2005 Village of Mayo Well Rehabilitation and Resource Assessment on PW1 and PW2

Prepared for
Energy Solutions Centre

Submitted by
Gartner Lee Limited

January 2006

Gartner Lee

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January 30, 2006

Ron Gee
ENERGY SOLUTIONS CENTRE
206A Lowe St.
Whitehorse, Yukon
Y1A 1W6

Dear Mr. Gee;

Re: 50931 - 2005 Village of Mayo Well Rehabilitation and Resource Assessment on PW1 and PW2.

Gartner Lee Limited is pleased to provide you with a draft report summarizing the well rehabilitation and resource assessment activities performed on the Village of Mayo Warm Water wells PW1 and PW2 in November and December 2005. The following report provides an overview of the procedures and results from the variable rate pumping tests (i.e. step test), which were conducted to evaluate the effectiveness of the well rehabilitation procedures. Drawdown data collected as part of this study as well as available historical drawdown data was assessed to determine the long-term sustainable yield for each well. Routine well cleaning maintenance schedules and costing have also been provided. Water quality samples were collected at the end of each cleaning procedure and analyzed to ensure that the groundwater quality had returned to normal.

I look forward to discussing the findings of this report at your convenience.

Yours very truly,
GARTNER LEE LIMITED

Kirk Cameron
Principal / Manager Whitehorse Office
JK:jk

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Executive Summary

The purpose of this project is to assess the potential for using two deep warm water groundwater wells (formally known as PW1 and PW2) in an Open Loop "Ground Source Heat Pump" (GSHP) application. The ultimate project goal is to extract heat energy from the groundwater and to use this energy to heat a select number of municipal buildings. An energy audit and a cost benefit analyses is currently being conducted in association with this work, to determine if the project is economically feasible.

The wells produce warm groundwater year round at a constant temperature of approximately 15°C. The wells are owned and operated by the Village of Mayo and are located adjacent to the municipal utility building in Mayo, Yukon. The estimated cost to replace a well similar to PW1 or PW2 is on the order of $200,00 to $250,000.

A major challenge of utilizing PW1 and PW2 as a warm groundwater supply is that fact that the groundwater is highly mineralized, which over time, leads to a combination of corrosive and mineral encrusting (scale) related issues. According to the Water Quality Association, scaling is the number one water quality issue in the United States (Rafferty 2000) and can lead to significant operational issues if not properly considered in GSHP applications.

The accumulation of scale material through time, specifically across the screen interval or production zone of the well, has led to a restriction in groundwater flow and an apparent drop in well productivity. It should be understood that these processes are natural and that routine well maintenance must be considered if this resource is to be utilized in a sustainable manner. Costs options to perform these tasks have been provided in this report. It is also important to understand that the reductions in well productivity are in no way related to limitations in the aquifer resource itself. The *aquifer* could likely sustain long-term flow rates on the order of two hundred litres per second.

Based on a detailed review of the available historical drawdown data, it appears that pumping levels in both wells dropped off significantly within the first year or two after production started. It is recommended that the wells be rehabilitated on an annual basis. Additional benefits could be possible if more frequent cleaning cycles are performed. The wells have historically been operated seasonally, which may also contribute to the observed rate decreases in well efficiency / productivity. It is suspected that if the wells were run on a continual basis (i.e. year round), than the rates of well efficiency decline may be reduced.

The most recent rehabilitation data indicates that the well efficiency of PW1 has improved by approximately 4.4 times as a result of this rehabilitation program. However, PW1 is 31 years old and is showing significant signs of degradation, including corrosion and pitting on the well casing. It is estimated that PW1 may only have an expected life span of approximately 2 to 4 years. Based on video inspections of PW1, there are two identified locations where fine sand appears to be entering into the

well. It is possible that these holes can be sealed with a liner casing, which may extend the longevity of the well, however it is difficult to predict precisely by how much. Currently, very little sand production occurs when flow rates are less than approximately 7.9 L/sec (125 US gal/min). However, it is difficult to predict how long these conditions will last. PW1 is currently flowing at an artesian flow rate of approximately 2.8 L/sec (45 US gal/min). Therefore it may be advantageous to utilize this groundwater on a continual basis in order to take advantage of this passive flow and energy component.

Based on the drawdown data, it appears that little improvement in well efficiency on PW2 was achieved during this rehabilitation program. It is hypothesized that the reasons the chemical treatment may not have been as effective on PW2 as PW1 are two fold.

1. The acid was pumped through the packer located above the top of the screen, and may have entered only the most permeable, upper zones, of the screen / formation, limiting contact of the acid to the lower portion of the screen interval.
2. As a result of a different well construction configuration, approximately ¼ the acid volume used on PW1 was used on PW2.

Based on the knowledge gained during this project, it is anticipated that a more aggressive rehabilitation of PW2 using higher acid volumes, could result in similar improvements in well efficiency as were obtained on PW1. The physical condition of PW2 appears to be good. It is predicted that PW2 could have a life span of an additional 15 to 20 years, if a routine and effective well maintenance program is carried out. Based on an extrapolation of the historical and current drawdown data, it appears today that PW2 could sustain a flow rate of 16 L/sec (250 US gal/min). This rate however may require the pump to be located at a deeper level in the well.

When PW2 was first drilled, it could produce 16 L/sec with approximately 16 m of drawdown. Given the current post rehabilitation performance of PW2, a pumping rate of 16 L/sec could potentially create a stabilized pumping level as great as 150 to 175 m below the top of casing. If similar improvements in efficiency were obtained on PW2 as were on PW1, pumping levels could be reduced to less than 50 m. For cost comparison purposes, it costs approximately $12,000 more per year to operate a well pumping water from 175 m versus 50 m below ground surface (based on a pumping duration of 150 days at 16L/sec).

Additionally, given the historical performance of PW2, a pumping level of 175 m at 16 L/sec suggests that flow into PW2 is currently quite restricted. This restriction is likely creating high entry velocities (the speed the groundwater enters the casing) and may lead to excessive screen wear and somewhat reduce the longevity of the well screen. More concerning however, is that increased levels of drawdown may promote the geochemical processes associated with scale build-up and potentially may lead to an increased rate of well efficiency decline.

1. Introduction

The purpose of this project is to assess the potential for using two deep geothermal groundwater wells (formally known as PW1 and PW2) in an "Open Loop Ground Source Heat Pump" (GSHP) application. The wells produce warm groundwater year round at a constant temperature of approximately 15°C. The wells are owned and operated by the Village of Mayo and are located adjacent to the municipal utility building in Mayo, Yukon. The ultimate project goal is to extract heat energy from the groundwater and to use this energy to heat a select number of municipal buildings. Stantec Engineering is the project lead and is conducting both an energy audit and a cost benefit analysis to determine if the project is economically feasible. Currently PW1 and PW2 provide a source of medium grade geothermal energy to the municipal potable water supply via a single direct plate heat exchanger. The potable water well, located in the same vicinity as PW1 and PW2 however at a much shallower depth, produces cold groundwater that requires supplementary heat during winter months prior to entering the municipal distribution system. Water is pumped from PW1 and PW2, passed through the heat plate exchanger, and is then discharged through an buried pipe that discharges directly to the Mayo River. This operation is currently permitted under Yukon Class A Water Licence MN00-029.

A major challenge of utilizing PW1 and PW2 as a warm groundwater supply is that fact that the groundwater is highly mineralized, which over time, has lead to a combination of corrosive and mineral encrusting related issues. These issues will be discussed in detail throughout this report, however in the context of this project, Garter Lee Limited has been retained to focus on three main project objectives.

1. To design and oversee a mechanical and chemical well rehabilitation (i.e. well cleaning) program on both PW1 and PW2.

2. To evaluate the rate at which well clogging related issues occur and to provide options and cost estimates to deal with the issue on a routine basis; and

3. To conduct a resource assessment to determine the long term sustainable yield of the wells. *(E.g., How much groundwater can the wells produce on a continual basis?).*

2. Background Information

PW1 and PW2 are two deep geothermal wells that have been completed in overburden material to a depth of approximately 250 m. A well construction diagram of PW1 and PW2 is provided in Appendix A.

2.1 PW1

PW1 was drilled in 1975 by Midnight Sun Drilling Ltd. and was immediately utilized on a continual basis during winter months only. Hydrogeological Consultants Ltd. documented the construction details of PW1 in a report published in 1979. Drawdown data at this time was not collected as it was decided to continue pumping at a continuous rate of 15.2 L/sec (or 200 Igpm) throughout the winter of 1975/76 (Lissey, 1986).

Throughout the winter of 1975/76 the production rate of PW1 was 15L/sec. During the winter months of 1976/77 and 1977/1978 the average production rate dropped to 7.5 L/sec. Production decreased drastically in the winter of 1978/79 necessitating well rehabilitation work in late 1979 (Clissold 1980). The well rehabilitation work at this time consisted of mechanical surging. Although improvements in pumping rates as high as 11.4 L/sec were obtained, the pumping capability of PW1 again declined notably within the next few pumping seasons (Lissey, 1986). It should be noted that work completed by Lissey (1986), indicates that the decline in the observed pumping rates is attributed to a number of factors including pumps that decreased in efficiency as a result of corrosion and decreases in well efficiency as a result of encrustation of the screen and casing. This is an important observation, as these factors do NOT indicate that there has been a decrease in aquifer capacity. Namely, the problems associated with PW1 appear to be related to efficiency problems in the well and pump assembly. Hydrogeological testing work completed in 1986 (Lissey 1986), noted considerable improvements in well efficiency in comparison to data obtained during rehabilitation work in 1979. However, Lissey suspected that this discrepancy was likely attributed to the fact that the pump used in 1979 had an extremely small annular space for flow and that this flow restriction caused excessive head losses in the system, which in turn was reflected in the drawdown data. The best estimate of the aquifer transmissivity in the vicinity of PW1 was made by Lissey (1986), and is approximately 39 m^2/day. Given the available drawdown a theoretical long-term sustainable yield of 57.6 L/sec was predicted for PW1. However, given the screen / well casing configuration together with a reasonable well efficiency, the “practical” long-term theoretical yield of PW1 is estimated at 15 L/sec (Lissey, 1986).

The most recent rehabilitation work prior this project was completed by Aqua Tech Supplies and Services. This work was documented in Gartner Lee Limited (GLL) in 2003. PW1 production had fallen off considerably as a result of encrustation and clogging of the well casing and screen. In 2003, only air lifting development was completed. Approximately two to three 20 L pails of black scale like precipitate debris was removed, however only marginal improvements in the well's efficiency (specific capacity) were obtained.

2.2 PW2

Hi-Rate Drilling Ltd drilled PW2 in 1990, and Lissey (1990) of MLM Ground-Water Engineering provided documentation of the well construction details. Upon completion, PW2 was tested and shortly thereafter was put on-line to provide a supplementary warm water supply to the Village of Mayo. PW2 is completed in a slightly more productive zone than PW1 and has a measured aquifer transmissivity of 160 m^2/day (Lissey, 1990). Given the available drawdown, a theoretical long-term sustainable yield up to 134 L/sec was calculated (Lissey (1986), however, given the screen / well casing configuration and a reasonable level of well efficiency, the "practical" long-term theoretical yield for PW2 is approximately 16.4 L/sec (Lissey 1990).

3. General Description of Field Methodology

3.1 Introduction

As discussed, Gartner Lee Limited (GLL) developed a work plan to address issues associated with reduced well efficiency caused by mineral precipitation/scale accumulations within the well screen and casing of both wells. The work plan was developed to maximize the effectiveness of the cleaning process. Well rehabilitation techniques have become more advanced in recent times and therefore the adoption of these techniques and experiences have been applied to this project. The publication *"Chemical Cleaning, Disinfection & Decontamination of Water Wells"*, by Johnson Screens Inc. (Schnieders 2003), was used as a guide to develop the cleaning methodology applied during this program.

