3.0 Field Investigations

In order to develop a better understanding of the geology and hydrogeology of the study area, and to confirm the availability of sufficient groundwater resources to sustainably meet the needs of this project, a series of field investigations were undertaken. These investigations included the following main components:

- Completion of a exploratory test hole program to refine the stratigraphy and identify a suitable target aquifer,
- Following the identification of a potentially suitable aquifer, completion of a preliminary pumping test to confirm the initial exploratory results,
- Completion of a full scale aquifer pumping test to obtain the necessary information on the aquifer properties and to measure the aquifers response to large scale pumping.

Details of the investigations and the results obtained are provided in the following sections.

3.1 Exploration Drilling Program

The exploration drilling program consisted of the drilling of ten test holes at the locations shown on Figure 03 (test holes TH-1 through 10) using mud rotary equipment owned and operated by Friesen Drillers Ltd.. The field work was supervised by Mr. Arne Pederson. Driller's Reports describing the soil stratigraphy are provided in Appendix B. As part of the exploration drilling, 50 mm (two inch) wells were installed in selected test holes to allow a groundwater sample to be airlift pumped from the target formation for field testing and to obtain preliminary scoping level information on the transmissivity of the formation. The results of these tests are documented in the Driller's Reports included in Appendix B. Also included in Appendix B are copies of the geophysical logs completed on selected test holes by provincial Groundwater Management Section staff.

The location of the test holes were selected to enhance the information from previous drilling and allow a more refined understanding of the stratigraphy to be developed. In general, the test holes were drilled at regular intervals along an east-west line paralleling Trail 16 (Figure 11, Section B) and a north-south line paralleling Highway 404 (Figure 12, Section C).

3.1.1 Study Area Stratigraphy

The information from the current test holes were used in conjunction with the information from previous test holes (Appendix A) to prepare the interpreted geologic sections provided on Figures 04, 11 and 12. Note: The stratigraphy presented on the geologic sections are considered to be major stratigraphic units with defined common characteristics. Subdivision of the stratigraphy into individual beds is not practical at the scale of these sections (horizontal scale – 1:100,000, vertical scale – 1:2,000) and with the spacing of the test holes. The defined common characteristics of these major stratigraphic units are as follows:

- **Upper Sand Unit** – The Upper Sand Unit is consistently encountered in all test holes throughout the area. This unit is on the order of 30 to 40 metres thick beneath the uplands, thinning to approximately 10 metres thick in the lowlands to the west of the Bedford Ridge. It is typically described in the test hole logs as sand varying from very fine to coarse grained with occasional gravel. Silt is present within this unit either as an accessory constituent (silty sand) or as discrete silt units. Some clay is present but it does not appear to be a significant component of this unit. The descriptions of this unit suggest that it has a distinct layering of finer to coarser beds that appear to vary from centimetres to metres in thickness. Such a layering is to be expected for sediments deposited in a distal glaciofluvial environment (Figure 05).

- **Upper Silt Unit** – Beneath the Upper Sand Unit is a unit that is generally described in the test hole logs as consisting primarily of silt with varying amounts of clay and sand. In places, it is described as consisting of interlayered clay, silt and sand. Overall, this unit appears to be a finer grained variant of the Upper Sand Unit. The demarcation between the upper and lower units was generally placed where the test hole logs indicate that the predominant grain size changes from sand to silt. This unit is generally found beneath the upper unit (ie: Figure 04) but does also appear to occur within the upper unit (ie: Figure 11 and 12) suggesting that it is part of a single depositional event. It has been subdivided out from the upper unit for the purposes of this study due to its hydrogeologic significance relative to the understanding of the groundwater flow regime.

