# Aquifer Capacity Study Report

## Norwood Water Supply Aquifer
## Village of Norwood, ON

**D.M. Wills Project Number 21-7128**

**D.M. Wills Associates Limited**
Partners in Engineering, Planning and
Environmental Services
Peterborough

**August 2022**

**Prepared for:**
**The Township of Asphodel-Norwood**

# Summary of Revisions

| Revision No. | Revision Title | Date of Release | Summary of Revisions |
|---|---|---|---|
| 0 | Draft Report Submission | June 17, 2022 | NA |
| 1 | Final Report Submission | August 18, 2022 | Client Comments |
| 2 | Final Report for Council | August 19, 2022 | Summary for Council |
| | | | |
| | | | |

This report has been formatted considering the requirements of the Accessibility for Ontarians with Disabilities Act.

# Table of Contents

## Tables

## Figures

## Appendices

## Executive Summary

D.M. Wills Associates Limited (Wills) was retained by the Township of Asphodel-Norwood (Township) to complete an Aquifer Capacity Study (Study) for the Village of Norwood (Norwood) Water Supply Aquifer (Aquifer). The Study was requested to assess the capacity of the Municipal Well Field (including Water Supply Wells 1B, 2, 3, and 4) in context of the approved Permit to Take Water (PTTW).

Furthermore, the Study has been requested to determine whether the Aquifer can meet the future growth demands (20 year planning horizon) of the Township. A separate memo which evaluates the Aquifer capacity in relation to the Village's long term demand requirements to serve the projected development to 2042 will be submitted under separate cover.

The water supply for Norwood is provided by the Norwood Drinking Water System that includes four Water Supply Wells (Municipal Well Field) located on and to the east of the Norwood esker crest line. The Norwood esker is a glacial landform that was deposited during the Quaternary period consisting of permeable core deposits consistent with high energy deposition (including gravel, cobbles, and boulders), and lower permeability flank deposits consistent with lower energy deposition (including silt, clay, sand, and gravel).

In order to refine the understanding of the local geological conditions as they relate to the Aquifer's capacity, Wills' Study included subsurface investigations conducted on Township owned lands (Study Area), including:

- Southern Parcel – The Norwood Drinking Water System (42 Ridge Street, Norwood, Ontario), 1.6 hectare (ha)
- Northern Parcel - The Norwood Cemetery (40 Wellington Street, Norwood, Ontario), 4.3 ha

Wills approved Scope of Work to complete the Study included advancing 11 boreholes and installing 10 monitor wells between November 15, 2021 and December 2, 2022. Monitor wells and borehole locations were geodetically surveyed, and all monitor wells were subjected to constant head tests following well development. Four long-term (24 to 36 hour) pumping tests were completed on Water Supply Wells 1B, 2, 3, and 4 between December 9, 2021 and January 7, 2022, and static water level monitoring was conducted on the 10 monitor wells (observation wells) during the pumping tests.

Field data interpretation included geology, hydraulic conductivity (permeability K) obtained from grain size, monitor well testing and pumping tests, and analysis of Aquifer parameters including transmissivity (T), storativity (S), and K. Following completion of the field activities and data analysis, the 2018 groundwater model was revised, and predictive modelling was conducted in order to assess the capacity of the Aquifer in the context of the approved PTTW.

Based on Wills investigation, the following conclusions and recommendations are provided:

- Aquifer test parameters were generated from the pumping tests carried out on Wells 1B, 2, 3 and 4 and observation wells MW21-01 through MW21-10. While most of the test data was relatively simple to process in order to produce aquifer parameters, some of the tests were a challenge to interpret. While this is not that unusual in aquifer test analysis, the reasons for these difficulties could have been because of the configuration of the aquifer:

  - A long, relatively thin granular deposit, flanked by lower permeability deposits.
  - Variability (from boulders to sand, silt and clay) in the texture of the core deposits.
  - The minimal drawdowns experienced even at high pumping rates. The analytical methods are based on assumptions including an 'infinite acting' aquifer and a consistent aquifer saturated thickness as well as isotropic conditions. While these assumptions were mostly satisfied, the varying hydraulic conductivity and somewhat variable saturated aquifer thickness across the aquifer complicated analysis.

- The higher permeability deposits are quite variable in texture with significant percentages of silt and sand, and predominance of gravel and cobbles / boulders. The finer materials, especially the silt and trace to minor clay fractions will significantly affect the hydraulic conductivity of the formation.
- The aquifer test analyses involved repeated rounds of data analysis to establish representative aquifer parameters. A considerable amount of professional judgment was required to arrive at a set of parameters which were supported by the multiple lines of evidence from assessing previous reports and maps, and from computer modelling, which resulted in a consistent conceptual model of the groundwater system at Norwood.
- While a considerable volume of water moves toward the Municipal Well Field from the northeast along the Norwood esker, significant groundwater also moves from the northwest. Monitor wells MW21-01 to MW21-04 appear to experience detectable but limited drawdown especially with Well 4 pumping during the pumping test. The well logs indicate that much of the material encountered in MW21-01 to MW21-04 was silty sand with some sandy gravel layers or lenses, and appear to constitute the flank deposits or the edge of the flank deposits. However, a hydraulic connection does exist between the Municipal Well Field and these northwest monitor wells.
- To meet the Village's population requirements, the current pumping rates of the Municipal Well Field account for approximately 35% of the PTTW rate of 1,965 $m^3$/day (averaging approximately 650 $m^3$/day). The drawdown from pumping at this rate and pumping intermittently each day appear to be minimal. A consequence of this is that the capture zones determined by the 2022 modelling bear little resemblance to the current pattern of groundwater flow at current pumping rates as expected.
- The drawdown (decline in water level in the well) after 36 hours of pumping at 1,782.4 $m^3$/day in Well 4 during the December, 2021 pumping test was 0.55 m, and the drawdown in Well 1B was between 7.68 to 8.05 m after 24 hours pumping at 1,477.6 $m^3$/day. The drawdown in Wells 2 (at a rate of 494.4 $m^3$/day) and 3 (at a rate of 1542.5 $m^3$/day) were 0.70 m and 2.11 m respectively. The saturated portion of the

aquifer was approximately 9.93 m (Well 4), 8.45 m (Well 3), 10.74 (Well 1B), 7.4 (Well 2) in December 2021-January, 2022. Water levels appear to vary seasonally about 0.5 m in the area of the Norwood Transfer Station, north of the Village, and this could be the case in the area of the Municipal Well Field. If this seasonal fluctuation also occurs in the area of the Water Supply Wells, then there would be more water available in spring and early summer with water levels declining in late summer into the winter. The limiting factor in supplying large amounts of water is the limited saturated thickness combined with the screen setting of the existing Water Supply Wells.

- The groundwater model of Municipal Wells 2, 3 and 4 continuously pumping (20 years) at 655 m$^3$/day each, for a total of 1,965 m$^3$/day (the PTTW rate) was shown to be sustainable.
    - The simulated pumping levels were higher in elevation than the estimated pump intakes, indicating the wells can pump continuously without the water levels in the wells falling below the pump intakes.
    - Pumping continuously at the PTTW rate was shown to have no effect on Mill Pond and the Ouse River.

# 1.0 Introduction

D.M. Wills Associates Limited (Wills) was retained by the Township of Asphodel-Norwood (Township) to complete an Aquifer Capacity Study (Study) for the Village of Norwood's (Norwood) Water Supply Aquifer (Aquifer). The Study was requested to assess whether the municipal wells could continuously supply water at the PTTW rate (1,965 $m^3$/day) without dewatering the aquifer or affecting nearby surface water bodies. Wills Study considered the following documents:

- Norwood Municipal Wells Updated Modelling Report, November, 2018, Wills;
- Hydrogeology Review, Municipal Groundwater Supply Report, July 10, 2018, Ted Rannie;

## 1.1 Site Location and Description

The Township owned lands (Study Area) that were subject to subsurface investigation as part of the Study are approximately 5.9 hectares (ha), and include two parcels:

- Southern Parcel – The Norwood Drinking Water System (42 Ridge Street, Norwood, Ontario), 1.6 ha
- Northern Parcel - The Norwood Cemetery (40 Wellington Street, Norwood, Ontario), 4.3 ha

The Study Area is shown on **Figure 1**. Note that Wills' Study Area also included Township owned lands directly adjacent to the Mill Pond, which will be described under the Northern Parcel due to the similar geological conditions encountered.

# 2.0 Background

## 2.1 The Norwood Esker

The Norwood esker is a glacial landform that was deposited during the Quaternary period. Quaternary esker deposits typically consist of permeable core deposits consistent with high energy deposition (including gravel, cobbles, and boulders), and lower permeability flank deposits consistent with lower energy deposition (including silt, clay, sand, and gravel).

The Norwood esker was formed at the end of the last ice age, when high volumes of sediment-laden glacial meltwater flowed through tunnels within and underneath the retreating ice sheets. Under these depositional conditions, heavier coarse-grained materials (i.e. gravel, cobbles, and boulders) were able to drop out of suspension in the centre of these flow regimes where water velocities were the highest. Lower water velocities towards the edge of these flows permitted lighter fine-grained materials (i.e. silt, clay, sand and finer gravel) to drop out of suspension and ultimately form the flank deposits of the Norwood esker. The Norwood esker is a relatively long and thin esker with moderate relief, which transects Norwood and locally contains the Aquifer.

## 2.2 Norwood Drinking Water System

The Norwood Drinking Water System includes four Water Supply Wells (Municipal Well Field) located on and to the east of the Norwood esker crest line, including Water Supply Wells 1, 2, 3, and 4 (Well 1, Well 2, Well 3, and Well 4). Additionally, Well 1B was constructed in December 2017 with the intention to replace Well 1, however, Well 1B has yet to be connected to the Norwood Drinking Water System. The locations of the Water Supply Wells are shown on **Figure 2**.

The Norwood Drinking Water System maintains one pump house with a treatment system, and one water tower, located at 42 Ridge Street, Norwood, Ontario. Specifics of the Norwood Drinking Water System are outlined below:

- Current Amended Permit To Take Water (PTTW) No. 7130-BMCT9C dated March 4, 2020 allows for a total combined water takings of 1,965 cubic metres per day ($m^3$/day), from the four existing Water Supply Wells (1, 2, 3, and 4).
- Well 1 (MECP Well Tag A002060) was originally constructed in 1949 (Well Record No. 51-2505), and was subsequently replaced by Well 1A (now Well 1) in March 2017 following demolition of Pump House No. 1, where it was housed. Well 1 is equipped with a submersible pump rated at 7.9 litres per second (L/s) (683 $m^3$/d).
- Well 1B (MECP Well Tag A230643) was constructed in December 2017, directly northeast of Well 1, and was intended to replace Well 1 due to silting problems. Well 1B is currently not connected to the Norwood Drinking Water System.
- Well 2 (MECP Well Tag not available) was constructed in 1972 (Well Record No. 51-5882), and is located inside Pump House No. 2. Well 2 is equipped with a vertical turbine pump rated at 7.9 L/s (683 $m^3$/d).
- Well 3 (MECP Well Tag not available) was constructed in 1993 (Well Record No. 134169), and is located on the crest of the Norwood esker within a concrete well pit, approximately 60 m northwest of Pump House No. 2. Well 3 is equipped with a submersible pump rated at 7.6 L/s (683 $m^3$/d).
- Well 4 (MECP Well Tag A230644) was constructed in December 2017, and is located on the crest of the Norwood esker, southwest of Well 3. Well 4 is connected to the Norwood Drinking Water System and has been on-line since October 2021.

## 2.3 Historic Short-Term Pumping Tests

During individual step pumping tests completed in December 2017 and February 2018, the following results for the Water Supply Wells were determined:

- Well 4 could pump, in the short term (300 minutes), 20.8 L/s (1,800 $m^3$/d) with a maximum drawdown of 0.28 metres (m). The drawdown remained at 0.28 m for 18 minutes (min) at which point the pump was shut down. Recovery to pre-pumping static water level (SWL) took 20 minutes. This demonstrates that the yield of Well 4 could be considerably higher, considering Well 4 reached equilibrium in terms of drawdown, and the rapid recovery.
- Well 3 sustained a flow of 10.4 L/s (897 $m^3$/d) in 92 minutes with a maximum drawdown of 0.36 m. From 82 to 92 minutes into the test, the drawdown stabilized at 0.36 m. Recovery to the pre-pumping SWL took 30 minutes.
- Well 2 sustained a flow of 5.9 L/s (510 $m^3$/d) with a maximum drawdown of 0.53 m after 80 minutes. From 41 to 80 minutes, the drawdown stabilized at 0.53 m. Recovery to the pre-pumping SWL took 18 minutes.
- Well 1B sustained a flow of 17.1 L/s (1,473 $m^3$/d) with a maximum drawdown of 7.1 m. Drawdown increased slowly at the end of the test, at 230 minutes. Well 1B recovered to within 0.11 m of the pre-pumping SWL in 30 minutes. The available drawdown in Well 1B was10.4 m, excluding the pump. Pumping at this high rate would likely dewatered Well 1B within a relatively short time.

From these well performance tests, it was concluded that Wells 2, 3, and 4 could sustain higher pumping rates. This was indicated by minimal drawdown, relatively high pumping rates, and rapid recovery, in addition to high efficiency at the pumping rates tested.

### 2.3.1 Historical Aquifer Characteristics

The approximate transmissivity values, as determined from the historical step tests were:

- Well 4: 18,697 $m^2$/d
- Well 3: 3,363 $m^2$/d
- Well 2: 775 $m^2$/d
- Well 1B: 516 $m^2$/d.

Well 1B is considered a bedrock well, however the 2018 pumping test indicated that the bedrock and saturated surficial deposits (sand, gravel) overlying the bedrock are hydraulically connected, meaning that much of the water pumped in this well could come from the surficial deposits. The other Water Supply Wells are screened within the overlying surficial deposits (Well 4 partially penetrates the bedrock).

In general, it is likely that the bedrock, and overlying surficial deposits, are hydraulically connected. The hydraulic conductivities (K) derived from grain size analysis in the surficial deposits were:

- Well 4, 3 x $10^{-2}$ m/s (2,592 m/d)

- Well 3, 4 x $10^{-3}$ m/s (346 m/d)
- Well 2, 1 x $10^{-3}$ m/s (86 m/d)
- Well 1B, 3 x $10^{-4}$ m/s (26 m/d)

Considering that Well 4 partially penetrates the bedrock, it is reasonable to assume that the transmissivity of the bedrock at Well 4 is similar to the transmissivity of the bedrock in Well 1B. Therefore, it is likely that most of the yield in Well 4 comes from the surficial deposits overlying the bedrock.

### 2.4 Pumping Test Constraints

Discussions with the licensed well contractor that completed the historic pumping tests, G. Hart & Sons Well Drilling Ltd. (G. Hart), indicated that Well 4 may be pumped at a higher rate than the 20.8 L/s rate used during the historical short-term pumping test. However, pumping test constraints were identified that could limit the potential to complete testing at higher rates. These constraints included:

- The diameter of Well 4 which could not accommodate a larger pump, as well as the available drawdown (difference between the SWL and the bottom of Well 4). The available drawdown in Well 4 is 9.0 m, however, with the pump located above the screen, the available drawdown is reduced to approximately 5 m. Available drawdown in the other Water Supply Wells will be reduced by approximately 4 m when accounting for the pumps in each well.
- The analytical plot of pumping rate versus drawdown for Well 1B indicates that the Q/s slope (pumping rate/drawdown) flattens at about 8.3 L/s. This flatter slope represents increased well losses, and lower well efficiency at higher pumping rates due to turbulence at the well screen.
- Small slope changes also occurred in the plots for the other Water Supply Wells, but were not as pronounced as in Well 1B.

## 3.0 Scope of Work

Wills approved Scope of Work to complete the Study included the following:

- 11 boreholes were advanced within the Study Area. The location of the boreholes considered the results of the 2018 step testing on the Water Supply Wells (Rannie, 2018). Boreholes were terminated on, or in close proximity to the underlying bedrock, or due to practical refusal on overlying cobble and boulder materials.
- Standard Penetration Tests (SPT) and split spoon sampling was completed when drilling methods permitted (detailed in **Section 5.0**), and the encountered soil stratigraphy and depth to groundwater was documented at each drilling location.
- 15 representative soil samples were collected and submitted to WSP Canada Inc. (WSP), a Canadian Certified Independent Laboratory (CCIL), in Peterborough, Ontario for particle size distribution and hydrometer testing.

- Ten 51 mm diameter PVC groundwater monitor wells were constructed and developed. All monitor wells were screened within the saturated portion of the Aquifer.
- A geodetic survey of the top of the Water Supply Wells, monitor well casings, and ground surface elevations was conducted on January 10, 2022 (Wills Survey).
- Constant head tests were conducted on each monitor well to determine hydraulic conductivities (K).
- Four long-term (24 to 36 hour) pumping tests were conducted on Wells 1B, 2, 3, and 4 by G. Hart Well Drilling (G. Hart), a Licensed Well Contractor.
- During all pumping tests, pressure transducers (Solinst leveloggers) were installed in the observation wells (monitor wells and Water Supply Wells) and the pumping well to monitor the water levels.
- Manual water levels were collected using a Solinst Water Level Tape throughout the duration of the pumping tests in all of the observation wells.
- Pumping rates were monitored by G. Hart during the pumping tests using a flow meter for pumping tests on Well 1B, Well 3, and Well 4. The pumping rate for the Well 2 pumping test was monitored through the municipal water treatment system. Due to the quantity of daily water taking needs exceeding 50,000 L/day, the pumping tests were registered with the Environmental Activity and Sector Registry (EASR), Service ID R-011-3154159764.
- During the Well 1B, Well 3, and Well 4 pumping tests, water was discharged through a pipe to the stormwater sewer on County Road 40, southeast of the Municipal Well Field. The discharged water from the Well 2 pumping test was directed to the water tower.
- Field data interpretation included geology; hydraulic conductivity (K) obtained from grain size, monitor well testing, and pumping tests; and analysis of Aquifer parameters including transmissivity (T), storativity (S), and hydraulic conductivity.
- Preparation of this Aquifer Capacity Study Report, including:
    - Description of field investigations and resulting data.
    - Geological and hydrogeological interpretation with respect to the Aquifer capacity.
    - An assessment of the Aquifer capacity with respect to the existing PTTW.

# 4.0 Geology

## 4.1 Physiography

The Study Area is situated within the physiographic region known as the Dummer Moraines (Chapman and Putnam, 1984), which is characterized by rough stony land adjacent to the Canadian Shield, and extends eastward from the Kawartha Lakes. Moraines within this region often contain angular fragments and blocks of limestone with numerous Precambrian boulders. High-level Ontario Geological Survey (OGS) mapping (2003) suggests the Study Area is located within a spillway (glacial drainage channel) that cross-cuts the Norwood esker. The Regional Physiography Map showing the Study Area with respect to the OGS mapping is included in **Appendix A.**

### 4.2 Surficial Geology

Surficial geology mapped by the OGS (2003) suggests that the Study Area is located within two distinct surficial geology regions. The Northern Parcel mapping includes glaciofluvial river and delta topset facies, specifically gravelly deposits. The Southern Parcel includes ice-contact stratified deposits of sand and gravel, minor silt, clay and till found in moraines, eskers, kames and crevasse fills.

The Regional Surficial Geology Map showing the Study Area with respect to the OGS mapping is included in **Appendix A.**

Based on the information obtained during Wills' Investigation, the native overburden material is generally aligned with the depositional models and includes predominantly sand with layers of gravel, and lesser amounts of silt, clay, and occasional cobbles / boulders on the Northern Parcel. The Southern Parcel overburden was found to be coarser-grained, including cobble / boulder rich gravels with layers of sand, and minor silt and clay fractions. The deposits on the Southern Parcel were generally aligned with high-energy depositional environments associated with the core deposits of the Norwood esker, and the deposits on the Northern Parcel were representative of lower-energy environments where investigated.

### 4.3 Bedrock Geology

Although bedrock classification was outside of Wills' Scope of Work, OGS mapping (1986-1990) suggests the underlying bedrock includes limestone, dolostone, shale, arkose, and sandstone belonging to the Upper Ordovician Formation of the Ottawa and Simcoe Groups. The Bedrock Geology Map in included in **Appendix A**.

## 5.0 Subsurface Investigation

### 5.1 Drilling and Monitor Well Installation

Soil and groundwater conditions within the Study Area were assessed via subsurface investigation (Wills' Investigation) that included advancing boreholes and installing monitor wells. Canadian Environmental Drilling & Contractors Inc. (Canadian Environmental), and Insitu Contractors Inc. (Insitu) were retained as the drilling contractors. Under the supervision of Wills staff, Canadian Environmental advanced nine boreholes between November 15 and November 30, 2021. Insitu advanced two boreholes between November 29, 2021 and December 2, 2021. All boreholes were completed as monitor wells, with the exception of BH21-11 that was terminated above the saturated zone due to refusal on presumed boulder / cobble material. Following refusal, BH21-11 was backfilled with bentonite pellets in accordance with Ontario Regulation 903.

