Aquifer Vulnerability Study Report

Norwood Water Supply Aquifer
Village of Norwood, ON

D.M. Wills Project Number 21-7128

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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	NA
2	Final Report for Council	August 19, 2022	Summarized

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

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Executive Summary

D.M. Wills Associates Limited (Wills) was retained by the Township of Asphodel-Norwood (Township) to complete an Aquifer Vulnerability Study (Study) for the Village of Norwood's water supply aquifer (Aquifer). The Study was requested to assess potential impacts to the Aquifer from proposed residential development activities on lands located directly northwest of the Norwood Drinking Water System (Proposed Development Lands).

The Study was requested by the Township following recommendations made in Wills' Hydrogeological Assessment Peer Review Report (December 10, 2020), which provided a detailed review of the following documents (Cambium Reports):

- Hydrogeological Assessment – Tower Lands Development, Norwood, Ontario, for BGS Homes, dated January 29, 2018, Cambium Reference No.: 6401-001.
- Review of Scope of Work Proposal for Tower Lands Development, Norwood, Ontario, Letter to Berardo Mascioli, Planner, 1807086 Ontario Inc., dated May 8, 2020, Cambium Ref. No: 6401-001.

Wills' Peer review concluded that insufficient geological information was available on the Proposed Development Lands to evaluate the vulnerability of the Aquifer with respect to future development activities, and the resulting impacts to Norwood's water supply.

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 an attempt to refine the understanding of the local geological conditions as they relate to the Aquifer's vulnerability, Wills' Study was conducted on Township owned lands directly northwest and southeast of the Proposed Development Lands (Study Area). The Study Area included:

- 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

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 to January 7 2022, and static water level monitoring was conducted on the 10 monitor wells (observation wells) during the pumping tests.

Ten water samples were collected from six of the monitor wells and four of the existing Water Supply Wells between February 1 and February 2, 2022. Groundwater samples were submitted to an accredited laboratory for analysis of general chemistry parameters, petroleum hydrocarbons (PHCs), and bacterial analysis to determine baseline conditions.

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 K. Following completion of the field activities and data analysis, the 2018 groundwater model was revised, and updated vulnerability zones incorporating modified unsaturated zone advection time (UZATS) and water table to well advection time (WWATS) were generated.

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

- Borehole data suggests that a contact between the Norwood esker core deposits (Southern Parcel) and relatively finer grained flank deposits (Northern Parcel) lies beneath the Proposed Development Lands. Both deposits are considered coarse-grained (predominantly gravel and sand) and no significant layers of silt or clay-rich sediments were encountered that would constitute an aquitard and afford the Aquifer protection from contaminating activities at surface.
    - Based on Wills' cross section interpretations, the saturated zone of the Aquifer may be encountered at a shallow depth of approximately 2.0 meters below grade (mbg) in areas along the northern boundary of the Proposed Development Lands.
- Aquifer test parameters were generated from the pumping tests carried out on Water Supply Wells 1B, 2, 3, and 4 and observation wells MW21-01 to MW21-10. While most of the test data was relatively simple to interpret, 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 at high pumping rates.
- 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 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 in Norwood.

- The aquifer test analysis and computer modelling confirmed that the Aquifer is highly vulnerable to contamination. 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 under the Proposed Development Lands and from further north all along the Norwood esker north of the village. Monitor wells MW21-01 to MW21-04 appear to experience limited drawdown especially with Well 4 pumping during the pumping test. The well logs indicate that much of the material encountered is silty sand with some sandy gravel layers or lenses within the screened intervals, and appear to be in the flank deposits or on the edge of the flank deposits. However, a hydraulic connection does exist between the Municipal Well Field and these northwest monitor wells.
- Monitor wells on the Northern Parcel (i.e. MW21-01 to MW21-04) were screened in layers of the sand material that were observed to have higher silt content (silty) than the stratigraphically higher units. Within the saturated zone, the stratigraphically higher sand generally contained greater proportions of gravel, and some to trace amounts of silt. It is possible that these units would show a greater response to the pumping (i.e. greater hydraulic connection), although this cannot be demonstrated with the current data set and well configurations.
- The current pumping rates of the Municipal Well Field to meet the Village's population requirements is approximately 35% of the PTTW rate at less than 700 m^3/day. The drawdown from pumping at this rate and pumping intermittently each day appears to be minimal. A consequence of this is that the capture zone determined by the 2022 modelling bears little resemblance to the current pattern of groundwater flow at current pumping rates. Since there is a component of groundwater flow from the northwest under the Proposed Development Lands to the Water Supply Wells, development of any kind should be discouraged. If development is allowed, transport pathways including infiltration galleries for runoff and basement excavations with tile drainage should be prohibited as these will exacerbate the flow of contaminants from surface to the saturated portion of the Aquifer.
- Proposed development activities that are prohibited including infiltration galleries should be evaluated with respect to maintaining the water balance and groundwater flows to the wellhead protection area, and the resulting impacts to the Aquifer's recharge capabilities. Diverted run-off from impermeable surfaces (e.g. roofs, roadways, sidewalks, and driveways) is expected to be significant as a result of residential development, and may negatively impact the Aquifer's recharge if this water cannot be infiltrated into the Aquifer proximal to the source. This impact would be expected to worsen in the future, as increased water demand from the Aquifer will be required to meet the future growth demands of the village of Norwood.
- The unconfined Aquifer is considered highly vulnerable to anthropogenic activities, and investigative activities completed to date have not identified any natural means of protection of the municipal water source.
- Proposed development activities in such close proximity to a highly vulnerable aquifer introduce a level of risk to the town of Norwood's sole water source. This risk is not only limited to foreseeable activities resulting from development, but also any

future activities in the area that cannot be predicted at the current time (e.g. private land uses). It is likely that any development activities would result in a lower quality of water that infiltrates to the saturated zone of the Aquifer, in comparison to the property's pre-developed state.