- **Lower Sand Unit** – Throughout the study area, the majority of the test hole logs describe a transition at a depth of approximately 50 metres from sediments consisting predominantly of silts to sediments consisting predominantly of sand. This predominantly sand unit extends to a depth of 70 metres (locally to 100 metres) and has been classified as the Lower Sand Unit for the purposes of this study. It is generally described as consisting of fine to coarse sand with occasional gravel. Based on the descriptions in the logs, the unit likely has a distinct layering. Silt and possibly clay may also be present however the standard mud rotary drilling technique is not suitable to log finer materials at this depth. For example, test hole TH-5 was drilled using standard mud rotary techniques and the drillers report indicated that a silty sand was present from a depth of 58 to 84 metres (see test hole log TH-5 in Appendix B). This location was redrilled (test hole TH-5A) with a surface casing installed in the upper 18 metres to allow more representative samples to be obtained from depth without interference from the upper sediments. Using this method, it was found that the sediments from 57 to at least 106 metres consisted of sand varying from fine to coarse grained. Subsequent pumping tests indicated that the transmissivity of this zone is 4.6×10^{-2} m^2/s (320,000 USgpd/ft), consistent with the expected transmissivity for clean sand units. It is expected that similar difficulties were encountered in logging the previous test holes drilled using standard mud rotary techniques, and that the previous logs should be interpreted accordingly. This unit appears to extend continuously to the east, west, north and southeast (Figures 04, 11 and 12) and also likely extends to the northwest towards Marchand where inter-till sand and gravel layers are noted in the test hole logs at the approximate correct stratigraphic position. Locally, the unit appears to be absent (ie: Figure 11, Test Hole TH-2 and Figure 12, Test Hole TH-6).

- **Lower Till Unit** – The base of the Lower Sand Unit was interpreted to be at the depth at which the test hole logs describe the transition from a predominantly sand unit to a unit this is variably described as being "till", clay, silty clay or silt and clay. The Lower Sand Unit was the target unit for this groundwater exploration program and therefore most test holes were terminated when this lower unit was encountered. Based on the previous test hole logs, this unit appears to consist primarily of clayey silt or silty clay with varying amounts of sand and gravel, including possible inter-till sand and gravel layers. The reported presence of firm clay, granitic rubble, etc. suggests that this unit may be a basal till unit in the correct genetic description. From a hydrogeologic perspective, it is expected that the presence of the finer clay and silt materials will significantly limit the vertical and lateral movement of groundwater.

- **Red River Formation** – As is shown on Figure 03, the eastern limit of the Red River Formation limestones and dolomites is located approximately 5 to 8 kilometres west of the Bedford Ridge. Some minor outliers of limestone may be present closer to the Bedford Ridge but these are either discontinuous or too thin to be significant from a hydrogeologic perspective. This unit was not encountered in any of the current test holes.

- **Winnipeg Formation** – The eastern erosional limit of the Winnipeg Formation shales and sandstones does extend under the Bedford Ridge Uplands where they thin out against the basal Precambrian Shield granites as shown on Figure 11.

- **Precambrian Metamorphic** – Precambrian Shield metamorphic bedrock is present beneath the study area at a depth of 125 to 150 metres. For the purposes of this study, these granites are considered impermeable and form the base of the stratigraphic profile capable of hosting significant groundwater resources.

3.1.2 Preliminary Water Quality and Transmissivity Results

The results of the field water quality tests conducted on samples collected by air lift pumping from the Lower Sand Unit indicate that the water is of very high quality with electrical conductivity of approximately 300 umhos, low hardness and iron, and nondetectable manganese. The results of the air lift pumping tests also provided indicated transmissivities for the Lower Sand Unit varying from 4,000 Igpd/ft (TH-1) to 70,000 Igpd/ft (TH-8). Suitable indicated transmissivities for the development of wells of sufficient capacity for this project were found at test holes TH-5 and TH-7 along Highway 404, test hole TH-4 near Highway 210, and test hole TH-8 located approximately 6 kilometres east of Highway 210 along Trail 16 (Figure 03).

3.2 Preliminary Pumping Test

Based on the positive results from the exploration program, the decision was made to proceed with the completion of a preliminary pumping test of the Lower Sand Unit to: verify the indicated transmissivity of the aquifer; and obtain a representative water sample for laboratory analysis. Based on the indicated transmissivities from the exploration program, test hole location TH-5, near the intersection of Highway 404 and Trail 16 was selected for further testing.

A 150 mm (6 inch) well (designated as test well TH-5A) was installed at a distance of 14 metres from test well TH-5. The 150 mm well consisted of 9.1 metres of stainless steel screen installed at a depth of 90.0 to 99.1 metres below grade and PVC riser pipe. The static water level in this well was measured to be approximately 23 metres below grade. The pumping test was conducted at a rate of 12.3 L/s (195 USgpm) for a period of 24 hours with drawdown measurements made periodically in the pumping well, well TH-5 and well TH-7 located 1650 metres to the south (Figure 03). Following 24 hours of pumping, a drawdown of 4.6 metres was measured in the pumping well, and 0.29 metres in well TH-5 (distance of 14 metres). No detectable drawdown was measured at well TH-7, 1400 metres to the south. The pumping well efficiency was estimated to be a low 15%.