Details of the drilling activities are summarized in **Table 1** below.

**Table 1 – Drilling Details**

| Monitor Well / Borehole ID | Drilling Contractor | Drilling Method | Depth |
|---|---|---|---|
| MW21-01 | Canadian Environmental | 8" Hollow Stem Auger & SS sampling | 8.25 m |
| MW21-02 | Canadian Environmental | 8" Hollow Stem Auger & Mud Rotary with SS sampling | 16.80 m |
| MW21-03 | Canadian Environmental | 6" Solid Stem Auger & Mud Rotary With SS sampling | 17.50 m |
| MW21-04 | Canadian Environmental | 6" Solid Stem Auger & Mud Rotary With SS sampling | 11.50 m |
| MW21-05 | Canadian Environmental | 8" Hollow Stem Auger & Mud Rotary with SS sampling | 23.10 m |
| MW21-06 | Canadian Environmental | 8" Hollow Stem Auger & SS sampling | 10.00 m |
| MW21-07 | Canadian Environmental | Mud Rotary with SS sampling | 27.80 m |
| MW21-08 | Canadian Environmental | Mud Rotary with SS sampling | 26.95 m |
| MW21-09 | Insitu | Sonic Drilling with Continuous sampling | 26.50 m |
| MW21-10 | Insitu | Sonic Drilling with Continuous sampling | 30.65 m |
| BH21-11 | Canadian Environmental | 8" Hollow Stem Auger & Mud Rotary with SS sampling | 15.85 m |

*MW – Monitor Well BH – Borehole SS – Split Spoon m - Metres

Monitor wells were constructed using 2" PVC pipe with 10 point slotted well screens. The annular space was filled with No. 3 Quartz Sand to approximately 0.3 – 0.6 metres (m) above the top of the screen. Holeplug bentonite 3/8" chips were used to seal the annular space above the sand to the existing ground surface. The 10 monitor wells were capped with J-plugs and protected using steel monuments equipped with locks. Monitor wells were developed by purging at least three well volumes with a submersible pump and dedicated Waterra tubing prior to any sampling or hydraulic testing activities.

Subsurface soil samples collected during Wills' Investigation were field classified on the basis of grain size, stratigraphy, and relative soil compactness. Fifteen representative soil samples were collected and submitted to WSP for particle size distribution, including sieve and hydrometer analysis.

Borehole and monitor well locations are shown on the Subsurface Investigation Plan included as **Figure 3**. Borehole logs detailing the encountered subsurface conditions and monitor well construction details are included in **Appendix B**.

# 6.0 Subsurface Profile

## 6.1 Southern Parcel

Six boreholes (MW21-05, MW21-07, MW21-08, MW21-09, MW21-10, and BH21-11) were advanced on the crest of the Norwood esker. Due to the steep gradients on the northwest property boundary of the Southern Parcel, drilling pads comprised of granular fill were constructed at surface to facilitate the drilling activities. The drilling pads extended to a maximum depth of 2.7 meters below grade (mbg), and are excluded from the stratigraphic descriptions below (shown on the borehole logs in **Appendix B**).

All boreholes advanced on the Southern Parcel were terminated due to practical refusal in cobble/boulder material at depths ranging from 15.9 to 30.7 mbg. With the exception of BH21-11 (terminated at 15.9 mbg), all boreholes were assumed to have been terminated proximal to the bedrock-overburden contact based on Wills' review of the MECP Water Well Records for the Water Supply Wells and corresponding bedrock elevations.

The stratigraphy of the Southern Parcel generally includes a thin layer of silty sand topsoil, underlain by sand with varying amounts of silt, gravel, and cobbles / boulders, and ranged in composition from silty sand (MW21-10 and BH21-11) to gravelly sand (MW21-09) with cobbles. The sand generally contained some silt and trace amounts of clay.

Gravel was encountered in all boreholes and was the predominant soil type found on the Southern Parcel. The gravel was found to be interbedded with sand, and was described as containing trace sand, to sand and gravel. This material generally contained trace to some silt, and trace amounts of clay (generally less than 4%). Cobble / boulder material was frequently encountered in the gravel units, and the content was observed to increase with depth (general coarsening downwards).

Nine laboratory particle size distribution analyses were completed on samples of the gravel material. The results are summarized in **Table 2** on the basis of the Unified Soil Classification System (USCS). Note that cobble / boulder material is not reflected in the particle size distributions, and the presence of this material was determined based on observations made during the drilling activities (e.g. grinding augers and recovery of freshly broken rock fragments).

**Table 2 - Summary of Particle Size Distribution for Southern Parcel**

| Location ID | Sample No. | Gravel (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|
| MW21-05 | SS-10 | 40 | 46 | 11 | 3 |
| MW21-05 | SS-15 | 3 | 83 | 11 | 3 |
| MW21-07 | SS-12 | 44 | 40 | 13 | 3 |
| MW21-08 | SS-6 | 57 | 28 | 12 | 3 |
| MW21-08 | SS-9 | 45 | 35 | 16 | 4 |
| MW21-09 | ST-4A | 81 | 18 | < 1 | < 1 |
| MW21-09 | ST-9 | 56 | 30 | 11 | 3 |
| MW21-10 | ST-7B | 34 | 38 | 22 | 6 |
| MW21-10 | ST-10 | 53 | 35 | 7 | 5 |

## 6.2 Northern Parcel

Four boreholes (MW21-01, MW21-02, MW21-03, and MW21-04) were advanced on the Northern Parcel, as well as MW21-06 that was advanced directly adjacent to the Mill Pond. Boreholes were terminated at depths ranging from 8.3 to 17.5 m due to practical refusal on cobble / boulder material, and were assumed to be proximal to the bedrock-overburden contact. The stratigraphy of the Northern Parcel generally includes a thin layer of silty sand topsoil, underlain by sand. Sand material was encountered beneath the topsoil at all borehole locations on the Northern Parcel, including adjacent to the Mill Pond. The sand was found to be variably interbedded with gravel, and generally contained some silt, trace amounts of gravel and clay, and occasional cobbles / boulders. The sand contained interbeds of fine to coarse grained fractions, and was generally described as silty within the lower 2 m prior to borehole termination. Cobble / boulder content was found to increase proximal to the termination depth.

Six laboratory particle size distribution analyses were completed on samples of the sand material. The results are summarized in **Table 3** on the basis of the Unified Soil Classification System (USCS).

**Table 3 - Summary of Particle Size Distribution for Northern Parcel**

| Location ID | Sample No. | Gravel (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|
| MW21-01 | SS-5 | 0 | 61 | 35 | 4 |
| MW21-02 | SS-11B | 0 | 70 | 25 | 5 |
| MW21-03 | SS-7 | 3 | 76 | 17 | 4 |
| MW21-03 | SS-11 | 4 | 70 | 22 | 4 |
| MW21-04 | SS-8A | 3 | 83 | 11 | 3 |
| MW21-06 | SS-7 | 3 | 76 | 17 | 4 |

## 7.0 Cross Sections

Based on Wills Investigation, three representative cross sections of the Study Area were constructed. Cross Section A-A' and B-B' are generally aligned west to east through the Study Area, and Cross Section C-C' is aligned south to north along the Norwood Esker.

The geology depicted on the Cross Sections is congruent with the current understanding of the Norwood esker core deposits. It should be noted that based on the locations of the boreholes with respect to the cross section lines (borehole data transposed onto the cross section line), the lateral extent and configuration of the stratigraphic contacts beyond the boreholes locations cannot be confirmed, and are interpreted with a higher degree of uncertainty.

Within the core of the Norwood esker, the water table is encountered at an approximate elevation of 197.3 meters above sea level (masl), and the saturated zone is observed to be generally within the coarser Norwood esker deposits.

The locations of the cross section lines are shown on **Figure 4**, and detailed cross sections showing the interpreted stratigraphy are include as **Appendix C.**

## 8.0 Hydrogeological Context

The Aquifer is an esker deposit that is unconfined and is limited in width but much longer in length. Methods have been designed to determine if the flow to the wells during the pumping test was horizontally radial and whether the Aquifer appears to be infinite acting. These conditions are met for the Norwood Aquifer except in a few cases where noted.

The Aquifer is characterized by northeast-southwest trending permeability zones with high permeability core deposits and lower permeability flank deposits. Therefore, it is not homogeneous or isotropic (similar characteristics in terms of grain size and aquifer parameters in all directions) and the saturated portion of the aquifer itself is somewhat variable with minor differences in thickness (7-11 m thick). However, the contrast in homogeneity and anisotropy is minor compared to deposits in other areas that are interbedded or bounded by aquitards of much lower permeable material.

The piezometric surface (in this case, the water table) slopes with a gentle northeast-southwest decline in elevation along the trend line of the Norwood esker and with a minor component of groundwater flow from west to east in the area of the Municipal Well Field, as shown on **Figure 5**. This is the gradual slope of the horizontal hydraulic gradient. The drawdown of the pumping wells was a maximum of 0.55 m (with the exception of Well 1B) which is approximately 5% of the saturated thickness. The pumping wells are only partially penetrating the saturated portion of the aquifer as the screen lengths are less than the saturated thickness of the aquifer. Well diameters are small but not zero with some wellbore storage possible. This can usually be determined with diagnostic methods. Despite these deficiencies, the assumptions of the various methods of aquifer analysis were substantially met.

## 9.0 Pumping Tests

The pumping tests were conducted to assess the performance of the wells over sustained pumping activity and the effect of this prolonged pumping on the Aquifer as a whole. The pumping rate for each test was determined by referencing the maximum pumping rates achieved during the December 2017 and February 2018 step tests, as described in the following reports:

- Hydrogeology Review, Municipal Groundwater Supply, Norwood, Ontario (Final Report), August 2018, Ted Rannie M.Sc. P. Geo. (Report 18-8.1)
- Norwood Municipal Wells Updated Modelling (Final Report), November 2018, D.M. Wills Associates Limited (Wills Project No. 7128)

The maximum pumping rate for Well 2 was limited due to its location within the pumping house and the maximum pumping rate of the pump installed in the well.

G. Hart completed four pumping tests within the Study Area. The pumping tests were conducted on Well 1B, Well 2, Well 3, and Well 4. Details of the pumping tests are included in **Table 4** below.

**Table 4 – Pumping Test Details**

| Pumping Well | Pumping Test Date | Duration | Max Pumping Rate (Average) |
|---|---|---|---|
| Well 1B | December 9 – December 10, 2021 | 24 hours | 270 USGPM |
| Well 2 | December 16 – December 17, 2021 | 24 hours | 90.67 USGPM |
| Well 3 | January 6 – January 7, 2022 | 24 hours | 283 USGPM |
| Well 4 | December 7 – December 8, 2021 | 36 hours | 326.5 USGPM |

*USGPM – US Gallons Per Minute

Real-time data logging technology (Solinst Leveloggers) was employed at all wells to record the drawdown and groundwater level fluctuations resulting from the pumping tests. Manual monitoring of the groundwater levels in the observation wells was conducted using a Solinst water level tape. The measuring points of the wells (the top of the PVC casing for the monitor wells and top of metal casing for the Water Supply Wells) was determined using survey data collected by Wills. The locations and well identifiers of the wells used for each pumping test are shown on **Figure 4**.

Well details, including SWL measured in the observation wells prior to the initiation of each pumping test are summarized in **Appendix D**.

## 9.1 Aquifer Parameter Results

### 9.1.1 Well 3 and Well 4 Transmissivity (T) and Hydraulic Conductivity (K)

The results represent the T value between the pumping well and the monitor well in question. For instance, T can vary between Well 3 and a specific observation well and Well 4 and the same observation well. T is then divided by the average saturated thickness of the aquifer between the pumping well and the specific observation well, to obtain hydraulic conductivity (K). The latter values are used in the groundwater model.

T determined by different analytical methods can vary. The geometric mean (geomean) of T is determined between the Neuman and Moench methods of analysis as these are most applicable to the Norwood Aquifer. These geometric means are then divided by the average saturated thickness to obtain K values.

The drawdown results in MW21-01 to MW21-04 should be regarded with caution as the actual drawdown values are minimal (less than 10 mm). Nevertheless, pumping of Well 3 and Well 4 at the rates indicated did influence the water levels in MW21-01 to MW21-04. The current pumping rates of the Water Supply Wells likely have a very small influence on the water levels in these monitor wells. The extent of the drawdown cone is related to the pumping rate and the K values of the materials between the pumping well and the observation wells. The Aquifer parameter results for Well 3 and Well 4 from the pumping tests are included in **Appendix E**.

### 9.1.2 Well 1B Transmissivity (T) and Hydraulic Conductivity (K)

**Table 5** details aquifer parameters derived from the pumping test on Well 1B. Due to the limited drawdown in the observation wells during the pumping test (less than 10 mm which can be confused with natural variations in water levels) and the disjointed drawdown response in Well 1B shown in **Figure 6**, possibly from other Water Supply Wells pumping, the observation well data analysis did not yield clearly defined aquifer parameters.

**Table 5 - Well 1B Pumping Test Aquifer Parameters Transmissivity (T) and Hydraulic Conductivity (K)**

| Monitor | T m²/day | K m/d | Saturated Thickness m | K m/sec |
|---|---|---|---|---|
| WELL 1B Pumping<br>WELL 1B OBS | - | - | - | - |
| Neuman | 486 | 45.2 | - | - |
| Moench | 486 | 45.2 | - | - |
| Geomean | 486 | 45.2 | 10.74 | 5.23E-4 |

### 9.1.3 Well 2 Transmissivity (T) and Hydraulic Conductivity (K)

**Table 6** details aquifer parameters derived from the pumping test on Well 2.

**Table 6 - Well 2 Pumping Test Aquifer Parameters Transmissivity (T) and Hydraulic Conductivity (K)**

| Monitor | T m²/day | K m/d | Saturated Thickness m | K m/sec |
|---|---|---|---|---|
| Well 2 OBS | - | - | - | - |
| Neuman | 1384 | 187.0 | 7.4 | 2.16E-3 |
| Tartakovsky-Neuman | 1593 | 215.3 | 7.4 | 2.49E-3 |

The observation wells produced minimal drawdown at the Well 2 pumping rate and were examined but could not be analyzed effectively for aquifer parameters.

## 9.2 Well 4 Pumping Test Analysis

Analysis on the Well 4 pumping test was conducted first as it was of longest duration (36 hours) and in the core deposits of the Norwood esker.

The pumping test on Well 4 began at 10:05 a.m. December 7, 2021 and the pumping phase ended December 8, 2021 at 8 p.m. During the pumping test on Well 4 the municipal water supply was still in operation. As such, Wells 1, 2, and 3 pumped 468.97 $m^3$, 10.37 $m^3$, and 143.93 $m^3$ independent of the pumping test on December 7, 2022 and 579.07 $m^3$, 0.67 $m^3$, and 1.3 $m^3$ respectively, on December 8, 2021.

The pumping of Well 3 on December 7 may have affected the response in Well 4 during the pumping test, although the pumping appeared to be before the test on Well 4 began and recovery in the Water Supply Wells is rapid. Due to the distance between Well 4, Well 1, and Well 2, and the relatively low pumping rates, these wells were unlikely to have affected the response in Well 4.

**Table 7** details the drawdown response at the end of the pumping phase in the observation wells and Well 4, during the Well 4 pumping test. Furthermore, the **Table 8** provides the model simulated drawdown.

**Table 7 - Well 4 Pumping Test, Maximum Observed and Simulated Drawdowns**

| Observation Well | Observed Drawdown (m) | Distance from Pumping Well (m) | Simulated Drawdown (m) | Model Corrected Drawdown Pumping Well (m) |
|---|---|---|---|---|
| Well 4 | 0.55 | 0.0 | 0.41 | 0.44 |
| MW21-07 | 0.31 | 19.1 | 0.34 | - |
| MW21-08 | 0.28 | 24.8 | 0.22 | - |
| Well 3 | N/A | 32.9 | 0.28 | - |
| MW21-09 | 0.26 | 61.6 | 0.23 | - |
| MW21-05 | 0.26 | 62.6 | 0.25 | - |
| MW21-10 | 0.26 | 106.5 | 0.18 | - |
| Well 2 | 0.10 | 125.6.0 | 0.14 | - |
| MW21-04 | 0.03 | 134.4 | 0.05 | - |
| MW21-03 | 0.04 | 153.9 | 0.06 | - |
| Well 1B | 0.08 | 161.4 | 0.09 | - |
| MW21-02 | 0.10 | 177.5 | 0.06 | - |
| MW21-01 | 0.04 | 303.0 | 0.03 | - |
| MW21-06 | 0.0 | 696.1 | 0.0 | - |

### 9.2.1 Well 4 Pumping Test Conclusions

In theory, drawdown diminishes with distance from the pumping well in a homogeneous aquifer. MW21-07, MW21-09, MW21-05, and MW21-10 appear to be in a relatively homogeneous aquifer with limited drawdown at a high pumping rate (1,782.4 $m^3$/day), following the predictable pattern.

Plotting the maximum drawdown on a linear scale with the distance on a logarithmic scale can illustrate the extent of the cone of influence of the pumping well at the specified pumping rate. The radius of the drawdown cone could exceed 700 m in a northwest-southeast direction. The data indicates the drawdown cone is larger along the trendline of the Norwood esker. However, from as close as 19.1 m (MW21-07) from the pumping well, the drawdown is minimal (0.31 m) at the pumping test rate. At MW21-10 (106.5 m from the pumping well) drawdown was 0.26 m.

Simulation of the Well 4 pumping test (the modelling details are discussed below) yielded the simulated drawdowns in column four in **Table 7** above. These simulated values are very close to the observed values and give confidence in the model assigned hydraulic conductivity values which were obtained from pumping tests.

The corrected drawdown is calculated for the pumping well using the Peaceman formula and is 0.44 m. The model gives drawdown in the cell in which the well is located and this must be corrected for the well diameter. The simulated corrected drawdown in the pumping well assumes 100% efficiency when pumping. Well 4 shows minimal inefficiency as the observed drawdown was 0.55 m. Pumping wells almost always show some degree of inefficiency at high pumping rates.

**Figure 7** is a graph of the maximum drawdown compared to the distance of the observation well from pumping Well 4 and thus an estimate of the cone of influence when pumping at the pumping test rate. The radius of the cone of influence for a drawdown of 0.01 m is approximately 700 m after 36 hours pumping.

**Figure 8** is a composite plot of the available drawdown data. This plot has a horizontal axis of time/radius$^2$ and a vertical axis of drawdown in metres. Radius is the distance from the pumping well to the observation well. According to theory, for wells located in the same pumped aquifer, drawdowns will fall on the same curve on a composite plot. The composite plot for the Well 4 pumping test illustrates that MW21-05, MW21-07, MW21-08, and MW21-09 fall more or less on the same curve. The curve for MW21-10 lies to the left of the MW21-07 to MW-09 group, indicating it could be in a different zone of the aquifer which may have different aquifer characteristics. Furthermore, MW21-05 plots to the right of the MW21-07 to MW-09 group. MW21-01, MW-02, MW-03, and MW21-04 also appear to be in a different aquifer or part of the aquifer with different characteristics.

The Well 4 drawdown curve is significantly displaced from the other curves. This may be because of wellbore (casing) storage affecting the response or that the well is in a much higher hydraulic conductivity field zone, or both. Wellbore storage is a phenomenon that occurs at the commencement of pumping a well when the compressibility and volume of the wellbore fluid dominates the flow over groundwater entering the wellbore (screen) from the formation. At the start of pumping, the production at surface is due to the expansion of the water in the wellbore, and not the surrounding aquifer. There is a time lag when the pumping rate becomes consistent with the screen entrance rate from the aquifer and this time lag defines the wellbore storage period.

The plot of Well 4 pumping with Well 4 also as the observation well (Well 4 obs) shows a drawdown vs time data curve with log-log axes which curve concave upward indicating increasing drawdown with time in a pattern that does not show the Theis curve response i.e. a curve concave downward eventually become parallel or sub-parallel with the x-axis. This likely indicates that the well is located in a very high hydraulic conductivity zone that is relatively long and narrow. During pumping of the well, the well ‘sensed’ a lower hydraulic conductivity boundary and thus drawdown increased more quickly to maintain the same pumping rate. This pattern does not occur in another well to the same extent. In the Well 3 pumping test, the Well 3 data exhibits a straight line with a slight upturn of the curve at late time.

Wills decided to use the high hydraulic conductivity result obtained during the 2018 step testing in the model because of the challenge to obtain T from the Well 4 drawdown observations in the Well 4 pumping test. The Well 4 pumping test was simulated in the model and it was found that a high hydraulic conductivity was required in the area around Well 4 to obtain the observed drawdown response in the pumping well in addition to the nearby observation wells. A hydraulic conductivity of 3 x $10^{-2}$ metres per second (m/sec) (2,592 m/day) for the sediments around Well 4 from step testing in 2018, was assigned in the model in a relatively thin, long strip more or less in the centre of the Norwood esker spanning the model domain. This hydraulic conductivity represents the core deposits of the Norwood esker which appear to have a smaller width than in the 2018 version of the model. Other hydraulic conductivities assigned to the model were consistent with the results of the aquifer testing detailed in **Appendix E**.