Given the nature of the accumulations and scale identified in the wells, a combination of mechanical and chemical well rehabilitation methods were applied. The following sections provide an overview of the rehabilitation methodology. Appendix B provides a photo log of the procedures beginning with the removal of the pump, the use of well cleaning brushes, the injection of the well chemistry followed by a final flushing of the well. Water quality samples were collected at the end of the cleaning procedure and analyzed to ensure that the groundwater quality had returned to normal.

A more detailed description of the well cleaning procedures is provided below.

3.2 Downhole Camera Well Inspections

Prior to and following the well rehabilitation activities, the wells were inspected using a downhole camera. This procedure provided an excellent means of inspecting the casing, casing joints, and well screens. The results of these finding are provided below in the appropriate results sections.

3.3 Pre and Post Well Performance Pumping Tests

The purpose of the "pre" and "post" well performance evaluation or "step tests", was to measure the effectiveness of the cleaning process and to obtain a base line level measurement of well efficiency (i.e. specific capacity).

Specific capacity is defined as the pumping rate in L/sec, which will induce one meter of drawdown in the well. Therefore if a well has a high specific capacity, less drawdown in the well is required to maintain a desired pumping rate. If the well deteriorates and clogs up over time due to biological, geochemical or physical processes, the well is said to become less efficient and therefore the specific capacity is reduced.

If possible, specific capacity values measured when the well was first completed were compared to levels measured prior to and following the well rehabilitation activities. This provided a measure of decline in well efficiency over time. This information provided a basis for developing a routine well cleaning and maintenance program. The pre and post pumping tests consisted of pumping the wells at selected pumping rates for selected periods of time. Where possible, the "step tests" were design similar to those conducted historically, to facilitate comparison with the historical data. Well losses often vary significantly at various pumping rates, therefore, selecting common pumping rates helped to reduce this uncertainty, and improve the over all comparison.

3.4 Mechanical Pre-Cleaning

Prior to the use of chemical well cleaning products, the production wells were first swabbed using a nylon brush designed for water well cleaning. Once this mechanical agitation was completed, the wells were then evacuated (i.e. bailed out using a suction bailer) to remove any loosened scale material. A photograph of the well brushes is provided in Appendix B. This procedure greatly reduced the amount of well chemicals needed, as the physical removal of these readily accessible accumulations would otherwise require chemicals to break them down.

3.5 Chemical Treatment

Two chemical treatments were used in combination during this project. The chemical cleaning products used consisted of a concentrated liquid acid descaler and a dispersant. The dispersant was used in combination with the acid as it improves the efficiency of acid treatment (Schnieders, 2003).

The cleaning products were provided by Cotey Chemical Corporation of Lubbock, Texas, who specialize in manufacturing products which can be safely and easily applied for maintenance, development or sterilization of household, industrial and irrigation water wells. All of the chemicals used during this project are certified for use under the ANSI/ NSF Standards 60. Health Canada recommends that, where possible, water utilities and consumers use drinking water grade materials that have been certified as conforming to the applicable ANSI/NSF health-based performance standard. These standards have been designed to safeguard drinking water by helping to ensure material safety and performance of products that come into contact with drinking water. A description of the chemical products used is provided in Appendix C.

Given the significant depth of PW1 and PW2 (255.0 m and 251.5 m respectively), it was extremely challenging to conduct this work, particularly given the fact that both the wells are flowing artesian. A requirement of the chemical treatment process was to allow the chemicals to sit in the screen interval overnight. Therefore a packer / chemical injection system was developed which allowed the well to be "shut down" (i.e. a no flow condition to be obtained) while at the same time providing a means of injecting the well cleaning chemicals directly above the screen interval. Appendix B provides a photo log of the injection procedure.

Following the required chemical doses and application period (~24 hrs), the packer was deflated at surface and the artesian flow of the well was reestablished. A suction pump was used at surface to maintain the water level in the well below the top of casing. This was particularity important as temperatures were commonly below –30°C so icing issues around the work area were a concern. The water was pumped into a nearby 500-gallon tub, where it was monitored. Once the slug of wastewater from the well screen interval reached the surface as was pumped into the tub, the pH was neutralized and a second transfer pump was used to discharge this water to a vacant lot adjacent to the Villages utility building.

Following the cleaning process, a downhole camera inspection of the well was conducted to visually inspect the effectiveness of the cleaning procedures. The results of these activities are presented in Section 4.

4. Results – Well Rehabilitation and Resource Assessment

4.1 Results from PW1

Once the packer on PW1 was released and the slug of wastewater was treated and discharge, it was noted by the crew that the natural artesian overflow rate in PW1 had significantly increased by approximately 30 gpm. The well was then again swabbed to the bottom using well brushes and a suction bailer was then tripped in to remove any remaining debris. However, upon lowering the bailer to the bottom of the hole, the crew discovered that as much as 40 ft of fine sand had seemingly heaved into the well bottom. The artesian flow rate of the well also dropped to approximately 10 gpm. An air development system was then tripped into the well and the well was developed for a period of 2 full days. After this time, a solid bottom appeared to be established, and a relatively sand free condition in the pumped water appeared to be obtained. The artesian flow rate that was obtained immediately following acid removal was once again reestablished.

4.1.1 PW1 Downhole Camera Inspections

Following the mechanical/chemical treatment and subsequent redevelopment of PW1, the well was again inspected using the downhole camera. A digital copy of the downhole video inspection is provided in Appendix D on CD ROM. The following important observations were made during the review of the video.

- The base plug of the well appears to have failed, however there is still 8 ft of screen exposed to the formation. Based on the as built drawing of the well, there was 10 ft of screen installed in PW1.
- The base of the well appears to be solid. Small stones can be seen jammed between the "ribs" of the wire wrap screen at the base, suggesting that the base plug potentially failed and allowed these larger diameter stones to enter the well bore. A gravel pack around the base of the screen however appears to have been developed. It also appears that a piece of lead packer may have fallen to the bottom and is potentially helping create the well bottom base.
- The well screen appears to be in very good condition, however the well casing is showing significant signs of pitting and corrosion.
- The lead packer located between the 8-inch and 6-inch casings at a depth of 163 m, as indicated on the as built drawings, appears to "leak" fine sand.
- Fine sand also appears to be "leaking" into the well through what appears to be a hole in the 6-inch casing at a depth of 818 ft (249.3 m), as indicated on the down hole camera post rehab.

Given these observations, it is likely that the holes in the casing are the likely source of the silica sand observed in the pump that was pulled from PW1. Appendix B provides a photo of the sand observed in the PW1 pump impellers. The mechanical wear was so extensive that the pump required replacement.

Although a "gravel pack" now appears to have been developed around the base of the well screen and sand production rates now seem to be minor when flow rates are less than 7.9 L/sec (125 US gal/min), it is unknown how long these conditions will last, especially given the fact that PW1 typically operates "completely on" or "completely off". John Ewing at the Village has been informed of these problems, and is therefore currently running PW1 as a "back up" to PW2 (i.e. PW1 is off line and will be used only if needed).

Given these observations, it is recommended for the time being, PW1 not be pumped in excess of 7.9 L/s (125 US gal/min). Additionally this well *should not* be used as a primary dedicated well for water production. The well is 34 years old and is showing significant signs of degradation as discussed above.

4.1.2 PW1 Step Test Results

Specific capacity values have been estimated based on pumping test data as far back as 1979. The well was first drilled in 1975 (Clissold 1979) however; drawdown data at this time was not obtained at as the well was put immediately into production at 15.2 L/sec (or 200 Igpm) throughout the winter of 1975/76 (Lissey, 1986). Table 1 provides a summary of the interpreted specific capacity values collected from PW1. It should be noted that the specific capacities values presented are slightly different than those presented in GLL 2003. This discrepancy has been created as the data has been extrapolated to a similar point in time allowing for a slightly more accurate comparison of data sets. A summary of the pumping test data is provided in Appendix E.

Table 1. Comparison of Specific Capacity Values from PW1

Date of Test	Specific Capacity [1] (L/sec/m)	Data Source	Notes
November 5, 1979	0.16	Clissold 1980	Data collected following well rehabilitation work in 1979
August 8, 1986	0.42	Lissey 1986	No rehab performed.
July 5, 2002	0.11	GLL 2003	Pre mechanical rehabilitation.
November 13, 2002	0.15	GLL 2003	Post mechanical rehabilitation.
November 16, 2005	0.09	GLL 2006	Pre mechanical and chemical rehabilitation.
December 14, 2005	0.40	GLL 2006	Post mechanical and chemical rehabilitation.

Note 1. Specific capacities values presented are slightly different than those presented in GLL 2003. This discrepancy has been created as the data has been extrapolated to a similar point in time allowing for a slightly more accurate comparison of data sets.

Based on the data, it appears that although PW1 was reportedly operating quite efficiently when first tested in 1975, the well rehabilitation work conducted in 1979 (Clissold 1980) appears to have not been very effective. As discussed, hydrogeological testing completed in 1986 (Lissey 1986), noted considerable improvements in well efficiency. Lissey suspected however that this discrepancy is likely attributed to the fact that the pump used in 1979 had an extremely small annular space for flow and that this flow restriction caused excessive head losses in the system, which intern was reflected in the drawdown data. That being the case, by 2003 we see a further decline in well efficiency, with marginal improvements as a result of the mechanical development. The most recent rehabilitation results however appear to have brought well efficiency levels of PW1 back up those observed by Lissey (1986).

4.2 Results from PW2

Once the packer on PW2 was released and the slug of wastewater was treated and discharge, it was noted by the crew that the virtually no change in the natural artesian overflow rate in PW2 had occurred. The well was again swabbed to the bottom using well brushes and a suction bailer was then tripped in to remove any remaining debris.

4.2.1 PW2 – Downhole Camera Inspections

Following the mechanical/chemical treatment and subsequent redevelopment of PW2, the well was again inspected using the downhole camera. A digital copy of the downhole video inspection is provided in Appendix D on CD ROM. The following important observations were made during the review of the video.

- The well screen appears to be in very good condition, however the well casing is showing moderate signs of pitting and corrosion. Overall, the integrity of the casing appears relatively good.
- Based on the as built drawing of the well, there is 15.9 ft of screen in PW2. However the video inspection suggests that only the upper 13 ft of the screen appears to be in the active flow field. The bottom 2.9 ft appears to be stagnant water that consists of blackish flocculent type precipitation.
- There does not appear to be any obvious "leaks" in the casing where fine sand is entering the well.

A more detailed discussion of these observations is provided in the subsequent section.

4.2.2 PW2 Step Test Results

Table 2 provides a summary of the interpreted specific capacity values collected from PW2. Besides the data collected during this project, no other pumping data, except that collected by Lissey (1990) when the well was first constructed, is believed to exist. A summary of the pumping test data is provided in Appendix E.

Table 2. Comparison of Specific Capacity Values from PW2

Date of Test	Specific Capacity (L/sec/m)	Data Source	Notes
June 4, 1990	1.11	Lissey 1990	Data collected following well construction in 1990
November 17, 2005	0.23	GLL 2006	Pre mechanical and chemical rehabilitation.
December 9, 2005	0.22	GLL 2006	Post mechanical and chemical rehabilitation.

Based on the data, it appears that the efficiency of PW2 has dropped significantly by approximately a factor of five since the well was first completed. It is also evident that the efficiency of PW2 after this rehabilitation program appears to have decreased marginally. Upon further study, it is suspected that this apparent small decrease is likely the result of pumping PW2 to overflow for a period of approximately 3 days, in combination with conducting pumping tests on PW1. As a result, this allowed for a modest depressurization (drop in head) of the aquifer prior to the post rehabilitation step test on PW2. It is concluded therefore that little improvement in well efficiency on PW2 was achieved during this rehabilitation program.

Downhole video inspections of PW2 suggest that the chemical product appears to have not entered the entire screen interval. As discussed, only the upper 13 ft of the screen is currently within the active flow field and the bottom 2.9 ft appears to be stagnant water consisting of a blackish flocculate type precipitation. It is hypothesized that the reason the acid treatment may not have been as effective in PW2 as in PW1 is two fold.