- Wills' Study provides a refined understanding of the Norwood esker geology and hydrogeology as it relates to the vulnerability of the Aquifer, albeit it reliant on the interpolation and extrapolation of data collected outside of the Proposed Development Lands.

The findings of Wills' Study support the need for further investigation on the Proposed Development Lands. Additional work is required to address outstanding data gaps and confirm the geologic and hydrogeologic conditions beneath the Proposed Development.

1.0 Introduction

D.M. Wills Associates Limited (Wills) was retained by the Township of Asphodel-Norwood (Township) to complete an Aquifer Vulnerability Study (Study) for the Village of Norwood Water Supply Aquifer (Aquifer). The Study was requested to assess potential impacts to the Aquifer from a proposed residential development on lands located directly northwest of the Norwood Drinking Water System (Proposed Development Lands).

The Study was requested by the Township following recommendations made in Wills' Hydrogeological Assessment Peer Review Report (December 10, 2020), which provided a detailed review of the following documents (Cambium Reports):

- Hydrogeological Assessment – Tower Lands Development, Norwood, Ontario, for BGS Homes, dated January 29, 2018, Cambium Reference No.: 6401-001.
- Review of Scope of Work Proposal for Tower Lands Development, Norwood, Ontario, Letter to Berardo Mascioli, Planner, 1807086 Ontario Inc., dated May 8, 2020, Cambium Ref. No: 6401-001.

Wills' Peer Review concluded that insufficient geological information was available on the Proposed Development Lands to evaluate the vulnerability of the Aquifer with respect to future development activities, and the resulting impacts to the Norwood Drinking Water System.

Wills' Study was conducted on Township owned lands directly northwest and southeast of the Proposed Development Lands (Study Area), in an attempt to refine the understanding of the local geological conditions as they relate to the Aquifer's vulnerability from the Proposed Residential Development.

1.1 Site Location and Description

The Township owned lands adjacent to the Proposed Development Lands are approximately 5.9 hectares (ha) in area, and include two parcels that were subject to investigation:

- 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 Township Lands and Proposed Development Lands are shown on **Figure 1:** Site Location Plan. 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 the Village of Norwood and locally contains the Aquifer.

The Norwood Drinking Water System is located on the Norwood esker, and the individual wells that tap the Aquifer are located along the crest line and east side of the Norwood esker.

2.2 Wills Peer Review

Wills conducted a peer review of the Cambium Reports and identified potential impacts to the Aquifer by the Proposed Development, specifically with respect to the creation of transport pathways via ground disturbance activities. The potential impacts to the Aquifer considered the following:

- The results of the field investigations and modelling completed by Wills and others to date indicated that no confining layer exists between the ground surface and the Aquifer that could afford protection, and the Aquifer extends to the existing ground surface.
- The vulnerability of the Aquifer may be increased by any land use activities or feature that disturbs the overlying ground surface, or which artificially enhances infiltration/flow to the Aquifer. Constructed transport pathways can circumvent the natural protection offered by soils and overlying materials.
- At the Norwood esker, the boundary between the coarse-grained core sediments and the finer grained flank sediments is known approximately on the south and east side of the Norwood esker crest line. However, no information is available to determine the boundary between the core and flank sediments on the north and northwest sides of the crest line where the Proposed Development is situated. The potential for a transport pathway to exist in the area overlying the core deposits is significantly greater than over the flank deposits.

3.0 Scope of Work

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

- 11 boreholes were advanced on the Township lands, directly adjacent to the Proposed Development Lands. The location of the boreholes were, in part, based on 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**).
- Encountered soil stratigraphy and depth to groundwater was documented at each borehole during drilling activities.
- 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).
- Ten water samples were collected from six of the newly installed monitor wells and four of the existing Water Supply Wells. Water samples were submitted to SGS Canada Inc. in Lakefield, Ontario, an accredited laboratory for general chemistry parameters, petroleum hydrocarbons (PHCs), and bacterial analysis to determine baseline conditions.
- 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 wells 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 Vulnerability Study Report, including:
    - Description of field investigations and resulting data.
    - Geological and hydrogeological interpretation with respect to the vulnerability of the Aquifer.
    - Revision of the groundwater model with changes to Aquifer parameters and simulation of the pumping tests.
    - Generation of vulnerability zones incorporating modified unsaturated zone advection times (UZATs) and water table to well advection time (WWATS).

Note that Wills' Subsurface Investigation was limited to the Township Lands surrounding the Proposed Development, as permission was not granted to access the Proposed Development Lands.

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. Detailed mapping and other historic investigations within the Study Area provide a more refined understanding of the local geology/physiography, and indicate that the Study Area is located on and adjacent to ridges associated with the Norwood esker. The Regional Physiography Map showing the Study Area with respect to the OGS mapping is included in **Appendix A.**

The 1978 Theses and Dissertations of John Arthur Dixon, titled *Morphology and Anatomy of the Norwood Esker, Ontario*, describes two morphologically distinct sections of the Norwood esker, including a north section of kame, and a southern section of elongate drumlins. The northern section of the Norwood esker includes single and multiple ridges, whereby the multiple ridges are found to be superimposed on a stratigraphically lower and broad plateau base. The southern section includes a high steep-sided single ridge that is observed to lack the plateau base. Dixon indicates that in both areas, the ridge is often found to locally split into two ridges, which are observed to rejoin a short distance downstream. Based on Dixon's work, the Study Area is interpreted to be located at the approximate divide between the north and south section of the Norwood esker, and Dixon provides the following with respect to the Study Area.

