OBTAINED THROUGH PUBLISHED REPORTS OR FIELD MEASUREMENTS.
5) DEPTHS OF WELLS ARE IN METRES BELOW GRADE.
6) GEOLOGY IS BASED ON WATER DRILL RECORDS AND WELL DEPTHS WERE OBTAINED THROUGH PUBLISHED REPORTS OR FIELD MEASUREMENTS.

Figure 4

Cross-Section A-A'

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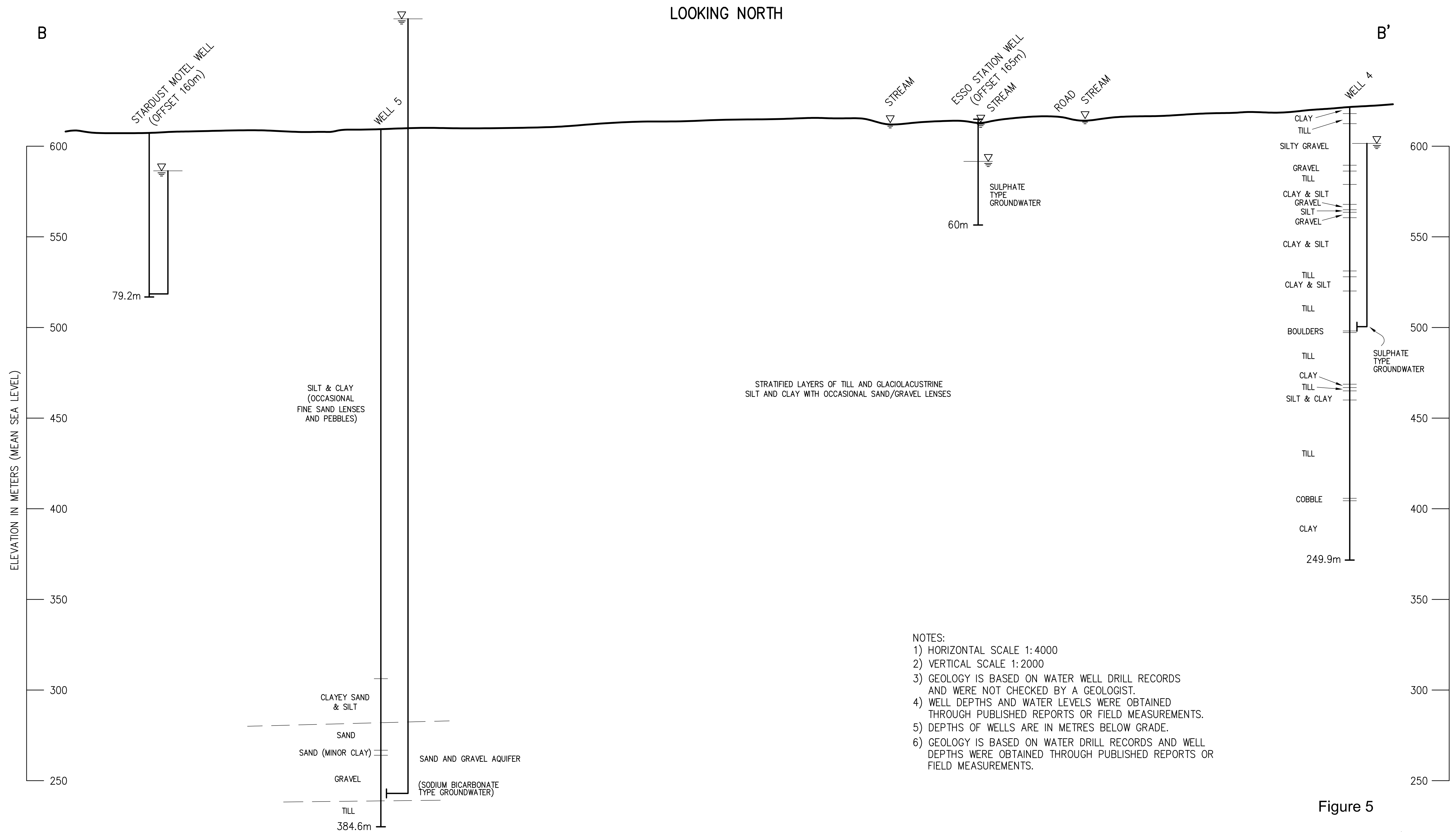


NOTES:
1) HORIZONTAL SCALE 1:4000
2) VERTICAL SCALE 1:2000
3) GEOLOGY IS BASED ON WATER WELL DRILL RECORDS AND WERE NOT CHECKED BY A GEOLOGIST.
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5) DEPTHS OF WELLS ARE IN METRES BELOW GRADE.
6) GEOLOGY IS BASED ON WATER DRILL RECORDS AND WELL DEPTHS WERE OBTAINED THROUGH PUBLISHED REPORTS OR FIELD MEASUREMENTS.

Figure 5

Cross-Section B-B'

1240049Q02a.dwg

### 4.7 Conceptual Regional Hydrogeology

Based on the geological information collected at Well # 5, Gartner Lee Ltd (2002) proposed a conceptual hydrogeological model for Well # 5. This model consisted of alluvial fans and/or deltas that have formed off the slope of the Auriol Range (see Photograph 1 on Page 13) south of the Dezadeash River as a result of deposition as either deltas directly into Glacial Lake Champagne or as fans during periods of fluctuating lake levels. Their model shows a confining layer of glaciolacustrine silt and clay with occasional sand lenses and a till layer between the inferred bedrock and the fans/deltas. Based on the information collected during the review of maps, historical reports, water well records, and the results of the field program, EBA has revisited the conceptual model in light of the new information. This is presented in Section 7.1.

## 5.0 FIELD PROGRAM METHODOLOGY

### 5.1 Aquifer Testing

In July 2003, the Yukon Water Board issued an amendment (amendment one) to the original Type B water license (MN99-027) for the Village of Haines Junction. This amendment provided authorization for the use of Well #5 (in addition to Wells 1 and 3 already listed on the water license) for water supply in the Village of Haines Junction. The amendment provides authorization for extraction of up to 667 $m^3$/day (7.7 L/s) as well as provisions for two pump tests at maximum discharge rates of 2333 $m^3$/day (or 27 L/s).

EBA was on site between July 7$^{th}$ and 13$^{th}$ to coordinate and supervise the pumping tests conducted at Well #5. EBA contracted Aqua Tech supplies and services Ltd. to supply and install a submersible pump capable of pumping in excess of 27 L/s at the expected head requirements for temporary use during the test. Aqua Tech also provided the necessary equipment (generator, flow meter, discharge pipe, trash pump etc.). The equipment set-up is shown in Photograph 2 on page 24. The pumping tests conducted by Aqua Tech and supervised by EBA consisted of a 2-hour step rate test followed by a 69-hour constant rate test.

Groundwater was piped through a 150 mm diameter lay-flat hose and some lengths of 200 inch diameter PVC pipe to a low lying area approximately 250 m northeast of the pumping well (See Photograph 3 on Page 24). The water then flowed overland on top of the till ground surface and was ultimately discharged to the sewage outfall ditch in accordance with the Water License amendment (Photograph 4 on Page 25).

**Photograph 2**: Set-up for pumping test. Note: Generator on trailer deck (left), trash pump beside wellhead, canopy over well head (right) and discharge line running north-west from wellhead.

**Photograph 3**: Discharge line running northwest into wooded area, towards sewage outfall ditch.

**Photograph 4:** Discharge during test flowing overland into sewage outfall ditch.

**Photograph 5:** Well flowing under Artesian pressure prior to beginning of pump test.

### 5.1.1 Well Shut down

The Village of Haines Junction has used Well #5 to provide approximately 100 $m^3$/day for water supply since November 26th, 2002. The well flowed under artesian pressure to Pumphouse 2 indicated on Figure 1 (page 3), where it was chlorinated and then flowed under artesian pressure into the water tower.

On Monday, July 7th 2003, at the request of EBA, all artesian flow from the well was closed off on the valve at the wellhead. The well was then allowed to recover over a period of approximately 36 hours. Pressure at the wellhead was monitored, and prior to opening of the well at 13:00 hours on July 8th, the pressure had increased to 81 psi, or equivalent to 56.95 m of water column above the wellhead. This was assumed to be the static water level prior to the pumping test. Note that this static level is slightly lower than the artesian pressure head of 84 psi (59.06 m of water column) observed by Gartner Lee in October 2002 when the well was drilled. This difference of artesian pressure at the wellhead could be accounted for by one or more of the following explanations:

- Seasonal fluctuations of the water level in the recharge end of the aquifer; and/or
- Incomplete recovery of the Well over the 36 hour period of well closure, and/or
- Atmospheric Pressure fluctuation effects on artesian pressure in a confined aquifer, and/or
- Accuracy of the pressure guage(s) used between these monitoring events, and/or
- The static water level had decreased over the seven months of use between well construction and the July pumping tests.

### 5.1.2 Pump and Monitoring Equipment Installation

At 13:00 on Tuesday July 8th, the well cap on Well #5 was removed to facilitate pump installation. With the well cap removed, the well flowed freely from the 150 mm diameter Victaulic connection on the side of the well casing. The discharge was piped into a temporary “discharge basin” (See Photograph 5 on page 25). The water from the basin was then pumped with a 100 mm turbine pump through a 150 mm diameter discharge line to the discharge area. The flow rate under artesian pressure was approximated by two different methods. The volume discharged to the basin was measured (based on the dimensions of the basin) over a finite time interval. Based on this calibration test, it was calculated that the pump was flowing under artesian pressure to the basin at a rate of approximately 12.4 L/s. Just prior to the first step of the pump test, when the well was pumping through the flow meter to the discharge basin, the flow was gauged at approximately 10.8 L/s. The difference in these two flow rates is explained by the resistance provided by the flow meter and the 245 m of discharge line. Since the discharge during artesian flow was routed to the discharge tub, prior to being pumped by a trash pump through the discharge piping, the friction losses from the piping would not have restricted the flow from the well. Therefore, the measure of flow at the discharge basin, although a crude measure, is likely more accurate than this other method. Hence, it is assumed that the well flowed under artesian pressure at approximately 12.4 L/s from the time that the wellhead was opened for pump installation for 24 hours prior to the test. In essence, the well discharge test was initiated once the wellhead was opened.

While the well was opened and flowing, a 3 phase multi stage submersible pump capable of pumping at 27 L/s was installed in the well. Pump specifications and a pump curve for this pump are included in Appendix C. The pump is made entirely of stainless steel and is fitted with a built in check valve. At a rate of 430 USgpm (27 L/s) the pump can provide approximately 102 m of head at an efficiency of 75.1%. The pump is equipped with a 50 hp Franklin 6 inch motor and Model 3853500-6, 4 inch discharge Grundfoss pump end. AquaTech set the pump intake at a depth of 99.97 m below the top of the well casing. The submersible pump was connected to one hundred meters of 100 mm diameter schedule 40 steel threaded pipe, suspended from the top of the casing.

A 100 mm Barton Flow Totalizer® with a digital display readout was installed in-line with the discharge line to monitor total and instantaneous flow during the pump test (See Photograph 6 on page 28). The flow meter precision is reportedly 0.25%. Specifications for the flow meter are included in Appendix C. The flow meter was installed according to manufacturers recommendations at a distance greater than 5 pipe diameters from the nearest fitting or instream device. A mechanical thermometer with a dial display was installed within the discharge pipe, at the top of the wellhead.

Ninety one metres of 25 mm diameter threaded PVC piping was installed within the well casing, alongside the piping to a depth of 91.5 m below the top of the wellhead. The purpose of this "dip tube" was to allow access of the water level meter to monitor water levels within the well without risk of the measuring device tangling with the electrical wires running to the pump. The top of the "dip tube" was 0.30 m above the top of the wellhead. This was used as the datum or reference point for all water level measurements during the pump test (See Photograph 7 on page 28).


**Photograph 6:** Barton flow totalizer flow meter measuring instant and total flow during second step of pump test (380 Usgpm)

**Photograph 7:** Obtaining manual water level readings during pump test at Well 5.

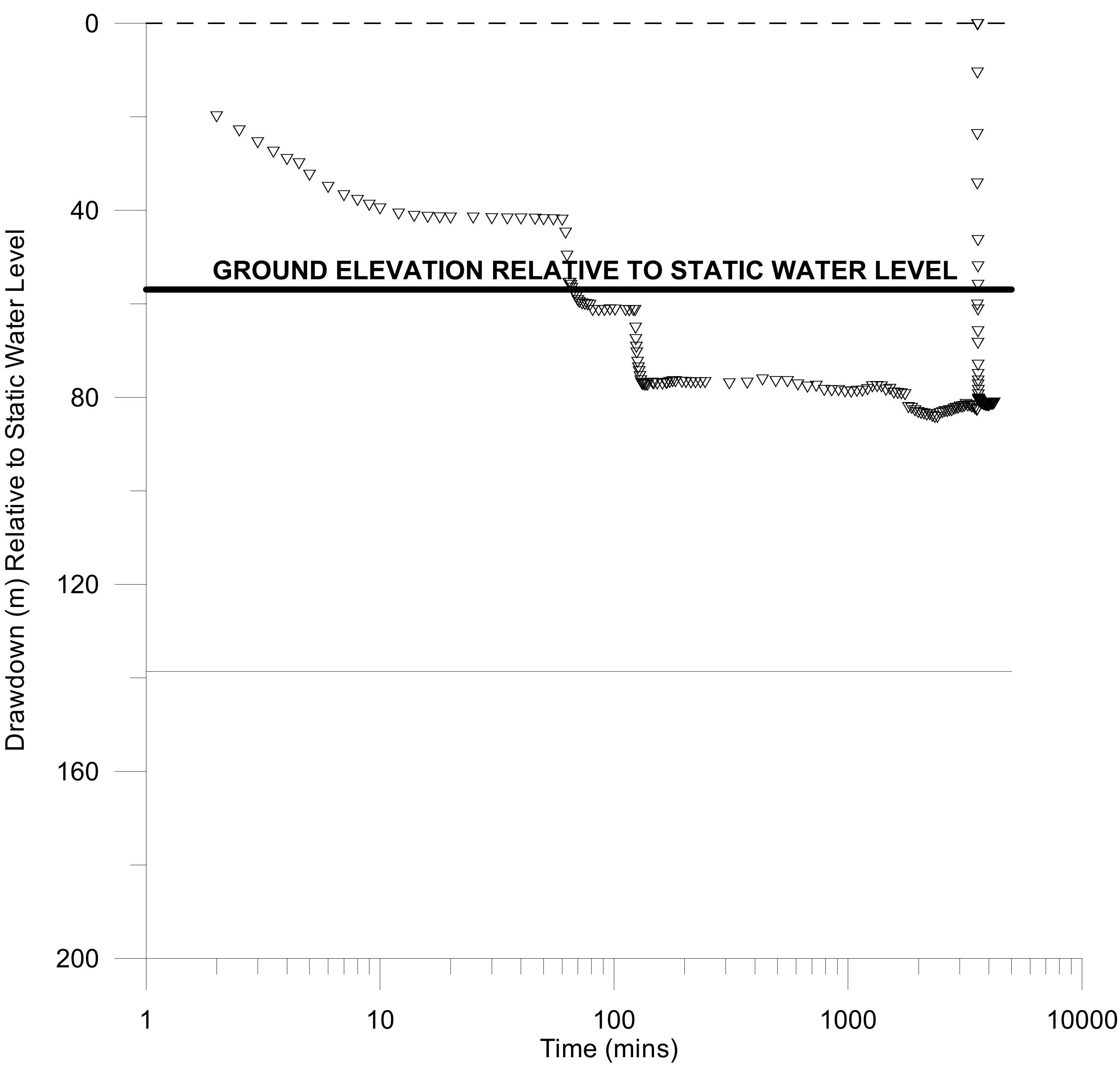
### 5.1.3 Step Test

A step rate pump test was conducted to verify the optimum pumping rate for a long-term test, and to see if the specific yield of the well was consistent with the observations made by Gartner Lee Ltd. (GLL) during the pumping test completed in Oct. 2002. The maximum pumping rate during the GLL pump test was 19.1 L/s. By design, the first step of the July 2003 test was completed at approximately the same discharge rate as the final GLL step (20 L/s). Flow rates were varied during each of the steps by adjusting the gate valve such that the desired flow rate was observed on the flow meter.

