2003-0436

Long Term Monitoring Well No. 1
Wolf Creek Subdivision

prepared for:
Indian and Northern Affairs Canada
Water Resources

prepared by:
Gartner Lee Limited

reference:
GLL 21-905

date:
February, 2003

distribution:
- **2 DIAND**
- **2 City of Whitehorse**
- **2 YTG Community Development**
- **1 YTG Environmental Health**
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February 11, 2003

Rick Janowicz
Northern Affairs Program
Water Resources
Room 345, 300 Main St.
Whitehorse, Yukon, Y1A 2B5

Dear Mr. Janowicz:

Re: 21-905 – Long Term Monitoring Well No. 1 Wolf Creek Subdivision

We are pleased to provide the report for the above noted project. Following the completion of the long term monitoring well a pumping test and water quality assessment of the bedrock aquifer was completed.

Thank you for allowing Gartner Lee Limited this opportunity to work with you on this important project which will provide key data to help with the management and sustainability of the Yukon's groundwater resources.

If you have any questions or comments please do not hesitate to call me at (867) 633-6474, extension 27.

Yours very truly,
GARTNER LEE LIMITED

Jonathan Kerr, M.Sc.
Hydrogeologist

JCK:jck

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1. Introduction

1.1 Background

In 2000, the Department of Indian and Northern Development (DIAND), Water Resources initiated the Upper Yukon River Surface and Groundwater Inventory. DIAND Water Resources successfully gained partnerships with the Government of Yukon and the City of Whitehorse to pursue this initiative. As follow-up to the 2000 projects, a series of new projects were initiated in 2001, including the completion of the Yukon's first long-term groundwater, instrumented, monitoring well. This report provides the construction and testing details for this monitoring well.

Long Term Monitoring Well (LTMW) No. 1 was installed in the Wolf Creek Subdivision in Whitehorse, Yukon. The Wolf Creek Subdivision is a rural residential development with one of the highest densities of private wells within the City of Whitehorse. Furthermore, the Wolf Creek and Pineridge subdivisions have been the focus of the 2000 research projects. Construction of LTMW No. 1 resulted as a recommendation from the *Wolf Creek and Pineridge Groundwater Usage Study* (Gartner Lee Limited 2001) and provides a logical follow-up to this previous work.

The goal of LTMW No. 1 is to observe both short term and long-term trends in water levels and groundwater quality. The data collected from the well will help further understand the water cycle in southern Yukon through continuous water level recording. Long-term impacts such as declining water levels and/or degradation of water quality as a result of human activity could also be documented.

A site location map of the Wolf Creek Subdivision is presented in Figure 1.

1.2 Scope of Work

The following scope of work was conducted as part of this project:

- Drilling of a Long Term Monitoring Well (LTMW) No. 1 on Lot 117 of the Wolf Creek Subdivision.
- Collection of stratigraphic information from the borehole.
- Completion of a pumping test consisting of a 2-hr step test followed by a 72-hr constant rate test.
- Collection and analysis of groundwater samples.
- Data analysis and preparation of project findings, conclusions and recommendations.

LTMW No. 1 was drilled between February 22nd and 23, 2001. Pumping tests were performed and water quality samples were collected between March 27th, and March 30th, 2001. Drilling was completed by Midnight Sun Drilling Company Limited and pumping test services were provided by Aqua Tech Supplies & Services Ltd., both of Whitehorse, Yukon. Drilling operations were supervised by Nicole

Hulstein, Geologist (GLL), while pumping tests were supervised by Dennis Lu, Environmental Technician also of GLL. Mr. Lu also conducted the water quality sampling.

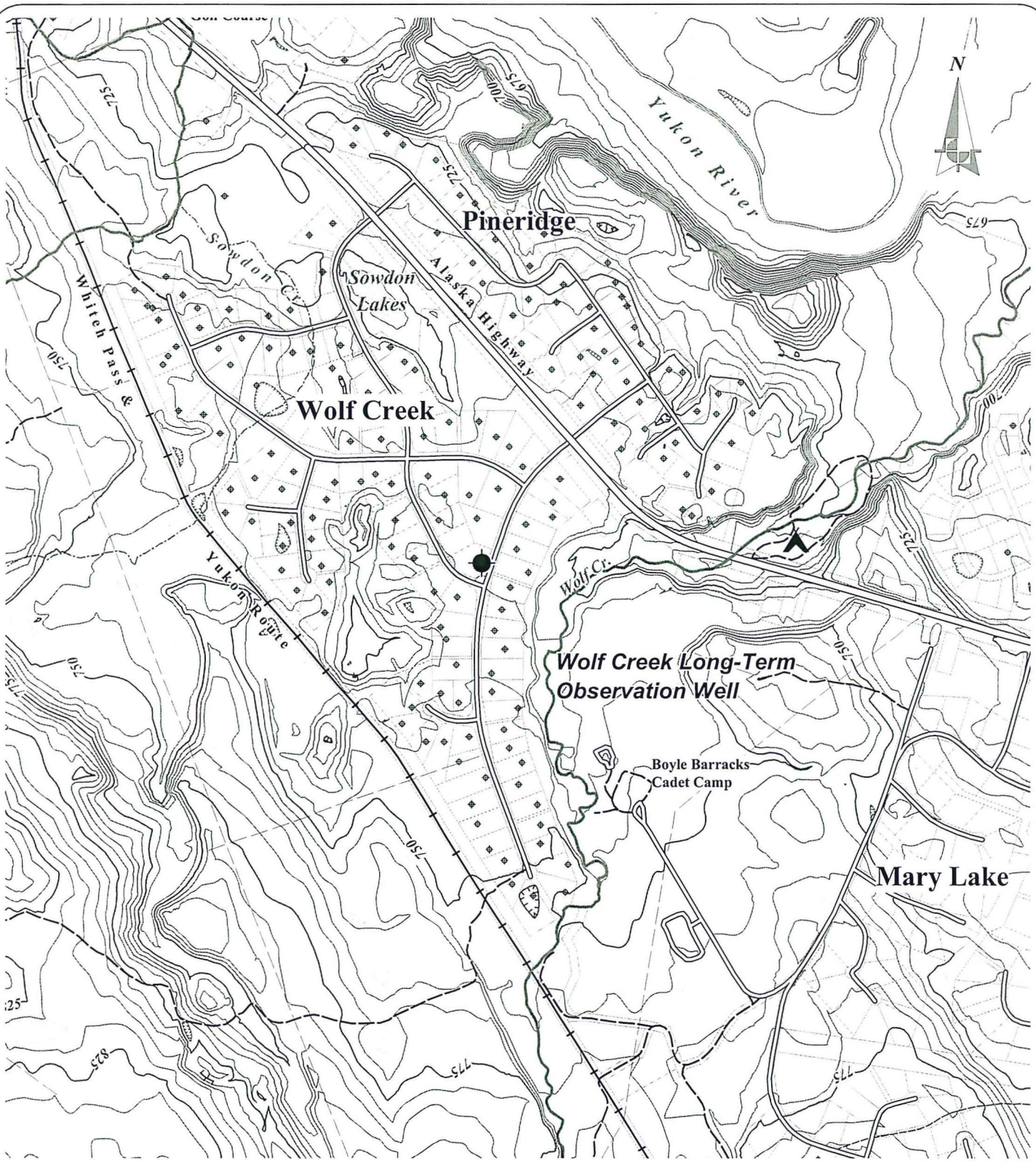
1.3 Site Description

LTMW No. 1 is located in the Wolf Creek subdivision (Lot #117) along Dawson Road. The lot is public space occupied by a playground and outdoor community ice rink. The site is located approximately 14 km south of downtown Whitehorse, directly across from the Pineridge Country Residential Subdivision and near the southern city limit of Whitehorse. This is one of the older rural residential subdivisions in Whitehorse, initially developed in the 1970s. Wolf Creek Subdivision is bounded to the south by Wolf Creek, to the east by the Alaska Highway and to the north by McRae Creek. Southest of the subdivision the terrain rises to Golden Horn Mountain. A map showing the location of LTMW No 1 and the area immediately surrounding the well is presented in Figure 2.

