September 1st, 2009

VILLAGE OF MONTROSE

Phase II Groundwater Protection Plan

Submitted to:
Corporation of the Village of Montrose
565 - 11th Avenue
Montrose, BC
V0G 1P0

REPORT

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1.0 INTRODUCTION

Golder Associates Ltd (Golder) is pleased to present this report, summarizing the results of the Phase II Groundwater Protection Plan (GWPP) being developed for the Village of Montrose (VOM), located in the West Kootenay Region of British Columbia (Figure 1).

The Terms of Reference for this study were outlined in our workplan submitted to the VOM on April 23, 2008 (Proposal No. P82-8021). Written authorization to proceed was received from Mr. Bryan Teasdale on May 5, 2008, who was representing the VOM at that time.

2.0 SCOPE OF WORK

The VOM is currently extracting water from two water supply wells (Well no. 1 and Well no. 2) located near the confluence of Beaver Creek and the Columbia River, approximately 1.5 km to the southwest of the VOM centre (Figure 2). Recent initiatives by the Interior Health Authority (IHA) require that groundwater protection planning and treatment to meet water quality objectives for public water supplies be undertaken.

Well no.1 was drilled in 1961 and Well no. 2 was drilled in 1981. Well no. 1 was not completed with a conventional well screen assembly, but rather with a torch-perforated casing. Well no. 2 has on-going accumulation of fine sand that is being pulled through the well screen during rehabilitation. Previous well testing and rehabilitation conducted by Precision Service & Pumps Inc. (Precision Pumps) has indicated that the efficiency of both wells has declined since the construction of the wells.

As such, the Village of Montrose is currently working on the development of a long-term water supply management strategy, as well as the identification of necessary improvements to their existing water system. Golder is providing hydrogeologic services to VOM to develop a GWPP and to provide recommendations on well monitoring, maintenance and potential replacement.

Golder recently completed the first phase of the GWPP for the VOM (Golder, 2008). Phase I of the GWPP comprised Steps 2, 3, and part of Step 4 of the BC Ministry of Environment's (BC MoE) Well Protection Toolkit (WPT). The completed work included the characterization of the aquifer, a preliminary GUDI (Groundwater Under the Direct Influence of surface water) assessment, the determination of the 60-day and 1-year preliminary time of travel zones for the VOM's two wells and completion of a preliminary contaminant inventory within the capture zones established for both active wells. In addition, the Phase I report included preliminary comments regarding the development of groundwater protection management strategies for the VOM wells and recommendations for continuing the GWPP process for the VOM.

Based on the results of the Phase I GWPP and discussions with the Village of Montrose's representatives, a scope of work for the Phase II GWPP was developed. The scope of work for the Phase II GWPP consisted of the following:

- Step 1: Development of a Community Planning Team
- Step 2: Refinement of Well Protection Areas and GUDI Assessment
- Step 3: Phase II Contaminant Inventory
- Step 4: Development of Groundwater Protection Management Strategies
- Step 5: Recommendations for Contingency Planning
- Step 6: Water Supply Well Monitoring Program

In addition to completing Phase II of the GWPP, the Village of Montrose requested that Golder conduct a long-duration pumping test of Wells no. 1 and no. 2 to evaluate the potential capacity of the Montrose Aquifer. It is our understanding that the VOM is considering the option of replacing the existing production wells by another proposed groundwater supply system to be completed within the Montrose Aquifer. The purpose of the pumping test was to assess the specific capacity and bench mark the efficiency of both wells, evaluate well interferences, and estimate the hydraulic characteristics of the Montrose Aquifer in the vicinity of the production wells. The pumping test information was also useful in the refined GUDI assessment.

This report presents the results of the pumping test, together with the results of Phase II of the GWPP.

3.0 BACKGROUND INFORMATION

3.1 Well no.1

Well no. 1 was drilled in 1961 by Bud Henning. A copy of the well completion diagram is included in Appendix I. Well no. 1 was drilled to a total depth of 38.9 metres below ground surface (mbgs) with a 600 mm (24 inch) casing. A 400 mm (16 inch) casing was installed within the working casing from ground surface to a depth of 29.0 mbgs, followed by 9.1 m of perforated casing to a total depth of 38.1 mbgs. According to Kala Groundwater Consulting Ltd (Kala), the screened area of Well no. 1 consists of torch-perforated casing containing eight vertical rows of staggered horizontal slots approximately 5.7 cm in length and 3.2 mm in width (Kala, 1998). The annular space between the outer casing and the inner casing was filled with a gravel pack, and the outer 600 mm casing was pulled back to a depth of 19.6 mbgs, to expose the perforated casing. It is not possible to estimate a well screen transmitting capacity of Well no. 1, as the well's open area is constructed with torch-slotted casing, rather than a conventional well screen. An original well yield of 47.3 L/s (750 USgpm) is reported from a 24-hr pumping test conducted at the time of construction.

Precision Pumps carried out a well rehabilitation program on Well no.1 in 1999. Rehabilitation work included two acidification treatments and surging and bailing with a cable tool rig. Short duration specific capacity pumping tests were conducted on the well before and after rehabilitation to monitor the effectiveness of the work. Only marginal gain in well performance was realized from the rehabilitation program but Precision Pumps reported that the program was successful in removing a significant amount of fine sand and scale from the well. Precision Pumps' interpretation was that the poor hydraulic characteristics of the torch-slotted casing and a relatively thick gravel pack absorbed most of the rehabilitation energy before it could penetrate outward into the aquifer formation.

3.2 Well no.2

Well no. 2 was drilled in 1981 by Thomas Well Drilling and Pump Sales Ltd. (Thomas Drilling). A copy of the well completion diagram is included in Appendix I. Well no. 2 was drilled to a total depth of 48.2 mbgs. A surface casing of 500 mm (20 inch) diameter was installed to a depth of 15.2 mbgs. A 400 mm (16 inch) diameter casing was installed within the larger casing to a depth of 35.5 mbgs. The well assembly, consisting of 350 mm (14 inch) riser pipe to a depth of 26.8 mbgs, 1.3 mm (0.050 in) slot screen to a depth of 28.6 mbgs, 0.5 mm (0.020 in) slot screen to 29.2 mbgs, 0.6 mm (0.025 in) slot screen to 31.6 mbgs, 1.3 mm (0.050 in) slot screen to 33.1 mbgs, and 0.6 mm (0.025 in) slot screen to 35.5 mbgs, was installed within the well. The 400 mm diameter (16 inch) casing was pulled back to a depth of 25.1 m to expose the well screen. The total screened interval is approximately 10.2 m in length. The recommended safe well yield reported by Pacific Hydrology Consultants Ltd (Pacific Hydrology) at the time of construction was 20.8 L/s (330 USgpm).

Precision Pumps carried out a well rehabilitation program on Well no.2 in 2002. Rehabilitation work included two acidification treatments and surging and bailing with a cable tool rig. Short duration specific capacity pumping tests were conducted on the well before and after rehabilitation to monitor the effectiveness of the work. A decrease in overall well performance resulted from this rehabilitation program. According to Precision Pumps, the program was successful in removing a large quantity of sand and accumulated scale from the well. The fine sand zone screened between depths of 28.9 m and 29.6 m (95 ft and 97 ft) in the well, which yielded high volumes of material during development, appears to be the primary reason that this well has remained unstable since construction. Pacific Hydrogeology (1982) reported that the surface casing and the 400 mm (16 in) casing began dropping at the start of well development and that there was evidence of settling of the ground around the casings after construction of the well. The report also mentions that the development by surging in the casing above the screen seemed to aggravate the difficulty with the casing and resulted in a flood of sand into the screen. Further settlement has occurred since the construction of Well no.2. The pumphouse of Well no.2 is not level and there is apparent sinking around the well on the southwest side of the pumphouse.

3.3 Water Consumption and Pumping Record

Water consumption and pumping records from 2007 to 2009 were provided by the VOM and reviewed by Golder. According to the available records, the annual water consumption was approximately 196,000 m^3 (51,700,000 US gal.) in 2007 and approximately 183,000 m^3 (48,300,000 US gal.) between September 2007 and August 2008 which represent an average flow rate of approximately 537 m^3/d (141,643 USgpd) and 500 m^3/d (132,329 USgpd) respectively. The highest water consumption was recorded in July 2007 with a flow rate of 1,268 m^3/d (335,028 USgpd or 233 USgpm). Due to the replacement of the main water pipe starting in September 2008, potable water for VOM was provided by Beaver Falls Waterworks District in the fall of 2008 and therefore, the records are not representative of normal consumption for this period.

Of the annual total water consumption, Well no.1 supplies approximately 68,000 m^3 (17,900,000 US gal.) which represents an average flow rate of 186 m^3/d (equivalent to 2.1 L/s or 34 USgpm if pumping continuously 24-hr/d) and Well no.2 supplies approximately 128,000 m3 (33,800,000 US gal.) which represents an average flow rate of 350 m^3/d (equivalent to 4.2 L/s or 64 USgpm if pumping continuously 24-hr/d). The maximum daily extraction measured for Well no.1 since 2008 was 898 m^3/d on August 16, 2008 and the maximum daily extraction measured for Well no.2 since 2008 was 1,336 m^3/d on June 30, 2008. Well no.1 has an operational flow rate of approximately 18.9 L/s (300 USgpm) and Well no.2 has an operational flow rate of approximately of 21.8 L/s (345 USgpm).

4.0 HYDRAULIC TESTING

4.1 Methodology

Hydraulic testing was completed in November 2008 by Aqua Tech Services (Aqua Tech) of Kelowna, BC. The proposed testing program was to initiate the pumping test on Well no.2 and commence pumping of Well no.1 after 48 hours of pumping to assess interference between both wells and the capacity of the Montrose Aquifer. The pumping test was conducted using the dedicated pumps in the wells. The services of Aqua Tech was retained to install required discharge piping, flow meters and adapters to connect to the existing discharge connections, to operate the testing equipment, and to record manual water level measurements. Golder staff provided input and inspection services for the design and completion of the pumping test.

During testing, discharged water from Well no.2 was routed away from the wellhead through the existing underground 150 mm (6 in.) PVC sewer pipe and connected to a 100 mm (4 in.) steel pipe before being discharged to the bank of Beaver Creek. Precautions were taken during testing to minimize any ground erosion or flooding. The flow rate at Well no.2 was measured using a Siemens Sitrans FM MagFlo Mag 5000 flow meter. After 48-hours of pumping, Well no.1 was started and pumped for 40 minutes before the pumping test had to be interrupted due to a significant leak and the risk of imminent failure of the flow control valve of the discharge pipe of Well no.2.

During the pumping test, water levels were measured manually, using a water level probe, in Well no.1, Well no.2, monitoring wells TW-1, TW-2, and TW-3 and in Beaver Creek and in Columbia River, where temporary water gauges were installed. Pressure transducers equipped with a datalogger were placed in Well no.2 and in monitoring wells TW-1 and TW-3 to provide backup data and to serve as a quality control check of the manually recorded data. Recovery data was collected after the end of the constant-rate pumping test.

4.2 Results

A 48-hour constant-rate pumping test was completed from November 3, 2008 to November 5, 2008 on Well no. 2, at a discharge rate of 19.7 L/s (312 USgpm).

The top of the packer in Well no. 2 is at an approximate depth of 25 mbgs (82.12 ft) and the permanent pump intake is set at a depth of 25.9 m (85 ft) according to the pump specification provided by VOM. The static water level prior to the beginning of the test was at 6.7 m below the top of the casing, resulting in approximately 19.2 m of available drawdown above the intake of the permanent pump. The maximum drawdown observed in Well no.2 after 48 hours of pumping at a constant discharge of approximately 19.7 L/s (312 USgpm) was 12.56 m. The drawdown observed in Well no.1 located at approximately 50 m away from Well no.2 was 0.44 m.

After approximately 2810 minutes, the flow control valve of Well no.2 started leaking through a hole on the pipe. As soon as the hole was discovered, Aqua Tech tried to reduce the leak by blocking the hole. After 2900 minutes (48.3 hours) of pumping Well no.2, the permanent pump in Well no. 1 was started and remained in operation for 40 minutes. Due to the excessive presence of air in the existing discharge pipe, the flow rate meter was not operating properly and it was not possible to obtain an estimate of the flow rate of Well no.1. In the mean time, the hole previously noticed on the flow control valve of Well no.2 grew in size and because the imminent failure of the valve represented a safety risk for the water supply system and the staff, the pumping test was ended after 49 hours of pumping.

Recovery data were also collected for each well at the end of the constant rate test. The water levels in Beaver Creek and Columbia River did not appear to be influenced by pumping from Well no.2 at a discharge of 19.7 L/s. The water level in Beaver Creek rose 1.5 cm during the course of the pumping test, likely the effect of heavy rain noted on November 4, 2008. The flow in Columbia River is considerably greater than the well discharge, so pumping influences on the river are expected to be insignificant.

A semi-logarithmic plot of the drawdown data for Well no. 2 is presented on Figure 3. Manually measured water level data collected from VOM Wells, observation wells TW-1, TW-2 and TW-3, Beaver Creek and Columbia River during the constant-rate pumping test and a semi-logarithmic plot of the drawdown data for Well no.1 are also included in Appendix II.

4.3 Interpretation of Hydraulic Testing Results

4.3.1 Well Screen Transmitting Capacity

The transmitting capacity of the well screen assembly for Well no.2 (based on well design and an industry-recommended entrance velocity of 0.03 m/s) is estimated to be approximately 41.6 L/s or 660 USgpm, which is well above the maximum daily withdrawals by the VOM from Well no. 2.

Convention within the water well industry and authorities on well design recommend that an entrance velocity of 0.03 m/s (0.1 ft/s) not be exceeded. Well screens designed to this specification have shown excellent resistance to chemical encrustation and corrosion in a wide variety of groundwater quality conditions.

In laboratory tests, the corrosion rate for stainless steel well screen in de-aerated water did not accelerate until an entrance velocity of 0.12 m/s (0.4 ft/s) was reached (Driscoll, 1986). Further testing in water with a dissolved oxygen content of 6 mg/L, indicated the corrosion rate of stainless steel well screens was somewhat higher than the corrosion rate determined from the tests done in de-aerated water (Driscoll, 1986). However, actual entrance velocities will vary along the screen and may change as the well screen ages. Thus, a conservative and prudent well yield which maintains an average entrance velocity of 0.03 m/s for the well screen will provide a safety factor so that slightly higher entrance velocities that may occur at some locations along the well screen will not cause excessive wear or encrustation on the screens.

4.3.2 Recommended Safe Well Yield of Well no. 2

As shown on Figure 3, the drawdown after 48 hours of pumping (before starting Well no.1) was 12.6 m and the extrapolated drawdown after 100 days of pumping at a discharge of 19.7 L/s (312 USgpm) is 12.8 m. This correlates to a long-term specific capacity for the well of 1.5 L/s/m (7.4 USgpm/ft). A similar specific capacity was calculated for Well no. 2 at the time of construction. The specific capacity of Well no. 2 calculated in 1981 after 925 minutes of pumping at 22.8 L/s (361 USgpm) was 1.4 L/s/m (6.6 USgpm/ft) (Pacific Hydrology, 1982). In 1982, the well was redeveloped and the specific capacity had increased to approximately 2 L/s/m (9.5 USgpm/ft) at a flow rate of 22.1 L/s (351 USgpm). In 2002, after Precision Pumps carried out a rehabilitation program, the specific capacity calculated was 1.8 L/s/m (8.54 USgpm/ft) at a flow rate of 22.9 L/s (363 USgpm). The result of the recent pumping test indicates that the specific capacity has decreased since the rehabilitation efforts in 2002.

Based on the static water level measured prior to constant rate testing, and interpreting the aquifer as being partially semi-confined, the available drawdown in the production well is approximately 20 m (distance from the static water surface to the bottom of the confining layer or top of aquifer). By convention, using only 70 percent of the total available drawdown provides a “safe” available drawdown of approximately 14 m.

Thus, the theoretical “safe” sustainable yield for Well no.2 is 21 L/s (332 USgpm) using the safe available drawdown. The theoretical sustainable yield calculated corresponds to the well capacity estimated in 1981 (Pacific Hydrology, 1982) and is similar to the operational flow rate of the well (21.8 L/s).

4.3.3 Aquifer Characteristics

Based on the drawdown and recovery data obtained from Well no.2, Well no.1, TW-1, TW-2 and TW-3 during the constant-rate pumping test, the aquifer transmissivity was calculated using AQTESOLV™, a commercial software package for pumping test analysis. Transmissivity (T) is the rate at which groundwater is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

The pumping test responses obtained for the pumping well (Well no.2) and the observation wells (Well no.1, TW-1, TW-2, and TW-3) indicates the presence of a semi-confined aquifer with a constant-head boundary located approximately 40 m south of Well no.2. The constant-head boundary could correspond to buried fluvial deposits associated with the presence of Beaver Creek. The derivative plots for all wells also confirmed the presence of a constant-head boundary. The pumping test response also indicates that a no flow boundary might have been reached close to the end of the test which likely corresponds to the limit of the sand and gravel aquifer. The drawdown and recovery data recorded during the constant-rate pumping test were analyzed using the analytical, type-curve solution by Theis (1935) and Cooper-Jacob (1946), available in AQTESOLV™. In order to provide a conservative value of transmissivity for the capture zone analysis, an analysis based on the composite plot approach was also used to estimate the transmissivity of the aquifer using the early-time data. Copies of the output file and plots of the solutions generated using the AQTESOLV™ program are included in Appendix III.

The aquifer transmissivity is estimated to be 770 m^2/day. The hydraulic conductivity (K) of the aquifer is estimated to be in the order of 1 x 10^{-3} m/s (84.6 m/day), assuming the approximate 9.1 m thickness of the sand and gravel aquifer material in which the production well is completed.

4.3.4 Well Capacity, Well Interference and Aquifer Capacity

The water level was measured in Well no.1 while pumping Well no.2. The drawdown observed in Well no.1 located at approximately 50 m away from Well no.2 was 0.44 m after 2900 minutes of pumping. Unfortunately, due to the failure of a control flow valve, Golder was not able to complete the pumping test as originally planned (i.e. pumping both wells simultaneously for 24 hours). Therefore, only limited information could be obtained on well interferences and the aquifer response to higher flow rates could not be assessed.

Golder reviewed existing reports for Well no.1 and Well no.2 (Kala, 1998 and Precision Service & Pumps, 1999 and 2002). Based on the information reviewed, it seems that the capacity of Well no.1 has decreased since its construction. It should be noted that Well no.1 was not completed with a stainless steel screen, but was rather completed with perforated casing and a gravel pack. This type of construction is not considered to be very efficient relative to percent open area. Precision Pumps carried out a rehabilitation program in 1999 on Well no.1. Only a marginal gain in well performance was realized compared to the original well capacity determined at the time of construction. Poor hydraulic characteristics of the torch-slotted casing and a relatively thick gravel pack were likely the limiting factors for improving the well capacity. However, it should be noted that Well no.1 was initially rated at 47.3 L/s (750 USgpm). Based on the original pumping test data (from pumping test conducted in 1961), Well no.1 was pumped for 24 hours at a flow rate of 45.4 L/s (720 USgpm) and the pumping level stabilized at 30.5 m. During the test in 1961, the well was also pumped for a few minutes at a flow rate of 47.1 L/s (747 USgpm) and the pumping level recorded was 31.3 m. The well log indicates that the top of the aquifer is at a depth of 29.6 m therefore, at a flow rate of 47.3 L/s (750 USgpm), the pumping level would have been below the top of the aquifer. Pumping below the top of the aquifer is not recommended because it leads to the dewatering of the aquifer, causes turbulent flow into the well intake and allows air to become entrapped within the aquifer. For this reason, pumps are usually set above the screen and above the top of the aquifer. In the case of Well no.1, the pump was initially set at the bottom of the section of perforated casing and historical data indicates that Well no.1 was over-pumped since it was first put into service. After Kala's assessment in 1998, it is our understanding that the pump was downsized and the operational flow rate was reduced.

The information reviewed and the results of the pumping test conducted by Golder during the present testing program also indicate that the flow rate available at Well no.2 is limited by the poor efficiency of the well. Pacific Hydrology (1982) reported the poor efficiency of Well no.2 after its construction. The rehabilitation program conducted by Precision Pumps in 2002 was not successful at increasing the capacity of Well no.2.

There is no indication that the flow rate available from Well no.1 and Well no.2 is limited by the capacity of the Montrose Aquifer. The relatively small well interference measured during the pumping test, the rapid stabilization of the pumping water level and also the rapid recovery of the water level following the termination of the pumping test tend to indicate that the Montrose Aquifer has a good water-yielding capacity. The flow rate available at both wells seems to be limited by the poor efficiency of the wells. Based on the pumping test conducted by Golder in November 2008, the safe sustainable yield for Well no.2 is 21 L/s (332 USgpm) using the safe available drawdown of 70 % of the total available drawdown. Well no.1 was not tested during the present testing program but based on previous testing conducted by Kala (1998), the safe yield of Well no.1 was estimated to be approximately 28.4 L/s (450 USgpm). Further testing on Well no.1 would be necessary to confirm the actual safe yield as the well capacity might have further decreased since 1998. Previous rehabilitation programs conducted on both wells were not successful in increasing significantly the capacity of the wells.

Given the age of the wells, their poor efficiency and the limited success obtained from previous rehabilitation programs, the VOM should consider replacing one or both wells as part of the long-term water supply management strategy.

5.0 GROUNDWATER PROTECTION PLAN

5.1 Community Planning Team

The development and implementation of the GWPP should be carried out with input from a wide range of community members. Local government bodies, citizens, business owners and community groups all have an interest in protecting groundwater in the area for domestic use. At this point, the primary focus in the development of the groundwater protection plan continues to be technical, and does not require the immediate input from the general public.

It is understood that the Village of Montrose will facilitate the development of a community planning team, with the assistance of Golder. At this time, it is suggested that the technical component of the Community Planning Team should consist of the following persons:

- CAO, Village of Montrose
- A representative from the Village of Montrose Council
- Dan Byron, Public Health Inspector, Interior Health Authority, Cranbrook (250-420-2240)
- Mr. Peter Gigliotti or Mr. Bander Abou Taka, Urban Systems Ltd, Kelowna (250-762-2517)
- Ms. Genevieve Pomerleau or Mr. Garrett Brown, Golder Associates Ltd., Castlegar (250-365-0344)

The objective of the initial planning committee is to understand the technical aspects of the water supply wells and the Montrose Aquifer in order to make decisions regarding the sustainability of a long-term water supply for the VOM.

5.2 Refinement of Capture Zone Analysis and GUDI Assessment

The preliminary GUDI assessment completed by Golder as part of the initial phases of the GWPP indicated that the VOM wells were flagged as potentially GUDI, based on the well locations possibly being within 100 days horizontal travel time from the Columbia River and Beaver Creek.

As such, further GUDI analyses were recommended. In addition to refining the time-of-travel capture zones, a water quality monitoring program was implemented during freshet to compare water quality of the VOM wells and the nearby source of surface water (Beaver Creek and Columbia River) and Microscopic Particulate Analysis (MPA) testing was conducted for both production wells. The results of the capture zone analysis and GUDI assessment are presented in the following sections.

5.2.1 Groundwater Flow Direction

A limited number of wells were available to determine the groundwater flow direction and hydraulic gradient when defining the capture zones in the Phase I GWPP. Therefore, it was recommended that static water levels, the groundwater flow direction and the hydraulic gradient of the Montrose Aquifer be confirmed and the capture zones be refined during the Phase II GWPP. The VOM was successful in locating three test wells (TW-1, TW-2 and TW-3) in the vicinity of Well no.1. The concrete slab of both pumphouses, the top of the casing of the nearby test wells and the water gauges installed in Beaver Creek and in the Columbia River were surveyed for horizontal and vertical control (Figure 4). Golder measured the water levels in both production wells, the test wells, the Columbia River and Beaver Creek on several occasions between September 2008 and July 2009 to assess seasonal variation. Table 1 presents the elevation of the water levels measured.

Table 1: Groundwater and Surface Water Elevations

Location	Reference Elevation[1] (masl)	Groundwater/Surface Water Elevation (masl)						
		10-Sep-08	23-Sep-08	30-Sep-08	3-Nov-08	11-Mar-09	10-Jun-09	20-Jul-09
Well no.1	411.34	401.57	401.60	NA	NA	NA	402.06	NA
Well no.2	407.11	401.43	NA	401.25	401.04	NA	401.95	401.67
TW-1	411.09	401.86	401.89	401.88	401.49	401.54	402.41	402.17
TW-2	411.38	401.89	401.93	401.89	401.50	401.52	402.42	402.20
TW-3	411.61	401.69	401.70	401.71	401.30	NA	NA	NA
Beaver Creek	403.47	403.40	403.44	403.42	403.44	> 403.44	NA	NA
Columbia River	401.29	400.62	400.25	400.24	400.24	< 400.24	>400.62	NA

Notes:
masl: metres above sea level
NA: Data not available
[1] The reference elevation was the elevation of the top of casing for the production wells and the test wells and the surveyed measuring point elevation on the water gauges installed in Beaver Creek and the Columbia River.

From September 2008 to November 2008, the groundwater elevations in the wells and the surface water level in the Columbia River decreased by approximately 0.4 m whereas the water level in Beaver Creek remained constant at a level approximately 1.5 m to 2.0 m above the groundwater levels in the vicinity of Well no.1. When measured in March 2009, the groundwater levels in TW-1 and TW-2 had decreased by approximately an additional 0.5 m. The water levels in the Columbia River could not be measured because it was considerably lower than the gauging station reference point. The water level in Beaver Creek was higher than previously measured and could not be measured because the water gauge was not easily accessible from shore. Both water gauges were swept away during freshet, therefore, the water levels in Beaver Creek and in the Columbia River could not be measured in June 2009 and July 2009.

The groundwater flow direction and hydraulic gradient have been updated since the Phase I GWPP report using the new data available and are presented on Figure 4. Based on the groundwater levels measured on September 10, 2008, the groundwater flow direction is inferred to be to the west. The hydraulic gradient calculated in the vicinity of the wells is 0.008 m/m. Water level measured in Well no.1 was not utilized to generate groundwater elevation contours because the total depth of Well no.1 is not consistent with the total depth of the surrounding test wells (TW-1, TW-2 and TW-3) explaining the slight elevation difference. The water level measured in Beaver Creek indicates that Beaver Creek is perched and therefore it was also not utilized to generate groundwater elevation contours. Based on measurements taken in September 2008, November 2008, March 2009, June 2009 and July 2009, the groundwater flow direction and the hydraulic gradient appear to be consistent throughout the year.

5.2.2 Capture Zone Analysis

5.2.2.1 Methodology

To efficiently manage and protect a groundwater supply, an understanding of the well "capture zone" and the "time of travel" are required. A capture zone is the area of an aquifer from which all groundwater will eventually arrive at the well after an infinite amount of time. The capture zone should not be confused with the zone of influence or the cone of depression, which is the area surrounding a pumping well within which the water table or potentiometric surface has been lowered due to groundwater withdrawal. A time of travel zone is the area within the capture zone from which groundwater will be derived in a predefined amount of time. For example, if a conservative aqueous contaminant is released within the 100-day time of travel zone, it can be expected to arrive at the well within approximately 100 days. Once the capture zone and time of travel zones are estimated, the appropriate monitoring and protective measures can be implemented.

Additional background information on capture zone analysis and time-of-travel was provided in the Phase I GWPP. Among the several methods of capture zone analysis available, the time of travel zones were estimated in the Phase I GWPP using both the Calculated Fixed Radius (CFR) Method and analytical solutions (Golder, 2008). As the direction of groundwater flow within the Montrose Aquifer was initially estimated based on limited information (i.e. direction of groundwater flow and hydraulic gradient), it was recommended in the Phase I GWPP to refine the capture zone analysis by collecting additional data such as static water levels, groundwater flow direction and hydraulic gradient. Additional site-specific data were collected during the Phase II GWPP and the capture zone analysis was refined using a more accurate analytical solution.

To assist with the selection of the most appropriate analytical solution for delineation of the time-of-travel capture zones, a dimensionless time-of-travel parameter (T^*) derived by Ceric and Haitjema (2005), was calculated. The results of this calculation provided a basis for selection from three types of analytical solutions for capture zone estimation: the Centric Circular (CC) (this method is similar to the CFR method), the Eccentric Circular (EC), and the Boat-Shaped (BS) capture zone.

Calculations and detailed descriptions of these solutions and T^* are provided in Appendix IV. The travel times for Well no.1 and Well no.2 were computed for:

- 100 days (0.274 year) – generally considered to be the approximate time required by biological pathogens moving in groundwater to degrade based on BC MoE draft GUDI guidance document; and
- 1 year – intermediate time selected based on the hydrogeologic conditions prevailing in the area.

5.2.2.2 Time-of-Travel Capture Zone Results

The results of the 100-day and 1-year capture zones for Well no.1 and Well no.2 using the analytical solution method are summarized in Table 2. The capture zones were calculated using an aquifer thickness of 9.1 m, a porosity of 0.25 (conservative porosity for sand and gravel mixtures) and the average flow rates calculated for each well based on the review of the pumping records from 2007 to 2009. The average flow rate for Well no.1 is 2.1 L/s (34 USgpm) and the average flow rate for Well no.2 is 4.2 L/s (64 USgpm). In addition to the flow rate, aquifer thickness and porosity, the hydraulic conductivity, the groundwater flow direction and the hydraulic gradient are required to calculate the capture zones using the analytical solution methodology. As discussed in section 5.2.1, the groundwater flow direction is inferred to be to the west and the hydraulic gradient calculated in the vicinity of the wells is 0.008 m/m. The hydraulic conductivity (K) of the aquifer is estimated to be in the order of 1×10^{-3} m/s (84.6 m/day) based on the pumping test results.

