Buried Valley Aquifer – Promising New Water Supply For Port Perry, Ontario

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ABSTRACT
Seismic reflection profiles identified two buried valleys or "tunnel channels" that may have eroded the Newmarket Till in the vicinity of Port Perry. Drilling in the first interpreted channel found only fine-grained sediments, however, the second channel was filled with coarser sediments forming three aquifers. Testing detected iron and odours in the deepest aquifer and better water quality in the shallower aquifers. A test well in the upper aquifer produced 22.7 L/s for 72 hours with no evidence of channel boundaries. The tests suggest this buried valley aquifer offers a promising source for municipal water supply in Port Perry.

RÉSUMÉ
Les profils de réflexion sismiques ont identifié deux vallées enterrées qui peuvent avoir érodé le Newmarket Till jusqu'à aux alentours du Port Perry. Le forage dans le premier canal interprété a trouvé du sédiments seulement à grain fin, toutefois, le deuxième canal a été rempli des sédiments plus grossiers formant trois aquifers. La mise à l'essai du fer découvert et des odeurs dans aquifer le plus profond et la meilleure qualité d'eau dans l'aquifers peu profond. Une épreuve bien dans aquifer supérieur a produit 22,7 L/s depuis 72 heures sans évidence de limites de canal. Les épreuves suggèrent que cette aquifer vallée enterrée offre une source prometteuse pour l'approvisionnement d'eau municipal a Port Perry.

1 INTRODUCTION

The existing municipal water supply for the Community of Port Perry, Ontario draws groundwater from three artesian wells located to the south of Port Perry. The quality of the groundwater from these wells is relatively high in hydrogen sulphide and iron. These parameters are not health concerns, however, they affect the aesthetic quality of the water by causing odours and reddish-brown staining of plumbing fixtures.

In an effort to improve the municipal water quality, the Regional Municipality of Durham (RMD) has been exploring for a new groundwater source for the Port Perry area. Geophysical surveys completed in association with the York-Peel-Durham-Toronto (YPDT) and the Conservation Authorities Moraine Coalition (CAMC) in 2006 identified a study area of interest for exploration south of Port Perry (Figure 1). Seismic reflection profiles (Seismic Solutions, 2007) identified two potential buried-valley features that became target areas for further water supply exploration (Figure 2).

An exploratory well drilling program initiated in 2008 included the installation of a test well in each of the target areas drilled all the way to bedrock to confirm the local stratigraphy and seismic survey interpretations. Granular sand and gravel sediments were encountered through almost the entire depth of the borehole in Target Area 1 (TW08-1; Figure 2), and as discussed further in this paper, these sediments have been interpreted as buried-valley or channel-fill deposits. The drilling in Target Area 2 (TW4-08; Figure 2) encountered only silty clay sediments and no evidence of granular channel fill deposits. Therefore, the focus of all further drilling and testing was on Target Area 1.

A series test wells were installed in Target Area 1 (TW1-08, TW2-08, TW3-08 and TW5-08) and pumping tests were completed to assess the aquifer conditions, potential well yields and groundwater quality in the target area. This paper discusses the results of the test well drilling and groundwater supply testing program.