1.4 Physical Setting

1.4.1 Physiography

The landforms of the Whitehorse area can be largely attributed to the last ice age, estimated to have occurred between 10 000 and 35 000 years ago. The Whitehorse valley has a complex sequence of glacial, glaciofluvial and glaciolacustrine deposits that are typical of deglaciation in mountainous terrain (Mougeot GeoAnalysis and Agriculture and Agri-Food Canada, 1997). Meltwater channels are another important landscape feature within the Whitehorse area. These are deeply incised features cut into the bedrock, till, or other sediments, and were created by meltwater streams as the glaciers retreated, generally parallel in direction of the current day, Yukon River. Meltwater channels are visible to the south and west of the Wolf Creek and Mary Lake country residential subdivisions.



Site Name:	Wolf Creek
File Name:	FIG1.WOR

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Scale: 1: 20,000

Department of Indian and Northern Affairs Canada
Water Resources

Wolf Creek Long-Term Observation Well

Site Location Map

Project No:	21-905
Date Issued:	January 2003

Figure 1

Site Name: Wolf Creek File Name: 21905-F1_2.WOR Gartner Lee Scale: 1: 10,000	**Department of Indian and Northern Affairs Canada** **Water Resources** **Wolf Creek Long-Term Observation Well** **Well Location Map**	Project No: 21-905 Date Issued: January 2003 **Figure 2**

1.4.2 Surficial Geology

The surficial geology of the Whitehorse area is quite varied, including, modern fluvial and ancient glaciofluvial sand and gravel, glaciolacustrine silt and clay, glacial tills (composed of sand, silt and clay), bedrock outcrops, and organic rich areas (Mougeot GeoAnalysis and Agriculture and Agri-Food Canada, 1997). The Wolf Creek Residential Subdivision is situated on a relatively flat terrace. Surficial sediments that underlie this subdivision are primarily composed of glaciofluvial sand and cobble gravel (Gartner Lee Limited 2001c). This outwash sediment ranges in thickness form 4 to 16 m, and generally overlies the glacial till deposits. Numerous small closed depressions, called kettles are present throughout the Wolf Creek subdivision. These kettles are the result of stagnant ice blocks that detached during glacial retreat and formed depressions as they melted. One such kettle feature is that of Sowdon Lake, a pair of ponds located between the Alaska Highway and Cronkhite Road. Tills in many parts of the City are often coarse grained, and are commonly confused with glaciofluvial gravel sediments. Additionally, tills in the area are generally between 11 and 30 m thick. Bedrock throughout the study are is composed of granite (northwestern portion of subdivision) or basalt, with depth to bedrock ranging from 10 m in the north west, to a non uniform, variable depth throughout the remainder of the subdivision.

1.4.3 Stratigraphy

The borehole log from LTMW No. 1 is provided in Figure 3. The stratigraphy encountered during the completion of the monitoring well consisted predominantly of layered sands and gravels underlain by bedrock. A simplified stratigraphy is provided in Table 1.

Table 1. Simplified Stratigraphy at LTMW No. 1

Depth (meters below ground surface)	Material Texture	Interpreted Stratigraphic Unit
0 - 9.1 m	ORGANIC SILT	Glaciofluvial Outwash
9.1 - 22.9 m	SILTY SAND and GRAVEL	Till
22.9 - 36.6 m	SILT SAND	Glaciofluvial Outwash ??
36.6 - 41.2 m	GRAVELLY SITLY SAND	Till
41.2 - 43.6 m	SAND AND GRAVEL	Basal Till
43.6 - 48.8 m	BASALT	Miles Canyon Basalt

BOREHOLE LOG	PROJECT: 21-905	BOREHOLE: LTMW No.1
Long Term Monitoring Well No. 1 Wolf Creek Subdivision **FOR:** DIAND Water Resources		**DATE:** 22 February 2001 **GEOLOGIST** NH **ELEVATION** 738.0 m ASL

DEPTH (m)	STRATIGRAPHY	STRATIGRAPHIC DESCRIPTION	MONITOR DETAILS & NUMBER	SAMPLE NUMBER	SAMPLE INTERVAL	SAMPLE TYPE	COMMENTS
1.5		**ORGANIC SILT** Orange-brown organic silt, trace sand.		1	=	GS	**Well Construction Details**
		SAND AND GRAVEL Light grey sand and medium to coarse gravel (subangular to subrounded).		2	=	GS	**Location of Well:** Lot 117, Wolf Creek **Drilling Company:** Midnight Sun Drilling Limited of Whitehorse, Yukon.
5		-Increasing sand content and fraction with some fine gravel below about 6.1 m.		3	=	GS	**Well Depth:** 48.8 m (160.1 ft) **Completion Method:** Open Hole in Basalt (5 1/2" OD). **Casing Diameter and Type:** 6 5/8" x 0.250 Steel Casing. **Total Casing Depth:** 44.5 m (146 ft)
9.1				4	=	GS	
10		**SILTY SAND WITH GRAVEL** Olive grey silty sand, trace fine gravel with local zones of higher gravel content, moist.		5	=	GS	
				6	=	GS	
				7	=	GS	
				8	=	GS	
				9	=	GS	
15				10	=	GS	
				11	=	GS	**Static Water Level:** 16.48 m (March 27, 2001)
				12	=	GS	
				13	=	GS	
20				14	=	GS	
				15	=	GS	
22.9		**SILTY SAND** Yellowish orange silty fine sand.		16	=	GS	
25				17	=	GS	
				18	=	GS	
				19	=	GS	
				20	=	GS	
30		-Some medium sand and becoming grey in colour below about 30.5 m. -Some gravel content between about 32 and 34 m.		21	=	GS	
				22	=	GS	
				23	=	GS	
35				24	=	GS	
36.6		**GRAVELLY SILTY SAND** Grey silty fine sand with fine to coarse rounded to subangular pebble gravel.		25	=	GS	
				26	=	GS	
40				27	=	GS	
41.2		**SAND AND GRAVEL** Grey very coarse sand with fine to coarse pebble gravel.		28	=	GS	
43.6		**BASALT** (Miles Canyon) Reddish brown basalt.		29	=	GS	
45				30	=	GS	
				31	=	GS	
				32	=	GS	
48.8		Borehole terminated at 48.77 m in basalt.					

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2. Monitoring Well Completion

LTMW No. 1 was drilled by Midnight Sun Drilling Company Ltd. of Whitehorse, Yukon using a truck mounted Schramm, T450 air rotary rig. The well was completed on February 23, 2001 and drilled to a total depth of 48.8 m. Steel casing (168 mm OD x 6 mm thickness) was set to a depth of 44.5 m below ground surface. Below this depth the hole was open hole drilled (OD of 140 mm) to a final depth of 48.8 m. Well completion details are provided on the borehole log presented in Figure 3.

Drill cutting samples were collected through the drill cyclone at 1.5 m intervals and logged in the field. The well was developed by air surging for approximately 4 hours until no fine sand was visible in the purged groundwater. Due to the open-hole bedrock completion of the well, development occurred relatively quickly and an acceptable level of groundwater clarity was obtained relatively quickly. Laboratory samples tested for turbidity confirmed the field observations. A detailed discussion is provided in section 4.