The first step test was started at 13:31 PM on July 9$^{th}$, 2003. For the first sixty-one minutes of the test, the Well was pumped at approximately 20 L/s, then 23.5 L/s for the next sixty-one minutes of the step rate pump test. Water levels in the pumping well (Well #5) were monitored frequently following the change in discharge rate, and then regularly throughout the test. A graph indicating drawdown vs. time during the step test is provided in Figure 6 (page 30). Note that the water levels became relatively stable soon after each change in the pumping rate for each step. A graph of drawdown vs. discharge (See Figure 7, page 31) indicated that the specific capacity was consistent with previous observations by Gartner Lee. After two successive pumping steps indicated that the well was performing as expected, it was determined that the constant rate test could be conducted at the maximum pumping rate allowed by the water license. Based on a linear extrapolation of the observed drawdown vs. discharge trendline, 27 L/s is also the discharge rate that would cause drawdown to the safe available drawdown level previously estimated by GLL (140.1 m).

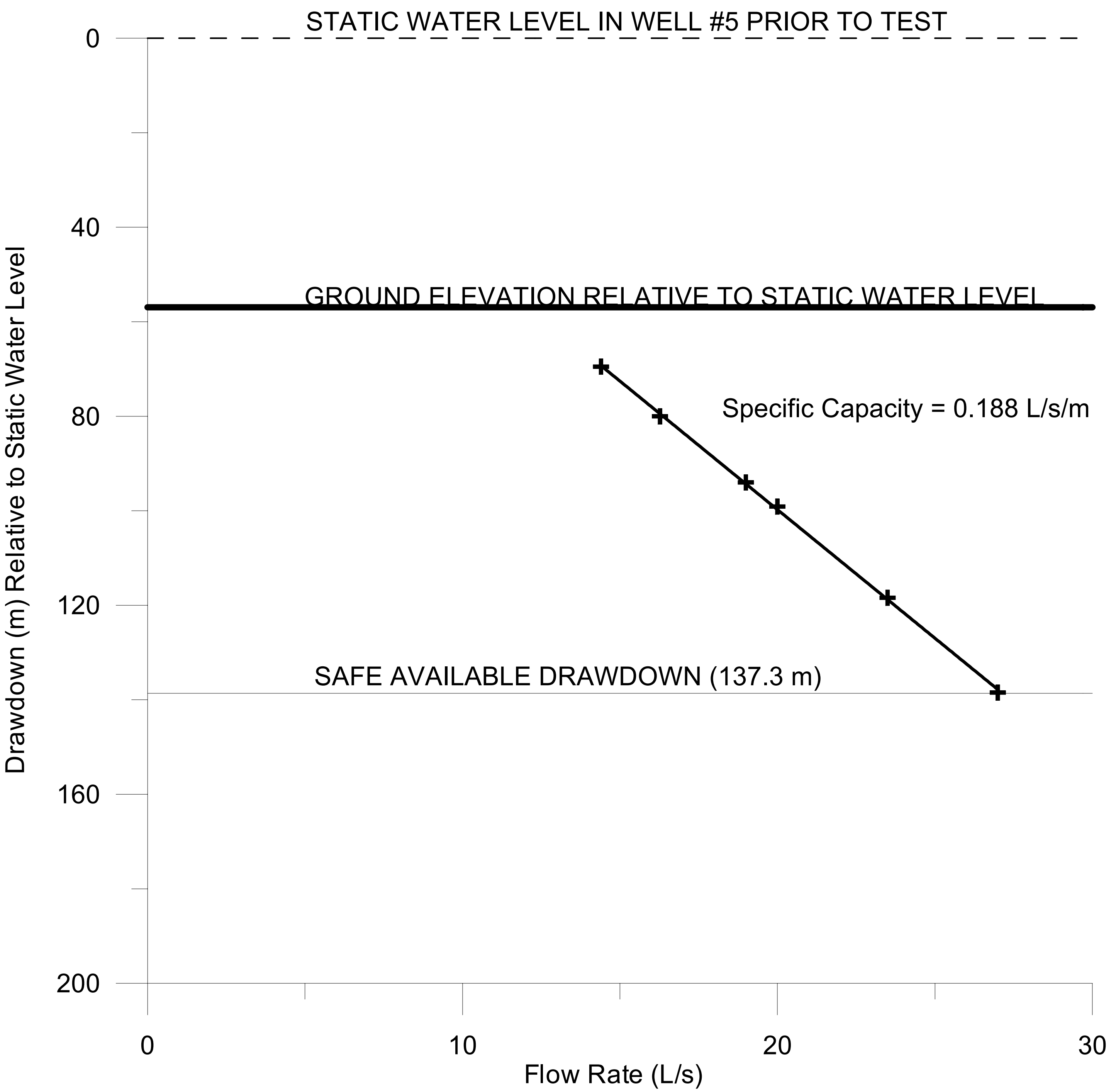
### 5.1.4 Long Term Constant Rate Pump Test

It would have been preferable to allow the well to fully recover before starting the long-term constant rate pump test. However, because the well is artesian and flow from the well could not be completely closed off with the pump and piping installed, full recovery was not possible prior to initiation of the constant rate test. There would be no genuine benefit in stopping the test, allowing it to recharge to the wellhead and then beginning the constant rate test. Hence, it was decided to progress immediately from the step test into the constant rate test. Beginning at 3:24 PM on July 9$^{th}$, pumping was initiated at Well #5 at a constant rate of 27 L/s (430 USgpm).




EBA Engineering Consultants Ltd.

| | | | |
|---|---|---|---|
| PROJECT | RESOURCE ASSESSMENT<br>ASSESSMENT OF AQUIFER | | |
| CLIENT | LESSOWAY MOIR PARTNERS for<br>ENERGY SOLUTIONS CENTRE and<br>VILLAGE OF HAINES JUNCTION | TITLE | PUMPING TEST DATA<br>STEP TEST AND<br>CONSTANT RATE TEST |
| DATE AUG. 2003 | DWN. RMM | CHKD. GW | |
| FILE NO. | 1240049 | DRWG. | FIGURE 6, pg. 30 |




| | |
|---|---|
| EBA Engineering Consultants Ltd. | PROJECT RESOURCE ASSESSMENT<br>ASSESSMENT OF AQUIFER |
| CLIENT ENERGY SOLUTIONS CENTRE<br>and<br>VILLAGE OF HAINES JUNCTION | TITLE FLOW RATE vs. DRAWDOWN<br>WELL #5 |
| DATE SEPT. 2003 / DWN. RMM / CHKD. GW | FILE NO. 1240049 / DRWG. FIGURE 7, Pg. 31 |

Water level data collected during the constant rate test is also provided in Appendix C. Figure 6 (page 30) shows drawdown vs. time for the constant rate test. Following the flow increase from the last 1 hour step to the constant rate step, the water level became relatively constant and did not continue to decline significantly or consistently after approximately 8 minutes of pumping at 27 L/s.

As can be seen on Figure 6 (page 30) undulations in the water level within the pumping well (Well #5) were observed during pumping. After approximately 11 hours of pumping, the water level dropped in elevation by approximately 1 m, and then re-stabilized. After 21 hours of pumping, the average discharge rate had fallen below 27 L/s and it was decided by the contractor that the gate valve on the discharge would be adjusted slightly to increase the average flow rate back to 27 L/s. Once adjusted the water level dropped approximately 0.8 m and it continued to drop slightly until 27 hours into the constant rate test; however, the digital display on the flow meter indicated that the discharge rate was also dropping to slightly less than 27 L/s on average. After 27 hours, the flow rate was adjusted slightly again to ensure an average of 27 L/s. The slight adjustment had resulted in a drop in the water level by almost 3 m when the next water level was taken an hour later. Again, the water level continued to drop gradually another 2 m until approximately 38 hours into the constant rate test. From 38 hours to 48 hours the water level recovered again by approximately 2 m and then remained relatively constant until approximately 56.5 hours into the constant rate test.

A coolant hose on the generator began to leak coolant at approximately 56.5 hours into the test. Sorbent spill kit material was immediately put into place to absorb any coolant under the trailer. Attempts were made to repair the leak while the generator was still running so as not to interrupt the constant rate test. With the repair attempts failing, and the generator temperature rising, it was determined that the generator had to be shut down temporarily to make the hose repair. At 12:50 AM on July 12$^{th}$, after approximately 57 hours of constant rate pumping and 59 hours of total pumping duration, the generator and pump were shut down. Recovery was monitored as often as possible as the water level responded to the wellhead. As it was recovering, the contractor switched the discharge piping from the pump discharge to the turbine pump connected to the overflow basin. The water level had fully recovered to the wellhead after 2.5 minutes and the well began to overflow into the tub from which it was pumped with the turbine pump. With the generator down, the contractor was able to repair the coolant line. At 1:08 AM on July 12th, after having been shut down for 18 minutes, the generator and pump were re-started. Water levels were monitored frequently over the first hour of the test. After one hour of pumping, the water level had dropped to within one meter of its level prior to pump shutdown. Between 1:08 AM and 12:08 PM on July 12$^{th}$ the pump test was continued at a discharge rate of approximately 27 L/s. No adjustments to the gate valve were made during this time. The water level remained very constant over this 11 hour period. At 12:00 PM, the coolant line began to leak coolant once again. The generator was shut-down again at 12:08 PM. The contractor observed that the water level had responded to the wellhead at 12:10:30 PM, two and a half minutes after pump shut-down, consistent with the previous initial recovery. Since the hose could not be repaired, the test was terminated approximately 69 hours into the "constant rate" test.

The well flowed openly at approximately 12.4 L/s while the pump and piping were removed from the well. A photograph during the removal of the down-hole piping and pump is provided as Photograph 8 on page 34. Following disinfection of the well by super chlorination through the PVC monitoring tube, the well was capped at 16:08. A pressure gauge was fitted to the discharge line on the side of the well. The specifications for the mechanical pressure gauge are provided in Appendix C. The new mechanical gauge, supplied by Aqua Tech was similar to the gauge that had been used by the Village prior to the test. The pressure at the wellhead was initially 70 psi after the cap was re-installed. This is equivalent to 49.7 m of water column at the wellhead. The difference in pressure at the wellhead relative to the start of the test (81 psi) is not unexpected, as the well was still recovering. The pressure response at the wellhead (indicative of recovery) was monitored daily over the following week by the Village. This data was very important as it provided the late time recovery data.

#### 5.1.5 Temperature Monitoring

The pumped water temperature was monitored with a mechanical gauge installed within the discharge piping at the elbow on the top of the wellhead. Water temperatures remained consistent throughout the test at 17$^{o}$C. As mentioned previously, the geophysical investigation indicated that the temperature of ground formation and groundwater within the well screen was observed to be approximately 19.75$^{o}$C during the GLL assessment. Therefore, there was approximately a 3$^{o}$C difference between the water temperature within the aquifer, and the temperature at the wellhead. At a discharge rate of 27 L/s, it would take approximately 7 minutes for water to travel from the well screen to the wellhead. It does not seem reasonable for such a significant loss in that time frame, and therefore, the hypothesis presented by GLL that the drilling mud that had been pumped into the well prior to the geophysical investigation may have influenced the observed temperature, is likely correct.


**Photograph 8:** Solinst Levelogger® and Barologger® dataloggers for monitoring water level and barometric fluctuations during pumping test.

**Photograph 9:** Aqua Tech pulling pump and piping at termination of pump test

### 5.1.6 Monitoring of Water Levels in Other Wells

Electronic dataloggers were installed in Wells #2 and #4 (the Village already has one in Well #3) to continuously monitor the variation of water levels for the whole duration of the pumping test. The Solinst® Leveloggers and Barologger (see Photograph 9 on page 34) used in Wells #2 and #4 were rented from Solinst® in Toronto. Below are the durations and time intervals for datalogger water level monitoring at each well:

- **Well #2:** 10-minute intervals from 12:00 on July 9$^{th}$ to approx. 12:00 on July 13$^{th}$.
- **Well #4:** 10-minute intervals from 17:00 on July 7$^{th}$ to 12:00 on July 13$^{th}$.
- **Well #3:** Daily max and min. One-hour intervals during pump test.

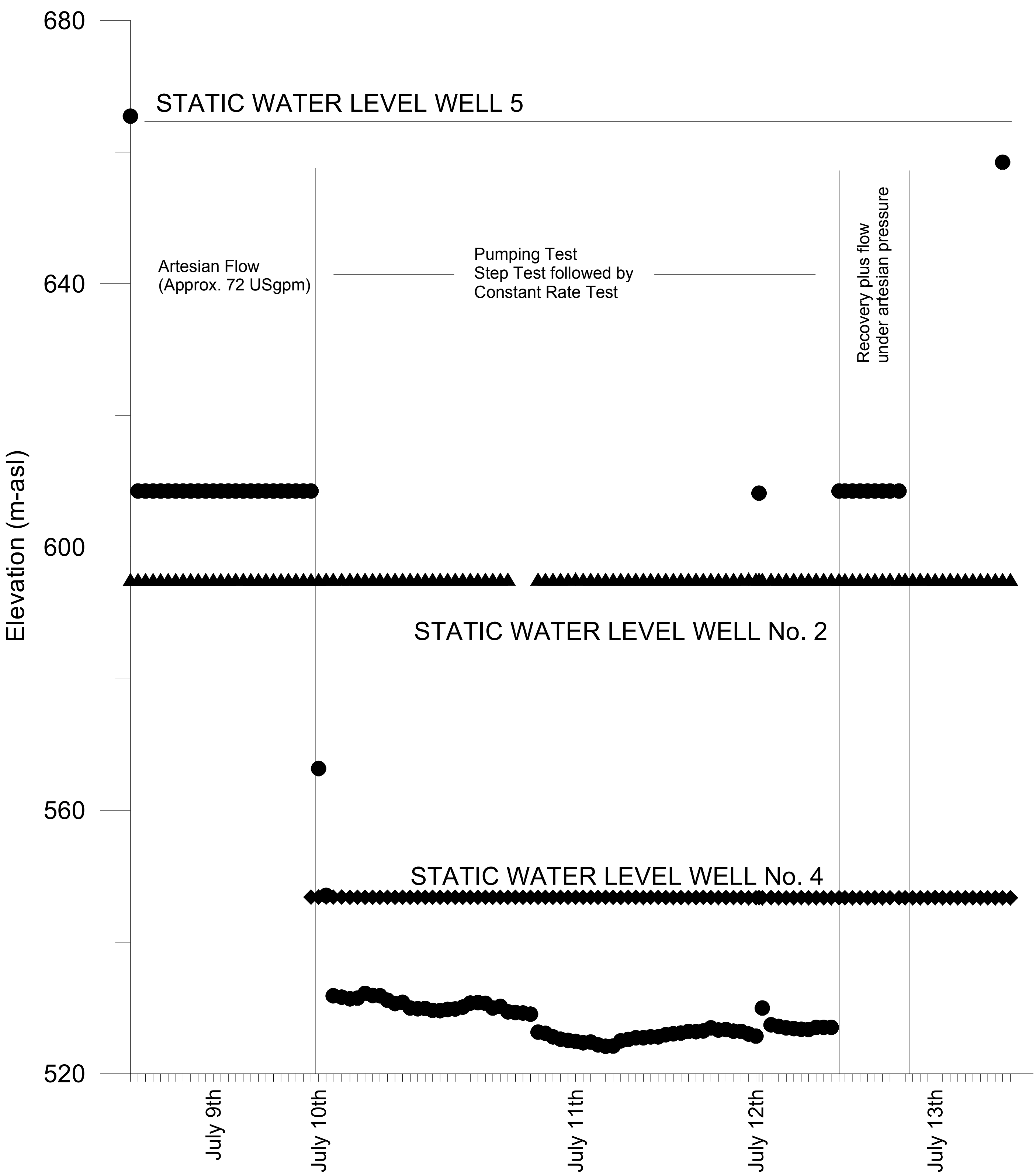
Water level observations in these other wells during the pumping test are indicated on Figure 8 on page 36. Note that no significant fluctuations in the water levels were observed. There was no indication of response at these other wells at the beginning of pumping, during the pump test, nor during recovery. This suggests that the aquifers that Well #2 and #4 are completed within are not hydraulically connected to the aquifer at Well #5.

## 5.2 Temperature Gradient Observations

A Solinst® T4 Multimeter equipped with a T4 Temperature sleeve was used to measure temperature profiles within several of the wells in the Village. As mentioned previously, the purpose of this profiling was to gather information regarding the regional geothermal gradient in the Haines Junction area. The T4 sleeve has an enclosed thermistor to measure resistance. The resistance is then be converted into temperature. Following the pump test program, the T4 Multimeter was used to obtain temperature readings at 10 foot (3.05 m) intervals within Wells #2, #4 and #5.