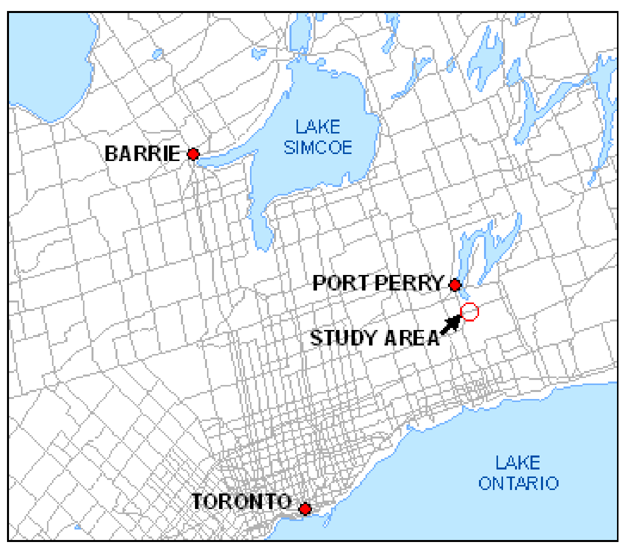

Figure 1. Location of Study Area

2 HYDROGEOLOGICAL SETTING

In 2001, regional groundwater studies were initiated by the YPDT/CAMC Groundwater Management Study to investigate the hydrogeological conditions of the Oak Ridges Moraine (ORM). The conceptual regional stratigraphic model of the ORM developed by the Geological Survey of Canada (Barnett et al. 1998; Logan et al. 2002) formed the basis of the geology and groundwater modelling work completed by the YPDT/CAMC Technical Report Number 01-06 (Kassenaar and Wexler, 2006). This regional stratigraphic framework and the geological information from the test well records was used to develop a schematic cross-section through the target areas. The cross-section location is shown on Figure 2 and the interpreted cross-section is shown on Figure 3.

Starting from the bedrock, the major stratigraphic layers are briefly described below (refer to Figure 3).

1) Bedrock – The bedrock is Upper Ordovician aged shale and limestone found about 120 m below ground at elevations between about 155 masl and 165 masl.

2) Lower Sediments – A thick coarsening-upward sequence of glaciolacustrine and glaciofluvial sediments. The GSC notes that the Lower Sediments in the study area can be further broken down into the Scarborough Formation (or equivalent), the Sunnybrook Drift (or equivalent) and the Thorncliffe Formation (or equivalent).

3) Newmarket Till – This unit is a dense, silt to silty-sand till with pebble and boulder-size clasts. The thickness of the Newmarket till layer ranges from about 15 m to 25 m in the study area. The GSC geological model postulates that meltwater systems beneath the glacier eroded channels through the Newmarket till and then filled these channels with glaciofluvial sediments. It was these types of 'buried valleys' or 'tunnel channels' that were the subject of the seismic reflection surveys completed by the RMD. The test wells in Target Area 1 did not encounter Newmarket till, consistent with the seismic interpretation (Figure 3). This was not the case for Target Area 2, however, where it appears that the Newmarket till is present in the area interpreted as a channel on the seismic reflection profile (Figure 3)

4) Channel Deposits – In Target Area 1, layers of gravel, sand and silt were found between elevations of about 175 masl and 235 masl that are interpreted to be buried valley or channel fill deposits.

5) Oak Ridges Moraine Sediments – The ORM sediments comprises a complex layering of fine sand, gravel, silt, clay and diamicton occurring above an elevation of about 240 masl in the study area. Regionally the ORM sediment thickness ranges from about 20 m to over 60 m.

6) Glaciolacustrine Sediments - The study area is blanketed by 10 m to 25 m of silt and clay glaciolacustrine sediments. These fine-grained sediments form a protective cap over the underlying sandy ORM deposits.

2.1 Local Aquifers

Layers within the Lower Sediments, Channel Deposits and ORM Sediments can form significant local aquifers, whereas the Newmarket till and fine-grained surficial glaciolacustrine silts and clays generally form aquitards. On Figure 3, three main regional aquifer layers have schematically been interpreted to correspond to the ORM Sediments, the Thorncliffe Formation and the deeper Scarborough (or equivalent) Formation.

As described above, the Newmarket till has been eroded in Target Area 1 and the channel has been filled with sand and gravel layers that form aquifers. Based on the test wells drilled in Target Area 1, two aquifer zones are interpreted within the channel sediments and these are referred to in this paper as the Upper Channel and Intermediate Channel aquifers (Figure 3). The Upper Channel aquifer is interpreted to be within an elevation range of about 215 masl to 235 masl and may be partially separated from the Intermediate Channel aquifer (180 masl to 210 masl) by a silty clay layer encountered in TW08-2 between about 210 masl and 215 masl (Figure 3). It is expected that in complex stratigraphy there will be considerable overlap and hydraulic communication between the various deposits that form these aquifer layers, and it is interpreted that these layers form permeable connections between the ORM and Thorncliffe aquifers.