## 9.3 Well 3 Pumping Test Analysis

The pumping test on Well 3 began at 12:30 p.m. January 6, 2022 at a rate of 1542.5 $m^3$/d. The pumping phase ended January 7, 2022 at 12:30 p.m. During the pumping test on Well 3 the municipal water supply was still in operation. As such, Wells 1, 2, and 3 pumped 138.81 $m^3$, 475.94 $m^3$, and 1.14 $m^3$ on January 6, 2022 and 134.4 $m^3$, 541.01 $m^3$, and 1.14 $m^3$ respectively on January 7, 2022. These wells were pumped before and after the Well 3 pumping test, so likely had a minimal effect on the Well 3 pumping test drawdowns. Due to the distance from Well 3 to Well 1 and Well 2, and the relatively low pumping rates, these wells were unlikely to have affected the response in Well 3 or the observation wells.

**Table 8** shows the drawdown response at the end of the pumping phase in the observation wells during the Well 3 pumping test as well as simulated results from the 2022 groundwater model.

**Table 8 - Well 3 Pumping Test & Observation Wells Observed & Simulated Drawdown**

| Observation Well | Observed Drawdown (m) | Distance from Pumping Well (m) | Simulated Drawdown (m) | Corrected Drawdown Pumping Well (m) |
|---|---|---|---|---|
| Well 3 | 2.11 | 0.11 | 0.98 | 1.21 |
| Well 4 | 0.23 | 32.9 | 0.21 | - |
| MW21-08 | 0.28 | 33.7 | 0.14 | - |
| MW21-09 | 0.26 | 38.9 | 0.20 | - |
| MW21-07 | 0.21 | 51.7 | 0.20 | - |
| MW21-10 | 0.26 | 76.1 | 0.16 | - |
| MW21-05 | 0.26 | 89.5 | 0.15 | - |
| Well 2 | 0.1 | 93.3 | 0.13 | - |
| Well 1B | 0.08 | 128.6 | 0.08 | - |
| MW21-04 | 0.04 | 142.1 | 0.02 | - |
| MW21-03 | 0.05 | 145.4 | 0.03 | - |
| MW21-02 | 0.1 | 162.9 | 0.03 | - |
| MW21-01 | 0.03 | 275.6 | 0.02 | - |
| MW21-06 | 0.0 | 655.7 | 0.0 | - |

### 9.3.1 Well 3 Pumping Test Conclusions

The corrected drawdown is calculated for the pumping well using the Peaceman formula and is 1.21 m. The model gives drawdown in the cell in which the well is located and this must be corrected for the well diameter. The simulated corrected drawdown in the pumping well assumes 100% efficiency when pumping. Well 3 shows some inefficiency as the observed drawdown was 2.11 m. Pumping wells almost always shows some degree of inefficiency at high pumping rates.

**Figure 9** is a graph of the maximum drawdown compared to the distance of the observation well from pumping Well 4 and thus an estimate of the cone of influence when pumping at the pumping test rate. The radius of the cone of influence is approximately 180 m at the pumping test rate after 24 hours of pumping.

**Figure 10** is a composite plot of the available drawdown data. This plot has a horizontal axis of time/radius$^2$ and a vertical axis of drawdown in metres. Radius is the distance from the pumping well to the observation well. The composite plot shown on **Figure 10** for the Well 3 pumping test shows that the drawdown curves for all wells except the pumping well itself and MW21-03 more or less fall on the same curve. Displacement on the Y-axis is a synonym for drawdown. The curve for MW21-03 is offset from the main group possibly indicating a part of the aquifer with different aquifer characteristics and parameters.

Well 3, the pumping well, is significantly displaced from the other curves. This may be due to wellbore storage affecting the response or the well is in a much higher hydraulic conductivity field zone, or both. Modelling indicates the hydraulic conductivity of the material surrounding Well 3 is consistent with the results of the Aquifer testing and the results of the 2018 Aquifer testing (Rannie, 2018).

## 9.4 Well 1B Pumping Test Analysis

The pumping test on Well 1B started December, 9, 2022 at 2:00 p.m. and ran for 24 hours to 2:00 p.m. December 10, 2021 at a pumping rate of 1477.6 m$^3$/d. During the pumping test on Well 1B the municipal water supply was still in operation. As such, on December 9, 2021, Well 1 pumped 240.81 m$^3$, Well 2 pumped 15.88 m$^3$ and Well 3 pumped 348.34 m$^3$ independent of the pumping test. Well 1 and Well 2 were operated in the morning before the Well 1B pumping test was started. Well 3 was operating at approximately 10 p.m. December 9, 2021 and may have had a slight impact on the response in Well 1B. On December 10, 2021, Well 1 pumped 162.61 m$^3$, Well 2 pumped 2.25 m$^3$, and Well 3 pumped 593.62 m$^3$. Well 2 was operated during the Well 1B pumping test but the rate was negligible. Well 1 and Well 3 were operated after the Well 1B pumping test was completed. The operation of Well 3 during the Well 1B pumping test indicates there is minimal interference between wells at current pumping rates.

**Table 9** below details the drawdown response at the end of the pumping phase in the observation wells, and Well 1B during the Well 1B pumping test. Furthermore, the table provides the model simulated drawdown.

**Table 9 - Well 1B Pumping Test - Observed and Simulated Drawdown**

| Observation Well | Observed Drawdown (m) | Distance from Pumping Well (m) | Simulated Drawdown (m) | Corrected Drawdown Pumping Well (m) |
|---|---|---|---|---|
| Well 1B | 7.68-8.05 | 0.11 | 2.18 | 3.21 |
| Well 2 | N/A | 38.3 | 0.23 | - |
| MW21-10 | 0.04 | 76.1 | 0.13 | - |
| MW21-09 | 0.04 | 119.1 | 0.09 | - |
| Well 3 | 0.07 | 128.6 | 0.07 | - |
| Well 4 | 0.09 | 161.4 | 0.05 | - |
| MW21-08 | 0.03 | 156.3 | 0.05 | - |
| MW21-02 | 0.01 | 177.5 | 0.02 | - |
| MW21-07 | 0.03 | 179.6 | 0.05 | - |
| MW21-03 | 0.02 | 188.2 | 0.01 | - |
| MW21-01 | 0.0 | 196.7 | 0.03 | - |
| MW21-05 | 0.01 | 208.8 | 0.04 | - |
| MW21-04 | 0.02 | 228.8 | 0.01 | - |
| MW21-06 | 0.01 | 555.6 | 0.0 | - |

### 9.4.1 Well 1B Pumping Test Conclusions

The observed drawdown in the pumping well, Well 1B, was between 7.68 and 8.05 m during the test and confirms the inefficiency of this well when pumped at high rates as first detailed in Rannie (2018). However, the data and the modelling also show that the major drawdown of the water table is limited to the immediate area of Well 1B.

## 9.5 Well 2 Pumping Test Analysis

The Well 2 pumping test was started December 16, 2021 at 11:15 a.m. and ran for 24 hours to 11:15 a.m. December 17, 2021 at an average pumping rate of 497.13 $m^3$/d. Prior to and following the pumping test on Well 1B, the Norwood Drinking Water System was in operation. As such, the other Water Supply Wells pumping on December 16, 2021 were Well 1, which pumped 137.72 $m^3$, and Well 3 which pumped 1.19 $m^3$. On December 17, 2021, Well 1 pumped 181.44 $m^3$, and Well 3 pumped at 1.21 $m^3$. Wells 1 and Well 3 were not pumping during the Well 2 pumping test.

**Table 10** below details the drawdown response at the end of the pumping phase in the observation wells, and Well 2 during the Well 2 pumping test. Furthermore, the table provides the model simulated drawdown.

**Table 10 - Well 2 Pumping Test - Observed and Simulated Drawdown**

| Observation Well | Observed Drawdown (m) | Distance from Pumping Well (m) | Simulated Drawdown (m) | Corrected Drawdown Pumping Well (m) |
|---|---|---|---|---|
| Well 2 | 0.53 | 0.11 | 0.48 | 0.77 |
| Well 1B | 0.03 | 38.3 | 0.11 | - |
| MW21-10 | 0.02 | 60.5 | 0.09 | - |
| MW21-09 | 0.005 | 91.5 | 0.06 | - |
| Well 3 | N/A | 93.3 | 0.06 | - |
| MW21-08 | 0.005 | 123.5 | 0.03 | - |
| Well 4 | N/A | 125.6 | 0.04 | - |
| MW21-07 | 0.005 | 143.3 | 0.04 | - |
| MW21-02 | 0.02 | 175.9 | 0.02 | - |
| MW21-03 | 0.005 | 178.7 | 0.01 | - |
| MW21-05 | 0.0 | 170.7 | 0.01 | - |
| MW21-04 | 0.005 | 208.4 | 0.01 | - |
| MW21-01 | 0.0 | 224.8 | 0.03 | - |
| MW21-06 | 0.015 | 592.7 | 0.0 | - |

### 9.5.1 Well 2 Pumping Test Conclusions

The maximum observed drawdown in Well 2 during the pumping test was 0.53 m. The simulated corrected drawdown was 0.77 m. The model generally over predicted drawdown by a minor amount in the Well 2 pumping test. Observed drawdowns in all observation wells except the Well 2 pumping well and Well 1B could be the result of natural variations in water levels.

## 10.0 Updated Groundwater Model - Norwood Municipal Water Supply

The 2018 updated groundwater model (MODFLOW2005 using the graphical user interface Groundwater Vistas) [model] was used in this modelling exercise and modified with the results of the 2021 and 2022 hydraulic conductivity fields and storage parameters based on the Aquifer testing results. These new inputs were verified with the simulation of the four pumping tests where the simulated drawdowns aligned with the drawdowns observed during Aquifer testing.

## 10.1 Discussion - Norwood Municipal Well Field 2022 Updated Groundwater Model

The 25-year WHPAs generated in the 2022 model differs somewhat from the 2018 updated model. In the 2022 model, the aquifer parameters and aerial extent of the hydraulic conductivity (K) fields were refined. The hydraulic conductivity field representing the high permeability core deposits is narrower in the northeast-southwest direction than in the 2018 model. The Aquifer testing results, with the exception of the drawdown observations in the Well 4 pumping test in the pumping well itself, reflected hydraulic conductivities between 45 and 300 m/day.

The response of Well 4 during the pumping test was anomalous as indicated by the composite chart of drawdowns. The response indicates that Well 4 is in a part of the aquifer that had different characteristics from those of the nearby observation wells. In addition, the drawdown curve of Well 4 did not follow the usual Theis curve as expected, (water level change slowing as the test advanced) but instead showed increasing drawdown as the test advanced. This indicates the potential for a hydraulic boundary in the early portion of the test. This boundary was likely a significantly reduced hydraulic conductivity of lower permeability materials adjacent to the core deposits which was confirmed from observations during drilling and from grain size analyses.

In the 2022 updated model, the high permeability zone was extended north and south along the Norwood esker to the limits of the model. Whether this zone exists and its aerial extent to the northeast and southwest of the Municipal Well Field cannot be determined based on the Aquifer testing results. The 2022 groundwater model simulates the drawdowns during the pumping test relatively well with the high permeability zone extending to the edges of the model domain in both the northeast and southwest directions.

The 25-year WHPA veers north from the northeast-southwest trend of the Norwood esker approximately three kilometres (km) from the Norwood village centre. In this area, a bedrock high likely controlled the Norwood esker deposition and also may have some influence on the groundwater flow directions. Groundwater in this area flows from the northwest and flows around this bedrock high. Since backward tracking pathlines follow the groundwater flow direction (but in reverse) it is not surprising that the pathlines veer from the Norwood esker.

During the continuous pumping of the Water Supply Wells at the PTTW rate simulated in the groundwater model, most of the water pumped from the Water Supply Wells comes from the Norwood esker northeast of the Municipal Well Field. At the current average pumping rate (just less than 700 m$^3$/day in December 2021-January 2022) and with the Water Supply Wells pumping intermittently depending on demand, the drawdown due to pumping is minimal as seen during the pumping tests. While much of the groundwater flow comes from the northeast in the Norwood esker, a component of groundwater flow comes from the northwest. This pattern can be seen in the Static Groundwater Contour Map included as **Figure 5**, and the extent of the drawdown cones of Wells 3 and 4 during the 2021-2022 pumping tests. Currently, some of the precipitation falling on the northwest side of the Norwood esker and beyond to the area of MW21-01 to MW21-04 infiltrates and reaches the saturated portion of the Aquifer where it will flow relatively rapidly to the Water Supply Wells. This pattern will continue for many years and may be a perennial feature depending on the cycle times and demands of the Water Supply Well pumps in the future, as well as locations and pumping rates of newly installed Water Supply Wells, if required.

There is uncertainty in the actual configuration of the high permeability core deposits. Modelling results confirmed relatively narrow but elongated northeast-southwest high permeability core deposits surrounding Well 4. The hydraulic conductivity of the material in MW21-05 and MW21-07 to MW21-10 and Well 3 appear to be an order of magnitude less than those materials surrounding Well 4.

The continuity of these high permeability core deposits are essential to the performance of the groundwater model. It may be possible that the high permeability core deposits could form a narrow corridor to the northeast from Well 4 through the area of the monitor wells at the peak of the Norwood esker. However, because eskers tend to meander, the core deposits may move northwest from Well 4 and then turn northeast.

# 11.0 Predictive Modelling

## 11.1 Long-Term Pumping at the existing PTTW Rate

The groundwater model was used to simulate the effects of pumping Municipal Wells 2, 3 and 4 at 655 m$^3$/day each, for a total of 1,965 m$^3$/day, the PTTW rate. **Table 11** shows the simulated groundwater levels and drawdowns in the municipal wells.

**Table 11- Existing Municipal Pumping Wells, Simulated PTTW Long-Term Rate, and Simulated Drawdowns**

| Hypothetical Water Supply Well | Pumping Final Rate | Simulated SWL (masl) | Simulated Pumping water Level (masl) | Simulated Drawdown (m) | Estimated Top of Pump Intake Elevation (masl) |
|---|---|---|---|---|---|
| Well 4 | 655 | 197.88 | 196.69 | 1.19 | 192.33 |
| Well 3 | 655 | 197.96 | 196.48 | 1.48 | 195.12 |
| Well 2 | 655 | 198.23 | 196.83 | 1.40 | 193.76 |

**Table 11** also shows the estimated top of the pump intake in each well. The simulated pumping levels are higher in elevation than the estimated pump intakes indicating the wells can pump continuously without the water levels in the wells falling below the pump intakes.

The drawdown from continuous pumping at the PTTW rate in MW21-06 adjacent to Mill Pond is 0.33 m. MW21-06 is located in the aquifer under Mill Pond. There was no change in water level in Mill Pond over the simulated 20 years.

Pumping continuously at 1,965 $m^3$/d has no effect on Mill Pond and the Ouse River. The drawdown cone of the existing Water Supply Wells Pumping at 1,965 $m^3$/d is shown on **Figure 11**.

# 12.0 Conclusions

Wills provides the following conclusions and recommendations based on the investigative results of the Aquifer Capacity Study:

## 12.1 Conclusions

- Aquifer test parameters were generated from the pumping tests carried out on Wells 1B, 2, 3 and 4 and observation wells MW21-01 to 10. While most of the test data was relatively straightforward to analyze for aquifer parameters, some of the tests were a challenge to interpret. While this is not that unusual in aquifer test analysis, the reasons for these difficulties could have been because of the configuration of the aquifer:
    - A long, relatively thin granular deposit, flanked by lower permeability deposits.
    - Variability (from boulders to silt and clay) in the texture of the core deposits.
    - The minimal drawdowns experienced even at high pumping rates. The analytical methods are based on assumptions including an 'infinite acting' aquifer and a consistent saturated aquifer thickness as well as isotropic (properties similar in all directions) conditions.
- The higher permeability deposits are quite variable in texture with significant percentages of silt and sand with a predominance of gravel and boulders. The finer materials, especially the silt and trace to minor clay fractions will affect the hydraulic conductivity of the formation.
- The aquifer test analyses involved repeated rounds of data analysis to establish representative aquifer parameters. A considerable amount of professional judgment was required to arrive at a set of parameters which were supported by the multiple lines of evidence from assessing previous reports and maps, and from computer modelling, which resulted in a consistent conceptual model of the groundwater system at Norwood.
- While a substantial volume of groundwater moves toward the Municipal Well Field from the northeast along the Norwood esker, significant groundwater also moves from the northwest. Monitor wells MW21-01 to 04 appear to experience limited drawdown especially with Well 4 pumping during the pumping test. The well logs indicate that much of the material encountered in MW21-01 to 04 was silty sand with some sandy gravel layers or lenses and appear to constitute the flank deposits or the edge of the flank deposits. However, a hydraulic connection does exist between the Municipal Well Field and these northwest monitors.
- To meet the Norwood's population requirements, the current pumping rates of the Municipal Well Field account for approximately 35% of the PTTW rate of 1,965 $m^3$/day (averaging approximately 650 $m^3$/day). The drawdown from pumping at this rate and pumping intermittently each day appear to be minimal. A consequence of this is that the capture zones determined by the 2022 modelling bear little resemblance to the current configuration of capture zones at current pumping rates.
- The drawdown after 36 hours of pumping at 1,782.4 $m^3$/day in Well 4 during the December, 2021 pumping test was 0.55 m, and the drawdown in Well 1B was

between 7.68 to 8.05 m after 24 hours pumping at 1,477.6 m³/day. The drawdown in Wells 2 (at a rate of 494.4 m³/day) and 3 (at a rate of 1542.5 m³/day) were 0.70 m and 2.11 m respectively. The saturated portion of the aquifer was approximately 9.93 m (Well 4), 8.45 m (Well 3), 10.74 (Well 1B), 7.4 (Well 2) in December 2021-January 2022. Water levels appear to vary seasonally about 0.5 m in the area of the Norwood Transfer Station, north of Norwood, and this could be the case in the area of the Municipal Well Field. If this seasonal fluctuation also occurs in the area of the Water Supply Wells, then there would be more water available in spring and early summer with water levels declining in late summer into the winter. The limiting factor in supplying large amounts of water is the limited saturated thickness combined with the screen setting of the existing Water Supply Wells.

- The groundwater model of Municipal Wells 2, 3 and 4 continuously pumping (20 years) at 655 m³/day each, for a total of 1,965 m³/day (the PTTW rate) was shown to be sustainable.
  - The simulated pumping levels were higher in elevation than the estimated pump intakes, indicating the wells can pump continuously without the water levels in the wells falling below the pump intakes.
  - Pumping continuously at the PTTW rate was shown to have no effect on Mill Pond and the Ouse River.
- The simulated pumping levels are higher in elevation than the estimated pump intakes indicating the wells can pump continuously without the water levels in the wells falling below the pump intakes.

We trust that the information contained in and attached to this report meets your needs at this time. The following Statement of Limitations should be read carefully and is an integral part of this report. Do not hesitate to contact the undersigned if you have any questions or concerns.

Respectfully submitted,

Prepared by: ______________________

David Ruttan, B.A.Sc., P. Eng.
Senior Hydrogeologist/Senior Groundwater Modeller

______________________

Ian Ames, M.Sc., P.Geo.
Environmental Monitoring and
Management Lead

# 13.0 Statement of Limitations

This report is intended solely for The Township of Asphodel-Norwood (Client) in assessing the capacity of the Norwood Water Supply Aquifer, and is prohibited for use by others without Wills' prior written consent. This report is considered Wills' professional work product and shall remain the sole property of D.M. Wills Associates Limited (Wills). Any unauthorized reuse, redistribution of or reliance on this report shall be at the Client and recipient's sole risk, without liability to Wills. The Client shall defend, indemnify and hold Wills harmless from any liability arising from or related to the Client's unauthorized distribution of the report. No portion of this report may be used as a separate entity; it is to be read in its entirety and shall include supporting drawings and appendices.

The recommendations made in this report are based on Wills' present understanding of the project, the current and proposed site use, ground and subsurface conditions, and are based on the work scope approved by the Client and described in the report. The services were performed in a manner consistent with the level of care and skill ordinarily exercised by members of geoscience or engineering professions currently practicing under similar conditions in the same locality. No other representations, and no warranties or representations of any kind, either expressed or implied, are made. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the sole responsibility of such third parties.

Soil, groundwater, and bedrock conditions between and beyond the test locations may differ both horizontally and vertically from those encountered at the test locations. Should any conditions within the Study Area be encountered which differ from those found at the test locations, Wills must be notified immediately in order to permit a reassessment of our recommendations. If different conditions are identified during future activities on the Site, no matter how minor, the recommendations in this report shall be considered invalid until sufficient review and written assessment of said conditions by Wills is completed.