Well #5 Temperature Profile

An attempt was made to monitor temperature in Well #5, however, only the top 90 m above the submersible pump could be accessed for temperature readings. As well, since the water was flowing at the time of the measurements, accurate and meaningful readings could not be obtained, and the data captured was subsequently abandoned.




**EBA Engineering Consultants Ltd.**

PROJECT: RESOURCE ASSESSMENT
ASSESSMENT OF AQUIFER

CLIENT: LESSOWAY MOIR PARTNERS for
ENERGY SOLUTIONS CENTRE and
VILLAGE OF HAINES JUNCTION

TITLE: WATER LEVELS IN PUMPED WELL,
WELL No. 2 and WELL No. 4 DURING
ARTESIAN FLOW, PUMPING TEST AND RECOVERY

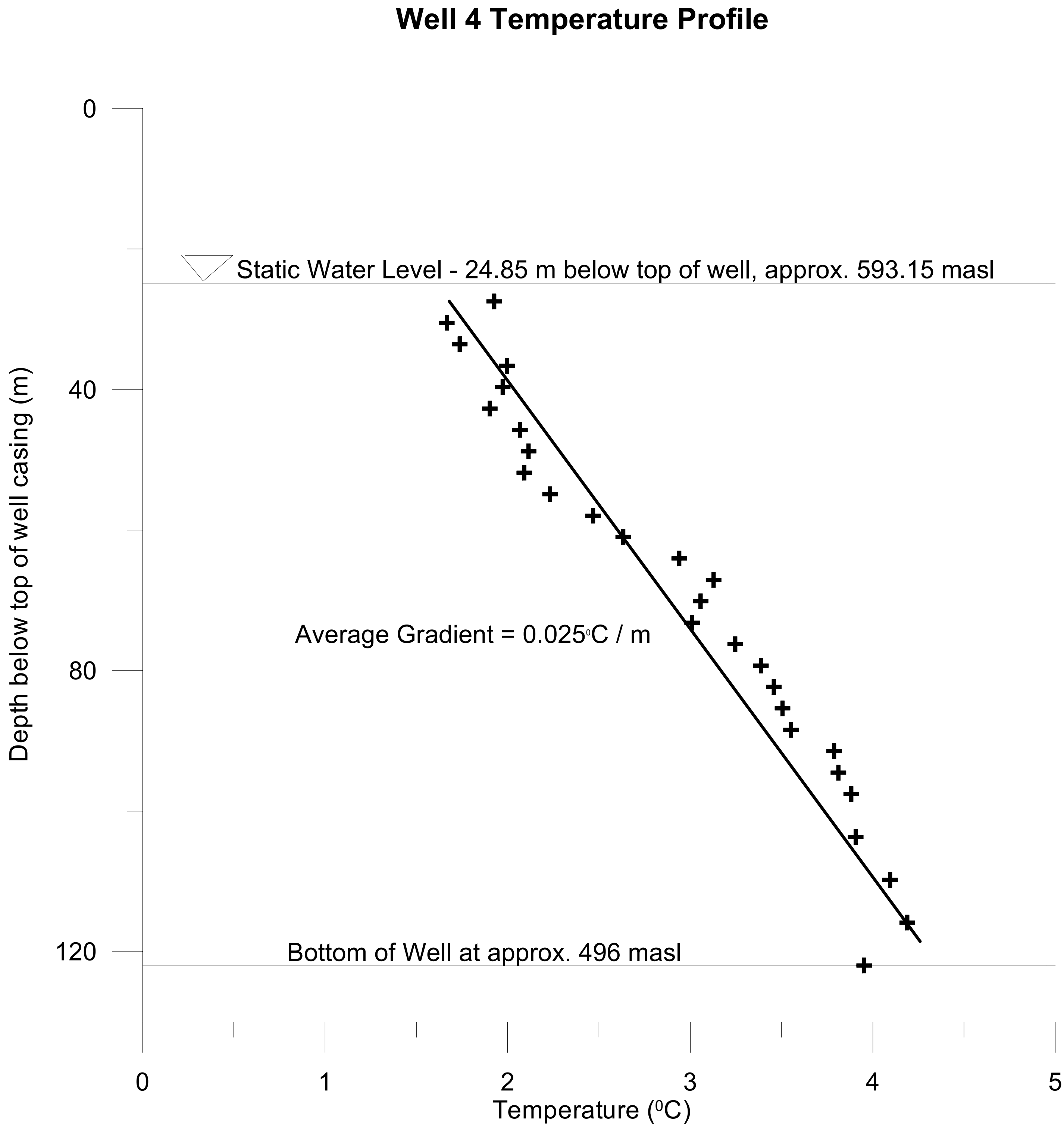
| DATE AUG. 2003 | DWN. RMM | CHKD. GW | FILE NO. 1240049 | DRWG FIGURE 8, pg. 36 |
|---|---|---|---|---|

Water temperature was measured within the lower portion of Well #5 during a geophysical investigation of the well by Aurora Geosciences for Gartner Lee in 2002. Figure 3 of the GLL report shows that the temperature was observed to range from approximately 18.5°C at 305 m btwc to 19.75°C at 365 m btwc (below top of well casing). The temperature increased most rapidly between the depths of 305 m and 330 m within the glaciolacustrine silt and clay unit (0.04 °C/m). Once in the transition facies and the sand and gravel aquifer, the temperature gradient increased only slightly with depth (0.75°C over 50 m or 0.015 °C/m). It appears that the temperature below the well screen and within the till drops slightly below 19.75 °C. However, Gartner Lee pointed out that the drilling mud that had been pumped into the well prior to the geophysical investigation may have influenced the observed temperature.

Assuming that the ground temperature near ground surface is somewhere between 2 and 4 $^{o}$C (as observed in Wells #2 and #4 (see below), the gradient from the near surface soils to the highest observed temperature at 370 m btwc is approximately 0.045 °C/m. Assuming that the observed temperature within the well screen is incorrect, and the temperature at 370 m below grade is in the order of 17 °C , the gradient would be approximately 0.04 °C/m.

Well # 4 Temperature Profile

On July 14$^{th}$, 2002, EBA completed a groundwater temperature profile survey at Well #4. Using the Solinst Multimeter, water temperature was observed at 10 feet (3.05 m) intervals from the static groundwater level to the bottom of the well. The temperature readout was allowed to stabilize for 3 minutes at each location and the resistance was observed from the digital display. A correction factor to compensate for cable resistance (supplied by Solinst based on instrument calibration) was applied to the measured resistance, and the in-situ resistance was converted to temperature using the conversion table provided by Solinst. In Well #4, groundwater temperatures ranged from approximately 1.7$^{o}$C at 30 m below the top of the well, to 4.2$^{o}$C at approximately 116 m below the top of well casing. Temperature vs. depth is plotted on Figure 9 (page 38). Note that the slope of the temperature vs. depth line is relatively consistent at approximately 0.025°C/m.




**EBA Engineering Consultants Ltd.**

PROJECT: RESOURCE ASSESSMENT
ASSESSMENT OF AQUIFER

CLIENT: LESSOWAY MOIR PARTNERS for
ENERGY SOLUTIONS CENTRE and
VILLAGE OF HAINES JUNCTION

TITLE: TEMPERATURE PROFILE
FOR WELL No. 4

| DATE AUG. 2003 | DWN. RMM | CHKD. GW | FILE NO. 1240049 | DRWG. FIGURE 9, pg. 38 |
|---|---|---|---|---|

Well #2 Temperature Profile

Using the same methodology as for Well #4, the groundwater temperature profile was measured at Well #2 (see Figure 10, page 40). The temperature profile extends from the static water level to approximately 47.5 m btwc. The bottom of well is reported to be at 78.3 mbgs according to the drillers well construction report. Reportedly this well had been taken off-line due to a siltation problem, and it is possible that the observed soft obstruction at 47.5 m is due to silt accumulation within the well casing. The observed gradient within Well #2 is generally consistent to that at Well #4 and is approximately 0.022°C/m.

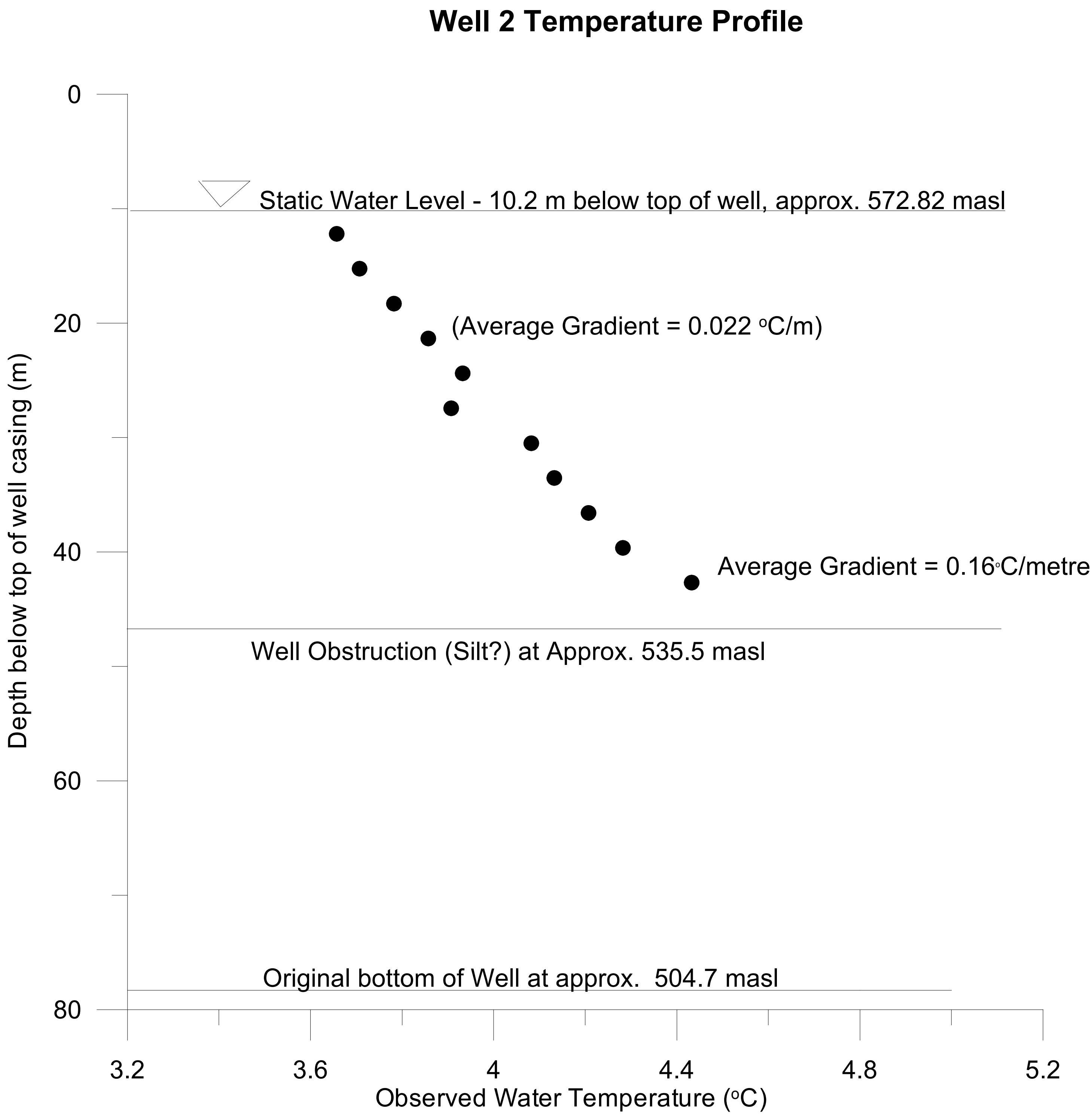
## 5.3 Water Sampling

Groundwater samples were collected at the end of the pumping test by Ryan Martin of EBA. The samples were collected from the discharge line approximately 3 m from the wellhead. Samples were collected according to laboratory recommendations described in more detail below.

### 5.3.1 Analytical

All samples were collected in pre-cleaned bottles provided by ALS Analytical Laboratories. Samples were collected in the volume and container type recommended by the laboratory. Samples submitted for dissolved metals were field filtered using a dedicated disposable 45 micron filter and acidified using laboratory supplied and measured nitric acid. Samples submitted for total metals were acidified using pre-measured and laboratory-supplied nitric acid.

Samples were placed on ice, and shipped by Air Canada Cargo under chain of custody to ALS Environmental in Vancouver. ALS is a member of the Canadian Association for Environmental Analytical Laboratories (CAEAL). ALS completed all previous analytical work during the GLL well testing. Analytical results are summarized in the Table 2 on page 41. Laboratory analytical reports provided in Appendix D. The lab report provides details on analytical methodologies utilized.




| | |
|---|---|
| **EBA Engineering Consultants Ltd.** | PROJECT RESOURCE ASSESSMENT ASSESSMENT OF AQUIFER |
| CLIENT LESSOWAY MOIR PARTNERS for ENERGY SOLUTIONS CENTRE and VILLAGE OF HAINES JUNCTION | TITLE TEMPERATURE PROFILE WELL No. 2 |
| DATE AUG. 2003 / DWN. RMM / CHKD. GW | FILE NO. 1240049 / DRWG. FIGURE 10, pg. 40 |

## Table 2: Summary of Groundwater Analytical Results
## Physical, Anions, Nutrients and Metals Results

| | Groundwater Sample | | | | Applicable Standards |
|---|---|---|---|---|---|
| **Sample ID** | Well 5 | Well 5 | Well 5 | Well 5 | **CCME** |
| **Date Sampled** | 2/10/2002 (2:25am)[C] | 2/10/2002 (4:46am)[C] | 2/10/2002 (12:19pm)[C] | 7/12/03 | **CDWQG[A]** |
| **Physical Tests** | | | | | |
| Conductivity (uS/cm) | 252 | 251 | 249 | 243 | NG |
| Total Dissolved Solids | 172 | 171 | 164 | 178 | 500[B] |
| Hardness CaCO3 | 15.1 | 14.4 | 10.1 | 10.7 | NG |
| pH | **8.61** | **8.71** | **8.74** | **8.78** | 6.5-8.5 |
| Total Suspended Solids | | | | <3 | NG |
| Colour (CU) | <5 | <5 | <5 | <5 | ≤.[B] |
| Turbidity (NTU) | **25** | **22.8** | **13** | 2.9 | 1 or 5 ≤. |
| | | | | | |
| **Dissolved Anions** | | | | | |
| Alkalinity-Total CaCO3 | 112 | 115 | 115 | 115 | NG |
| Alkalinity-Bicarbonate CaCO3 | | | | 115 | NG |
| Alkalinity-Carbonate CaCO3 | | | | <1 | NG |
| Bromide Br | | | | | NG |
| Chloride Cl | <0.5 | <0.5 | <0.5 | <0.5 | 250[B] |
| Fluoride F | 0.27 | 0.26 | 0.26 | 0.23 | 1.5 |
| Sulphate SO4 | 15 | 15 | 15 | 15 | 500[B] |
| | | | | | |
| **Nutrients** | | | | | |
| Nitrate Nitrogen N | <0.1 | <0.1 | <0.1 | <0.1 | 45 |
| Nitrite Nitrogen N | <0.1 | <0.1 | <0.1 | <0.1 | NG |
| | | | | | |
| **Total Metals** | | | | | |
| Aluminum T-Al | 0.61 | 0.63 | 0.32 | 0.06 | |
| Antimony T-Sb | <0.0005 | <0.0005 | <0.0005 | <0.0005 | 0.006 |
| Arsenic T-As | 0.02 | 0.021 | 0.02 | 0.021 | 0.025 |
| Barium T-Ba | 0.71 | 0.58 | 0.41 | 0.03 | 1 |
| Boron T-B | 0.1 | 0.1 | 0.1 | <0.1 | 5 |
| Cadmium T-Cd | <0.0002 | <0.0002 | <0.0002 | <0.0002 | 0.005 |
| Calcium T-Ca | 4.8 | 4.5 | 4 | 3.5 | |
| Chromium T-Cr | <0.002 | <0.002 | <0.002 | <0.002 | 0.05 |
| Copper T-Cu | <0.01 | <0.01 | <0.01 | <0.01 | |
| Iron T-Fe | **0.73** | **0.75** | **0.45** | 0.08 | 0.3[B] |
| Lead T-Pb | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 |
| Magnesium T-Mg | 0.8 | 0.8 | 0.6 | 0.4 | NG |
| Manganese T-Mn | 0.025 | 0.023 | 0.013 | 0.003 | 0.05[B] |
| Mercury T-Hg | <0.0002 | <0.0002 | <0.0002 | <0.0002 | 0.001 |
| Potassium T-K | 0.4 | 0.4 | 0.4 | 0.3 | NG |
| Selenium T-Se | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 |
| Sodium T-Na | 52 | 52 | 52 | 57 | 200[B] |
| Uranium T-U | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.02 |
| Zinc T-Zn | <0.05 | <0.05 | <0.05 | <0.05 | 5[B] |
| | | | | | |
| **Dissolved Metals** | | | | | |
| Aluminum D-Al | - | - | <0.01 | 0.01 | - |
| Antimony D-Sb | - | - | <0.0005 | <0.0005 | - |
| Arsenic D-As | - | - | 0.02 | 0.021 | - |
| Barium D-Ba | - | - | <0.02 | <0.02 | - |
| Boron D-B | - | - | 0.1 | <0.1 | - |
| Cadmium D-Cd | - | - | <0.002 | <0.0002 | - |
| Calcium D-Ca | - | - | 3.4 | 3.4 | - |
| Chromium D-Cr | - | - | <0.002 | <0.002 | - |
| Copper D-Cu | - | - | <0.001 | <0.001 | - |
| Iron D-Fe | - | - | <0.03 | 0.11 | - |
| Lead D-Pb | - | - | <0.001 | <0.001 | - |
| Magnesium D-Mg | - | - | 0.4 | 0.4 | - |
| Manganese D-Mn | - | - | <0.002 | <0.002 | - |
| Mercury D-Hg | - | - | <0.0002 | <0.0002 | - |
| Potassium D-K | - | - | 0.3 | 0.3 | - |
| Selenium D-Se | - | - | <0.001 | <0.001 | - |
| Sodium D-Na | - | - | 52 | 54 | - |
| Uranium D-U | - | - | <0.0001 | <0.0001 | - |
| Zinc D-Zn | - | - | <0.05 | <0.05 | - |

**Footnotes:** Results are expressed as milligrams per litre except where noted.

< = Less than the detection limit indicated.