"The northern side of the ridge becomes narrower to the west of the Ouse River gap, here consisting of only two ridges, the main ridge and a less steep ridge to the north. A number of kettle holes are also present in the ridge to the north and the plateau-like base has all but disappeared"

The location of these two ridges (North Ridge and Main Ridge) with respect to the Township Lands and Proposed Development Lands is shown on **Figure 2**. Lidar and elevation contours from Peterborough County's Public GIS database were used to show the topographic relief associated with the two Norwood esker ridges.

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. It should be noted that significant layers of silt or clay-rich sediments reflecting quiescent deposition were not encountered in any of Wills' investigation areas.

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 is 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. 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 the 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

The results of the drilling program indicate the overburden is generally coarse-grained within the Study Area, although variations in the relative abundance of gravel and sand material was observed between the Southern Parcel (Main Ridge) and the Northern Parcel (North Ridge).

6.1 Southern Parcel (Main Ridge)

Six boreholes (MW21-05, MW21-07, MW21-08, MW21-09, MW21-10, and BH21-11) were advanced on the crest of the Norwood esker, four of which were advanced directly adjacent to the Proposed Development Lands. 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 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.

6.1.1 Topsoil

Topsoil was encountered at all borehole locations with the exception of MW21-07, and had a maximum thickness of approximately 0.3 m. The topsoil was generally described as silty sand with trace clay, and was described as being moist at the time of the investigation.

6.1.2 Sand

Sand was encountered below the topsoil at MW21-05, MW21-09, MW21-10, and BH21-11, and ranged in thickness from approximately 0.4 to 8.2 m. The sand material contained varying amounts of silt, gravel, and cobbles, 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.

At depth, layers of sand ranging in thickness from approximately 1.5 to 3.0 m were found interbedded with predominantly gravel material. Within the sand layers, discrete beds of fine to coarse grained sand were encountered, however, were predominantly described as being medium to coarse-grained. Sand material was not encountered at depth in MW21-09.

Based on SPT, N-values ranged from 3 to over 50 blows per 305 mm of penetration, the sand has a loose to very dense relative compactness. It should be noted that the N-values may have been impacted as a result of the numerous cobbles / boulders encountered throughout the investigated depth. SPTs were only completed at MW21-05 and BH21-11.

6.1.3 Gravel to Sand and Gravel

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).

Based on SPT, N values ranged from 15 to greater than 100 blows per 305 mm of penetration, the gravel has a compact to very dense relative compactness. N values may have been impacted by the abundance of cobble / boulders within these deposits.

Nine laboratory particle size distribution analyses were completed on samples of the gravel material. Certificates of Analysis for the physical soil testing results are included in **Appendix C**. 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).

6.2 Northern Parcel (North Ridge)

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.

6.2.1 Topsoil

Topsoil was encountered at all of the borehole locations and had a maximum thickness of approximately 0.1 m. The topsoil was generally described as silty sand with trace amounts of clay, and was described as being moist at the time of the investigation.

Based on available SPT N-values that ranged from 3 to 14 blows per 305 millimetres (mm) of penetration, the topsoil has a very loose to compact relative compactness.

6.2.2 Sand

Sand material was encountered beneath the topsoil at all of borehole locations on the Northern Parcel, including adjacent to the Mill Pond. The sand was found to be variable interbedded with gravel, and generally contained some silt, trace amounts of gravel and clay, and occasional cobbles. The sand material 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 also found to increase proximal to the termination depth.

Based on SPT N-values that ranged from 3 to over 50 blows per 305 mm of penetration, the sand material has a loose to very dense relative compactness. It should be noted that the N-values may have been impacted as a result of the cobbles / boulders encountered throughout the investigated depth.

Six laboratory particle size distribution analyses were completed on samples of the sand material. Certificates of Analysis for the physical soil testing results are included in **Appendix C**.

6.2.3 Sandy Gravel

Sandy gravel was interbedded with the sand material in boreholes MW21-02, MW21-03, MW21-06, and a thin layer of gravel and sand was encountered proximal to the termination depth in MW21-01.

The sandy gravel generally contained trace amounts of silt and clay, occasional cobbles, and was described as being silty in MW21-06. This material varied in sand content, and was described as ranging from sandy gravel to sand and gravel. This material generally contained coarse grained sand fractions.

Based on SPT N-values that ranged from 12 to over 50 blows per 305 mm of penetration, the sandy gravel has a compact to very dense relative compactness. It should be noted that the N-values may have been impacted as a result of the cobbles / boulders encountered throughout the investigated depth.

7.0 Cross Sections and Geological Context

Based on Wills Investigation, three representative cross sections of the Study Area were constructed. Cross Section A-A' and B-B' are generally aligned perpendicular with the strike of the Norwood esker's Main Ridge, and Cross Section C-C' is parallel to the crest of the Main Ridge.

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

The geology depicted on Cross Section C-C' is congruent with the current understanding of the Norwood esker core deposits. The core deposits of the Norwood esker are generally comprised of heavier coarse-grained sediments, including gravel, cobbles, and boulders, with beds or lenses of sand material. 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.

Cross Sections A-A' and B-B' transect the Northern Parcel (North Ridge), Southern Parcel (Main Ridge), and Proposed Development Lands. The results of Wills' subsurface investigation suggest that a contact between the coarse-grained Norwood esker core deposits (predominantly gravel, cobble, boulders, with lesser sand) and relatively finer grained deposits (predominantly sand, with lesser gravel) on the Northern Parcel likely lies beneath the Proposed Development Lands.

Geological extrapolation for subsurface conditions beneath the Proposed Development Lands is complicated as a result of the two ridges (North Ridge and Main Ridge) within the Study Area, which may reflect different depositional environments and possibly temporal relationships. The temporal relationship (relative time of deposition) between the deposits is unknown, and may have affected the orientation/nature of the contact if one deposit was formed prior to the other, or if the ice channels that carried the sediment-laden waters (and ultimately formed the ridges) interacted with one another, resulting in an erosional contact.