A deeper aquifer encountered above the bedrock between elevations of about 155 masl and 165 masl is interpreted to be part of the Scarborough Formation (or equivalent) sediments. Based on the seismic reflection profile, it is postulated that the eroded channel may have also cut down into these deep sediments. So this deepest aquifer zone is referred to here as the Deep Channel/Scarborough aquifer (Figure 3).

2.2 Test Drilling

TW08-1 was drilled 120 m deep to bedrock. More than 80 m of sand and gravel sediments were found underlying a 10 m thick protective layer of surficial silt and clay. TW08-1 was completed in the deep sandy layer encountered directly above the bedrock contact that appears to be separated from the interpreted channel fill deposits by a 15 m thick layer of silty clay (Figure 3).

TW08-2 was drilled to a depth of 96 m, however, due to screen installation difficulties, the lower portion of the test hole was sealed and an upper granular zone was screened within the Upper Channel aquifer sediments (Figure 3). A third well (TW08-3) was then drilled beside TW08-2 to complete a test well in the Intermediate Channel aquifer (Figure 3).

A fourth well (TW08-5) was installed in the Upper Channel Aquifer for monitoring purposes. All of the wells are 15 cm diameter steel casing, with stainless-steel well screens.

2.3 Preliminary Water Quality Assessment

The RMD's key requirement for a new municipal supply well with respect to water quality is to locate a water supply with no hydrogen sulphide odour and low iron if possible. So a preliminary water quality assessment was completed by collecting groundwater samples from TW08-1, TW08-2 and TW08-3 to assess the background water quality in each of the three aquifer zones, i.e., the

Upper Channel, the Intermediate Channel and the Deep Channel aquifers.

The deep aquifer (TW08-1) reported an iron concentration of 1.13 mg/L (above the drinking water guideline of 0.3 mg/L), high colour (10 TCU) and an ammonia concentration of 1.13 mg/L. The two shallower wells (TW08-2 in the Upper Channel aquifer and TW08-3 in the Intermediate Channel aquifer) had better water quality with lower iron in the 0.1 mg/L to 0.15 mg/L range, clear colour, lower ammonia (not detected in TW08-2 and less than 0.12 mg/L in TW08-3) and no sulphide. No odours were detected in TW08-2, however, a slight hydrogen sulphide odour was noted in the field at TW08-3. The reported sulphate concentrations at TW08-3 were also higher than at TW08-1 and TW08-2. So overall, the groundwater quality appeared to be the best at TW08-2 and therefore, the Upper Channel aquifer was selected as the best candidate well for further water supply testing.

3 TEST PUMPING

The testing program at TW08-2 involved 4 step-drawdown tests and a 72-hour aquifer production test. The step-drawdown pumping tests were completed to provide an indication of the potential water yield from TW08-2 and involved pumping the test well for 30 minute periods at increasing flow rates. The results of the four-step tests show that the water level in TW08-2 stabilized quickly at all pumping rates. The calculated specific capacity (pumping rate/drawdown) was about 1 L/s/m at the final step pumping rate of 22.7 L/s.

During the step-test and longer-term well pumping, the water level in TW08-2 was monitored at regular intervals using an automatic water level recorder (datalogger) to record the drawdown of the water level in response to pumping. In addition, throughout the test pumping period, the groundwater and surface water levels were monitored in the surrounding monitoring network to assess the potential impacts, if any, of the test well pumping.

3.1 Monitoring Network

A groundwater and surface water monitoring network was established for the well testing program as outlined below. All of the monitoring locations are shown on Figure 4.