A) Canadian Drinking Water Quality Guidelines (Updated April 2002)

B) Aesthetic Objective

C) Analytical results from Gartner Lee Ltd (2002)

### 5.3.2 Isotopes

A water sample from Well #5, collected in a 1 L sterilized amber glass container was shipped under chain of custody to the Environmental Isotope Lab at the Department of Earth Sciences at the University of Waterloo, in Waterloo Ontario. Care was taken to ensure that there was no entrapped air, or "headspace" within the sampling container. The sample was analysed for the following isotope concentrations:

- Enriched Tritium ($^{3}H$)
- Deuterium ($^{2}H$)
- Oxygen – 18 ($^{18}O$)

Isotope analytical results are summarized in Table 3 below:

**Table 3: Summary of Isotope Analytical Results**

| | Groundwater Sample | |
|---|---|---|
| **Sample ID** | Well 5 | |
| **Date Sampled** | 12/07/03 | Repeat |
| **Physical Tests** | | |
| Oxygen-18 | -23.34 | -23.22 |
| Deuterium | -176.63 | -177.93 |
| Tritium | <0.8 +/- 0.5 | |
| | | |

**Notes:**
Tritium is reported in Tritium Units.
1TU = 3.149 Picocuries/L
1TU = 0.11815 Becquerels/L
Analyses conducted by University of Waterloo Isotope Laboratory

The Environmental Isotope Laboratory analytical report is provided in Appendix D.

### 5.3.3 BART™

Samples for BART™ testing were collected using aseptic techniques in the sample vials provided by Droycon Bioconcepts Inc. The samples were collected while wearing clean latex gloves, and care was taken to ensure that the inside of the bottles and lids did not come into contact with any foreign objects during the sampling process. The samples were transported to the EBA office in Whitehorse where they were stored away from direct sunlight and at room temperature. The samples were inspected daily, or as often as possible for visual reactions.

Observations were recorded and are presented in Table 4 (page 44). A photograph of the BART samples on Day 4 of observation is shown below (Photograph 10).


**Photograph 10:** Biological Reactivity Test (BART) on day 4. SRB (sulphate reducing) on left (black), IRB (iron reducing) in middle (red) and SLYM (slime forming) on right (green).

### 5.4 Determining Geothermal Conditions in Shallow Soils

EBA reviewed shallow borehole information from previous investigations completed by EBA and JR Paine Associates. Climate data from the Canadian Climate Normals (1961-1990) as recorded at the Haines Junction airport was also reviewed. Using a numerical model, EBA calculated the soil thermal properties based on grain size and moisture contents. A one dimensional soil temperature profile was developed. This information may be used by the other team partners to calculate seasonal heat losses from the pipe distribution system to ground. Additional details are presented in Section 6.5.

**Table 4: Observations During BART TESTS**

| | Day 1 | Day 2 | Day 3 | Day 5 | Day 6 | Day 7 | Day 9 | Comments |
|---|---|---|---|---|---|---|---|---|
| **Iron Reducing BART IRB BART** | fine bubbles on side wall and bottom of ball, clear, yellowish green pigment in bottom half of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, clear, yellowish green pigment in bottom half of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, clear, yellowish green pigment in bottom half of column, may be some solids accumulating in bottom of cone. | fine bubbles on side wall from half way down to bottom of column, some yellowish brown solids forming on sidewall above line and in meniscus, yellowish green pigment in bottom half of column, may be some solids accumulating in bottom of cone. | Coarse bubbles on top half of ball, yellowish orange slime above line around ball, yellowish orange pigment from top to bottom. | Coarse bubbles on top half of ball, orangish brown slime above line around ball and within meniscus, yellowish orange pigment from top to bottom, fluid becoming cloudy. | Coarse bubbles on top half of ball, orangish brown slime above line around ball and within meniscus, yellowish orange pigment from top to bottom, fluid becoming cloudy. | Observations indicate that IRB bacteria are present and relatively aggressive. Noticeable reactions were visible after approximately 4 days. Order of magnitude population is 5,000 cfu/mL. After 6 days anaerobic bacteria presence was also indicated. |
| **Slime Forming Bacteria BART SLYM BART** | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, reddish brown pigment across bottom third of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, reddish brown pigment across bottom third of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, reddish brown pigment across bottom third two thirds of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, reddish brown pigment across bottom third two thirds of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, yellowish pigment from bottom of ball to bottom of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, yellowish pigment from bottom of ball to bottom of column, no solids or biofilm noticeable. | fine bubbles on side wall and bottom of ball, water level approx. 3 mm above line, clear, yellowish pigment from bottom of ball to bottom of column, very small threadlike strands in base of cone (only noticeable when inner vial removed). | Observations indicate that although there may be some tight slime bacteria present, they are not aggressive. |
| **Sulphate Reducing Bacteria BART SRB BART** | fine bubbles on side wall, clear, water level approx. 5 mm above line, slight yellow tinge near bottom of column, no solids or biofilm noticeable. | fine bubbles on side wall, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, no solids or biofilm noticeable on ball or base of column. | fine bubbles on side wall on bottom 3/4 of vial, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, possibly some in bottom of cone, no black discolouration. | fine bubbles on side wall on bottom 1/2 of vial, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, solids in bottom of cone, no black discolouration. | fine bubbles on side wall on bottom 1/2 of vial, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, solids in bottom of cone, no black discolouration. | fine bubbles on side wall on bottom 1/2 of vial, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, solids in bottom of cone, no black discolouration. | fine bubbles on side wall on bottom 1/2 of vial, clear, thin yellowish layer of slime on the bottom 4 mm of column, water level approx. 5 mm above line, some solids in bottom of cone, no black discolouration. | Observations indicate that although some reactions were observed, they were not consistent with any of the standard SRB reactions. No black was ever observed. Therefore, if SRB bacteria are present, they are not considered aggressive. |

# 6.0 RESULTS

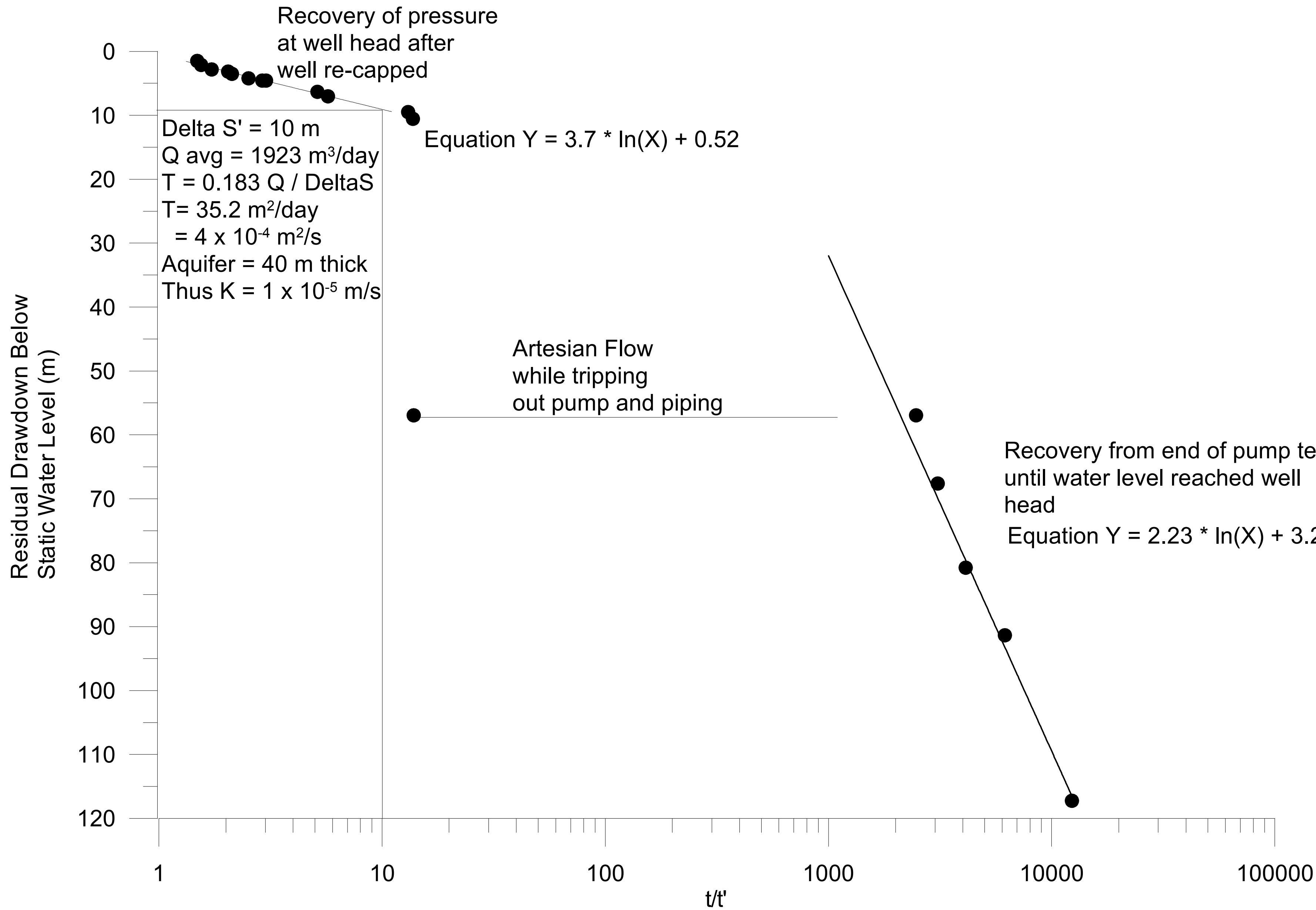
## 6.1 Aquifer Testing

### 6.1.1 Pumping Test Results

The trends observed during the pumping tests were interpreted to determine aquifer characteristics. For the analysis below, it is assumed that the aquifer thickness is 40.2 m (as reported by GLL).

When pumping is stopped, aquifer water levels rise toward their static water level. This rate of recovery provides a means of calculating the transmissivity. If no observation well is available, the recovery data from the pumped well usually provides the best means for calculating the transmissivity of the aquifer . The Theis recovery method is commonly used to determine the aquifer transmissivity. Note that storativity (the volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline in the component of hydraulic head normal to that surface) cannot be determined from recovery data. Storativity is an important aquifer characteristic for flow modelling and geothermal design.

Using appropriate equations, the transmissivity of an aquifer can be evaluated through the interpretation of the residual drawdown plot, or the residual drawdown versus the ratio(t/t') of time since the pump started (t) to the time since the beginning of the recovery period (t'). A plot of the recovery (residual drawdown) vs. t/t' is provided as Figure 11 (page 46). The pumping duration (t) was considered to include the time during the pump installation when the well was flowing under artesian pressure, as well as the step test and constant rate test.




| | |
|---|---|
| EBA Engineering Consultants Ltd. | PROJECT RESOURCE ASSESSMENT ASSESSMENT OF AQUIFER |
| CLIENT LESSOWAY MOIR PARTNERS for ENERGY SOLUTIONS CENTRE and VILLAGE OF HAINES JUNCTION | TITLE RECOVERY DATA FOLLOWING PUMPING TEST |
| DATE AUG. 2003 DWN. RMM CHKD. GW | FILE NO. 1240049 DRWG. FIGURE 11, pg. 46 |

For an “ideal” aquifer the residual drawdown approaches zero as the t/t’ approaches 1. Therefore, as indicated in Figure 11 (page 46), the aquifer in which Well #5 is completed responded in an ideal fashion. Based on the slope of the late time data recovery (measured as pressure at the wellhead), a transmissivity value of 4 x $10^{-4}$ $m^2$/s was calculated for the deep aquifer. By analysing the late time data, the effects of well casing storage are eliminated. The flow rate of 22 L/s, was used for the calculation is the average flow rate of the artesian flow, the step test and the constant rate test. Assuming an aquifer thickness of 40.2 m as reported by GLL, this translates to a hydraulic conductivity (K) value of 1 x $10^{-5}$m/s. According to Freeze and Cherry, this is typical of a silty to clean sand (Freeze, 1979). This is also relatively consistent with the T and K values obtained by GLL where they analysed the pumping data using the Hantush Jacob Solution for a leaky confined aquifer.

There was no observed drawdown that could be attributed to the pumping of Well # 5 in any of the observation wells (Well #2, #3 and #4). Unfortunately, since there are no observation wells completed within the same aquifer as Well #5, aquifer storativity could not be calculated. As previously mentioned, storativity is an important aquifer characteristic for flow modelling and aquifer thermal energy storage design.

Horizontal Hydraulic Gradient and Groundwater Flow Direction

Without at least three observation points completed in the same aquifer, the direction of the groundwater flow cannot be estimated and a groundwater gradient cannot be calculated. Without storativity and gradient information for the aquifer, the potential for hydrological and geothermal modelling is significantly limited.

### 6.1.2 Temperature Profiling

The temperature gradient observed during the temperature measurements within Well #2 and Well #4 were 0.022 and 0.025 °C/m (22 °C /km, and 25 °C/km), respectively. Driscoll (1986) states that at depths greater than 30 m, the average geothermal gradient is approximately 19.7 $^{o}$C/km. Therefore, the geothermal gradients observed within each of these wells lie within the range of, or perhaps slightly above, typical geothermal gradients. Note that a slightly higher geothermal gradient for this area may be anticipated based on the level of tectonic (seismic) activity. If it is assumed that the geothermal gradients measured at Well #2 and Well #4 are representative for the shallow aquifers, then if the gradient was extrapolated to a depth of 365 m (depth of Well #5), the temperature would be roughly 8 to 9 °C, not 17°C as observed at Well #5 at this depth. This suggests that the groundwater intercepted by Well #5 is heated relative to its predicted temperature. The source of heat is uncertain; it may be at depth (beneath the aquifer) or water itself may retain heat from a distant source. Some theories on the source of the heat energy are provided in Section 7.2 and 7.3.

## 6.2 Groundwater Analytical Results

### 6.2.1 Analytical

As indicated in Table 2 (page 41), for the parameters tested, there were no exceedences of any health based, Canadian Drinking Water Quality (CDWQ) guidelines with the exception of Turbidity. As well, there were no exceedences of any aesthetic guidelines, with the exception of pH.

Not surprisingly, there were some significant differences between the water sampling results obtained during this field program, and those obtained by GLL in October 2002. As indicated by GLL in their report, the results presented were reflective of the water quality immediately following the development process. GLL pointed out that trace amounts of drilling fluid, used during the completion of the well, may influence water quality. Also, GLL commented that elevated concentrations of iron during the 2002 sampling program may be related to elevated turbidity levels, and that a reduction in groundwater turbidity may reduce the iron concentrations.