Dixon's work suggests that the multiple ridges of the Norwood esker are likely a result of the shape of the ice roof and the melting of internal ice (i.e. the flows that deposited the two ridges may have been partially or completely separated prior to ice melt). Based on the height of the Main Ridge (Southern Parcel) with respect to adjacent ridges, Dixon suggests that the Main Ridge was the preferred channel that carried most of the sediment and water. For the purpose of the cross section interpretations (A-A' and B-B') Wills has assumed a cross cutting relationship, whereby the coarse grained, high energy sediments associated with the Main Ridge form an erosional northwest-dipping contact with the finer grained sediments encountered on the North Ridge. This contact is interpreted to follow the topography of the southwest slope of the Main Ridge and extend below the Proposed Development Lands.

If confirmed, the location and orientation of this contact could result in the Proposed Development Lands being underlain by differing amounts of sand or gravel material, however, neither would afford the Aquifer with protection from any potentially contaminating activities or contaminants of concern. The potential for Aquifer contamination is exacerbated by the shallow water table inferred along the northern side of the Proposed Development Lands, which may be encountered at an approximate depth of 2.0 mbg on the basis of the Cross Section A-A' interpretation.

For the purpose of the hydrogeological interpretation and discussion, the finer-grained deposits encountered on the Northern Parcel can be described as flank deposits, as it cannot be confirmed whether or not these sediments (especially at depth within the saturated zone) are associated with the deposition of the Main Ridge sediments, or a separate depositional environment associated with the North Ridge.

8.0 Hydrogeology

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 not homogeneous, isotropic and of uniform thickness. It shows 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 aquifer itself is of variable thickness. However, the contrast in homogeneity and anisotropy is minor compared to deposits that are interbedded or bounded by aquitards of much lower permeable material. The saturated portion of the aquifer is also relatively constant at eight to 10 m thick.

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 methods of aquifer analysis were substantially met.

9.0 Pumping Tests

The pumping tests were conducted to modify the current aquifer groundwater model, to generate updated vulnerability zones based on the revised model and wellhead protection areas (WHPAs), and to assess the performance of the wells over sustained pumping activity. 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 1** below.

Table 1 – 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 static water levels measured in the observation wells prior to the initiation of each pumping test are summarized in **Appendix E**. Results of the pumping tests including pumping test analyses are provided under separate cover in Wills' Aquifer Capacity Study Report (August 2022).

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 observation well in question. For instance, T can vary between Well 3 and a specific observation well and Well 4 and the same observation well because of differences in the texture of the sediments between both pumping wells and the 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.

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 observation 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 outlined in **Appendix F**.

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

Table 2 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 2 - Well 1B Pumping Test Aquifer Parameters Transmissivity (T) and Hydraulic Conductivity (K)

Monitor	T m^2/day	K m/d	Saturated Thickness m	K m/sec
WELL 1B Pumping 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 3 details aquifer parameters derived from the pumping test on Well 2.

Table 3 - 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.

10.0 Updated Groundwater Model - Norwood Municipal Water Supply

The 2018 updated groundwater model (MODFLOW2005 using the graphical user interface Visual Modflow by Waterloo Hydrogeologic) [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.

The steady-state version of the model was used to generate well capture zones/WHPAs based on the two scenarios used in the 2018 updated groundwater model.

Scenario 1: Wells 1B, 2, and 3 each pumping at 655 m^3/d for a total of 1965 m^3/d, equivalent to the PTTW rate.

Scenario 2: Wells 2, 3, and 4 each pumping at 655 m^3/d for a total of 1965 m^3/d.

For both scenarios, particles were backward tracked for two years, five years, and 25 years to delineate the two year, five year, and 25-year WHPAs. Scenario 1 and Scenario 2 overlain with Quaternary Geology is shown on **Figure 7**.

Unsaturated zone travel time was calculated using the digital ground surface modified in the area of the Municipal Well Field and the steady-state groundwater levels generated by the model. WWATs were calculated by combining the 25-year WHPAs and placing forward tracking particles at 500 m intervals from the north end of the WHPA to the Municipal Well Field area. In areas where the travel times changed rapidly, intermediate lines of particles were tracked to the Water Supply. These were then contoured in the contouring program Surfer, and a grid file was generated. This was added to the grid file of UZATs to obtain surface to well advection times (SWATs). The UZATs and locations of lines of particles are shown on **Figure 8**.

Next, SWATs were combined with the 25-year WHPA and vulnerability zones two to eight were generated, as shown on **Figure 9**. The 100 metre radius WHPA-As were then placed around the Water Supply Wells, as shown **Figure 10**.

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.

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 from the Municipal Well Field (**Figure 7**). 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.

10.2 Simulation of Water Table to Well Advective Times (WWATs)

The WWAT analysis was performed by placing east-west lines of forward tracking particles just under the simulated water table of the model beginning at the north limit of the 25-year WHPAs. These particles were placed within the granular deposits on the flanks of the Norwood esker and in the Norwood esker core itself. The limits of the composite 25-year capture zone were spanned by particles in each grid cell and particles were added east and west of the granular deposits to their boundary with lower permeability materials. Particles were also placed in some areas where the composite 25-year WHPA extended into the low permeability materials.

Particles were tracked forward until they reached one of the Water Supply Wells to determine the travel time in days. This process was repeated every 500 m southward to the Municipal Well Field. The minimum travel time for Scenario 1 and 2 at each location was used to prepare the vulnerability analysis.

In areas where the travel times showed a large change in the north-south direction, intermediate lines of particles were included and tracked to the Water Supply Wells to refine WWAT estimates.