The boat-shape capture zone solution for 100-day and 1-year time of travel best represents the hydrogeological conditions prevailing at the site based on the results obtained for the dimensionless time-of-travel parameter ($T^* > 1$). A description of this analytical solution, with calculations for T* and the 100-day and 1-year capture zones for Well no.1 and Well no.2, are provided in Appendix IV. To estimate the uncertainty in the capture zone analysis using the analytical solution methodology, additional calculations were performed to estimate the most conservative time-of-travel capture zones. Sources of uncertainty affecting the size of the capture zones originate mainly from the hydraulic conductivity value which can vary considerably in the aquifer. The time-of-travel capture zones were therefore also calculated using a hydraulic conductivity value an order of magnitude lower ($K=2 \times 10^{-4}$ m/s). Table 2 presents the results obtained using the analytical solution for both wells and both scenarios ($K=1x10^{-3}$ m/s and $K=2x10^{-4}$ m/s). The calculated 100-day (and inferred 1-year) capture zones for both wells and for both scenarios using the analytical solution methodology have been plotted on Figure 5.

The sand and gravel aquifer presumably extends laterally to the bedrock aquifer located to the east. The distribution of recharge between the bedrock and the sand and gravel aquifers is unknown; however, it is assumed that the bedrock aquifer discharges into the sand and gravel aquifer which discharges into the Columbia River. Therefore, it is inferred that the capture zones extend into the bedrock aquifer. However, since the hydraulics properties of the bedrock aquifer differ from the hydraulic properties of the sand and gravel aquifer, the capture zones will likely have a different shape and potentially a different direction. The uncertainty associated with the capture zone delineation in the bedrock aquifer is shown by the presence of question marks on Figure 5.

Table 2: Analytical Solution Time-of-Travel Zone Estimates

Parameter	Well no.1		Well no.2	
	100-day	1-year	100-day	1-year
Base Scenario : K=1x10^{-3} m/s				
Capture Zone Type	Boat Shaped	Boat Shaped	Boat Shaped	Boat Shaped
Lu=Distance to furthest upgradient point	297 m	1036 m	307 m	1051 m
Ls=Distance to furthest downgradient point	5 m	5 m	9 m	9 m
Y_1=Half width of capture zone at well	8 m	8 m	14 m	14 m
Y_2=Half width of capture zone at farthest upgradient of well	16 m	16 m	27 m	27 m
Uncertainty Scenario : K=2x10^{-4} m/s				
Capture Zone Type	Boat Shaped	Boat Shaped	Boat Shaped	Boat Shaped
Lu=Distance to furthest upgradient point	95 m	262 m	116 m	289 m
Ls=Distance to furthest downgradient point	25 m	25 m	44 m	44 m
Y_1=Half width of capture zone at well	40 m	40 m	69 m	69 m
Y_2=Half width of capture zone at farthest upgradient of well	64 m	72 m	105 m	120 m

5.2.2.3 Limitations of Capture Zone Delineation Method Employed

The analytical solution used to estimate the time-of-travel capture zones for Well no.1 and Well no.2 are calculations based on simple physical assumptions of the aquifer system. The methodology assumes that:

- The aquifer is homogeneous and isotropic with a constant thickness and porosity;
- The aquifer has an infinite aerial extent;
- The hydraulic conditions within the aquifer are at steady state; and,
- The flow field is simple (unidirectional) in that there is an absence of interfering flow features.

The analytical methodology is considered fairly accurate for short travel times. Capture zone distances for longer time-of-travel begin to decrease in accuracy as other physical characteristics of the aquifer for which there is little to no data (variation in hydraulic gradients, stratigraphic changes at increased distances from the well, increased likelihood of encountering aquifer boundaries), are not taken into consideration using this method. Also, once the capture zones overlap with surface water bodies or physical boundaries, they are considered invalid. For the Montrose Aquifer, the capture zone distances calculated using the analytical solution methodology are considered fairly accurate for travel times up to 100 days. For longer travel times, the capture zones overlap the limit of the sand and gravel aquifer where the hydraulic conditions are inferred to be considerably different.

In addition, capture zone analyses using the analytical methodology do not account for the following:

- Seasonal fluctuations in precipitation and recharge from surface water bodies (streams, creeks, rivers or lakes);
- Interferences due to bedrock or stratigraphic changes;
- Interactions with other wells;
- Dispersion, retardation or degradation of contaminants in groundwater; and,
- Changes in pumping rates, based on daily and seasonal variations controlled by water supply demands and down time due to maintenance.

5.2.3 Water Quality

5.2.3.1 Historic Bacteriological Data

The VOM collects water samples from the water distribution system at the VOM office (565 11th Ave) on a weekly basis, submitting the samples to CARO Environmental Services (CARO) in Kelowna for the analyses of total coliforms and *E.coli*. Starting in 2009, water samples are also collected at the Community Hall (490 9th Avenue). Historical data for 2006, 2007, 2008 and 2009 (January to March 2009) were provided by VOM and reviewed by Golder. Results indicated that *E.coli* was never detected in any of the water samples collected since 2006. Total coliforms are usually not detected in the water samples collected weekly, with a few exceptions. Between January 2006 and March 2009, total coliforms were detected in the distribution system on April 14, 2008 (1 CFU/100 mL), on June 11, 2007 (2 CFU/100 mL) and on six occasions in 2006 (February 27, March 5, March 13, April 24, August 8 and September 5) with results ranging from 1 CFU/100mL to 4 CFU/100 mL. Because water samples collected from the distribution system do not allow for the identification of the source of contamination (aquifer or distribution system) when sampling results exceed the applicable guidelines, Golder recommends that the VOM collect water samples from both wells in addition to their normal sampling program of the distribution system.

5.2.3.2 Water Quality Monitoring

Field parameters (pH, conductivity, temperature, oxidation-reduction potential, and dissolved oxygen) were measured by Golder during the pumping test conducted in November 2008 and every site visit conducted during the course of the project. On March 9, 2009, the VOM started monitoring water quality weekly at Well no.1 and Well no.2 in addition to the distribution system in order to obtain water samples representative of the water quality of the aquifer. The water samples collected at both production wells were sent to CARO and analysed for total coliforms, E.coli, heterotrophic plate count, pH, conductivity, turbidity and UV transmittance. Following Golder's request, the VOM also started monitoring water quality of Beaver Creek and Columbia River in May 2009.

The tabulated results are presented in Appendix V. Total coliforms and *E.coli* were not detected in any of the samples collected in Well no.1 and Well no.2. Electrical conductivity remained relatively constant at both wells, ranging from 192 uS/cm and 229 uS/cm at Well no.1 and between 186 uS/cm and 224 uS/cm at Well no.2. The turbidity remained low at both wells (< 0.1 NTU to 0.2 NTU). UV transmittance was also monitored from May

2009 to July 2009 in both wells and ranged between 96.2% and 99.9% at Well no.1 and between 94.7% and 97.4% at Well no.2.

Figures 6 and 7 present graphs of electrical conductivity and turbidity versus time for both VOM wells, Beaver Creek and Columbia River. Figure 6 shows that the electrical conductivity measured in Beaver Creek varied considerably between baseline conditions (233 uS/cm-250 uS/cm measured in November 2008 and March 2009) and freshet (low of 116 uS/cm in May 2009). The data indicates that the electrical conductivity measured in Beaver Creek slowly increases with a reduction in flow during the summer months. For the same period, the electrical conductivity remained low in the Columbia River (114 uS/cm to 148 uS/cm) and constant in both wells. Figure 7 shows that turbidity measurements in Beaver Creek were also higher during freshet whereas they remained low and constant in both VOM wells. Turbidity also remained constant in the Columbia River during the monitoring period.

In summary, it was not possible to correlate the variations of conductivity and turbidity observed in Beaver Creek with the values measured at the wells. There was also insufficient variation in Columbia River to assess its influence.

5.2.3.3 MPA and Method 1623 Testing

The preliminary GUDI assessment completed by Golder as part of the Phase I GWPP indicated that the VOM wells were flagged as potentially GUDI, based on the well locations potentially being within 100 days horizontal travel time from the Columbia River and Beaver Creek. A more detailed GUDI analysis using Microscopic Particulate Analysis (MPA) and the EPA Method 1623 was conducted to assess whether the wells are influenced by surface water. This analysis was supported by the refined estimates of time-of-travel.

MPA Testing

Microscopic Particulate Analysis (MPA) testing was conducted for both production wells. MPA testing was conducted in accordance with the United States Environmental Protection Agency (EPA) “Consensus Method for Determining Groundwater Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (Consensus Method)” (USEPA, 1992). The intent of the test is to identify organisms that only occur in surface water (as opposed to groundwater) and whose presence in groundwater would provide indication of hydraulic connection with a surface water source.

A MPA test was conducted on Well no.2 on June 9, 2009 and on Well no.1 on June 10, 2009. The tests were conducted after the peak of freshet which is the time of the year when there is the greatest potential impact of nearby surface water. The tests were conducted after the peak of freshet to allow for time-of-travel from the surface water bodies to the wells. The MPA samples were collected using a MPA Sampling Device which consists of an inlet hose with a backflow preventor, a ten-inch (254 mm) cartridge filter housing, a water meter, a flow control valve and a discharge hose. The samples, collected using ten-inch yarn wound (string) filters, were sent to Hyperion Research Ltd. (Hyperion) for analysis. Hyperion is accredited by the Canadian Association for Laboratory Accreditation Inc. (CALA) to conduct this type of analysis. Both samples were collected following the sampling procedure proposed by USEPA (1992) as recommended by Peter Wallis, analyst at Hyperion. A sample filtration amount between 2000 L and 4000 L was suggested at a flow rate not exceeding 10 L/min. Prior to starting the test, the sampling apparatus was flushed without a filter with the source of water during approximately 15 minutes. The filter was then placed in the filter holder and sampling proceeded. The sampling unit was allowed to run for approximately 6-7 hours. The total volume filtered for Well no.2 was 3,004 L and 3,016 L for Well no.1. The filters were transferred to labelled bags and sealed for transport. The samples were immediately placed on ice in a cooler for shipment (under chain-of-custody) to Hyperion for analysis.

EPA Method 1623

In addition to the MPA tests, Well no.2 was also tested using the new EPA Method 1623. Well no.2 was selected for the Method 1623 because the well is located closer to Beaver Creek and is pumped at a higher flow rate. In 1999, the USEPA validated a method for simultaneous detection of *Crytosporidium* and *Giardia* and designated the combine procedure as EPA Method 1623. The latest method was published in 2005 following a number of revisions. Method 1623 is considered to be a more sensitive test for *Giardia* compared to the MPA test and especially sensitive for *Cryptosporidium*. The test involves filtering a relatively small volume of water (e.g. 100 to 500 litres) and using a Filta-Max filter. The Method 1623 test was conducted on Well no.2 on July 20, 2009. A total of 150 L was filtered during the test. Water samples collected at Well no.2, Beaver Creek and Columbia River were also provided to Hyperion. The result indicated that there is no *Giardia* and no *Cryptosporidium* in Well no.2. The Aerobic Spore Forming Bacteria test, which was conducted as part of the Method 1623 protocol, showed 0 CFU/mL for Well no.2 and 12 CFU/mL for Beaver Creek. The risk level obtained from Method 1623 is in the low range according the USEPA Consensus Method. It should be noted that the risk calculation ranges of the Consensus Method are calibrated for the less sensitive method (MPA test) used in the original protocol. Therefore, the low risk factor obtained for the Method 1623 confirmed the low risk obtained for the less sensitive MPA test. This is also corroborated by the absence of Aerobic Spore Forming Bacteria, total coliform, faecal coliform bacteria in the well even though Beaver Creek was positive for both. The field measurements also support the hypothesis that the well water is significantly different from the nearby surface water sources.

The MPA and Method 1623 test results are summarized in Table 3 along with the risk of surface water contamination according to the USEPA Consensus Method. The Certificates of Analysis from the laboratories including the numerical range of each primary bio-indicator and the relative surface water risk factors associated with scoring of primary bio-indicators are presented in Appendix VI.

Table 3: MPA Testing Results

Production Well	Well no.1	Well no.2	Well no.2
Date	10-06-2009	09-06-2009	20-07-2009
Method	MPA test	MPA test	Method 1623
Risk Factor	0	0	5
Risk of Surface Water Contamination[1]	Low	Low	Low

1 Based on Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (USEPA, 1992).

5.2.4 Results of GUDI Assessment

The time-of-travel capture zone results indicate that the 100-day capture zones for both wells calculated using the analytical solution does not intercept Beaver Creek when calculated using a K value of 1 x 10^{-3} m/s (obtained from the pumping test interpretation). However, when the 100-day capture zone is calculated with the analytical solution using a lower K value (2 x 10^{-4} m/s), the 100-day capture zone intercepts Beaver Creek in the case of Well no.2. It should be noted that the capture zones calculated using the analytical solution assumed that the aquifer is homogeneous and isotropic and does not account for vertical separation between the aquifer and the surface water bodies. In addition to the horizontal distance between the VOM wells and Beaver Creek which is about 35 m for Well no.2 and 50 m for Well no.1, the vertical separation between the creek bed and the top of the aquifer is approximately 20 m. The geological material above the aquifer is a combination of sand, silt, gravel and clay which would considerably reduce the travel time expected for surface water to reach the aquifer.

The water quality monitoring program conducted between March 2009 and July 2009 along with the historical data reviewed does not indicate that the groundwater extracted from Well no.1 and Well no.2 is under the direct influence of surface water. Groundwater quality remained constant during the monitoring period and could not be correlated with surface water quality fluctuations measured in Beaver Creek. In addition, MPA testing conducted on Well no.1 and Well no.2 indicated that the risk of surface water contamination was low based on the Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (USEPA, 1992). In addition to the MPA test, further testing for *Giardia* and *Cryptosporidium* using Method 1623 was conducted on Well no.2 located closer to Beaver Creek. The result of the Method 1623 indicated the absence of *Giardia* and *Cryptosporidium* and a low risk of surface water contamination.

Based on the water quality monitoring program, historical data and the results of MPA and Method 1623 testing, Well no.1 and Well no.2 at the Village of Montrose are not considered to be under the direct influence of surface water. Even though the capture zone analysis indicated that the 100-day capture zone intercepted Beaver Creek in the case of Well no.2 when using a lower K value, the water chemistry and the MPA test result indicates that there is sufficient stream bank filtration to likely eliminate any risk of pathogens reaching the wells under the present operating conditions.

5.3 Phase II Contaminant Inventory

The results of the preliminary contaminant inventory indicated that the majority of the Groundwater Protection Area (defined as the area within the boundaries of the Montrose Aquifer) contains rural forested land. In general, land uses of concern identified within the Groundwater Protection Area identified for both wells were limited to a transportation route (Highway 22A) located to the northeast/east of the VOM wells, a Fortis Substation, a private residence and a property registered with the Ministry of Environment Contaminated Site Registry located to the southeast of the wells. It was recommended that an assessment of the locations and conditions of the test wells be conducted so that a determination can be made regarding the potential requirements for decommissioning of the test holes.

The results obtained for the additional tasks completed as part of the second phase of the contaminant inventory are described below.

5.3.1 Transportation Corridor

Highway 22A, also referred to as the Waneta Highway, is located within the Montrose Aquifer approximately 100 m northeast and hydraulically up-gradient of the VOM wells. Golder contacted Joe Mottishaw at Emcom Services Inc. (250-442-2025) to gather additional information related to the transport of dangerous goods and the application of road salt and/or other de-icing substances along the highway. Emcon Services Inc. provides services for the maintenance of Highway 22A. Highway 22A is a short highway section that leads to the Waneta Border (Can/US Border). Because the Waneta Border is not open 24 hours/day, Highway 22A is not subjected to significant traffic. According to Mr. Mottishaw, Highway 22A is not considered a major transportation route and therefore only a minor amount of road salt (NaCl) is used, if any. The transport of dangerous goods is also considered to be limited since other border crossings (Patterson or Grand Forks), opened 24 hours/day, are usually preferred by truckers.

5.3.2 Existing Test Holes/Unused Wells

According to the BC MoE Water Resources Atlas (WRA), a total of 23 water wells (including both VOM wells) are present within the Montrose Aquifer. Based on available information, all these wells, except for one, were test holes drilled as part of the groundwater exploration programs conducted in 1961 and 1979 for the Village of Montrose. It is unclear whether or not these test holes were completed as water wells, test wells or merely boreholes (i.e. casing removed from the ground).

Improperly abandoned wells can provide direct conduits for the migration of surface contaminants to the underlying aquifer. In some cases, abandoned wells are used for the disposal of wastes such as motor oil. Because improperly abandoned wells provide direct pathways to underlying aquifers, their presence represents a threat to groundwater. As part of the Phase II of the GWPP, the VOM was successful in locating three test wells in the vicinity of Well no.1. These three wells were dug out and Golder found that there was no proper sealed or welded cap protecting objects or substances from entering these existing wells. Golder recommended that the VOM extend the casing of these wells and install a secured well cap. Well caps, provided by Aqua Tech, were installed on TW-1 and TW-2. A mound using the soil around the well was also formed to ensure that any surface water flowing around the well would not pond but would be directed away from the well head. The plate of TW-3 was welded back to secure access to this observation well.

5.3.3 Fortis Substation

Beaver Park substation is located approximately 150 m north of the VOM wells and hydraulically side-gradient. The Beaver Park substation is located within the Montrose Aquifer but outside the 100-day and 1-year capture zones. Information on the substation was obtained from Scott Bartlett, station foreman for the Kootenay area (250-231-0453). Mr. Bartlett indicated that the substation was built approximately 40 years ago. The only chemical that is used and stored at the substation is mineral oil contained in the transformers. The approximate amount of mineral oil present at the substation is approximately 2000 gal. An empty tank trailer is kept at Beaver Park substation in case it is required in the area but is not used for storage at the substation. Fortis conducts monthly inspections at the substation and a complete clean-up of the substation following special washing procedures every six years. No spill has ever been recorded for the Beaver Park substation. On occasion, it is possible to observe a very small quantity of oil leaking from old transformers. When it occurs, the leaks are cleaned up during the monthly inspections. Additional information can be obtained from Jennifer Frumento, Environmental Technologist for FortisBC. In case of emergency, contact Fortis BC at 1-866-436-7847.

5.3.4 Residential Property

There is only one dwelling located within the footprint of the Montrose Aquifer (8735 Highway 22A). The dwelling was built in 1998 and is located on the crest of a slope approximately 60 m north of Well no.2 and 130 m northwest of Well no.1. The difference in elevation between the dwelling and Well no.2 is about 13 meters. The house is serviced by a private well and sewage disposal system. The well was drilled in 1998 to a total depth of 53 m (175 ft) and potentially extracts water from the same sand and gravel aquifer as the VOM wells. The private well is located north of the house. The sewage disposal system is located on the north side of the house, approximately 46 m north of the private well, approximately 75 m to 80 m north of the VOM wells and hydraulically side-gradient. The sewage disposal system consists of a 1000 gallon concrete tank and a septic field. The owner confirmed that the sewage disposal system is properly maintained. While septic systems can sometimes pose a threat to groundwater quality, given the location septic field on the property and considering that the installation is recent and well maintained, it does not likely represent a concern.

5.3.5 Search of Ministry of Environment Contaminated Site Registry

Golder conducted a review of the BC MoE Site Registry system, which identifies those properties for which the MoE holds environmental information. These records are limited to information obtained since approximately 1989. The existence of a property within the Site Registry system does not necessarily imply that the site is contaminated, as under the existing Contaminated Sites Regulation, the site registration process can be triggered by a number of mechanisms including property transactions and facility upgrades, and not only subsurface contamination. Similarly, there may be a number of contaminated sites within the District that have not been identified by the site registry.

Based on the results of the search, only one property of environmental concern was registered on the Site Registry within a 1 km radius of the VOM wells. This property is located approximately 240 m – 300 m to the east and potentially hydraulically upgradient of the VOM wells. The coordinates of the Site are 49º4'6.6"N and 117º36'16.1" W, and it is located approximately 100 m north of Beaver Creek along Highway 22A (MoE Site ID No. 6438). This property was the site of a diesel spill of approximately 34 gallons, when a fuel tank on a tractor trailer ruptured, spilling diesel fuel onto the ground. The petroleum hydrocarbon contaminated soil was reportedly immediately removed for remediation and disposal. The status of the property is "Inactive – No Further Action". The location of this property relative to the VOM wells is shown on Figures 2, 5 and 6. A copy of the detailed site report was provided in the Phase I GWPP.

Although this property is located hydraulically upgradient from the VOM wells, due to the reported removal of the contaminated soil and the relatively small amount that was spilled, it is unlikely that this spill represents an environmental concern to the water quality within the VOM wells.

5.4 Recommendations for Groundwater Protection Management Strategies

It is recommended that an aquifer protection approach be considered in the development of groundwater protection measures for the VOM wells. The groundwater protection area proposed for the VOM wells is the extent of the Montrose Aquifer as shown on Figure 8. This can be conducted with other stakeholders such as the BC MoE and IHA. Once the groundwater protection area has been designated, the VOM can consider embarking on the development of groundwater protection measures. Groundwater protection measures can be implemented at the municipal/regional level through both regulatory and non-regulatory measures. In our opinion, while non-regulatory measures, such as public education and best management practices can be highly effective, some degree of regulatory control may be required to ensure the protection of the groundwater resources. These regulatory strategies often involve the use of municipal land use planning and zoning bylaws to restrict certain high-risk land use activities within protection areas. While the development and implementation of groundwater protection measures will require some effort and expense on behalf of the VOM, these costs are considered relatively minor in comparison with costs associated with the loss of water supplies as a result of contamination.

The contaminant inventory identified land-uses within the groundwater protection area that may represent some level of risk to groundwater quality. Based on the results of the Phase II contaminant inventory, the transportation corridor, existing test holes/unused wells and the Fortis Substation were identified as representing possible threats to the VOM wells. Protection management strategies for these are proposed below.

5.4.1 Public Education

In our opinion, public education serves as an important means of achieving groundwater protection. Public education involves informing the public about the location of the wells and the groundwater protection area. Specifically, the owner of the private residence should be informed of the groundwater protection zone. Information on septic system maintenance, private well maintenance and proper handling and disposal of household and garden chemicals should also be provided to the owner. In addition to the general public, the VOM employees should be educated about requirements for groundwater protection. Handling of lawn care and other chemicals in the vicinity of the well heads should not be permitted. The use of heavy machinery on unpaved areas adjacent to the wellheads should be prohibited or, if necessary, should be authorized only if strict procedures are followed. Only well maintained machinery should be used and machinery should be inspected daily to make sure that there is no leakage of petroleum hydrocarbons on the ground. On-site fuelling or maintenance of the machinery should be prohibited.

5.4.2 Transportation Corridor

Highway 22A, also referred to as the Waneta Highway, is located within the Montrose Aquifer approximately 100 m northeast and hydraulically up-gradient of the VOM wells. Although, Highway 22A is not considered a major transportation route, there is always the possibility of a spill occurring along the highway. In fact, a search conducted on the Site Registry indicated that a diesel spill occurred approximately 240 m to 300 m east of the VOM wells.

It is recommended that Groundwater Protection Area signs (currently available through the BC MoE) be placed within the maximum extent of the Montrose Aquifer along Highway 22A to inform the public that they are entering in a Groundwater Protection Area. The signs should provide a phone number to call to report spills or dumping. It is also recommended that the speed limit be reduced along Highway 22A when entering the Groundwater Protection Area to minimize chances of accident and potential spill. The use of road-side pesticides/herbicides should also be prohibited.

Because the Kootenay Boundary Regional Fire Rescue is likely to have the lead role for response to a spill potentially occurring along Highway 22A, Golder recommends that the VOM communicates with the Kootenay Boundary Regional Fire Rescue (250-364-1737) and informs them about the location of the VOM wells and the Groundwater Protection Area. The Kootenay Boundary Regional Fire Rescue should notify the VOM of any leak or spill reported along Highway 22A in the vicinity of the wells so the VOM can take appropriate actions.

5.4.3 Existing Test Holes/Unused Wells

In order to ensure that unused wells do not pose a safety risk or act as a conduit for contamination to the subsurface, the BC Groundwater Protection Regulation requires that a well which is unused for 5 years be either deactivated or closed, and a well that has been deactivated or not used for 10 years be closed. Based on the above we recommend that the VOM decommission TW-2 and TW-3 and keep TW-1 as a monitoring well for further hydraulic testing and monitoring. TW-2 and TW-3 should be decommissioned in accordance with section 6 of the Code of Practice for Construction, Testing, Maintenance, Alteration and Closure of Wells in British Columbia set out in Appendix A of the Groundwater Protection Regulation.

We would also recommend that the VOM continue to search for potential existing test wells within the Montrose Aquifer so they can be properly decommissioned.

5.4.4 Fortis Substation

Communication with a Fortis BC's representative should be engaged by the VOM. The VOM should inform Fortis BC that the Beaver Park substation is located within a Groudwater Protection Area and as such, additional precaution should be undertaken by Fortis BC. The VOM should ask Fortis BC to notify the VOM of any leak or spill observed at the Beaver Park substation.

5.5 Water Supply Well Monitoring Program

The development and implementation of a water supply well monitoring program is recommended to monitor both water quality and well performance. Routine well inspection (monitoring) and maintenance are required to prolong the life of a well. Any changes in the water chemistry and operating characteristics of the well (such as decline in specific capacity) should be closely monitored and dealt with promptly, as both the well and pump can deteriorate beyond repair if problems are left unattended.

5.5.1 Well Performance Monitoring and Maintenance

For non-domestic (municipal) wells completed in alluvial aquifers, the typical frequency for major well maintenance is usually every 5 to 10 years.

Previous well testing conducted by Kala Groundwater Consulting Ltd and Precision Service and Pumps has indicated that the efficiency (specific capacity) of both wells has declined since the wells were drilled. The result of the pumping test conducted by Golder in November 2008 indicates that the specific capacity at Well no.2 has further decreased since 2002. The decline in well efficiency at Well No. 2 appears to be attributed to fine sand entering the well through an inappropriately sized section of the well screen and probably partial plugging of the well screen openings. The decline in well efficiency at Well No. 1 can most likely be attributed to the use of a torch-slotted casing as a well screen and the subsequent plugging of the casing slots.

The VOM is already monitoring water consumption and operational data. Every month, pumping data from both wells and both reservoirs are downloaded and compiled. The pumping rate at both wells and both reservoirs, the pumping duration and total consumption are recorded. Monthly consumptions are plotted and compared to previous years. The water levels in both reservoirs (min and max) and wells (static and dynamic) are also recorded. However, there are inconsistencies with the recorded values, especially for Well no. 2. The recorded water levels are in percentage (inferred to be percentage of submergence of the pressure transducer installed in wells) and are difficult to correlate with actual depths of groundwater since the depth of installation of the instruments is unknown. In 2008, the static and dynamic water levels measured at Well no.1 were consistent throughout the year. The recorded water levels were 100% under static (non-pumping) conditions and were oscillating around 50% under dynamic (pumping) conditions. In 2009, the data reviewed from January to April indicated that the static water levels recorded were 100% and the dynamic water levels oscillated around 45%. These data indicate that the drawdown during dynamic conditions is about 50 % of the water column. In 2008, the static and dynamic water levels measured at Well no.2 were consistent throughout the year. The recorded water levels ranged from 51 % to 55% under static conditions (where it should read 100 %) and were oscillating around 16% under dynamic conditions. In 2009, the data reviewed from January to April indicated that the static water levels recorded were approximately 32% and the dynamic water levels oscillated around 0.6%. Typically, these results would indicate a decline in the water table and well capacity; however, the timeline corresponds to the period where the pumping test was conducted and it is likely that the automatic pressure transducer was not repositioned at its original position after the test resulting in different readings. However, it should be noted that the recorded values can't easily be correlated with exact water level measurements because there is no record of the installation of the automatic pressure transducers and the depth of installation is unknown.

Golder recommends that the VOM continue the on-going well performance monitoring program. The monitoring program should include the measurements of static and dynamic (pumping) water levels, pumping rates, and duration of pumping for Well no. 1 and Well no. 2. It is important that the VOM keep downloading, compiling and reviewing the data monthly to identify any irregularities. All data should be compiled and reviewed annually by a qualified professional. Action should be taken if the data indicates a decline in the static and dynamic water levels or any other irregularities. In addition to the well performance monitoring program, the following tasks are recommended:

- Next time that the pumps at Well no. 1 and Well no.2 are removed for scheduled inspection and servicing, a down-hole video camera inspection should be completed. A down-hole camera inspection is required to assess the integrity of the well casing and well screen. A decline in well capacity has been noted at both wells. Typically, if the specific capacity of the production well decreases by more than 10 to 20 percent, this is indication that a well rehabilitation program may be needed. For non-domestic (municipal) wells completed in sand and gravel aquifers, the typical frequency for major well maintenance is usually every 5 to 10 years. Because previous rehabilitation programs were not successful at improving the well efficiency, it is recommended to proceed with a down-hole camera inspection before attempting any other rehabilitation programs; and
- Additional information should be obtained from the company who installed and provide maintenance to the electronic components of the water supply system. The dedicated pressure transducers should be repositioned if required or reprogrammed so the readings can be correlated with an actual depth or height of water.

5.5.2 Water Quality Monitoring

The VOM collects water samples from the water distribution system at two locations on a weekly basis, submitting the samples to CARO Environmental Services (CARO) in Kelowna for the analyses of total coliforms and *E.coli*. In addition to the water samples collected on the distribution system, Golder recommends the collection of samples at Wells nos.1 and 2 on a weekly basis to allow for the identification of the source of contamination (aquifer or distribution system) when sampling results exceed the applicable guidelines.