- Test wells TW08-1, TW08-3 and TW08-5 served as groundwater observation wells. Automatic water level recorders (dataloggers) were installed in each well to obtain continuous water level monitoring data throughout the test pumping and recovery period.
- Six of the local residents permitted monitoring of their water supply wells throughout the test period. These residential wells are referred to as wells R1 to R6 on Figure 4.
- Four standpipe nests (SP1 to SP4) were installed on the banks of the local watercourses where they cross Shirley Road (Figure 4). Six staff gauges (SG1 to SG6) were also installed into the watercourses and local ponds to permit monitoring of the surface water levels to assess possible impacts on groundwater/surface water interactions during pumping.
- An automatic datalogger was used to measure atmospheric pressure throughout the well testing period.

3.2 72-Hour Pumping Test at TW08-2

Based on the results of the step-tests, a pumping rate of 22.7 L/s was selected for a longer-term production test. This pumping rate was held constant throughout a 72-hour continuous pumping period. The static water level in TW08-2 prior to the start of the pumping was 7.05 m below the top of the well casing. The water level drawdown in the well in response to the pumping is shown on Figure 5. The water level in TW08-2 dropped slowly and steadily throughout the first 1000 minutes of the test and then began to stabilize. At the end of the test, the water level was 32.81 m below the top of casing, resulting in a total water level drawdown in response to pumping of 25.76 m. 90% recovery of the water level in TW08-2 was achieved about 20 minutes after the pumping was stopped.

The barometric pressure was rising and falling throughout the test period with a fluctuation of about 15 cm of water gauge over the monitoring period. The continuous monitoring of water levels during the test suggests only minor variations in water levels occur in response to barometric variations (less than about 0.1 m).

The total available drawdown in TW08-2 is about 44 m. In operation, it is not recommended to draw the water level down to the top of the screen, therefore, the maximum recommended operational drawdown is 40 m. The total drawdown during the 72-hour pumping test was 25.76 m and the rate of water level change was low and relatively stable (Figure 5). This is only about 65% of the total available drawdown in this well.

The specific capacity of TW08-2 at the end of the test was 0.89 L/s/m. With an available drawdown in the well of 40 m, the maximum theoretical capacity of this 15 cm diameter test well would be about 35 L/s.

3.3 Aquifer Characteristics

The coefficient of transmissivity (T) varies with aquifer hydraulic conductivity and thickness, however, based on the test data, the T value in the vicinity of the pumped well is calculated at about 276 m^2/day. Assuming a total hydraulically connected channel aquifer thickness of about 75 m in the area of the well (Figure 3), the average hydraulic conductivity of the aquifer is calculated to be about 4.2×10^{-3} cm/sec.

Variations in storativity (S) occur with variations in the grain-size and distribution of the aquifer material. S was calculated based on observation well water level response data at a value of 1.3×10^{-4}.

3.4 Observation Well Response to Pumping

TW08-5 is completed at a similar depth as TW08-2 in the Upper Channel aquifer (Figure 3). Drawdown in TW08-5 began almost immediately and the pattern of drawdown mimicked the pumping well. The water level reached a maximum drawdown of 4.1 m at the end of 72-hours of pumping (Figure 5).

TW08-3 is completed in the Intermediate Channel aquifer (Figure 3). Drawdown in TW08-3 began about 30 minutes into the test and reached a maximum water level change of about 2.5 m at the end of 72-hours of pumping (Figure 5).

TW08-1 is completed in the deepest aquifer layer (Figure 3). There was a lag in the well response at this location with water levels not beginning to drawdown until about 200 minutes into the test period. The drawdown in TW08-1 reached a maximum water level change of about 1.5 m at the end of 72-hours of pumping (Figure 5).

The overall response to the pumping confirmed that all of the aquifer layers are hydraulically connected in this area, and the lag shows the effects of the lower hydraulic conductivity sediments that are found between the Deep and Intermediate channel aquifer zones (Figure 3).

3.5 Interference in Residential Wells

Drawdown effects were observed in R3, R4, R5 and R6, however, the magnitude of the water level response to the TW08-2 pumping was in the range of 1.2 m to 1.8 m. This minor water level interference did not adversely affect the groundwater supply to any of the residential wells.