1. The acid was pumped through the packer onto the top of the screen, and may have entered only the most permeable zones of the formation. Which, consequently are suspected to be the upper part of the screen interval. Typically, this issue would not be a concern as mechanical agitation is normally used to distribute the well chemistry throughout the screen interval.

However, the fact that the wells were artesian and required a no flow condition to be maintained by the packer inhibited the project team's ability to mechanically agitate during the chemical treatment period.

2. As a result of a different well construction configuration, approximately ¼ the acid volume used on PW1 was used on PW2.

Based on these observations, subsequent acid injections on PW2 should take place directly across the screen interval and the chemical injection volumes should be significantly higher than the manufactures recommended dose. It is anticipated that a more aggressive rehabilitation of PW2 could result in similar improvements in well efficiency as were obtained on PW1. The condition of PW2 appears to be good. It is predicted that PW2 could have a life span of an additional 15 to 20 years, if a routine and effective well maintenance program is carried out. Based on an extrapolation of the historical and current drawdown data, it appears today that PW2 could sustain a flow rate of 16 L/sec (250 US gal/min). This rate however may require the pump to be located at a deeper level in the well.

When PW2 was first drilled, it could produce 16 L/sec with approximately 16 m of drawdown. Given the current post rehabilitation performance level of PW2, a pumping rate of 16 L/sec could potentially create a pumping level as great as 150 to 175 m below the top of casing. If similar improvements in efficiency were obtained on PW2 as were on PW1, pumping levels could be reduced to less than 50 m. For cost comparison purposes, it costs approximately $12,000 more per year to operate a well pumping water from 175 m versus 50 m below ground surface (based on a pumping duration of 150 days at 16L/sec).

Additionally, given the historical performance of PW2, a pumping level of 175 m at 16 L/sec suggests that flow into PW2 is currently quite restricted. This restriction is likely creating high entry velocities (the speed the groundwater enters the casing) and may lead to excessive screen wear and somewhat reduce the longevity of the well screen. More concerning however, is that increased levels of drawdown may promote the geochemical processes associated with scale build-up and potentially may lead to an increased rate of well efficiency decline.

5. Geochemical Results

5.1 Results of Groundwater Sampling

5.1.1 Field Parameters

Field parameters were monitored on the discharge water during the pre and post rehabilitation step tests using a digital YSI 556 Multi-probe. The parameters included measurements of temperature, conductivity, and pH. Overall, there appeared to be no significant fluctuations in the measured field parameters. Average values are provided in Table 3.

Table 3. Summary of Average Field Parameters

Field Parameters	PW1	PW2
Temperature	15.3 °C	14.7 °C
Field Conductivity	473 µS/cm	479 µS/cm
Field pH	7.8	7.7

Based on a review of historical documents associated with the wells, it appears that the groundwater temperatures have been relatively constant since the wells were first constructed.

5.1.2 Analytical Water Quality Results

The purpose of collecting water quality samples were to ensure that the groundwater had returned to a stable condition after rehabilitation, to evaluate the corrosive and or encrusting nature of the water and to compare the findings to historical results that may indicate if there has been a change in water quality over time.

Two rounds of sampling were conducted. Water samples were first collected part way through the rehabilitation process and prior to the end of completing the post-rehabilitation pumping test. The samples collected part way through the well cleaning process from PW1 where found to indicate the groundwater was still influenced slightly by the chemical rehabilitation process. However, the second round of sampling, collected at the end of the post rehabilitation step test, indicated the groundwater had no evidence of the cleaning products. If fact, it was found that the groundwater from both PW1 and PW2 is of very similar quality to when the wells were first drilled (Lissey 1986/1990).

A summary of the water quality results is presented in Table 4. Industry standard and laboratory recommended water quality sampling and preservation techniques were followed. Copies of the original laboratory reports can be found in Appendix F.

Table 4. Groundwater Quality Results

Well Location		**PW1**			**PW2**	
Sample ID		**PW1**	**PW1**	**PW1-D** *(Duplicate Sample)*	**PW2**	**PW2**
Sample Date	**Guidelines for Canadian Drinking Water Quality (GCDWQ)**	**Nov 27, 2005**	**Dec 14, 2005**	**Dec 14, 2005**	**Nov 27, 2005**	**Dec 14, 2005**
Physical Tests						
Colour	<= 15 (AO)	<5.0	<5.0	-	<5.0	<5.0
Conductivity (uS/cm)		616	591	-	604	603
TDS	< = 500 (AO)	371	368	-	355	372
Hardness CaCO3	*(see Note 1)*	198	185	185	196	201
pH	6.5-8.5 (AO)	7.99	8.09	-	8.16	8.22
Turbidity (NTU)	1 (MAC)	**23.4**	**2.39**	-	**1.98**	**1.10**
Dissolved Anions						
Alkalinity-Total CaCO3		279	262	-	284	263
Chloride	<250 (AO)	7.71	1.75	-	1.70	1.64
Fluoride	1.5 (MAC)	0.093	0.166	-	0.171	0.175
Sulphate	<500 (AO)	74.0	74.4	-	77.4	78.9
Nutrients						
Nitrate Nitrogen	10 (MAC)	<0.10	<0.10	-	<0.10	<0.10
Nitrite Nitrogen	1	<0.10	<0.10	-	<0.10	<0.10
Total Metals						
Aluminum		0.012	0.019	0.013	<0.010	0.013
Antimony	0.006 (IMAC)	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Arsenic	0.025 (IMAC) (See Note 2)	0.00052	0.00023	0.00022	<0.00010	0.00023
Barium	1 (MAC)	0.056	0.058	0.057	0.062	0.061
Boron	5 (IMAC)	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium	0.005 (MAC)	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Calcium		46.6	42.4	42.8	44.0	44.5
Chromium	0.05 (MAC)	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Copper	<1.0 (AO)	<0.0010	<0.0010	<0.0010	<0.0010	0.0017
Iron	<0.3 (AO)	**2.71**	**0.334**	**0.328**	**0.371**	**0.936**
Lead	0.010 (MAC)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Magnesium		20.0	18.9	19.0	22.7	21.7
Manganese	<0.5 (AO)	0.173	0.0602	0.0604	0.0584	0.0603
Mercury	0.001 (MAC)	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Potassium		1.63	1.64	1.63	1.62	1.68
Selenium	0.01 (MAC)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Sodium	<200 (AO)	67.4	62.5	60.6	62.3	57.1
Uranium	0.02 (IMAC)	0.00038	0.00015	0.00015	0.00014	0.00017
Zinc	<5 (AO)	0.091	<0.050	<0.050	<0.050	<0.050
Dissolved Metals						
Aluminum		0.012	<0.010	-	<0.010	<0.010
Antimony	0.006 (IMAC)	<0.00050	<0.00050	-	<0.00050	<0.00050
Arsenic	0.025 (IMAC) (See Note 2)	0.00043	0.00020	-	<0.00010	0.00010
Barium	1 (MAC)	0.055	0.058	-	0.061	0.061
Boron	5 (IMAC)	<0.10	<0.10	-	<0.10	<0.10
Cadmium	0.005 (MAC)	<0.00020	<0.00020	-	<0.00020	<0.00020
Calcium		46.4	42.8	-	42.3	44.6
Chromium	0.05 (MAC)	<0.0020	<0.0020	-	<0.0020	<0.0020
Copper	<1.0 (AO)	<0.0010	<0.0010	-	<0.0010	<0.0010
Iron	<0.3 (AO)	**1.94**	0.269	-	**0.360**	**0.706**
Lead	0.010 (MAC)	<0.0010	<0.0010	-	<0.0010	<0.0010
Magnesium		20.0	18.9	-	22.0	21.8
Manganese	<0.5 (AO)	0.168	0.0595	-	0.0563	0.0582
Mercury	0.001 (MAC)	<0.00020	<0.00020	-	<0.00020	<0.00020
Potassium		1.65	1.65	-	1.58	1.67
Selenium	0.01 (MAC)	<0.0010	<0.0010	-	<0.0010	<0.0010
Sodium	<200 (AO)	66.3	61.8	-	62.4	60.1
Uranium	0.02 (IMAC)	0.00038	0.00014	-	0.00014	0.00015
Zinc	<5 (AO)	<0.050	<0.050	-	<0.050	<0.050

Comments

All results are expressed as milligrams per litre unless otherwise stated.

(MAC) - Maximum Acceptable Concentration

(IMAC) - Interim Maximum Acceptable Concentration

(AO) - Aesthetic Objective (taste, odour, appearance, etc.)

Chemical Analysis perfomred by ALS, Vancouver, BC

Bold = Exceeds associated GCDWQ standard.

Note 1: A maximum acceptable level has not been established for hardness because public acceptance may vary considerably. Water supplies with a hardness greater than 200 mg/L are considered poor but have been tolerated by consumers; those in excess of 500 mg/L are unacceptable for most domestic purposes. (Summary of Guidelines for Canadian Drinking Water Quality, April 2004)

Note 2: There is currently a proposed MAC Canadian Federal-Provincial-Territorial Arsenic Guideline of 0.005 mg/L. The World Health Organization uses a MAC of 0.01 mg/L.

5.2 Scaling and Corrosive Tendency of the Groundwater

The Ryznar Stability Index (RSI) and the Langelier Saturation Index (LSI) are two commonly used methods for predicting the potential precipitation of carbonate minerals on metal objects in saturated subsurface environments (i.e. mineral scaling). According to the Water Quality Association, scaling is the number one water quality issue in the United States (Rafferty 2000) and can lead to significant operational issues if not properly considered in GSHP applications.

Table 5 presents the results of the calculated LSI and RSI based on the groundwater quality data collected during the well rehabilitation program.

Table 5. Results of Groundwater Stability Indices

Stability Index	PW1 *(Calculated Index Value)*	PW2 *(Calculated Index Value)*
Langelier Saturation Index (LSI)	0.77	0.76
Ryznar Stability Index (RSI)	6.7	6.6

The calculated LSI and RSI values indicate the groundwater from each of the wells over saturated with respect to calcium carbonate and therefore there is a scaling tendency present. Not surprisingly, this is supported by the geochemical data obtained in the analysis conducted on the scale material collected and analyzed from the wells.

Additionally, given the observations made during the downhole camera inspections, namely the corrosive pitting in the casing, as well as the problems noted historically with pump and riser pipe degradation, the groundwater also appears to be considerably corrosive. The presence of the black iron sulfide precipitate (charcoal like substance), and the rotten egg odor (hydrogen sulfide) are all supportive evidence that there is a significant potential for iron corrosion. Based on this information, it is recommended that the pump riser pipe assembly be constructed of high density PVC (i.e. Certain Teed Certa-Lok PVC Drop Pipe for submersible pumps or similar) and that pump components be made of corrosive resistant materials.

Table 6 provides a summary of the chemical composition of both the well scale and the fine sand that was identified during the initial stages of the project. The purpose of this testing was to definitively determine the composition of each material in order to assess if the sand was in anyway associated with the biological/geochemical processes that have long been identified as source of scaling and well performance degradation. It was found that the two materials are geochemically very different, and that the sand is not likely associated with the precipitation / encrustation problems. In fact, it is believed that the source of the sand is directly from the formation (see as built drawings and geological log of PW1, Appendix A). This conclusion is supported by the downhole video inspection where sand particles were observed to be entering the well at a casing joint and what appeared to be a small hole in the casing.

Copies of the original laboratory reports can be found in Appendix F.

A sample of the scale material was sent to Vancouver Petrographics to perform a mineralogical analysis. This analysis was carried out in combination with the geochemical testing described above. The results of this analysis are provided in Appendix F.

In general, the following important conclusions were made (J.F. Harris, 2006 - Appendix F):

- The observed features of this sample are consistent with the deposition of iron (Fe) and calcium (Ca) within the well as a poorly consolidated scale.
- It seems probable that much of the Fe is derived by corrosive dissolution of the steel well casing and subsequent precipitation in hydroxide form.
- Microbial activity most likely plays a part in this process and in the formation of the minor co-precipitated Fe sulfides in the scale.
- The estimated composition of the scale material is as follows:
    - Quartz, (Quarzite) 15%
    - Carbonate ($CaCO_3$) 25%
    - Limonite ($FeO(OH)\cdot nH_2O$) 60%
    - Pyrite (FeS_2) trace
- The siliceous component occurs as discrete clasts ranging in size from 0.2 - 7.0 mm in size. These are clearly of mechanically transported origin, presumably introduced into the well by the inflowing water.