Standard potability analyses, including physical parameters (color, turbidity, pH, conductivity), total metals, anions and nutrients, should be conducted, at a minimum, annually for each well. Groundwater samples should be submitted to a Canadian Association for Environmental Analytical Laboratories (CAEAL) certified laboratory for the analyses. Should a specific contaminant of concern be identified as a result of local contamination within the area, the groundwater sampling frequency and list of parameters should be adjusted accordingly to account for this event. For example, if a fuel truck tips over along Highway 22A, spilling its fuel load, hydrocarbon parameters would be added to the list of required analyses at an increased frequency, to ensure that hydrocarbon concentrations were not adversely impacting the water quality.

Analytical data should be compiled within a database and reviewed annually by a qualified professional. Adjustments to the groundwater monitoring program would be made, if necessary.

5.6 Recommendations for the Development of a Contingency Plan

The goal of implementing groundwater protection management strategies is to prevent the contamination of drinking water supplies. Even under the best prevention plans, contamination may occur. When this happens, a contingency plan directing a coordinated and timely response is an effective tool for assuring a continued supply of potable water. Following the implementation of groundwater protection management strategies, Golder recommends that the VOM develop a contingency plan (including an emergency response plan) to allow for the protection of the Montrose Aquifer, as well as the entire water supply system. Some guidance on the development of a contingency plan is presented in this section.

The development of a contingency plan is necessary to ensure that the VOM reacts in a timely and efficient manner to a contamination event in the area of Well no. 1 and Well no. 2 or within the footprint of the Montrose Aquifer. The contingency plan would outline the events or actions required to reduce potential impacts of a nearby spill on the water quality within the Montrose Aquifer and the VOM wells. Specifically, contingency planning involves developing a response to a range of possible contamination events identified for each of the potential sources listed within the contaminant inventory. In addition, contingency planning identifies alternate sources of water supply in the event that contamination results in the temporary or permanent loss of a water supply well. There are a number of scenarios that could potentially lead to the loss or contamination of the water supply. Periodic emergencies or disruptions may occur due to natural disasters, chemical or bacteriological contamination, and physical disruption. These threaten the supply and distribution of public drinking water supplies to some degree; ranging from a few hours of disruption to contamination of an entire water supply source. The objective of a contingency plan is to minimize the impact of disruption, primarily related to chemical and bacteriological contamination of groundwater, on the public, and restore the water supply service through improved response capabilities and enhanced public education.

Key to the contingency planning process is assuring that proper personnel, equipment, and technical resources are available in case of a water supply disruption. The plan should therefore include a list of contacts and resources (related to equipment, contractors, personnel, etc).

5.6.1 Potential Conditions Resulting in Loss of Water Supply

Conditions that potentially could lead to the loss or contamination of the water supply are listed below:

- Contaminated source (chemical) – spill of petroleum hydrocarbon or other chemicals reported along Highway 22A, spill or leak reported at Beaver Park Fortis substation, contaminated surface water (Beaver Creek or Columbia River);
- Contaminated source (biological) – contaminated surface water (Beaver Creek or Columbia River), contamination of groundwater from septic fields;
- Power outage – loss of regional power or local power supply disruption;
- Flooding – Columbia River inundation of pumphouse and loss of power or contamination of water supply;
- Earthquake – power loss, distribution line breaks, well house building damage, reservoir damage, etc;
- Fire - at pumphouse;
- Water main break-due to corrosion, impact, earthquake;
- Vandalism; and
- Explosion/bomb-terrorist activity, accident;

Where the conditions are physical (e.g., water main break) the corrective action is both straightforward and part of the normal activities of the Public Works crews. Where other conditions are present, such as contamination due to a spill or a leak, a greater variety of approaches is possible with some being significantly more costly and complex than others. In those cases, a planned approach is required and may require involvement of contaminant hydrogeologists.

5.6.2 Preventing Contamination of Water Supply – First Response

5.6.2.1 Recognition of Spill and/or Leak within Groundwater Protection Area

The Groundwater Protection Area is shown on Figure 8 and corresponds to the extent of the Montrose Aquifer. All parties potentially involved in a spill clean-up within the Groundwater Protection Area, must recognize that a spill in the Groundwater Protection Area may not only represent an immediate danger to persons in the area, but also an immediate danger to the water supply source.

Because the Kootenay Boundary Regional Fire Rescue is likely to have the lead role for response to a spill potentially occurring along Highway 22A, Golder recommends the VOM to communicate with Kootenay Boundary Regional Fire Rescue (250-364-1737) and to inform them about the location of the VOM wells and the Groundwater Protection Area. The Kootenay Boundary Regional Fire Rescue should notify the VOM of any leak or spill reported along Highway 22A in the vicinity of the wells so the VOM can take appropriate actions. The Groundwater Protection Area should be noted on the Kootenay Boundary Regional Fire Rescue reference maps. Response personnel must consider that there is an unseen receptor beneath the ground surface that must also be protected. Without specific education on the need to protect the groundwater resource, it is unlikely that response personnel will take the necessary steps to protect it adequately.

The VOM should inform Fortis BC about the location of the Beaver Park substation within a Groudwater Protection Area. The VOM should ask Fortis BC to notify the VOM of any leak or spill observed at the Beaver Park substation. Fortis BC should develop an Emergency Response Plan specific to Beaver park substation so they would react promptly in the case of a spill or leak on the substation.

A spill occurring in Beaver Creek should also be recognized as a treat to the groundwater quality of the VOM wells and should be assessed and remediated if required.

5.6.2.2 Spill Response

The Montrose Aquifer consists primarily of sand and gravel and is considered vulnerable. Spill response depends on a number of factors relating to site-specific conditions, the material spilled, weather, available resources, etc. For groundwater protection, the most significant difference is between liquid and solid materials and these are discussed separately below.

Liquids

If a liquid spill of a Dangerous Good[1] in quantities greater than about 1,000 litres occurs within the Groundwater Protection Area, the VOM wells should be shut down immediately, pending further assessment of the conditions and the adequacy of the spill response. A spill of a Dangerous Good, even in small quantities, within the 100-day capture zone should also result in a shut-down of the VOM wells.

If the product spilled is either flammable or immediately dangerous to life or health, it is preferable to use foam to decrease the immediate risk, if appropriate. The foam can reduce the fire risk and mixture of spilled product and foam can then be vacuumed up with a suction truck. Certain fire fighting foams contain toxic chemicals that may

[1] A Dangerous Good is defined in the Canadian Transport of Dangerous Goods Act and Regulation (http://www.tc.gc.ca/tdg/clear/tofc.htm)

contaminate the groundwater supply if allowed to disperse in the ground. The Fire Department should evaluate their foam used and consider non –toxic alternatives if toxic foams are used. When foam is used within a capture zone, it should be vacuumed up to limit the risk of groundwater impact.

If the product is non –flammable, not immediately dangerous to life and health, and provided an exclusion zone can be maintained around the area, then other recovery methods should be considered. Because of the nature of the soils in the VOM wells area, action to contain the material is likely required within hours if the groundwater is to be preserved. Some of the methods for recovery of liquids spilled to the ground include the following: berming and pumping, interception trenches, product recovery wells, mass excavation. Other methods are available and the personnel in charge of Hazardous Materials response at the Kootenay Boundary Regional Fire Rescue or Fortis BC should have a copy of a HazMat response manual to aid with selection of a response method. A spill response must be conducted by appropriately trained and equipped personnel or contractors. Knowledge of the appropriate level of person protective equipment is essential. Hazards associated with Dangerous Goods are compiled in the Emergency Response Guidebook available online (http://www.tc.gc.ca/CANUTEC/en/GUIDE/menu.htm). The 2008 Emergency Response Guidebook was developed by Transport Canada, the U.S. Department of Transportation, the Secretariat of Transport and Communications of Mexico and with the collaboration of the Centro de Informacion Quimica para Emergencias of Argentina, for use by fire fighters, police, and other emergency services personnel who may be the first to arrive at the scene of a transportation incident involving dangerous goods.

When the majority of the spilled has been recovered, the soil that is contaminated with the liquid will require treatment. The type of treatment will depend on a number of factors. If there is no significant contaminant mobilization condition likely to occur in the near future (e.g., heavy rainfall, fire suppression water intrusion), the treatment of contaminated soil does not need to proceed immediately and should await expert advice.

Solids or Sludges

Spilled solids do not normally pose an immediate risk to the groundwater supply, provided there is no mobilization conditions present (e.g. heavy rainfall, fire suppression water intrusion). Spilled solids or sludges should be removed as soon as possible, before a mobilizing condition is present. In the interim, the material should be covered with a waterproof cover to limit rainwater infiltration. If the material is fine grained, wet or very hazardous, the upper layer of soil beneath the spill should also be removed. The extent of removal of such soils can be assessed in consultation with environmental professionals.

5.6.3 Preventing Contamination of Water Supply - Follow-up Phase

Once a spill has occurred and initial clean-up completed or a historical spill has been determined, an evaluation of the safety of the water supply needs to be initiated. If the water supply is potentially jeopardized, additional mitigation measures may be required. Where a spill has occurred within the Groundwater Protection Area and within the capture zone, monitoring of the spill and its effect on the well should be initiated. The installation of groundwater monitoring wells might be recommended to monitor water quality between the spill and the VOM wells. The monitoring frequency should be assessed in consultation with contaminant hydrogeologist. If contaminants are detected in the groundwater in the monitoring wells, a mitigation measures should be selected. The selection of a mitigation measure will depend on the specific contaminant and the nature and extent of the release. To ensure the most appropriate measure is selected, a contaminant hydrogeologist and/or a remediation engineer should be consulted. Examples of mitigation measures include: discontinuing pumping at the VOM wells, installation of a pump and treat system between the source of contamination and the VOM wells, in situ treatment of contaminated soil and groundwater and/or installation of a treatment system at the VOM wells.

5.6.4 Procedures for Non-Contamination Events

Natural causes, ranging from lightning and storms to floods and earthquakes, may result in telephone or power outages, structural failure of facilities, or pipeline breaks. These events are likely to affect the water supply but the solutions to the issues are relatively straightforward. For example, if the power is lost at the pumphouse, resumption of power can be readily facilitated by bringing a generator to the site. If distribution lines are damaged, temporary supply lines for emergency water supply can be installed around damaged areas. Flooding may affect a well by introduction of flood water contaminants in to the well casing. Flood protection should be provided for each pumphouse and provisions for groundwater chlorination should be available.

5.6.5 Water Supply Loss Impact and Replacement Alternatives

The two major issues with respect to loss of a water supply source are alternate supplies (both short-term and long-term) and delivery method. In tandem with these supply alternatives, imposed conservation measures are the most common method of reducing demand.

5.6.5.1 Short-Term Water Supply

In general, the categories of short-term alternative water supplies are: supply from within the system, supply from outside the system; and water supply treatment.

If one of the VOM wells can still be used, it might be possible to increase the flow rate and/or duration of pumping of the other well on a temporary basis. While a significant increase in short term capacity is known to be available, the duration that higher flow rates can be sustained would require additional investigation. Using an alternate groundwater source (e.g. Beaver Falls Waterworks District) could also be considered for short-term water supply considering that a connection between both systems already exists. If required, bottled water may be used to deliver clean drinking water. When a water source has been contaminated, a short-term method of restoring the supply may be to add a package water treatment unit at the pumphouse or reservoir, given the volume of water to be treated.

5.6.5.2 Long-Term Replacement Alternatives

Long-term water replacement is different from emergency and short-term options in two ways: 1) the amount of time to evaluate is longer allowing for more analysis and future needs evaluation prior to a decision being made; and 2) the viable alternative range is larger. Once the VOM has implemented an interim source, they may evaluate replacement options that are more capital intensive and take longer to implement.

5.6.5.3 Water Distribution

In addition to supply sources, the delivery method may need consideration if either the source is remote to the system or the distribution system is damaged in an area. Alternative delivery methods include: tanker trucks, bottled water; and temporary pipelines.

5.6.5.4 Conservation Activities

The most effective method of meeting the supply requirements is to implement conservation measures. While some water restrictions would be enacted by bylaw or emergency order, the VOM can take steps at present to reduce the overall water demand and thereby increase or maintain the excess capacity in the system.

During water supply shortages, it is normal and generally expected that water use restrictions will be imposed. If a curtailment in water supply is required, the following facilities should be considered priority water users and should be provided with an uninterrupted water supply: hospital or medical center, emergency facilities, fire fighting systems, and public drinking water supplies.

A variety of stages of water use restriction may be considered and imposed. However, the success of the restrictions in the VOM will more likely be due to education than enforcement.

5.6.6 Reviewing and Updating the Plan

Contingency planning is not a one-step process. Any changes to this plan such as response agency telephone numbers, shifts in land use, turnover in personnel can affect the plan. It is important that the Contingency Plan and Emergency Response Plan be reviewed and updated annually.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following sections present the conclusions and recommendations of long-term pumping test and Phase II GWPP which comprised this study.

6.1 Hydraulic Testing

A long-duration pumping test of Well no. 2 was carried out to assess the specific capacity and bench mark the efficiency of the well, evaluate well interferences, estimate the hydraulic characteristics of the Montrose Aquifer in the vicinity of the production wells and make recommendations for either maintenance or replacement of the existing wells.

A 48-hour constant-rate pumping test was completed in November 2008 on Well no. 2, at a discharge rate of 19.7 L/s (312 USgpm). The static water level prior to the beginning of the test was at 6.7 m below the top of the casing. The maximum drawdown observed in Well no.2 after 48 hours of pumping at a constant discharge of approximately 19.7 L/s (312 USgpm) was 12.6 m. The drawdown observed in Well no.1 located at approximately 50 m away from Well no.2 was 0.44 m. The aquifer transmissivity is estimated to be 770 m^2/day. The hydraulic conductivity (K) of the aquifer is estimated to be in the order of 1 x 10^{-3} m/s (84.6 m/day), assuming the approximate 9.1 m thickness of the sand and gravel aquifer material in which the production well is completed.

Based on the results of the recent pumping test and the information reviewed from previous reports, there is no indication that the flow rate available from Well no.1 and Well no.2 is limited by the capacity of the Montrose Aquifer. The relatively small well interference measured during the pumping test, the rapid stabilization of the pumping water level and also the rapid recovery of the water level following the termination of the pumping test tend to indicate that the Montrose Aquifer has a good water-yielding capacity. The flow rate available at both wells seems to be limited by the poor efficiency of the wells. Based on the pumping test conducted by Golder in November 2008, the safe sustainable yield for Well no.2 is 21 L/s (332 USgpm) using the safe available drawdown of 70 % of the total available drawdown. Well no.1 was not tested during the present testing program but based on previous testing conducted by Kala (1998), the safe yield of Well no.1 was estimated to be approximately 28.4 L/s (450 USgpm). Further testing on Well no.1 would be necessary to confirm the actual safe yield as the well capacity might have further decreased since 1998. Previous rehabilitation programs conducted on both wells were not successful in increasing significantly the capacity of the wells.

Given the age of the wells, their poor efficiency, the decreasing specific capacity measured and the limited success obtained from previous rehabilitation programs, the VOM should consider replacing one or both wells as part of the long-term water supply management strategy.

6.2 Groundwater Protection Plan

6.2.1 Development of a community planning team

The development of a community planning team should be initiated by the VOM. The objective of the initial planning committee is to understand the technical aspects of the water supply wells and the Montrose Aquifer in order to make decision for long-term water supply. At this time, it is suggested that the technical component of the Community Planning Team should consist of the following persons:

- CAO, Village of Montrose
- A representative from the Village of Montrose Council
- Dan Byron, Public Health Inspector, Interior Health Authority, Cranbrook (250-420-2240)
- Mr. Peter Gigliotti or Mr. Bander Abou Taka, Urban Systems Ltd, Kelowna (250-762-2517)
- Ms. Genevieve Pomerleau or Mr. Garrett Brown, Golder Associates Ltd., Castlegar (250-365-0344)

6.2.2 Capture Zone Analysis and GUDI Assessment

The preliminary GUDI assessment completed by Golder as part of the initial phases of the GWPP indicated that the VOM wells were flagged as potentially GUDI, based on the well locations possibly being within 100 days horizontal travel time from the Columbia River and Beaver Creek.

As such, further GUDI analyses were recommended. In addition to refining the time-of-travel capture zones, a water quality monitoring program was implemented during freshet to compare water quality of the VOM wells and the nearby source of surface water (Beaver Creek and Columbia River) and Microscopic Particulate Analysis (MPA) testing was conducted for both production wells.

The time-of-travel capture zone results indicate that the 100-day capture zones for both wells calculated using the analytical solution does not intercept Beaver Creek when calculated using a K value of 1×10^{-3} m/s (obtained from the pumping test interpretation). However, when the 100-day capture zone is calculated with the analytical solution using a lower K value (2×10^{-4} m/s), the 100-day capture zone intercepts Beaver Creek in the case of Well no.2. It should be noted that the capture zones calculated using the analytical solution assumed that the aquifer is homogeneous and isotropic and does not account for vertical separation between the aquifer and the surface water bodies. In addition to the horizontal distance between the VOM wells and Beaver Creek which is about 35 m for Well no.2 and 50 m for Well no.1, the vertical separation between the creek bed and the top of the aquifer is approximately 20 m. The geological material above the aquifer is a combination of sand, silt, gravel and clay which would considerably reduce the travel time expected for surface water to reach the aquifer.

The water quality monitoring program conducted between March 2009 and July 2009 along with the historical data reviewed does not indicate that the groundwater extracted from Well no.1 and Well no.2 is under the direct influence of surface water. Groundwater quality remained constant during the monitoring period and could not be correlated with surface water quality fluctuations measured in Beaver Creek. In addition, MPA testing conducted on Well no.1 and Well no.2 indicated that the risk of surface water contamination was low based on the Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (USEPA, 1992). In addition to the MPA test, further testing for *Giardia* and *Cryptosporidium* using Method 1623 was conducted on Well no.2 located closer to Beaver Creek. The result of the Method 1623 indicated the absence of *Giardia* and *Cryptosporidium* and a low risk of surface water contamination.

Based on the water quality monitoring program, historical data and the results of MPA and Method 1623 testing, Well no.1 and Well no.2 at the Village of Montrose are not considered to be under the direct influence of surface water. Eventhough the capture zone analysis indicated that the 100-day capture zone intercepted Beaver Creek in the case of Well no.2 when using a lower K value, the water chemistry and the MPA test result indicates that there is sufficient stream bank filtration to likely eliminate any risk of pathogens reaching the wells under the present operating conditions.

6.2.3 Contaminant Inventory

The contaminant inventory identified land-uses within the Montrose Aquifer that may represent some level of risk to groundwater quality. Based on the results of the contaminant inventory, the transportation corridor, existing test holes/unused wells and the Fortis Substation were identified as potential threats to the VOM wells.

6.2.4 Recommendations for Groundwater Protection Management Strategies

It is recommended that an aquifer protection approach be considered in the development of groundwater protection measures for the VOM wells. The groundwater protection area proposed for the VOM wells is the extent of the Montrose Aquifer as shown on Figure 8. Once the groundwater protection area has been designated, the VOM can consider embarking on the development of groundwater protection measures. Below is a summary of the groundwater protection measures recommended:

- Promote groundwater protection through education to VOM employees and general public. Specifically, the owner of the private residence should be informed of the groundwater protection zone. Information on septic system maintenance, private well maintenance and proper handling and disposal of household and garden chemicals should also be provided to the owner;
- Protect the pumphouse and the area in the vicinity of the well heads (handling, use and storage of chemical or petroleum hydrocarbons prohibited, use of heavy machinery restricted);
- Install Groundwater Protection Area signs (currently available through the BC MoE) placed within the maximum extent of the Montrose Aquifer along Highway 22A to inform the public that they are entering in a Groundwater Protection Area;
- Communicate with the Kootenay Boundary Regional Fire Rescue (250-364-1737) to inform them about the location of the VOM wells and the Groundwater Protection Area. The Kootenay Boundary Regional Fire Rescue should notify the VOM of any leak or spill reported along Highway 22A in the vicinity of the wells so the VOM can take appropriate actions.

- Decommission observation wells TW-2 and TW-3 and keep TW-1 as a monitoring well for further hydraulic testing and monitoring. TW-2 and TW-3 should be decommissioned in accordance with section 6 of the Code of Practice for Construction, Testing, Maintenance, Alteration and Closure of Wells in British Columbia set out in Appendix A of the Groundwater Protection Regulation. The VOM should keep searching for potential existing test wells within the Montrose Aquifer so they can be properly decommissioned.

- Communicate with a Fortis BC's representative to inform Fortis BC that the Beaver Park substation is located within a Groudwater Protection Area and as such, additional precaution should be undertaken by Fortis BC. The VOM should ask Fortis BC to notify the VOM of any leak or spill observed at the Beaver Park substation.

6.2.5 Water Supply Well Monitoring Program

The development and implementation of a water supply well monitoring program is recommended to monitor both water quality and well performance. Routine well inspection (monitoring) and maintenance are mandatory to prolong the life of a well. Any changes in the water chemistry and operating characteristics of the well (such as decline in specific capacity) should be closely monitored and dealt with promptly, as both the well and pump can deteriorate beyond repair if problems are left unattended.

In addition to the well performance and well quality monitoring program already in place at the VOM, the following tasks are recommended:

- Next time that the pumps at Well no. 1 and Well no.2 are removed for scheduled inspection and servicing, a down-hole video camera inspection should be completed. A down-hole camera inspection is required to assess the integrity of the well casing and well screen. A decline in well capacity has been noted at both wells. Because previous rehabilitation programs were not successful at improving the well efficiency, it is recommended to proceed with a down-hole camera inspection before attempting any other rehabilitation programs;

- Additional information should be obtained from the company who installed and provide maintenance to the electronic components of the water supply system. The dedicated pressure transducers should be repositioned if required or reprogrammed so the readings can be correlated with actual an depth or height of water;

- In addition to the water samples collected on the distribution system, Golder recommends the collection of samples at Well no.1 and Well no.2 on a weekly basis to allow for the identification of the source of contamination (aquifer or distribution system) when sampling results exceed the applicable guidelines;

- Standard potability analyses, including physical parameters (color, turbidity, pH, conductivity), total metals, anions and nutrients, should be conducted, at a minimum, annually for each well. Should a specific contaminant of concern be identified as a result of local contamination within the area, the groundwater sampling frequency and list of parameters should be adjusted accordingly to account for this event; and

- Operational and analytical data should be compiled and reviewed annually by a qualified professional.

6.2.6 Recommendations to Develop a Contingency Plan

Following the implementation of groundwater protection management strategies, Golder recommend that the VOM develop a contingency plan to allow for the protection of the Montrose Aquifer, as well as the entire water supply system.

There are a number of scenarios that could potentially lead to the loss or contamination of the water supply. Periodic emergencies or disruptions may occur due to natural disasters, chemical or bacteriological contamination, and physical disruption. These threaten the supply and distribution of public drinking water supplies to some degree; ranging from a few hours of disruption to contamination of an entire water supply source. The objective of a contingency plan is to minimize the impact of disruption, primarily related to chemical and bacteriological contamination of groundwater, on the public, and restore the water supply service through improved response capabilities and enhanced public education.

There are a number of conditions that potentially could lead to the loss or contamination of the water supply. Where the conditions is physical (e.g., water main break) the corrective action is both straightforward and part of the normal activities of the Public Works crews. Where other conditions are present, such as contamination due to a spill or a leak, a greater variety of approaches is possible with some being significantly more costly and risky than others. In those cases, a planned approach is required and may require involvement from contaminant hydrogeologists.

The contingency plan should include the following components:

- A list of contacts and resources (related to equipment, contractors, personnel, etc);
- Prevention of contamination of water supply. This include the recognition of the presence of a spill and/or a leak within the groundwater protection area, communication with the different stakeholders (Kootenay Boundary Regional Fire Rescue, Fortis BC), the development of an adequate spill response plan and a follow up phase if a spill occur;
- Procedures for non-contamination events;
- Water supply loss impact and replacement alternatives including short-term and long-term options;
- Conservation activities; and
- Review and update of contingency plan.

7.0 LIMITATIONS AND USE OF THIS REPORT

This report was prepared for the exclusive use of the Village of Montrose. The assessment was performed according to current professional standards and practices in the groundwater field and has been made using historical and technical data obtained from the sources noted within this report. In evaluating the requirements for the Groundwater Protection Plan, Golder Associates Ltd. has relied in good faith on information provided by sources noted in this report. We accept no responsibility for any deficiency, misstatements or inaccuracy contained in this report as a result of omissions, misstatements or fraudulent acts of others.

The assessment is based on currently available information and does not account for interference created by additional wells which may be constructed in the future. It also does not consider the potential for other external factors which could affect the water balance for the Study Area, such as climate change and additional groundwater or surface development in the upland areas to the east of the Study Area. Additional limitations related to the analytical methods used for the delineation of time-of-travel capture zones are presented in the report. If new information is discovered during future work, Golder should be requested to provide amendments to this report as required.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

8.0 CLOSURE

We trust that this report provides you with the information you require at this time. Should you have any questions or require additional information, please do not hesitate to contact the undersigned.

Report Signature Page

ORIGINAL SIGNED

Geneviève Pomerleau, M.Sc., P.Eng.
Senior Hydrogeologist

ORIGINAL SIGNED

Garrett Brown, M.Sc., P.Geo.
Senior Hydrogeologist

ORIGINAL SIGNED

Jillian Sacré, M.Sc. P.Geo.
Principal, Senior Reviewer

GP/WGB/JS/gp

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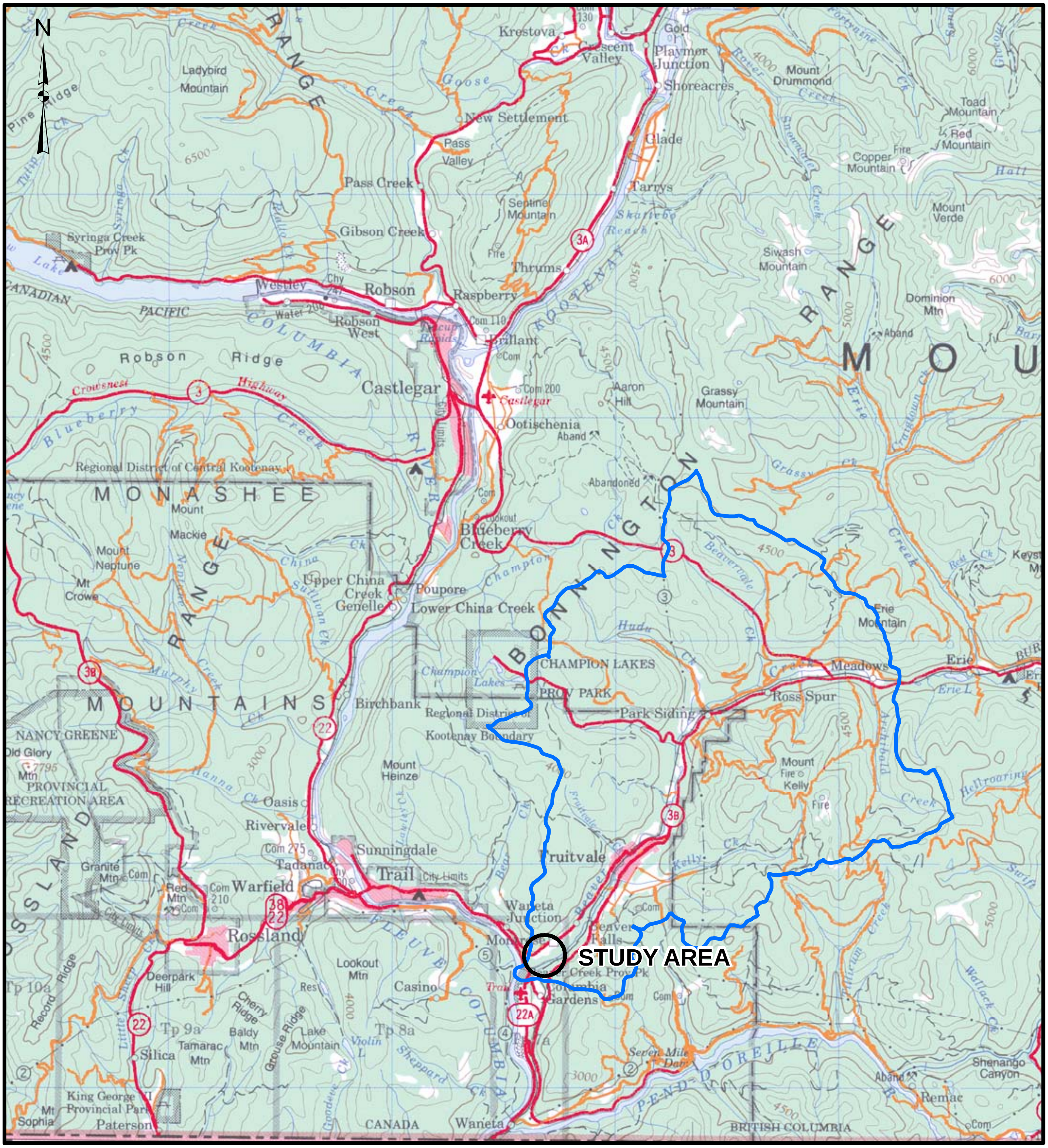

LEGEND

Beaver Creek Catchment Area

5,000 0 5,000

SCALE 1:250,000 METRES

PROJECT	VILLAGE OF MONTROSE PHASE II GROUNDWATER PROTECTION PLAN MONTROSE, B.C.
TITLE	KEY PLAN

Golder Associates
Greater Vancouver Offices, B.C.