3. Hydrogeological Testing & Analysis

3.1 Field Methodology

The basalt bedrock encountered at a depth of 44 m was developed as the water bearing formation. To help characterize both the hydraulic performance and aquifer parameters, two single well pumping tests were performed on the observation well:

1. A 2-hr variable pumping rate test on March 27th, 2001;
2. A 72-hr constant rate pumping test on March 28th, 2001.

Water levels were measured for 1 hour following the completion of each pumping test. Time drawdown graphs showing water levels measured throughout the tests are provided in Appendix A.

3.2 Variable Rate Pumping Test

A variable rate, or "step test", was conducted on the monitoring well on March 27th, 2001. The step test comprised of four 30 minute steps. Pumping rates ranged from 0.2 L/s (3 ipgm) to 0.6 L/s (8 igpm). Within 60 minutes after pumping stopped, the water level had recovered to 96% of its static level (16.61 m below top of casing). Data from the variable rate pumping test were evaluated and a pumping rate of approximately 0.6 L/s (8 igpm) was selected for the constant rate test.

The drawdown of water levels in the well over the duration of the step test, and the associated pumping rate are provided in Figure 4. Although groundwater entering LTMW No. 1 is derived primarily from fractures, the nature of the time drawdown curve suggests the hydraulic behavour of the bedrock (over the duration of the test period) is similar to that of a uniform porous medium. Therefore it was reasonable to use an equivalent porous media approach and conventional porous media curve matching techniques for the analyses.

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

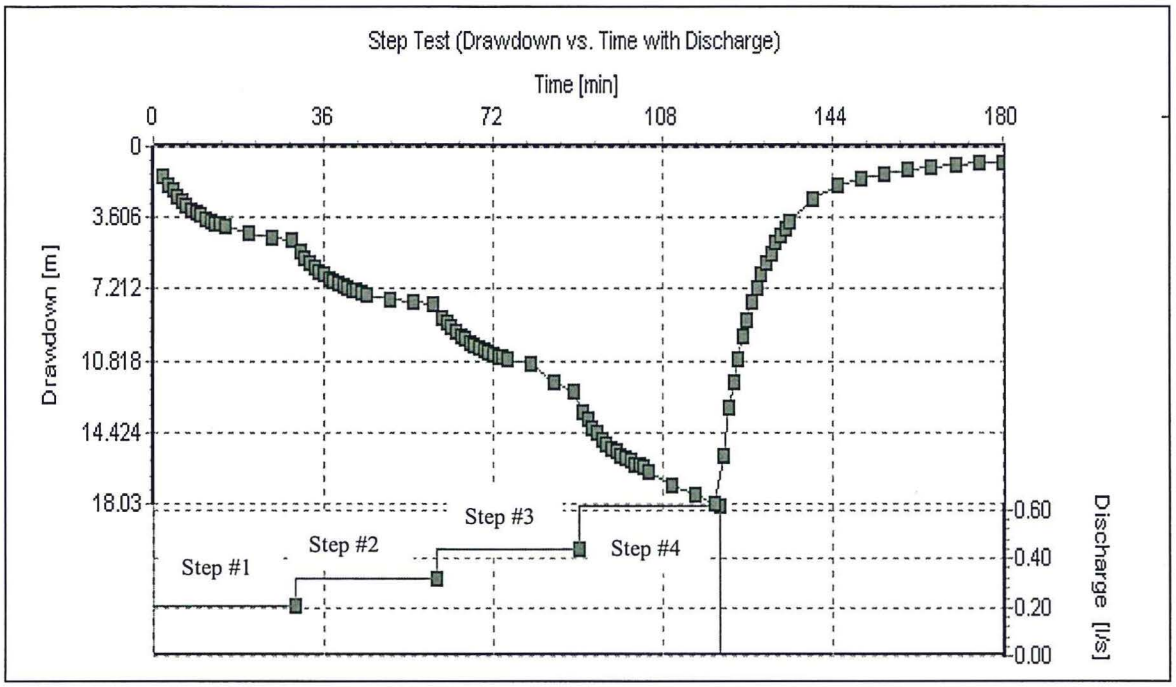

Figure 4. Drawdown in LTMW No 1. - 2-hr Variable Rate Pumping Test

3.3 Constant Rate Pumping Test

Water levels in the well had recovered fully since the end of the step test and the initiation of the constant rate pumping test. The constant rate test was conducted from March 28th to April 1st. The pumping test consisted of a 72-hour pumping period followed by a one-hour recovery period. At the start of the constant rate test, the well had a static water level of 16.61 m below the top of the casing. The water level was 38.35 m below the top of the casing at the end of the 72-hour pumping period, for a total drawdown of 21.74m. The pumping rate throughout the test was 0.6 L/s (8 igpm). A graph showing the drawdown in the well and the associated pumping rate is provided in Figure 5.

Water levels during the pumping test dropped steadily within the first 270 minutes to approximately 36.8 m at which time the levels generally stabilize for the duration of the test.

Hydraulic properties of the aquifer were estimated based on the behavior of the time drawdown data collected during the long term pumping test. The data indicate that early time-drawdown (i.e. first 10 min) was significantly affected by borehole storage as the pumping rate was relatively small compared to overall volume of the borehole. Consequently, this early time data was ignored.

As discussed previously, the hydraulic response of the bedrock aquifer during the step pumping test is consistent with that of a "confined aquifer" however, given the longer duration of the 72 hr test and the collection of late time data there appears to be leakage from overlying or underlying stratum. Consequently the time-drawdown data was fit to the Hantush-Jacob Solution (1955, 1961a, 1961b). The pumping data and analyses summarized in Appendix A. Based on this analyses the estimated transmissivity of the aquifer is 0.37 m^2/day. Considering the length of the open portion of the borehole (5.2 m), the hydraulic conductivity of the aquifer is estimated at approximately 8.3 x 10^{-7} m/s.