Noteworthy changes between the water quality results from samples collected at the end of the GLL pump test in November 2002 and the water quality at the end of the long-term pump test in July 2003 are the following:

- Considerably reduced turbidity (from 13 to 2.9 NTU)
- Significantly decreased total aluminum concentrations (from 0.32 mg/L to 0.06 mg/L). The most recent sampling results are now below the CDWQG aesthetic objectives.
- Considerably decreased total iron concentrations (0.45 mg/L to 0.08 mg/L). The most recent sampling results are now below the CDWQG aesthetic objectives.
- A more than 10 times reduction in barium concentrations. The GLL report states that at depth to overcome hydrostatic conditions, a barite compound was added to the bentonite mud to increase its density. The reduction in barium concentration is likely due to the fact that most of the residual barite-based drilling fluid has been removed from the aquifer formation around the well.

With the exception of turbidity, all significant changes in water quality between the samples collected by GLL in 2002 and the recent water sampling results are for total metals concentrations. Dissolved metals concentrations for all metals tested are very similar. The use of Well #5 by the Village of Haines Junction since November 2002, coupled with the aggressive pumping of the well during this most recent long-term pump test has continued to develop the well. It is obvious from the reduced turbidity readings between the two sampling events that there are less solids or organic matter within the groundwater. This observation suggests that the GLL hypothesis that "elevated concentrations of total iron in the groundwater may be related to elevated turbidity levels and that a reduction in groundwater turbidity may reduce the total iron concentrations" was accurate. Due to the significant decrease in barium concentrations, it is likely that the use of the well by the Village, and the most recent pumping test have also been successful in removing much of the residual drilling fluid (with barite additive) from within the aquifer.

The Village of Haines Junction routinely monitors turbidity, water temperature, and pressure at the wellhead and pumphouse. Based on a review of the monitoring data, it has been observed that turbidity values are typically lower than 1 NTU, and average lower than 0.1 NTU when the well is flowing under artesian pressure (See Section 6.4). Pumping during the pumping test has resulted in a partial development of the well and probably mobilized part of the large volume of grout injected during sealing and completion of the well. This would explain the turbidity value measured in the sample collected at the end of the pumping test.

### 6.2.2 Geothermometry

Chemical geothermometry can be a useful tool for determining the equilibration (or source) temperature of a fluid based on its chemical composition. A fundamental assumption of geothermometry is that the effects of dilution from surface and/or shallow groundwaters are insignificant and that thermodynamic equilibrium has been attained (Fournier, 1981). Geothermometric calculations are based on the assumption that groundwater equilibrates with hydrothermal minerals in the reservoir rock. The concentrations of various ions (e.g., $Na^+$, $K^+$ and $Ca^{2+}$) and silica ($SiO_2$) are temperature-dependent, and reactions with the circulating aqueous solutions are typically sluggish (Yorath et al., 1991). Therefore, for relatively rapid transit times to the surface, such as would be accomplished up fracture zones, it is unlikely that re-equilibration with the surrounding rocks could occur. This suggests that the chemical signature of a water can provide some idea as to temperature regime when the minerals were first dissolved.

There are many types of geothermometers; some more suitable than others for different types of temperature conditions. In general, geothermometers based on ratios are more resistant to dilution effects than those based on absolute concentrations (Banks et al., 1998); however dilution by mixing with fresh meteoric waters can significantly limit geothermometry.

The silica-based geothermometers could not be used (no dissolved silica analyzed), and several ion-based geothermometers gave negative values, indicating that the methods were inappropriate. The Na/K geothermometer (Fournier 1979) yielded an equilibration temperature of 52ºC and the Na-K-Ca geothermometer (Fournier, 1979) yielded a temperature of 26ºC. Although these values may appear to be realistic, the total dissolved solids (TDS) concentration of the groundwater was 178 mg/L, and the concentrations of metals, such as Na (54 mg/L) and Ca (3.4 mg/L), and total alkalinity (115 mg/L) suggest a very immature groundwater, not one that has equilibrated at high temperature. Furthermore, the aquifer materials present would suggest a Ca-bicarbonate type water, rather than a Na-bicarbonate water, therefore the source of Na is questionable. Because both geothermometers are based on Na, the geothermometry calculations are deemed unreliable.

6.2.3 Isotopes

<u>Oxygen-18 ($^{18}0$) and Deuterium ($^{2}H$)</u>

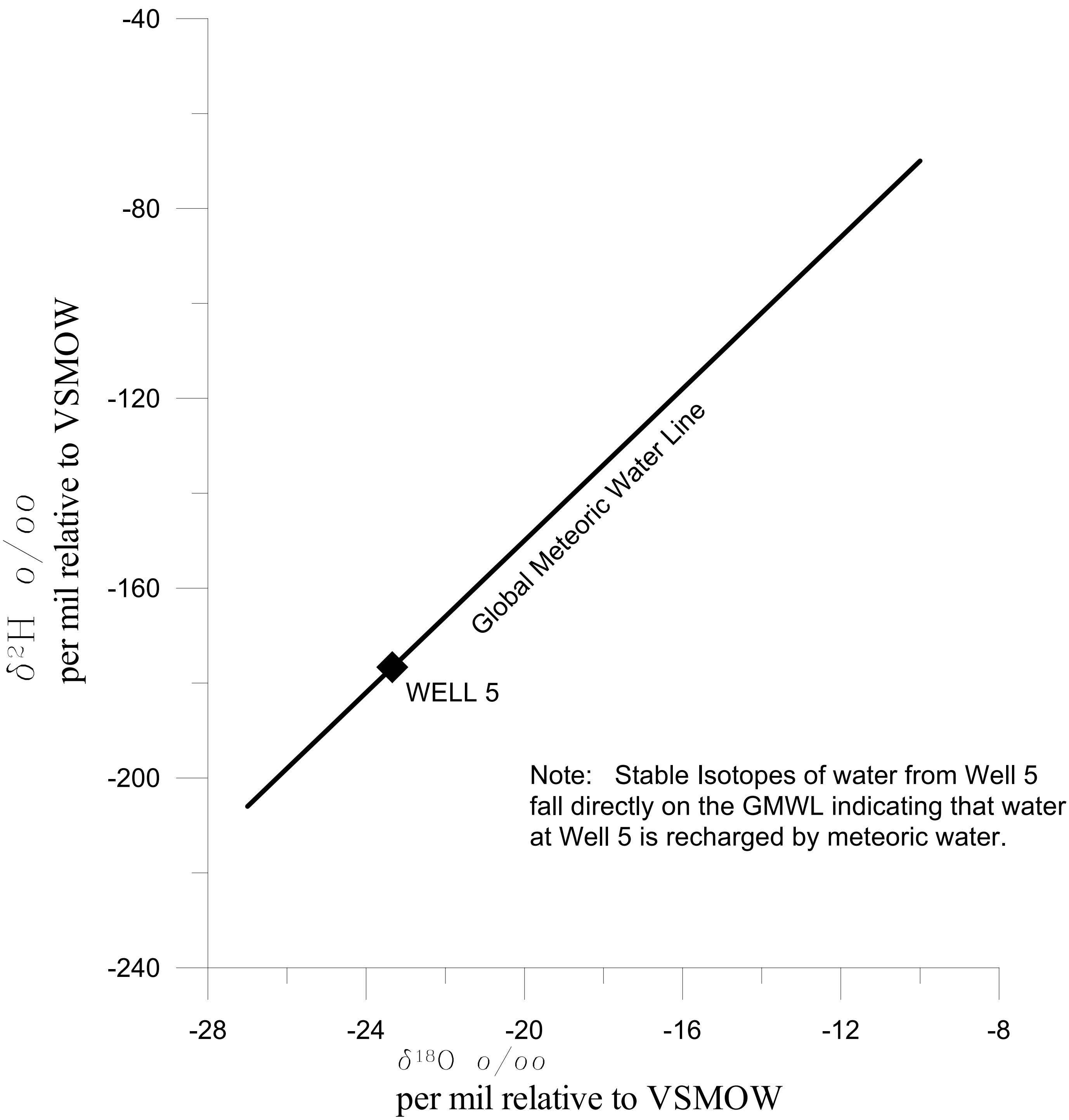
The isotopes of water ($^{18}O$, $^{2}H$) are incorporated within the water molecule ($H_2{}^{18}O$, $1H_2H^{16}O$). The ratio of these isotopes is important because species-dependant behaviour during phase changes (evapouration, condensation, sublimation, freezing), mixing, and diffusion within the water cycle produce a natural labeling effect. Such isotope fractionation processes contribute to a systematic global distribution of stable isotopes in precipitation and in various hydrological components. The statistical evaluation of isotope measurements in precipitation shows that Deuterium values of precipitation and natural waters of meteoric origin are linearly correlated with those of $^{18}O$, forming the so-called global meteoric waterline (See Figure 12, page 51). For water subjected to evaporation, the linear correlation between the Deuterium and $^{18}O$ values still holds, but the slope of this line is less steep. Therefore, the meteoric water line can be used as a reference line against which any measuring point can be compared. The result of the comparison provide a fingerprint of a sample and indicates whether the sample represents surfacewater, groundwater recharged by rain (which falls along the meteoric line, or a mixture between fresh groundwater and another source such as evapourated lake water. Isotope results for Oxygen-18 vs. Deuterium were plotted for Well # 5 on Figure 12 (page 52). Note that they fall along the global meteoric water line. This indicates that the water is of meteoric origin.

In glaciers, the lighter oxygen isotope preferentially gets locked in the ice leading to the enrichment of heavy oxygen in the glacial meltwater. Based on the fact that the isotope ratio for Well #5 falls directly on the GMWL, it appears that the source of the water from Well #5 is not significantly related to glacial meltwater. However, more detailed stable isotope data for glaciers in the region would be needed to confirm this.

Tritium ($^3H$)

Radiogenic tritium ($^3H$), another isotope found in the water molecule ($^1H^3H^{16}O$), is useful for dating water. Tritium is a naturally occurring radioactive isotope of hydrogen. Atmospheric nuclear weapons testing beginning in about 1952 increased tritium levels in the environment by several orders of magnitude. This bomb pulse has provided a large event marker that can be used in time scale studies. With a half-life of 12.3 years, it can be used as a tracer for dating groundwater. The naturally occurring tritium level in pre-bomb rainwater was 5 to 10 Tritium Units (TU).

In Anchorage in 1994, precipitation had concentrations between 5 and 38 TU (USGS website). Based on these levels, and the Tritium half-life, water containing $^3H$ concentrations greater than 1.3 TU is considered “modern” post 1951 recharge. The concentration of tritium in a sample collected from Well #5 was less than 0.8 TU +/- 0.5 (See Table 3, page 42). Therefore, it appears that the groundwater sampled from Well #5 was recharged from atmosphere prior to 1952. As such, it can be inferred that groundwater may have flowed in the subsurface for at least 50 years before reaching Well #5. However, given the low concentration of Total Dissolved Solids (TDS) for the water sampled at Well #5, it is unlikely that the water is significantly older than 50 years, otherwise the concentration of TDS would be considerably higher.

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|---|---|
| **EBA Engineering Consultants Ltd.** | PROJECT RESOURCE ASSESSMENT ASSESSMENT OF AQUIFER |
| CLIENT LESSOWAY MOIR PARTNERS for ENERGY SOLUTIONS CENTRE and VILLAGE OF HAINES JUNCTION | TITLE ISOTOPE PLOT FOR OXYGEN-18 AND DEUTERIUM |
| DATE AUG. 2003 / DWN. RMM / CHKD. GW | FILE NO. 1240049 / DRWG. FIGURE 12, pg. 52 |

### 6.2.4 BART

As indicated previously, a summary of the individual observations and interpretation of the results of the BART™ testing conducted from the well field is attached as Table 4, page 44. Moderately aggressive very aerobic slime forming iron related bacteria have been observed, iron related bacteria may be active and heterotrophic bacteria are present. No sulphate reducing bacteria were observed. Dense slime forming heterotrophic bacteria were detected, but are considered to have a very low aggressivity at this time. The results do not appear to demonstrate significant biofouling bacteria activity in the well.

The specific capacity of 0.19 L/s/m for this current long-term pump test is the equivalent to the specific capacity data reported by GLL for the pump test completed in October 2002. This also indicates that there has been little or no clogging due to biofouling occurring in and around Well #5.

It should be noted that the BART™ tests did not identify sulphur reducing bacteria populations within the well. The absence of a positive test result does not preclude the presence of these bacteria, as the nature of these bacteria is that they tend to form a tight biofilm against the well screens or other materials that is often covered by other more aerobic bacteriological populations. The test is dependent on the bacteria being released into the water flow during the sampling event and it can, therefore, be difficult to show a definite absence.

### 6.2.5 Variation of Water Quality vs. Time during pump test

During the pumping test, EBA routinely measured the conductivity of the discharge water to determine whether there were any anomalies or trends. Conductivity values were relatively consistent throughout the test. No noticeable change was observed.

## 6.3 Water Quality - Operation and Maintenance Issues

The Langelier Saturation Index (LSI) and the Ryznar Stability Index (RSI), and some of the water quality indicators were analyzed to determine the corrosiveness of the groundwater from Well #5.

Langelier Saturation Index

The Langelier Saturation Index (LSI) is an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium and carbonate. Water with a LSI of 1.0 is one pH unit above saturation and by reducing the pH by 1 unit the water will be brought into equilibrium. The results of the LSI are defined as:

- If the LSI is negative: No potential to scale, the water will dissolve $CaCO_3$;
- If the LSI is positive: Scale can form and $CaCO_3$ precipitation may occur;
- If LSI is close to zero: Borderline scale potential. Water quality or changes in temperature, or evaporation could change the index.

The LSI is probably the most widely used indicator of water scale potential and is defined as:

$$LSI = pH - pH_s$$

Where:

- pH is the measured groundwater pH
- $pH_s$ is the pH at saturation in calcite or calcium carbonate.

The pH of the groundwater at Well # 5 was 8.78 on July 12, 2003, while the $pH_s$ was calculated as 9.02. Therefore the LSI of the groundwater at Well # 5 was –0.24 and indicates that the groundwater does not have any potential for scaling.

The Ryznar Stability Index

The Ryznar stability index (RSI) attempts to correlate an empirical database of scale thickness observed in municipal water systems to the water chemistry. Like the LSI, the RSI has its basis in the concept of saturation level. RSI attempted to quantify the relationship between calcium carbonate saturation state and scale formation. The RSI is defined as:

$RSI = 2(pH_s) – pH$;

or as

$I = S – C – pH$

Where:

- S is obtained using the total dissolved solids of the groundwater and a graph that has the S value as a function of the total dissolved solids; and
- C is obtained using the methyl orange alkalinity, the calcium ion concentration of the groundwater and a graph that has the C value as a function of the methyl orange alkalinity and the calcium ion concentration;

The empirical correlation of the Ryznar stability index can be summarized as follows:

- If the RSI is less than 6, the scale tendency increases as the index decreases;
- If the RSI is greater than 7, the calcium carbonate formation probably does not lead to a protective corrosion inhibitor film;
- If the RSI is greater than 8, mild steel corrosion becomes an increasing problem.

The pH of the groundwater at Well #5 was 8.78 on July 12, 2003, while the $pH_s$ was calculated as 9.02, C was calculated as 5.4, and S equals 23.03. Therefore the RSI of the groundwater at Well # 5 was calculated to be 9.26 and 8.85 using the two different methods. The RSI indicates that the groundwater does not have any potential for scaling but may be corrosive to mild steel.

The water quality from Well # 5 on July 12, 2003, had a high pH of 8.78, and low total dissolved solids, chlorides, carbonate hardness, iron, and manganese. Therefore, the pH indicates that encrusting is likely to occur while the other indicators do not suggest corrosion or scaling.

The Langelier Saturation Index and Ryznar Stability Index indicate that the groundwater from Well # 5 will not deposit scale but may be corrosive to mild steel. We agree with the conclusions of Gartner Lee Ltd (2002) that while the RSI and LSI indices are more useful as scaling potential than of corrosion potential, and that corrosion is unlikely to occur as the groundwater has a high pH of 8.78. Since the well screen is constructed of stainless steel, it is not anticipated that corrosion will result at the well screen, and it is not likely that significant corrosion of distribution piping will occur due to the high pH.