Analysis of the pumping test data using analytical methods resulted in an estimate of transmissivity for the aquifer of 4.6×10^{-2} m^2/s (320,000 USgpd/ft). The estimated storativity was 1×10^{-4}. The result is considered to be a better estimate of the actual transmissivity than was obtained from the TH-5 50 mm test well. However, it should be noted that for a high transmissivity aquifer of this type, a much higher pumping rate is required to induce sufficient drawdown to estimate the bulk aquifer transmissivity. The results of the pumping test are included in Appendix C.

The results of the laboratory water quality testing of a groundwater sample collected during the preliminary pumping test are included in Appendix D. As indicated, the water quality is very high. Total dissolved solids were measured at 177 mg/l, hardness is 153 mg/l, iron is 0.3 mg/l, manganese is 0.0437 mg/l and arsenic was undetectable. The results are considered representative of the water quality within this aquifer.

3.3 Groundwater Monitoring

In order to obtain detailed information on the current regional groundwater levels and flow directions, the observation wells installed as part of this and previous investigations were surveyed to establish the geodetic elevations and the groundwater levels were measured. As the aquifers in this area are essentially undeveloped, the water level measurements are considered to be representative of static, non-pumping conditions. As is illustrated on Figures 08 and 09, groundwater levels do vary seasonally in response to recharge events but the magnitude of the seasonal variation is small (typically << 1 metre).

The measured depths to groundwater and the calculated groundwater elevations are summarized in Table 1. Contour plots for groundwater levels in the Upper Sand Unit, Lower Sand Unit and Sandstone are presented on Figures 13, 14 and 15, respectively. The correlation of water level measurements to individual major stratigraphic units is based on the interpreted stratigraphy presented in Section 3.1.1 and Figures 04, 11 and 12. As is discussed in this section, within the major stratigraphic units there is a vertically downward hydraulic gradient. Where multiple, nested, water level readings are available at a single location, the upper reading has been used in the preparation of the contour plots.

Based on the results of this groundwater monitoring, the following observations and conclusions are made concerning the groundwater flow regime in the study area:

- Within the Upper Sand Unit, the measured depth to groundwater varied from a high of 38.5 metres beneath Bedford Ridge (well OH-034) to a low of 2.5 metres in the lowlands west of the Bedford Ridge (well TH-16). The corresponding groundwater elevations are 356.6 metres and 310.4 metres respectively, a groundwater elevation difference of 46.2 metres over a horizontal difference of approximately 7,500 metres. The indicated groundwater flow direction in this unit is generally from east to west, consistent with the expected flow regime of recharge within the pervious uplands and drainage towards the lowlands to the west and northwest. Between wells TH-15 and TH-16, the indicated hydraulic gradient is 0.008. The monitoring information from well nests installed in this unit indicate that there is a slight vertically downward hydraulic gradient through this unit, consistent with the expected flow regime within a fine to coarse layered sequence of sediments (Table 1 – well nests 9803, GSC 9902, 9806, and GSC 9901).

- Within the Lower Sand Unit, the measured depth to groundwater varied from a high of 24.0 metres beneath Bedford Ridge (well TH-5) to a low of 0.2 metres in the lowlands west of the Bedford Ridge (well TH-17). The corresponding groundwater elevations are 342.5 metres and 312.7 metres respectively, a groundwater elevation difference of 29.8 metres over a horizontal difference of approximately 6,000 metres. The indicated groundwater flow direction in this unit is generally from a groundwater high centred near well TH-8 (groundwater elevation of 371.5 metres) outwards to the west, north and east. The results suggest that recharge occurs in the area of well TH-8 and that groundwater flows laterally outwards to the lowlands from there. However, it should be noted that limited information is available to the east, south, and north of well TH-8 and further monitoring points may refine this interpretation. Also, it should be noted that within the Lower Sand Unit, there is a distinct vertically downward hydraulic gradient consistent with the expected flow regime within a layered sequence of sediments (Table 1 – well nest TH-12 and 19). Between wells TH-5A and TH-17, the indicated hydraulic gradient is 0.005.