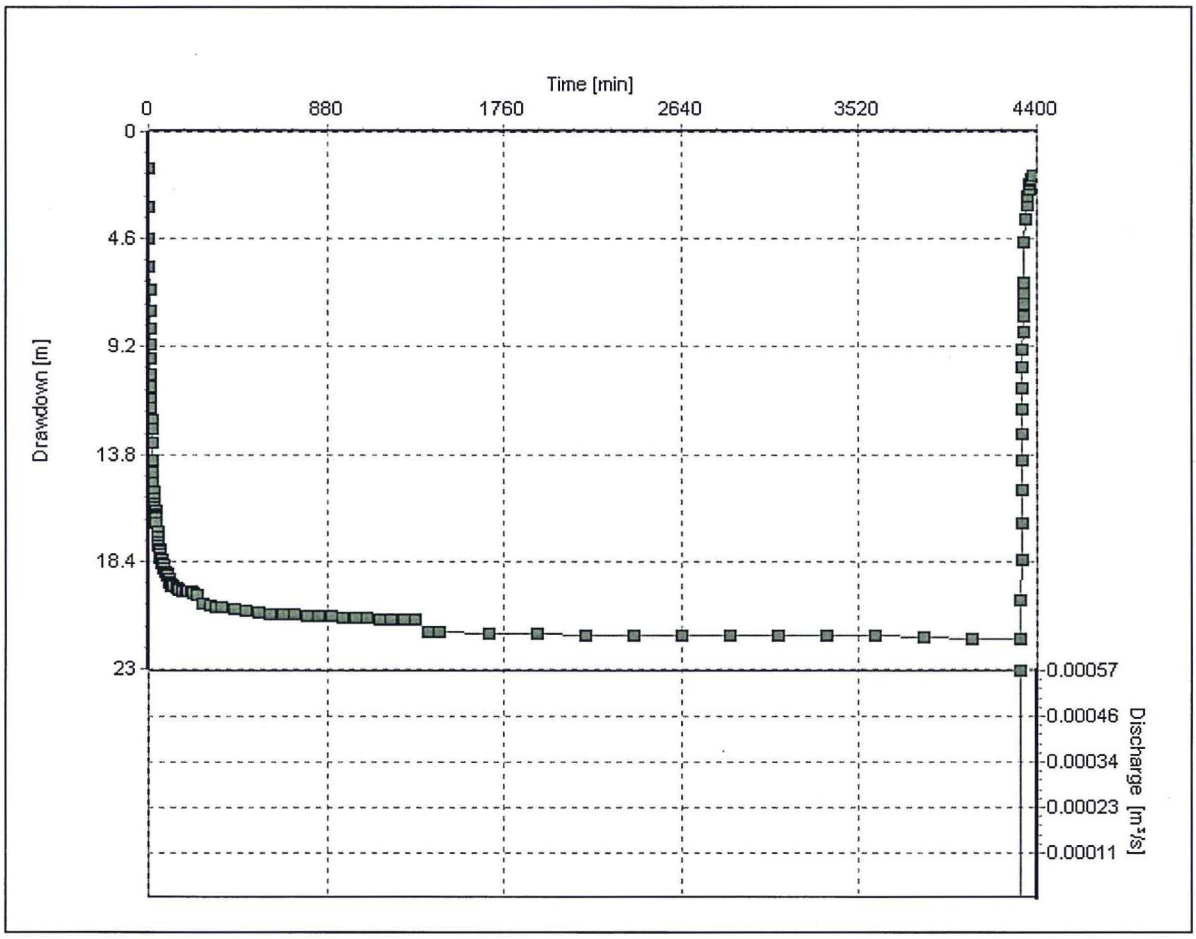

Figure 5. Drawdown in LTMW No. 1. - 72hr Constant Rate Pumping Test

3.4 Water Level Data from LTMW No. 1

Transient water level data to date collected from LTMW No. 1 that has been provided to Gartner Lee Limited, is presented in Figure 6. The observed increase in water levels during the spring (i.e. March through the end of May) is interpreted to be associated with spring snowmelt and recharge to the aquifer. This recharge event is then followed by a slow and steady decline in water levels throughout the remainder of the fall and winter months.

This interpretation is supported by an independent Precipitation Water Balance Model conducted by Environment Canada in 2000, based on a methodology adopted by C.W. Thornthwaite and J.R. Mather, 1957. The Environment Canada study (GLL 2001b) found that periods of precipitation water surplus (i.e. water available for infiltration) only occurs during three months out of the entire year (i.e. March, April and part of May), with the maximum surplus occurring during the 2nd week in April. After this time, a precipitation water deficit occurs until end of October. Not surprisingly, the Environment Canada study also found that throughout the winter months (i.e. November through March) there was neither a surplus or deficit of water, as precipitation during this time was frozen (i.e. snow) and was effectively in storage Figure 6.

As shown in Figure 6 there appears to be a time lag associated with the occurrence of water surplus and the time at which water levels in the aquifer fully recover following winter low levels. It is likely that this time lag is a transient effect attributed to recharge water infiltrating through the vadose zone prior to influencing the water table. The opposite effect appears to occur, following the start of the precipitation deficit period and the observed decline in groundwater elevations, however at comparatively, slower rate. During this time, it is likely that the decline of groundwater levels in the aquifer is the result of evapotranspiration and groundwater discharge to streams and rivers.

Additionally, seasonal water level lows in LTMW No. 1 (i.e. lowest water level observed in 2001 and 2003) appear to be similar (approx. 16.6 m below top of casing) and occur mid to late February. Given the observation period presented in Figure 6 over course of a year, the water levels in LTMW No. 1 have fluctuated a total of approximately 0.6 m.

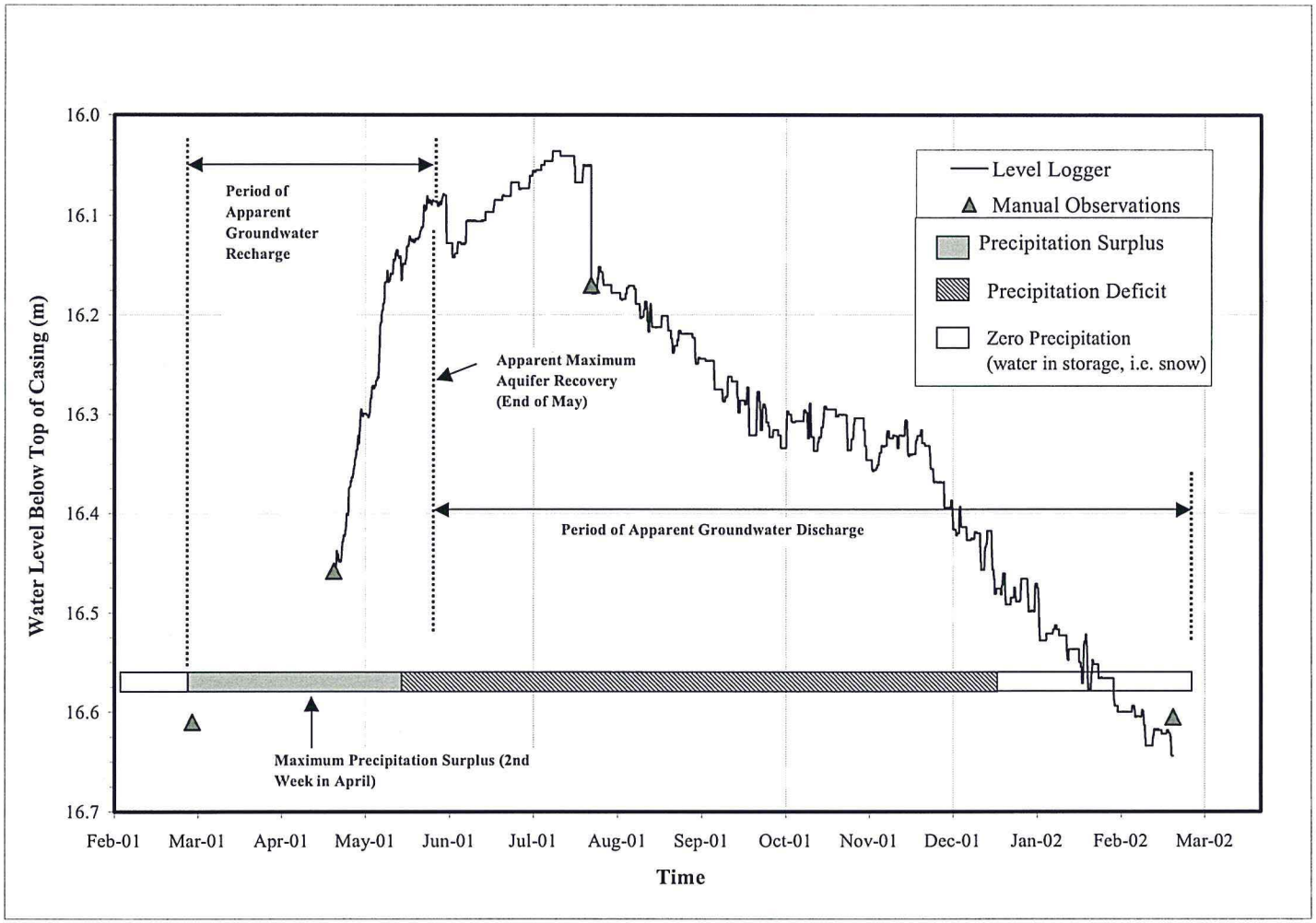

Figure 6. Hydrograph of Water Levels from Long Term Monitoring Well No. 1

4. Groundwater Quality

4.1 Sample Collection

All samples submitted for analyses were collected in pre-cleaned bottles supplied by ALS Environmental of Vancouver, BC. The following sampling and preservation methods were applied:

- Samples submitted for metal analysis were collected in 250 mL high density polyethylene (HDPE) bottles, preserved with nitric acid (pH < 2) immediately after collection.
- Samples submitted for general parameters (i.e. hardness) were collected in 1-L HDPE plastic bottles with no acid preservative.
- Samples for bacteriological analysis were collected in plastic bottles with preservative provided by the laboratory.