### 6.4 Well # 5 Long Term Data Analysis

Since the beginning of the use of Well #5, turbidity and temperature readings have been recorded by the Village of Haines Junction. Mechanical pressure and temperature gauges fitted at the wellhead and pumphouse were observed daily. Turbidity readings were also recorded daily. EBA reviewed the daily records for 2003 up to the time of the well shut down prior to the pump Test. Table 5 provides a summary of the long-term data and the variations of the parameters monitored with time.

**Table 5: Village Monitoring of Turbidity, Pressure and Water Temperature**

| | Turbidity at Wellhead (NTU) | Pressure at Wellhead (psi) | Water Temperature at Wellhead (°C) | Water Temperature at Pumphouse (°C) |
|---|---|---|---|---|
| Period | January 1st 2003 to July 4 2003 | | | |
| Number of Samples | 106 | 107 | 107 | 95 |
| Avearage | 0.08 | 72.95 | 15.21 | 14.26 |
| Maximum | 0.15 | 78 | 16 | 16 |
| Minimum | 0.02 | 50 | 14 | 14 |

The following observations and trends are made from the long term monitoring data:

- The temperature at the wellhead was constant and did not indicate any seasonal variation over the duration of monitoring period.
- The temperature at the pumphouse was relatively consistent seasonally and over the duration of monitoring period. Heat losses to the surrounding near surface soils did not appear to be more significant in the winter months.
- There was an average loss of approximately 0.95 ºC between the wellhead and the pumphouse.
- The average and maximum turbidity readings are both below the CDWQG aesthetic and health based objectives.
- The pressure at the wellhead is variable and dependant on the discharge rate to the pumphouse but does not indicate any decreasing trend with time.

The following observations and trends can be determined from comparing the Village long-term data with the observations during the pump test:

- The turbidity appears to be lower when the well is flowing under artesian pressure than when it is being pumped.
- The temperature is consistently higher during pumping than during artesian discharge. This is likely a function of the velocity of the water in the well, and thus the retention time within the well casing over which the water loses heat energy to the cooler formations surrounding the well casing as the water travels to the surface.

EBA concurs with the Gartner Lee recommendation that the collection of long-term water usage and pressure at Well #5 will help to predict the long-term sustainability of this important groundwater resource. Following the recovery period after the long-term pump test, the Village resumed use of Well #5. Since the amendment to the water license allows significantly increased use of the well, it has been relied upon as the primary potable water supply for the Village since July 23rd, 2003. The Village monitors the daily extraction from Well #5. Prior to the amendment to the Water license, the Village extracted just less than 100 $m^3$ per day (1.15 L/s) from Well #5 on average. Since July 23rd, the average daily use from Well 5 averages approximately 300 $m^3$/day. When the Well is in use, pressure at the wellhead and at the pumphouse is also monitored and recorded by the Village. Obviously, when the well is flowing, the pressure at the wellhead and within the distribution line is lower than when the well is closed. Minor variations in flow alter the pressure at the wellhead. Therefore, to get an accurate interpretation of the piezometric level, or artesian pressure within the aquifer, it is best to observe the pressure when the well is not flowing. Monitoring of the pressure response and the total pressure after a standard shut down period gives a basis for comparing long term effects of use of the well. Soon after the Well use was resumed, EBA proposed the implementation of pressure response monitoring at Well #5. The well is shut down for 24 hours on a weekly basis, and the Village observes the pressure recovery at the wellhead. Data are presented in Table 6 below:

**Table 6: Pressure at Wellhead after 24 hour shutdown**

| Well 5 Shut Down Period | Initial Pressure Prior to Shut Off | Pressure at Well Head after 8 hrs | Pressure at Well Head after 24 hrs |
|---|---|---|---|
| Aug 6,7 | 69.5 psi | NR | 77 psi |
| Aug 13,14 | 68 psi | 78 psi | 78 psi |
| Aug 20, 21 | 67 psi | 78 psi | 78 psi |
| Aug 27, 28 | 67 psi | 76 psi | 76 psi |
| Aug 3, 4 | 67 psi | 77 psi | 78 psi |

The information summarized in Table 6 indicates, that although the well is flowing under artesian pressure at an average daily rate of 300 $m^3$/day, it is still responding consistently to near static pressure after 24 hours. Full recovery would likely take longer. Slight variations would reflect gauge reading error, or barometric and earth tide effects as previously described.

### 6.5 Geothermal Conditions in Shallow Soils

EBA completed an analysis to predict soil temperatures at depth in Haines Junction. Soils information has been obtained from both JR Paine and EBA borehole logs from Haines Junction, and climate data from the Canadian Climate Normals (1961-1990) as recorded at the Haines Junction airport. Details are as follows:

- assumed 2.0 m of clay and silt at a moisture content of 20% over silt till at a moisture content of 10%
- unfrozen thermal conductivity of 2.0 W/m $^{o}$C for clay and silt, 2.6 W/m $^{o}$C for silt till
- Latent Heat of 110.2 MJ/$m^3$ for clay and silt, 56.1 MJ/$m^3$ for silt till.
- applied surface temperature of -13.3 $^{o}$C over 6 months of winter

Assuming a symmetric distribution, the computed temperature ranges are:

- Depth = 0.5 m, T = -8 to +8 $^{o}$C
- Depth = 1.0 m, T = -5 to +5 $^{o}$C
- Depth = 1.5 m, T = -3 to +3 $^{o}$C
- Depth = 2.0 m, T = -1 to +1 $^{o}$C
- Depth = 2.5 m, T = -0.5 to +0.5 $^{o}$C
- Depth = 3.0 m, T= 0 $^{o}$C

## 7.0 INTERPRETATION AND DISCUSSION

### 7.1 Revised Conceptual Hydrogeology Models

EBA has considered two potential conceptual models as presented herein. The first conceptual hydrogeology model is consistent with the model presented by Gartner Lee in their 2002 report. We will refer to this as the “Alluvial fans/deltas controlled conceptual hydrogeological model”. This conceptual hydrogeological model is presented schematically in Figure 13 (page 60). This model proposes that a likely recharge zone is the alpine moraine glacial deposits on the foothills of the Auriol Range. The water bearing units encountered at Well #5 could represent alluvial fans or deltas that have formed off the slope of the Auriol range south of the Dezadeash River. These deposits likely formed through deposition of sand and gravel either as deltas directly into the Glacial Lake Champagne or as fans during periods of fluctuating lake levels and are inferred to be connected with the alpine moraine deposits. The sand and gravel deposits are confined above by glaciolacustrine silt and clay and below by clay-rich till.

The travel time for the groundwater to flow to Well #5 was estimated for the alluvial fans/deltas controlled conceptual hydrogeological model as follows:

A travel time was estimated using:

1) Darcy's law, Q = KiA;
2) The transmissivity calculated during this assessment (with a slight degree of variability (half an order of magnitude above and below the calculated value),
3) The aquifer thickness reported by GLL (2002);
4) An estimated porosity that is typical of sand and gravel aquifers;
5) The elevation difference and horizontal distance between the inferred recharge zone and Well # 5; and
6) The expected groundwater travel distance.

Aquifer characteristics are spatially variable and it is likely that the transmissivity, aquifer thickness, and porosity are not constant between the recharge zone and Well # 5. Therefore, a sensitivity analysis was conducted on these variables and the expected travel time for the groundwater to flow from the Auriol Range to Well #5 is given as a possible range. The sensitivity of the transmissivity and thickness of the aquifer was represented by hydraulic conductivity because within a confined aquifer the hydraulic conductivity equals transmissivity divided by the aquifer thickness (see Table 7).

**Table 7: Travel Time Sensitivity Analysis for Conceptual Model**

| Aquifer Characteristics | | Estimated Travel Time (years) |
|---|---|---|
| Hydraulic Conductivity (m/sec) | Porosity (%) | |
| $5 \times 10^{-5}$ (thick aquifer – 40 m) | 30 | 24 |
| $5 \times 10^{-5}$ (thin aquifer – 20 m) | 30 | 12 |
| $1 \times 10^{-5}$ (thick aquifer – 40 m) | 30 | 120 |
| $1 \times 10^{-5}$ (thin aquifer – 20 m) | 30 | 60 |
| $5 \times 10^{-6}$ (thick aquifer – 40 m) | 20 | 240 |
| $5 \times 10^{-6}$ (thin aquifer – 20 m) | 20 | 120 |

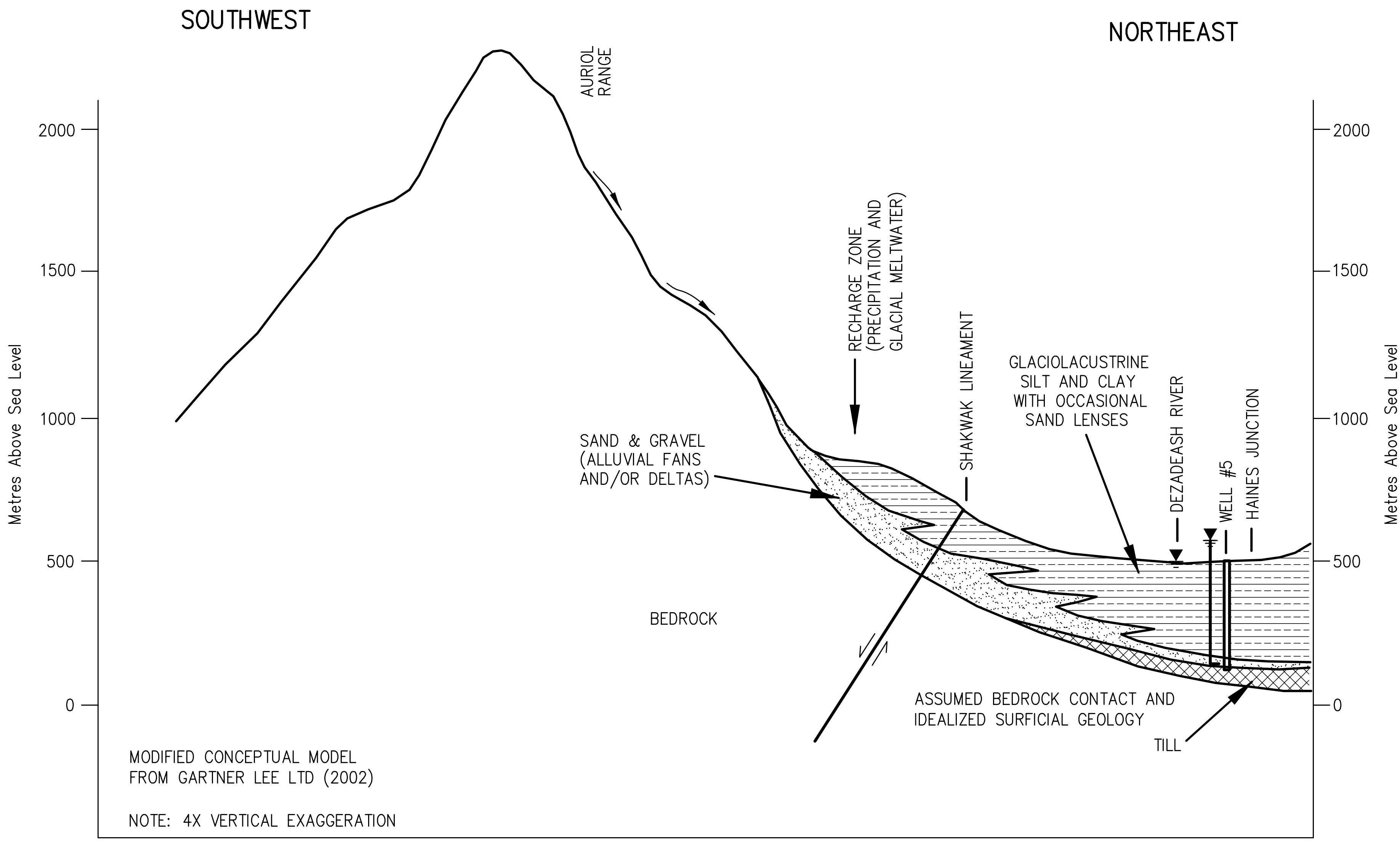


Figure 13, Pg. 60
Conceptual Hydrogeological Model of Well #5
Alluvial Fans/Deltas Control

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The estimated travel time for the groundwater to flow from the Auriol Range to Well # 5 is between 12 to 240 years depending on the variable aquifer characteristics. Based on the dissolved mineral content and TDS of the water at Well #5, and the tritium results, it is likely that the actual travel time is towards the middle of this estimate. This supports the transmissivity value obtained by evaluation of the recovery data.

Bedrock Structure Controlled Conceptual Hydrogeological Model

A second potential conceptual model consisting of a "bedrock structure controlled conceptual hydrogeological model" is presented schematically in Figure 14 (page 62). Given the complex structure of the area, and the presence of the Shakwak Fault, it is possible that regional structure plays some role in the movement of groundwater and its thermal characteristics. However, there are too many unknown variables to estimate the time it would require for groundwater to flow from the Auriol Range to Well # 5 if it flowed through structurally controlled flow paths. It is predicted that the travel time would be longer than the estimated time for the alluvial fans/deltas controlled conceptual hydrogeological model, as the structurally controlled flow path would be longer and would still have to flow through some of the same sands and gravels as the other model.

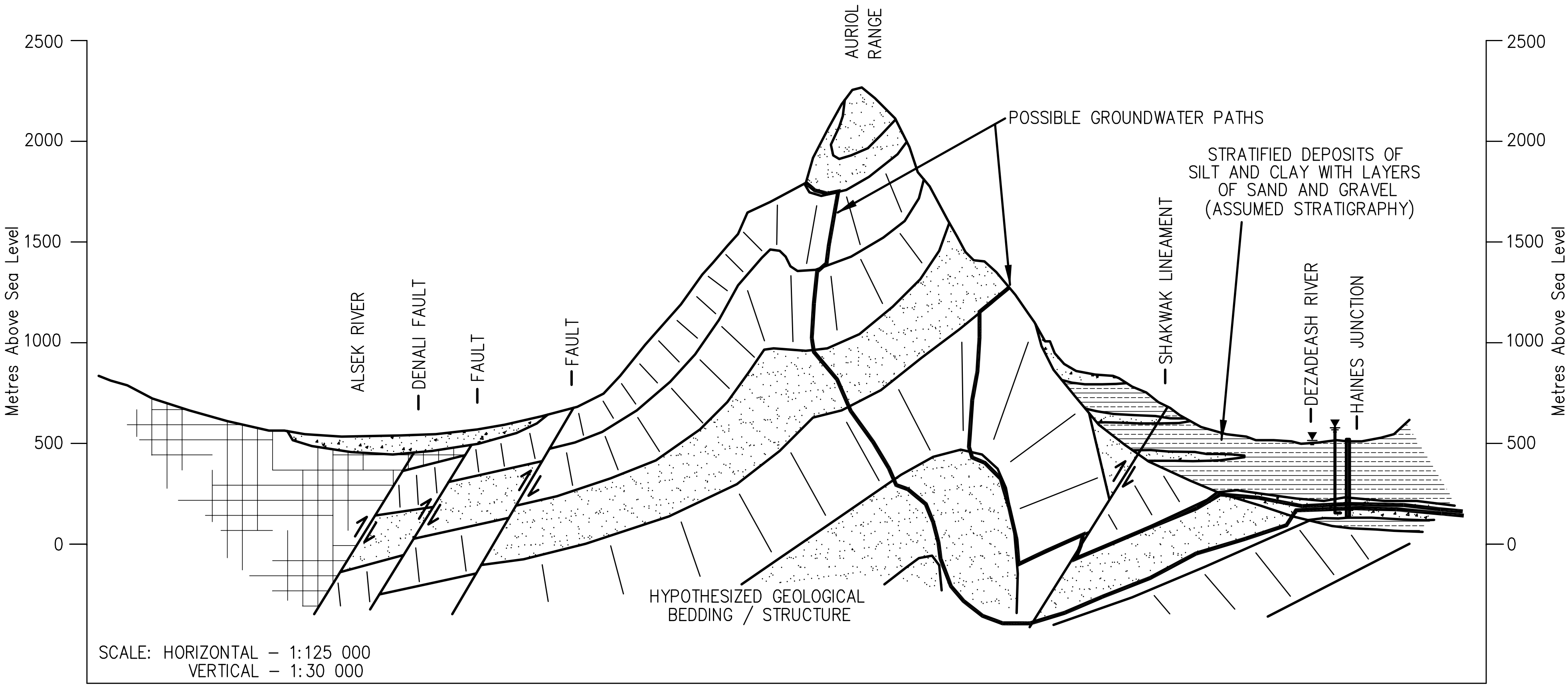


Figure 14, Pg. 62
Conceptual Hydrogeological Model of Well #5
Bedrock Structural Control