# Figures

**Legend**

— Township Property Boundary

### Site Location Plan

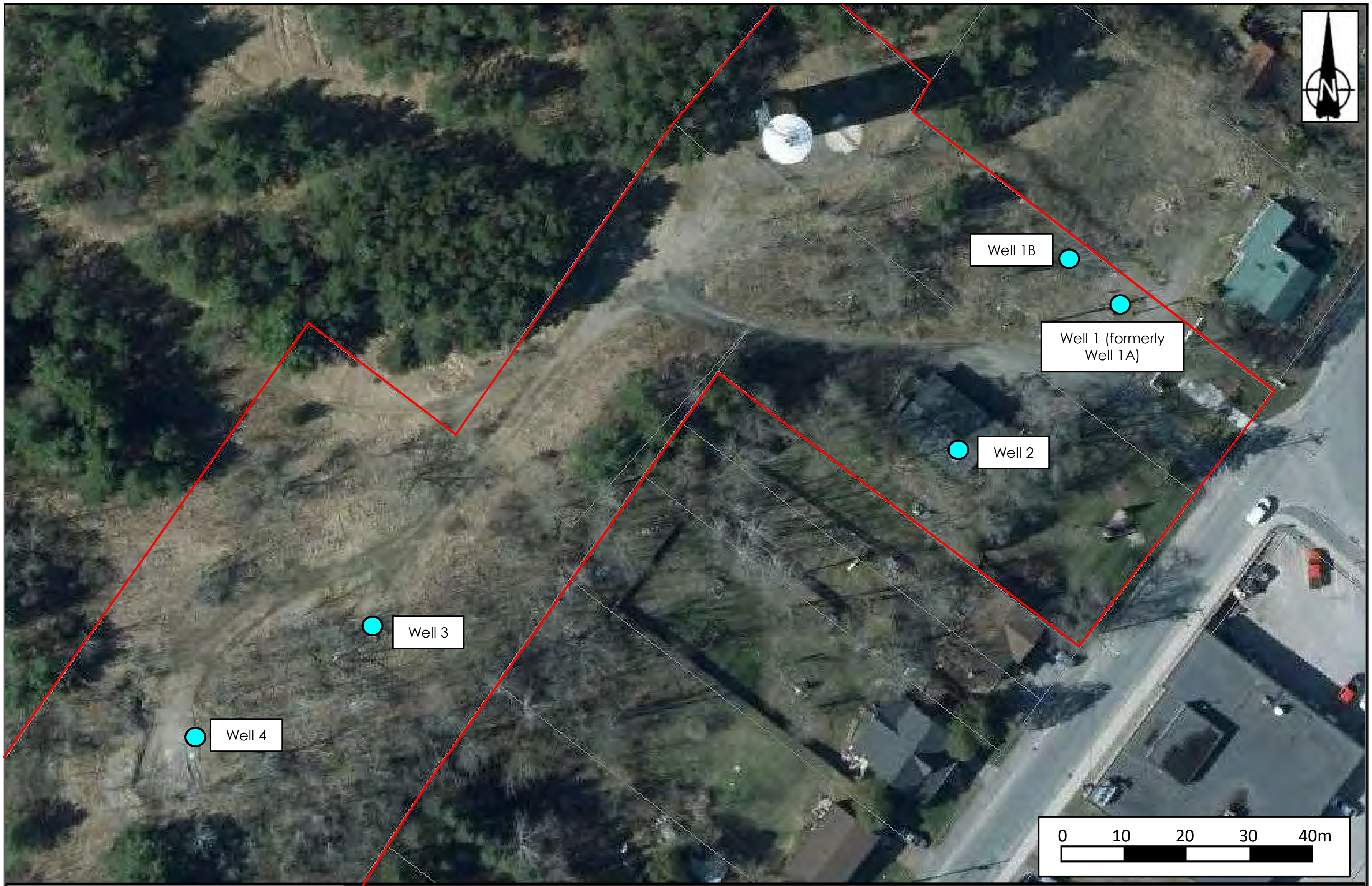
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| Drawn By | LT | Scale | See scale bar |
| Checked | IA | Date | June 2022 |
| | | | |
| Project No. | 21-7128 | Drawing File No. | Figure 1 |



**Legend**

● Existing Municipal Well

— Township Property Boundary

**Water Supply Well Locations**

Aquifer Capacity Study
Norwood, Ontario

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| Drawn By | LT | Scale | See scale bar |
| Checked | IA | Date | June 2022 |
| | | | |
| Project No. | 21-7128 | Drawing File No. | Figure 2 |

## Legend

- 🟡 2021 Borehole/Monitor Well
- 🔵 Existing Municipal Well
- — Township Property Boundary

**Subsurface Investigation Plan**

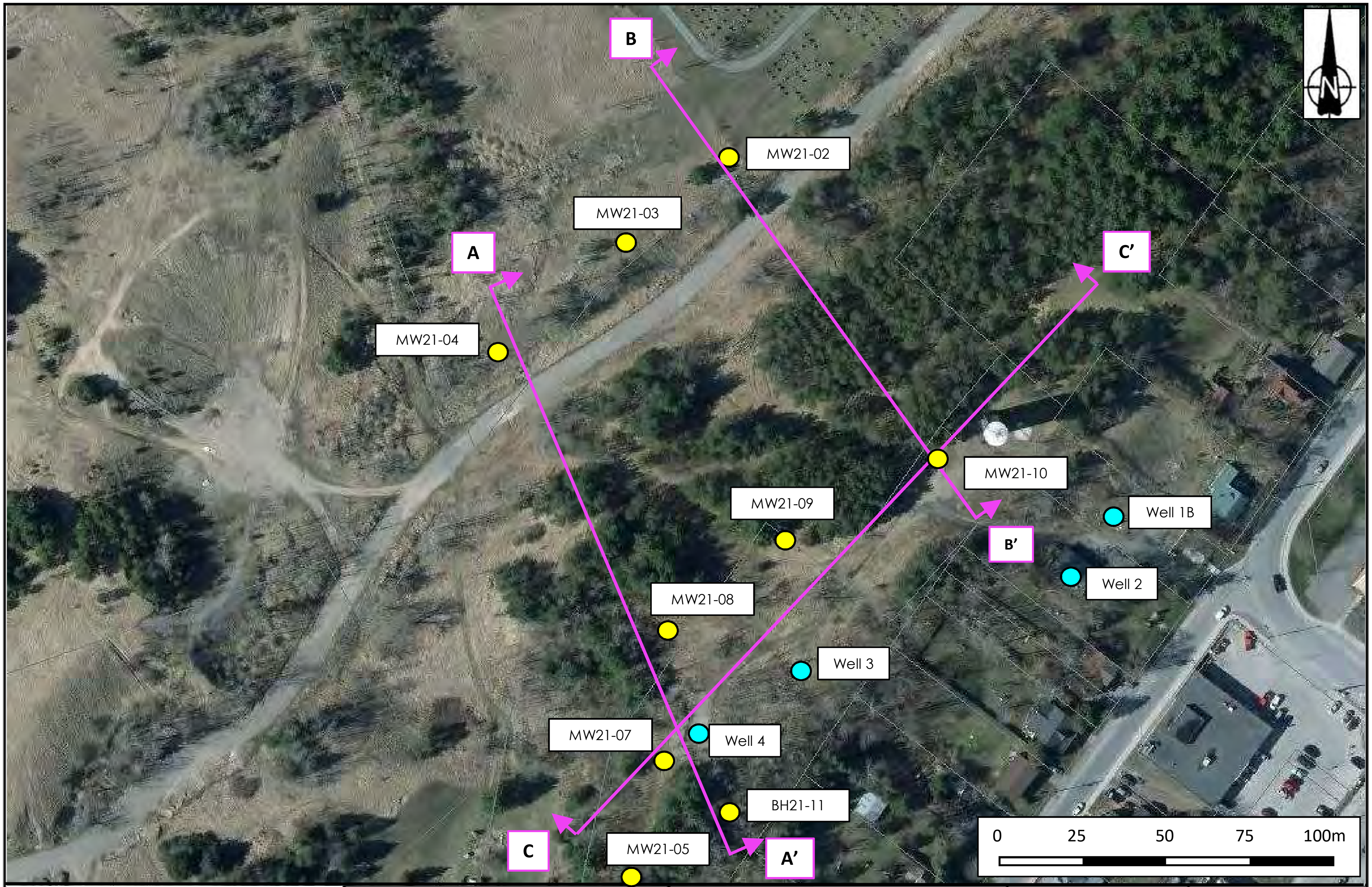
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| Drawn By | LT | Scale | See scale bar |
| Checked | IA | Date | Dec 2021 |
| | | | |
| Project No. | 21-7128 | Drawing File No. | Figure 3 |



**Legend**

● 2021 Borehole/Monitor Well

● Existing Municipal Well

— Cross Section

**Cross Section Locations**

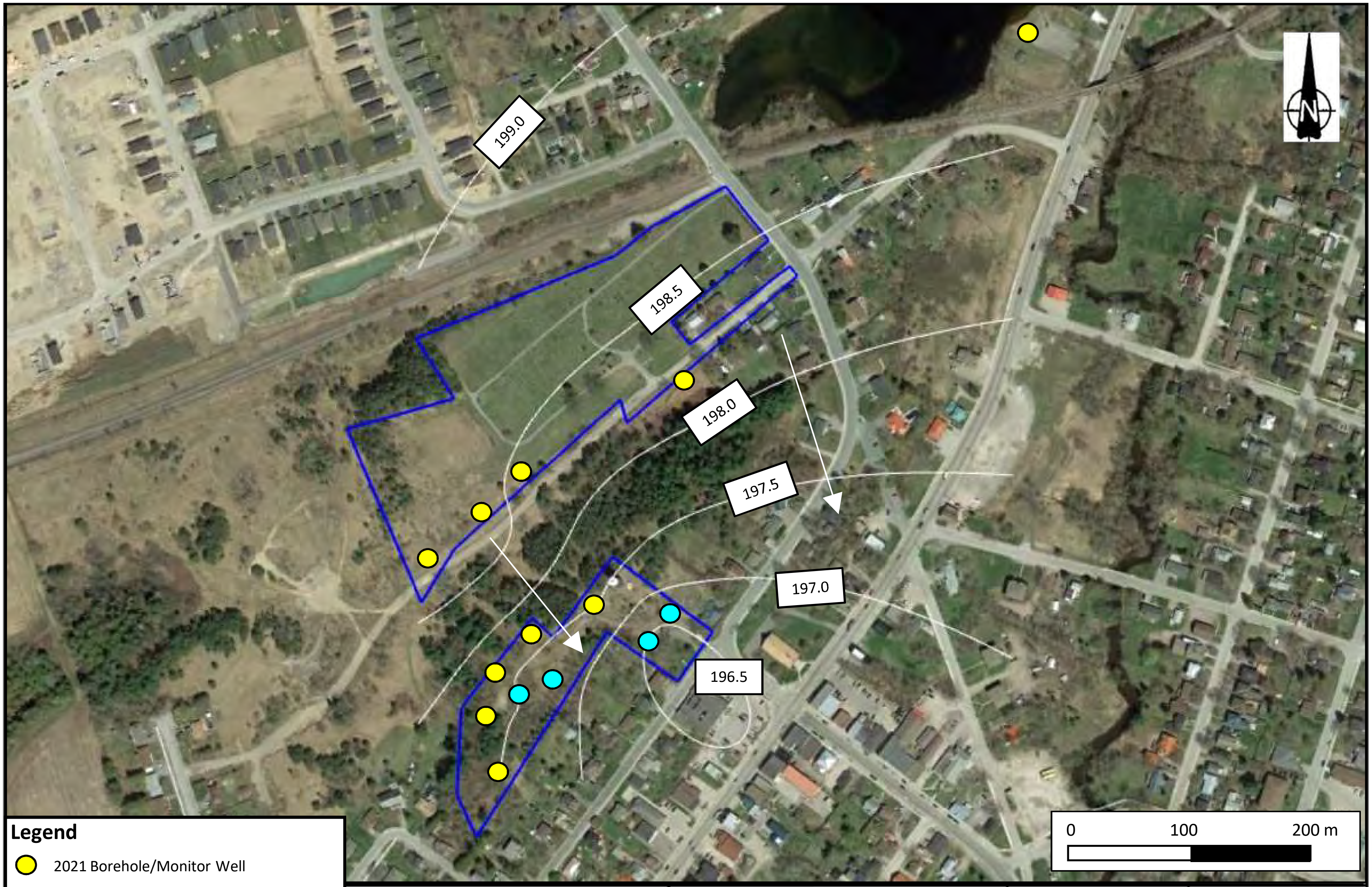
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| Drawn By | LT | Scale | See scale bar |
| Checked | IA | Date | June 2022 |
| | | | |
| Project No. | 21-7128 | Drawing File No. | Figure 4 |



**Legend**

- ● 2021 Borehole/Monitor Well
- ● Municipal Well
- 190 Groundwater Contour Elevation (masl) Showing Inferred Flow Direction
- ╲ Township Lands

## Static Groundwater Level Contour Map

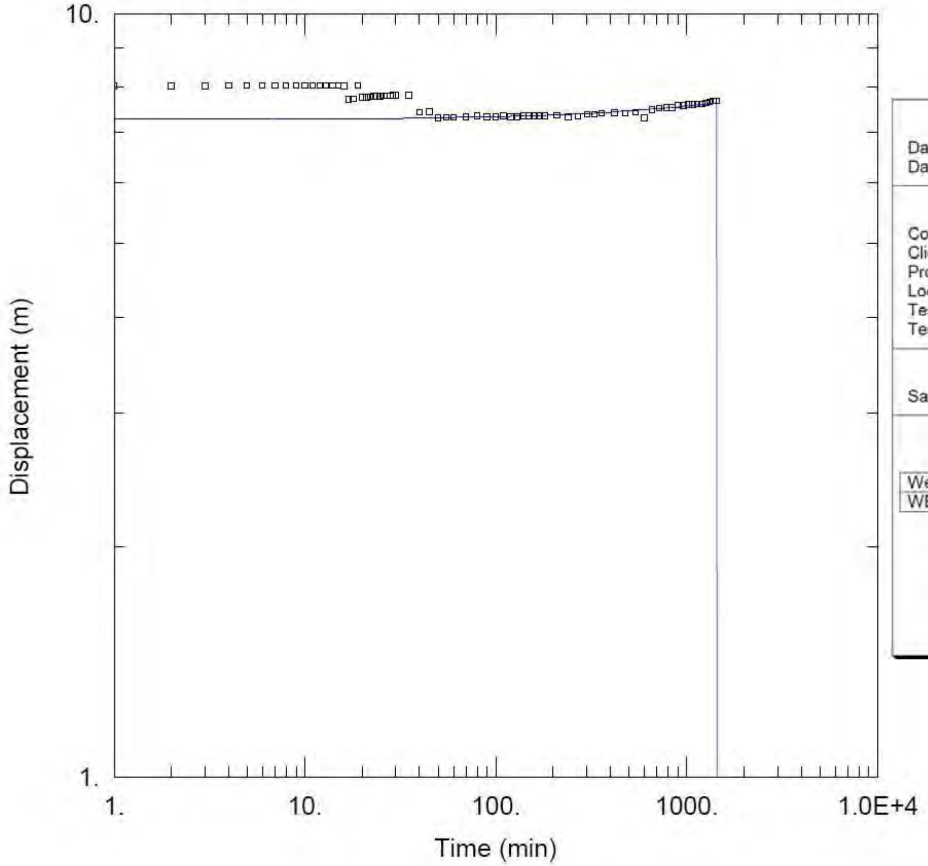
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| **Drawn By** | LT | **Scale** | See scale bar |
| **Checked** | IA | **Date** | June 2022 |
| | | | |
| **Project No.** | 21-7128 | **Drawing File No.** | Figure 5 |



WELL TEST ANALYSIS

Data Set: C:\...\WELL 3 P COMPOSITE.aqt
Date: 03/09/22
Time: 12:20:14

PROJECT INFORMATION

Company: WILLS
Client: NORWOOD
Project: 7128
Location: NORWOOD
Test Well: WELL 3 PUMPING TEST P WELL
Test Date: 2018

AQUIFER DATA

Saturated Thickness: 9.4 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| WELL 3 | 740367.2 | 4918787.2 |

Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ WELL 3 | 740367.2 | 4918787.2 |
| MW21-05 | 740323.75 | 4918709.1 |
| MW21-07 | 740326.1 | 4918755.9 |
| MW21-08 | 740334.2 | 4918793.9 |
| MW21-09 | 740364.3 | 4918826 |
| MW21-10 | 740406.3 | 4918852.6 |
| MW21-03 | 740309 | 4918921 |
| WELL 4 | 740339.3 | 4918769.7 |

**Well 1B Composite Pumping Test**

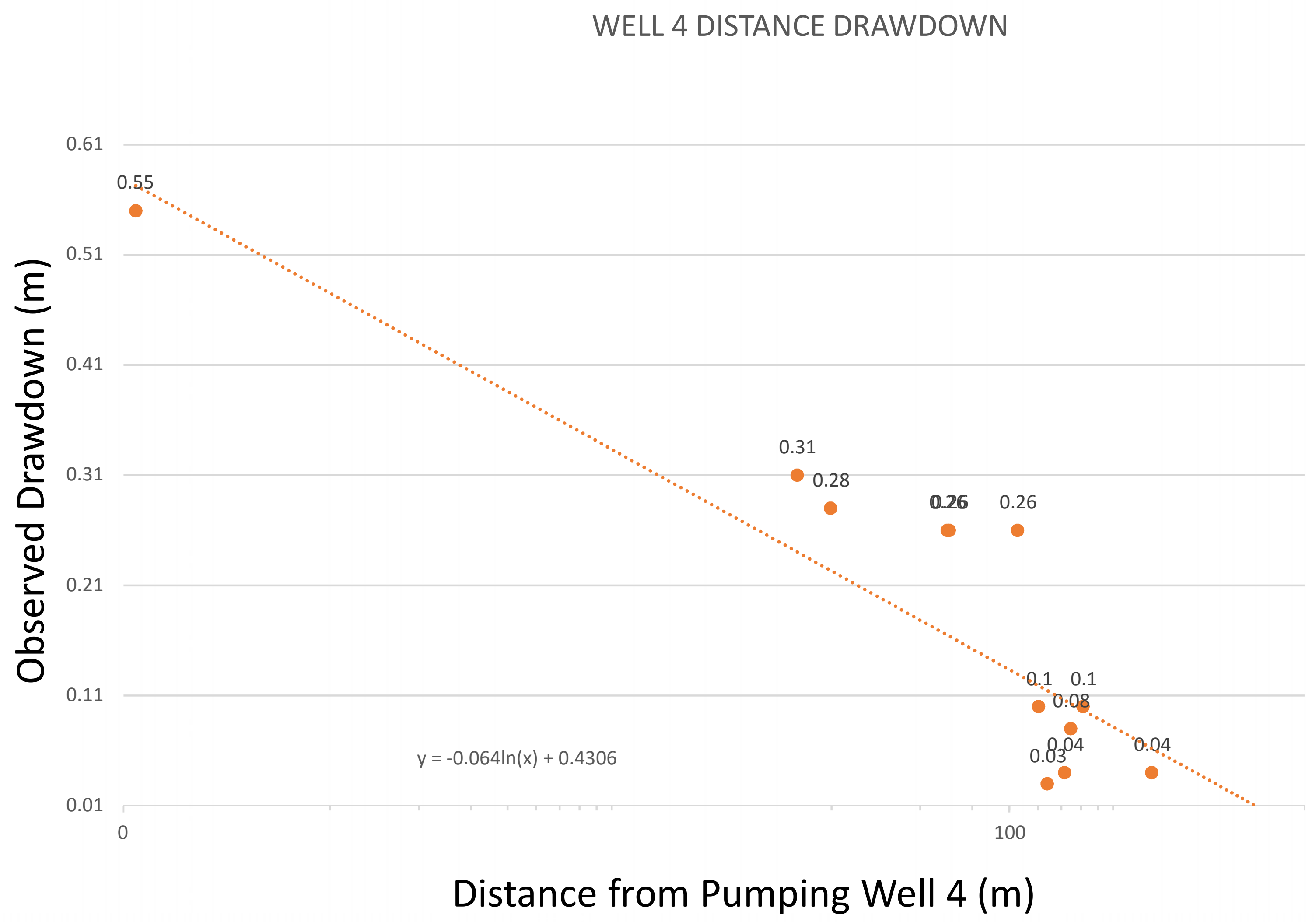
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | |
|---|---|
| Drawn By DR | Scale See scale bar |
| Checked IA | Date May 2022 |
| | |
| Project No. 21-7128 | Drawing File No. Figure 6 |



**Legend**

● Observed Drawdown (m)

⋯ Log Observed Drawdown (m)