The geochemical and microbiological processes that are responsible for the precipitation/scale build up in both PW1 and PW2, are not expected to stop occurring. It must be understood that these processes are natural and that routine well maintenance must be considered if this resource is to be utilized in a sustainable manner. As discussed, the U.S. Water Quality Association identifies scaling as the number one water quality issue in the United States (Rafferty 2000) and can lead to significant operational issues if not properly considered in GSHP applications.

Table 6. Chemical Composition of Well Scale and Sand

Sample ID	S1 - Scale	S2 - Sand
Sample Date	**Dec 1, 2005**	**Dec 1, 2005**
Physical Tests		
pH	6.58	7.69
Total Metals		
Aluminum	1 030	2 970
Antimony	<50	<10
Arsenic	32	21.5
Barium	71.9	43.4
Beryllium	<2.5	<0.50
Bismuth	<100	<20
Cadmium	<2.5	<0.50
Calcium	101 000	7 390
Chromium	142	6.8
Cobalt	19	8.7
Copper	199	22.2
Iron	343 000	20 700
Lead	<250	<50
Lithium	<10	6.4
Magnesium	3 240	3 220
Manganese	2 440	301
Mercury	<0.050	<0.050
Molybdenum	36	<4.0
Nickel	138	19.2
Phosphorus	480	275
Potassium	<1000	260
Selenium	<10	<2.0
Silver	<10	<2.0
Sodium	<1000	<200
Strontium	333	31.7
Thallium	<250	<50
Tin	<25	<5.0
Titanium	21.1	63.9
Vanadium	<10	5.7
Zinc	97.1	276

Notes:

All results are expressed as milligrams per dry kilogram unless otherwise stated.

6. Conclusions and Recommendations

A major challenge of utilizing PW1 and PW2 as a warm groundwater supply is that fact that the groundwater is highly mineralized, which over time, leads to a combination of corrosive and mineral encrusting (scaling) related issues. According to the Water Quality Association, scaling is the number one water quality issue in the United States (Rafferty 2000) and can lead to significant operational issues if not properly considered in GSHP applications.

The accumulation of these materials through time, specifically across the screen interval or production zone of the well, has led to a restriction in groundwater flow and an apparent drop in well productivity. It should be understood that these processes are natural and that routine well maintenance must be considered if this resource is to be utilized in a sustainable manner. Costs options to perform these tasks have been provided in this report. It is also important to understand that the reductions in well productivity are in no way related to limitations in the aquifer resource itself. The *aquifer* could likely sustain long term flow rates on the order of two hundred litres per second.

Based on a detailed review of the available historical drawdown data, it appears that pumping levels in both wells dropped off significantly within the first year or two after production started. It is recommended that the wells be rehabilitated on an annual basis. Additional benefits could be possible if more frequent cleaning cycles are performed. The wells have historically been operated seasonally, which may also contribute to the observed rate decreases in well efficiency / productivity. It is suspected that if the wells were run on a continual basis (i.e. year round), than the rates of well efficiency decline may be reduced.

The most recent rehabilitation data indicates that the well efficiency of PW1 has improved by approximately 4.4 times as a result of this rehabilitation program. However, PW1 is 31 years old and is showing significant signs of degradation, including corrosion and pitting on the well casing. It is estimated that PW1 may only have an expected life span of approximately 2 to 4 years. Based on video inspections of PW1, there are two identified locations where fine sand appears to be entering into the well. It is possible that these holes can be sealed with a liner casing, which may extend the longevity of the well, however it is difficult to predict precisely by how much. Currently, very little sand production occurs when flow rates are less than approximately 7.9 L/sec (125 US gal/min). However, it is difficult to predict how long these conditions will last. PW1 is currently flowing at an artesian flow rate of approximately 2.8 L/sec (45 US gal/min). Therefore it may be advantageous to utilize this groundwater on a continual basis in order to take advantage of this passive flow and energy component.

The pump from PW1 exhibited significant signs of mechanical wear as a result of pumping sand. The mechanical wear was so extensive that the pump was replaced. PW1 should *not* be used as a primary dedicated well for water production. Although a "gravel pack" now appears to have been developed around the base of the well screen and sand production rates seem to be minor when flow rates are less than 7.9 L/sec (125 US gal/min), it is unknown how long these conditions will continue, especially given the fact that PW1 typically operates "completely on" or "completely off".

Based on the drawdown data, it appears that little improvement in well efficiency on PW2 was achieved during this rehabilitation program. It is hypothesized that the reasons the chemical treatment may not have been as effective on PW2 as PW1 are two fold.

1. The acid was pumped through the packer located above the top of the screen, and may have entered only the most permeable, upper zones, of the screen / formation, limiting contact of the acid to the lower portion of the screen interval.
2. As a result of a different well construction configuration, approximately ¼ the acid volume used on PW1 was used on PW2.

From the knowledge gained during this project, it is anticipated that a more aggressive rehabilitation of PW2 using higher acid volumes, could result in similar improvements in well efficiency as were obtained on PW1. The condition of PW2 appears to be good. It is predicted that PW2 could have a life span of an additional 15 to 20 years, if a routine and effective well maintenance program is carried out. Based on an extrapolation of the historical and current drawdown data, it appears today that PW2 could sustain a flow rate of 16 L/sec (250 US gal/min). This rate however may require the pump to be located at a deeper level in the well.

When PW2 was first drilled, it could produce 16 L/sec with approximately 16 m of drawdown. Given the current post rehabilitation performance level of PW2, a pumping rate of 16 L/sec could potentially create a pumping level as great as 150 to 175 m below the top of casing. If similar improvements in efficiency were obtained on PW2 as were on PW1, pumping levels could be reduced to less than 50 m. For cost comparison purposes, it costs approximately $12,000 more per year to operate a well pumping water from 175 m versus 50 m below ground surface (based on a pumping duration of 150 days at 16L/sec).

Additionally, given the historical performance of PW2, a pumping level of 175 m at 16 L/sec suggests that flow into PW2 is currently quite restricted. This restriction is likely creating high entry velocities (the speed the groundwater enters the casing) and may lead to excessive screen wear and somewhat reduce the longevity of the well screen. More concerning however, is that increased levels of drawdown may promote the geochemical processes associated with scale build-up and potentially may lead to an increased rate of well efficiency decline.

If both wells were to operate at the recommended pumping rates, there would be a cumulative drawdown effect on the order of approximately 10 m. Given the large available drawdown; it is not anticipated that cumulative draw down effects would be problematic (i.e. combined flow of 24 L/sec). Again, it should be noted that it is recommended that PW1 not be used as a primary dedicated well, so such a flow rate currently could not be obtained.

Based on a review of the historical documents associated with PW1 and PW2, it appears that the groundwater temperatures have been relatively constant since the wells were first constructed. The groundwater temperatures of PW1 and PW2 measured at surface during this study are 15.3 °C and 14.7 °C respectively.

Water quality samples collected at the end of the rehabilitation program indicate that the groundwater has been returned to its original quality prior to well cleaning. A comparison of the water quality data to historical data suggests the water quality appears to have not changed since the wells were first drilled, both from a chemical and a physical (i.e. temperature) perspective.

To help provided a cost effective way to help mitigate the problems associated with steel pipe pitting and corrosion, it is recommended that the pump riser pipe assembly be constructed of high density PVC material.

The calculated water indices for the wells show that the groundwater is scale forming (i.e. over saturated with respect to calcium carbonate). Additionally the mineralogical and analytical tests on the scale fragments suggest that its composition is consistent with the deposition of iron (Fe) and calcium (Ca) within the well as a poorly consolidated material. It seems probable that much of the Fe is derived by corrosive dissolution of the steel well casing and subsequent precipitation of hydroxides form microbial activity most likely plays a part in this process and also in the formation of the minor co-precipitated Fe sulfides. The estimated composition of the scale material is as follows:

- Quartz, (Quarzite) 15%
- Carbonate ($CaCO_3$) 25%
- Limonite ($FeO(OH)\cdot nH_2O$) 60%
- Pyrite (FeS_2) trace

The estimated cost to replace a well with similar construction and depth to PW2 is on the order of $200,00 to $250,000.

6.1 Well Maintenance Options and Costs

Each of the cleaning methods discussed below provide a relatively comparable level of cleaning. Cost estimates for each technology are provided for both wells. A 30% contingency has been added to the costs for budgeting purposes. Detailed costing and or specific mechanical requirements for actual system construction/requirements have *not* been confirmed at this time. However, the information below has been provided by appropriate professionals in the industry and should be sufficient for the current feasibility study.

Option 1. Current method of rehabilitation: $55 K (for both wells).

- Local pump contractor (e.g. Aqua Tech Supplies and Services) conduct mechanical and chemical rehabilitation program.
- Down time of approximately 7 days per well.

Option 2. In-situ Well Maintenance Technology

These technologies involve installing a well cleaning system "on-top of" the existing wellhead infrastructure. Two methods (Option 2A and 2B) have been investigated.

Option 2A. In-situ Acid Injection System: $120 K (for both wells).

- This would involve a dedicated injection line to the bottom of each well that would deliver an acid solution across the entire screen interval.
- A dedicated chemical pump and reservoir would be installed within the adjacent utility building.
- A waste stream on the wellhead would be installed to divert the wastewater during a flush cycle.
- The wastewater would then be pumped into an on-site reservoir and neutralized.
- Once neutralized, the wastewater would be pumped into the municipal sewage system.
- Training of personnel would be required as well as routine equipment maintenance and purchase of chemicals.
- Down time would be approximately 24 to 48 hrs.

Option 2B. In-situ CO_2 Injection System: $80K plus $10K per cleaning cycle (for both wells).

- This would involve the installation of a CO_2 injection system that would deliver liquid CO_2 to the entire screen interval.
- A waste stream on the wellhead would be installed to divert the wastewater during a cleaning cycle.
- The waste stream could be discharged directly to ground surface as there would be no requirement for neutralization or treatment.
- No training of personnel would be required, as a technician would travel to the site to conduct the work. Training could take place during site visits if the Village so chooses.

7. Acknowledgments

This study has been produced with the assistance of the Canadian Geoexchange Coalition and the Green Municipal Enabling Fund. The Green Municipal Enabling Fund is a Fund financed by the Government of Canada and administered by the Federation of Canadian Municipalities. Notwithstanding this support, the views expressed are the personal views of the author(s), and the Government of Canada, Canadian Geoexchange Coalition and the Federation of Canadian Municipalities accept no responsibility for them.

8. Closure

This report was prepared for Energy Solution Centre. The report, which specifically includes all text, tables and appendices, is based on data and information collected during the investigations conducted by Gartner Lee Limited, and is based solely on the conditions of the site at the time of the investigation, supplemented by historical information obtained by Gartner Lee Limited, as described in this report.

The work described in this report, were conducted in a manner consistent with the level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

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. Gartner Lee Limited accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on the information contained in this report.