PROJECT NO. 08-1480-0028			SCALE AS SHOWN	REV. 0
DESIGN	GP	05MAY2009	FIGURE 1	
GIS	MCM	05MAY2009		
CHECK				
REVIEW				

REFERENCE

Base data provided by Geogratis: NTS mapsheet 82F.
Other data provided by LRDW.
Datum: NAD 83 Projection: UTM Zone 10

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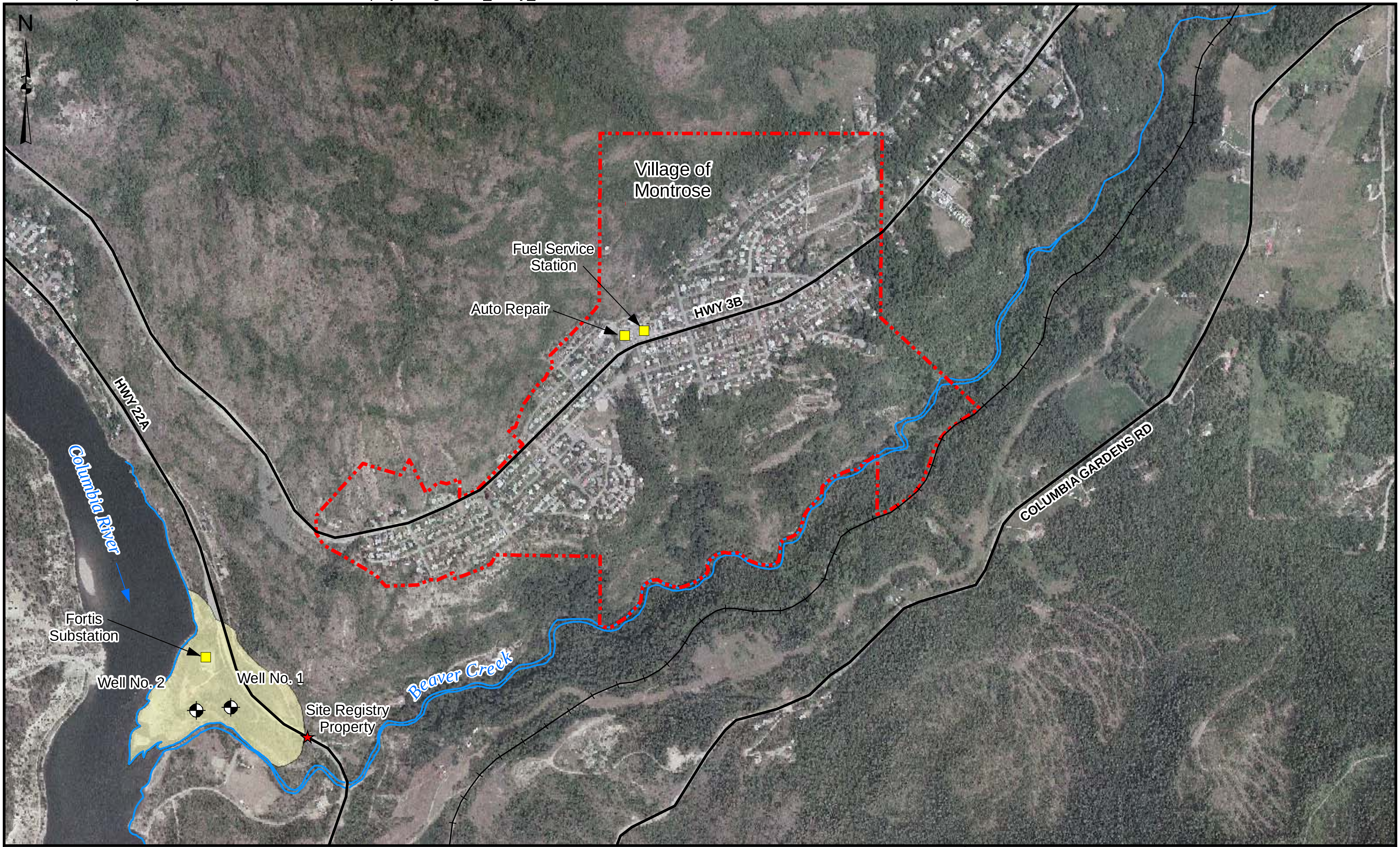


LEGEND

- Wells
- Businesses of Potential Environmental Concern
- Site Registry Property
- Montrose Aquifer
- Stream / Creek
- Montrose Municipal Boundary

REFERENCE

Base mapping provided by Village of Montrose and Province of BC Web Mapping Service (WMS Server: http://openmaps.gov.bc.ca/images/base.xml?)

300 0 300

SCALE1:15,000 METRES

PROJECT

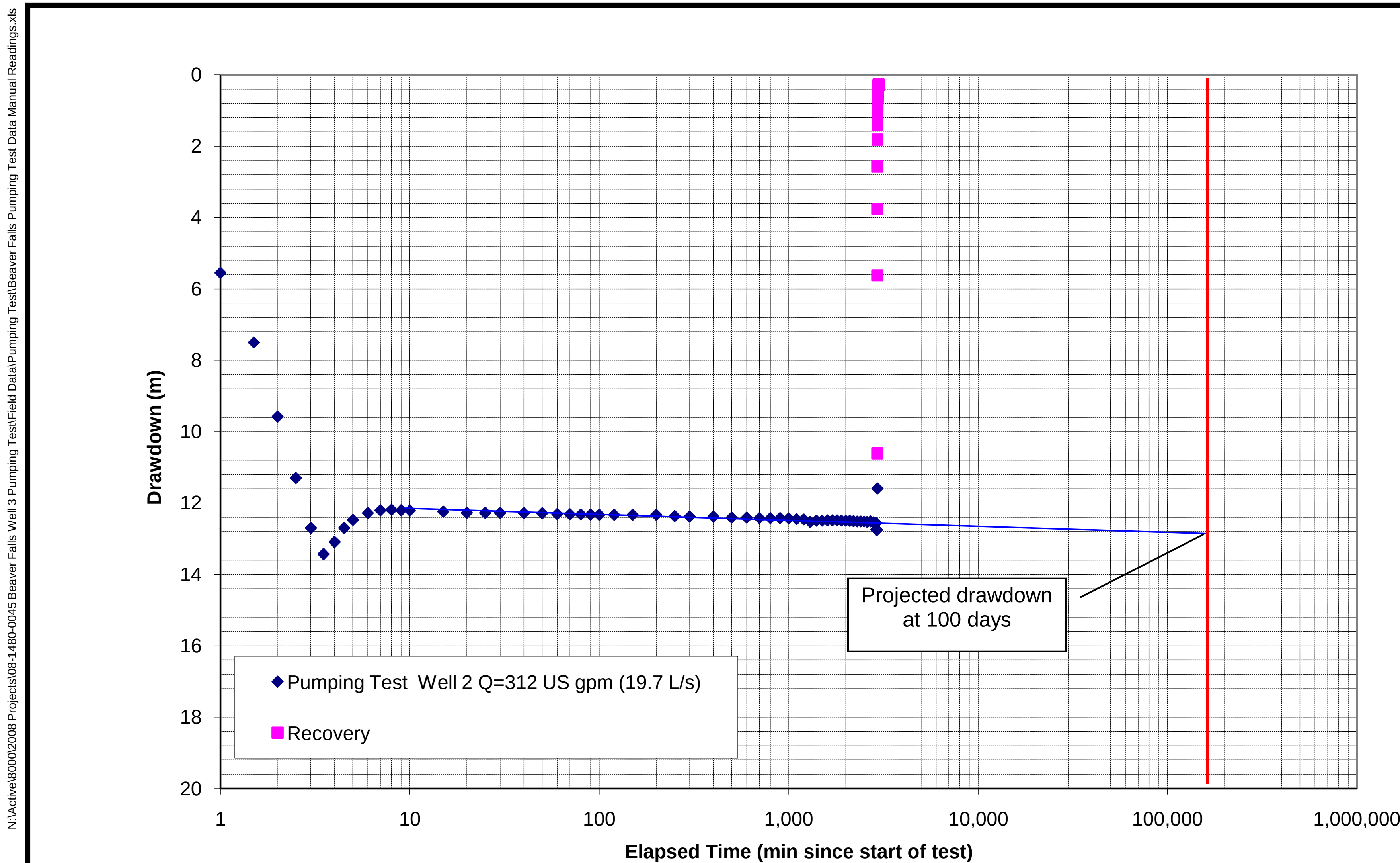
VILLAGE OF MONTROSE
PHASE II GROUNDWATER PROTECTION PLAN
MONTROSE, B.C.

TITLE

STUDY AREA PLAN

Golder Associates
Greater Vancouver Offices, B.C.

PROJECT No. 08-1480-0028			SCALE: 1:15,000	REV. 0
DESIGN	GP	05MAY2009	FIGURE 2	
GIS	MCM	05MAY2009		
CHECK				
REVIEW				



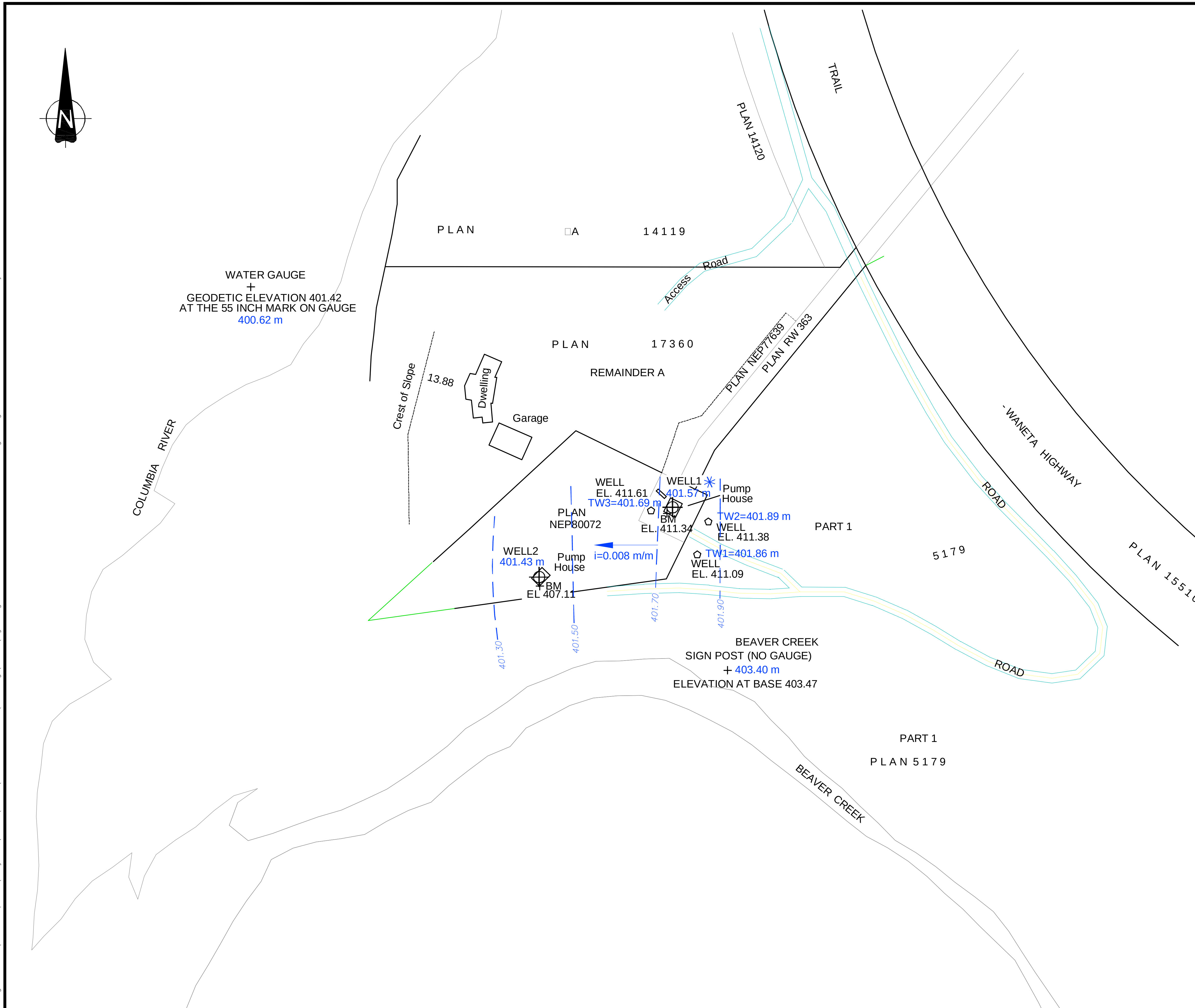
Project No. 08-1480-0028
Drawn GP
Reviewed WGB
Date November 3, 2008

Golder Associates

49-Hour Constant Rate Pumping Test
VOM Well no.2

Village of Montrose, BC

FIGURE 3



LEGEND

⌖	VOM PRODUCTION WELL
401.43	GROUNDWATER ELEVATION (m) MEASURED ON SEPTEMBER 10, 2008
401.5 (dashed line)	GROUNDWATER ELEVATION CONTOUR (m)
←	GROUNDWATER FLOW DIRECTION (m)
i	HYDRAULIC GRADIENT (m/m)
*	WATER LEVEL IN WELL NO.1 NOT UTILIZED TO GENERATE GROUNDWATER ELEVATION CONTOURS BECAUSE THE TOTAL WELL DEPTH IS NOT CONSISTENT WITH THE TOTAL WELL DEPTH OF THE SURROUNDING OBSERVATION WELLS TW1, TW2 AND TW3.

REFERENCE

BASE PLAN PROVIDED BY HINTERLAND SURVEYING & GEOMATICS INC. CANADA & B.C. LAND SURVEYOURS, TRAIL, B.C., DATED SEPTEMBER 8, 2008.

0 12.5 25 37.5 50 62.5

SCALE IN METRES

PROJECT

VILLAGE OF MONTROSE
MONTROSE, B.C.

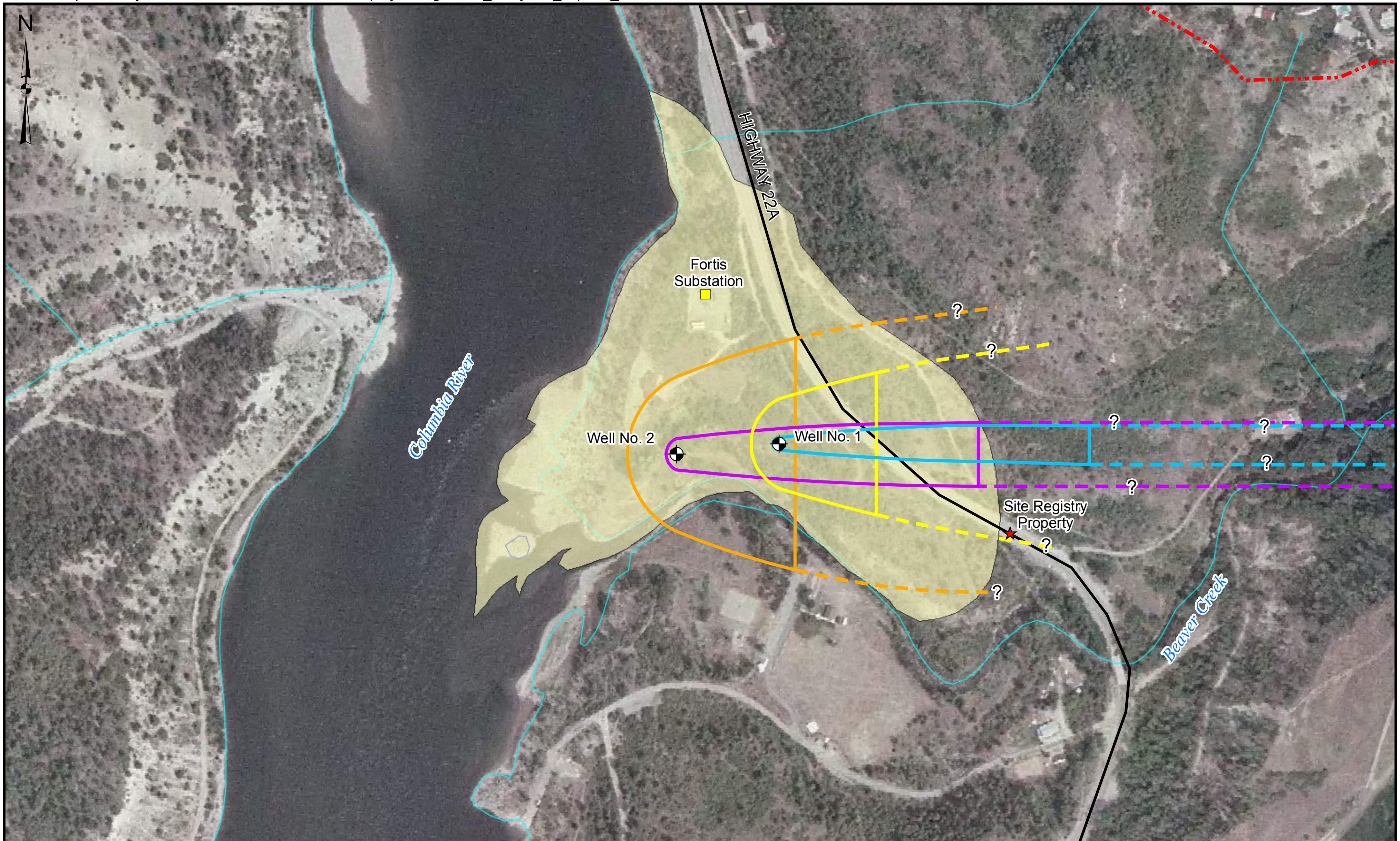
TITLE

GROUNDWATER ELEVATION CONTOURS

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 08-1480-0028			PHASE No.	1000
DESIGN	PG	29JUL09	SCALE AS SHOWN	REV. –
CADD	OD	25AUG09	FIGURE 4	
CHECK				
REVIEW				

N:\Bur-Graphics\Projects\2008\1480\08-1480-0028\GIS\projects\figure-05_analytical_capture_zones.mxd



LEGEND

- Wells
- Businesses of Potential Environmental Concern
- Site Registry Property
- Montrose Aquifer
- Stream / Creek
- Montrose Municipal Boundary

Time-of-Travel Capture Zones

Base Scenario $K=1x10^{-3}$ m/s	Uncertainty Scenario $K=2x10^{-4}$ m/s
Well No.1 - 100 days	Well No.1 - 100 days
Well No.2 - 100 days	Well No.2 - 100 days
Well No.1 - 1 year	Well No.1 - 1 year
Well No.2 - 1 year	Well No.2 - 1 year

REFERENCE

Base mapping provided by Village of Montrose and Province of BC Web Mapping Service (WMS Server: http://openmaps.gov.bc.ca/images/base.xml?)

100 0 100

SCALE 1:5,000 METRES

PROJECT

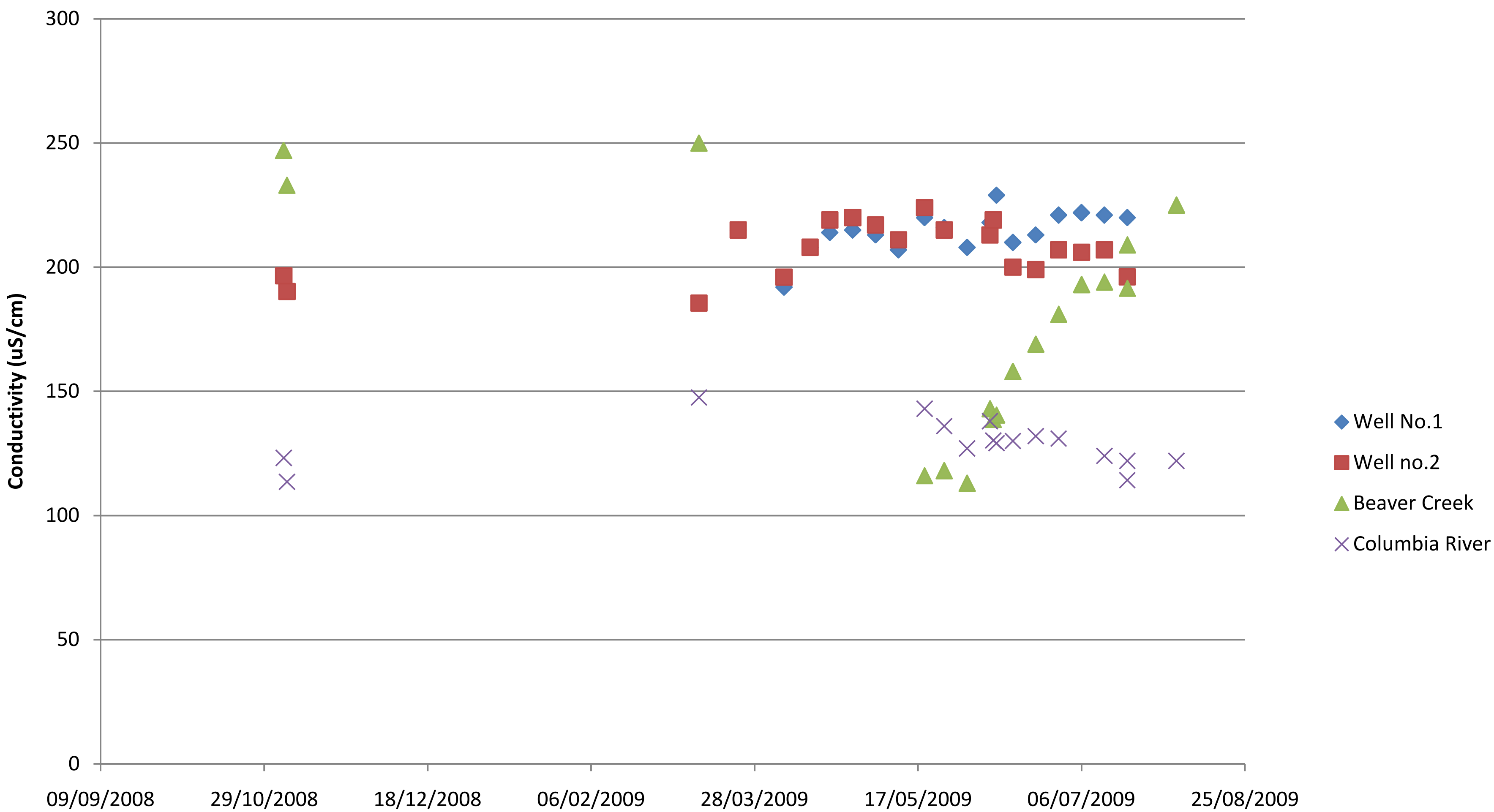
VILLAGE OF MONTROSE
PHASE II GROUNDWATER PROTECTION PLAN
MONTROSE, B.C.

TITLE

ANALYTICAL SOLUTION
TIME-OF-TRAVEL CAPTURE ZONES

Golder Associates
Greater Vancouver Offices, B.C.

PROJECT No. 08-1480-0028			SCALE: 1:5,000	REV. 0
DESIGN	GP	23JUL2009		
GIS	MCM	23JUL2009	**FIGURE 5**	
CHECK				
REVIEW				



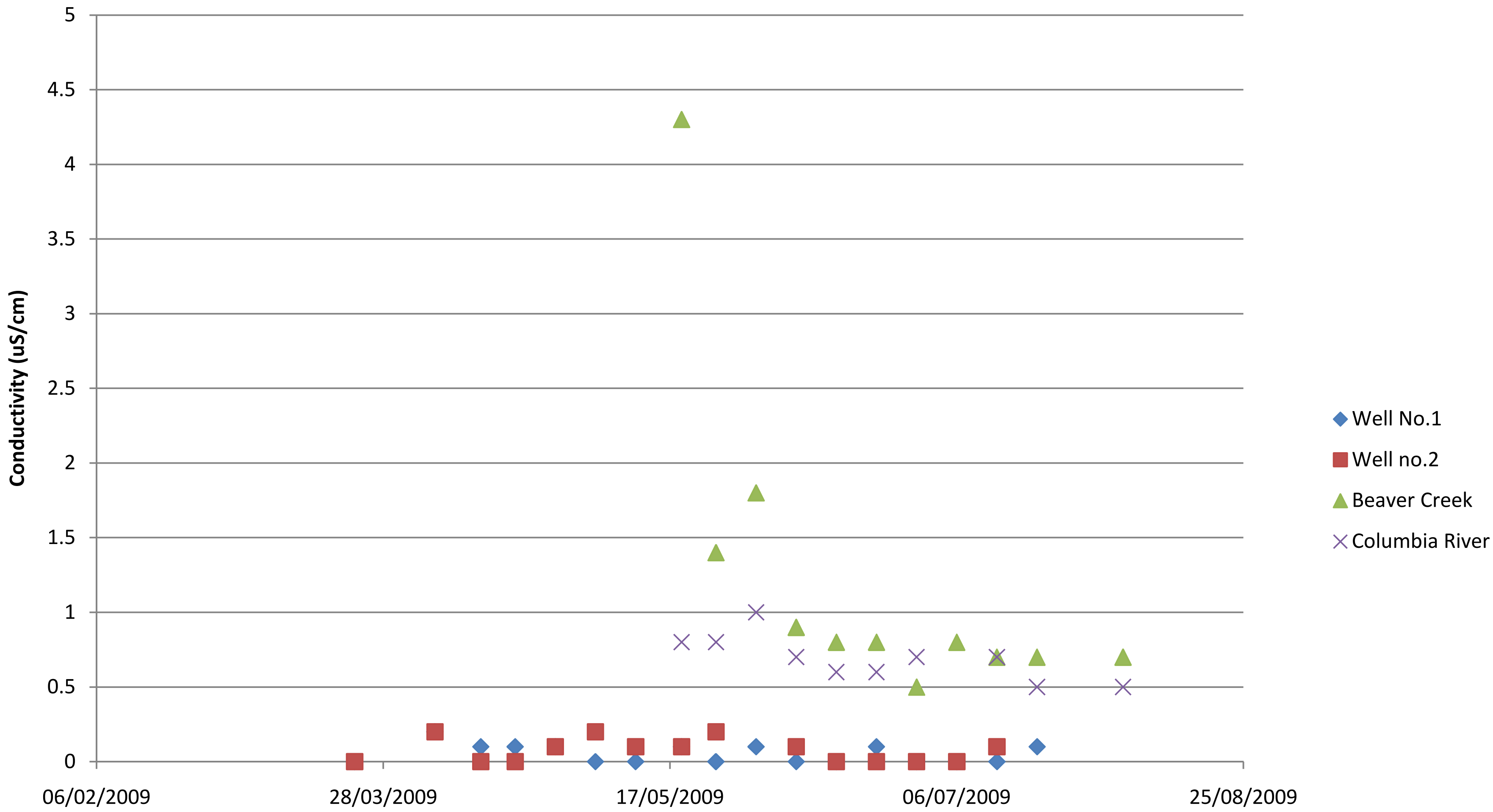
Project No. 08-1480-0028
Drawn: GP
Reviewed: WGB
Date: July 28, 2009

Golder Associates

Comparison of Conductivity Measurements

Village of Montrose, BC

Figure 6



Project No. 08-1480-0028
Drawn: GP
Reviewed: WGB
Date: July 28, 2009

Golder Associates

Comparison of Turbidity Measurements

Village of Montrose, BC

Figure 7

N:\Bur-Graphics\Projects\2008\1480\08-1480-0028\GIS\projects\figure-08_groundwater_protection_area.mxd

LEGEND

- Wells
- Businesses of Potential Environmental Concern
- Site Registry Property
- Groundwater Protection Area - Montrose Aquifer
- Stream / Creek
- Montrose Municipal Boundary

REFERENCE

Base mapping provided by Village of Montrose and Province of BC Web Mapping Service (WMS Server: http://openmaps.gov.bc.ca/images/base.xml?)

100 0 100

SCALE1:5,000 METRES

PROJECT

VILLAGE OF MONTROSE
PHASE II GROUNDWATER PROTECTION PLAN
MONTROSE, B.C.

TITLE

GROUNDWATER PROTECTION AREA

Golder Associates
Greater Vancouver Offices, B.C.