**Maximum Drawdown Vs. Distance from Well 4**

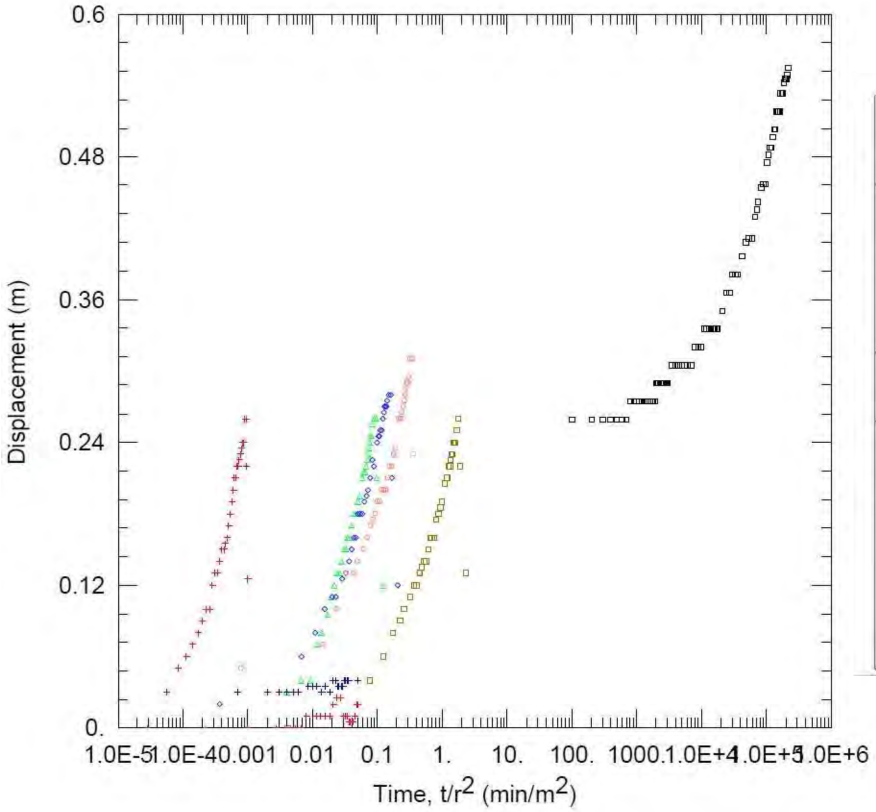
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | |
|---|---|
| **Drawn By** DR | **Scale** See scale bar |
| **Checked** IA | **Date** May 2022 |
| | |
| **Project No.** 21-7128 | **Drawing File No.** Figure 7 |



WELL TEST ANALYSIS

Data Set: C:\...\WELL 4 PUMPING TEST COMPOSITE.aqt
Date: 05/11/22 Time: 13:41:16

PROJECT INFORMATION

Company: WILLS
Client: NORWOOD
Project: 7128
Location: NORWOOD
Test Well: WELL 4 logger
Test Date: 12/07/21

AQUIFER DATA

Saturated Thickness: 9.93 m

WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| WELL 4 | 740339 | 4918678 |

Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ WELL 4 | 740339 | 4918678 |
| + MW21-10 | 740406.3 | 4918852.6 |
| ◇ MW21-09 | 740364.3 | 4918826 |
| △ MW21-08 | 740334.2 | 4918793.9 |
| ○ MW21-07 | 740326.1 | 4918755.9 |
| □ MW21-05 | 740323.75 | 4918709.1 |
| + MW21-03 | 740309 | 4918921 |
| + MW21-04 | 740254.9 | 4918874.4 |

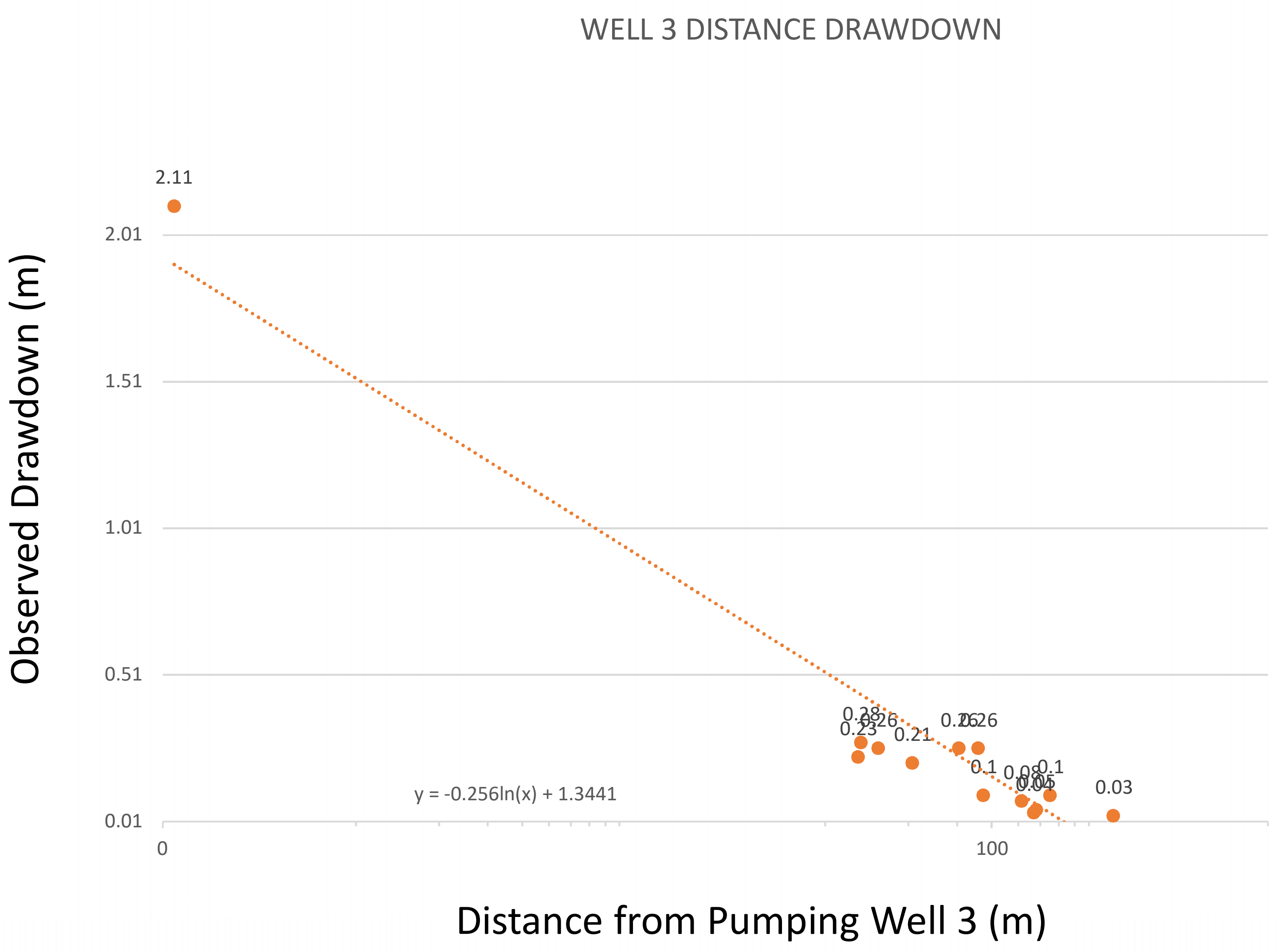
**Well 4 Composite Pumping Test**

Aquifer Capacity Study
Norwood, Ontario

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| **Drawn By** | DR | **Scale** | See scale bar |
| **Checked** | IA | **Date** | May 2022 |
| | | | |
| **Project No.** | 21-7128 | **Drawing File No.** | Figure 8 |



● Observed Drawdown (m)

⋯ Log Observed Drawdown (m)

**Maximum Drawdown Vs. Distance from Well 3**

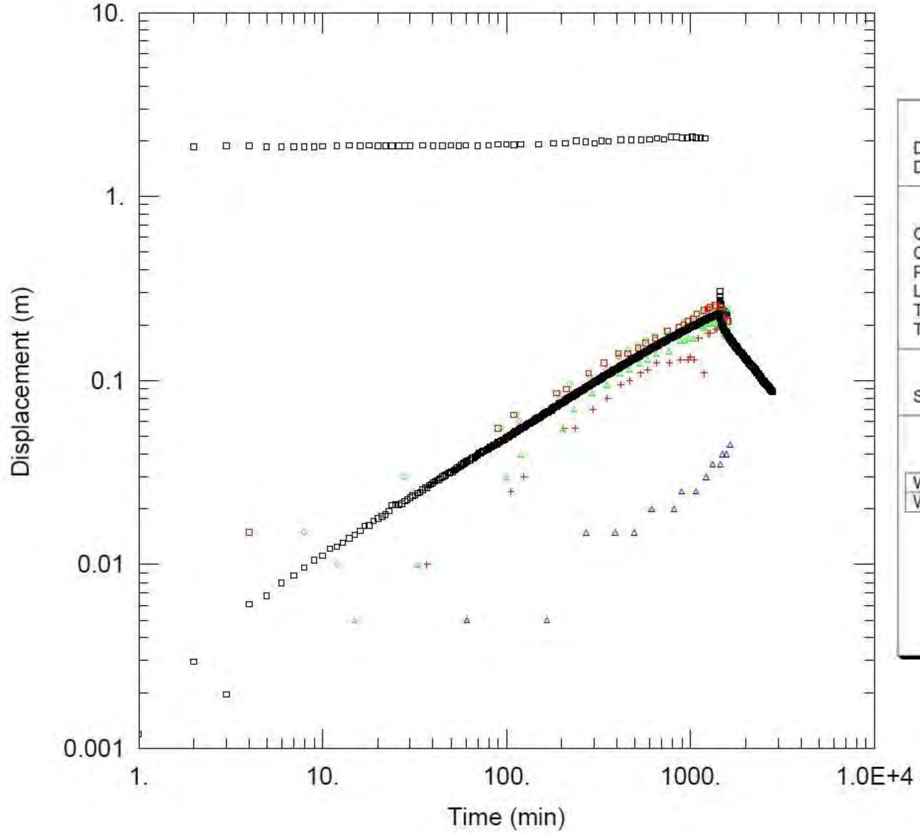
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | |
|---|---|
| **Drawn By** DR | **Scale** See scale bar |
| **Checked** IA | **Date** May 2022 |
| | |
| **Project No.** 21-7128 | **Drawing File No.** Figure 9 |



WELL TEST ANALYSIS

Data Set: C:\...\WELL 3 P COMPOSITE.aqt
Date: 03/09/22 Time: 12:20:14

PROJECT INFORMATION

Company: WILLS
Client: NORWOOD
Project: 7128
Location: NORWOOD
Test Well: WELL 3 PUMPING TEST P WELL
Test Date: 2018

AQUIFER DATA

Saturated Thickness: 9.4 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| WELL 3 | 740367.2 | 4918787.2 |

Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ WELL 3 | 740367.2 | 4918787.2 |
| + MW21-05 | 740323.75 | 4918709.1 |
| MW21-07 | 740326.1 | 4918755.9 |
| MW21-08 | 740334.2 | 4918793.9 |
| MW21-09 | 740364.3 | 4918826 |
| ○ MW21-10 | 740406.3 | 4918852.6 |
| △ MW21-03 | 740309 | 4918921 |
| ○ WELL 4 | 740339.3 | 4918769.7 |

**Well 3 Composite Pumping Test**

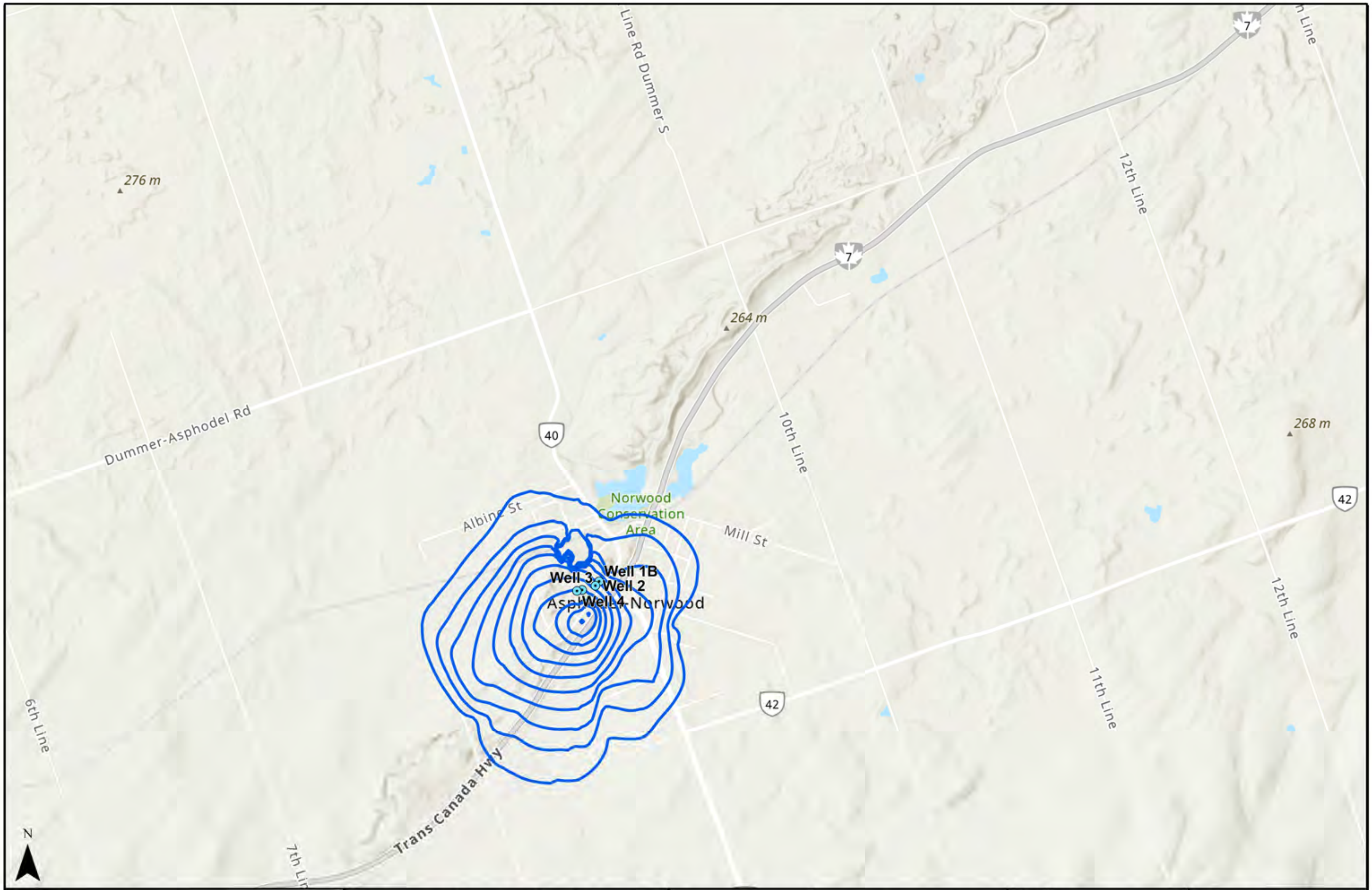
Aquifer Capacity Study
Norwood, Ontario

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | |
|---|---|
| **Drawn By** DR | **Scale** See scale bar |
| **Checked** IA | **Date** May 2022 |
| | |
| **Project No.** 21-7128 | **Drawing File No.** Figure 10 |



Legend

◉ Municipal Wells

━ Drawdown Cone of Existing Municipal Wells Pumping at 1,965 $m^3$/day

SOURCE CREDITS:ESRI, NASA, NGA, USGS, PROVINCE OF ONTARIO, ESRI CANADA, ESRI, HERE, GARMIN, SAFEGRAPH, GEOTECHNOLOGIES, INC, METI/NASA, USGS, EPA, NPS, USDA, NRCAN, PARKS CANADA

## Drawdown Cone of Wells 2,3, and 4 Pumping at PTTW Rate – 1,965 m3/day (655 m3/day each).

Norwood Well Field, Norwood Ontario

Figure 11

W I L L S

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.741.3568
E. wills@dmwills.com

**Drawn By** J Whalen

**Checked** D Ruttan

**Project No.** 7128

**Scale** Scale: 1:50,000

**Date** August, 2022

**Drawing File No.** Name: 7128-CapacityFiguresJune2022

# Appendix A

## Regional Maps

**Legend**

- 🟧 Spillway
- 🟩 Esker
- 🟪 Till Moraines
- — Subject Property Boundary

## Regional Physiography Map

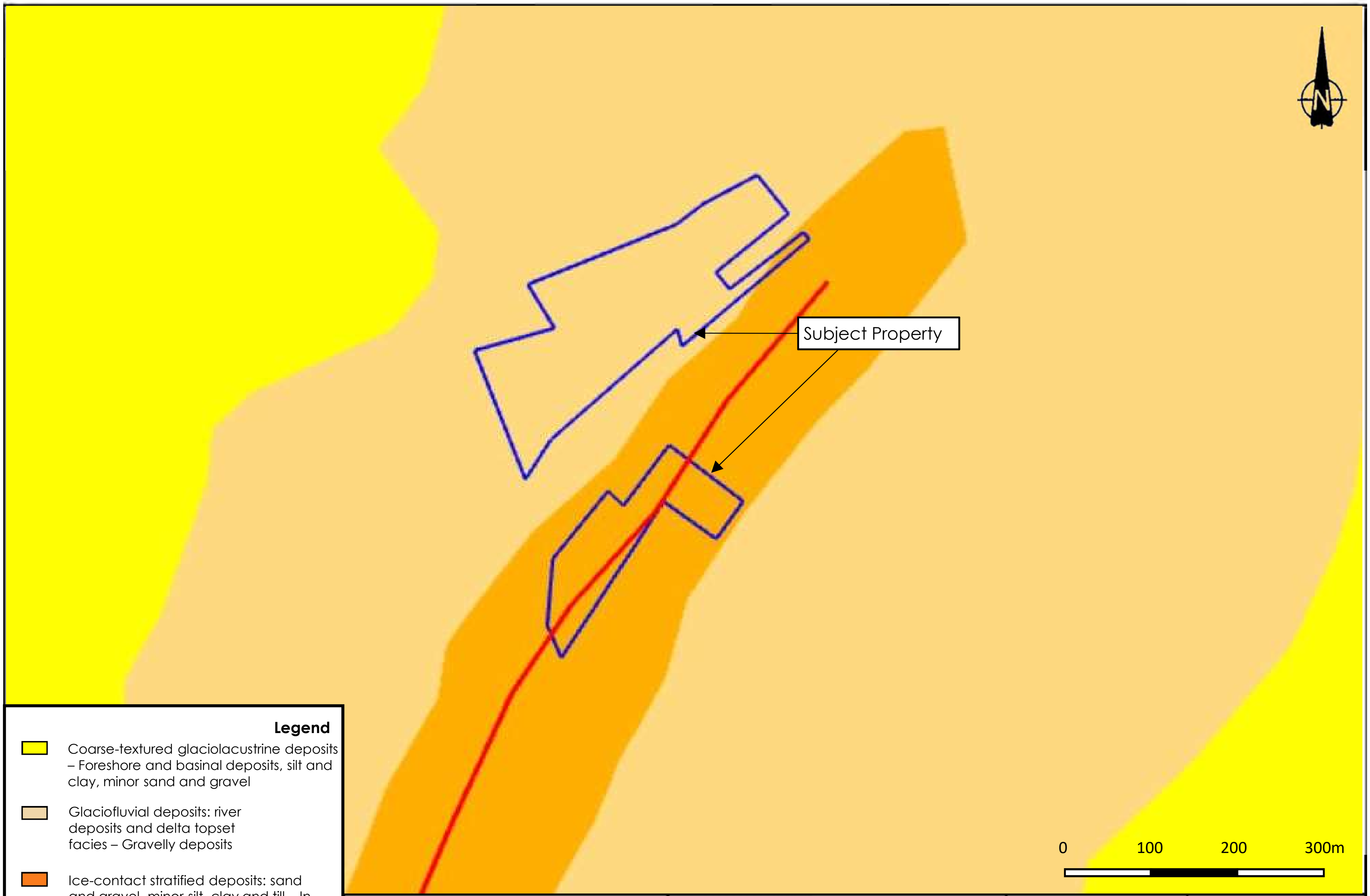
Capacity Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| **Drawn By** | LT | **Scale** | See Scale Bar |
| **Checked** | IA | **Date** | May 2022 |
| | | | |
| **Project No.** | 21-7128 | **Drawing File No.** | APP-A1 |