At the north end of the 25-year WHPAs, and just outside the WHPAs, additional lines of particles were placed in the model and tracked to the Municipal Well Field. Most of these did not reach the Water Supply Wells in 25 years; however, a small area to the northwest of the Norwood esker at model x 2553m, y 6925-6960 m, reached the Water Supply Wells within 1930 days.

In general, in the model, forward tracking particles placed just under the water table flow in the direction of groundwater flow and perpendicular to contours of the water table. When particles reach the Norwood esker, and especially the high permeability core, they flow within the core to the Water Supply Wells. In the area of the bedrock high, the water table is in layer 3 and 4 (the bottom layer) of the model where the well screens are located. The travel times tend to be less in this area than in some areas south of the area of the bedrock high. The bedrock high also modified the particle pathline flow directions.

11.0 Aquifer Vulnerability

The vulnerability scores are based on Table 2B from the Ministry of Environment Conservation and Parks (MECP) Technical Rules, 2017. **Table 4** below shows the vulnerability scores that are to be assigned based on SWAT times for the Municipal Well Field. It should be noted that since WHPA-C1 refers to a 2-10 yr. WHPA, this category does not apply in this instance.

Table 4 - Wellhead Protection Vulnerability Scores – SWAT

Groundwater Vulnerability Category for the Area	Location Within a WHPA: WHPA-A	Location Within a WHPA: WHPA-B	Location Within a WHPA: WHPA-C	Location Within a WHPA: WHPA-C1	Location Within a WHPA: WHPA-D
High	10	10	8	8	6
Medium	10	8	6	6	4
Low	10	6	2	2	2

Note: SAAT – Surface to Aquifer Advection Time SWAT – Surface to Well Advection Time

Figure 11 shows vulnerability scores based on **Table 4** and vulnerability categories which depend on SWAT travel times in the 2022 composite Scenario 1 and 2 WHPAs.

The vulnerability areas, shown on **Figure 11**, in the vicinity of the Water Supply Wells have been modified from those presented in the 2018 updated modelling report. The UZATs are modified slightly in the areas northwest of the Proposed Development Lands as determined from the 2021 borehole logs. The Aquifer parameters were modified in the 2022 model based on analysis and the results of simulation of the 2021-2022 pumping tests.

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 under the Proposed Development Lands and beyond. This pattern can be seen in the Static Groundwater Level 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.

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 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 under the Proposed Development Lands and then turn northeast. The lack of monitor wells on the Proposed Development Lands make this possibility a challenge to interpret. Nevertheless, development on the Proposed Development Lands should be prohibited. If the Proposed Development is allowed, the use of infiltration galleries and basement excavations (including tile drainage) should be prohibited as this would significantly increase the unsaturated zone travel times during rainstorms or during snow melt.

12.0 Conclusions and Recommendations

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

- Borehole data suggests that a contact between the Norwood esker core deposits (Southern Parcel) and relatively finer grained flank deposits (Northern Parcel) lies beneath the Proposed Development Lands. Both deposits are considered coarse-grained (predominantly gravel and sand) and no significant layers of silt or clay-rich sediments were encountered that would constitute an aquitard and afford the Aquifer protection from potential contamination at surface.
    - Based on Wills' cross section interpretations, the saturated zone of the Aquifer may be encountered at a shallow depth of approximately 2.0 mbg in areas along the northern boundary of the Proposed Development Lands.
- Aquifer test parameters were generated from the pumping tests carried out on Wells 1B, 2, 3, and 4 and observation wells MW21-01 to MW21-10. While most of the test data was relatively simple to interpret, some of the tests were a challenge to interpret. While this is not that unusual in aquifer test analyses, 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 at high pumping rates.
- The higher permeability core deposits in the Norwood esker 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 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 Norwood Water Supply Aquifer.
- The Aquifer test analyses and computer modelling confirmed that the Norwood Aquifer is highly vulnerable to contamination. 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 under the Proposed Development Lands and from further north all along the Norwood esker north of the Village. Monitors MW21-01 to MW21-04 appear to experience limited drawdown especially with Well 4 pumping during the pumping test. The well logs indicate that much of the material encountered is silty sand with some sandy gravel layers or lenses within the screened intervals, and appear to be in the flank deposits or on the edge of the flank deposits. However, a hydraulic connection does exist between the Municipal Well Field and these northwest monitor wells.

- Monitor wells on the Northern Parcel (i.e. MW21-01 to MW21-04) were screened in layers of the sand material that were observed to have higher silt content (silty) than the stratigraphically higher units. Within the saturated zone, the stratigraphically higher sand generally contained greater proportions of gravel, and some to trace amounts of silt. It is possible that these units would show a greater response to the pumping (i.e. greater hydraulic connection), although this cannot be demonstrated with the current data set and well configurations.
- The current pumping rates of the Municipal Well Field to meet the Village's population requirements is approximately 35% of the PTTW rate at less than 700 m^3/day. The drawdown from pumping at this rate and pumping intermittently each day appears to be minimal. A consequence of this is that the capture zone determined by the 2022 modelling bears little resemblance to the current pattern of groundwater flow at current pumping rates. Since there is a component of groundwater flow from the northwest under the Proposed Development Lands to the Water Supply Wells, development of any kind should be discouraged. If development is allowed, transport pathways including infiltration galleries for runoff and basement excavations with tile drainage should be prohibited as these will exacerbate the flow of contaminants from surface to the saturated portion of the Aquifer.
- Proposed development activities that are prohibited from including infiltration galleries should be evaluated with respect to maintaining the water balance and groundwater flows to the Wellhead Protection Area, and the resulting impacts to the Aquifer's recharge capabilities. Diverted run-off from impermeable surfaces (e.g. roofs, roadways, sidewalks, and driveways) is expected to be significant as a result of the Proposed Development, and may negatively impact the Aquifer's recharge if this water cannot be infiltrated into the Aquifer proximal to the source. This impact would be expected to worsen in the future, as increased water demand from the Aquifer will be required to meet the future growth demands of the Village of Norwood.
- The unconfined Norwood Water Supply Aquifer is considered highly vulnerable to anthropogenic activities.
- Investigative activities completed to date have not identified any natural means of protection of the Norwood Water Supply Aquifer.
- Proposed development activities in such close proximity to a highly vulnerable Aquifer introduce a level of risk to the Village's sole water source. This risk is not only limited to foreseeable activities resulting from the Proposed Development, but also any future activities in the area that cannot be predicted at the current time (e.g. private land uses). It is likely that any development activities would result in a lower quality of water that infiltrates to the saturated zone of the Aquifer, in comparison to the property's pre-developed state.
- Wills' Study provides a refined understanding of the Norwood esker geology and hydrogeology as it relates to the vulnerability of the Aquifer, albeit it reliant on the interpolation and extrapolation of data collected outside of the Proposed Development Lands.