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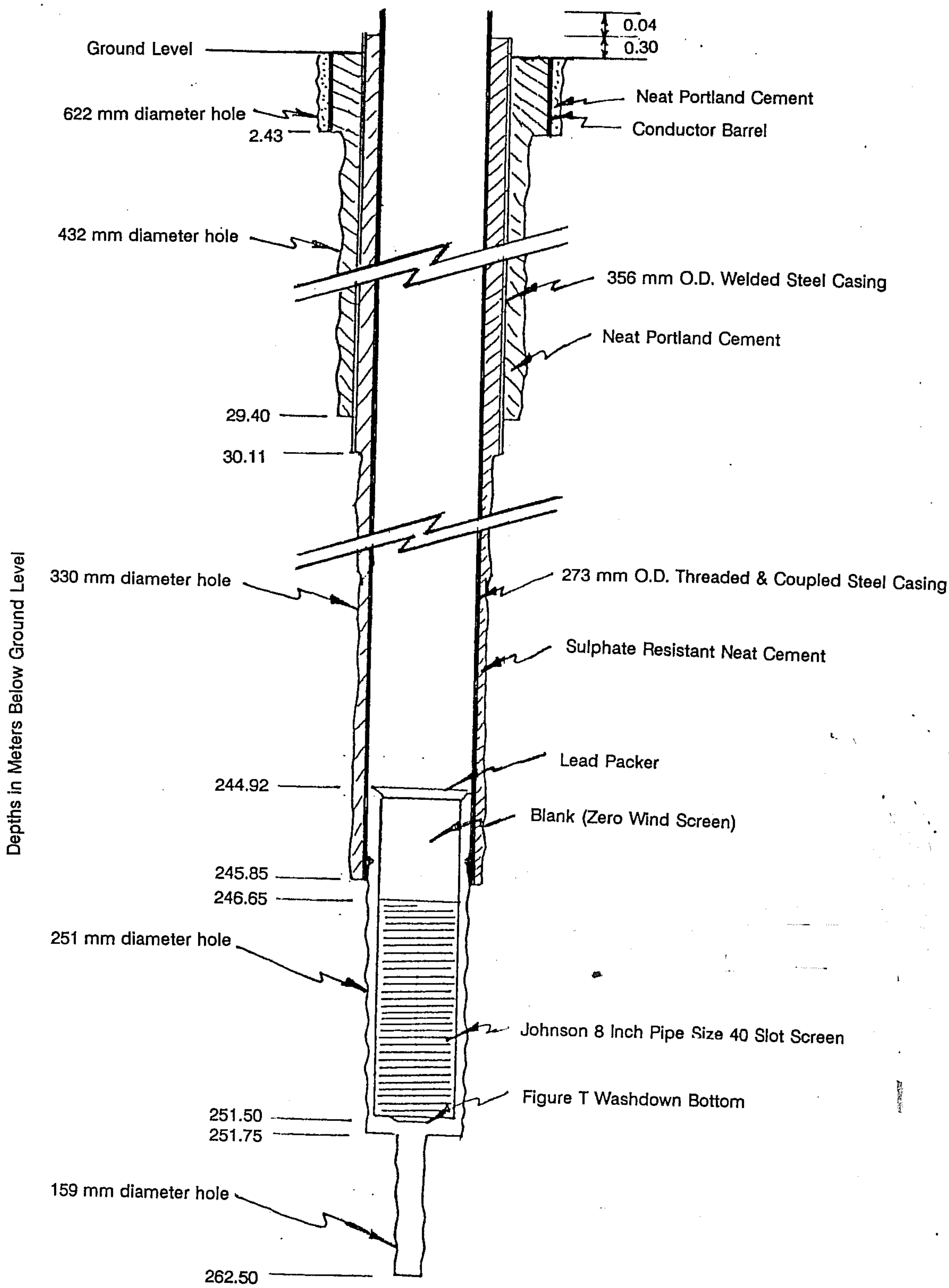
Appendices

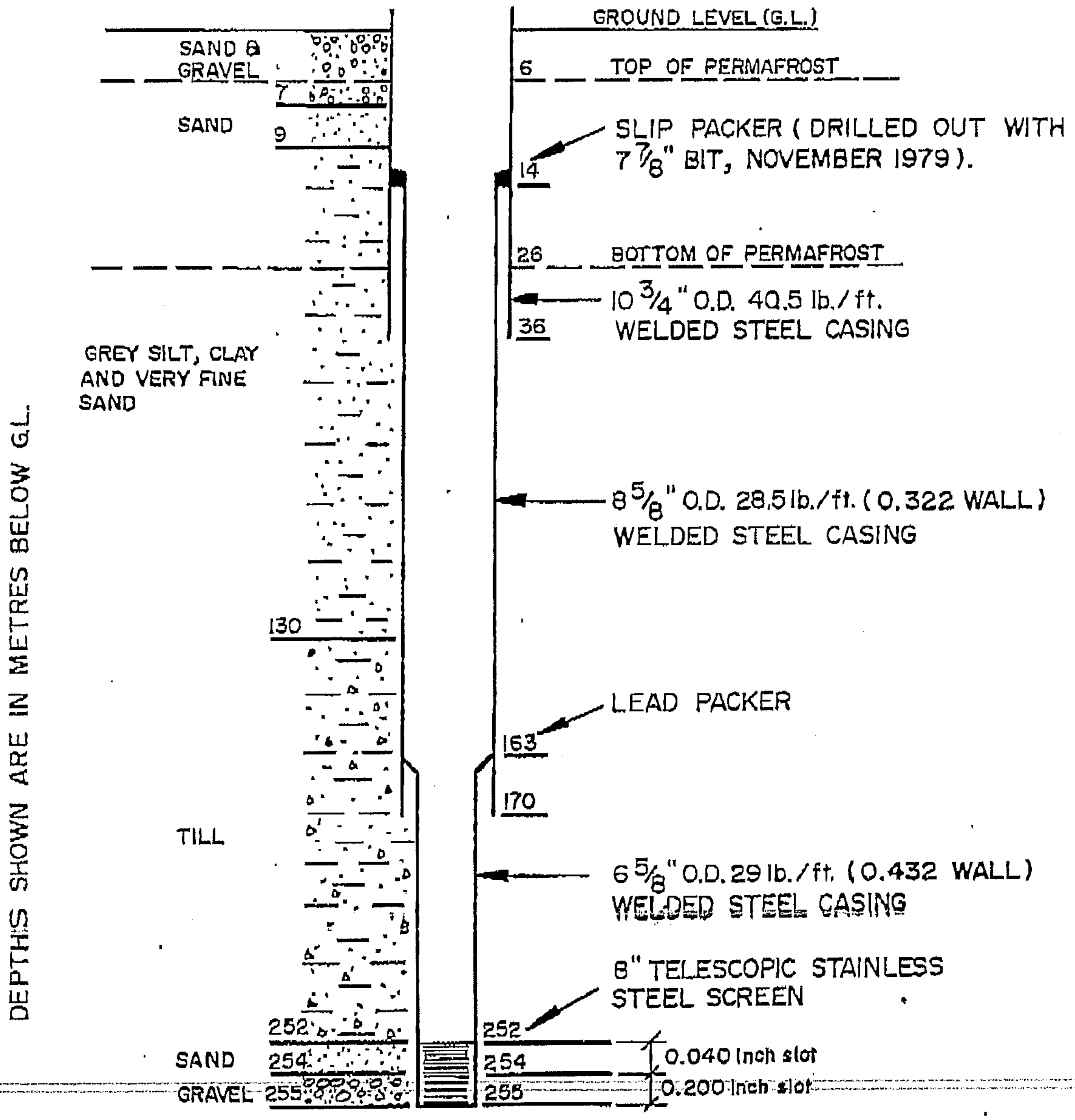
Appendix A

As Built Drawing of the Production Wells



JOB No. 90E-353-1	CONSTRUCTION DETAILS OF MAYO WARM WATER WELL PW 2	DATE 07/06/90	
SCALE NTS		FIGURE 4	

MLM Ground-Water Engineering



SCALE: NTS	PW1 CONSTRUCTION DETAILS OF MAYO WARM WATER WELL	JOB No. 86A-280-6
DATE: OCT. / 86		FIGURE: 3

MLM Ground-Water Engineering Ltd.

Appendix B

Photo Log

Photograph 1: Following the initial step test and prior to well cleaning, the riser pipe and pump were removed from the well to provide access with the rehabilitation tools and well cleaning chemicals.

Photograph 2: Silica sand was found within the impellers from pump PW1. Silica sand was NOT found in PW2. Both pumps however were removed and replaced as it was determined the pumps had lost efficiency due to mechanical wear.

Photograph 3: A close-up of the pump impellers from PW1. Note the mechanical wear at the base of the impeller.

Photograph 4: Well brushing tool used to swab the side walls of the casing and screen. Various sizes were on-site to accommodate different casing diameters.

Photograph 5: Air inflatable (blue line) packer used to isolate the bottom portion of the well. Once the lower portion of the well was "packered off" (I.e. no flow condition was established), the well cleaning chemicals were injected from surface down the metal riser pipe (shown above), into the screen interval.

Photograph 6: Metal riser pipe attached to top off packer. The pipe / valve on the left was used to inject the well cleaning chemicals. Once pumped into the well this valve was closed and a pressure gauge was used to monitor "off gas" pressure build up. The valve shown at top was used to periodically vent the system. A hose was attached to this pipe (not shown in photo) to ensure that any vented gas or liquid was discharged in an appropriate area.

Photograph 7: A pump used to inject the well cleaning chemicals below the packer into the screen interval. An artesian pressure of approximately 9 psi had to be overcome in order to pump the chemicals into the system.

Photograph 8: Close up of precipitate and scale debris that was removed from the well.

Appendix C

Product Data Sheets of Well Cleaning Chemicals

MATERIAL SAFETY DATA SHEET

OSHA - Meets 29 CFR 1910.1200 Standards	HMIS HAZARD RATINGS			
COTEY CHEMICAL CORP.	HEALTH	1	0 = INSIGNIFICANT	3 = HIGH
	FLAMMABILITY	0	1 = SLIGHT	4 = EXTREME
	PHYSICAL HAZARD	0	2 = MODERATE	

TRANSPORTATION INFORMATION

PROPER SHIPPING NAME:	Corrosive liquid, acidic, organic, n.o.s. (hydroxyacetic acid)		
HAZARD CLASS / PKG GRP:	8 / III	REF:	49 CFR 173.154, .203, .241
IDENTIFICATION NUMBER:	UN 3265	LABEL:	CORROSIVE

SECTION 1 - PRODUCT / COMPANY IDENTIFICATION

IDENTITY (AS USED ON LABEL AND LIST)
BIOCLEAN

MANUFACTURER'S NAME Cotey Chemical Corporation	EMERGENCY TELEPHONE NUMBER Infotrac (800) 535-5053 Outside USA (352) 323-3500
ADDRESS (NUMBER, STREET, P.O. BOX) 4410 M.L.K. Blvd.	TELEPHONE NUMBER FOR INFORMATION (800) 457-2096
(CITY, STATE AND ZIP CODE) Lubbock, TX 79404	DATE PREPARED: August 10, 2004 SUPERSEDES: November 10, 2001

SECTION 2 - HAZARDOUS INGREDIENTS / IDENTITY INFORMATION

HAZARDOUS COMPONENTS (SPECIFIC CHEMICAL IDENTITY; COMMON NAME(S))	CAS #	% (OPTIONAL)	OSHA PEL		ACGIH TWA		SARA TITLE III	RQ LBS
			PPM	MG/M3	PPM	MG/M3		
Hydroxyacetic acid	79-14-1	30 - 60	not established					

SECTION 3 - HEALTH HAZARD DATA

ROUTES OF ENTRY - SIGNS AND SYMPTOMS OF EXPOSURE	EMERGENCY AND FIRST AID PROCEDURES
INHALATION: Corrosive and irritating to upper respiratory tract.	Remove affected person to fresh air; if breathing has not returned to normal within a few minutes after exposure, get medical attention.
SKIN: Corrosive and irritating; chemical burns may result from contact.	Remove contaminated clothing; wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention.
EYES: CORROSIVE; Contact with eyes is painful and irritating and will cause chemical burns.	Remove contact lenses. Immediately flush eyes for 15 minutes in clear running water while holding eyelids open; seek medical attention immediately.
INGESTION: Corrosive and irritating to digestive tract; vomiting may occur.	Drink two glasses of water followed by milk, milk of magnesia or other non-alcoholic liquids; DO NOT induce vomiting; seek medical attention immediately.

HEALTH HAZARDS (ACUTE AND CHRONIC): Corrosive to skin and eyes; prolonged inhalation of this product may cause ulcers to the upper respiratory tract; no long term health effects are known at this time, however, repeated contact with eyes may cause severe irritation.