- Within the Sandstone Unit, the measured depth to groundwater varied from a high of 14.1 metres beneath Bedford Ridge (well GSC 9901-4) to a low of 0.4 metres in the lowlands west of the Bedford Ridge (well TH-18). The corresponding groundwater elevations are 368.5 metres and 312.5 metres respectively, a groundwater elevation difference of 56 metres over a horizontal difference of approximately 11,000 metres. The indicated groundwater flow direction in this unit is to the northwest based on the three available monitoring points. Further monitoring points may refine this interpretation. Between wells GSC 9901-4 and TH-18, the indicated hydraulic gradient is 0.005.

- The results of the monitoring of well nests where information is available both within the Upper and Lower Sand Unit, indicates that there is a strong vertically downward hydraulic gradient between the two units (Table 1 – well nests TH-15/5A, TH-13/14, GSC 9902-1 to 3, and GSC 9901-1 to 3). In the immediate area of the pumping well (TH-15/5A), the groundwater level in the Upper Sand Unit is 16.1 metres higher than in the Lower Sand Unit. The exception to this downward trend is the TH-16/17 well nest in the lowlands west of the pumping well where the vertical gradient is upwards and the elevation difference is 2.3 metres (flowing artesian conditions in the Lower Sand Unit). This information provides a strong indication that the Upper Silt unit is an effective aquitard and that the hydraulic conductivity of the aquitard limits vertical flow either downward or upward. It is therefore reasonable to expect in this hydrogeologic situation that pumping from the Lower Sand Unit would primarily draw water laterally and would have a very limited effect on the shallow Upper Sand Unit and the surficial environment. Recharge to the Upper Sand Unit would also be expected to be restricted from moving downwards and would preferentially flow laterally through the Upper Sand Unit to the adjoining lowlands.
- A similar vertically downward hydraulic gradient is also present between the Lower Sand Unit and the Sandstone Unit (Table 1 – well nests TH-17/18, GSC 9901-3/4, and GSC 9902-3/4). This information provides a strong indication that the Lower Till Unit is an effective aquitard and that the hydraulic conductivity of that unit limits vertical flow. Therefore, it is reasonable to expect that pumping from the Lower Sand Unit would have a very limited effect on the Sandstone Unit.

3.4 Full Scale Pumping Test

The results of the exploration investigations undertaken provided a strong indication that the Lower Sand Unit hosted a potentially suitable aquifer for the development of a water supply of the size required for this project. Therefore, the decision was made to proceed with the installation of a full scale pumping well and completion of a pumping test. The first step in this process was to obtain a Groundwater Exploration Permit for MB Water Stewardship (copy in Appendix E) and obtain an easement to install the works on Crown land (copy of the easement application in Appendix F). The selected location for the full scale test well was in the southwest corner of SE22-05-09E, adjacent to well TH-5A.

3.4.1 Full Scale Test Well Construction

The installation of the full scale test well was completed by Friesen Drillers Ltd. on October 17 to 21, 2005. The locations of the full scale test well and the observation wells installed in the area of the test well are illustrated on Figure 16. The full scale test well consists of 406 mm (16 inch) steel casing installed from grade to a depth of 61 metres, followed by 254 mm (10 inch) 25 slot stainless steel screen installed from a depth of 61 to 99 metres. The annulus around the screen has been backfilled with a 10-20 sand pack. The casing was installed using the dual-rotary method which does not require the hole to be overdrilled. Therefore, grout around the casing is not required. The casing extends approximately 0.6 metres above grade. The well was constructed in a manner that made it suitable for use as a permanent pumping well with minor modifications to the well head.

3.4.2 Observation Well Network

In addition to the full scale test well, additional 50 mm diameter observation wells were installed at selected location to enhance the existing observation well network so that full information could be obtained on the aquifer response to pumping. Driller's Reports and well construction details for these additional wells are included in Appendix B. These additional observation wells included the following:

- **Pump Test Site** – An additional observation well (TH-15) was installed in the Upper Sand Unit adjacent to the pumping well. This well supplements the two wells (TH-5 and TH-5A) installed in the Lower Sand Unit at this location and allowed the Upper Sand Unit directly above the confined aquifer being pumping to be monitored.