- The findings of Wills' Study support the need for further investigation on the Proposed Development Lands. Additional work is required to address outstanding data gaps and confirm the geologic and hydrogeologic conditions beneath the Proposed Development. Included in **Appendix G** is a Scope of Work that details the additional investigative requirements for the Proposed Development Lands.

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:

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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 vulnerability of the Norwood Water Supply Aquifer, and is prohibited for use by others without D.M. Wills Associates Limited (Wills) prior written consent. This report is considered Wills' professional work product and shall remain the sole property of 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 within the Study Area, 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

— BGS Proposed Development Property Boundary (approximate)

Site Location Plan

Aquifer Vulnerability Study
Norwood, Ontario

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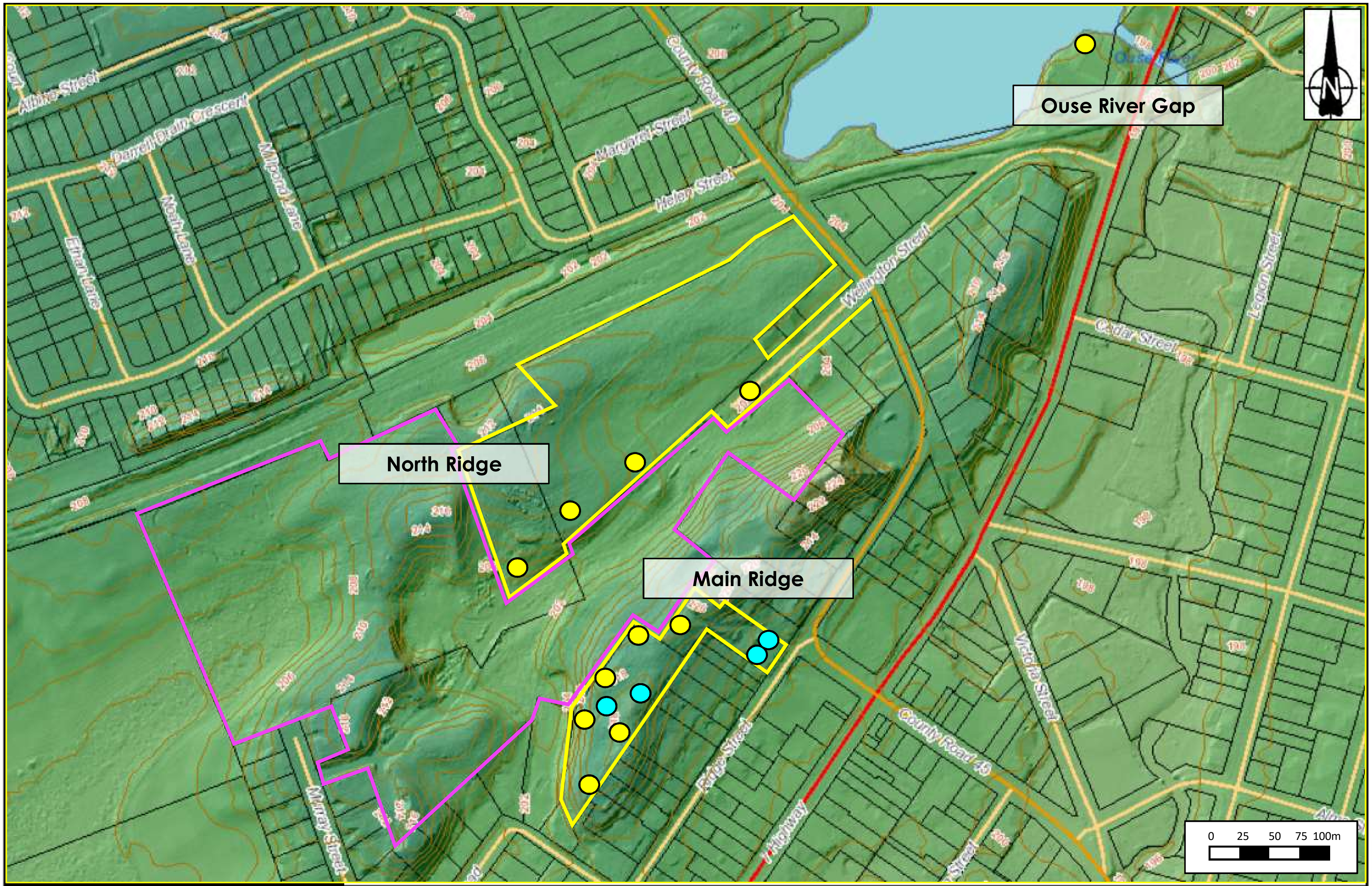
Drawn By	LT	Scale	See scale bar
Checked	IA	Date	June 2022
Project No.	21-7128	Drawing File No.	Figure 1