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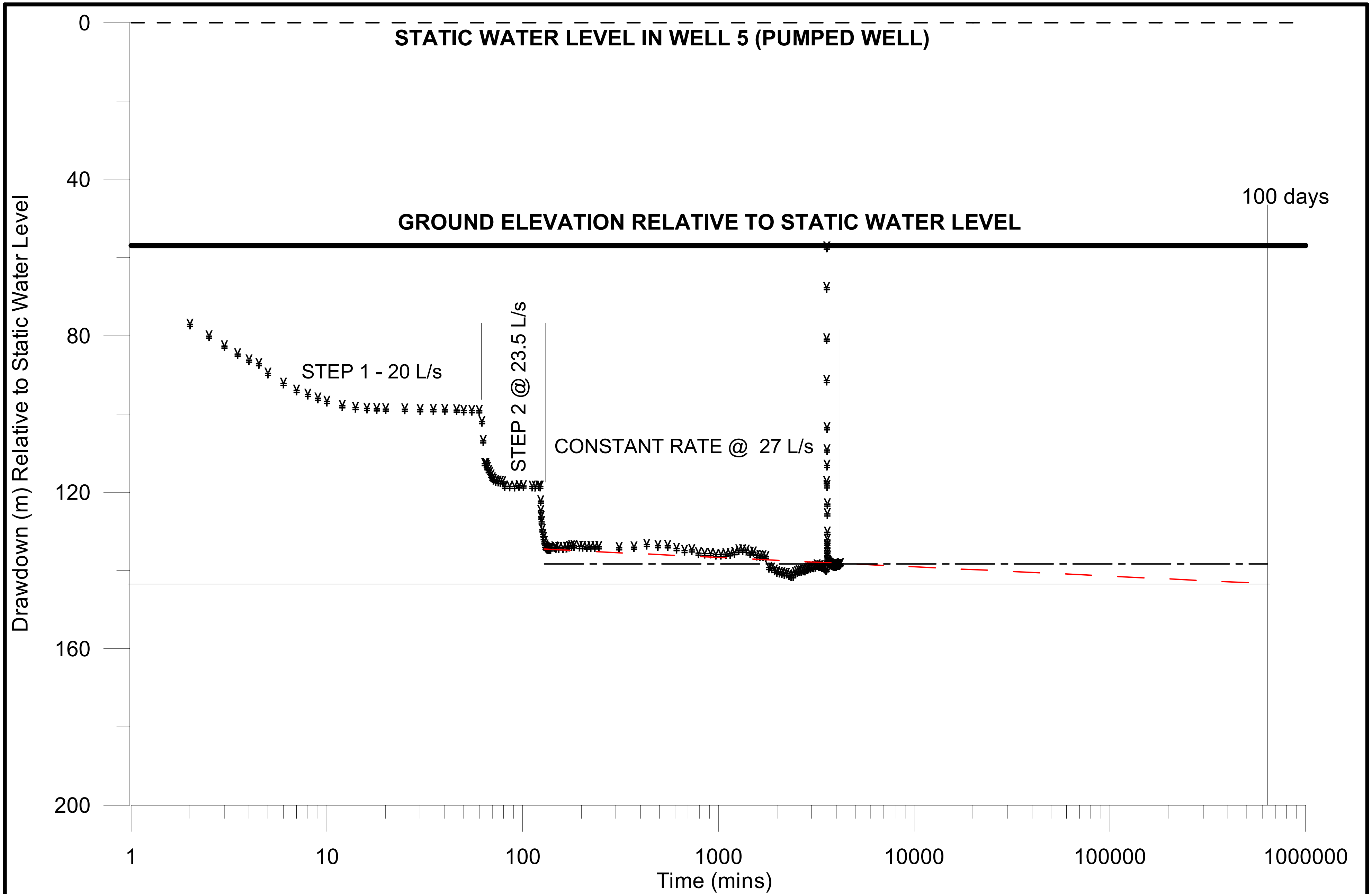
## 7.2 Long Term Well Capacity

The specific capacity of a well is a measure of its productive capacity and is calculated by dividing the flow rate during the test by the observed drawdown during the test. The specific capacity of Well #5 following 69 hours of continuous pumping at 27 L/s is 0.19 L/s/m. To calculate the well capacity for a Certificate of Public Convenience and Necessity in the Province of BC, the BC Ministry of Water Lands and Parks (MWLAP), Groundwater Section requires the yield of a well based on the specific capacity of the well at a given pumping rate to be multiplied by the safe available drawdown. The safe available drawdown is based on the slope of the time versus drawdown curve and assumes that the well will be pumped for 100 days of continuous pumping with no recharge to the aquifer. The available drawdown in the well is determined by the length of the water column above the pump intake at the time of year when groundwater levels are lowest, subtracted by pumping interference from neighbouring wells and multiplied by a safety factor of 70 percent. As mentioned by Gartner Lee, it is assumed that if a pump is installed, it would be housed within the 244 mm diameter casing (i.e above the Liner Hanger) to maximize pump size and capacity. The slope of the latter portion of the drawdown versus time curve is used to determine the amount of drawdown after 100 days of continuous pumping (see Figure 15, page 64). Table 8 illustrates the computation of the safe available drawdown and long term yield of Well #5 assuming that there are no other wells utilized within the deep aquifer.

**Table 8: Computation of Safe Available Yield:**

| Parameter | Unit | Key | Value |
|---|---|---|---|
| Specific capacity of well [*1] | L/s/m | a | 0.188 |
| Depth to top of liner casing | m | b | 141.1 |
| Estimated lowest static water level (depth from ground level) | m | c | -55 |
| Interference from other wells | m | d | 0.0 |
| CPCN Safety Factor (70%) | | e | 0.70 |
| Available drawdown (assuming well pump at 141.1 m btwc) | m | f = b-c-d | 196.1 |
| Safe available drawdown | m | g = e x f | 137.3 |
| Safe estimated sustainable yield | L/s | h = a x g | 25.8 |

NOTE: [1] Estimated from the drawdown versus time curve, after 100 days of continuous pumping with no recharge.

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CLIENT LESSOWAY MOIR PARTNERS for ENERGY SOLUTIONS CENTRE and VILLAGE OF HAINES JUNCTION

DATE AUG. 2003 DWN. RMM CHKD. GW

PROJECT RESOURCE ASSESSMENT ASSESSMENT OF AQUIFER

TITLE PUMPING TEST DATA STEP TEST AND CONSTANT RATE TEST

FILE NO. 1240049 DRWG. FIGURE 15, pg. 64

The amount of safe available drawdown in Well #5 is 137.3 m, assuming that:

- the pump intake is positioned just above the casing liner,
- there is no pumping interference from other wells (other wells not yet completed in this aquifer),
- the estimated lowest static water level is 1.75 m lower than the static water level observed during this study, and
- a 70 percent safety factor is applied.

Based upon the drawdown versus time curve, a conservative estimate of the specific capacity after 100 days of continuous pumping with no recharge would be 0.188 L/s/m. Considering a safe available drawdown, the well could theoretically be pumped at a rate of 25.8 L/s.

Field experience and laboratory tests show that the average entrance velocity of water moving into the screen should not exceed 0.03 m/s (Driscoll, 1986). At flows lower than this velocity, the friction losses in the screen openings are negligible and the rates of incrustation and corrosion will be minimal. A pumping rate of 25.8 L/s (the safe estimated sustainable yield) would result in an entrance velocity of approximately 0.02 m/s. This is considered acceptable for the proper operation of the well.

### 7.3 Aquifer Parameters

As mentioned previously, the only aquifer parameters that could be ascertained from this hydrogeological investigation are the transmissivity and the hydraulic conductivity. Based on the late time recovery data, these have been estimated at $4 \times 10^{-4}$ m/s and $1 \times 10^{-5}$ m/s, respectively.

### 7.4 Aquifer Boundaries

During the pumping test, no trends were observed that would be indicative of a boundary condition being intercepted by the drawdown cone generated during the long term pumping test. Aside from the slight undulations in the drawdown, or pumping water level (PWL) during the test, the PWL became relatively flat. As mentioned in the GLL report, this type of hydraulic response (i.e. no additional change in drawdown with respect to time) is indicative that the confined aquifer is a “leaky” aquifer. This means that the aquifer is recharged during pumping from the less permeable stratums above and below the aquifer.

### 7.5 Water Temperature Variation vs. Time

The Village has monitored temperature at the wellhead during use of Well #5. There has been no significant or noticeable change over the use of the well thus far. Given the significantly high volume of water that has been extracted from Well #5 to date and the observation that there has been no significant change in the water temperature, this supports the fact that this aquifer could support a sustainable source of heat energy. Continued monitoring of temperatures over time, however, is necessary.

### 7.6 Variation of Water Quality vs. Time

As indicated in Section 6.2.5, there were no obvious changes in the conductivity during the long term pumping test. As well, after reviewing the routine monthly analytical results for this well (provided by John Gibson), it is obvious that the water quality has remained relatively constant over the past six months of use of this well. Given the significant volume of water that has been abstracted from Well #5 to date and the observation that there has been no significant change in the water quality, this supports the fact that this aquifer is large in extent which is encouraging with respect to the long term sustainability of this aquifer

### 7.7 Preliminary Conceptual Geothermal Regime

The following presents a conceptual geothermal regime in the subsurface below Haines Junction. The relatively young chemical composition of the groundwater at Well #5 (as evidenced by its low TDS), and its origin as meteoric water suggests a relatively fast contact time of meteoric water with subsurface materials. Normally, geothermal fluids (i.e. fluids of high temperature) have significantly higher TDS because minerals are more readily dissolved at higher temperatures. Consequently, the water in the aquifer at Well #5 likely does not originate as a high temperature source; otherwise it would have a high TDS. Rather, it might be concluded that the fresh groundwater travels quite rapidly from its place of origin and that it is heated up rather quickly en-route to Well #5 or beneath the aquifer that Well #5 taps. This might suggest the presence of a conduit system at depth, which is consistent with the fracturing present in this area. Heat energy may be provided by conduits such as deep seated faults that extend to great depth (note seismic activity in proximity to the Shakwak lineament) or perhaps associated plutonism. The southern Yukon and Northern BC have several thermal springs that originate from deep-seated fractures. Shallow groundwater, recharged at high elevation may flow briefly through a fracture zone associated with the Shakwak Fault and acquires heat energy during its travel. As it travels further within the aquifer, it retains its heat energy. The conceptual model presented is highly speculative and would require considerable detailed information to confirm, nevertheless, it does offer an explanation for the observed warm temperatures at Well #5.

### 7.8 Energy Balance, Conceptual Geothermal Storage Options and Re-injection

Aquifer Thermal Energy Storage (ATES) scenarios that encompass cold storage, have not yet been completed as cooling demands have not yet been provided. At this time, it is assumed that only heating demands are required.

In order to minimize the impact on the aquifer and reduce the risk of supply depletion, excess water not used by the Community should be re-injected into the aquifer. EBA considers the surface release of waste cold water (water from which heat has been extracted for heating) to be non-environmentally sound because ecosystems supported by surface water are inherently sensitive. In addition, the continued abstraction of water from the aquifer may, over the long term, jeopardise the sustainability of the resource, both hydraulically and thermally.

EBA has discussed the potential of extending Well #4 into the deep aquifer. Trent Jamieson, of Midnight Sun Drilling, does not think that this would be possible. There is no viable option for placing the necessary grouting around the top of the well to withstand the artesian pressures of this deeper well.

If groundwater is re-injected to an aquifer, the injection well should be located downgradient from the production well so that the waste colder water is distributed downgradient from the production well. Plugging of injection wells by sand, chemical deposits, or bacterial growth is a major problem that can be alleviated, but usually not completely eliminated by specifying longer screens for the injection well. According to Driscoll (1986), where possible, the well screen for an injection well should be at least twice as long as an equivalent production well screen.

For future business case consideration, it should be noted that the cost of an injection well, including capital costs, operation, monitoring and maintenance are likely to be in the range of three to four times that of an extraction well. It should also be noted that in order to overcome the artesian pressure within Well #5, pumping would be required, and therefore, this cost should be included in capital, operational and maintenance costs in consideration of the business case.

It is not advisable to re-inject chemically altered water be re-injected to any aquifer. This would include chlorinated water.

There is insufficient hydrogeological information at present (ie. gradient, flow direction and travel times are yet unknown) to recommend minimum distances for locating a re-injection well relative to the source well (Well #5).

### 7.9 Seismic Risk to Long Term Sustainability of Resource

Since the aquifer in which Well #5 is completed is possibly hydraulically connected with, and is in close proximity to a parallel fault (Shakwak Lineament), there is some risk that seismic activity may result in alteration of the aquifer and well performance. Assessment of this risk is beyond the scope of the current study.

## 8.0 CONCLUSIONS

One of the objectives of this long term pumping test was to assess if other existing wells would respond to pumping from Well #5. None of the wells monitored indicated a response to pumping from Well #5. Therefore the data collected during the pumping test only provided information on:

- The transmissivity and hydraulic conductivity of the aquifer;
- The well efficiency;
- The water chemistry; and
- The water temperature.

The following cannot be assessed because they would need at least two monitoring locations.

- Storativity of the aquifer;
- Hydraulic gradient;
- Groundwater flow direction;
- Horizontal temperature gradient in the deep aquifer; and
- Recharge area.

The high discharge rate pumping test followed a long time period when the well was left flowing and was used as a water supply; being equivalent to a long term pumping test at a lower pumping rate. Based on the interpretation of the available information, the following can be concluded:

- Boundary conditions (either indicative of an impermeable barrier or of a recharge) have not been identified;

- The aquifer behaves as a "leaky" aquifer with an estimated transmissivity of 4 x $10^{-4}$ and a resulting hydraulic conductivity of 1 x $10^{-5}$ m/s, assuming an aquifer thickness of 40 m. These values are similar to the values proposed by GLL. Based on the pumping tests, the specific capacity of Well #5 is calculated to be 0.19 L/s/m. If Well #5 is pumped exclusively (no well interference), the estimated safe yield is 25.8 L/s.

- The various parameters monitored on the water flow, the water chemistry and the water temperature have indicated relatively constant conditions. The high flow rates used during the pumping test have not resulted in an apparent stress to the aquifer;

- The water chemistry and isotope analysis indicate that the water is low to moderately mineralized, of meteorological origin and has been resident in the subsurface for more than 50 years. Combined with the fact that a higher elevation recharge zone would be required to maintain the observed artesian conditions, it is probable that the groundwater originates from the Auriol range;

- Data are not available to predict on the size or lateral extent of this deep aquifer;

- The temperature observed in the deep aquifer has remained constant at 17°C over the period of extraction of the groundwater. This temperature is not due to the natural temperature gradient observed in the area (i.e. using the temperature gradient calculated in Wells #2 and #4 in the overburden deposits), which would result in a temperature of 8 to 9°C at 365 m. Therefore another heat transfer process creates the observed conditions. The Dezadeash valley borders a series of major geologic faults and an area where the seismic activity is high. Therefore it is possible that "en route" to the deeper aquifer, the groundwater is heated as it comes in contact either with high temperature rock or thermal fluids. It appears that the heat transfer is well established, due to the constant temperature observed, and is not impacted by the change in groundwater flow generated both during the recent use of the well and the high discharge rate pump test.

- The topography of the rock substratum at the bottom of the valley, the geometry of the fracture network and faults, the contact between the deep aquifer and any warm rock or groundwater are not presently known. Therefore it is not possible to define the conceptual model that would describe the geothermal conditions in the valley. Only hypothetical conceptual models can be generated.

- For the duration, and under the conditions used and tested, Well #5 has provided water of good quality and at a constant temperature of 17°C. Therefore the Well should be considered as a source of both water and energy. However, the use of Well #5 as a geothermal source should proceed with caution to take into account the various parameters that are still unknown and that would be presently very costly to characterize.

## 9.0 RECOMMENDATIONS

### 9.1 Production Rate

A safe sustainable yield of 25.8 L/s has been calculated for Well #5, based on limited available information. However, the level of uncertainty of the long term (e.g. 20 years) sustainability of Well #5 is still relatively high due to the number of unknown parameters characterizing both the groundwater regime and thermal regimes.