- **400 and 800 Metres North of the Pump Test Site** – Additional wells were installed at distances of 369 (TH-11) and 778 (TH-12 and 19) metres to the north of the pump test site to allow the near field response of the aquifer to pumping to be measured. Well TH-11 was installed at the top of the Lower Sand Unit at a depth of 45.7 to 48.8 metres. The borehole encountered a very coarse portion of the Lower Sand Unit at that location and all return flow/cuttings were lost. Therefore, the well could not be advanced further. Well TH-12 was installed in a deeper portion of the Lower Sand Unit at a depth of 105 to 110 metres. Well TH-19 was installed at approximately the same elevation as the pumping well screen at a depth of 75.3 to 78.3 metres. The three observation wells were designed to provide measurements of both the lateral and vertical response within the Lower Sand Unit to pumping.

- **Pocock Lake Ecologic Reserve** – The Pocock Lake Ecologic Reserve was identified as a significant environmental feature that required special attention. Therefore, two observation wells (TH-13 and 14) were installed within the highway right-of-way adjacent to the reserve to allow both the Upper sand Unit and the Lower Sand Unit to be monitored during pumping. Well TH-13 was installed in the Upper Sand Unit at a depth of 19.8 to 21.3 metres and well TH-14 was installed in the Lower Sand Unit at a depth of 59.1 to 65.2 metres.

- **West Side of WMA** – A nest of three observation wells were installed on the west side of the Watson P. Davidson WMA, directly west of the pumping well to allow groundwater to be monitored in the Upper Sand Unit (TH-16), the Lower Sand Unit (TH-17) and the Sandstone (TH-18) so that the potential effects of pumping on downgradient groundwater users and the environment could be assessed.

The other existing observation wells monitored as part of this pumping test are summarized on Table 2, with the locations shown on Figures 13, 14 and 15.

3.4.3 72 Hour Pumping Test

A 72 hour pumping test was completed on pumping well PW-1 using equipment supplied by Friesen Drilling Ltd., and under the supervision of UMA personnel. During the test, well PW-1 was pumped at a rate of 107 litres per second (1,700 USgpm), and the water was discharged a distance of approximately 100 metres onto a trail which drained the water west away from the well and towards the lowlands below the Bedford Ridge. During the test, water levels in the pumping well and the observation well network were measured periodically using either manual measurements or water pressure transducers, as summarized in Table 2. Water level recovery readings were taken up to 74 hours after the cessation of pumping. Time versus recorded drawdown plots for all wells monitored are included in Appendix G.

The following direct observations were made either during the test or from the measured drawdown responses in Appendix G:

- After 3 hours and 44 minutes of pumping, a temperature sensor on the generator failed and the generator shut down. The sensor was disabled and power was restored. Typically after shut downs, a pump test is cancelled and the test restarted after the water levels had restabilized. This was not considered necessary and the test results were not adversely affected for the following reasons:

- Following the resumption of pumping, the water levels rapidly returned to their pre-shut down drawdown levels. Review of the graphs for pumping well PW-1 and observation well TH-5A in Appendix G shows that the pre and post shut down trends follow the same curve and that no significant drawdown was lost.

- The shut down occurred after the early time drawdown effects were recorded. Therefore, the near field transmissivity and storativity calculated from this information is valid. Late time calculations of transmissivity (used for assessing long term effects) were not affected.

- During the test, a number of small rain showers passed through the area. Review of the monitoring data for observation wells not affected by the pumping indicates that this precipitation did not affect the results, as expected given that the test was completed on a deep confined aquifer.

- The results of the monitoring of observation well TH-15, installed in the Upper Sand Unit beside the pumping well, show that the water levels in the upper unit was not affected by either the pumping or the infiltration of the discharge water from the pump.

- During the test, 27.8 million litres (7.3 million US gallons) of water were pumped. The water flowed freely along natural drainage paths to the west and no flooding of land was observed.

- Based on the time versus recorded drawdown plots in Appendix G, the following observations are made:

  - **Pumping Well** – A total of 23.7 metres of drawdown was measured after 72 hours of pumping.