CARCINOGENICITY	NTP?	IARC MONOGRAPHS?	OSHA REGULATED?
	No	No	No

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE: Preexisting skin, eye, or respiratory disorders may become aggravated through prolonged exposure.

MATERIAL SAFETY DATA SHEET

IDENTITY (AS USED ON LABEL AND LIST)	
BIOCLEAN	Date: August 10, 2004

SECTION 4 - FIRE FIGHTING MEASURES

FLASH POINT (METHOD USED)	NFPA RATING	FLAMMABLE LIMITS
Non-flammable	None	LEL: Not applicable UEL: Not applicable

EXTINGUISHING MEDIA
Carbon dioxide, water, water fog, dry chemical, chemical foam

SPECIAL FIRE FIGHTING PROCEDURES
Keep containers cool with water spray to prevent container rupture due to steam buildup; CAUTION - material is corrosive.

UNUSUAL FIRE AND EXPLOSION HAZARDS
None

SECTION 5 - ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: CAUTION - CORROSIVE. Wash small spills to sanitary sewer. Large spills - confine spill, soak up with approved absorbent, shovel product into approved container for disposal.

SECTION 6 - HANDLING AND STORAGE

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Keep container closed when not in use; protect containers from abuse; protect from extreme temperatures. CAUTION - material is corrosive. Keep this and other chemicals out of reach of children.

SECTION 7 - EXPOSURE CONTROLS / PERSONAL PROTECTION

RESPIRATORY PROTECTION (SPECIFY TYPE): None required while threshold limits (Section 2) are kept below maximum allowable concentrations; if TWA exceeds limits, NIOSH approved respirator must be worn. Refer to 29 CFR 1910.134 or European Standard EN 149 for complete regulations.

VENTILATION	LOCAL EXHAUST: Required MECHANICAL (GENERAL): Yes	SPECIAL: To maintain minimum TWA and STEL levels. OTHER: Engineering and work controls as required.
PROTECTIVE GLOVES: Neoprene or rubber gloves with cuffs.		EYE PROTECTION: Goggles with side shields; safety eyebath nearby.

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Coveralls, apron, or other equipment should be worn to minimize skin contact.

WORK / HYGIENIC PRACTICES: Practice safe workplace habits. Minimize body contact with this, as well as all chemicals in general.

SECTION 8 - PHYSICAL / CHEMICAL PROPERTIES

BOILING POINT 212° F	SPECIFIC GRAVITY (WATER = 1) 1.170
VAPOR PRESSURE (MM Hg) 17 mm Hg @ 20 ° C	pH 1.2
VAPOR DENSITY (AIR = 1) > 1	EVAPORATION RATE (WATER = 1) < 1
SOLUBILITY IN WATER Complete	% VOLATILE (BY WEIGHT) 50%
APPEARANCE AND ODOR Amber to colorless liquid, characteristic odor	

SECTION 9 - STABILITY AND REACTIVITY

STABILITY UNSTABLE: STABLE: XXX	CONDITIONS TO AVOID: Extreme temperatures

INCOMPATIBILITY (MATERIALS TO AVOID):
Strong oxidizers, strong acids, strong alkalies

HAZARDOUS DECOMPOSITION OR BYPRODUCTS: Decomposition will not occur if handled and stored properly. In case of a fire, oxides of carbon, hydrocarbons, fumes, and smoke may be produced.

HAZARDOUS POLYMERIZATION MAY OCCUR: WILL NOT OCCUR: XXX	CONDITIONS TO AVOID: None

SECTION 10 - DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Dispose of in accordance with Local, State, and Federal Regulations. Refer to "40 CFR Protection of Environment Parts 260 - 299" for complete waste disposal regulations for corrosive materials. Consult your local, state, or Federal Environmental Protection Agency before disposing of any chemicals.

MATERIAL SAFETY DATA SHEET

OSHA - Meets 29 CFR 1910.1200 Standards

COTEY CHEMICAL CORP.

HMIS HAZARD RATINGS

HEALTH	2	0 = INSIGNIFICANT	3 = HIGH
FLAMMABILITY	0	1 = SLIGHT	4 = EXTREME
PHYSICAL HAZARD	0	2 = MODERATE	

TRANSPORTATION INFORMATION

PROPER SHIPPING NAME:	Corrosive liquid, n.o.s. (hydrochloric acid)		
HAZARD CLASS / PKG GRP:	8 / II	REF:	49 CFR 173.154, .202, .242
IDENTIFICATION NUMBER:	UN 1760	LABEL:	CORROSIVE

SECTION 1 - PRODUCT / COMPANY IDENTIFICATION

IDENTITY (AS USED ON LABEL AND LIST)

LIQUID ACID DESCALER

MANUFACTURER'S NAME Cotey Chemical Corporation	EMERGENCY TELEPHONE NUMBER Infotrac (800) 535-5053 Outside USA (352) 323-3500
ADDRESS (NUMBER, STREET, P.O. BOX) 4410 M.L.K. Blvd.	TELEPHONE NUMBER FOR INFORMATION (800) 457-2096
(CITY, STATE AND ZIP CODE) Lubbock, TX 79404-	DATE PREPARED: August 10, 2004 SUPERSEDES: March 21, 2001

SECTION 2 - HAZARDOUS INGREDIENTS / IDENTITY INFORMATION

HAZARDOUS COMPONENTS (SPECIFIC CHEMICAL IDENTITY; COMMON NAME(S))	CAS #	% (OPTIONAL)	OSHA PEL		ACGIH TWA		SARA TITLE III	RQ LBS
			PPM	MG/M3	PPM	MG/M3		
Hydroxyacetic acid	79-14-1		not established					
Hydrochloric acid (a,b,c)	7647-01-0		5C	7 C	5 C			5000

(a) The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) has notification requirements for releases or spills to the environment of the Reportable Quantity (RQ for this mixture = 20,000 lbs) or greater amounts, according to 40 CFR 302.

(b) A "C" in the OSHA PEL or ACGIH TWA column indicates ceiling limits, the concentration that should not be exceeded during any part of the working exposure.

(c) OSHA proposed a regulation (29 CFR 1910.119) to monitor and control safety at certain types of industrial facilities. Compliance is triggered by specified quantities of specific chemicals. Minimum threshold quantity for this Highly Hazardous Chemical is 5,000 lbs.

SECTION 3 - HEALTH HAZARD DATA

ROUTES OF ENTRY - SIGNS AND SYMPTOMS OF EXPOSURE	EMERGENCY AND FIRST AID PROCEDURES
INHALATION: Corrosive and irritating to upper respiratory tract.	Remove affected person to fresh air; if breathing has not returned to normal within a few minutes after exposure, get medical attention.
SKIN: Corrosive and irritating; chemical burns may result from contact.	Remove contaminated clothing; wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention.
EYES: CORROSIVE; Contact with eyes is painful and irritating and will cause chemical burns.	Remove contact lenses. Immediately flush eyes for 15 minutes in clear running water while holding eyelids open; seek medical attention immediately.
INGESTION: Corrosive and irritating to digestive tract; vomiting may occur.	Drink two glasses of water followed by milk, milk of magnesia or other non-alcoholic liquids; DO NOT induce vomiting; seek medical attention immediately.

HEALTH HAZARDS (ACUTE AND CHRONIC): Corrosive to skin and eyes; prolonged inhalation of this product may cause ulcers to the upper respiratory tract; no long term health effects are known at this time, however, repeated contact with eyes may cause severe irritation.

CARCINOGENICITY NTP? No IARC MONOGRAPHS? No OSHA REGULATED? No

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE: Preexisting skin, eye, or respiratory disorders may become aggravated through prolonged exposure.

MATERIAL SAFETY DATA SHEET

IDENTITY (AS USED ON LABEL AND LIST)	
LIQUID ACID DESCALER	Page 2 of 2 Date: August 10, 2004

SECTION 4 - FIRE FIGHTING MEASURES

FLASH POINT (METHOD USED)	NFPA RATING	FLAMMABLE LIMITS
Non-flammable	None	LEL: Not applicable UEL: Not applicable

EXTINGUISHING MEDIA
Carbon dioxide, water, water fog, dry chemical, chemical foam

SPECIAL FIRE FIGHTING PROCEDURES
Keep containers cool with water spray to prevent container rupture due to steam buildup; CAUTION - material is corrosive.

UNUSUAL FIRE AND EXPLOSION HAZARDS
None

SECTION 5 - ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: CAUTION - CORROSIVE. Wash small spills to sanitary sewer. Confine large spill, soak up with approved absorbent, shovel product into approved container; for spills in excess of allowable limits (RQ) notify the National Response Center (800) 424 - 8802; refer to CERCLA 40 CFR 302 for detailed instructions concerning reporting requirements.

SECTION 6 - HANDLING AND STORAGE

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Keep container closed when not in use; protect containers from abuse; protect from extreme temperatures. CAUTION - material is corrosive. Keep this and other chemicals out of reach of children.

SECTION 7 - EXPOSURE CONTROLS / PERSONAL PROTECTION

RESPIRATORY PROTECTION (SPECIFY TYPE): None required while threshold limits (Section 2) are kept below maximum allowable concentrations; if TWA exceeds limits, NIOSH approved respirator must be worn. Refer to 29 CFR 1910.134 or European Standard EN 149 for complete regulations.

VENTILATION — LOCAL EXHAUST: Required MECHANICAL (GENERAL): Yes	SPECIAL: To maintain minimum TWA and STEL levels. OTHER: Engineering and work controls as required.
PROTECTIVE GLOVES: Neoprene or rubber gloves with cuffs.	EYE PROTECTION: Goggles with side shields; safety eyebath nearby.

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Coveralls, apron, or other equipment should be worn to minimize skin contact.

WORK / HYGIENIC PRACTICES: Practice safe workplace habits. Minimize body contact with this, as well as all chemicals in general.

SECTION 8 - PHYSICAL / CHEMICAL PROPERTIES

BOILING POINT 212° F	SPECIFIC GRAVITY (WATER = 1) 1.190
VAPOR PRESSURE (MM Hg) 17 mm Hg @ 20 ° C	pH < 1.0
VAPOR DENSITY (AIR = 1) > 1	EVAPORATION RATE (WATER = 1) < 1
SOLUBILITY IN WATER Complete	% VOLATILE (BY WEIGHT) 100%
APPEARANCE AND ODOR Pale yellow liquid, burnt sugar odor	

SECTION 9 - STABILITY AND REACTIVITY

STABILITY — UNSTABLE: STABLE: XXX	CONDITIONS TO AVOID: Extreme temperatures

INCOMPATIBILITY (MATERIALS TO AVOID):
Strong oxidizers, strong acids, strong alkalies

HAZARDOUS DECOMPOSITION OR BYPRODUCTS: Decomposition will not occur if handled and stored properly. In case of a fire, oxides of carbon, chlorine, hydrocarbons, fumes, and smoke may be produced.

HAZARDOUS POLYMERIZATION — MAY OCCUR: WILL NOT OCCUR: XXX	CONDITIONS TO AVOID: None

SECTION 10 - DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Dispose of in accordance with Local, State, and Federal Regulations. Refer to "40 CFR Protection of Environment Parts 260 - 299" for complete waste disposal regulations for corrosive materials. Consult your local, state, or Federal Environmental Protection Agency before disposing of any chemicals.