3.6 Surface Water Monitoring Results

The water level hydrographs for the stream-bed piezometers and staff gauges remained stable throughout the pumping period and there was no interference effect from the groundwater pumping at TW08-2. It is concluded that the thick layer of surficial silt and clay hydraulically separates the ORM and channel aquifer layers from the ground surface in this area (Figure 3).

3.7 Predicted Area of Influence for Well Operation

The drawdown that occurred during the testing interval in the observation network was minor. Theoretical drawdown-distance analysis suggests the potential area of influence from continuous pumping at TW08-2 would be less than 800 m from the wellhead and it is likely that drawdown effects would not be measurable at distances over 500 m. It is noted that the actual long-term drawdown effects would be expected to be even less than this type of theoretical analysis predicts because generally, a municipal groundwater supply well would not be expected to pump continuously for so long during actual usage. There is no predicted impact to the surface water resources in the area, which are separated from the aquifers by thick layers of silt and clay sediments.

4 WATER QUALITY

The water chemistry test results for groundwater samples collected throughout the pumping interval are comparable and no significant changes were noted over the 72-hour test. The results indicate that the groundwater is of very good quality with respect to the Ontario Drinking Water Quality Standards (Ontario MOE, 2006). Key characteristics of the groundwater are noted below:

- moderately hard (195 mg/L);
- very low chloride (0.56 mg/L) compared to the ODWQS of 250 mg/L with no evidence of anthropogenic influences (i.e., road salt);
- low nitrate concentrations (0.11 mg/L) compared to the ODWQS of 10 mg/L showing no evidence of agricultural impacts;
- low sulphate (26 mg/L) compared to the ODWQS of 500 mg/L;
- no odour noticed at the wellhead and no hydrogen sulphide reported;
- iron was reported by the laboratory in the 0.002 to 0.053 mg/L range and all of the field measurements were below 0.12 mg/L (below the 0.3 mg/L ODWQS for iron);
- there were no organic compounds reported in the groundwater for the tests completed, i.e., no traces of organochlorine pesticides, organophosphorus pesticides, triazine pesticides, phenoxy acid herbicides and volatile organic compounds (VOCs).

5 SUMMARY

- Test drilling in Target Area 1 found thick layers of permeable sediments that are interpreted as channel aquifer deposits. These findings were consistent with seismic reflection survey interpretations of a buried valley.
- TW08-2, a test well completed at a depth of 96 m below ground level and screened within the Upper Channel aquifer, was pumped for 72-hours at a continuous pumping rate of 22.7 L/s.
- The total water level drawdown in TW08-2 in response to pumping was 25.76 m and only about 65% of the total available drawdown in the well.
- The drawdown that occurred during the test period in the surrounding wells was minor (less than 2 m).
- There was no observed or predicted impact to the surface water resources in the area, which are separated from the underlying aquifers by thick layers of silt and clay sediments.
- The groundwater at TW08-2 is of very good quality with respect to the Ontario Drinking Water Quality Standards.

6 CONCLUSION AND RECOMMENDATIONS

The results of the tests completed at TW08-2 suggest that the buried valley aquifers in Target Area 1 are a very promising area for municipal water supply development.

A concern with buried valley or channel aquifers is the potentially limited extent for long-term sustainable groundwater supplies. Further drilling to delineate the extent and orientation of the channel in Target Area 1 is recommended, along with the completion of longer-term pumping tests to evaluate boundary conditions.