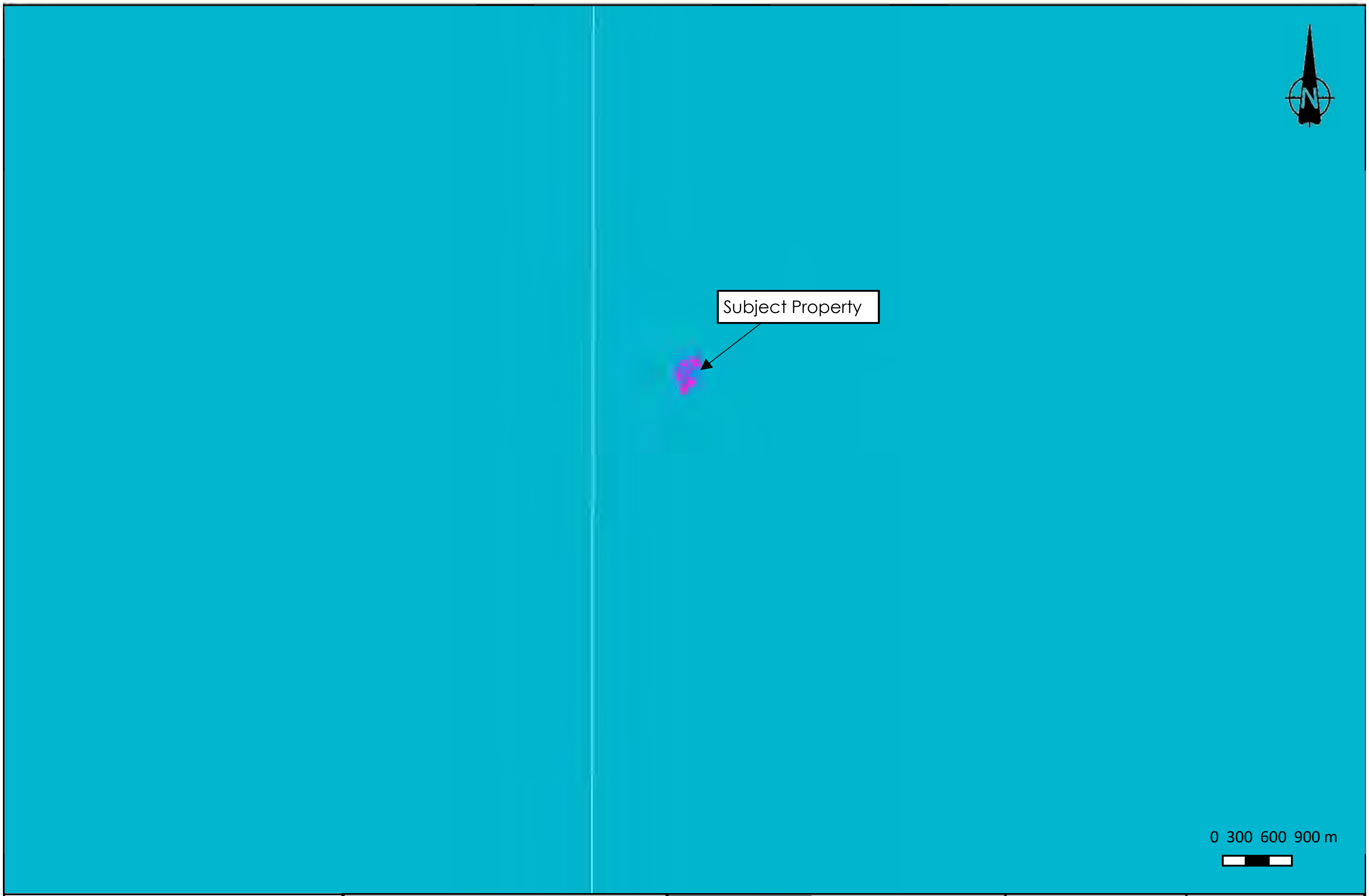
## Regional Surficial Geology Map

Capacity Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| **Drawn By** | LT | **Scale** | See Scale Bar |
| **Checked** | IA | **Date** | May 2022 |
| | | | |
| **Project No.** | 21-7128 | **Drawing File No.** | APP-A2 |



**Legend**

🟦 Middle Ordovician, Ottawa Group-Limestone, dolostone, shale, arkose, sandstone

— Subject Property Boundary

## Regional Bedrock Geology Map

Capacity Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

WILLS

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
Canada K9J 0B9

P. 705.742.2297
F. 705.749.9944
E. wills@dmwills.com

| | | | |
|---|---|---|---|
| **Drawn By** | LT | **Scale** | See Scale Bar |
| **Checked** | IA | **Date** | May 2022 |
| | | | |
| **Project No.** | 21-7128 | **Drawing File No.** | APP-A3 |

# Appendix B

## Borehole Logs & Monitor Well Construction Details

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# BORING NUMBER BH21-11

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT NUMBER** 21-7128

**PROJECT LOCATION** Norwood, Ontario

**DATE STARTED** 11/22/21 **COMPLETED** 11/23/21

**UTM EASTING** 262393.4256 **NORTHING** 4918639.4989

**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.

**GROUND ELEVATION** 218.72 masl

**DRILLING METHOD** 8" Hollow Stem Auger/Mud Rotary with Split Spoons

**GROUNDWATER LEVELS:**

**LOGGED BY** LT **CHECKED BY** IA

**AT END OF DRILLING** ---

**NOTES** 8" Hollow Stem Auger 0.00 m to 1.50 m, Mud Rotary 1.50 m to 15.85 m

**AFTER DRILLING** ---

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE | GRAPHIC LOG | | MATERIAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|
| | SS-1 | 38 | 3 | | 0.05 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, rootlets, moist, loose | 218.67 |
| | | | | | | SILTY SAND:<br>Brown silty sand, some gravel, trace clay, occasional cobble, moist, compact | |
| | SS-2 | 46 | 23 | | | -trace gravel | |
| | | | | | 3.05 | | 215.67 |
| | SS-3 | 17 | 15 | | | GRAVEL:<br>Grey gravel, trace sand, trace silt, compact | |
| 5 | SS-4 | 31 | 17 | | | | |
| | SS-5 | 31 | 23 | | | -occasional cobble | |
| | SS-6 | 54 | 10 | | | -coarse grained sand bed (upper 0.1 m of split spoon), some gravel, trace silt<br>-some sand | |
| 10 | SS-7 | 48 | 13 | | | -coarse sand and gravel, trace silt | |
| | SS-8 | 0 | 50+ | | | -very dense | |
| | SS-9 | 40 | 50+ | | | | |
| | | | | | 13.70 | -boulder, compact | 205.02 |
| | SS-10 | 38 | 50+ | | | SAND:<br>Grey brown sand (coarse to medium grained), trace to some silt, occasional cobble/boulder, very dense | |
| 15 | | | | | | | |
| | SS-11 | 8 | 50+ | | 15.85 | -increasing cobble/boulder content | 202.87 |

Borehole terminated at 15.85 m in sand due to practical refusal on cobble/boulder material.

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-01

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 11/15/21 **COMPLETED** 11/15/21
**UTM EASTING** 262542.5859 **NORTHING** 4918931.382
**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.
**GROUND ELEVATION** 202.23 masl
**DRILLING METHOD** 8" Hollow Stem Auger with Split Spoons
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES**
▽ **AFTER DRILLING** 4.06 m / Elev 198.17 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE |
|---|---|---|---|
| | SS-1 | 50 | 3 |
| | SS-2 | 67 | 28 |
| | SS-3 | 46 | 39 |
| 5 | SS-4 | 75 | 25 |
| | SS-5 | 87 | 18 |
| | SS-6 | 100 | 46 |

REMARKS

Static Water Level
3.75 mbg
Dec 3/21

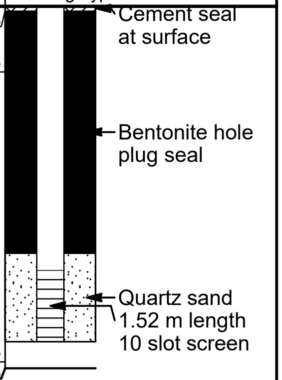
GSA SS-5:
Gravel - 0%
Sand - 61%
Silt - 35%
Clay - 4%

| | MATERIAL DESCRIPTION | |
|---|---|---|
| 0.10 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, moist, loose | 202.13 |
| 1.50 | SILTY SAND:<br>Medium brown silty sand, trace clay, moist, loose | 200.73 |
| | SAND:<br>Brown sand, some silt, trace gravel, moist, dense<br>▽ -some gravel, occasional cobble<br>-gravel and coarse sand, saturated, compact<br>-trace gravel<br>-interbedded coarse and fine grained sand, silty, no gravel | |
| 8.10 | | 194.13 |
| 8.25 | GRAVEL AND SAND:<br>Grey gravel and sand, trace silt, trace clay, abundant cobble/boulder, dense | 193.98 |

Borehole terminated at 8.25 m in gravel and sand due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 203.27 (m)
Casing Type: Monument



TESTING 7128 BOREHOLE LOGS.GPJ OVERBURDENBHLOGNVALUE.GDT 5/25/22

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

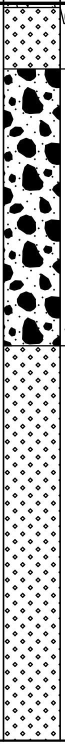
# WELL NUMBER MW21-02

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 11/15/21 **COMPLETED** 11/16/21
**UTM EASTING** 262399.661 **NORTHING** 4918847.0905
**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.
**GROUND ELEVATION** 208.24 masl
**DRILLING METHOD** 8" Hollow Stem Auger/Mud Rotary with Split Spoons
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES** 8" Hollow Stem Auger to 6.10 m, Mud Rotary 6.10 m to 16.80 m
▽ **AFTER DRILLING** 10.15 m / Elev 198.09 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE | REMARKS |
|---|---|---|---|---|
| | SS-1 | 42 | 13 | |
| | SS-2 | 62 | 12 | |
| | SS-3 | 44 | 27 | |
| 5 | SS-4 | 67 | 22 | |
| | SS-5 | 56 | 42 | |
| | SS-6 | 40 | 28 | |
| | SS-7 | 46 | 25 | Static Water Level<br>10.15 mbg<br>Dec 3/21 |
| 10 | SS-8 | 56 | 26 | |
| | SS-9 | 75 | 26 | |
| | SS-10 | 83 | 20 | GSA SS-11b:<br>Gravel - 0%<br>Sand- 70%<br>Silt-25%<br>Clay-5% |
| 15 | SS-11 | 87 | 30 | |
| | SS-12 | 29 | 50+ | |

GRAPHIC LOG



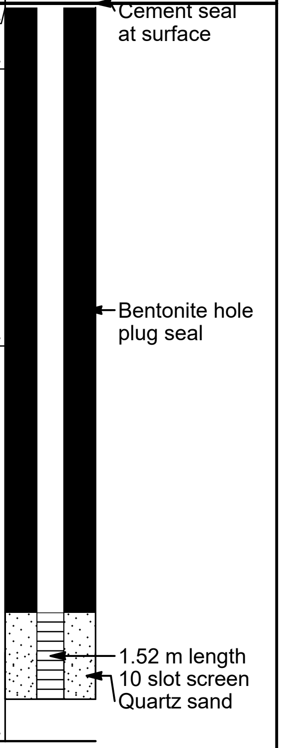
MATERIAL DESCRIPTION

| | | |
|---|---|---|
| 0.10 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, moist, loose | 208.14 |
| 1.50 | SAND:<br>Brown sand, some gravel, trace silt, trace clay, occasional cobble, moist, compact | 206.74 |
| 7.80 | SAND AND GRAVEL:<br>Brown sand and gravel, some silt, trace clay, occasional cobble, moist, compact | 200.44 |
| 16.80 | SAND:<br>Brown sand, some gravel, some silt, trace clay, occasional cobble/boulder<br>-trace gravel ▽<br>-sandy gravel bed (0.2 m thick), dense<br>-interbedded fine and coarse sand, silty, no gravel<br>-very dense, increasing cobble/boulder content | 191.44 |

Borehole terminated at 16.80 m in sand due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 209.29 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-03

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 11/17/21 **COMPLETED** 11/17/21
**UTM EASTING** 262370.6982 **NORTHING** 4918822.6306
**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.
**GROUND ELEVATION** 208.8 masl
**DRILLING METHOD** 6" Solid Stem Auger/Mud Rotary with Split Spoons
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES** 6" Solid Stem Auger to 4.60 m, Mud Rotary 4.60 m to 17.50 m
▽ **AFTER DRILLING** 9.99 m / Elev 198.81 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE |
|---|---|---|---|
| | SS-1 | 29 | 14 |
| | SS-2 | 65 | 8 |
| | SS-3 | 52 | 16 |
| 5 | SS-4 | 29 | 50+ |
| | SS-5 | 71 | 23 |
| | SS-6 | 50 | 26 |
| | SS-7 | 65 | 32 |
| 10 | SS-8 | 77 | 41 |
| | SS-9 | 58 | 19 |
| | SS-10 | 69 | 21 |
| 15 | SS-11 | 54 | 21 |
| | SS-12 | 35 | 50+ |

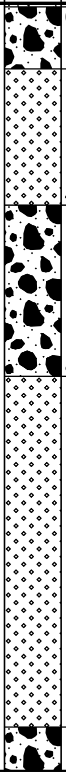
REMARKS

Static Water Level
9.99 mbg
Dec 3/21

GSA SS-7:
Gravel - 3%
Sand- 76%
Silt-17%
Clay-4%

GSA SS-11:
Gravel - 4%
Sand- 70%
Silt-22%
Clay-4%

GRAPHIC LOG



MATERIAL DESCRIPTION

0.08 — TOPSOIL: Dark brown silty sand topsoil, trace clay, rootlets, moist, compact — 208.72

1.50 — SAND AND GRAVEL: Brown sand and gravel, some silt, trace clay, occasional cobble, moist, compact — 207.30

4.60 — SAND: Brown sand (coarse grained), trace gravel, trace silt, trace clay, moist, loose
-medium grained sand, compact
-some gravel, occasional cobble — 204.20

8.50 — SANDY GRAVEL: Grey brown sandy gravel (coarse grained sand), trace silt, occasional cobble, very dense
-fine grained sand over 0.15 m, compact — 200.30

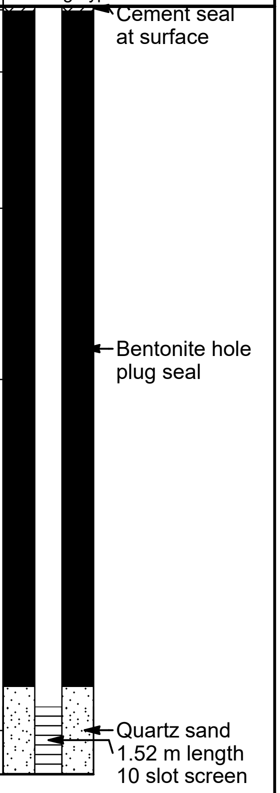
16.50 — SAND: Brown sand (medium grained), trace silt, trace clay, trace gravel, dense
▽
-some silt
-gravelly sand bed (0.2 m thick), compact
-some gravel, occasional cobble/boulder
-silty, trace gravel
-fine grained sand fraction — 192.30

17.50 — SANDY GRAVEL: Grey sandy gravel, trace silt, trace clay, abundant cobble/boulder, very dense — 191.30

Borehole terminated at 17.50 m in sandy gravel due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 209.92 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-04

PAGE 1 OF 1

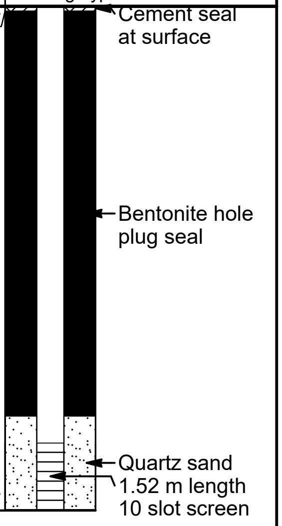
**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 11/18/21 **COMPLETED** 11/18/21
**UTM EASTING** 262313.0887 **NORTHING** 4918780.278
**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.
**GROUND ELEVATION** 202.57 masl
**DRILLING METHOD** 6" Solid Stem Auger/Mud Rotary with Split Spoons
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES**
▽ **AFTER DRILLING** 3.48 m / Elev 199.09 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE | REMARKS | GRAPHIC LOG | MATERIAL DESCRIPTION |
|---|---|---|---|---|---|---|
| | SS-1 | 58 | 6 | | | 0.10 TOPSOIL: Dark brown silty sand topsoil, trace clay, rootlets, moist, compact 202.47 |
| | SS-2 | 56 | 4 | Static Water Level<br>3.48 mbg<br>Dec 3/21 | | SAND: Brown sand (medium grained), trace silt, trace clay, trace gravel, occasional cobble/boulder, loose |
| | SS-3 | 77 | 6 | | | ▽ -fine textured sand fraction, no gravel<br>-light brown |
| 5 | SS-4 | 79 | 11 | | | -brown, coarse textured sand fraction, trace gravel, wet, compact |
| | SS-5 | 100 | 3 | | | -loose |
| | SS-6 | 100 | 11 | | | -grey brown, compact |
| 10 | SS-7 | 100 | 16 | GSA SS-8A:<br>Gravel - 3%<br>Sand- 83%<br>Silt-11%<br>Clay-3% | | |
| | SS-8 | 100 | 90 | | | -some silt, increasing cobble/boulder content, very dense<br>11.50 191.07 |

Borehole terminated at 11.50 m in sand due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 203.58 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

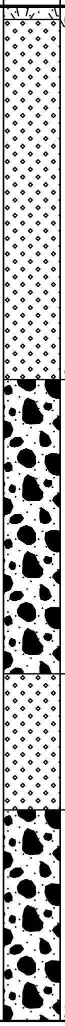
# WELL NUMBER MW21-05

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 11/18/21 **COMPLETED** 11/21/21
**UTM EASTING** 262369.7851 **NORTHING** 4918610.3916
**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.
**GROUND ELEVATION** 216.98 masl
**DRILLING METHOD** 8" Hollow Stem Auger/Mud Rotary with Split Spoons
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES** 8" Hollow Stem Auger to 7.60 m, Mud Rotary 7.60 m to 23.10 m
▼ **AFTER DRILLING** 19.64 m / Elev 197.34 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE | REMARKS |
|---|---|---|---|---|
| | SS-1 | 58 | 3 | |
| | SS-2 | 58 | 53 | |
| | SS-3 | 67 | 27 | |
| 5 | SS-4 | 44 | 51 | |
| | SS-5 | 50 | 38 | |
| | SS-6 | 58 | 50+ | |
| | SS-7 | 50 | 70 | |
| 10 | | | | |
| | SS-8 | 17 | 50+ | |
| | SS-9 | 58 | 37 | |
| | SS-10 | 75 | 72 | GSA SS-10:<br>Gravel - 40%<br>Sand- 46%<br>Silt-11%<br>Clay-3% |
| 15 | | | | |
| | SS-11 | 73 | 60 | |
| | SS-12 | 99 | 65 | |
| | SS-13 | 42 | 50+ | Static Water Level<br>19.63 mbg<br>Dec 6/21 |
| 20 | SS-14 | 75 | 113 | GSA SS-15:<br>Gravel - 3%<br>Sand- 83%<br>Silt-11%<br>Clay-3% |
| | SS-15 | 62 | 50+ | |

GRAPHIC LOG



MATERIAL DESCRIPTION

0.30 **TOPSOIL:** Dark brown silty sand topsoil, trace clay, rootlets, moist, loose — 216.68

**SAND:** Brown sand, some silt, trace gravel, trace clay, occasional cobble, very dense
-grey brown medium grained sand fraction, some gravel, dense
-trace silt, very dense
-fine grained sand fraction, increasing cobble content, dense
-trace gravel, very dense
8.50 — 208.48

**SAND AND GRAVEL:** Grey sand and gravel, trace silt, trace clay, occasional cobble, very dense
-dense
-very dense
15.20 — 201.78

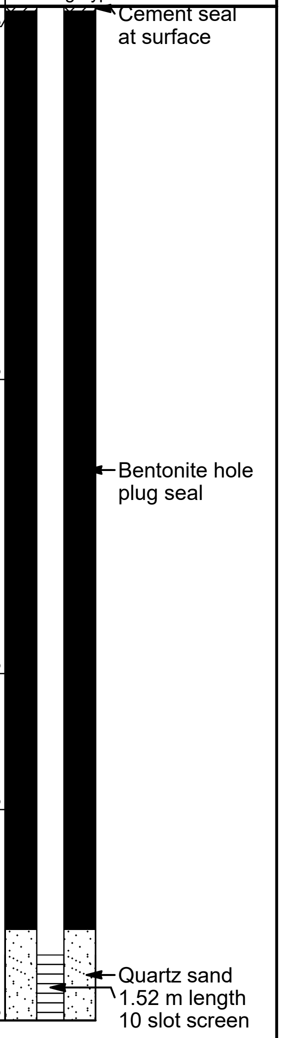
**SAND:** Grey brown sand, some gravel to gravelly, trace silt, trace clay, occasional cobble, very dense
-some silt
18.30 — 198.68

**SANDY GRAVEL:** ▼ Grey brown sandy gravel, some silt, trace clay, occasional cobble/boulder
-fine grained sand bed (0.3 m thick), some silt, trace clay, trace gravel
-increasing cobble/boulder content, very dense
23.10 — 193.88

Borehole terminated at 23.10 m in sandy gravel due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 218.16 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-06

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT NUMBER** 21-7128

**PROJECT LOCATION** Norwood, Ontario

**DATE STARTED** 11/30/21 **COMPLETED** 11/30/21

**UTM EASTING** 262838.8228 **NORTHING** 4919201.2321

**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.

**GROUND ELEVATION** 202.21 masl

**DRILLING METHOD** 8" Hollow Stem Auger with Split Spoons

**GROUNDWATER LEVELS:**

**LOGGED BY** LT **CHECKED BY** IA

**AT END OF DRILLING** ---

**NOTES**

▽ **AFTER DRILLING** 3.54 m / Elev 198.67 m

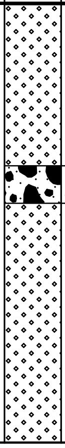
| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | N VALUE |
|---|---|---|---|
| | SS-1 | 42 | 2 |
| | SS-2 | 25 | 4 |
| | SS-3 | 58 | 14 |
| 5 | SS-4 | 96 | 8 |
| | SS-5 | 56 | 16 |
| | SS-6 | 75 | 24 |
| 10 | SS-7 | 100 | 13 |

REMARKS

Static Water Level
3.54 mbg
Dec 3/21

GSA SS-7:
Gravel - 3%
Sand- 76%
Silt-17%
Clay-4%

GRAPHIC LOG



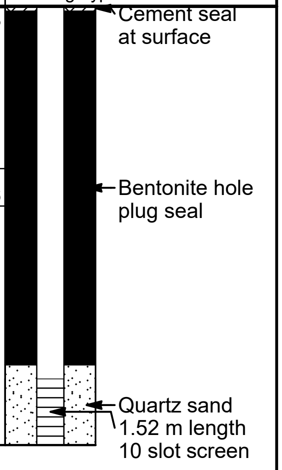
MATERIAL DESCRIPTION

| | | |
|---|---|---|
| 0.03 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, moist, loose | 202.18 |
| | SAND:<br>Brown sand, some gravel, trace silt, moist, loose<br>-some silt, occasional cobble | |
| 3.70 ▽ | | 198.51 |
| 4.55 | SILTY SAND AND GRAVEL:<br>Grey brown silty sand and gravel, wet, occasional cobble, compact | 197.66 |
| | SAND:<br>Grey (coarse grained) sand, some gravel, some silt, trace clay, saturated, loose<br>- occasional cobble, compact | |
| 10.00 | -trace gravel, silty | 192.21 |

Borehole terminated at 10.00 m on assumed bedrock.