Legend

- Township Lands
- Proposed Development Lands
- ● Monitor Well
- ● Water Supply Well

Norwood Esker Ridges

Aquifer Vulnerability Study
Norwood, Ontario

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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 Vulnerability Study
Norwood, Ontario

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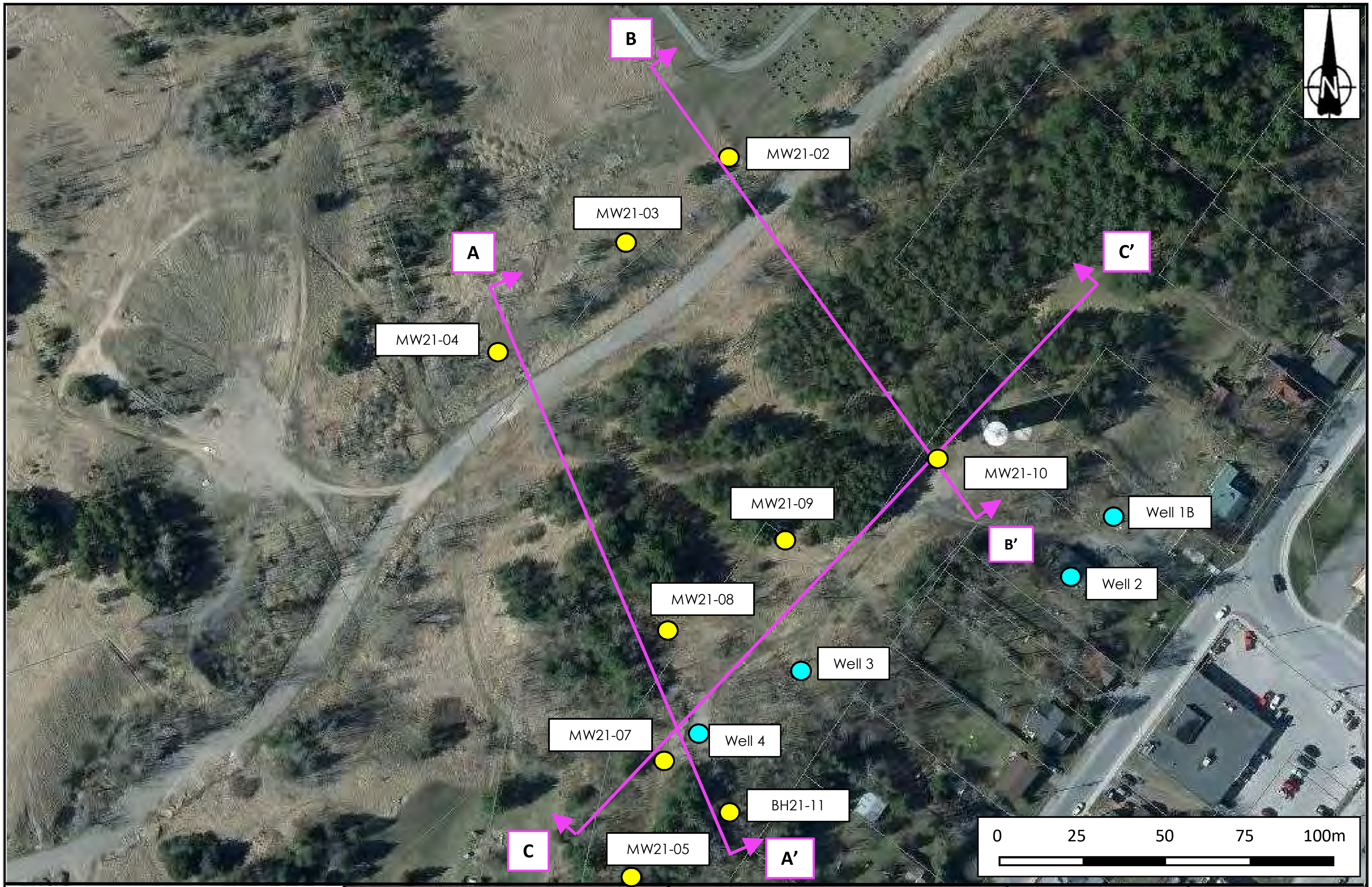
Drawn By LT	**Scale** See scale bar
Checked IA	**Date** Dec 2021
Project No. 21-7128	**Drawing File No.** Figure 3