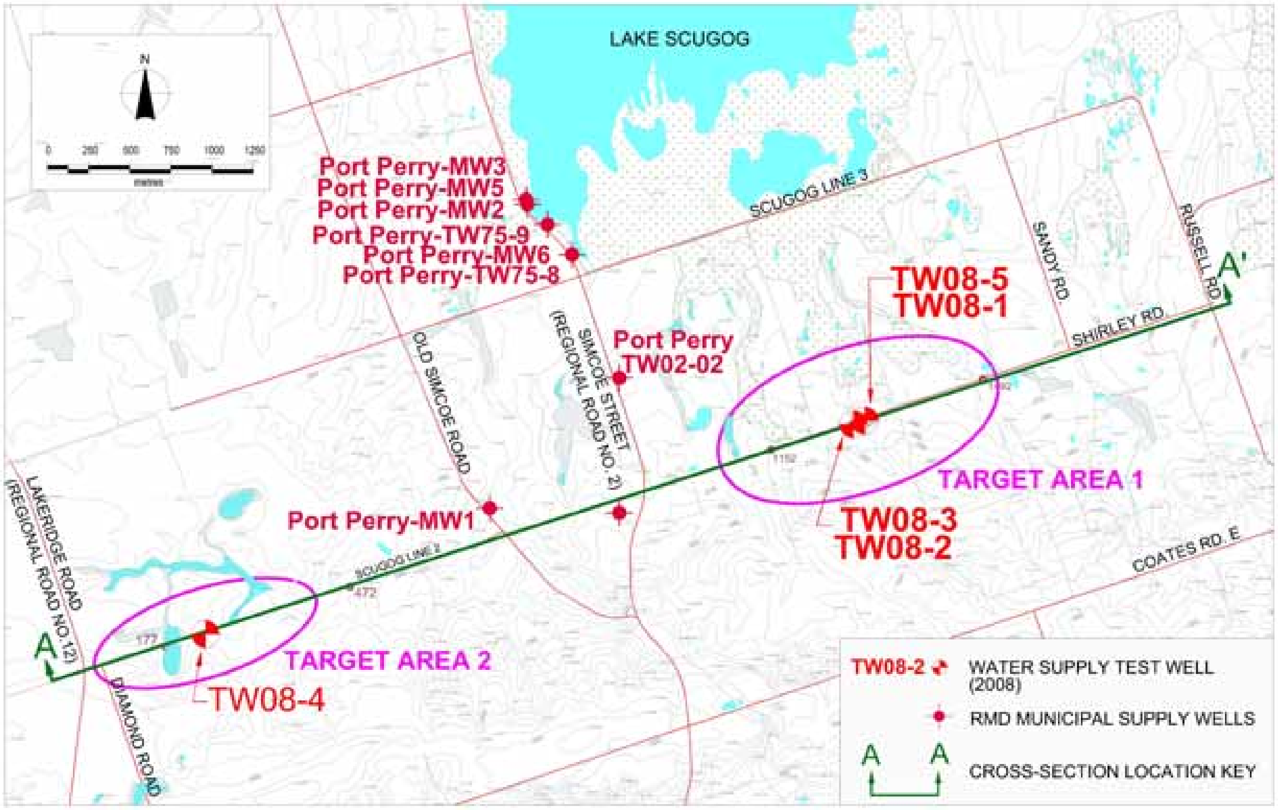

Figure 2. Buried Valley Target Areas Identified by Seismic Reflection Profiles

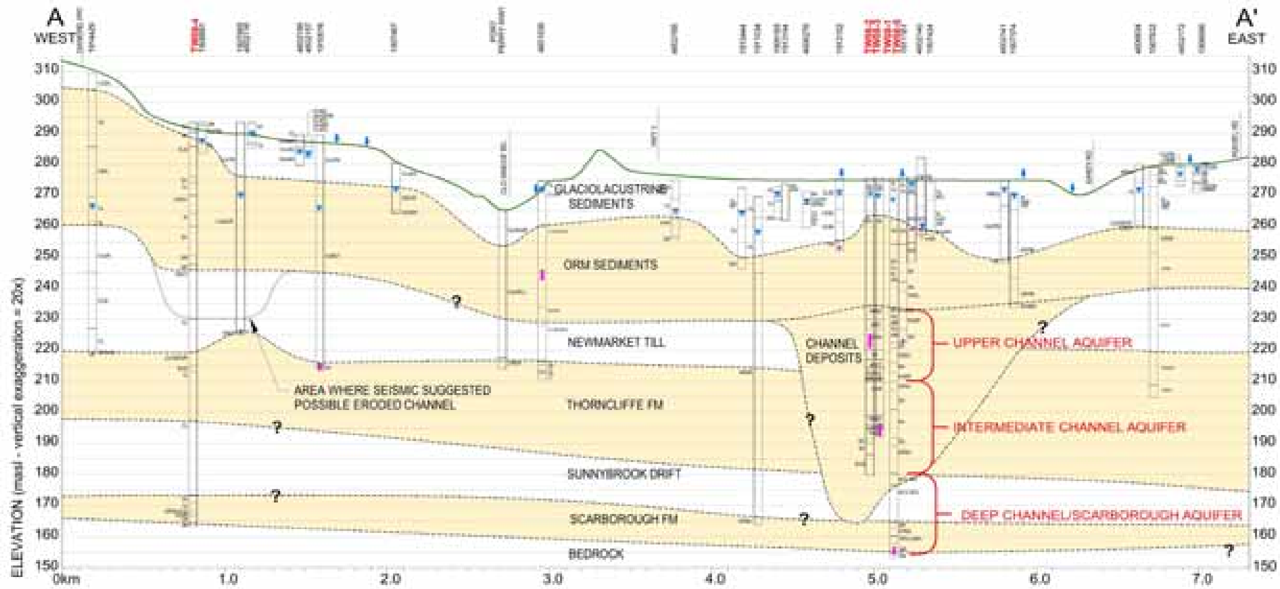