PROJECT No. 08-1480-0028		SCALE: 1:5,000	REV. 0
DESIGN	GP	05MAY2009	
GIS	MCM	05MAY2009	
CHECK			
REVIEW			

FIGURE 8

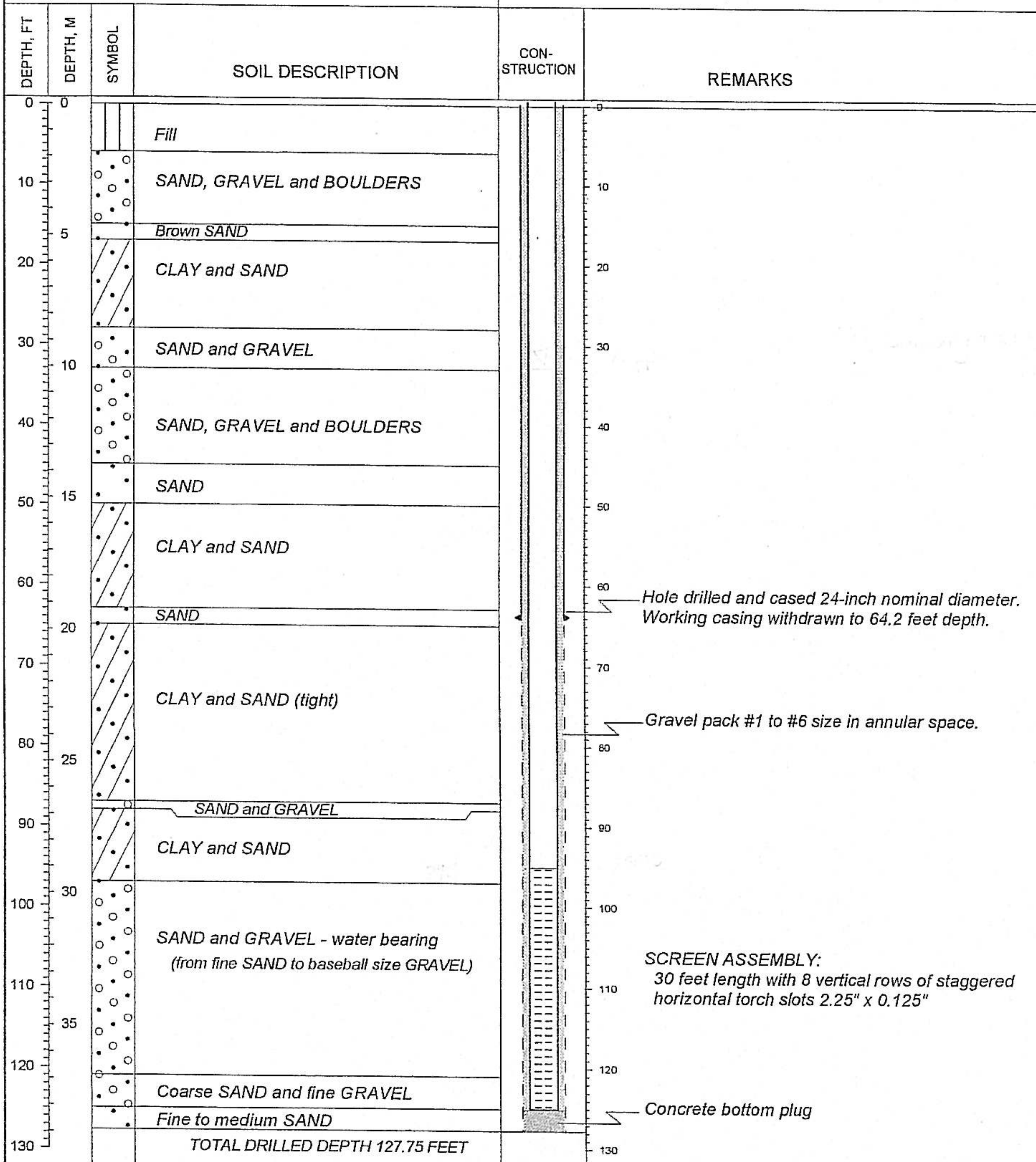
APPENDIX I

Village of Montrose Well Information

BOREHOLE NO. WELL NO. 1

LOCATION MONTROSE B.C.

NOTE: Well constructed by BUD HENNING DRILLING CO. LTD.
Started 18 June 1961, completed 11 October 1961.
Capacity 750 USgpm when constructed.
- Log compiled from faded copy on file - may vary slightly from original.



VILLAGE OF MONTROSE

PRECISION SERVICE & PUMPS INC. ABBOTSFORD B.C.

PROJECT	DRILLHOLE LOG	W.O. NO.	DATE
WELL NO. 2 REDEVELOPMENT	WELL NO. 2 - CONSTRUCTION	2489	28 OCT 1999
		BY: HWR	DRAWING NO. 2

MONTROSE #1 WELL OFFICIAL 24 HOUR PUMPING TEST — 24 Hr Test, Well No. 1

Measurement by 10" x 6" pipe orifice.
Pumping levels by "Fisher M-Scope" water level tester.
Gauge hole, 6" I.D., 25' from permanent 16" well.

	TIME	G.P.M.	WELL Pumping Level	GAUGE HOLE Pumping level	INCHES ORIFACE	REMARKS
8:00	8:00 A.M.	Start	Static 30'	30'		
8:30	8:30	720	99'½"	44'11½"	26" +	No sand. R.H. L.R.
9:00	9:00	720	99'4"	45'	26" +	No sand.
	10:00	720	99'6"	45'1"	26" +	No sand.
	11:00	720	99'7½"	45'1½"	26" +	No sand.
	12:00	720	99'8"	45'5"	26" +	No sand.
	1:00	720	99'9"	45'5"	26" +	No sand.
	2:00	720	99'8½"	45'6½"	26" +	No sand.
	3:00	720	99'9½"	45'7"	26" +	No sand. (Roberts)
	4:00	720	99'9¼"	45'7½"	26" +	No sand. (C. Fitzp
	5:00	720	99'9¾"	45'6"	26" +	No sand. (Flyp)
	6:00	720	99'10"	45'7"	26" +	No sand.
	7:00	720	99'11"	45'6"	26" +	No sand.
	8:00	720	99'11"	45'8"	26" +	No sand.
	9:00	720	99'10"	45'8"	26" +	No sand.
	10:00	720	100'	45'9"	26" +	No sand. (Fitz-
	11:00	720	100'1"	45'10"	26" +	No sand. patrick)
	12:00	720	100'3/4"	45'10"	26" +	W. Fenske
	1:00 A.M.	720	100'½"	45'10 3/4"	26" +	W. Fenske
	2:00	720	100'½"	45'10-3/4"	26" +	W. Fenske
	3:00	720	100'1"	45'10½"	26" +	W. Fenske
	4:00	720	100'1"	46'	26" +	W. Fenske
	5:00	720	100'2"	46'½"	26" +	W. Fenske
	6:00	720	100'1-3/4"	45'10"	26" +	W. Fenske
	7:00	720	100'½"	46'1"	26" +	(W. Fenske
8:00	8:00	747	102'8"	46'7"	28" +	No sand. (Roberts)
	8:45 Stopped pump					

RECOVERY

1	minute	41'8"
2	"	37'5"
3	"	35'5"
4"	"	34'2"
5	"	33'5"
6	"	33'0"
7	"	32'8"
8	"	32'5"
9	"	32'2"
10	"	32'1"
11	"	32'0"
12	"	31'11"
14	"	31'10"
✓16"	"	31'8"
✓22	"	31'6"
✓35	"	31'4"
✓50	"	31'3"
✓1½	Hours	31'2"
✓2	"	31'1"
✓2½	"	31'½" L.H.R.
✓3	"	30'11½"
✓3½	"	30'11"
✓4½	"	30'10"
✓5½	"	30'7"
✓6½	"	30'8"
9½	"	30'5"

Bud Henning Drilling Co., Ltd.
by Bud Henning

PUMPTEST (Drawdown)

Well No. 1

Village of Montrose - Grdwtr. Evaluation

Date test started: Nov. 6/98
Time test started: 11:00 AM
Ave. pumping rate: 700 USgpm
Pre-test water level: 9.99 metres

Reference Point: Opening at base of motor
Height of ref. point: 0.2 m. above grade
Depth of well: 38.1 metres
Screen Interval: 29.0 to 38.0 metres

Time (t) since pumping started in minutes	Depth to water in metres	Drawdown in metres	Comments
0	9.99	0.00	
1	33.75	23.76	Pumping rate: 720 USgpm
2	33.78	23.79	
3	33.80	23.81	
4	33.85	23.86	
6	33.87	23.88	
8	33.83	23.84	Pumping rate: 700 to 704 USgpm
10	33.83	23.84	
13	33.83	23.84	
16	33.83	23.84	
20	33.83	23.84	
25	33.83	23.84	
32	33.83	23.84	
40	33.83	23.84	
50	33.83	23.84	
64	33.83	23.84	Pumping rate: 700 to 704 USgpm

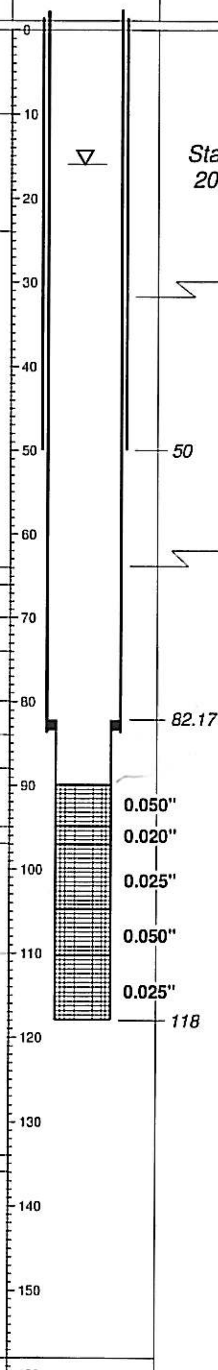
BOREHOLE I.D.	WELL NO. 2	DRILLER	THOMAS WELL DRILLING
LOCATION	VILLAGE OF MONTROSE	EQUIPMENT	CABLE TOOL DRILL RIG

DEPTH, FT | DEPTH, M | SYMBOL | SOIL DESCRIPTION | CONSTRUCTION | REMARKS

SOIL DESCRIPTION

- *Brown SAND and BOULDERS*
- *Brown SAND and GRAVEL*
- *Brown SAND and SILT*
- *Clean coarse SAND*
- *Coarse SAND and GRAVEL, tight*
- *CLAY and GRAVEL*
- *SAND and GRAVEL, tight*
- *SAND and GRAVEL, some CLAY*
- *GRAVEL, tight*
- *SAND and GRAVEL, faily loose*
- *Fine SAND*
- *Coarse SAND and GRAVEL*
- *Fine to medium SAND, some SILT binder.*
  - Drilled open hole 117 to 134 feet, some water loss.
- *Fine SAND. Clean, heaving.*
- *Fine SILTY SAND with some GRAVEL and compact SILT layers. Drilled open hole.*

DRILLED DEPTH 158 FEET



REMARKS

Static water level 16.14 feet 20 September 2000

Surface casing 20-inch diameter

Hole drilled and cased 16-inch diameter.

SCREEN ASSEMBLY:
Wire wound stainless steel, 29 feet length. Nominal diameter 16-inch. Slot size as noted. Total assembly 35.83 feet length with neoprene packer.

CORPORATION OF THE VILLAGE OF MONTROSE			
PROJECT: *PRODUCTION WELL CONSTRUCTION MONTROSE B.C.*	LOG OF WELL: *WELL NO. 2*	PROJ. NO.:	DATE: *DEC 1981*
		BY: *HWR*	DRAWING NO.: *-01*

PUMP TEST – DRAWDOWN DATA

PAGE 1 OF 3

21	DEC	81
DAY	MONTH	YEAR

CONTRACTOR Thomas Well Drilling

PROJECT Montrose Production Well

Location

Well

Pumping Rate (Q) 361 US gpm

Datum Point top of casing

Elevation of Datum Point 1.15 feet above ground.

Static Water Level 16.14 feet below ground

Screen Location top of packer 82' Screen 38 - 118'

all measurements below ground

TIME HR.	TIME MIN.	ELAPSED TIME (MIN.)	DISTANCE TO WATER (H)	DRAWDOWN			PUMPING RATE	REMARKS
10	00		16.14	0.0			(US gpm)	
16	50	0	16.63	0.49				adjacent production
		0.5	38.09	21.95			412	well pumping 1635-1710
		1.0	51.80	35.66				
		1.5	—					
		2.0	—					
		2.5	70.01	53.87				
		3.0	72.77	56.63				
		3.5	73.75	57.61				
		4.0	74.28	58.14				
		4.5	74.74	58.60				
		5.0	75.06	58.92				5" orifice - 6" pipe
		6	75.26	59.12			412	11" - orifice
		7	73.69	57.55			361	8½" - orifice
		8	71.23	55.09				
		9	70.18	54.04				
17	00	10	73.10	56.96				
		12	72.34	56.20				
		14	70.11	53.97				
		16	70.41	54.27				
		18	70.08	53.94				
		20	70.69	54.55				
		25	70.99	54.85				
17	20	30	70.57	54.43				
		35	70.41	54.27				
		40	70.70	54.56	Sc=6.62			
		45	70.70	54.56				
17	40	50	[illegible]	54.82			361	

PUMP TEST – DRAWDOWN DA

21	DEC	'81
DAY	MONTH	YEAR

CONTRACTOR

PROJECT Montrose Production Well

Location

Well

Pumping Rate (Q) 361 US gpm

Datum Point

Elevation of Datum Point

Static Water Level

Screen Location

TIME HR.	MIN.	ELAPSED TIME t (MIN.)	DISTANCE TO WATER	DRAWDOWN			PUMPING RATE	REMARKS
18	05	75	70.37	54.23			(US gpm)	
18	30	100	71.98	55.84			361	
19	00	130	71.19	55.05				
19	20	150	70.64	54.50				
20	10	200	71.95	55.81				adjacent production
21	00	250	70.99	54.85				well pumping 1955 – 2025
21	50	300	70.77	54.63				
23	30	400	70.70	54.56				
24	30	460	72.34	56.20				adjacent production
01	10	500	70.54	54.40				well pumping 2415 – 2445
01	45	535	71.13	54.99				
02	15	565	71.36	55.22				
02	45	595	71.36	55.22				
03	15	625	71.23	55.09				
03	45	655	70.93	54.79				
04	30	700	71.29	55.15				
07	00	850	71.06	54.92				adjacent production well
07	50	900	70.65	54.51				pumping 0730 – 0800
08	15	925	70.70	54.56			361	

PUMP TEST — RECOVERY DATA

PAGE 3 OF 3

PROJECT: Montrose Production Well

22	Dec	81
DAY	MONTH	YEAR

Well

Datum Point: top of casing　　Elevation of Datum Point

Static Water Level: 16.14 feet below ground　　Total Drawdown: 54.56 feet below static

TIME HR.	TIME MIN.	ELAPSED TIME SINCE PUMPING STARTED t (min.)	ELAPSED TIME SINCE PUMPING STOPPED t' (min.)	RATIO (t/t')	DISTANCE TO WATER	RESIDUAL DRAWDOWN		REMARKS
08	15	925	0		70.70	54.56		
			0.4	2313	48.06	31.92		
			1.0		——			
			1.4	662	31.66	15.52		
			2.0	463	25.59	9.45		
			2.5	371	22.70	6.56		
			3.0	309	20.93	4.79		
			3.5	265	19.46	3.32		
			4.0	232	18.57	2.43		
			4.5	207	17.75	1.61		
08	20		5.0	186	17.19	1.05		
			6	155	16.54	0.40		
			7	133	16.21	0.07		
			8	117	15.98	+ 0.16		
			9	104	15.78	+ 0.36		
			10	93	15.65	+ 0.49		
			12	78	15.65	+ 0.49		
			14	67	15.55	+ 0.59		
			16	59	15.58	+ 0.56		
			18	52	15.42	+ 0.72		
			20	47	15.42	+ 0.72		
08	45		30	32	15.29	+ 0.85		
			40	24	15.29	+ 0.85		
09	05		50	19.5	15.12	+ 1.02		
			75	13.3	15.09	+ 1.05		
09	55		100	10.25	15.22	+ 0.92		
10	45		150	7.2	16.60	− 0.46		
11	35		200	5.6	15.22	+ 0.92		

PUMPTEST (Drawdown)

Well No. 2

Village of Montrose - Grdwtr. Evaluation

Date test started: Nov. 6/98
Time test started: 1:00 PM
Ave. pumping rate: 425 USgpm (350 Igpm)
Pre-test water level: 6.51 metres

Reference Point: Opening at base of motor
Height of ref. point: 0.4 m. above grade
Depth of well: 37.5 metres
Screen Interval: 26.8 to 37.5 metres

Time (t) since pumping started in minutes	Depth to water in metres	Drawdown in metres	Comments
0	6.51	0.00	
1	20.80	14.29	Pumping to waste (creek) at unknown rate
2	25.36	18.85	
3	25.88	19.37	
4	25.89	19.38	
6	25.89	19.38	
8	25.87	19.36	
10	23.13	16.62	Pumping into system at 425 USgpm
13	22.50	15.99	
16	22.00	15.49	
20	21.97	15.46	
25	21.94	15.43	
32	21.91	15.40	
40	21.89	15.38	
50	21.86	15.35	
64	21.85	15.34	Pumping rate: 425 USgpm

APPENDIX II

November 3-5, 2008 Pumping Test on Well no.2
Data and Graphs

Golder Associates

49-Hour Constant Rate Test of VOM Production Well No. 2
Montrose, BC- November 3-5, 2008

Date	Clock Time	Time since pump started, t (minutes)	Time since pump stopped, t' (minutes)	t/t'	Water Level (ft btoc)	Water Level (m btoc)	Draw-down (ft)	Draw-down (m)	Residual Drawdown (s' in ft)	Pumping Rate (L/s)	Pumping Rate (USgpm)	Water Quality Field Parameters
3-Nov-08	13:28:00	0.0	--	--	21.98	6.700	0.00	0.00	--	--	--	
	13:28:30	0.5	--	--	31.07	9.470	9.09	2.77	--	--	--	
	13:29:00	1.0	--	--	40.19	12.250	18.21	5.55	--	14.5	230	
	13:29:30	1.5	--	--	46.59	14.200	24.61	7.50	--	--	--	
	13:30:00	2.0	--	--	53.41	16.280	31.43	9.58	--	20.2	320	
	13:30:30	2.5	--	--	59.06	18.000	37.08	11.30	--	--	--	
	13:31:00	3.0	--	--	63.65	19.400	41.67	12.70	--	24.0	380	
	13:31:30	3.5	--	--	66.05	20.130	44.06	13.43	--	--	--	
	13:32:00	4.0	--	--	64.93	19.790	42.95	13.09	--	21.4	340	
	13:32:30	4.5	--	--	63.65	19.400	41.67	12.70	--	19.6	310	
	13:33:00	5	--	--	62.90	19.170	40.91	12.47	--	19.2	305	
	13:34:00	6	--	--	62.27	18.980	40.29	12.28	--	19.6	310	
	13:35:00	7	--	--	62.01	18.900	40.03	12.20	--	--	--	
	13:36:00	8	--	--	61.98	18.890	40.00	12.19	--	--	--	
	13:37:00	9	--	--	62.01	18.900	40.03	12.20	--	19.6	310	
	13:38:00	10	--	--	62.04	18.910	40.06	12.21	--	--	--	
	13:43:00	15	--	--	62.14	18.940	40.16	12.24	--	19.6	310	
	13:48:00	20	--	--	62.24	18.970	40.26	12.27	--	19.4	308	
	13:53:00	25	--	--	62.26	18.975	40.27	12.28	--	--	--	
	13:58:00	30	--	--	62.26	18.975	40.27	12.28	--	--	--	
	14:08:00	40	--	--	62.27	18.980	40.29	12.28	--	19.4	308	pH=8.34, T=7.5oC, cond=181.0 uS/cm, TDS=90.6 ppm
	14:18:00	50	--	--	62.29	18.985	40.31	12.29	--	19.5	309	
	14:28:00	60	--	--	62.37	19.008	40.38	12.31	--	--	--	
	14:38:00	70	--	--	62.39	19.017	40.41	12.32	--	--	--	
	14:48:00	80	--	--	62.40	19.018	40.42	12.32	--	--	--	
	14:58:00	90	--	--	62.41	19.023	40.43	12.32	--	--	--	
	15:08:00	100	--	--	62.44	19.030	40.45	12.33	--	--	--	
	15:28:00	120	--	--	62.43	19.028	40.45	12.33	--	--	--	
	15:58:00	150	--	--	62.43	19.028	40.45	12.33	--	--	--	
	16:48:00	200	--	--	62.44	19.031	40.46	12.33	--	19.5	309	
	17:38:00	250	--	--	62.55	19.063	40.56	12.36	--	19.6	310.1	
	18:28:00	300	--	--	62.60	19.081	40.62	12.38	--	--	--	
	20:08:00	400	--	--	62.60	19.080	40.62	12.38	--	--	--	
	21:48:00	500	--	--	62.70	19.110	40.72	12.41	--	19.6	310	
	23:28:00	600	--	--	62.70	19.110	40.72	12.41	--	--	--	
4-Nov-08	1:08:00	700	--	--	62.73	19.119	40.75	12.42	--	19.6	310	
	2:48:00	800	--	--	62.73	19.120	40.75	12.42	--	19.6	310	
	4:28:00	900	--	--	62.75	19.125	40.77	12.43	--	19.6	310	
	6:08:00	1000	--	--	62.77	19.132	40.79	12.43	--	--	--	
	7:48:00	1100	--	--	62.83	19.149	40.85	12.45	--	19.6	311	
	9:28:00	1200	--	--	62.85	19.155	40.86	12.46	--	19.6	311	
	11:08:00	1300	--	--	63.09	19.229	41.11	12.53	--	19.7	312	pH=7.19, T=7.7oC, cond=196.5 uS/cm, TDS=98.2 ppm
	12:48:00	1400	--	--	62.98	19.195	41.00	12.50	--	--	--	
	14:28:00	1500	--	--	62.98	19.195	41.00	12.50	--	19.6	311	Raining Heavily
	16:08:00	1600	--	--	62.94	19.183	40.96	12.48	--	19.7	312	
	17:48:00	1700	--	--	62.95	19.185	40.96	12.49	--	--	--	
	19:28:00	1800	--	--	62.95	19.187	40.97	12.49	--	19.7	312	
	21:08:00	1900	--	--	62.97	19.192	40.99	12.49	--	19.7	312	
	22:48:00	2000	--	--	62.99	19.197	41.00	12.50	--	19.7	312	

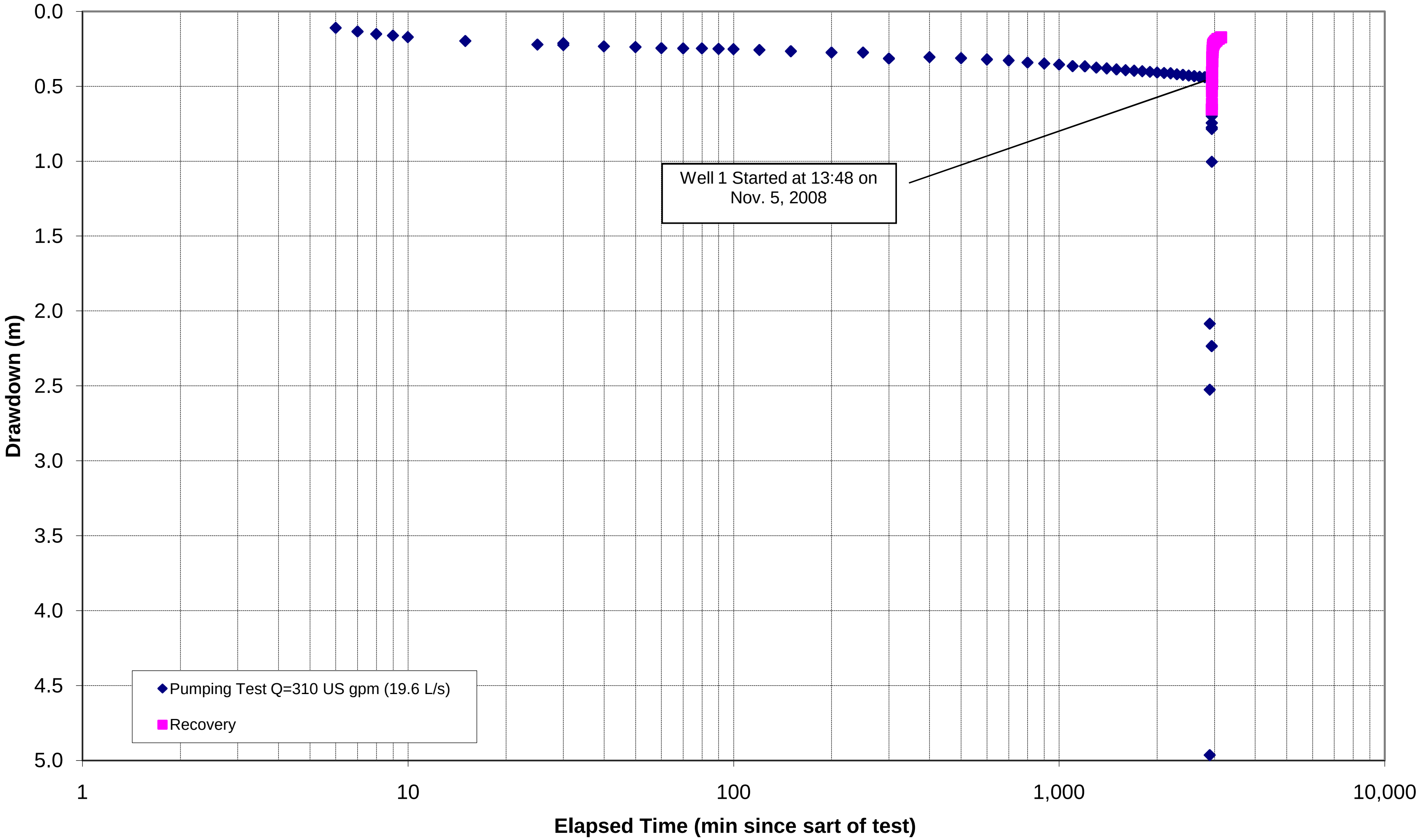
Date	Clock Time	Time since pump started, t (minutes)	Time since pump stopped, t' (minutes)	49-Hour Constant Rate Test of VOM Production Well No. 2 Montrose, BC- November 3-5, 2008								
				t/t'	Water Level (ft btoc)	Water Level (m btoc)	Draw-down (ft)	Draw-down (m)	Residual Drawdown (s' in ft)	Pumping Rate (L/s)	Pumping Rate (USgpm)	Water Quality Field Parameters
5-Nov-08	0:28:00	2100	--	--	63.00	19.201	41.02	12.50	--	--	--	
	2:08:00	2200	--	--	63.02	19.207	41.04	12.51	--	19.7	312	
	3:48:00	2300	--	--	63.05	19.216	41.06	12.52	--	--	--	
	5:28:00	2400	--	--	63.05	19.216	41.06	12.52	--	19.7	312	
	7:08:00	2500	--	--	63.05	19.218	41.07	12.52	--	--	--	
	8:48:00	2600	--	--	63.09	19.230	41.11	12.53	--	19.7	312	at approx. 9:30, flow rate increase at Well 2 for about 15
	10:28:00	2700	--	--	63.04	19.213	41.06	12.51	--	--		minutes.
	12:08:00	2800	--	--	63.14	19.244	41.16	12.54	--	--		hole in the valve of Well 2
	13:31:00	2883	--	--	63.19	19.260	41.21	12.56	--	--		pH=6.51, T=8.0oC, cond=190.2 uS/cm, TDS=95.2 ppm
	13:46:00	2898	--	--	63.19	19.260	41.21	12.56	--	--		
	13:48:00	2900	--	--	63.81	19.447	41.82	12.75	--	--		Start of Well 1
	14:06:00	2918	--	--	63.83	19.453	41.84	12.75	--	--		Hole in the valve of Well 2 getting bigger. Can not sustain
	14:08:00	2920	--	--	63.83	19.455	41.85	12.76	--	18.1	287.0	the constant rate. Risk for the valve to explode.
	14:28:00	2940	0.0	--	60.02	18.292	38.03	11.59	50.06	--	--	Start of recovery data
	14:28:30	2940.5	0.5	5,881	56.79	17.310	34.81	10.61	46.83	--	--	
	14:29:00	2941.0	1.0	2,941	40.42	12.320	18.44	5.62	30.46	--	--	
	14:29:30	2941.5	1.5	1,961	34.32	10.460	12.34	3.76	24.36	--	--	
	14:30:00	2942.0	2.0	1,471	30.42	9.272	8.44	2.57	20.46	--	--	
	14:30:30	2942.5	2.5	1,177	27.94	8.516	5.96	1.82	17.98	--	--	
	14:31:00	2943.0	3.0	981	26.64	8.118	4.65	1.42	16.68	--	--	
	14:31:30	2943.5	3.5	841	25.78	7.858	3.80	1.16	15.82	--	--	
	14:32:00	2944.0	4.0	736	25.16	7.668	3.18	0.97	15.20	--	--	
	14:32:30	2944.5	4.5	654	24.88	7.584	2.90	0.88	14.92	--	--	
	14:33:00	2945	5	589	24.61	7.500	2.62	0.80	14.65	--	--	
	14:34:00	2946	6	491	24.15	7.362	2.17	0.66	14.19	--	--	
	14:35:00	2947	7	421	23.95	7.300	1.97	0.60	13.99	--	--	
	14:36:00	2948	8	369	23.77	7.246	1.79	0.55	13.81	--	--	
	14:37:00	2949	9	328	23.65	7.209	1.67	0.51	13.69	--	--	
	14:38:00	2950	10	295	23.55	7.178	1.57	0.48	13.59	--	--	
	14:40:00	2952	12	246	23.41	7.135	1.43	0.44	13.45	--	--	
	14:42:00	2954	14	211	23.36	7.120	1.38	0.42	13.40	--	--	
	14:44:00	2956	16	185	23.23	7.081	1.25	0.38	13.27	--	--	
	14:46:00	2958	18	164	23.18	7.066	1.20	0.37	13.22	--	--	
	14:48:00	2960	20	148	23.14	7.052	1.15	0.35	13.18	--	--	
	14:53:00	2965	25	119	23.08	7.033	1.09	0.33	13.12	--	--	
	14:58:00	2970	30	99	23.03	7.018	1.04	0.32	13.07	--	--	
	15:03:00	2975	35	85	22.96	6.997	0.97	0.30	13.00	--	--	
	15:08:00	2980	40	75	22.87	6.970	0.89	0.27	12.91	--	--	
	15:18:00	2990	50	60	22.92	6.985	0.94	0.29	12.96	--	--	
	15:28:00	3000	60	50	22.89	6.977	0.91	0.28	12.93	--	--	
	15:38:00	3010	70	43	22.86	6.967	0.88	0.27	12.90	--	--	
	15:48:00	3020	80	38	22.84	6.962	0.86	0.26	12.88	--	--	
	15:58:00	3030	90	34	22.82	6.955	0.84	0.26	12.86	--	--	
	16:08:00	3040	100	30	22.81	6.952	0.83	0.25	12.85	--	--	
	16:28:00	3060	120	26	22.79	6.945	0.80	0.25	12.83	--	--	
	16:58:00	3090	150	21	22.75	6.935	0.77	0.23	12.79	--	--	
	17:48:00	3140	200	16	22.71	6.922	0.73	0.22	12.75	--	--	