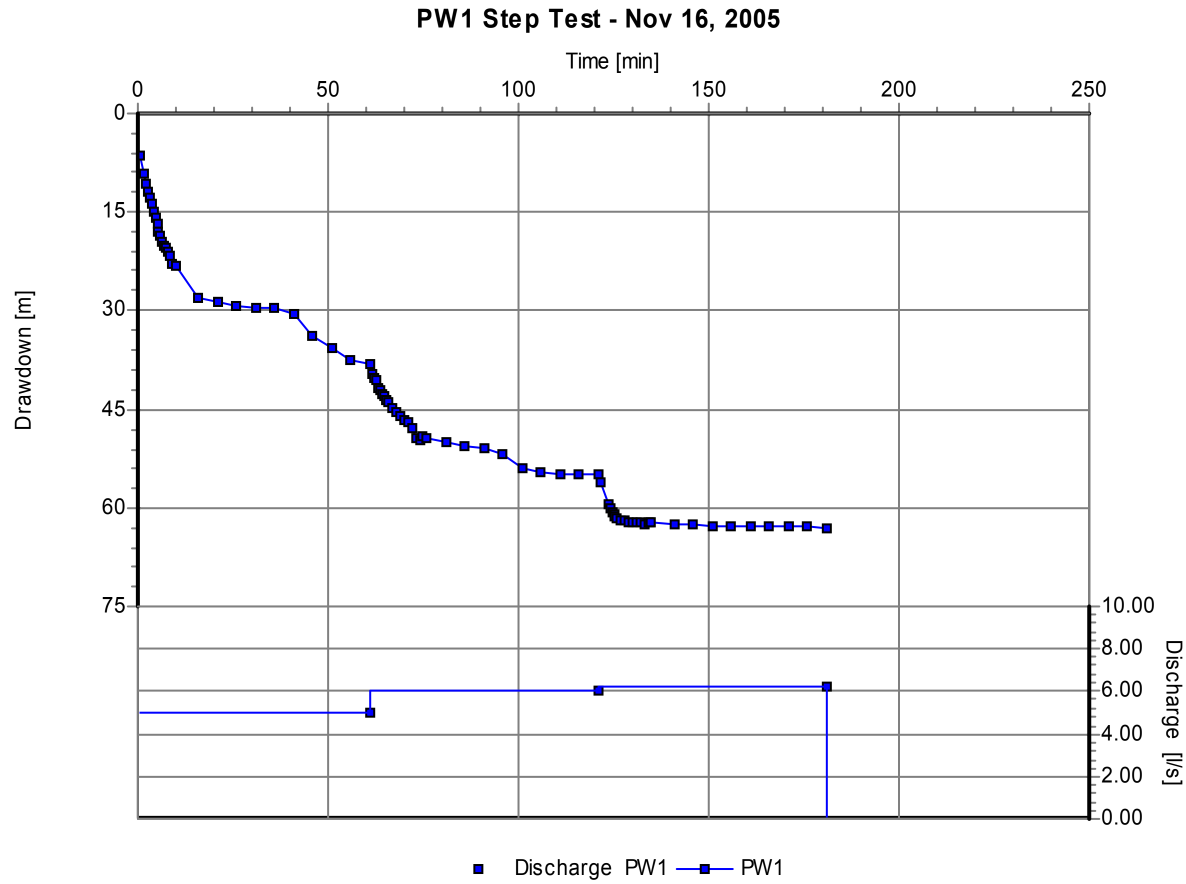
Appendix D

Results of Downhole Video Inspections

Appendix E

Summary of Pumping Test Data

Gartner Lee Limited	**Pumping Test Analysis Report**
2251 2nd Ave	Project: Well Rehab 2005
Whitehorse Yukon	Number: 50931
Phone: +1 867 633 6474	Client: Energy Solution Centre



Pumping Test: **No. 4 PW1 Step Test - Nov 16, 2005**

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

Analysis Results:

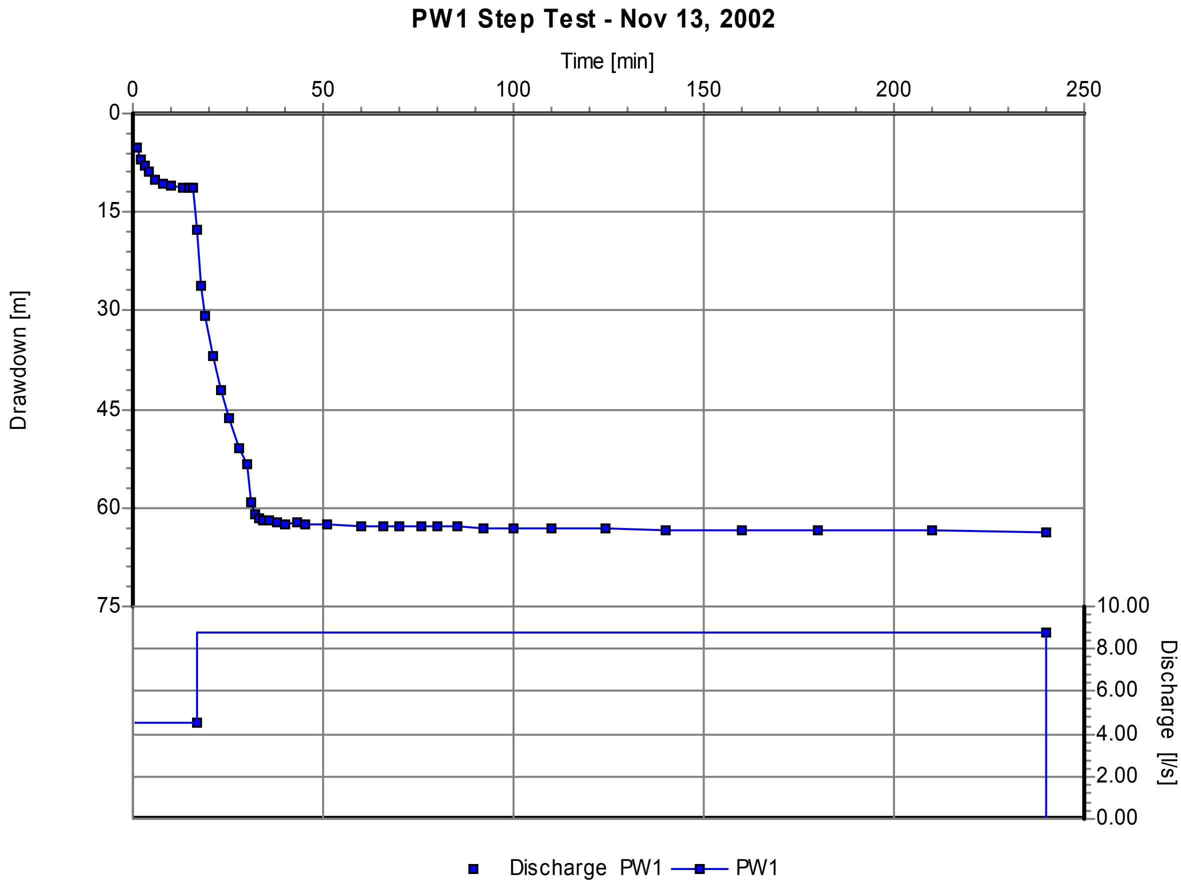
Test parameters:			
	Pumping Well:	PW1	Aquifer Thickness:
	Casing radius:	0.127 [m]	
	Screen length:	3.048 [m]	
	Boring radius:	0.076 [m]	
	Discharge Rate:	5.7370251 [l/s]	

Comments:

Evaluated by:

Evaluation Date: 1/16/2006

Gartner Lee Limited	**Pumping Test Analysis Report**
2251 2nd Ave	Project: Well Rehab 2005
Whitehorse Yukon	Number: 50931
Phone: +1 867 633 6474	Client: Energy Solution Centre



Pumping Test: **No. 3 PW1 Step Test - Nov 13, 2002**

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

Analysis Results:

Test parameters:

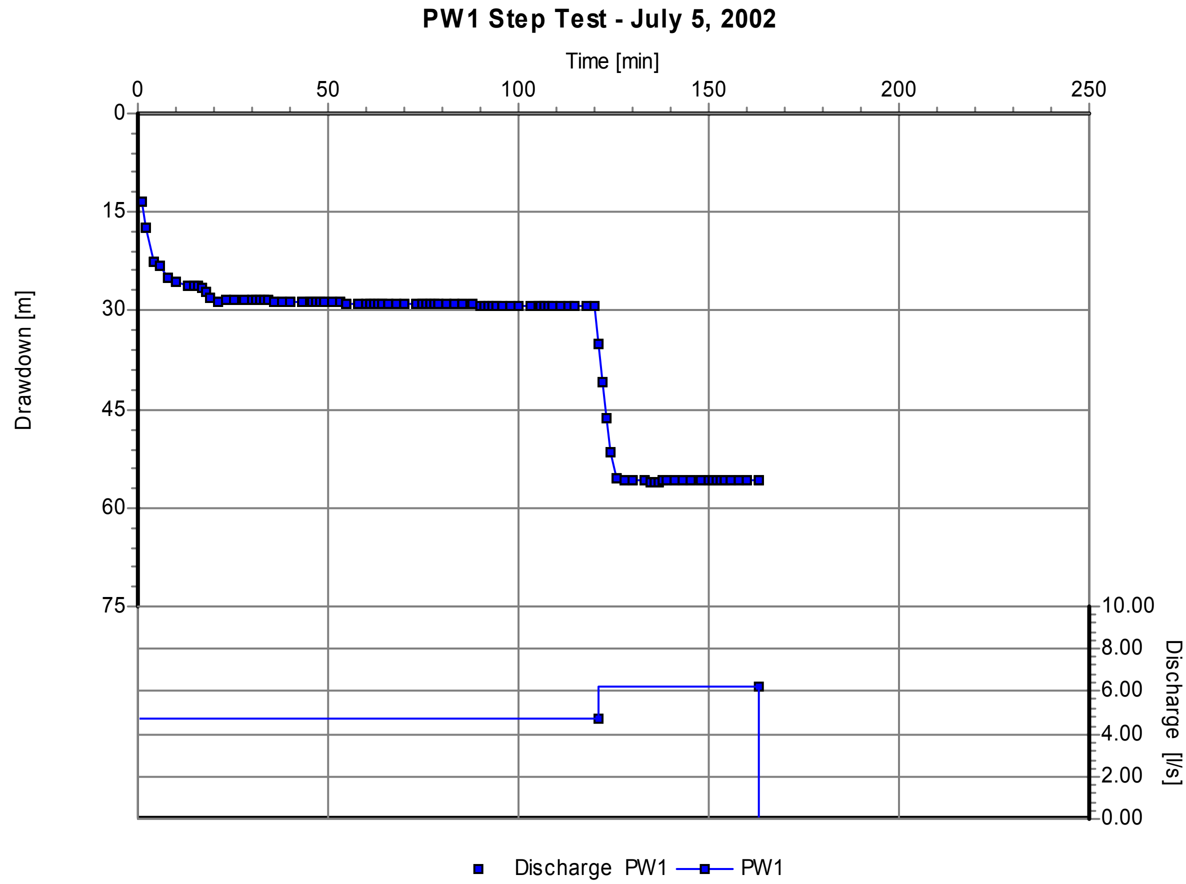
Pumping Well:	PW1	Aquifer Thickness:
Casing radius:	0.127 [m]	
Screen length:	3.048 [m]	
Boring radius:	0.076 [m]	
Discharge Rate:	8.4854096 [l/s]	

Comments:

Evaluated by:

Evaluation Date: 3/11/2003

Gartner Lee Limited 2251 2nd Ave Whitehorse Yukon Phone: +1 867 633 6474	**Pumping Test Analysis Report** Project: Well Rehab 2005 Number: 50931 Client: Energy Solution Centre



Pumping Test: **No. 2 PW1 Step Test - July 5, 2002**

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

Analysis Results:

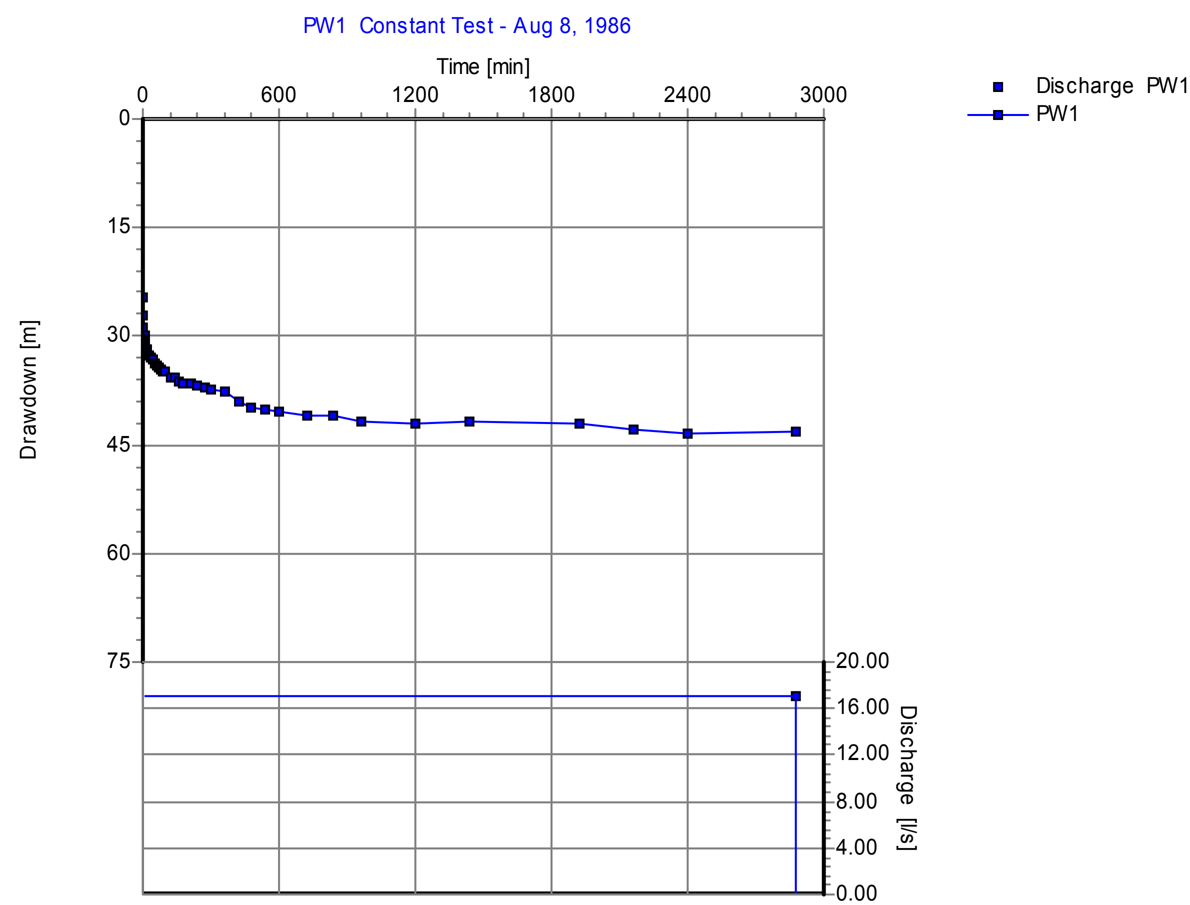
Test parameters:			
	Pumping Well:	PW1	Aquifer Thickness:
	Casing radius:	0.127 [m]	
	Screen length:	3.048 [m]	
	Boring radius:	0.076 [m]	
	Discharge Rate:	5.1043411 [l/s]	

Comments:

Evaluated by:

Evaluation Date: 3/10/2003

Gartner Lee Limited	**Pumping Test Analysis Report**	
2251 2nd Ave	Project:	Well Rehab 2005
Whitehorse Yukon	Number:	50931
Phone: +1 867 633 6474	Client:	Energy Solution Centre



Pumping Test: **No. 1b PW1 Constant Test - Aug 8, 1986**

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

Analysis Results:

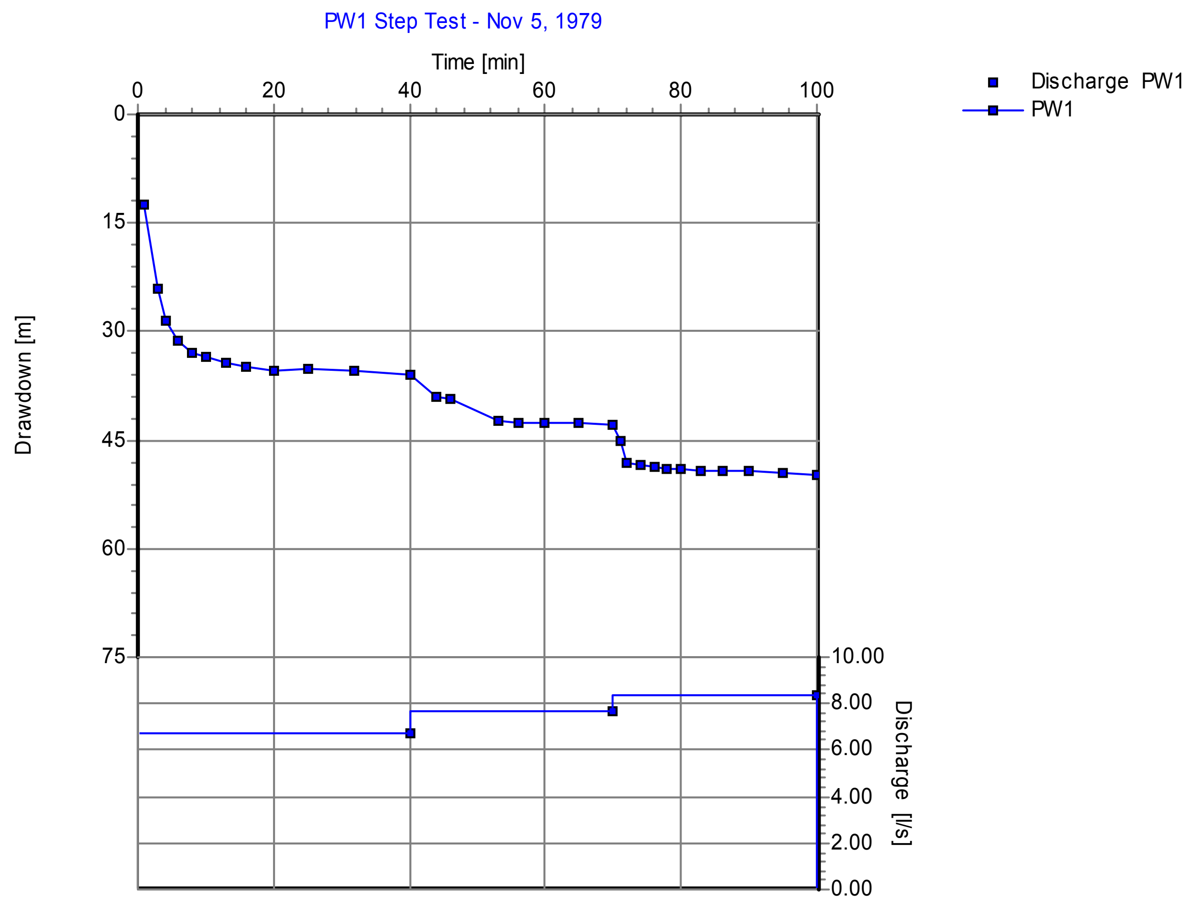
Test parameters:			
	Pumping Well:	PW1	Aquifer Thickness:
	Casing radius:	0.127 [m]	
	Screen length:	3.048 [m]	
	Boring radius:	0.076 [m]	
	Discharge Rate:	17.1 [l/s]	

Comments:

Evaluated by:

Evaluation Date: 1/31/2006

Gartner Lee Limited	**Pumping Test Analysis Report**	
2251 2nd Ave	Project:	Well Rehab 2005
Whitehorse Yukon	Number:	50931
Phone: +1 867 633 6474	Client:	Energy Solution Centre



Pumping Test: **No. 1a PW Step Test - Nov 5, 1979**

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

Analysis Results:

Test parameters:

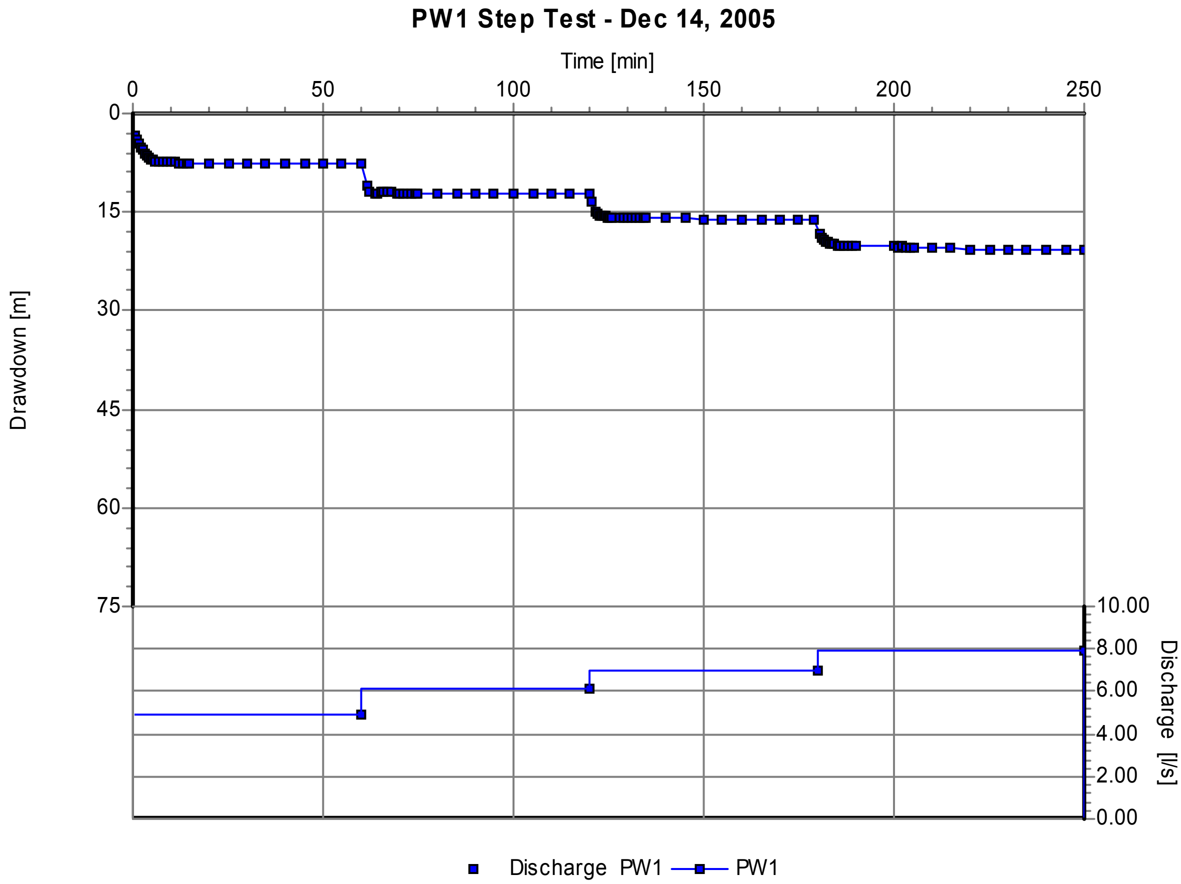
Pumping Well:	PW1	Aquifer Thickness:
Casing radius:	0.127 [m]	
Screen length:	3.048 [m]	
Boring radius:	0.076 [m]	
Discharge Rate:	7.49918 [l/s]	

Comments:

Evaluated by:

Evaluation Date: 1/19/2006

Gartner Lee Limited 2251 2nd Ave Whitehorse Yukon Phone: +1 867 633 6474	**Pumping Test Analysis Report** Project: Well Rehab 2005 Number: 50931 Client: Energy Solution Centre



<u>Pumping Test:</u> **No. 5 PW1 Step Test - Dec 14, 2005**

<u>Analysis Method:</u> **Drawdown vs. Time with Discharge**

<u>Analysis Results:</u>

<u>Test parameters:</u>

Pumping Well:	PW1	Aquifer Thickness:
Casing radius:	0.127 [m]	
Screen length:	3.048 [m]	
Boring radius:	0.076 [m]	
Discharge Rate:	6.538668 [l/s]	

<u>Comments:</u>

Evaluated by:

Evaluation Date: 1/16/2006

Appendix F

Original Copies of Laboratory Results