Figure 3. Schematic Cross-section through Target Areas

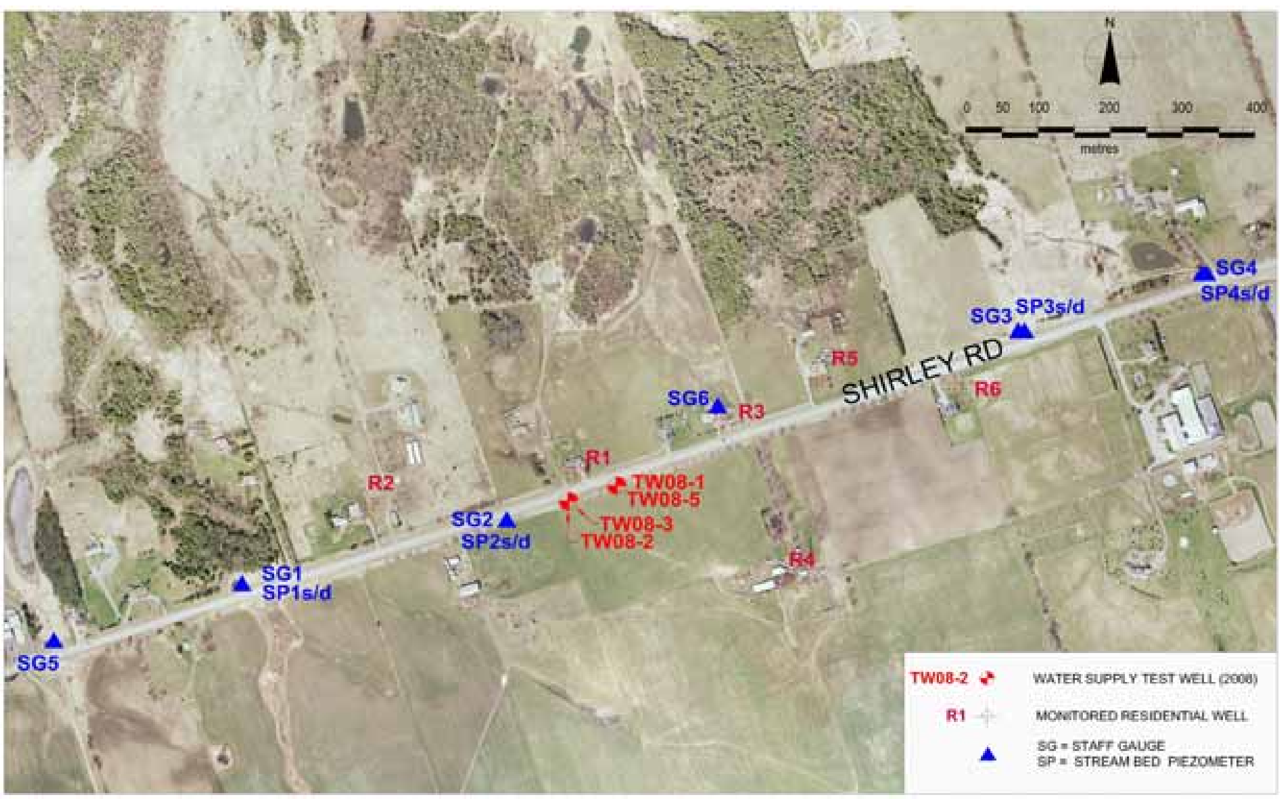

Figure 4. Monitoring Network for Test Pumping Program