WELL DIAGRAM

Casing Top Elev: 203.17 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-07

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood

**PROJECT NUMBER** 21-7128

**DATE STARTED** 11/24/21 **COMPLETED** 11/26/21

**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.

**DRILLING METHOD** Mud Rotary with Split Spoons

**LOGGED BY** LT **CHECKED BY** IA

**NOTES**

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT LOCATION** Norwood, Ontario

**UTM EASTING** 262375.3874 **NORTHING** 4918656.8643

**GROUND ELEVATION** 216.47 masl

**GROUNDWATER LEVELS:**

**AT END OF DRILLING** ---

▽ **AFTER DRILLING** 19.12 m / Elev 197.35 m

| SAMPLE TYPE NUMBER | RECOVERY % | N VALUE |
|---|---|---|
| SS-1 | 38 | 68 |
| SS-2 | 54 | 16 |
| SS-3 | 42 | 48 |
| SS-4 | 50 | 44 |
| SS-5 | 33 | 40 |
| SS-6 | 58 | 23 |
| SS-7 | 27 | 50+ |
| SS-8 | 50 | 48 |
| SS-9 | 46 | 87 |
| SS-10 | 54 | 59 |
| SS-11 | 48 | 46 |
| SS-12 | 96 | 50+ |

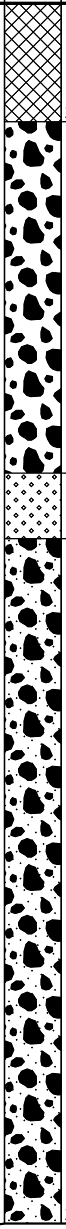
DEPTH (m): 5, 10, 15, 20, 25

REMARKS

Static Water Level
19.12 mbg
Dec 3/21

GSA SS-12:
Gravel - 44%
Sand- 40%
Silt-13%
Clay-3%

GRAPHIC LOG



MATERIAL DESCRIPTION

Augered through 2.74 m thick drill pad (granular fill)

2.70 — 213.77

GRAVEL:
Grey brown gravel, some sand (coarse grained), trace silt, trace clay, very dense

sandy, some silt, compact

-some sand, trace silt, occasional cobble, dense

10.70 — 205.77

SAND:
Brown sand (fine grained), trace silt, trace clay, compact

12.20 — 204.27

GRAVEL AND SAND:
Grey brown gravel and sand, some silt, trace clay, occasional cobble/boulder, very dense

-dense

▽ -very dense

-dense
-silty sand bed (0.05 m thick)

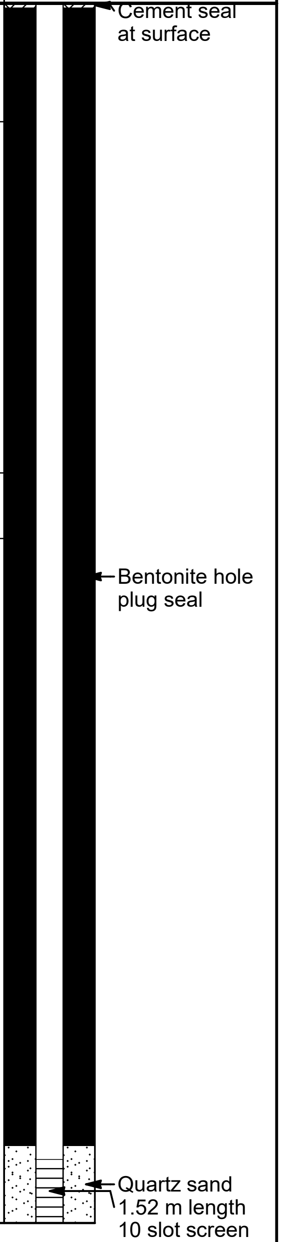
-increasing cobble/boulder content
-very dense

27.80 — 188.67

Borehole terminated at 27.80 m in gravel and sand due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 217.6 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-08

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT NUMBER** 21-7128

**PROJECT LOCATION** Norwood, Ontario

**DATE STARTED** 11/26/21 **COMPLETED** 11/29/21

**UTM EASTING** 262386.2744 **NORTHING** 4918694.1027

**DRILLING CONTRACTOR** Canadian Environmental Drilling & Contractors Inc.

**GROUND ELEVATION** 217.89 masl

**DRILLING METHOD** Mud Rotary with Split Spoons

**GROUNDWATER LEVELS:**

**LOGGED BY** LT **CHECKED BY** IA

**AT END OF DRILLING** ---

**NOTES**

⊻ **AFTER DRILLING** 20.59 m / Elev 197.30 m

| SAMPLE TYPE NUMBER | RECOVERY % | N VALUE |
|---|---|---|
| SS-1 | 75 | 26 |
| SS-2 | 23 | 14 |
| SS-3 | 42 | 19 |
| SS-4 | 71 | 36 |
| SS-5 | 62 | 36 |
| SS-6 | 58 | 53 |
| SS-7 | 54 | 80 |
| SS-8 | 58 | 28 |
| SS-9 | 42 | 50+ |

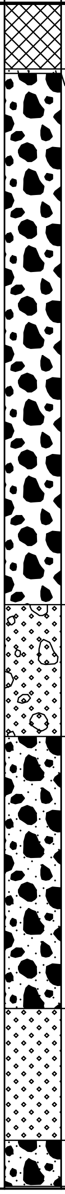
REMARKS

GSA SS-6:
Gravel - 57%
Sand- 28%
Silt-12%
Clay-3%

Static Water Level
20.59 mbg
Dec 6/21

GSA SS-9:
Gravel - 45%
Sand- 35%
Silt-16%
Clay-4%

GRAPHIC LOG

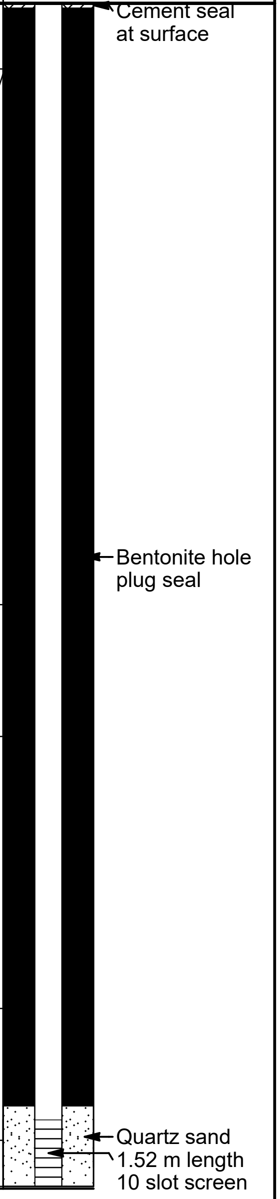


| DEPTH (m) | MATERIAL DESCRIPTION | Elev. |
|---|---|---|
|  | Augered through 1.50 m thick drill pad (granular fill) |  |
| 1.50 |  | 216.39 |
| 1.60 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, rootlets, moist, compact | 216.29 |
|  | GRAVEL:<br>Grey brown gravel, some sand, trace silt, trace clay, occasional cobble<br>-medium grained sand fraction<br>-sand and gravel, coarse grained sand fraction<br>-sandy |  |
| 13.70 |  | 204.19 |
|  | GRAVELLY SAND:<br>Grey brown gravelly sand, trace silt, trace clay, occasional cobble |  |
| 16.70 |  | 201.19 |
|  | SANDY GRAVEL:<br>Grey brown sandy gravel, some silt, trace clay, occasional cobble, very dense |  |
| 22.90 |  | 194.99 |
|  | SAND:<br>Brown sand (fine grained), trace silt, compact |  |
| 25.90 |  | 191.99 |
|  | GRAVEL AND SAND:<br>Grey brown gravel and sand, some silt, trace clay, occasional cobble/boulder, very dense |  |
| 26.95 |  | 190.94 |

Borehole terminated at 26.95 m in gravel and sand due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 218.83 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# WELL NUMBER MW21-09

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood

**PROJECT NUMBER** 21-7128

**DATE STARTED** 11/29/21 **COMPLETED** 12/1/21

**DRILLING CONTRACTOR** Insitu Contractors Inc.

**DRILLING METHOD** Sonic Drilling with Continuous Sampling

**LOGGED BY** LT **CHECKED BY** IA

**NOTES**

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT LOCATION** Norwood, Ontario

**UTM EASTING** 262418.6275 **NORTHING** 4918723.8931

**GROUND ELEVATION** 216.54 masl

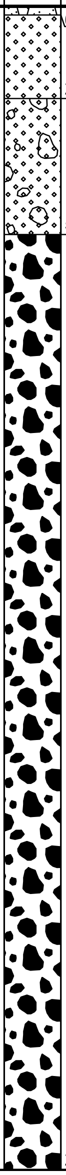
**GROUNDWATER LEVELS:**

**AT END OF DRILLING** ---

▽ **AFTER DRILLING** 19.20 m / Elev 197.34 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | REMARKS |
|---|---|---|---|
| | ST-1 | 71 | |
| 5 | ST-2 | 60 | |
| | ST-3 | 66 | GSA ST-4A:<br>Gravel - 81%<br>Sand- 18%<br>Silt & Clay-1% |
| 10 | ST-4 | 80 | |
| | ST-5 | 100 | |
| 15 | ST-6 | 100 | |
| 20 | ST-7 | 80 | Static Water Level<br>19.20 mbg<br>Dec 2/21 |
| | ST-8 | 85 | |
| 25 | ST-9 | 95 | GSA ST-9:<br>Gravel - 56%<br>Sand- 30%<br>Silt-11%<br>Clay-3% |

GRAPHIC LOG



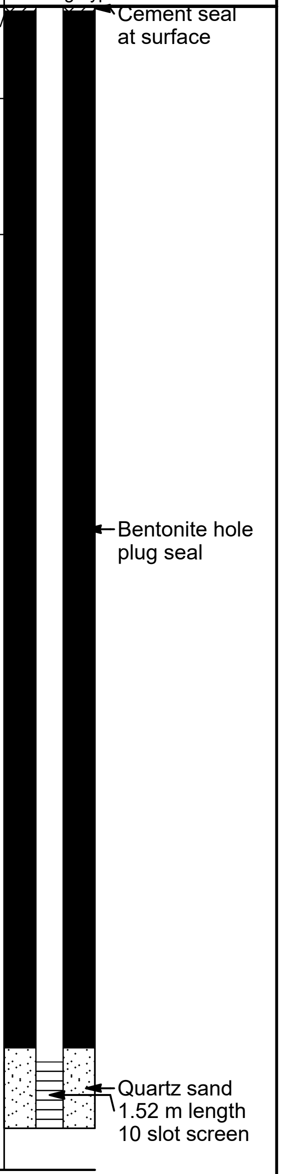
MATERIAL DESCRIPTION

| Depth (m) | Description | Elevation |
|---|---|---|
| 0.20 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, rootlets | 216.34 |
| 2.10 | SAND:<br>Brown sand, trace to some silt, trace clay<br>-some silt<br>-trace silt, trace gravel | 214.44 |
| 5.20 | GRAVELLY SAND:<br>Grey brown gravelly sand, trace silt, trace clay, occasional cobble<br>-trace gravel | 211.34 |
| 26.50 | GRAVEL:<br>Grey brown gravel, some sand, trace to some silt, trace clay, occasional cobble<br>-trace silt, medium grained sand fraction<br>-some silt<br>-sandy<br>-abundant cobbles<br>-some sand<br>▽<br>-coarse grained sand fraction<br>-sandy | 190.04 |

Borehole terminated at 26.50 m in sandy gravel due to practical refusal on cobble/boulder material.

WELL DIAGRAM

Casing Top Elev: 217.38 (m)
Casing Type: Monument



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

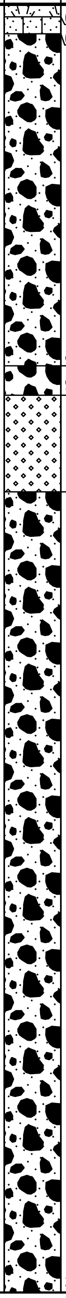
# WELL NUMBER MW21-10

PAGE 1 OF 1

**CLIENT** Township of Asphodel-Norwood
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT NUMBER** 21-7128
**PROJECT LOCATION** Norwood, Ontario
**DATE STARTED** 12/1/21 **COMPLETED** 12/2/21
**UTM EASTING** 262462.7064 **NORTHING** 4918747.46
**DRILLING CONTRACTOR** Insitu Contractors Inc.
**GROUND ELEVATION** 219.68 masl
**DRILLING METHOD** Sonic Drilling with Continuous Sampling
**GROUNDWATER LEVELS:**
**LOGGED BY** LT **CHECKED BY** IA
**AT END OF DRILLING** ---
**NOTES**
▼ **AFTER DRILLING** 22.31 m / Elev 197.37 m

| DEPTH (m) | SAMPLE TYPE NUMBER | RECOVERY % | REMARKS |
|---|---|---|---|
| | ST-1 | 80 | |
| 5 | ST-2 | 70 | |
| | ST-3 | 80 | |
| 10 | ST-4 | 80 | |
| 15 | ST-5 | 86 | |
| | ST-6 | 90 | |
| 20 | ST-7 | 100 | GSA ST-7B:<br>Gravel - 34%<br>Sand- 38%<br>Silt - 22%<br>Clay-6% |
| | ST-8 | 57 | Static Water Level<br>22.31 mbg<br>Dec 6/21 |
| 25 | ST-9 | 100 | |
| 30 | ST-10 | 85 | GSA ST-10:<br>Gravel - 53%<br>Sand- 35%<br>Silt-7%<br>Clay-5% |

GRAPHIC LOG

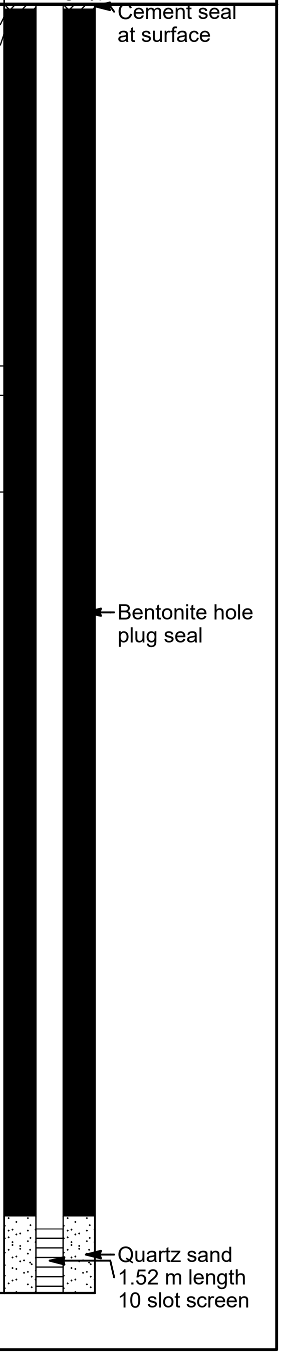


| Depth (m) | MATERIAL DESCRIPTION | Elevation |
|---|---|---|
| 0.30 | TOPSOIL:<br>Dark brown silty sand topsoil, trace clay, rootlets | 219.38 |
| 0.70 | SILTY SAND:<br>Medium brown silty sand, trace clay | 218.98 |
| | GRAVEL AND SAND:<br>Grey brown gravel and sand, trace to some silt, trace clay, occasional cobble<br>-some silt, well graded sand fraction<br>-trace silt | |
| 8.60 | | 211.08 |
| 9.30 | GRAVEL:<br>Grey gravel, trace sand, trace silt | 210.38 |
| | SAND:<br>Grey brown sand (interbedded fine and coarse grained), trace silt<br>-some gravel | |
| 11.60 | | 208.08 |
| | GRAVEL AND SAND:<br>Grey brown gravel and sand, some silt, trace clay, occasional cobble/boulder<br>-fine to medium grained sand fraction<br>-sand and gravel, silty, well graded, sand fraction<br>-trace silt, coarse grained sand fraction<br>-gravel and sand | |
| 30.65 | | 189.03 |

Borehole terminated at 30.65 m in gravel and sand.