Following collection, the sample bottles were placed in a cooler at approximately 4° C and shipped to ALS Laboratories in Vancouver, B.C. via air cargo. Bacteriological samples were submitted for analysis at the Environmental Health Services Branch of Yukon Health and Social Services in Whitehorse, Yukon, within 24 hrs of collection.

Two groundwater samples were collected midway through and prior to the end of the 72-hr constant rate pumping test. Samples were collected from a sampling port (i.e. valve) located on the pump assembly directly to top of the wellhead.

4.2 Sample Analyses

The water quality analyses conducted throughout this study provides a level assessment adequate for comparison to the Canadian Drinking Water Guidelines, 1996. ALS Environmental of Vancouver, BC, a certified member of the Canadian Association of Environmental Analytical Laboratories (CAEAL), conducted all analytical analyses.

4.3 Guidelines and Regulatory Framework

This report has adopted the Canadian Drinking Water Quality Guidelines (CDWQG) (Health Canada 2002) as the basis for all recommendations pertaining to water quality. Consequently, the analytical techniques used employ detection limits for comparison with the CDWQG.

Legislated drinking water quality standards do not exist in either the Yukon or federal jurisdictions. Communities can obtain guidance in the management of their drinking water systems by referring to a

comprehensive set of national guidelines (Health Canada 2002). These drinking water quality guidelines identify the following types of limits and objectives for specific contaminants in drinking water supplies:

- *Maximum Acceptable Concentrations* (MACs), have been established for certain substances that are known or suspected to cause adverse effects on health. MACs have been derived to safeguard health assuming lifelong consumption of drinking water containing the substance at that concentration.

- *Aesthetic Objectives* (AOs) apply to certain substances or characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good-quality water. Substances that exceed AOs and do not have specified MACs are not considered to constitute a health hazard.

- *Interim Maximum Acceptable Concentrations* (IMACs), which were established for parameters for which insufficient toxicological data is available to develop a MAC. Therefore, IMACs are based on larger safety factors than MACs.

4.4 Discussion of Results

4.4.1 Physical Tests

The physical tests conducted as part of this study included laboratory measurements of turbidity, colour, total dissolved solids, pH and hardness. It was found that the groundwater tested is considered as only "slightly hard" (Carrier 1965). As a result it is not surprising that water softening is not typically used in Wolf Creek, however a few homes are known to have water softeners. The analytical results are summarized in Table 2 and the original laboratory results are presented in the Appendix B.

4.4.2 Dissolved Anions

Concentrations from all dissolved anions tested were found to be below the applicable CDWQG. The analytical results are summarized in Table 2 and the original laboratory results are presented in Appendix B.

4.4.3 Nutrients

Water quality analysis for nutrient parameters included detection of dissolved nitrate-nitrogen (NO_3-N). Nitrogen is the nutrient applied in the largest quantities for lawn and garden care and crop production. Feedlots, animal yards, septic systems, and other waste treatment systems are also sources of nitrogen. Nitrogen occurs naturally in the soil in organic forms from decaying plant and animal matter. Bacteria in the soil convert various forms of nitrogen to nitrate, a nitrogen/oxygen ion (NO_3^-). This is desirable for plant uptake as the majority of the nitrogen used by plants is absorbed in the nitrate form. However, nitrate is highly leachable and readily moves with water through the soil. If there is excessive rainfall,

over-irrigation, or septic field use, nitrate will be leached below the root zone and may eventually reach the groundwater. Nitrate-nitrogen (NO_3-N) in groundwater may result from point sources such as sewage disposal systems and livestock facilities, or from non-point sources such as fertilized cropland, parks, golf courses, lawns, and gardens.

Nitrate concentrations of 1 mg/L or less are commonly observed in natural groundwaters, however concentrations in the range of 1-3 mg/L (or higher) typically are considered to have been impacted by anthropogenic nitrate sources such as septic systems. The Canadian Drinking Water Quality Guidelines (CDWQG) have set the dissolved nitrate maximum allowable concentration in water at 10 mg/L. All nutrient levels detected in the groundwater samples collected as part of this study were found to be below the method detection limit of 0.005 mg/L and therefore are well below the CDWQG. The analytical results are summarized and in Table 2 and the original laboratory results are presented in Appendix B.

4.4.4 Total Metals

All samples analyzed for selected total metal parameters were found to meet all of the health related CDWQG. However, a groundwater sample collected near the end of the pumping test was found to marginally exceeded (approx. 1.7 times) the CDWQG aesthetic objective (AO) for total manganese (0.05 mg/L). The analytical results are summarized in Table 2 and the original laboratory results are presented in Appendix B.

4.4.5 Bacteriological Tests

All of the groundwater samples collected and tested for bacteriological parameters were found to contain zero total coliform and E.coli counts per 100 mL of sample. The analytical results are summarized in Table 2 and the original laboratory results are presented in Appendix B.

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Table 2. Groundwater Analytical Results
Wolf Creek Long Term Monitoring Well

Parameter	Canadian Drinking Water Quality Guidelines [a]	Wolf Creek Long Term Monitoring Well Sample 1	Wolf Creek Long Term Monitoring Well Sample 2
Sample Collection Date/Time		29/03/2001 82000 AM Sample Taken Midway Through 72-hr Pumping Test	31/03/2001 70000 AM Sample Taken at End of 72-hr Pumping Test
ALS Sample ID		Pumping Well	Pump Test End
Physical Tests			
Colour (CU)	15	<5	<5
Conductivity (umhos/cm)	-	273	271
Total Dissolved Solids	500	158	135
Hardness CaCO3	-	118	129
pH	6.5 - 8.5	8.37	8.45
Turbidity (NTU)	5	0.6	0.3
Dissolved Anions (mg/L)			
Alkalinity-Total CaCO3	-	127	123
Chloride Cl	250	0.6	<0.5
Fluoride F	1.5	0.15	0.15
Sulphate SO4	500	19	19
Nutrients (mg/L)			
Nitrate Nitrogen N	10	<0.1	<0.1
Nitrite Nitrogen N	3.2	<0.1	<0.1
Bacteriological Tests			
Total Coliform (cfu)	<1	<1	na
E. coli (cfu)	<1	<1	na
Total Metals (mg/L)			
Aluminum T-Al	-	na	<0.005
Arsenic T-As	0.025	na	0.0042
Barium T-Ba	1	na	0.005
Boron T-B	5	na	<0.05
Cadmium T-Cd	0.005	na	<0.0002
Calcium T-Ca	-	na	38.8
Chromium T-Cr	0.05	na	<0.001
Copper T-Cu	1	na	<0.001
Iron T-Fe	0.3	na	<0.03
Lead T-Pb	0.01	na	<0.001
Magnesium T-Mg	-	na	7.8
Manganese T-Mn	0.05	na	0.085
Mercury T-Hg	0.001	na	<0.00005
Potassium T-K	-	na	1.48
Selenium T-Se	0.01	na	<0.001
Sodium T-Na	200	na	4.82
Uranium T-U	0.1	na	0.002
Zinc T-Zn	5	na	<0.005

Notes:

a *Heath Canada. Summary of Guidelines for Canadian Drinking Water Quality, April, 2002.*

< *Indicates less than detection limit*

\- *Indicates no guideline or analysis for this parameter*

bold *Indicates parameter exceeds Aesthetic Objective (taste, odour, appearance, etc.)*

bold, italic *Indicates parameter exceeds Maximum Acceptable Concentration (health related)*

na *not analyzed for that parameter*

5. Conclusions and Recommendations

5.1 Conclusions

A summary of relevant well details and testing results are provided in Table 3. Based on data collected as part of the completion of the Long Term Monitoring Well No. 1, the following conclusions can be made.