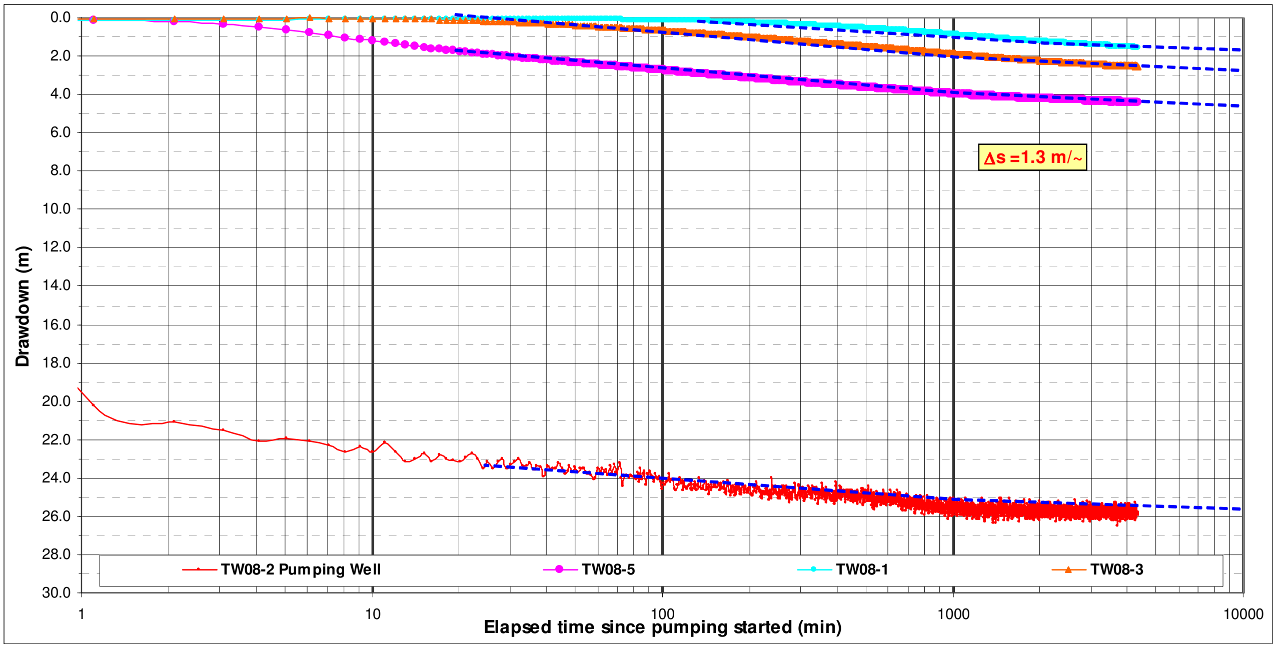

Figure 5. Pumping Test Results

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