Date	Clock Time	Time since pump started, t (minutes)	Time since pump stopped, t' (minutes)	48-Hour Constant Rate Test of VOM Production Well 2 Montrose, BC- November 3-5, 2008 - Observation Well 1								
				t/t'	Water Level (ft btoc)	Water Level (m btoc)	Draw-down (ft)	Draw-down (m)	Residual Drawdown (s' in ft)	Pumping Rate (L/s)	Pumping Rate (USgpm)	Water Quality Field Parameters
3-Nov-08	13:28:00	0.0	--	--	34.83	10.615	0.00	0.00	--	--	--	
	13:28:30	0.5	--	--					--	--	--	
	13:29:00	1.0	--	--					--	--	--	
	13:29:30	1.5	--	--					--	--	--	
	13:30:00	2.0	--	--					--	--	--	
	13:30:30	2.5	--	--					--	--	--	
	13:31:00	3.0	--	--					--	--	--	
	13:31:30	3.5	--	--					--	--	--	
	13:32:00	4.0	--	--					--	--	--	
	13:32:30	4.5	--	--					--	--	--	
	13:33:00	5	--	--					--	--	--	
	13:34:00	6	--	--	35.19	10.725	0.36	0.11	--	--	--	
	13:35:00	7	--	--	35.27	10.750	0.44	0.14	--	--	--	
	13:36:00	8	--	--	35.32	10.766	0.50	0.15	--	--	--	
	13:37:00	9	--	--	35.36	10.777	0.53	0.16	--	--	--	
	13:38:00	10	--	--	35.39	10.787	0.56	0.17	--	--	--	
	13:43:00	15	--	--	35.48	10.813	0.65	0.20	--	--	--	
	13:58:00	30	--	--	35.53	10.828	0.70	0.21	--	--	--	
	13:53:00	25	--	--	35.55	10.836	0.73	0.22	--	--	--	
	13:58:00	30	--	--	35.57	10.840	0.74	0.23	--	--	--	
	14:08:00	40	--	--	35.59	10.848	0.76	0.23	--	--	--	
	14:18:00	50	--	--	35.61	10.853	0.78	0.24	--	--	--	
	14:28:00	60	--	--	35.63	10.860	0.80	0.24	--	--	--	
	14:38:00	70	--	--	35.64	10.862	0.81	0.25	--	--	--	
	14:48:00	80	--	--	35.64	10.862	0.81	0.25	--	--	--	
	14:58:00	90	--	--	35.65	10.865	0.82	0.25	--	--	--	
	15:08:00	100	--	--	35.65	10.867	0.83	0.25	--	--	--	
	15:28:00	120	--	--	35.67	10.872	0.84	0.26	--	--	--	
	15:58:00	150	--	--	35.70	10.881	0.87	0.27	--	--	--	
	16:48:00	200	--	--	35.73	10.890	0.90	0.28	--	--	--	
	17:38:00	250	--	--	35.73	10.890	0.90	0.28	--	--	--	
	18:28:00	300	--	--	35.86	10.930	1.03	0.32	--	--	--	
	20:08:00	400	--	--	35.83	10.920	1.00	0.31	--	--	--	
	21:48:00	500	--	--	35.85	10.927	1.02	0.31	--	--	--	
	23:28:00	600	--	--	35.88	10.936	1.05	0.32	--	--	--	

Date	Clock Time	Time since pump started, t (minutes)	Time since pump stopped, t' (minutes)	48-Hour Constant Rate Test of VOM Production Well 2 Montrose, BC- November 3-5, 2008 - Observation Well 1								
				t/t'	Water Level (ft btoc)	Water Level (m btoc)	Draw-down (ft)	Draw-down (m)	Residual Drawdown (s' in ft)	Pumping Rate (L/s)	Pumping Rate (USgpm)	Water Quality Field Parameters
4-Nov-08	1:08:00	700	--	--	35.90	10.943	1.08	0.33	--	--	--	
	2:48:00	800	--	--	35.95	10.956	1.12	0.34	--	--	--	
	4:28:00	900	--	--	35.97	10.963	1.14	0.35	--	--	--	
	6:08:00	1000	--	--	35.99	10.970	1.16	0.36	--	--	--	
	7:48:00	1100	--	--	36.03	10.980	1.20	0.37	--	--	--	
	9:28:00	1200	--	--	36.03	10.982	1.20	0.37	--	--	--	
	11:08:00	1300	--	--	36.06	10.991	1.23	0.38	--	--	--	
	12:48:00	1400	--	--	36.08	10.996	1.25	0.38	--	--	--	
	14:28:00	1500	--	--	36.10	11.003	1.27	0.39	--	--	--	
	16:08:00	1600	--	--	36.12	11.008	1.29	0.39	--	--	--	
	17:48:00	1700	--	--	36.13	11.011	1.30	0.40	--	--	--	
	19:28:00	1800	--	--	36.14	11.015	1.31	0.40	--	--	--	
	21:08:00	1900	--	--	36.15	11.019	1.33	0.40	--	--	--	
	22:48:00	2000	--	--	36.17	11.023	1.34	0.41	--	--	--	
5-Nov-08	0:28:00	2100	--	--	36.18	11.026	1.35	0.41	--	--	--	
	2:08:00	2200	--	--	36.18	11.028	1.36	0.41	--	--	--	
	3:48:00	2300	--	--	36.21	11.035	1.38	0.42	--	--	--	
	5:28:00	2400	--	--	36.22	11.039	1.39	0.42	--	--	--	
	7:08:00	2500	--	--	36.24	11.044	1.41	0.43	--	--	--	
	8:48:00	2600	--	--	36.25	11.048	1.42	0.43	--	--	--	
	10:28:00	2700	--	--	36.26	11.052	1.43	0.44	--	--	--	
	12:08:00	2800	--	--	36.27	11.054	1.44	0.44	--	--	--	
	13:48:00	2900	--	--	36.28	11.058	1.45	0.44	--	--	--	
	13:48:30	2900.5	--	--	43.11	13.140	8.28	2.53	--	--	--	Start of Well 1
	13:49:00	2901.0	--	--	41.67	12.700	6.84	2.09	--	--	--	
	13:49:30	2901.5	--	--	51.12	15.580	16.29	4.97	--	--	--	
	13:50:00	2902.0	--	--	56.24	17.140	21.41	6.53	--	--	--	
	13:50:30	2902.5	--	--	59.06	18.000	24.23	7.39	--	--	--	
	13:51:00	2903.0	--	--	59.52	18.140	24.69	7.53	--	--	--	
	13:51:30	2903.5	--	--	60.34	18.390	25.51	7.78	--	--	--	
	13:52:00	2904.0	--	--	60.67	18.490	25.84	7.88	--	--	--	
	13:52:30	2904.5	--	--	61.91	18.870	27.08	8.26	--	--	--	
	13:53:00	2905.0	--	--	65.36	19.920	30.53	9.31	--	--	--	
	13:54:00	2906.0	--	--	67.95	20.710	33.12	10.10	--	--	--	
	13:55:00	2907.0	--	--	68.77	20.960	33.94	10.35	--	--	--	
	13:56:00	2908.0	--	--	69.16	21.080	34.34	10.47	--	--	--	
	13:57:00	2909.0	--	--	70.90	21.610	36.07	11.00	--	--	--	
	13:58:00	2910.0	--	--	75.07	22.880	40.24	12.27	--	--	--	

Date	Clock Time	Time since pump started, t (minutes)	Time since pump stopped, t' (minutes)	48-Hour Constant Rate Test of VOM Production Well 2 Montrose, BC- November 3-5, 2008 - Observation Well 1								
				t/t'	Water Level (ft btoc)	Water Level (m btoc)	Draw-down (ft)	Draw-down (m)	Residual Drawdown (s' in ft)	Pumping Rate (L/s)	Pumping Rate (USgpm)	Water Quality Field Parameters
	14:00:00	2912.0	--	--	76.76	23.395	41.93	12.78	--	--	--	
	14:04:00	2916.0	--	--	77.17	23.520	42.34	12.91	--	--	--	
	14:06:00	2918.0	--	--	77.27	23.550	42.44	12.94	--	--	--	
	14:08:00	2920.0	--	--	77.30	23.560	42.47	12.95	--	--	--	
	14:16:00	2928.0	--	--	77.30	23.560	42.47	12.95	--	--	--	
	14:18:00	2930.0	--	--	77.20	23.530	42.37	12.92	--	--	--	
	14:24:30	2936.5	--	--	77.30	23.560	42.47	12.95	--	--	--	
	14:28:00	2940	0.0	--	77.30	23.560	42.47	12.95	69.65	--	--	Start of recovery data
	14:28:30	2940.5	0.5	5,881	73.43	22.380	38.60	11.77	65.78	--	--	
	14:29:00	2941.0	1.0	2,941	51.84	15.800	17.01	5.19	44.19	--	--	
	14:29:30	2941.5	1.5	1,961	42.16	12.850	7.33	2.24	34.51	--	--	
	14:30:00	2942.0	2.0	1,471	38.13	11.620	3.30	1.01	30.48	--	--	
	14:30:30	2942.5	2.5	1,177	37.37	11.390	2.54	0.78	29.72	--	--	
	14:31:00	2943.0	3.0	981	37.40	11.400	2.58	0.79	29.75	--	--	
	14:31:30	2943.5	3.5	841	37.27	11.360	2.44	0.74	29.62	--	--	
	14:32:00	2944.0	4.0	736	37.12	11.315	2.30	0.70	29.47	--	--	
	14:32:30	2944.5	4.5	654	36.98	11.270	2.15	0.65	29.33	--	--	
	14:33:00	2945	5	589	36.85	11.230	2.02	0.62	29.20	--	--	
	14:34:00	2946	6	491	36.58	11.150	1.76	0.54	28.93	--	--	
	14:35:00	2947	7	421	36.42	11.100	1.59	0.48	28.77	--	--	
	14:36:00	2948	8	369	36.29	11.060	1.46	0.45	28.64	--	--	
	14:37:00	2949	9	328	36.16	11.020	1.33	0.40	28.51	--	--	
	14:38:00	2950	10	295	36.06	10.990	1.23	0.38	28.41	--	--	
	14:40:00	2952	12	246	35.93	10.950	1.10	0.33	28.28	--	--	
	14:42:00	2954	14	211	35.83	10.920	1.00	0.31	28.18	--	--	
	14:44:00	2956	16	185	35.76	10.900	0.94	0.29	28.11	--	--	
	14:46:00	2958	18	164	35.73	10.890	0.90	0.28	28.08	--	--	
	14:48:00	2960	20	148	35.68	10.875	0.85	0.26	28.03	--	--	
	14:54:00	2966	26	114	35.62	10.855	0.79	0.24	27.97	--	--	
	14:58:00	2970	30	99	35.57	10.840	0.74	0.23	27.92	--	--	
	15:03:00	2975	35	85	35.55	10.836	0.73	0.22	27.90	--	--	
	15:08:00	2980	40	75	35.54	10.831	0.71	0.22	27.89	--	--	
	15:18:00	2990	50	60	35.52	10.825	0.69	0.21	27.87	--	--	
	15:28:00	3000	60	50	35.51	10.822	0.68	0.21	27.86	--	--	
	15:38:00	3010	70	43	35.49	10.818	0.67	0.20	27.84	--	--	
	15:48:00	3020	80	38	35.48	10.815	0.66	0.20	27.83	--	--	
	15:58:00	3030	90	34	35.47	10.810	0.64	0.20	27.82	--	--	
	16:08:00	3040	100	30	35.47	10.810	0.64	0.20	27.82	--	--	
	16:28:00	3060	120	26	35.44	10.801	0.61	0.19	27.79	--	--	
	16:58:00	3090	150	21	35.43	10.798	0.60	0.18	27.78	--	--	
	17:48:00	3140	200	16	35.40	10.788	0.57	0.17	27.75	--	--	

48 Hour Constant Rate Test, VOM Well 2 (Observation Well 1) November 3-5, 2008



Observation Well TW-1 During Hydraulic Testing of VOM Well 2, November 3-5, 2008					
Date	Time	Water Level (ft)	Water Level (m)	Drawdown (m)	Comments
3-Nov-08	10:15:00	31.50	9.600	--	Before starting test. Static water level
3-Nov-08	12:11:00	31.48	9.595	0.00	
4-Nov-08	12:03:00	32.55	9.920	0.32	
5-Nov-08	12:16:00	32.74	9.980	0.38	
7-Nov-08	12:25:00	31.60	9.630	0.03	End of recovery

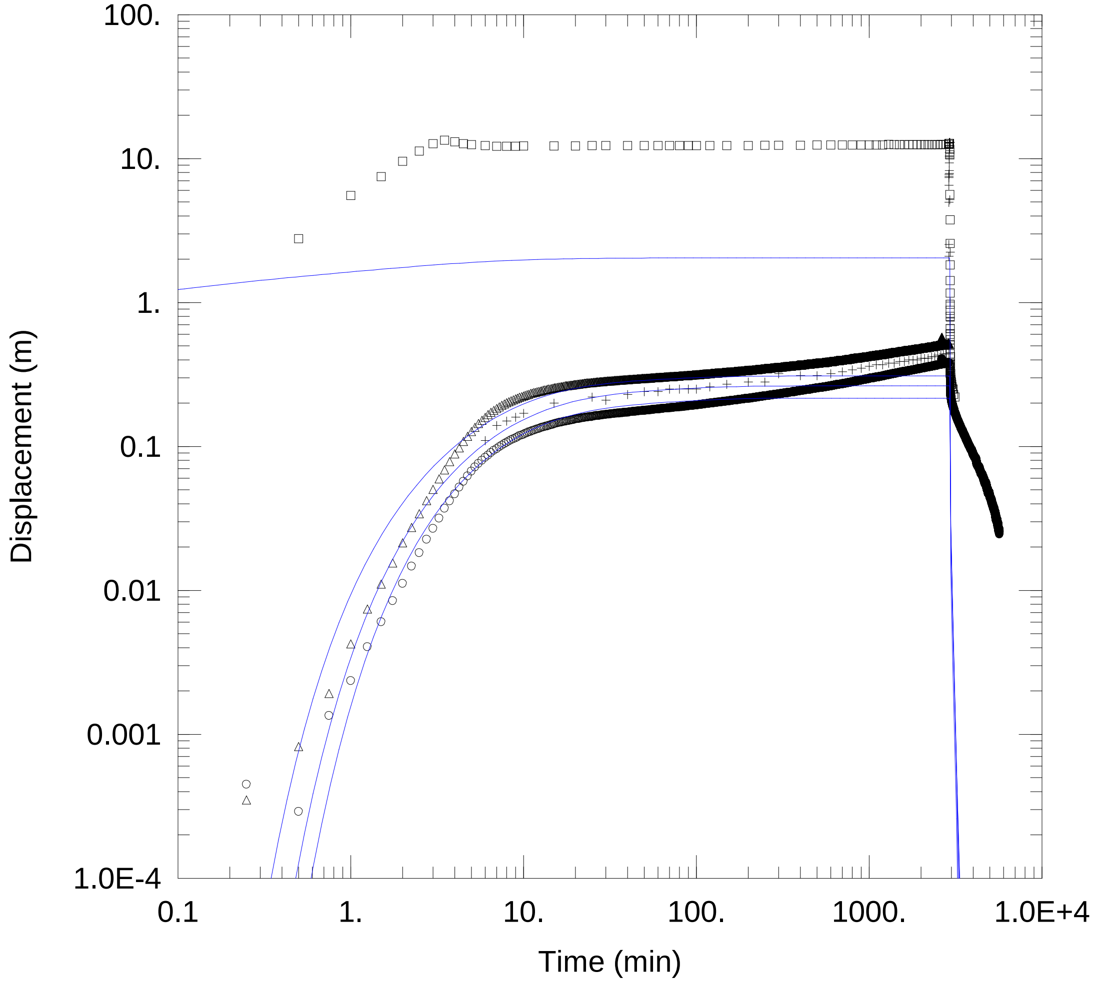
Observation Well TW-2 During Hydraulic Testing of VOM Well 2, November 3-5, 2008					
Date	Time	Water Level (ft)	Water Level (m)	Drawdown (m)	Comments
3-Nov-08	10:19:00	32.43	9.883	--	Before starting test. Static water level
3-Nov-08	12:12:00	32.41	9.878	0.00	
4-Nov-08	12:06:00	33.36	10.168	0.29	
5-Nov-08	12:22:00	33.55	10.225	0.34	
7-Nov-08	12:09:00	32.57	9.928	0.05	

Observation Well TW-3 During Hydraulic Testing of VOM Well 2, November 3-5, 2008					
Date	Time	Water Level (ft)	Water Level (m)	Drawdown (m)	Comments
3-Nov-08	10:21:00	33.84	10.313	--	Before starting test. Static water level
3-Nov-08	12:06:00	33.83	10.310	0.00	
4-Nov-08	12:08:00	35.31	10.763	0.45	
5-Nov-08	12:25:00	35.53	10.830	0.52	
7-Nov-08	12:18:00	33.93	10.342	0.03	End of Recovery

Beaver Creek Piezometer Measurements During Hydraulic Testing of VOM Well 2, November 3-5, 2008					
Date	Time	Water Level (ft)	Water Level (m)	Change in Water Level (m)	Comments
3-Nov-08	11:48:00	-0.10	-0.03	--	Before starting test.
4-Nov-08	11:50:00	-0.10	-0.03	0.00	pH=8.31, T=5.6oC, cond=247 uS/cm, TDS=124 ppm
5-Nov-08	13:18:00	-0.05	-0.015	0.015	pH=7.77 - 8.12, T=5.9oC, cond=233 uS/cm, TDS=117 ppm
7-Nov-08	12:46:00	-0.08	-0.025	-0.010	

APPENDIX III

AQTESOLV Type Curves and Output Files



PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22
△ TW3	33	23
○ TW1	51.4	10.7

SOLUTION

Aquifer Model: Confined

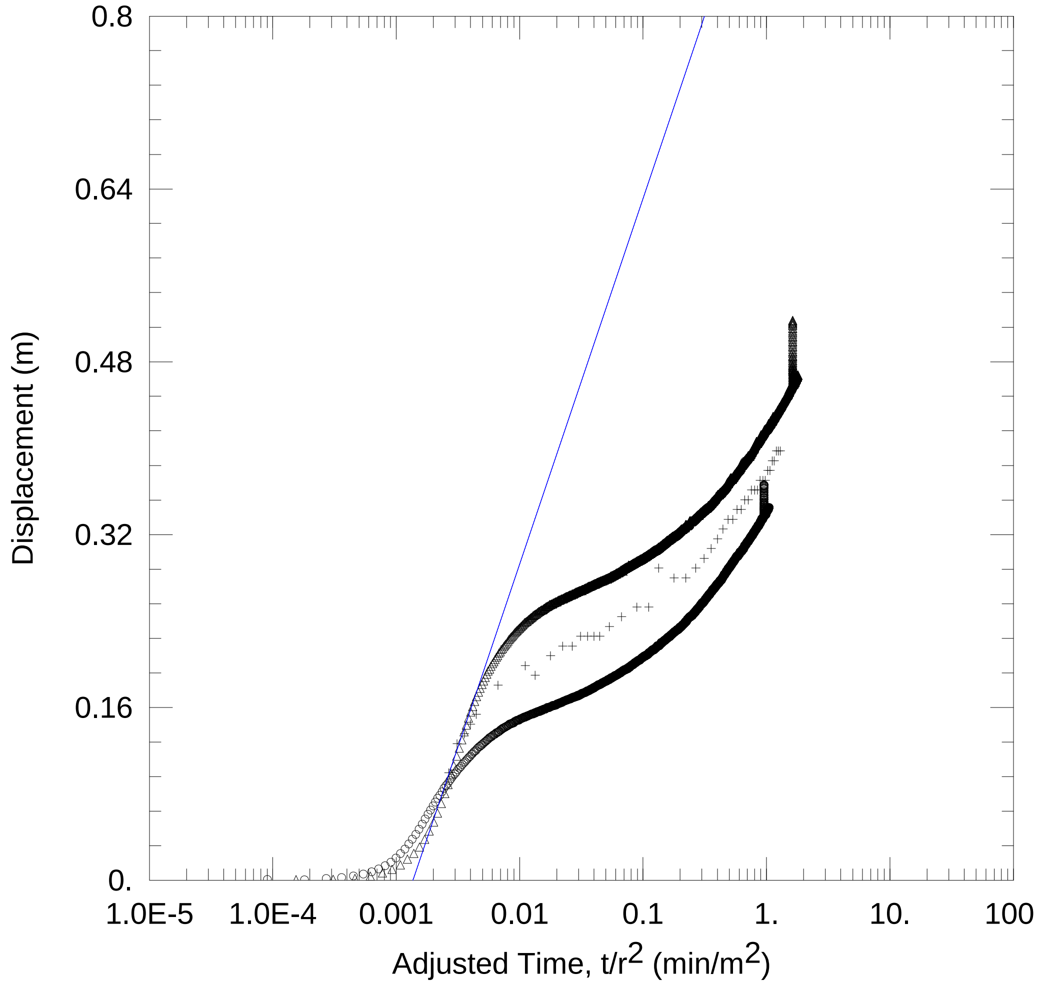
Solution Method: Theis

T = 769.6 m^2/day

S = 0.002557

Kz/Kr = 1.

b = 9.1 m



PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

AQUIFER DATA

Saturated Thickness: 9.1 m

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22
△ TW3	33	23
○ TW1	51.4	10.7

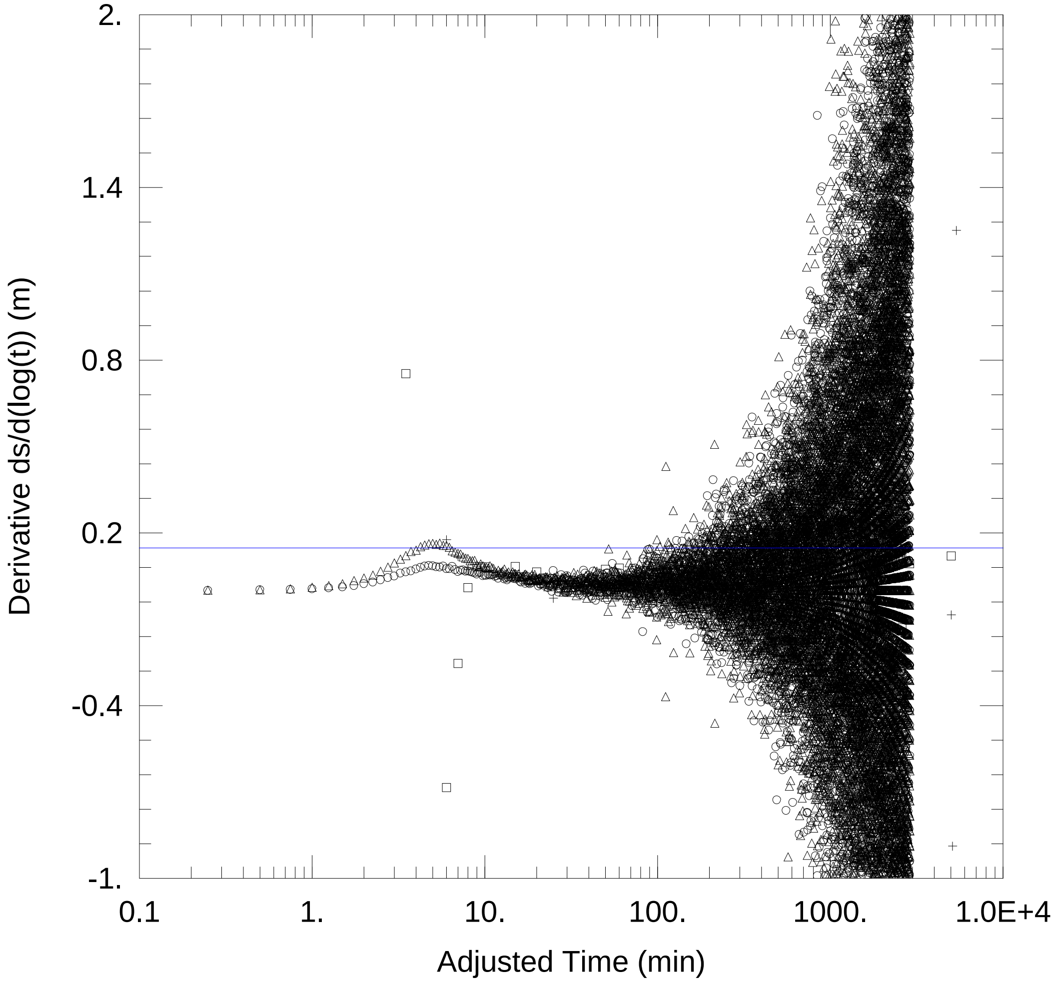
SOLUTION

Aquifer Model: Confined

Solution Method: Cooper-Jacob

T = 825.8 m^2/day

S = 0.001757



PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

AQUIFER DATA

Saturated Thickness: 9.1 m

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22
△ TW3	33	23
○ TW1	51.4	10.7

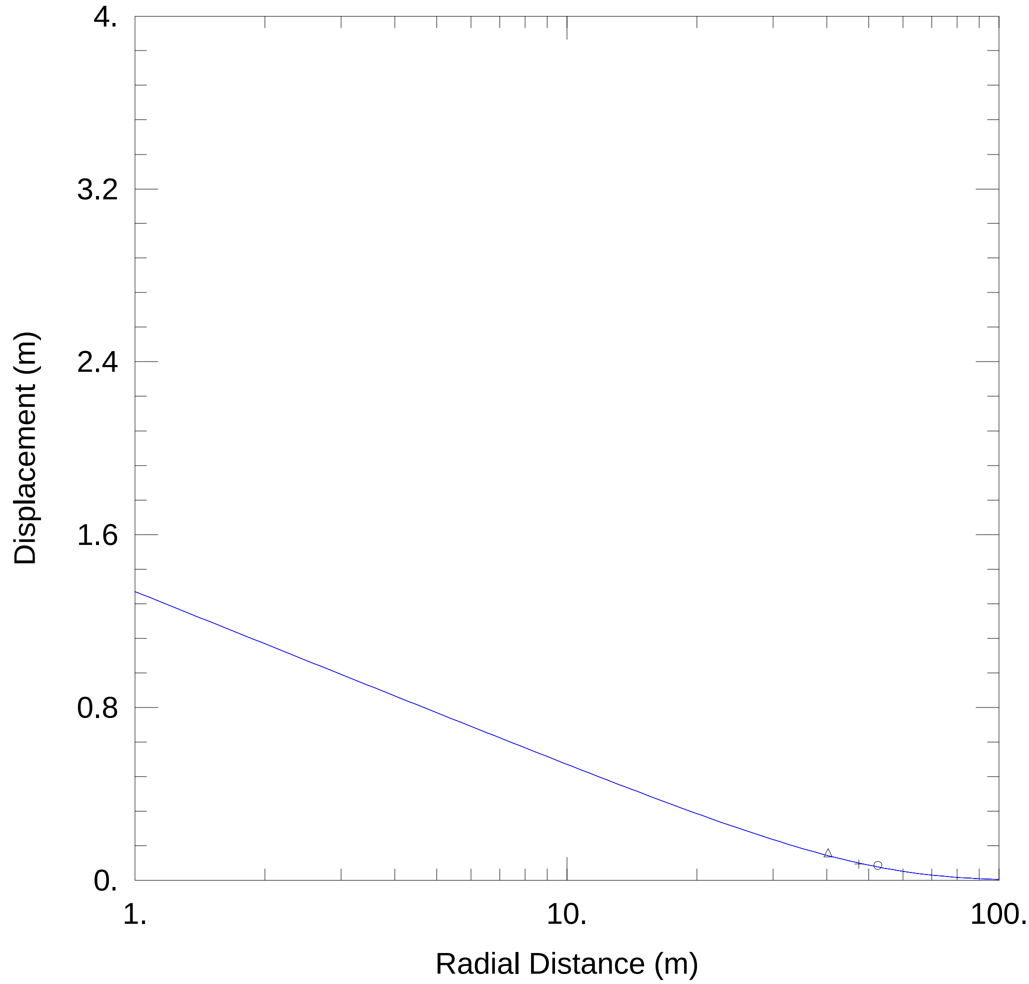
SOLUTION

Aquifer Model: Confined

Solution Method: Cooper-Jacob

T = 825.8 m^2/day

S = 0.001757



WELL TEST ANALYSIS

Data Set: N:\...\VOM Distance Drawdown.aqt
Date: 05/28/09 Time: 14:12:08

PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

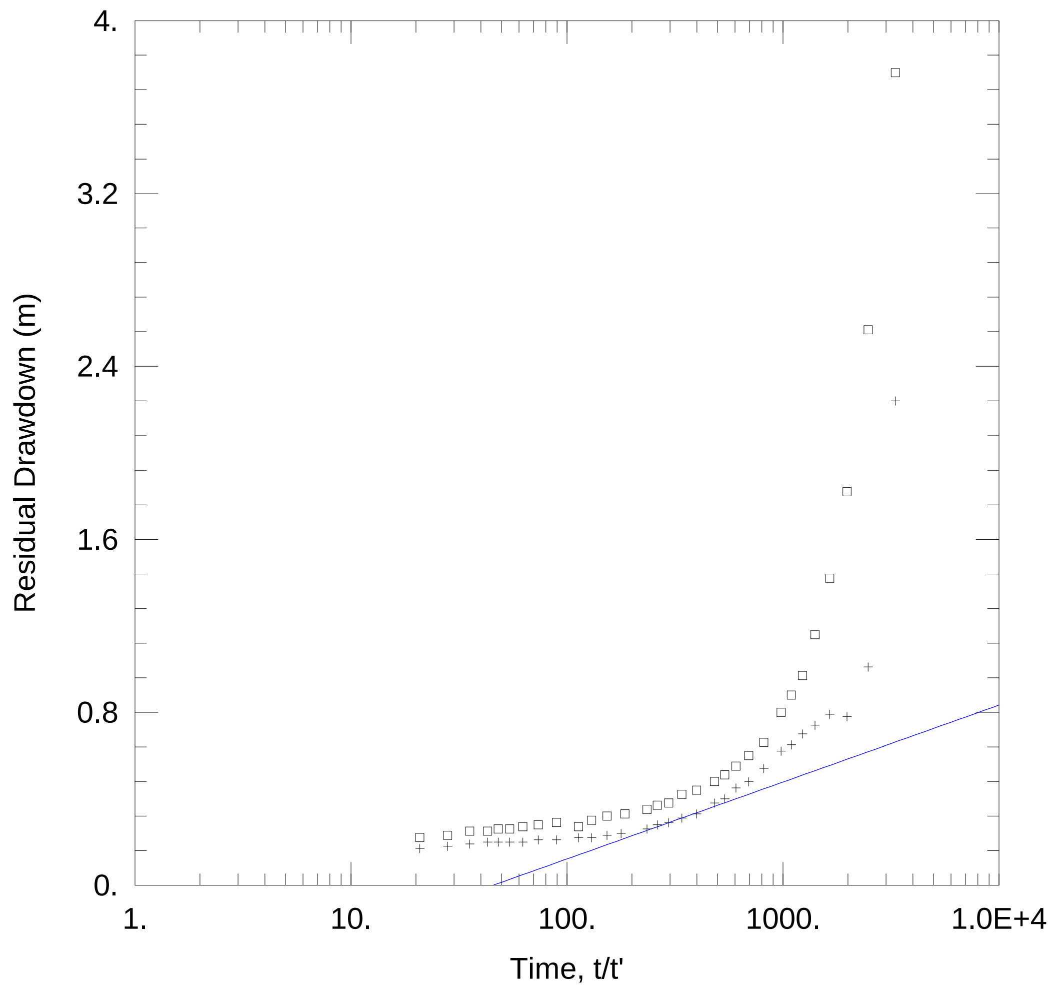
Observation Wells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22
△ TW3	33	23
○ TW1	51.4	10.7