As it is very costly to drill monitoring wells to further characterize both the aquifer and the geothermal conditions, design of mid-term and long term water and energy use should only consider using a portion of what the well has been estimated to yield. This will be done to reduce the risk of "mining" both the aquifer and the source of energy and to provide a margin of safety to adjust drinking water and energy supply management plans. For example, if after a certain period of time (e.g. 5 or 10 years after the well has been put into production), monitoring trends start indicating a reduction in the performance of the well (e.g. drop of artesian pressure or drop of water temperature) then it will be possible to compensate by increasing the yield of the well for a relative short term (e.g. up to a year) to come up with alternative plans.

If meanwhile another user shows interest in using this water supply, this user should be involved in the characterization of this resource.

### 9.2 Resource Assessment

#### 9.2.1 Ongoing long term monitoring and interpretation

It is recommended that a datalogger be installed at the wellhead to continuously record temperature and pressure. Specifications will be supplied at the request of the Village.

The 24 hour shut-down and monitoring of pressure response at the wellhead should be continued on a monthly basis. This information should be interpreted by a Hydrogeologist on a semi annual basis.

#### 9.2.2 Additional investigations

The first step of an additional investigation should consist of installing at least one monitoring well (that could potentially be converted into another production well or re-injection well). In addition, a passive pump test (letting Well #5 discharge under artesian pressure) or active (similar to the pump test recently conducted) could be conducted on that new well. Required information on the groundwater flow direction and groundwater regime would be gained as well as data that would allow a better assessment of the long term behaviour of the aquifer.

The costs associated with a thorough and long-term investigation should be included in a risk-cost-benefit analysis to assess if, how and when this investigation should be conducted.

### 9.3 Well Monitoring and Maintenance

EBA recommends the implementation of a monitoring program for Well #5 due to the fact that moderate to aggressive bacteriological populations have been measured within the Well. Specifically, EBA recommends the following actions:

- The Village should continue monitoring the iron and manganese concentrations, conductivity, TDS and pH on a monthly basis.
- The Village should repeat the BART™ sampling on a bi-annual basis to track any changes of the bio-chemistry of the Well so that if there is a shift in the bacteriological activity, it can be addressed before it significantly impacts well performance or water quality.
- EBA considers it important for the Village to track the well efficiency on a monthly basis to permit early detection in the event that conditions in and around the well begin to deteriorate.

### 9.4 Pump Installation

If it is desired to install a pump in Well #5 at some future date, it is recommended that the pump intake be positioned just above the casing liner (approximately 140 m below top of well casing) to maximize available drawdown. As per the agreement with Aqua Tech, the pump that was purchased by Aqua Tech for these pumping tests, could be purchased back from them by the Village of Haines Junction at a significant discount. Aqua Tech would credit 80% of the pump rental charged for the test, to the purchase of this pump.

## 10.0 LIMITATIONS

Information presented in this report is based on inferred lithology, and conceptual models. Conclusions and recommendations presented in this report are based on the Hydrogeological Assessment as described in the previous sections. This report has been prepared for the exclusive use of Lessoway Moir Partners, Energy Solutions Centre, and the Village of Haines Junction. It has been prepared in accordance with generally accepted hydrogeological practices. For further limitations regarding the use of this report, reference should be made to the EBA Environmental Report - General Conditions attached, which form a part of this report.

## 11.0 CLOSURE

EBA trusts this report meets your present requirements. If you have questions or concerns, please do not hesitate to call the undersigned.

Respectfully submitted;
EBA Engineering Consultants Ltd.

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Hydrogeological Consultants Limited, Feb. 1996. Haines Junction 1996 Groundwater Program (Re: Problems with Well # 4 and discussion of potential mitigation options)

Hydrogeological Consultants Limited, June 1989. Village of Haines Junction Groundwater Investigation (Re: second preliminary test hole near location of future Well # 4).

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# APPENDIX A

# SUMMARY OF HYDROGEOLOGICAL INVESTIGATIONS

## APPENDIX A – Summary of Previous Hydrogeological Assessment Work

(sorted chronologically)

Report: February 1974 – Hydrogeological Consultants Ltd. *A Review of Groundwater Data – Haines Junction, Y.T.*

Hydrogeological Consultants Ltd (HCL) reviewed the existing wells in Haines Junction with relation to the increasing the water supply for the community.
The wells in the Village are shown on an aerial photograph and consist of:

1) The community well (dug and cement-cribbed close to the river);
2) The Yukon Territorial Government Well (1000 feet upstream of Well #1); and
3) Domestic wells within the Village of Haines Junction (known as: Refinery Well, Mile 1018 Well, and Brewster's Loge Well).

HCL identifies a shallow and deep groundwater source. The deep groundwater source is the water source for the Brewster's Lodge Well, which is 156 m deep, flowing artesian and soft.

Chemical analyses were determined and are reported for:

1) Community well;
2) The Yukon Territorial Government Well;
3) Brewster's Loge Well; and
4) Pine Creek (surface water).

HCL suggests that the most favorable water source for an increased water supply for the Village of Haines Junction would be from a groundwater well that terminated in the deep aquifer.

Report: August 1974 – Hydrogeological Consultants Ltd. *Haines Junction, Y.T. 1974 – Water Well Drilling*

Hydrogeological Consultants Ltd (HCL) supervised the drilling of two water test holes that were completed by Midnight Sun Drilling Co. Ltd in April 1974. The test holes were located near the old excavated well in Haines Junction.

Test Hole #1 was drilled to a depth of 15.2 mbgl and was screened between 4.0 to 5.2 mbgl, while Test Hole #2 was drilled to a depth of 13.7 mbgl and was screened between 7.0 to 7.6 mbgl.

Test Hole #1 had siltation problems and was abandoned, while Test Hole #2 was tested using a step-drawdown pump test and a 960-minute continuous rate pump test. HCL concluded that Test Hole #2 was likely to be connected to the Dezadeash River and could yield 3.0 to 3.8 L/s. Test Hole #2 became known as Well #1.

The water chemistry analysis stated that the water supply was moderately hard and basically a calcium-bicarbonate water type with a temperature of 3°. The chemical analysis and pump data were presented in the report.

Report: April 1978 – Hydrogeological Consultants Ltd. Haines Junction, Yukon Territory – *Water Well #2*

The Government of the Yukon Territory decided to develop a second community water well, for the Village of Haines Junction, as a secondary water supply source. The government hoped that the water supply from the second well would be warmer than the existing 2°C water supply so that the water would not need to be heated prior to distribution. Hydrogeological Consultants Ltd (HCL) supervised the drilling and conducted a hydrogeological investigation of the test well.

A test hole was drilled approximately 21 m west of the existing pump house to a depth of 134.4 mbgl. Two potential productivity zones were screened between 133.8 mbgl to 134.7 mbgl, and 76.5 mbgl to 78.3 mbgl. Both of zones had flowing artesian conditions. Hydraulic testing and chemical analyses were conducted at each of the screened intervals and are included in the report.

Upon reviewing the drill cuttings and hydraulic tests, HCL concluded that the lower screen was within gravelly till and the upper screen was within clay till with gravel and cobbles. Well #2 was completed and screened in the upper unit at 76.5 mbgl to 78.3 mbgl.

The natural flow rate was in the order of 2.7 L/s and was anticipated sand-free water at a yield of 7.6 to 11.4 L/s.

Report: Stanley Associates Engineering Limited, March 1979 – Government of Yukon – *Haines Junction Water Supply Study*

As the municipal water system at the Village of Haines Junction was at its capacity, Stanley Associates Engineering Ltd (SAE) was contracted to evaluate the immediate and long-term water supply needs for the Village.

SAE projected population and water demands from 1979 to 1983 to increase from 300 to 1000 people and an average daily water demand from 215,935 L/d to 568,250 L/d. The maximum projected storage requirement increased from 886,500 L in 1979 to 1,409,250 L in 1983.

The current water supply wells, Well #1 and 2, produce 3.4 l/s and 2.6 l/s. Well #2 produced less than initially expected due to a persistent sediment problem. The aquifers at Haines Junction consist of a shallow gravel aquifer, a middle aquifer, and a deep aquifer.

Four additional and alternative water sources were studied and cost estimated. These water sources consisted of:

1) Expansion of the existing shallow well system;
2) Expansion of the existing deep well system;
3) Surface water from the Dezadeash River; and
4) Surface water from Pine Lake.

The cost analyses within the report stated that the future water supply for the Village of Haines Junction should be wells or the Dezadeash River.

Report: Stanley Associates Engineering Limited, July 1980 – *Warm Water Well #2 – Haines Junction, Yukon Territory*

Stanley Associates Engineering Ltd (SAEL) was retained by the Yukon Territorial Government to conduct the hydrogeological investigation and supervise the drilling of a deep-water well to replace Well #2 and increase the water supply capabilities of the Village of Haines Junction.

Well #3 was drilled by Midnight Sun Drilling Co. Ltd. 18.6 m west of Well #2 to a depth of 85.4 m. A well screen was installed from 79.3 mbgl to 82.3 mbgl within a fine to coarse sand and gravel aquifer that was flowing artesian. Aquifer testing, consisting of a step drawdown test and a constant rate test, was conducted on Well #3 and a maximum continuous safe yield of 690 $m^3$/day was estimated.

From the analyses of two groundwater samples, the groundwater quality was rated very good, a temperature between 6.5 to 7.0°C, but dissolved gas that should be treated through venting.

Well construction details, aquifer test data, and chemical analysis data are included in the report.

Report: November 1988 – UMA Engineering Ltd. Village of Haines Junction – Water System Improvements: Status Report and Improvement Options.

UMA Engineering Ltd. projected the future population and the maximum annual water demand in the Village of Haines Junction to be 1000 people and 263,165 $m^3$. The Village has three water supply wells but due to sediment problems Well #2 has virtually been abandoned and the water from Well #1 has to be heated in the winter prior entry into the distribution system. Therefore, the Village relies entirely on Well #3 and there is no backup source.

UMA reviewed the surface water and groundwater alternatives stated by SAEL, 1979, the existing wells within the Village, and all the previous reports. A map was included in the report that shows the location of the existing wells. Water quality analyses were also reviewed and reported for the existing wells. From these reports and analyses UMA recommended that a water test hole be drilled in the vicinity of the elevated storage tank to a maximum estimated depth of 150 m.

Letter: May 1989 – Hydrogeological Consultants Ltd. *Haines Junction Water Test Hole Adjacent to the Water Tower*

A letter from R.J. Clissold, President and Senior Hydrogeologist of Hydrogeological Consultants Ltd. (HCL) to UMA Engineering Ltd. stated the results of the Test Hole No. 1-89.

Test Hole No. 1-89 was drilled to 249.9 mbgl within the fenced area around the water tower. Three significant intervals were encountered:

Upper Interval: 57.3-61.6 m - sulphate type water that would require treatment
Middle Interval: 93.3-97.8 m – a lot of silt
Lower Interval: 157.0-159.1 m – silt with water

HCL recommended drilling a second test hole either 1) close proximity to the Brewster Water Well, or 2) on the west side of the Village of Haines Junction.

Letter: June 1989 – Hydrogeological Consultants Ltd. *Village of Haines Junction Groundwater Investigation*

A letter from R.J. Clissold, President and Senior Hydrogeologist of Hydrogeological Consultants Ltd. (HCL) to UMA Engineering Ltd. stated the results of the Test Hole No. 2-89.

Test Hole No. 2-89 was drilled to 182.9 mbgl approximately 100 m north of the water tower. A sand and gravel aquifer was encountered from 59.4 to 64.0 mbgl and from 120.4 to 123.1 mbgl. Water chemistry analyses were collected from each aquifer and indicated that the lower aquifer is more suitable to municipal needs.

Letter: February 1996 – Hydrogeological Consultants Ltd. *Haines Junction 1996 Groundwater Program*

A letter from R.J. Clissold, President and Senior Hydrogeologist of Hydrogeological Consultants Ltd. (HCL) to David Nairne & Associates Ltd. Summarized the groundwater investigations to date in the Village of Haines Junction. This included the attempts to control the silt problems at Well #4 (Test Hole No. 3-89).

HCL recommended that either 1) further investigations should be conducted on Well #4, or 2) that a new test well should be drilled to a similar depth of Well #4.

<u>Report: February 1996 – David Nairne and Associates. Status Report / Technical Brief – *Water Supply Well #4 and Proposal for Additional Investigations for the Village of Haines Junction*</u>

David Nairne & Associates Ltd. (DNA) produced a status report / technical brief regarding Well #4. This report included a detailed chronology of the events surrounding the construction of Well #4, recent investigations and status of the well, and the possible options for restoration of the much needed water supply in Haines Junction, which included cost estimates and recommendations.

DNA recommended that no further studies be conducted on Well #4 and that the locating and developing of a new Well #5 be conducted. The proposed work plan was included for the investigating and supervising of Well #5.

<u>Letter: March 1997 – Hydrogeological Consultants Ltd. *1996/97 Groundwater Program*</u>

A letter from R.J. Clissold, President and Senior Hydrogeologist of Hydrogeological Consultants Ltd. (HCL) to Building Industry Consultants that summarized the current water levels and production from Well #3, an aquifer test and chemical analysis from the Stardust Motel Water Well, and the proposed location and drilling costs for the 1997 Water Test Hole (proposed Well #5).

Based on the good groundwater quality and high-permeability aquifer at the Stardust Motel Water Well, HCL recommended a proposed drilling location for the 1997 Water Test Hole (proposed Well #5). A map showing the proposed location was included in the letter.

<u>Report: December 2002 – Gartner Lee Limited. *Haines Junction Water Well #5 Completion Report*</u>

The new groundwater well (Well #5) was completed by Midnight Sun Drilling Co. Ltd.,, between August 13 and September 13, 2003, to a depth of 369.2 m and was screened between 361.9m to 369.2 m below ground level (mbgl) with a 127 mm diameter, 60-slot stainless steel screen within a sand and gravel aquifer. Well #5 is a flowing artesian well with an estimated hydrostatic head of approximately 59 m above ground level and artesian flow rate of 13 L/s. The aquifer pump test was conducted by Aqua Tech Supplies & Services Ltd.

The simplified stratigraphy of Well #5 is shown in Table 1. GLL inferred that the artesian conditions at Well #5 were likely encountered at a depth of approximately 329 mbgl. The water bearing unit could represent alluvial fans or deltas that have formed off the slope of the Auriol Range south of the Dezadeash River.

Table 1: Simplified Stratigraphy of Well #5

| Depth (mbgl) | MATERIAL TEXTURE | Stratigraphic Unit |
|---|---|---|
| 0 – 329 m | SILT and CLAY, occasional fine sand lenses and pebbles | Glacial Lake Champagne Glaciolacustrine deposits |
| 329 – 343 m | SILT, SAND and GRAVEL | Transitional Facies – interbedded and mixed fluvial and glaciolacustrine deposits |
| 343 – 370 m | SAND and GRAVEL | Alluvial and/or deltaic deposits |
| > 370 m | CLAY, SILT and GRAVEL | Till |

Well #5 was developed by air lifting, between September 14 and September 25, 2002, to remove the fine sediments around the well screen and to maximize the water yield of the well. Following development, the maximum long-term safe yield of Well #5 was estimated at 27 L/s using a 6.8 hour, 3 stage step test with the maximum discharge rate of 19.94 L/s. On the basis of visual inspection, the discharged water appeared to be 'sand free' throughout the pumping test.

A relatively constant water temperature of 16.9°C was measured from the water discharged from Well #5 during the short-term pump test.

The water quality of Well #5, with the exception of turbidity, meet the applicable health-based Canadian Drinking Water Quality Guidelines (CDWQG) for the parameters that were tested. The elevated turbidity was inferred to be due to trace residual amounts of the drilling fluid and significantly less according to the Mayor of Haines Junction, John Farynowski, during a conversation on November 8, 2002.

Total iron concentrations in the groundwater from Well #5 exceeded the aesthetic CDWQG (0.3 mg/L) by a factor of two. Analysis of the dissolved and total metal concentrations indicated to GLL that the elevated iron concentrations may be related to the elevated turbidity levels and the reduction in turbidity may reduce the total iron concentrations.

The measured pH of the groundwater from Well #5 was between 8.5 to 9 pH units, while the CDWQG suggest an acceptable range for drinking water of 6.5 to 8.5 pH units.

# APPENDIX B
# WATER WELL RECORDS
# (Not included in Digital Copy)

# APPENDIX C
# PUMP AND EQUIPMENT SPECIFICATIONS
# (Not included in Digital Copy)

# APPENDIX D
# PUMP TEST DATA
# (Not included in Digital Copy)

# APPENDIX E
# ANALYTICAL RESULTS
# (Not included in Digital Copy)