WELL DIAGRAM

Casing Top Elev: 220.61 (m)
Casing Type: Monument



# Appendix C

## Geologic Cross-Sections

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

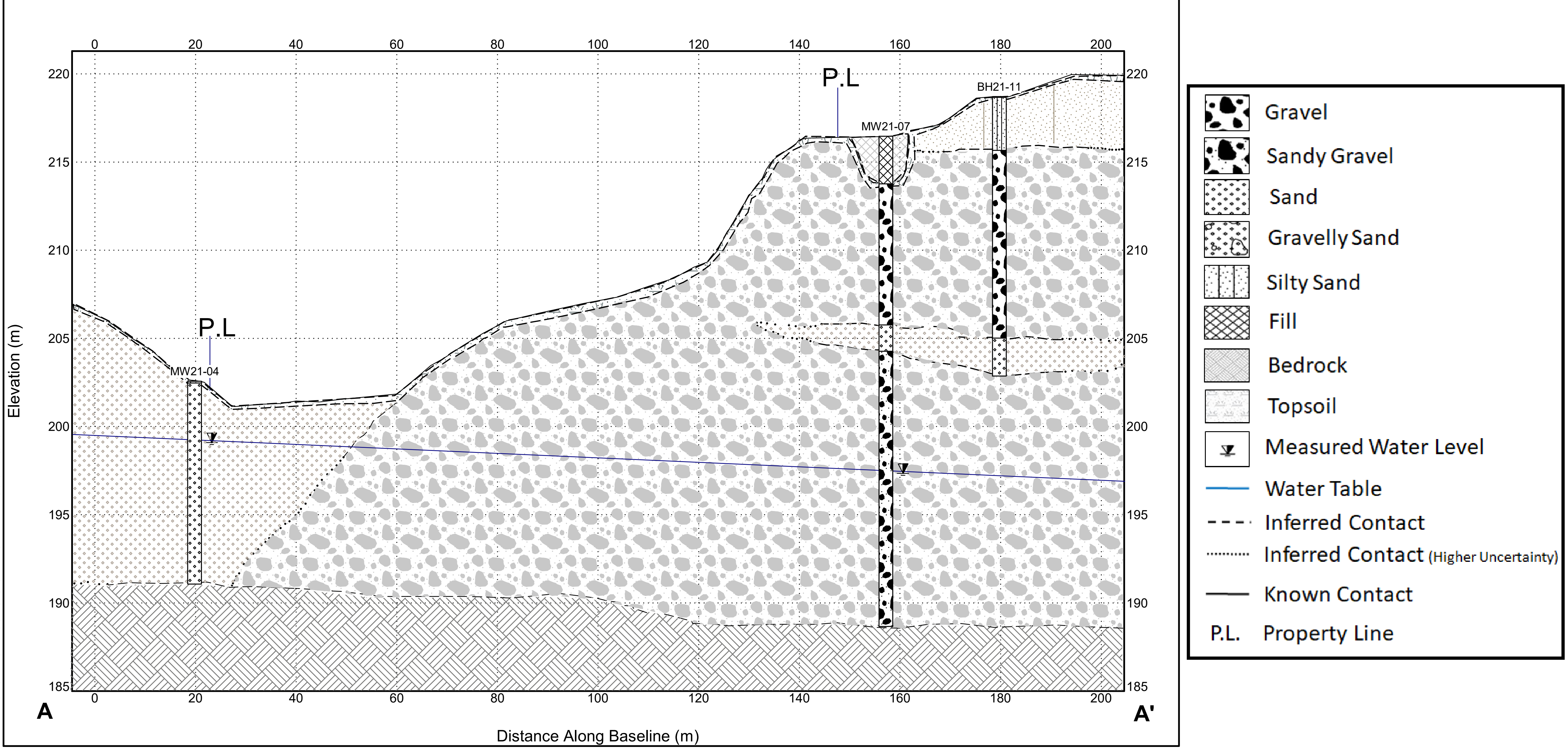
# Cross Section A - A'

**CLIENT** Township of Asphodel-Norwood

**PROJECT NUMBER** 21-7128

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

**PROJECT LOCATION** Norwood, Ontario



TEST 7128 BOREHOLE LOGS.GPJ OVERBURDENBHLOG.GDT 5/26/22

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

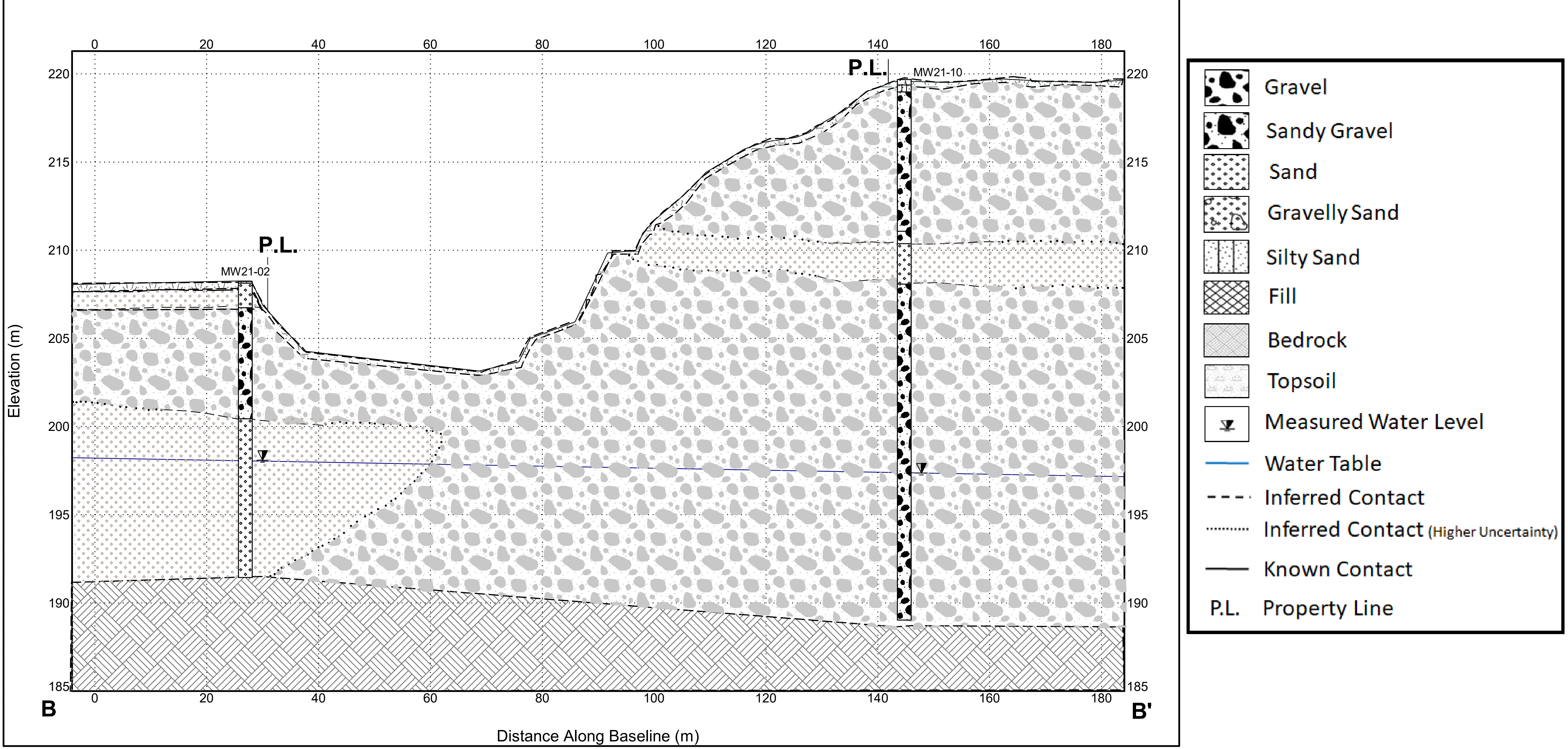
# Cross Section B-B'

**CLIENT** Township of Asphodel-Norwood

**PROJECT NUMBER** 21-7128

**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability

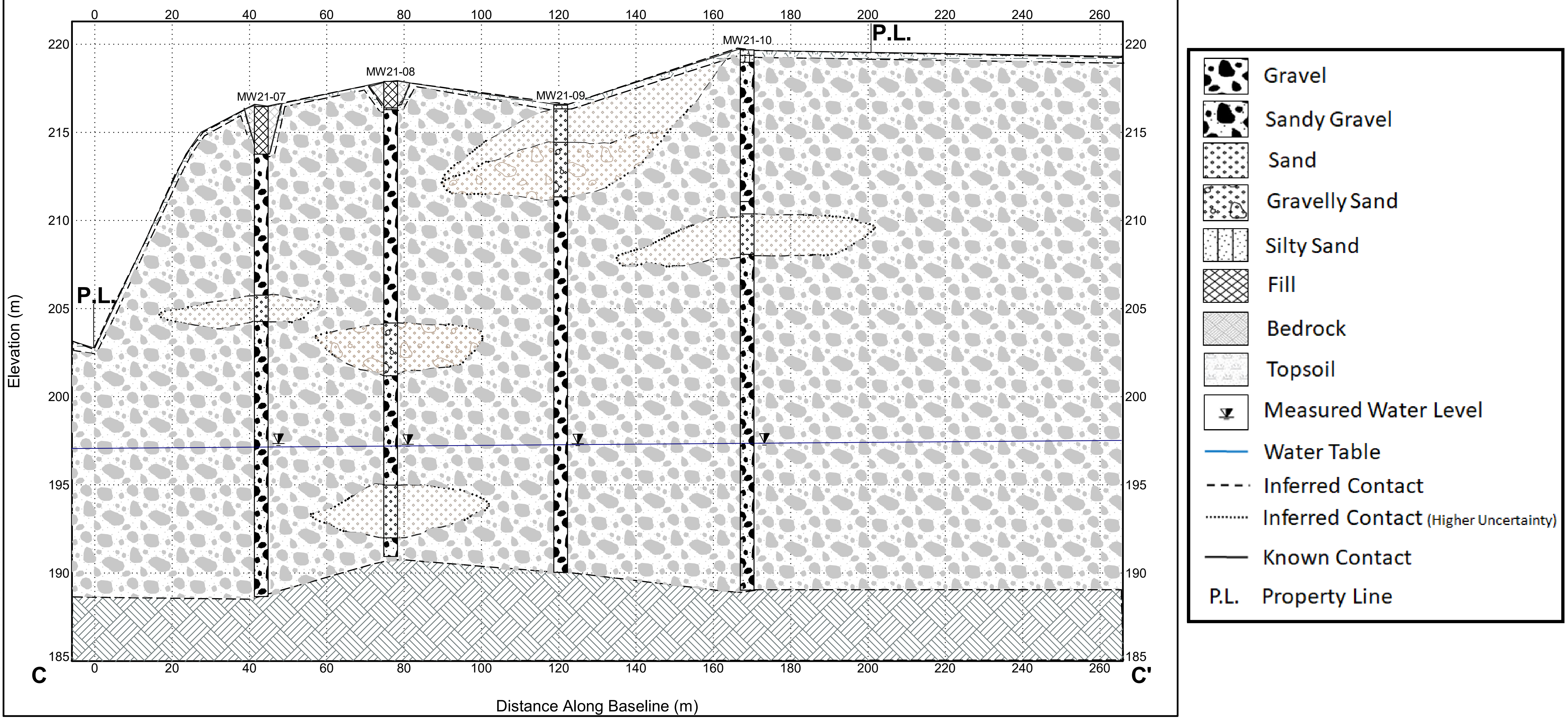
**PROJECT LOCATION** Norwood, Ontario



D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario K9J 0B9

# Cross Section C-C'

**CLIENT** Township of Asphodel-Norwood
**PROJECT NUMBER** 21-7128
**PROJECT NAME** Norwood Aquifer Capacity and Vulnerability
**PROJECT LOCATION** Norwood, Ontario



TEST 7128 BOREHOLE LOGS.GPJ OVERBURDENBHLOG.GDT 5/26/22

# Appendix D

## Pumping Tests – Observation Well Details

# Appendix D - Pumping Test Observation Well Details

| Well 1b Pumping Test | | | |
|---|---|---|---|
| Well ID | Well Depth | Well Stick Up | Static Water Level |
| MW21-01 | 8.68 | 1.04 | 5.15 |
| MW21-02 | 16.89 | 1.05 | 11.55 |
| MW21-03 | 18.6 | 1.12 | 10.99 |
| MW21-04 | 12.49 | 1.01 | 4.82 |
| MW21-05 | 24.29 | 1.15 | 20.92 |
| MW21-06 | 10.97 | 0.97 | 4.35 |
| MW21-07 | 29 | 1.13 | 20.36 |
| MW21-08 | 27.79 | 0.84 | 21.55 |
| MW21-09 | 26.36 | 0.8 | 20.14 |
| MW21-10 | 31.58 | 0.93 | 23.35 |

| Well 2 Pumping Test | | | |
|---|---|---|---|
| Well ID | Well Depth | Well Stick Up | Static Water Level |
| MW21-01 | 8.68 | 1.04 | 5.07 |
| MW21-02 | 16.89 | 1.05 | 11.37 |
| MW21-03 | 18.6 | 1.12 | 10.86 |
| MW21-04 | 12.49 | 1.01 | 4.68 |
| MW21-05 | 24.29 | 1.15 | 20.72 |
| MW21-06 | 10.97 | 0.97 | 4.27 |
| MW21-07 | 29 | 1.13 | 20.17 |
| MW21-08 | 27.79 | 0.84 | 21.34 |
| MW21-09 | 26.36 | 0.8 | 19.94 |

| Well 3 Pumping Test | | | |
|---|---|---|---|
| Well ID | Well Depth | Well Stick Up | Static Water Level |
| MW21-01 | 8.68 | 1.04 | 4.91 |
| MW21-02 | 16.89 | 1.05 | 11.21 |
| MW21-03 | 18.6 | 1.12 | 10.85 |
| MW21-04 | 12.49 | 1.01 | 4.64 |
| MW21-05 | 24.29 | 1.15 | 20.58 |
| MW21-06 | 10.97 | 0.97 | 4.34 |
| MW21-07 | 29 | 1.13 | 20.25 |
| MW21-08 | 27.79 | 0.84 | 21.44 |
| MW21-09 | 26.36 | 0.8 | 20.04 |
| MW21-10 | 31.58 | 0.93 | 23.23 |

| Well 4 Pumping Test | | | |
|---|---|---|---|
| Well ID | Well Depth | Well Stick Up | Static Water Level |
| MW21-01 | 8.68 | 1.04 | 5.17 |
| MW21-02 | 16.89 | 1.05 | 11.47 |
| MW21-03 | 18.6 | 1.12 | 10.96 |
| MW21-04 | 12.49 | 1.01 | 4.82 |
| MW21-05 | 24.29 | 1.15 | 20.79 |
| MW21-06 | 10.97 | 0.97 | 4.36 |
| MW21-07 | 29 | 1.13 | 20.24 |
| MW21-08 | 27.79 | 0.84 | 21.43 |
| MW21-09 | 26.36 | 0.8 | 20.03 |

# Appendix E

---

## Aquifer Parameter Results for Well 3 and Well 4

# Appendix E - Aquifer Parameters Derived From Well 3 and Well 4 Pumping Tests

| Monitor | WELL 4 TEST | | WELL 3 TEST | | SATURATED THICKNESS | SATURATED THICK NESS P WELL, m | SATURATED THICKNESS P WELL, m | AVERAGE SATURATED THICKNESS, m | AVERAGE SATURATED THICKNESS, m | K AVERAGE WELL 3 m/d | K AVERAGE WELL 4 m/d |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | T m$^2$/day | K m/d | T m$^2$/day | K m/d | MONITOR, m | WELL 3 | WELL 4 | WELL 3 | WELL 4 | | |
| MW21-05 | | | | | | | | | | | |
| Cooper-Jacob | | | | | | | | | | | |
| NEUMAN | 1244 | 356.4 | 853 | 244.4 | 3.49 | 8.45 | 9.93 | 5.97 | 6.71 | 142.9 | 163.6 |
| MOENCH | 969 | 277.7 | 853 | 244.4 | 3.49 | | | | | | |
| geomean | 1097.9 | 314.6 | 853 | 244.4 | | | | | | | |
| | | | | | | | | | | | |
| MW21-05 LOGGER | | | | | | | | | | | |
| NEUMAN | | | 1042 | 298.6 | 3.49 | | | | | | |
| MOENCH | | | 1042 | 298.6 | 3.49 | 8.45 | 9.93 | 5.97 | 6.71 | 174.5 | |
| geomean | | | 1042 | 298.6 | | | | | | | |
| overall geomean MW21-05 | | 314.6 | 1042 | 270.1 | | | | | | | |
| | | | | | | | | | | | |
| MW21-07 | | | | | | | | | | | |
| NEUMAN | 1516 | 179.8 | 1165 | 138.2 | 8.43 | | | | | | |
| MOENCH | 1562 | 185.3 | 1182 | 140.2 | 8.43 | | | | | | |
| TARTAKOVSKY-NEUMAN | 1728 | 205 | | | 8.43 | 8.45 | 9.93 | 8.44 | 9.18 | 139 | 174.2 |
| geomean | 1599.5 | 189.7 | 1173.5 | 139.2 | | 8.45 | 9.93 | | | | |
| | | | | | | | | | | | |
| MW21-08 MANUAL | | | | | | | | | | | |
| NEUMAN | 1395 | 215.9 | 1131 | 175.1 | 6.46 | | | | | | |
| MOENCH | 1396 | 216.1 | 1080 | 167.2 | 6.46 | 8.45 | 9.93 | 7.455 | 8.195 | 148.3 | 170.3 |
| geomean | 1395.5 | 216 | 1105.2 | 171.1 | | | | | | | |
| | | | | | | | | | | | |
| MW21-08 LOGGER | | | | | | | | | | | |
| NEUMAN | | | 1024 | 158.5 | 6.46 | 8.45 | 9.93 | 7.455 | 8.195 | 137.4 | |
| MOENCH | | | 1024 | 158.5 | 6.46 | | | | | | |
| geomean | | | 1024 | 158.5 | | 8.45 | 9.93 | 4.225 | 4.965 | | |
| overall geomean MW21-08 | | 216 | | 164.7 | | | | | | | |
| | | | | | | | | | | | |
| MW21-09 | | | | | | | | | | | |
| NEUMAN | 957 | 177.7 | 1256 | 176.9 | 7.1 | 8.45 | 9.93 | 7.775 | 8.515 | 165 | 122.4 |
| MOENCH | 938 | 177.7 | 1311 | 184.6 | 7.1 | 8.45 | 9.93 | | | | |
| TARTAKOVSKY-NEUMAN | 1262 | 177.7 | | | 7.1 | 8.45 | 9.93 | | | | |
| geomean | 1042.5 | 177.7 | 1283.2 | 180.7 | | | | | | | |
| | | | | | | | | | | | |
| MW21-09 LOGGER | | | | | | | | | | | |
| NEUMAN | | | 1223 | 172.3 | 7.1 | 8.45 | 9.93 | 7.775 | 8.515 | 157.7 | |
| MOENCH | | | 1229 | 173.1 | 7.1 | 8.45 | 9.93 | 7.775 | 8.515 | | |
| geomean | | | 1226 | 172.7 | | 8.45 | 9.93 | | | | |
| overall geomean MW21-09 | | 177.7 | | 176.7 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| MW21-10 LOGGER | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 825 | 98.8 | | | 8.35 | 8.45 | 9.93 | 8.4 | 9.14 | 101.3 | 89.4 |
| MOENCH | 809 | 96.9 | 851 | 101.9 | 8.35 | 8.45 | 9.93 | 8.4 | 9.14 | | |
| geomean | 817 | 97.8 | 851 | 101.9 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| MW21-10 MANUAL | | | | | | 8.45 | 9.93 | | | | |
| THEIS UNCONFINED | 1355 | 162.3 | | | 8.35 | 8.45 | 9.93 | 8.4 | 9.14 | 100.5 | 331.3 |
| NEUMAN | | | 855 | 102.4 | 8.35 | 8.45 | 9.93 | 8.4 | 9.14 | | |
| MOENCH | | | 834 | 99.9 | 8.35 | 8.45 | 9.93 | 8.4 | 9.14 | | |
| geomean | | | 844.4 | 101.1 | | 8.45 | 9.93 | | | | |
| overall geomean MW21-10 | | | | 101.9 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| WELL 3 OBS | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 1657 | 196.1 | 1271 | 150.4 | 8.45 | 8.45 | 9.93 | 8.45 | 9.19 | 122.6 | 181.5 |
| MOENCH | 1679 | 198.7 | 961 | 113.7 | 8.45 | 8.45 | 9.93 | 8.45 | 9.19 | | |
| RECOVERY MOENCH | | | 887 | 105 | 8.45 | 8.45 | 9.93 | 8.45 | 9.19 | | |
| RECOVERY NEUMAN | | | 1062 | 125.7 | 8.45 | 8.45 | 9.93 | 8.45 | | | |
| geomean | 1668 | 197.4 | 1035.7 | 122.6 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| WELL 4 OBS | | | | | | 8.45 | 9.93 | | | | |
| MOENCH RECOVERY | 1582 | 159.3 | 919 | 92.5 | 9.93 | 8.45 | 9.93 | 9.19 | 9.93 | 113 | 151.1 |
| MOENCH | 1423 | 143.3 | | | 9.93 | 8.45 | 9.93 | 9.19 | 9.93 | | |
| AGARWAL RECOVERY | | | 1174 | 118.2 | 9.93 | 8.45 | 9.93 | 9.19 | 9.93 | | |
| geomean | 1500.4 | | 1038.7 | | | 8.45 | 9.93 | | | | |
| | | | | | | | | | | | |
| MW21-04 MANUAL | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 944 | 137.6 | 1510 | 220.1 | 6.86 | 8.45 | 9.93 | 7.655 | 8.395 | 199 | 114.8 |
| MOENCH | 984 | 143.4 | 1537 | 224.1 | 6.86 | 8.45 | 9.93 | 7.655 | | | |
| geomean | 963.8 | 140.5 | 1523.4 | 222.1 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| MW21-03 MANUAL | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 1602 | 209.1 | 1510 | 197.1 | 7.66 | 8.45 | 9.93 | 8.055 | 8.795 | 189.1 | 168.2 |
| MOENCH | 1366 | 178.3 | 1537 | 200.7 | 7.66 | 8.45 | 9.93 | 8.055 | 8.795 | | |
| geomean | 1479.3 | 193.1 | 1523.4 | 198.9 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| MW21-02 MANUAL | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 2078 | 325.7 | 1453 | 227.7 | 6.38 | 8.45 | 9.93 | 7.415 | 8.155 | 195.9 | 254.8 |
| MOENCH | 2078 | 325.7 | 1452 | 227.6 | 6.38 | 8.45 | 9.93 | 7.415 | 8.155 | | |
| geomean | 2078 | 325.7 | 1452.5 | 227.7 | | 8.45 | 9.93 | | | | |
| | | | | | | 8.45 | 9.93 | | | | |
| MW21-01 MANUAL | | | | | | 8.45 | 9.93 | | | | |
| NEUMAN | 482 | 117 | 1310 | 318 | 4.12 | 8.45 | 9.93 | 6.285 | 7.025 | 208.4 | 66.7 |
| MOENCH | 456 | 110.7 | 1310 | 318 | 4.12 | 8.45 | 9.93 | 6.285 | 7.025 | | |
| geomean | 468.8 | 113.8 | 1310 | 318 | | 8.45 | 9.93 | 4.225 | 4.965 | | |
| | | | | | | | | | | | |
| | | | | | | | | | | 149.1 | 152.5 |