Table 3. Summary of Results from Long Term Monitoring Well No. 1

Parameter	Miles Canyon Basalt Aquifer (72 hr Pumping Test)
Total Well Depth (mbgs):	48.8
Production Interval (m):	5.2
Static Water Level (mbgs) :	16.61 (March 28, 2001)
Pumping Test Rate (L/sec):	0.57 L/sec (constant rate)
Pumping Test Duration:	72 hrs
Maximum Drawdown at End of Test (m):	21.74
Estimated Aquifer Transmissivity:	$0.37 m^2$/day
Estimated Hydraulic Conductivity: (based on aquifer thickness of 5.2m)	8.3 x 10-7 m/sec

- The overburden stratigraphy at LTMW No. 1 consists primarily of sands and gravels. The well was completed within the underlying bedrock aquifer, interpreted to be part of the Miles Canyon Basalt. The bedrock aquifer was encountered at a depth of 43.6 m below groundsurface (bgs). The open hole portion of the well extends from a depth of 44.5 m to 47.5 m bgs.

- All water quality results (i.e. physical tests, dissolved anions, nutrients, bacteriological, and total metals) were found to meet the health related CDWQG. Manganese concentrations were found to marginally exceed the aesthetic objectives (AO) of the CDWQG, which is typical of this aquifer system, given the inherent chemical composition of the bedrock (basalt) and the associated minerals.

- The observed increase in water levels at LTMW No. 1 during the spring (i.e. March through the end of May) is interpreted to be associated with spring snowmelt and recharge to the aquifer. This recharge event is then followed by a slow and steady decline in water levels throughout the remainder of the fall and winter months. This interpretation is supported by an independent Precipitation Water Balance Model conducted by Environment Canada in 2000, based on a methodology adopted by C.W. Thornthwaite and J.R. Mather, 1957.

5.2 Recommendations

Based on the conclusions presented above, it is recommended that:

- Water quality samples should be taken four times per year for at least one year to assess potential seasonal variability in water chemistry. The frequency of future long term water quality monitoring should be determined based on these results.

- The parameters which should be assessed as part of the water quality analyses should include physical tests (i.e. hardness), dissolved anions (i.e. sulfate), nutrients (i.e. nitrate), total metals, and fecal and total coliform. A certified member of the Canadian Association of Environmental Analytical Laboratories (CAEAL) should conduct the analyses. Additionally, sampling procedures should incorporate a quality assurance/quality control program to ensure an acceptable quality of data.

- Continuous measurements of water levels in LTMW No. 1 should continue in order to provide a more comprehensive data set that can be used to help assess the long-term sustainability of groundwater resources in the area.

6. Closure

This report was prepared by Gartner Lee Limited and the information in this report is intended for use by DIAND Water Resources. Any use which a third party makes of this report, or any reliance on or decisions to be made based on this report, are the responsibility of such third parties. Gartner Lee Limited accepts no responsibility for damages, if any, that are suffered by any third party as a result of decisions made or actions based upon the information contained in this report.

The scope of our investigation was limited to the described soil sampling and groundwater testing at the site. Gartner Lee Limited is not a guarantor of the environmental conditions of the site but warrants only that its work was undertaken and its report prepared in a manner consistent with the level of skill and diligence normally exercised by competent environmental professionals practicing in the Yukon Territory.

Report Prepared By:

Jonathan Kerr, M.Sc.
Hydrogeologist

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Appendices

Appendix A

Pumping Test Results and Analyses

Gartner Lee Limited
Suite C - 206 Lowe Street
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Phone:(867) 633-6474

Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Constant Rate**
Distance from PW:	0 [m]	Pumping Well:	Observation Well
Depth to Static WL:	16.61 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:	Dennis Lu	Screen length:	4.28 [m]
Date:	5/31/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
1	1	18.20	1.59
2	2	19.81	3.20
3	3	21.19	4.58
4	4	22.37	5.76
5	5	23.39	6.78
6	6	24.29	7.68
7	7	25.05	8.45
8	8	25.73	9.12
9	9	26.34	9.73
10	10	27.02	10.41
11	11	27.55	10.94
12	12	28.03	11.42
13	13	28.44	11.83
14	14	28.92	12.31
15	15	29.33	12.72
16	17	29.90	13.29
17	19	30.66	14.05
18	21	31.17	14.56
19	23	31.65	15.04
20	25	32.01	15.40
21	27	32.30	15.69
22	29	32.52	15.91
23	31	32.71	16.10
24	33	32.86	16.25
25	35	32.97	16.36
26	37	33.08	16.47
27	39	33.17	16.56
28	41	33.39	16.78
29	43	33.72	17.11
30	45	33.98	17.37
31	47	34.18	17.57

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Constant Rate**
Distance from PW:	0 [m]	Pumping Well:	Observation Well
Depth to Static WL:	16.61 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:	Dennis Lu	Screen length:	4.28 [m]
Date:	5/31/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
32	49	34.34	17.73
33	51	34.47	17.86
34	53	34.61	18.00
35	55	34.73	18.13
36	57	34.84	18.23
37	60	34.96	18.35
38	65	35.10	18.49
39	70	35.21	18.60
40	75	35.35	18.74
41	80	35.44	18.83
42	85	35.49	18.88
43	90	35.54	18.93
44	95	35.59	18.98
45	100	35.78	19.17
46	105	35.93	19.32
47	110	36.02	19.41
48	115	36.05	19.44
49	120	36.09	19.48
50	135	36.19	19.58
51	150	36.24	19.63
52	165	36.27	19.66
53	180	36.30	19.70
54	195	36.32	19.71
55	210	36.33	19.72
56	225	36.37	19.76
57	240	36.43	19.82
58	270	36.81	20.20
59	300	36.88	20.27
60	330	36.95	20.34
61	360	36.99	20.38
62	420	37.09	20.48

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Constant Rate**
Distance from PW:	0 [m]	Pumping Well:	Observation Well
Depth to Static WL:	16.61 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:	Dennis Lu	Screen length:	4.28 [m]
Date:	5/31/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
63	480	37.13	20.52
64	540	37.21	20.60
65	600	37.24	20.63
66	660	37.30	20.69
67	720	37.31	20.70
68	780	37.33	20.72
69	840	37.35	20.74
70	900	37.38	20.77
71	960	37.40	20.79
72	1020	37.44	20.83
73	1080	37.45	20.84
74	1140	37.48	20.87
75	1200	37.49	20.88
76	1260	37.52	20.91
77	1320	37.52	20.91
78	1380	38.03	21.42
79	1440	38.03	21.42
80	1680	38.07	21.46
81	1920	38.10	21.49
82	2160	38.15	21.54
83	2400	38.16	21.55
84	2640	38.19	21.58
85	2880	38.20	21.59
86	3120	38.21	21.60
87	3360	38.21	21.60
88	3600	38.20	21.59
89	3840	38.23	21.63
90	4080	38.30	21.69
91	4320	38.35	21.74
92	4321	36.71	20.10
93	4322	34.96	18.35

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Constant Rate**
Distance from PW:	0 [m]	Pumping Well:	Observation Well
Depth to Static WL:	16.61 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:	Dennis Lu	Screen length:	4.28 [m]
Date:	5/31/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
94	4323	33.40	16.79
95	4324	31.97	15.36
96	4325	30.67	14.06
97	4326	29.53	12.92
98	4327	28.48	11.87
99	4328	27.55	10.95
100	4329	26.68	10.07
101	4330	25.90	9.29
102	4331	25.18	8.57
103	4332	24.52	7.91
104	4333	24.01	7.40
105	4334	23.50	6.89
106	4335	23.06	6.45
107	4340	21.38	4.77
108	4345	20.39	3.79
109	4350	19.77	3.16
110	4355	19.36	2.75
111	4360	19.09	2.48
112	4365	18.89	2.28
113	4370	18.73	2.12
114	4375	18.61	2.00
115	4380	18.51	1.90