  - **Well TH-5A** (Distance = 3 metres) - A total of 6.3 metres of drawdown was measured after 72 hours of pumping, and approximately 80% recovery in water levels had occurred by 74 hours following the cessation of pumping. There were no significant positive or negative boundary effects evident in the data.

  - **Well TH-11** (Distance = 369 metres) – As discussed in Section 3.4.2, this well was installed in the upper portion of the Lower Sand Unit in a coarse granular unit at a higher elevation than the pumping well screen. Review of the drawdown plot in Appendix G indicates that the water level in this well was not affected by pumping. After the start of the pumping test, a slightly steeper decline in water levels from the pre-test natural decline was observed but this decline ceased early in the test and water levels remained stable for the remainder of the test. The results suggest that this upper portion of the Lower Sand Unit is not hydraulically connected or is only weakly hydraulically connected to the stratigraphic interval being pumped.

  - **Well TH-19** (Distance = 778 metres) – This well is installed in the Lower Sand Unit at the same elevation as the pumping well screen. A total of 1.4 metres of drawdown was measured after 72 hours of pumping, and approximately 80% recovery in water levels had occurred by 74 hours following the cessation of pumping. Review of the semi-log plots for this well (Appendix H) indicate that a negative boundary was intersected at approximately 500 minutes into the test, and that a positive boundary may have been intersected late in the test at approximately 2500 minutes.

- **Well TH-12** (Distance = 778 metres) – This well is installed in a coarser, deeper portion of the Lower Sand Unit at the same location as well TH-19. A total of 2.6 metres of drawdown was measured after 72 hours of pumping, and approximately 85% recovery in water levels had occurred by 74 hours following the cessation of pumping. No significant boundary effects are evident in either the linear or semi-log plots for this well.

- **Well TH-7** (Distance = 1646 metres) – This well is installed in the Lower Sand Unit to the south of the pumping well. A total of 0.9 metres of drawdown was measured after 72 hours of pumping, and approximately 55% recovery in water levels had occurred by 74 hours following the cessation of pumping. Review of the semi-log plots for this well (Appendix H) indicate that a negative boundary was intersected at approximately 1000 minutes into the test, and that a positive boundary may have been intersected late in the test at approximately 2500 minutes.

- **Pocock Lake ER Wells** (TH-13 and 14) – No discernable change in water levels due to pumping could be detected in either the well installed in the Upper Sand Unit (TH-13) or the Lower Sand Unit (TH-14).

- **West Side of WMA Wells** (TH-16, 17 and 18) - No discernable change in water levels due to pumping could be detected in either the well installed in the Upper Sand Unit (TH-16), the Lower Sand Unit (TH-17) or the Sandstone Unit (TH-18).

- **GSC Well Nests** (GSC 9901 and 9902) - No discernable change in water levels due to pumping could be detected in either the wells installed in the Upper Sand Unit (OH-038 and OH-039), the Lower Sand Unit (GSC 9901-3 and 9902-3) or the Sandstone Unit (GSC 9901-4 and 9902-4).

- **Other Lower Sand Unit Wells** (TH-1 and 4) - No discernable change in water levels due to pumping could be detected in either of these wells installed at distances of 4200 and 4800 metres, respectively.

- **Other Upper Sand Unit Wells** (OH-034 and 9803-1) - No discernable change in water levels due to pumping could be detected in either of these wells installed at distances of 2968 and 4400 metres, respectively.

- The review of the measured drawdowns over distance from the pumping well at the end of the pumping test (Figure 17) indicates that the results from well TH-5A, TH-7 and TH-19 fall within the expected straight line plot of drawdown over distance and that a higher level of drawdown was observed at well TH-12. The screen for well TH-19 was installed at approximately the same elevation as the screens for wells TH-5A and TH-7. The screen for well TH-12 is installed at a deeper elevation within the Lower Sand Unit. All available information indicates that the Lower Sand Unit consists of a series of horizontal layers and that groundwater flow is primarily horizontal and vertical flow is limited. The drawdown results are consistent with this interpretation. The pumping well is screened through a series of these layers and the drawdown results indicate that wells TH-5A, TH-7 and TH-19 are all screened within a single, relatively homogenous layer that has a distinct boundary. Well TH-12 is screened within a lower layer that has a lower transmissivity and does not appear to be bounded.