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 770. m^2/day
Kz/Kr = 1.
S = 0.002859
b = 9.1 m



PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

AQUIFER DATA

Saturated Thickness: 9.1 m

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22

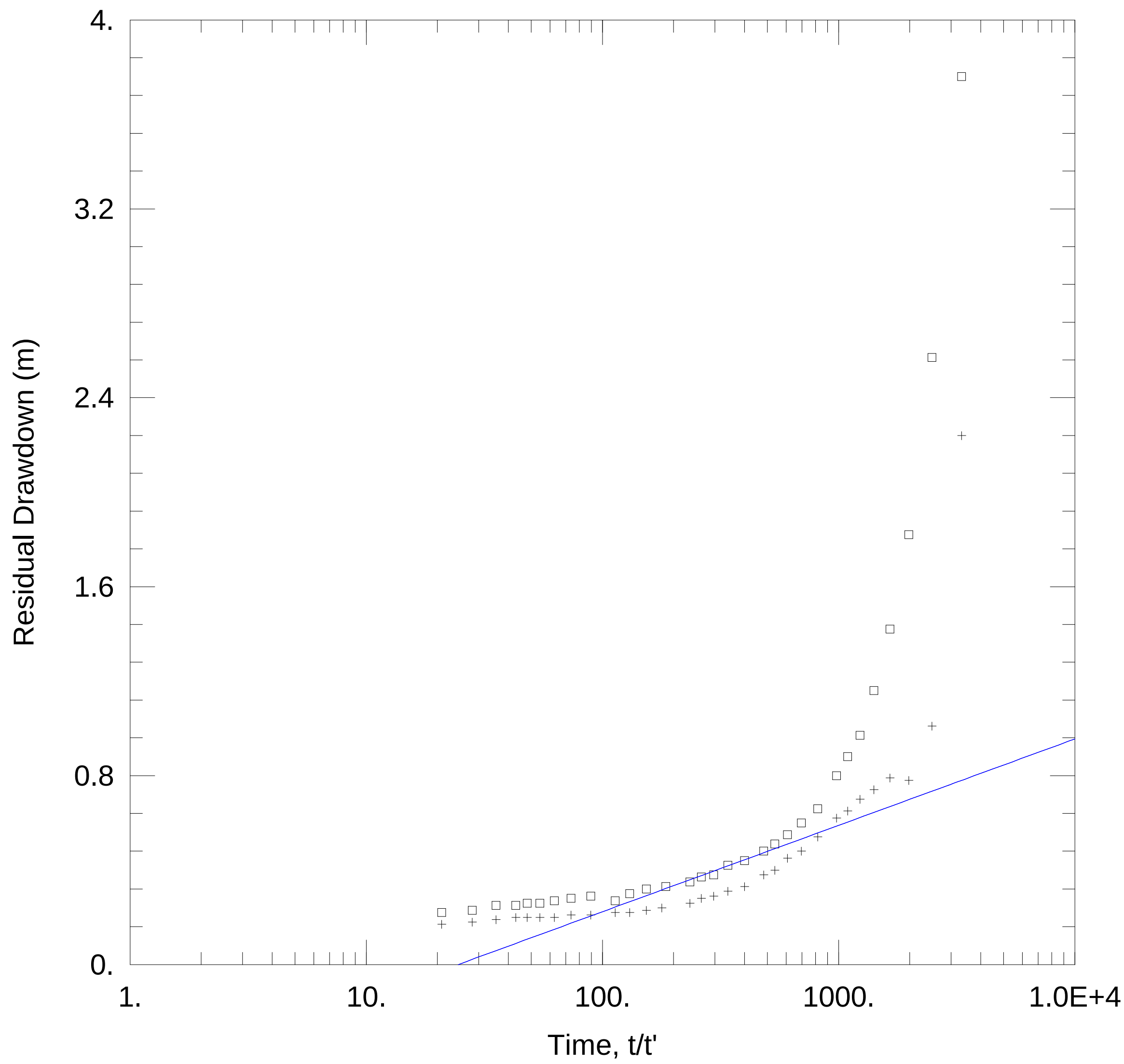
SOLUTION

Aquifer Model: Confined

Solution Method: Theis (Recovery)

T = 786.2 m^2/day

S/S' = 45.67



PROJECT INFORMATION

Company: Golder Associates Ltd
Client: Village of Montrose
Project: 08-1480-0028
Location: Montrose, BC
Test Well: Well 2
Test Date: November 3-5, 2008

AQUIFER DATA

Saturated Thickness: 9.1 m

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Well 2	0	0

Observation Waells

Well Name	X (m)	Y (m)
□ Well 2	0	0
+ Well 1	42	22
△ TW3	33	23
○ TW1	51.4	10.7

SOLUTION

Aquifer Model: Confined

Solution Method: Theis (Recovery)

T = 764.6 m^2/day

S/S' = 24.54

APPENDIX IV

Analytical Solutions

Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.1

Given

Parameter Description	*Symbol*	*Value*	*Unit*	Assumptions
Pumping rate	Q	0.0023	m^3/s	aquifer of inifinite areal extent
Time-of-Travel Zone Required (100 d)	T	8640000	s	aquifer of constant uniform thickness
Ambient groundwater flow rate (Qo =kHi)	Qo	7.28E-05	m^2/s per unit width of aquifer	constant effective porosity
regional gradient	i	0.008	-	constant isotropic hydraulic conductivity
hydraulic conductivity	k	1.00E-03	m/s	steady state conditions
aquifer thickness	H	9.1	m	
porosity	n	0.25	-	

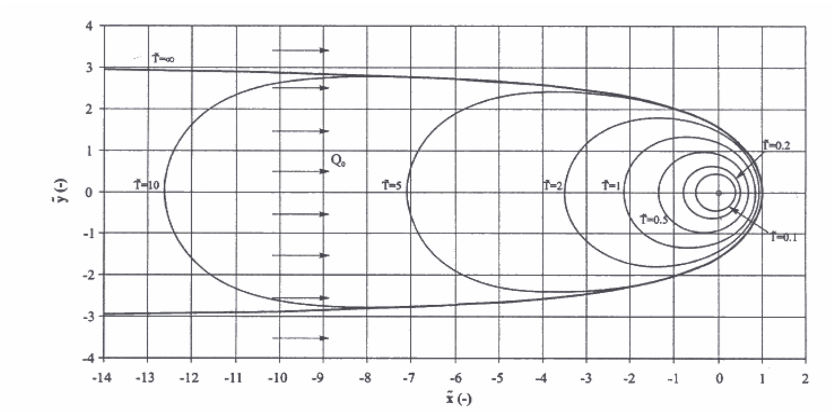
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \text{ or } \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 54.99 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 60.87 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \text{ or } \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s(0.00278 + 0.652\,T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls = 5.03 m		
Approximate fixed-radius capture zone	R = 26.02 m	R*=	5.18
Amount of upgradient shift of the circle centre	δ = 180.28 m	δ*=	35.85

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy \;/\, Q\right)}$$

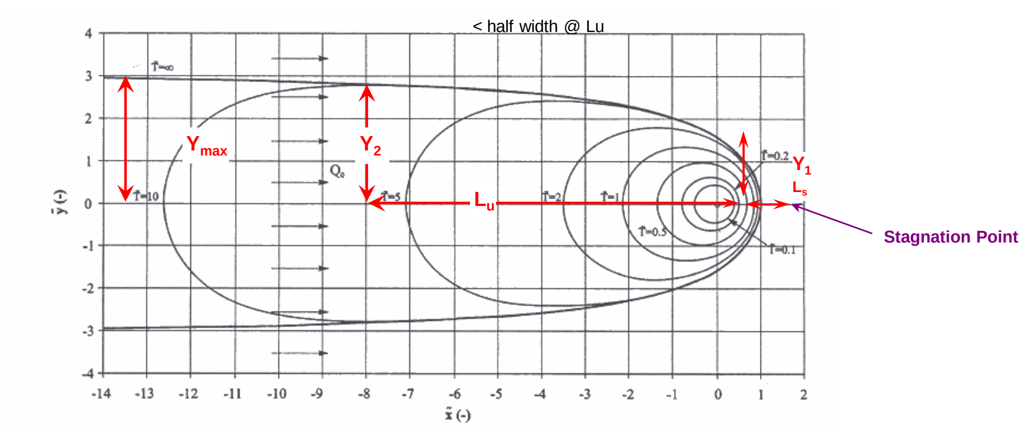
Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993) where tan(y) in radians

	Lu* =	59.04	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	296.87	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	5.03	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	7.90	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	15.80	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	0.79	x =	4.99	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	3.95	x =	3.95	m	
50% Y_{max}, or	y=	7.90	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	9.48	x =	-3.08	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	11.06	x =	-8.03	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	11.85	x =	-11.85	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	12.64	x =	-17.39	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	13.43	x =	-26.35	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	14.22	x =	-43.76	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	15.01	x =	-94.75	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

98.35% Y_{max}, or	Y_2=	15.54	x =	-299.45	m	< where -x ≈ Lu



01/09/2009

Approximate Time-of-Travel Capture Zones

Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.1

<u>Given</u>

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	0.0023	m^3/s
Time-of-Travel Zone Required (1 year)	T	31536000	s
Ambient groundwater flow rate (Qo =kHi)	Qo	7.28E-05	m^2/s per unit width of aquifer
regional gradient	i	0.008	-
hydraulic conductivity	k	1.00E-03	m/s
aquifer thickness	H	9.1	m
porosity	n	0.25	-

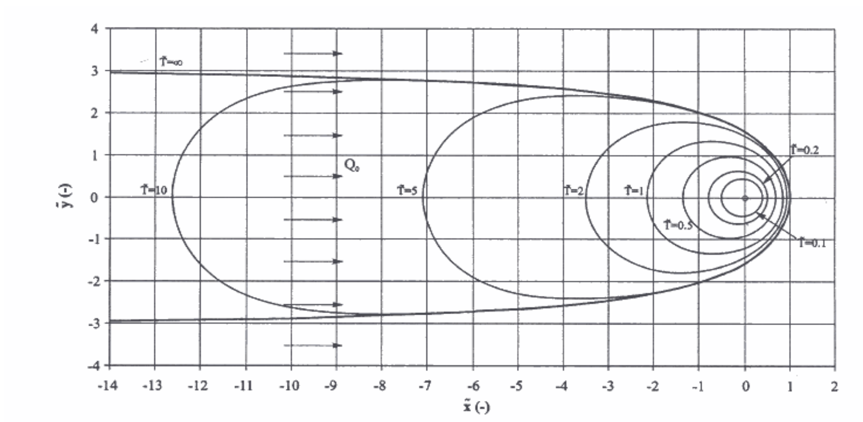
<u>Assumptions</u>
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

<u>Solution</u>

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \; or \; \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 200.70 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

<u>Solution</u>

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 116.28 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

<u>Solution</u>

$$L_s = \frac{Q}{2\pi Q_0} \; or \; \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln\left(0.39 + T^*\right)$$
$$R = R^* L_s$$
$$\delta = L_s\left(0.00278 + 0.652\, T^*\right)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	5.03	m
Approximate fixed-radius capture zone	R =	32.51	m
Amount of upgradient shift of the circle centre	δ =	657.98	m

R*= 6.46
δ*= 130.86

If T*>1, then calculate Boat-Shaped Capture Zone
(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan(2\pi kHiy / Q)}$$

Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993)
where tan(y) in radians

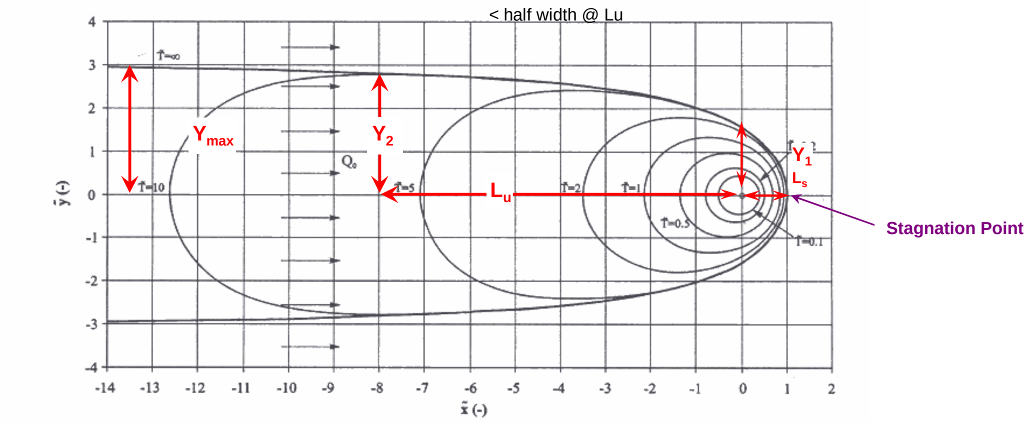
	Lu* =	206.01	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	1035.88	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	5.03	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	7.90	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	15.80	m	< symmetrical about the x-axis

5% Y_{max}, or	y= 0.79	x =	4.99	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y= 3.95	x =	3.95	m	
50% Y_{max}, or	y= 7.90	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y= 9.48	x =	-3.08	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y= 11.06	x =	-8.03	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y= 11.85	x =	-11.85	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y= 12.64	x =	-17.39	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y= 13.43	x =	-26.35	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y= 14.22	x =	-43.76	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y= 15.01	x =	-94.75	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

99.53% Y_{max}, or	Y_2= 15.72	x =	-1064.73	m	< where -x ≈ Lu

< half width @ Lu



Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.1

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	**0.0023**	m^3/s
Time-of-Travel Zone Required (100 d)	T	**8640000**	s
Ambient groundwater flow rate (Qo =kHi)	Qo	1.46E-05	m^2/s per unit width of aquifer
regional gradient	i	**0.008**	-
hydraulic conductivity	k	**2.00E-04**	m/s
aquifer thickness	H	**9.1**	m
porosity	n	**0.25**	-

Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

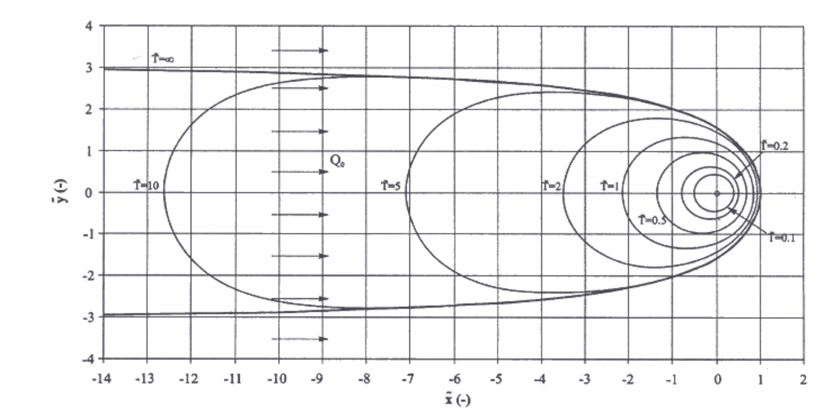
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \text{ or } \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 2.20 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 60.87 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \text{ or } \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s(0.00278 + 0.652\,T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	25.14 m		
Approximate fixed-radius capture zone	R =	53.11 m		R*=	2.11
Amount of upgradient shift of the circle centre	δ =	36.12 m		δ*=	1.44

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy / Q\right)}$$

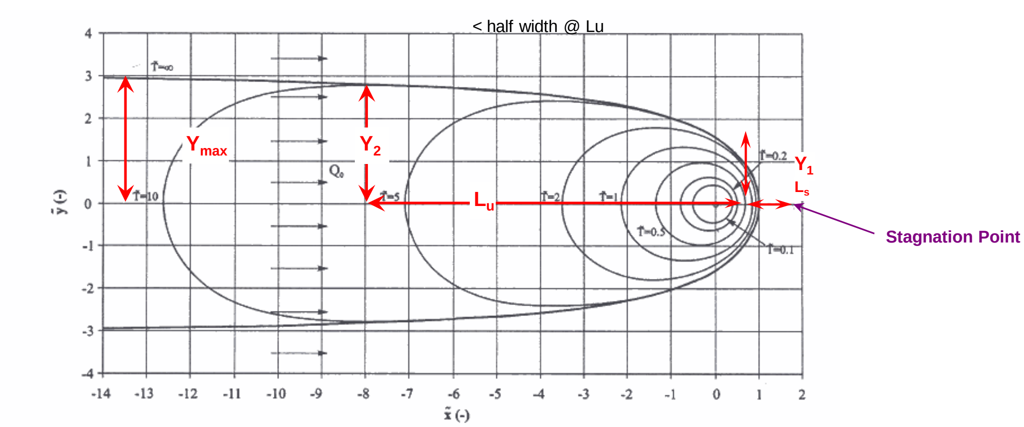
Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993)
where tan(y) in radians

	Lu* =	3.79	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	95.34	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	25.14	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	39.49	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	78.98	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	3.95	x =	24.93	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	19.75	x =	19.75	m	
50% Y_{max}, or	y=	39.49	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	47.39	x =	-15.40	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	55.29	x =	-40.17	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	59.24	x =	-59.24	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	63.19	x =	-86.97	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	67.14	x =	-131.76	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	71.09	x =	-218.78	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	75.03	x =	-473.75	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

81.00% Y_{max}, or	Y_2=	63.98	x =	-94.14	m	< where -x ≈ Lu



Approximate Time-of-Travel Capture Zones

Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.1

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	**0.0023**	m^3/s
Time-of-Travel Zone Required (1 year)	T	**31536000**	s
Ambient groundwater flow rate (Qo =kHi)	Qo	1.46E-05	m^2/s per unit width of aquifer
regional gradient	i	**0.008**	-
hydraulic conductivity	k	**2.00E-04**	m/s
aquifer thickness	H	**9.1**	m
porosity	n	**0.25**	-

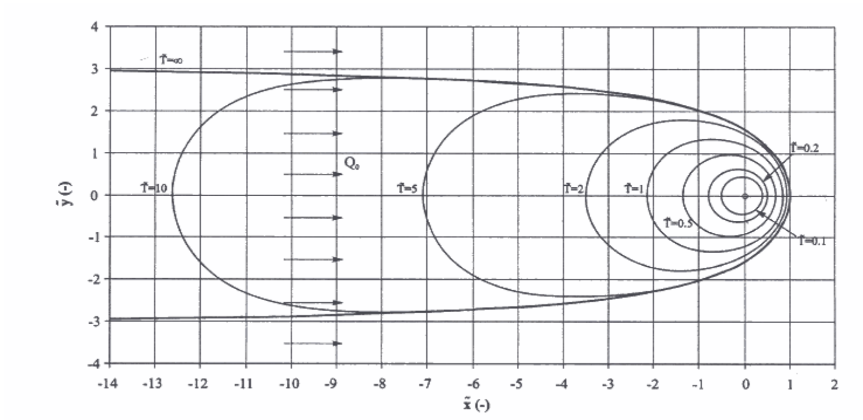
Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \; or \; \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 8.03 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543 \sqrt{\frac{QT}{\pi H n}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 116.28 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \; or \; \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s (0.00278 + 0.652\, T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	25.14	m		
Approximate fixed-radius capture zone	R =	82.75	m	R*=	3.29
Amount of upgradient shift of the circle centre	δ =	131.66	m	δ*=	5.24

If T*>1, then calculate Boat-Shaped Capture Zone
(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy / Q\right)}$$

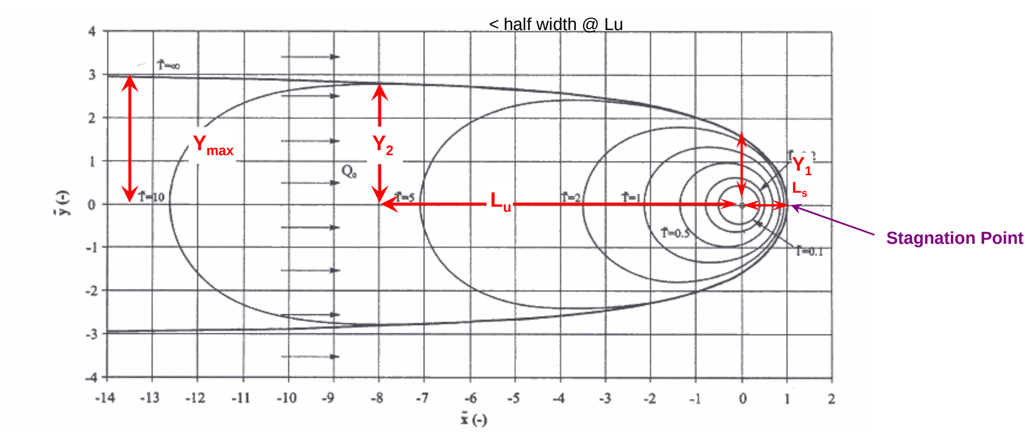
Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993)
where tan(y) in radians

	Lu* =	10.40	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	261.53	m	<WARNING, DOES NOT EQUATE TO X AT 99%Ymax
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	25.14	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	39.49	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	78.98	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	3.95	x =	24.93	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	19.75	x =	19.75	m	
50% Y_{max}, or	y=	39.49	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	47.39	x =	-15.40	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	55.29	x =	-40.17	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	59.24	x =	-59.24	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	63.19	x =	-86.97	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	67.14	x =	-131.76	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	71.09	x =	-218.78	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	75.03	x =	-473.75	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

91.50% Y_{max}, or	Y_2=	72.27	x =	-264.17	m	< where -x ≈ Lu



Approximate Time-of-Travel Capture Zones

Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.2

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	**0.004**	m^3/s
Time-of-Travel Zone Required (100 d)	T	**8640000**	s
Ambient groundwater flow rate (Qo =kHi)	Qo	7.28E-05	m^2/s per unit width of aquifer
regional gradient	i	**0.008**	-
hydraulic conductivity	k	**1.00E-03**	m/s
aquifer thickness	H	**9.1**	m
porosity	n	**0.25**	-

Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

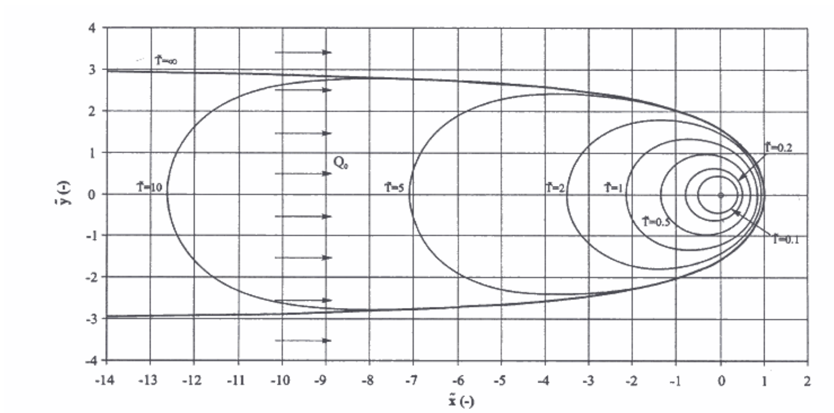
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \; or \; \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 31.62 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543 \sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 80.27 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \; or \; \frac{Q}{2\pi kHi}$$

$$R^* = 1.161 + \ln(0.39 + T^*)$$

$$R = R^* L_s$$

$$\delta = L_s(0.00278 + 0.652\, T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	8.74	m		
Approximate fixed-radius capture zone	R =	40.46	m	R*=	4.63
Amount of upgradient shift of the circle centre	δ =	180.29	m	δ*=	20.62

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$

$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy\ /Q\right)}$$

Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993) where tan(y) in radians

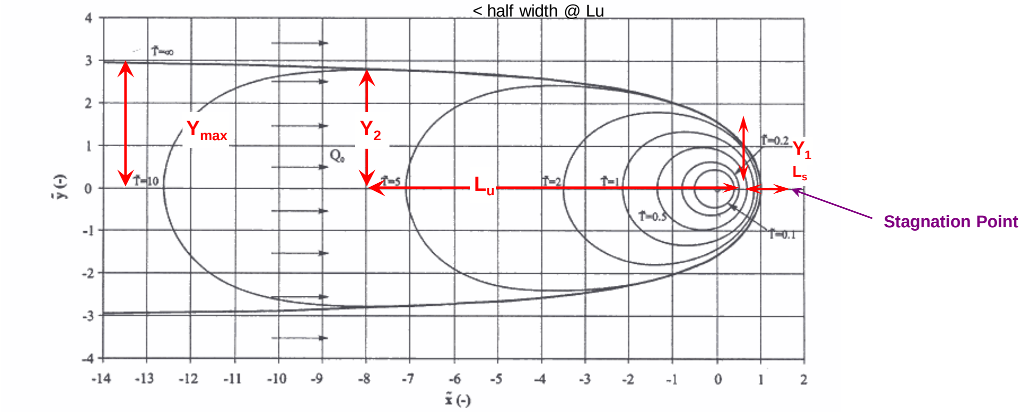
	Lu^* =	35.15	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	307.40	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	8.74	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	13.74	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	27.47	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	1.37	x =	8.67	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	6.87	x =	6.87	m	
50% Y_{max}, or	y=	13.74	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	16.48	x =	-5.36	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	19.23	x =	-13.97	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	20.60	x =	-20.60	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	21.98	x =	-30.25	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	23.35	x =	-45.83	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	24.73	x =	-76.10	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	26.10	x =	-164.78	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

97.25% Y_{max}, or	Y_2=	26.72	x =	-308.48	m	< where -x ≈ Lu

< half width @ Lu



Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: Calculate T* (dimensionless time of travel parameter)

Well no.2

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	0.004	m^3/s
Time-of-Travel Zone Required (1 year)	T	31536000	s
Ambient groundwater flow rate (Qo =kHi)	Qo	7.28E-05	m^2/s per unit width of aquifer
regional gradient	i	0.008	-
hydraulic conductivity	k	1.00E-03	m/s
aquifer thickness	H	9.1	m
porosity	n	0.25	-

Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

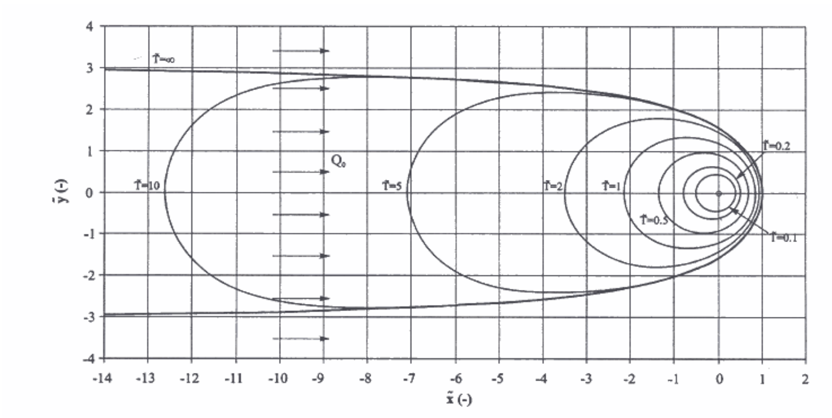
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \; or \; \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 115.40 -