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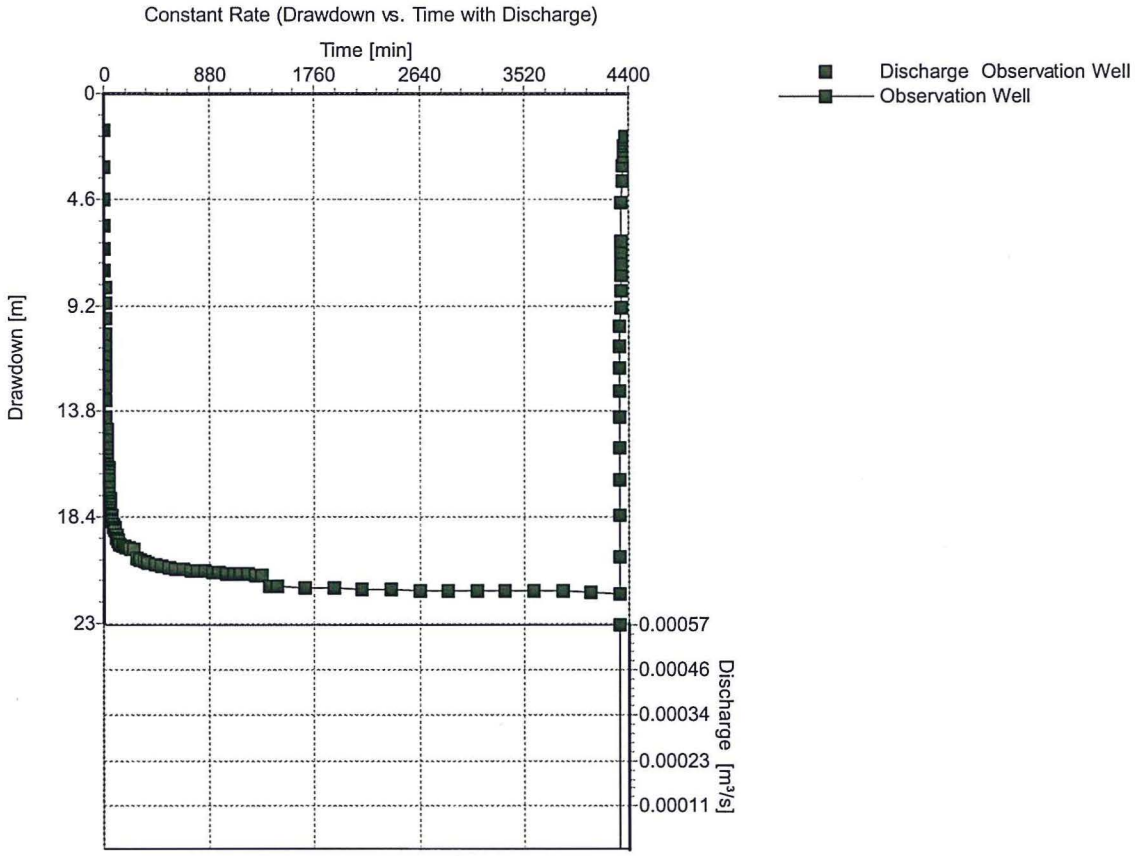
Pumping Test Analysis Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources



Pumping Test: **Constant Rate**

Analysis Method: **Drawdown vs. Time with Discharge**

Analysis Results:

Test parameters:				
	Pumping Well:	Observation Well	Aquifer Thickness:	5.2 [m]
	Casing radius:	0.152 [m]		
	Screen length:	4.28 [m]		
	Boring radius:	0.152 [m]		
	Discharge Rate:	0.00057 [m³/s]		

Comments:

Evaluated by:

Evaluation Date: 2/11/03

Gartner Lee Limited
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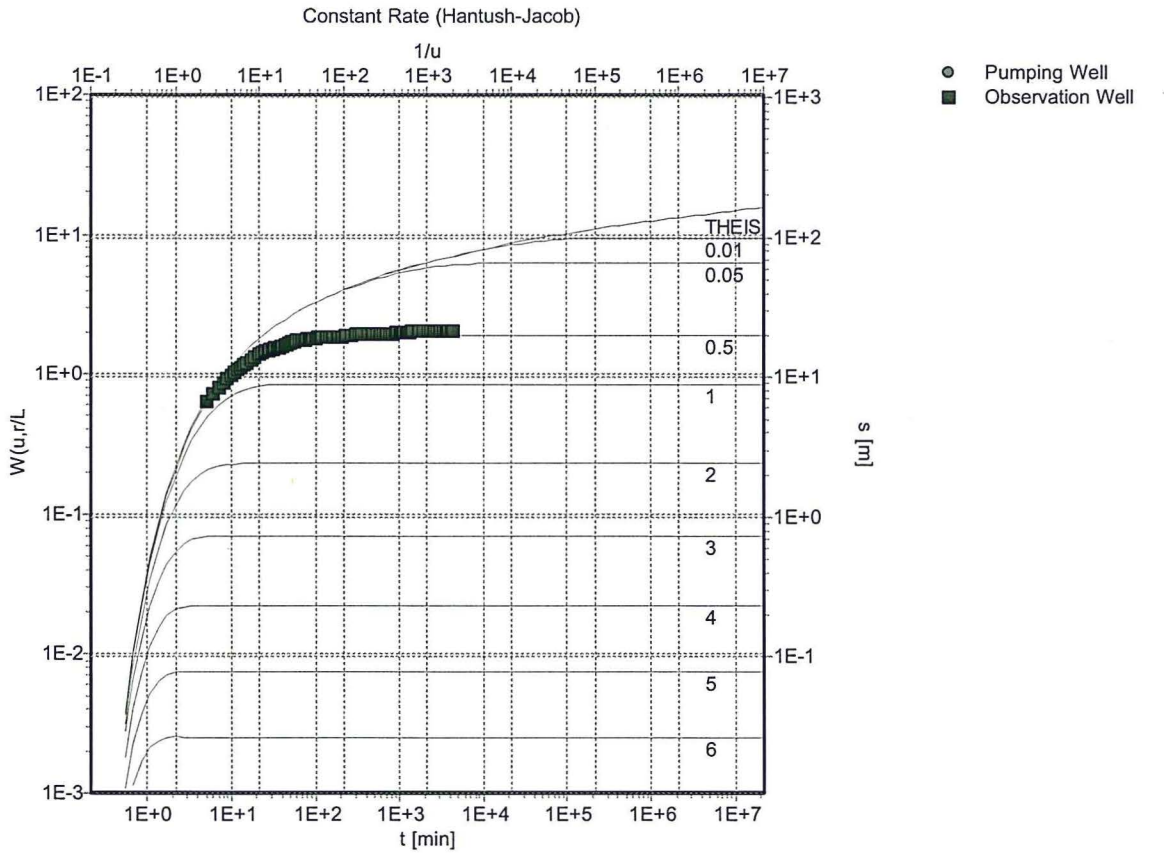
Pumping Test Analysis Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources



Pumping Test: **Constant Rate**

Analysis Method: **Walton**

Analysis Results:

Conductivity: 8.28E-7 [m/s]

Test parameters:	Pumping Well:	Observation Well	Aquifer Thickness:	5.2 [m]
	Casing radius:	0.152 [m]	r/L:	0.01
	Screen length:	4.28 [m]		
	Boring radius:	0.152 [m]		
	Discharge Rate:	0.00057 [m³/s]		

Comments:

Evaluated by:

Evaluation Date: 1/30/03

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Step Test**
Distance from PW:	0.17 [m]	Pumping Well:	Pumping Well
Depth to Static WL:	16.57 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:		Screen length:	4.28 [m]
Date:	6/1/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
1	2	18.10	1.53
2	3	18.51	1.94
3	4	18.82	2.25
4	5	19.12	2.55
5	6	19.36	2.79
6	7	19.58	3.01
7	8	19.78	3.21
8	9	19.96	3.39
9	10	20.09	3.52
10	11	20.23	3.66
11	12	20.35	3.78
12	13	20.45	3.88
13	14	20.55	3.98
14	15	20.63	4.06
15	20	20.97	4.40
16	25	21.17	4.60
17	29	21.30	4.73
18	31	21.90	5.33
19	32	22.22	5.65
20	33	22.45	5.88
21	34	22.69	6.12
22	35	22.89	6.32
23	36	23.07	6.50
24	37	23.23	6.66
25	38	23.37	6.80
26	39	23.52	6.95
27	40	23.61	7.04
28	41	23.73	7.16
29	42	23.80	7.23
30	43	23.89	7.32
31	44	23.96	7.39

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Step Test**
Distance from PW:	0.17 [m]	Pumping Well:	Pumping Well
Depth to Static WL:	16.57 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:		Screen length:	4.28 [m]
Date:	6/1/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
32	45	24.03	7.46
33	50	24.29	7.71
34	55	24.45	7.88
35	59	24.54	7.97
36	61	25.20	8.63
37	62	25.50	8.93
38	63	25.75	9.18
39	64	25.98	9.41
40	65	26.18	9.61
41	66	26.34	9.77
42	67	26.50	9.93
43	68	26.64	10.07
44	69	26.77	10.20
45	70	26.89	10.32
46	71	26.98	10.41
47	72	27.07	10.50
48	73	27.15	10.58
49	74	27.23	10.66
50	75	27.29	10.71
51	80	27.55	10.98
52	85	28.53	11.96
53	89	28.98	12.41
54	91	29.93	13.36
55	92	30.36	13.79
56	93	30.74	14.17
57	94	31.05	14.48
58	95	31.32	14.75
59	96	31.62	15.05
60	97	31.80	15.23
61	98	31.98	15.41
62	99	32.16	15.59

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Step Test**
Distance from PW:	0.17 [m]	Pumping Well:	Pumping Well
Depth to Static WL:	16.57 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:		Screen length:	4.28 [m]
Date:	6/1/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
63	100	32.31	15.74
64	101	32.45	15.88
65	102	32.58	16.01
66	103	32.68	16.11
67	104	32.77	16.20
68	105	32.96	16.39
69	110	33.72	17.15
70	115	34.12	17.55
71	119	34.60	18.03
72	121	32.20	15.63
73	122	29.73	13.16
74	123	28.46	11.89
75	124	27.28	10.71
76	125	26.20	9.63
77	126	25.31	8.74
78	127	24.46	7.89
79	128	23.71	7.14
80	129	23.05	6.48
81	130	22.47	5.90
82	131	21.96	5.39
83	132	21.48	4.91
84	133	21.08	4.51
85	134	20.71	4.14
86	135	20.38	3.81
87	140	19.23	2.66
88	145	18.58	2.01
89	150	18.18	1.61
90	155	17.93	1.36
91	160	17.75	1.18
92	• 165	17.61	1.04
93	170	17.51	0.94

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Pumping Test Data Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources

Data observed at:	**Observation Well**	**Pumping Test:**	**Step Test**
Distance from PW:	0.17 [m]	Pumping Well:	Pumping Well
Depth to Static WL:	16.57 [m]	Casing radius:	0.152 [m]
Location:	Lot 117 Wolf Creek	Boring radius:	0.152 [m]
Recorded by:		Screen length:	4.28 [m]
Date:	6/1/01	Aquifer Thickness:	5.2 [m]

	Time [min]	Depth to WL [m]	Drawdown [m]
94	175	17.43	0.86
95	180	17.36	0.79

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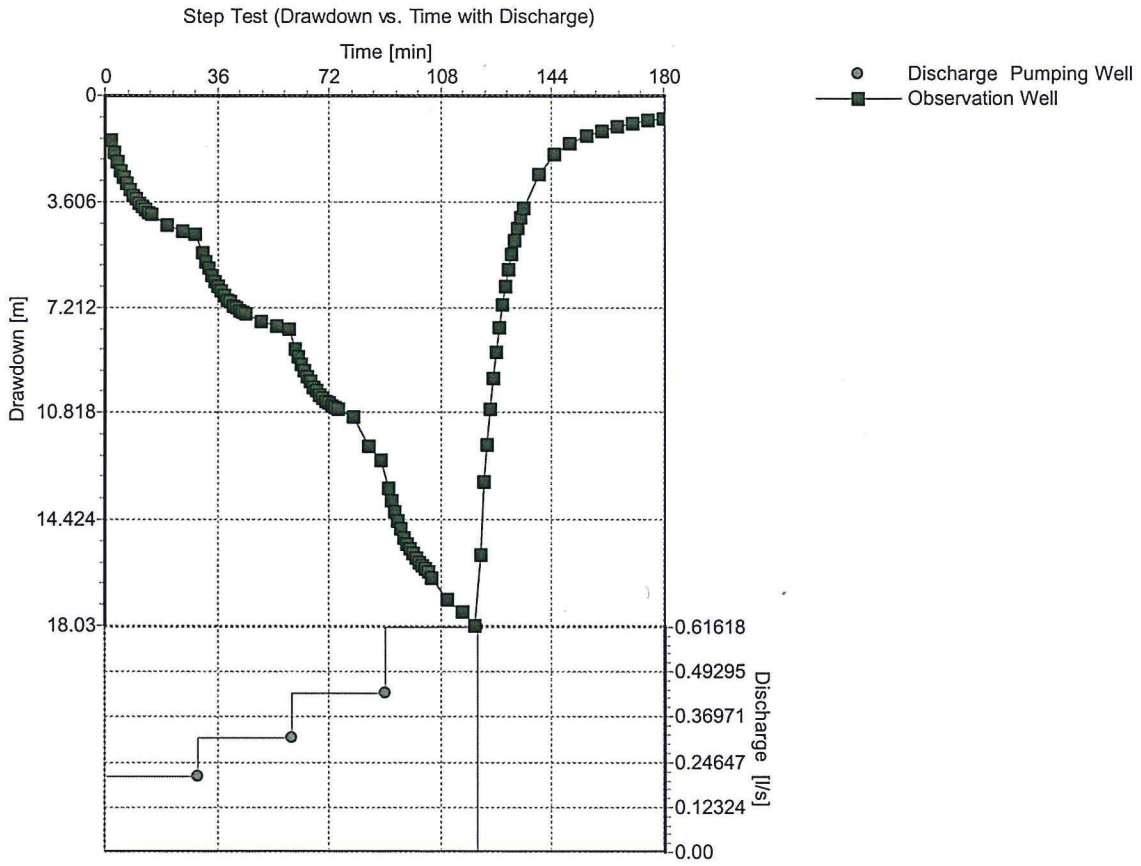
Pumping Test Analysis Report

Project: Wolf Creek - Observation Well

Number: 21-905

Client: DIAND Water Resources



Pumping Test: **Step Test**

Analysis Method: **Drawdown vs. Time with Discharge**

Analysis Results:

Test parameters:				
	Pumping Well:	Pumping Well	Aquifer Thickness:	5.2 [m]
	Casing radius:	0.152 [m]		
	Screen length:	4.28 [m]		
	Boring radius:	0.152 [m]		
	Discharge Rate:	0.39251517 [l/s]		

Comments:

Evaluated by:

Evaluation Date: 6/1/01

Appendix B

Analytical Laboratory Results

(Only Hardcopy Available)