3.4.4 Calculated Transmissivity and Storativity

The results of the water level drawdown measurements at observation wells TH-5A, TH-7, TH-12 and TH-19 were analyzed to estimate the appropriate values for the transmissivity and storativity of the aquifer.

Analyses were not completed on the measurements from the other observation wells as the pumping had no discernable effect on the water levels. The analysis was completed using the Aqtesolv for Windows software package and either the Theis (1935) or the Cooper-Jacob (1946) solution for a pumping test in a confined aquifer. These analytical methods and the supporting software are commonly accepted in the hydrogeologic industry for the analysis of pumping tests. Plots of the results of these analyses are included in Appendix H.

The methods of analysis and the results obtained are as follows:

- **Well TH-5A** – The results from this observation well were analyzed in 2 parts. The early time data (prior to the generator shutdown) was analyzed to obtain the near field transmissivity estimate and the storativity value. The late time data (well after the generator shut down effects had dissipated) was then analyzed to obtain the bulk transmissivity estimate for estimating long term effects. The results of the early time analysis provided estimates of 0.029 m^2/sec. (203,000 USgpd/ft) for the near field transmissivity and 4.4 x 10^{-5} for the storativity. The analysis of the late time data provided an estimate of 0.01 m^2/sec. (70,000 USgpd/ft) for the bulk transmissivity.

- **Well TH-7** – The results from this well were also analyzed in two parts. The first part was the analysis of the early time data before the negative boundary was intersected at approximately 1,000 minutes into the test. The results of this analysis provided an estimate of transmissivity of 0.18 m^2/sec. (1,200,000 USgpd/ft). Analysis of the late time data after the negative boundary was encountered provided an estimate of 0.012 m^2/sec. (88,000 USgpd/ft).

- **Well TH-12** – The results of the analysis of the drawdown data from this well provided an estimate of transmissivity of 0.008 m^2/sec. (56,000 USgpd/ft).

- **Well TH-19** - The results from this well were also analyzed in two parts. The first part was the analysis of the early time data before the negative boundary was intersected at approximately 1,000 minutes into the test. The results of this analysis provided an estimate of transmissivity of 0.065 m^2/sec. (474,000 USgpd/ft). Analysis of the late time data after the negative boundary was encountered provided an estimate of 0.012 m^2/sec. (81,000 USgpd/ft).

- Analysis of the drawdown results for wells TH-5A, TH-7 and TH-19 using the distance drawdown method provided an estimate of transmissivity of .01 m^2/sec. (66,000 USgpd/ft) and an estimate of storativity of 0.11.

Overall, the results of this analysis indicate that the appropriate value for near field transmissivity and storativity is 0.029 m^2/sec. (203,000 USgpd/ft) and 4.4 x 10^{-5}, respectively. These near field values are pertinent to the immediate area of the pumping well and are suitable for use in assessing potential well capacities. The results of the analysis of the late time data indicate that a value of approximately 0.01 m^2/sec (75,000 USgpd/ft) is suitable for use as a bulk transmissivity of the aquifer (ie: analyzing the long term effects). The results also indicate that transmissivity decreases from south (TH-7 area) to north (TH-12/19 area) and that there is a strong vertical anistrophy to the transmissivity (ie: TH-11/12/19 results indicate high differences in transmissivity depending on the position within the stratigraphic profile). The TH-11/12/19 results show that the pumping well is withdrawing water from a series of pervious horizontal stratigraphic layers that have varying transmissivities and varying vertical interconnectivity.

3.4.5 Water Quality Results

In order to characterize the water quality, a water sample was collected during the test and submitted for laboratory analysis of routine water quality parameters including alkalinity, total dissolved solids, turbidity, major cations and anions, metals, benzene, toluene, ethylbenzene, xylene, total volatile and total extractable hydrocarbons and bacteria. The laboratory results are included in Appendix D (Sample PW-1 collected on 13/11/05 @ 14:00).

As indicated in the results, the water quality is very good. Total dissolved solids were measured at 190 mg/l, hardness is 163 mg/l, and alkalinity is 173 mg/l. Iron is 0.35 mg/l and manganese is 0.045 mg/l. E. Coli was not detected and total coliform was measured at 3 MPN/100 ml (Note: neither the well nor the test equipment were disinfected prior to the pumping test. Disinfection will be required before the well is put in service).