Step 2: If T*<0.1, then calculate Centric Circular Capture Zone

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 153.35 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \; or \; \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s(0.00278 + 0.652\,T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	8.74	m		
Approximate fixed-radius capture zone	R =	51.71	m	R*=	5.91
Amount of upgradient shift of the circle centre	δ =	657.99	m	δ*=	75.24

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy / Q\right)}$$

Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993)
where tan(y) in radians

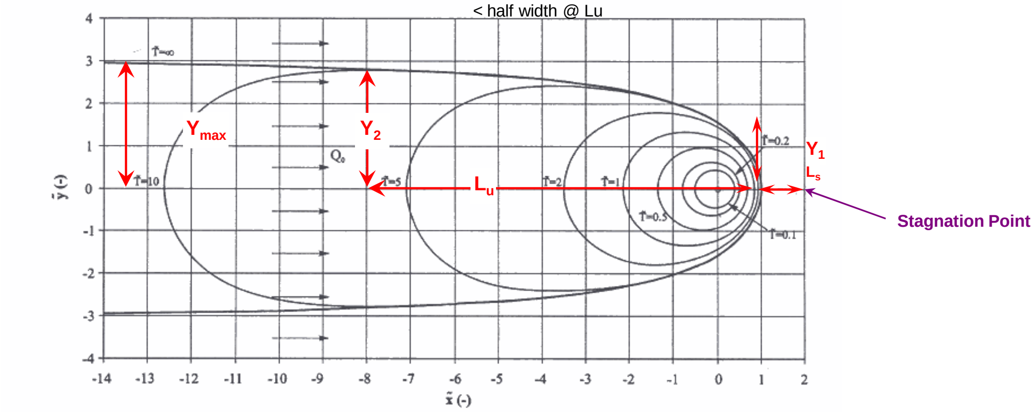
	Lu* =	120.17	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	1050.88	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	8.74	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	13.74	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	27.47	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	1.37	x =	8.67	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	6.87	x =	6.87	m	
50% Y_{max}, or	y=	13.74	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	16.48	x =	-5.36	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	19.23	x =	-13.97	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	20.60	x =	-20.60	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	21.98	x =	-30.25	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	23.35	x =	-45.83	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	24.73	x =	-76.10	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	26.10	x =	-164.78	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

99.17% Y_{max}, or	Y_2=	27.24	x =	-1044.61	m	< where -x ≈ Lu

< half width @ Lu



Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.2

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	0.004	m^3/s
Time-of-Travel Zone Required (100 d)	T	8640000	s
Ambient groundwater flow rate (Qo =kHi)	Qo	1.46E-05	m^2/s per unit width of aquifer
regional gradient	i	0.008	-
hydraulic conductivity	k	2.00E-04	m/s
aquifer thickness	H	9.1	m
porosity	n	0.25	-

Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

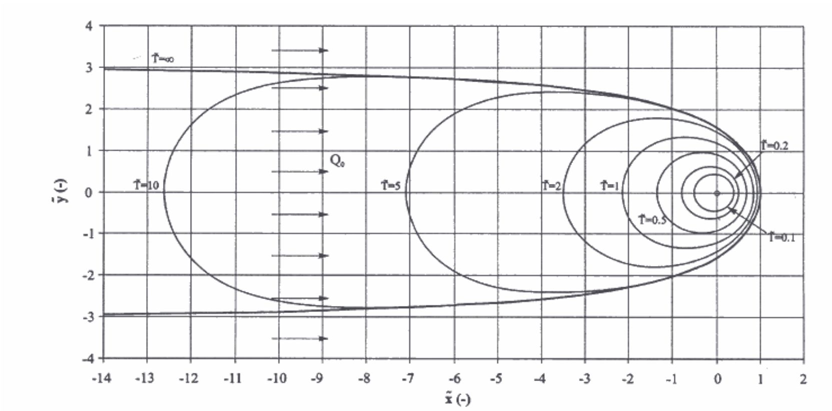
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \ or \ \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 1.26 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543\sqrt{\frac{QT}{\pi H n}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 80.27 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \ or \ \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s(0.00278 + 0.652\,T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	43.72	m		
Approximate fixed-radius capture zone	R =	72.78	m	R*=	1.66
Amount of upgradient shift of the circle centre	δ =	36.17	m	δ*=	0.83

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$

$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy\ /Q\right)}$$

Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993)
where tan(y) in radians

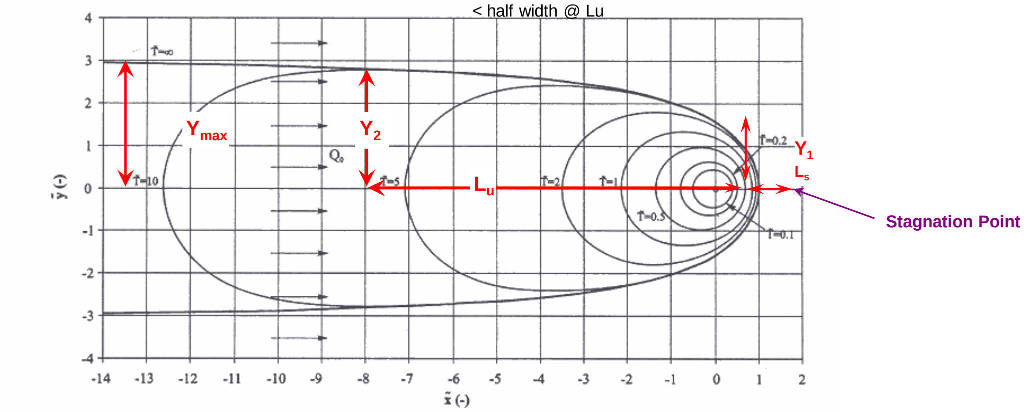
	Lu* =	2.65	-	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	115.72	m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	43.72	m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	68.68	m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	137.36	m	< symmetrical about the x-axis

5% Y_{max}, or	y=	6.87	x =	43.36	m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y=	34.34	x =	34.34	m	
50% Y_{max}, or	y=	68.68	x =	0.00	m	< x at origin (see figure below)
60% Y_{max}, or	y=	82.42	x =	-26.78	m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y=	96.15	x =	-69.86	m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y=	103.02	x =	-103.02	m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y=	109.89	x =	-151.25	m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y=	116.76	x =	-229.15	m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y=	123.63	x =	-380.48	m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y=	130.49	x =	-823.91	m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

76.50% Y_{max}, or	Y_2=	105.08	x =	-115.48	m	< where -x ≈ Lu

< half width @ Lu



Reference: Ceric, A., and Haitjema, H., 2005. **On Using Simple Time-of-Travel Capture Zone Delineation Methods**. *Ground Water* Vol 43, No. 3 pp 408-412.

Step 1: **Calculate T* (dimensionless time of travel parameter)**

Well no.2

Given

Parameter Description	*Symbol*	*Value*	*Unit*
Pumping rate	Q	0.004	m^3/s
Time-of-Travel Zone Required (1 year)	T	31536000	s
Ambient groundwater flow rate (Qo =kHi)	Qo	1.46E-05	m^2/s per unit width of aquifer
regional gradient	i	0.008	-
hydraulic conductivity	k	2.00E-04	m/s
aquifer thickness	H	9.1	m
porosity	n	0.25	-

Assumptions
- aquifer of inifinite areal extent
- aquifer of constant uniform thickness
- constant effective porosity
- constant isotropic hydraulic conductivity
- steady state conditions

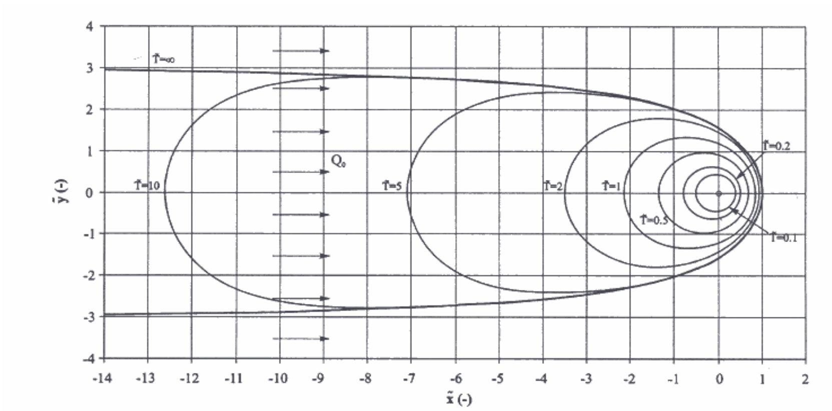
WARNING: INPUT DATA ONLY WHERE BLUE FONT APPEARS

Solution

$$T^* = \frac{2\pi Q_0^2 T}{nHQ} \text{ or } \frac{2\pi (kHi)^2 T}{nHQ}$$

where **T*** <0.1 indicates time-of-travel capture zones concentric (circular) around the well
where 0.1< **T*** <1 indicates time-of-travel capture zones which resemble circles but are shifted in the direction of upgradient regional groundwater flow
where **T*** >1 the time-of-travel capture zones are like ellipses and cannot reasonably be approximated by circles

Dimensionless time of travel parameter T* = 4.62 -



Step 2: **If T*<0.1, then calculate Centric Circular Capture Zone**

(this case typically occurs when ambient gw flow is small compared to well pumping rate)

Solution

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}}$$

where R is the approximate but conservative (15% larger than exact radius by volumetric method alone) fixed-radius capture zone (m)

Approximate conservative fixed-radius R = 153.35 m

If 0.1< T*<1, then calculate Eccentric Circular Capture Zone

(the capture zone circle in this case is shifted upgradient)

Solution

$$L_s = \frac{Q}{2\pi Q_0} \text{ or } \frac{Q}{2\pi kHi}$$
$$R^* = 1.161 + \ln(0.39 + T^*)$$
$$R = R^* L_s$$
$$\delta = L_s(0.00278 + 0.652\, T^*)$$

where Ls is the distance from the well to the well's stagnation point (m),
R is the approximate fixed-radius capture zone (m),
δ is the eccentricity (amount of shift) of the circle centre upgradient (m)

Distance from well to well's stagnation point (x at y = 0)	Ls =	43.72 m		
Approximate fixed-radius capture zone	R =	121.19 m	R*=	2.77
Amount of upgradient shift of the circle centre	δ =	131.71 m	δ*=	3.01

If T*>1, then calculate Boat-Shaped Capture Zone

(capture zone cannot reasonably be approximated by circle; propose replacement of actual time of travel capture zone by envelope of all capture zones.

Solution

$$L_u^* = T^* + \ln(T^* + e)$$
$$L_u = L_u^* L_s$$

where Lu is the distance from the well to the furthest upgradient point of the time of travel capture zone (m),

$$-x = \frac{-y}{\tan\left(2\pi kHiy / Q\right)}$$

Equation to describe the edge of the **steady-state capture zone** for a confined aquifer when steady state conditions have been reached (Todd 1980; Grubb 1993) where tan(y) in radians

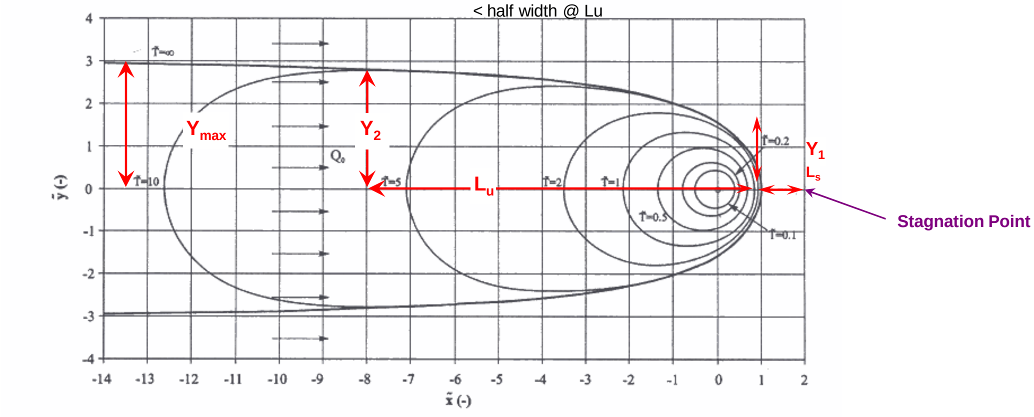
	Lu* =	6.61 -	
Distance to furthest upgradient point of the time of travel capture zone	Lu =	288.95 m	**<WARNING, DOES NOT EQUATE TO X AT 99%Ymax**
Distance to the furthest downgradient point of the time of travel capture zone (Ls) (x at y = 0)	Ls =	43.72 m	< stagnation point
Half width of capture zone at well location (y at x=0)	Y_1 =	68.68 m	< symmetrical about the x-axis
Maximum half width of capture zone (y at -x=infinity)	Y_{max} =	137.36 m	< symmetrical about the x-axis

5% Y_{max}, or	y= 6.87	x =	43.36 m	< downgradient of well (positive side of x axis on figure below)
25% Y_{max}, or	y= 34.34	x =	34.34 m	
50% Y_{max}, or	y= 68.68	x =	0.00 m	< x at origin (see figure below)
60% Y_{max}, or	y= 82.42	x =	-26.78 m	< upgradient of well (negative side of x axis on figure below)
70% Y_{max}, or	y= 96.15	x =	-69.86 m	< upgradient of well (negative side of x axis on figure below)
75% Y_{max}, or	y= 103.02	x =	-103.02 m	< upgradient of well (negative side of x axis on figure below)
80% Y_{max}, or	y= 109.89	x =	-151.25 m	< upgradient of well (negative side of x axis on figure below)
85% Y_{max}, or	y= 116.76	x =	-229.15 m	< upgradient of well (negative side of x axis on figure below)
90% Y_{max}, or	y= 123.63	x =	-380.48 m	< upgradient of well (negative side of x axis on figure below)
95% Y_{max}, or	y= 130.49	x =	-823.91 m	< upgradient of well (negative side of x axis on figure below)

Calculate half width of time of travel capture zone (y at -x ≈Lu): Use "trial-and-error" approach by changing %Ymax or y below until '-x' ≈ Lu

87.50% Y_{max}, or Y_2= 120.19 x = -290.17 m < where -x ≈ Lu

< half width @ Lu



APPENDIX V

Water Quality Monitoring

Well no.1

Date	Total Coliforms	E.coli	Heterotrophic Plate count	pH	Conductivity	Turbidity	Temperature	UV Transmittance	ORP	Dissolved Oxygen	Comments
	CFU/100mL	CFU/100 mL	CFU/1mL		uS/cm	NTU	oC	%	mV	mg/L	
09/03/2009	<1	<1	4								Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
23/03/2009				6.8	215	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
30/03/2009	<1	<1									Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
06/04/2009				7.1	192	0.2					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
14/04/2009				6.9	208	0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/04/2009				7.0	214	0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
27/04/2009				6.9	215	0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
04/05/2009				7.1	213	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
11/05/2009				7.1	207	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
19/05/2009				7.6	220	0.1		97.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
25/05/2009	<1	<1	2	7.8	216	<0.1		98.3			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
01/06/2009	<1	<1	1	7.9	208	0.1		98.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
08/06/2009	<1	<1	1	7.97	218	<0.1		96.2			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
10/06/2009				7.42	229		10.3		112	5.78	Golder Field Measurements
15/06/2009	<1	<1	2	7.96	210	<0.1	14.0	98.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
22/06/2009	<1	<1	<1	7.85	213	0.1	15.0	97.9			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
29/06/2009	<1	<1	<1	7.92	221	<0.1	12.0	96.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
06/07/2009	<1	<1	<1	7.94	222	<0.1	11.0	99.9			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
13/07/2009	<1	<1	<1	7.97	221	<0.1	11.1	97.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/07/2009	<1	<1	1	7.83	220	0.1	11.0	97.9			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.

Well no.2

Date	Total Coliforms	E.coli	Heterotrophic Plate count	pH	Conductivity	Turbidity	Temperature	UV Transmittance	ORP	Dissolved Oxygen	Comments
	CFU/100mL	CFU/100 mL	CFU/1mL		uS/cm	NTU	oC	%	mV	mg/L	
04/11/2008				7.19	196.5		7.7				Golder Field Measurments
05/11/2008					190.2		8				Golder Field Measurments
09/03/2009	<1	<1	2								Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
11/03/2009				6.5	185.5		5.3		116	4.93	Golder Field Measurments
23/03/2009				7.1	215	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
30/03/2009	<1	<1									Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
06/04/2009				7.1	196	0.2					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
14/04/2009				6.8	208	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/04/2009				6.9	219	<0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
27/04/2009				6.9	220	0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
04/05/2009				7.0	217	0.2					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
11/05/2009				7.0	211	0.1					Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
19/05/2009				7.6	224	0.1		97.4			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
25/05/2009	<1	<1	<1	7.7	215	0.2		96.4			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
08/06/2009	<1	<1	2	7.83	213	0.1		96.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
09/06/2009				7.17	219		8.4		63	6.87	Golder Field Measurements
15/06/2009	<1	<1	<1	8.05	200	<0.1	14.0	96.8			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
22/06/2009	<1	<1	<1	7.8	199	<0.1	13.0	96.5			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
29/06/2009	<1	<1	1	7.81	207	<0.1	9.0	94.7			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
06/07/2009	<1	<1	<1	7.85	206	<0.1	9.0	97.3			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
13/07/2009	<1	<1	<1	7.87	207	0.1	10.0	96.4			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/07/2009				7.08	196.1		8.5		85	5.45	Golder Field Measurements

Beaver Creek

Date	pH	Conductivity uS/cm	Turbidity NTU	Temperature oC	ORP mV	Dissolved Oxygen mg/L	Comments
04/11/2008	8.31	247		5.6			Golder Field Measurments
05/11/2008		233		5.9			Golder Field Measurments
11/03/2009		250		0.9	102	15.19	Golder Field Measurments
19/05/2009	7.4	116	4.3	10			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
25/05/2009	7.5	118	1.4				Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
01/06/2009	8.0	113	1.8	12			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
08/06/2009	8.05	143	0.9				Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
09/06/2009	8.08	138.7		9.9	66	10.86	Golder Field Measurments
10/06/2009	7.98	140.4		11.0	74	10.85	Golder Field Measurements
15/06/2009	8.17	158	0.8	15.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
22/06/2009	8.08	169	0.8	15.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
29/06/2009	8.17	181	0.5	16.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
06/07/2009	8.18	193	0.8	16.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
13/07/2009	8.2	194	0.7				Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/07/2009	8.18	191.5		15.8	65	9.46	Golder Field Measurements
20/07/2009	8.21	209	0.7	15.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
04/08/2009	8.35	225	0.7	18.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.

Columbia River

Date	pH	Conductivity uS/cm	Turbidity NTU	Temperature oC	ORP mV	Dissolved Oxygen mg/L	Comments
04/11/2008	6.6	123.2		9.8			Golder Field Measurements
05/11/2008		113.6		9.8			Golder Field Measurements
11/03/2009	5.97	147.5		1.8	119	14.15	Golder Field Measurements
19/05/2009	7.6	143	0.8	8.9			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
25/05/2009	7.7	136	0.8				Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
01/06/2009	8.0	127	1	12			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
08/06/2009	8.0	138	0.7				Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
09/06/2009	8.07	130.2		11.3	29	11.62	Golder Field Measurements
10/06/2009	8.13	129.1		11.6	93	11.8	Golder Field Measurements
15/06/2009	8.06	130	0.6	15.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
22/06/2009	7.99	132	0.6	15.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
29/06/2009	8.06	131	0.7	12.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
13/07/2009	8.04	124	0.7	16.6			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
20/07/2009	8.3	114.2		18.5	66	9.75	Golder Field Measurements
20/07/2009	8.11	122	0.5	17.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.
04/08/2009	8.19	122	0.5	20.0			Samples collected by VOM and sent to CARO lab. Temperature measured by VOM.

APPENDIX VI

MPA and Method 1623 Testing - Certificates of Analysis

Golder Associates

Hyperion Research Ltd.

1008 Allowance Ave. SE,
Medicine Hat, AB T1A 3G8
Tel: (403) 529-0847 Toll Free: (888) 529-0847
Fax: (403) 529-0852 Email: *hyperion@telusplanet.net*
Principal Scientist: Peter M. Wallis, Ph.D.

MICROSCOPIC PARTICULATE ANALYSIS REPORT SHEET (GUDI)

CLIENT:	Genevieve Pomerleau Golder Associates 201 Columbia Avenue Castlegar, BC V1N 1A8
TELEPHONE:	(250) 365-0344
FAX:	(250) 365-0988

Date of Sample:	10 June, 2009
Sample Location:	Village of Montrose Well #1
Type:	Raw
Volume Filtered (L):	3016
Temperature (°C):	10.3
pH:	7.42
Conductivity:	229

The methodology used to generate this report conforms to the USEPA Consensus Method for the Microscopic Particulate Analysis. Based on the validation data, the method is fit for its intended use.

Sample Processing Information

Final Pellet Vol. (μL): 20.0

Date Received	Time Received	Customer #	Temp. on Arrival (°C)	Lab ID	Density Medium	Sediment (mL)
11.VI.09	1630	174	8.8	49191	none	0.10

Total Wash (mL)	Concentrated (mL)	G/C Volume (μL)	MPA Volume (μL)	Suspension Vol. (μL)	Equiv. Vol. (L)
1000	1000	29	86	115	3,016

GIARDIA and *CRYPTOSPORIDIUM* RESULTS

Giardia **cysts/100 L:** 0.00 ***Cryptosporidium*** **oocysts/100 L:** 0.00

PARTICULATE ANALYSIS RESULTS

Primary Particulates	Total Count	#/380 L (100 US gal.)	Relative Risk Factor
Diatoms:	0	0.00	NS
Other Algae:	0	0.00	NS
Insect/larvae:	0	0.00	NS
Rotifers:	0	0.00	NS
Plant Debris:	115	19.32	R

Relative Risk Factors: EH - extremely heavy
M - moderate H - heavy
R - Rare NS - not significant

Secondary Particulates	Total Count	#/380 L (100 US gal.)
Pollen	78	13
Nematodes	0	0
Crustacea	0	0
Amoebae	0	0
Ciliates/flagellates	0	0
Other	0	0
Large Debris	low	
Fine Debris	iron floc	
Minerals	silica	

CONCLUSION: Based on this sample, the risk of surface water contamination is judged to be low and the risk factor is **0**

Additional Data: Lots of surface water organisms, diatoms in sample submitted.

Analyst:

Peter M. Wallis, Ph.D.

From the EPA Consensus Method:

Risk of Surface Water Contamination
20+ - high risk
10 to 19 - moderate risk
0 to 9 - low risk

Recovery efficiencies for particles are known to be low by this method but are compensated for by filtering a large volume of water. Minimum recovery was measured to be 6.5 +/-1.2% for *Giardia* cysts, 0.5 +/-0.2% for *Cryptosporidium* oocysts and 4.2 +/-2.3% for *Euglena* (algae). Despite the low recovery, the method reliably detected as few as 1 cell/L of groundwater in validation trials with no false positives.

Effective Date: 27/05/2006 Version #: 1.1
Revision Date: 02/01/2007 Document #: HR0013

Note: These results pertain to this sample only.

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Medicine Hat, AB T1A 3G8
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Fax: (403) 529-0852 Email: *hyperion@telusplanet.net*
Principal Scientist: Peter M. Wallis, Ph.D.

MICROSCOPIC PARTICULATE ANALYSIS REPORT SHEET (GUDI)

CLIENT: Genevieve Pomerleau
Golder Associates
201 Columbia Avenue
Castlegar, BC
V1N 1A8

TELEPHONE: (250) 365-0344
FAX: (250) 365-0988

Date of Sample: 9 June, 2009
Sample Location: Village of Montrose Well #2
Type: Raw
Volume Filtered (L): 3004
Temperature (° C): 8.4
pH: 7.17
Conductivity: 219

The methodology used to generate this report conforms to the USEPA Consensus Method for the Microscopic Particulate Analysis. Based on the validation data, the method is fit for its intended use.

Sample Processing Information

Final Pellet Vol. (µL): 30.0

Date Received	Time Received	Customer #	Temp. on Arrival (°C)	Lab ID	Density Medium	Sediment (mL)
11.VI.09	1630	174	8.8	49187	none	0.20

Total Wash (mL)	Concentrated (mL)	G/C Volume (µL)	MPA Volume (µL)	Suspension Vol. (µL)	Equiv. Vol. (L)
1000	1000	28	83	110	3,004

GIARDIA and *CRYPTOSPORIDIUM* RESULTS

***Giardia* cysts/100 L:** 0.00 ***Cryptosporidium* oocysts/100 L:** 0.00

PARTICULATE ANALYSIS RESULTS

Primary Particulates	Total Count	#/380 L (100 US gal.)	Relative Risk Factor
Diatoms:	0	0.00	NS
Other Algae:	0	0.00	NS
Insect/larvae:	0	0.00	NS
Rotifers:	1	0.17	NS
Plant Debris:	6	1.01	NS

Relative Risk Factors: EH - extremely heavy
M - moderate H - heavy
R - Rare NS - not significant

Secondary Particulates	Total Count	#/380 L (100 US gal.)
Pollen	4	1
Nematodes	0	0
Crustacea	0	0
Amoebae	0	0
Ciliates/flagellates	0	0
Other	0	0
Large Debris	low	
Fine Debris	iron floc	
Minerals	clay, low Mn	

CONCLUSION: Based on this sample, the risk of surface water contamination is judged to be low and the risk factor is **0**

Additional Data: Lots of surface water organisms, diatoms in sample submitted.

Analyst:

Peter M. Wallis, Ph.D.

From the EPA Consensus Method:

Risk of Surface Water Contamination
20+ - high risk
10 to 19 - moderate risk
0 to 9 - low risk

Recovery efficiencies for particles are known to be low by this method but are compensated for by filtering a large volume of water. Minimum recovery was measured to be 6.5 +/-1.2% for *Giardia* cysts, 0.5 +/-0.2% for *Cryptosporidium* oocysts and 4.2 +/-2.3% for *Euglena* (algae). Despite the low recovery, the method reliably detected as few as 1 cell/L of groundwater in validation trials with no false positives.

Effective Date: 27/05/2006 Version #: 1.1
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Note: These results pertain to this sample only.

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MICROSCOPIC PARTICULATE ANALYSIS REPORT SHEET (GUDI)

CLIENT:	Genevieve Pomerleau Golder Associates 201 Columbia Avenue Castlegar, BC V1N 1A8
TELEPHONE:	(250) 365-0344
FAX:	(250) 365-0988

Date of Sample:	20 July, 2009
Sample Location:	Village of Montrose Well #2
Type:	Raw
Volume Filtered (L):	150
Temperature (°C):	7.08
pH:	8.5
Conductivity:	196.1

The methodology used to generate this report conforms to the USEPA Consensus Method for the Microscopic Particulate Analysis. Based on the validation data, the method is fit for its intended use. Hyperion Research Ltd. is accredited for this analysis by CALA under the ISO/IEC 17025:2005 standard.

Sample Processing Information

Final Pellet Vol. (µL): 20.0

Date Received	Time Received	Customer #	Temp. on Arrival (°C)	Lab ID	Density Medium	Sediment (mL)
23.VII.09	0930	174	22.5	49252	none	0.10

Total Wash (mL)	Concentrated (mL)	G/C Volume (µL)	MPA Volume (µL)	Suspension Vol. (µL)	Equiv. Vol. (L)
1000	1000	50	50	100	150

GIARDIA and *CRYPTOSPORIDIUM* RESULTS

***Giardia* cysts/100 L:** 0.00

***Cryptosporidium* oocysts/100 L:** 0.00

PARTICULATE ANALYSIS RESULTS

Primary Particulates	Total Count	#/380 L (100 US gal.)	Relative Risk Factor
Diatoms:	0	0.00	NS
Other Algae:	5	25.33	R
Insect/larvae:	0	0.00	NS
Rotifers:	0	0.00	NS
Plant Debris:	15	76.00	M

Relative Risk Factors: EH - extremely heavy
M - moderate H - heavy
R - Rare NS - not significant

Secondary Particulates	Total Count	#/380 L (100 US gal.)
Pollen	0	0
Nematodes	0	0
Crustacea	0	0
Amoebae	0	0
Ciliates/flagellates	0	0
Other	0	0
Large Debris	none	
Fine Debris	low iron	
Minerals	silica chips	

CONCLUSION: Based on this sample, the risk of surface water contamination is judged to be low and the risk factor is **5**

Additional Data: Algae abundant in Beaver Cr. & Columbia R. Aerobic Spore Forming Bacteria Beaver Cr. 12 CFU/mL; Well 2 Negative; Total Coliforms Beaver Cr. +, Well 2 Negative; Faecal Coliforms Beaver Cr. +, Well 2 Negative

Analyst:

Peter M. Wallis, Ph.D.

From the EPA Consensus Method:

Risk of Surface Water Contamination

20+	- high risk
10 to 19	- moderate risk
0 to 9	- low risk

Recovery efficiencies for particles are known to be low by this method but are compensated for by filtering a large volume of water. Minimum recovery was measured to be 6.5 +/-1.2% for *Giardia* cysts, 0.5 +/-0.2% for *Cryptosporidium* oocysts and 4.2 +/-2.3% for *Euglena* (algae). Despite the low recovery, the method reliably detected as few as 1 cell/L of groundwater in validation trials with no false positives.

Note: These results pertain to this sample only.

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
201 Columbia Avenue
Castlegar, British Columbia, V1N 1A8
Canada
T: +1 (250) 365 0344

Golder Associates