Legend

🟡 2021 Borehole/Monitor Well

🔵 Existing Municipal Well

— Cross Section

Cross Section Locations

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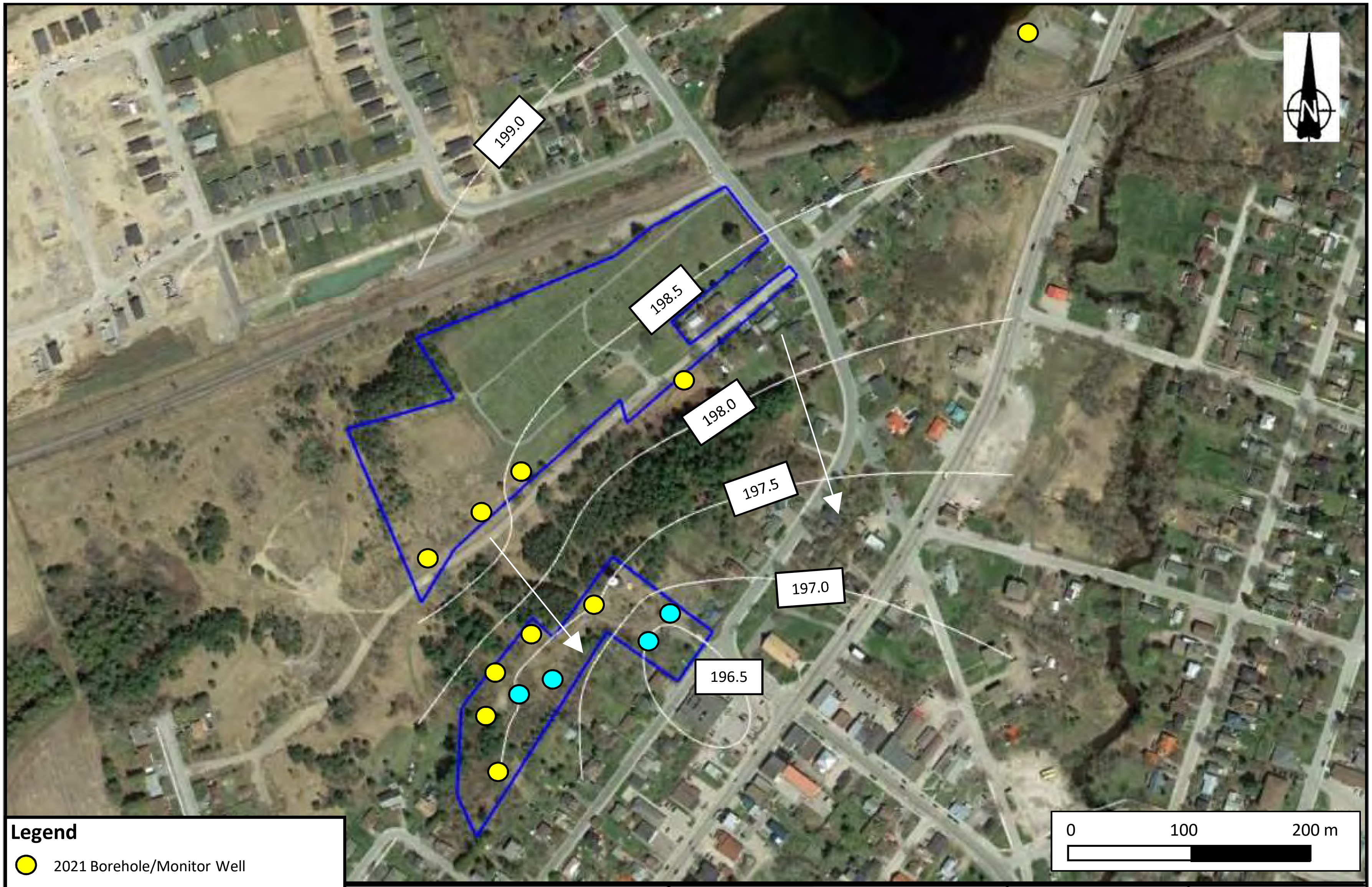
Checked	IA	**Date**	June 2022
Project No.	21-7128	**Drawing File No.**	Figure 4



Legend

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

Static Groundwater Level Contour Map

Aquifer Vulnerability Study
Norwood, Ontario

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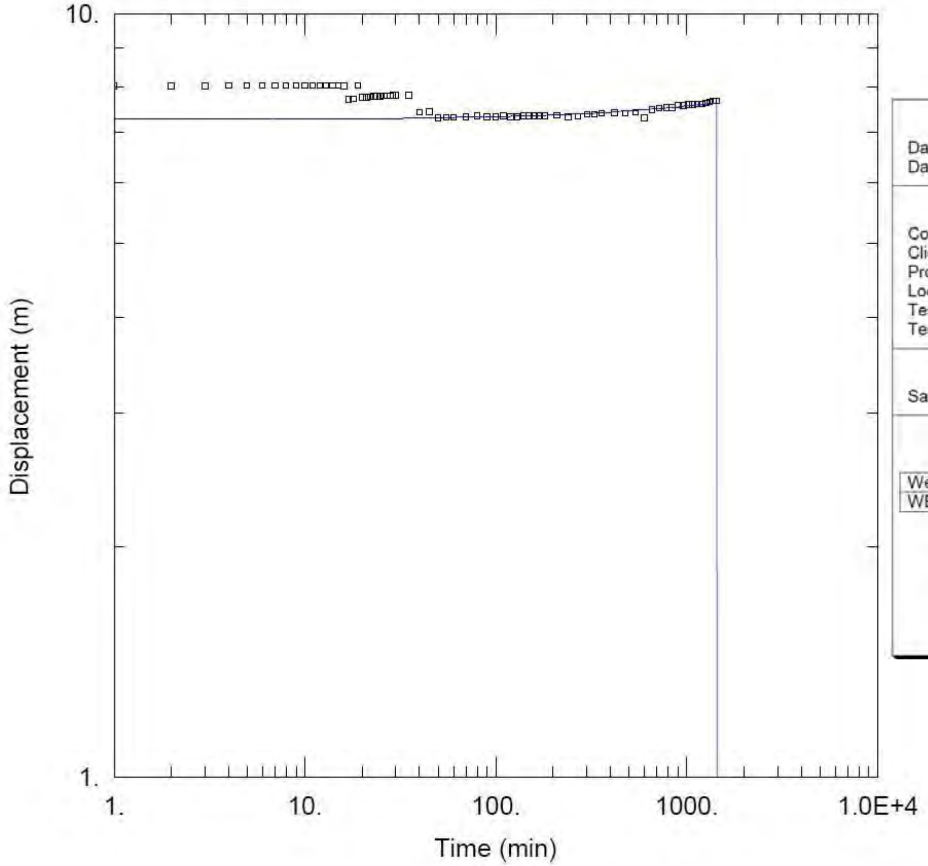
Checked	IA	Date	June 2022
Project No.	21-7128	Drawing File No.	Figure 5



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 Vulnerability Study
Norwood, Ontario

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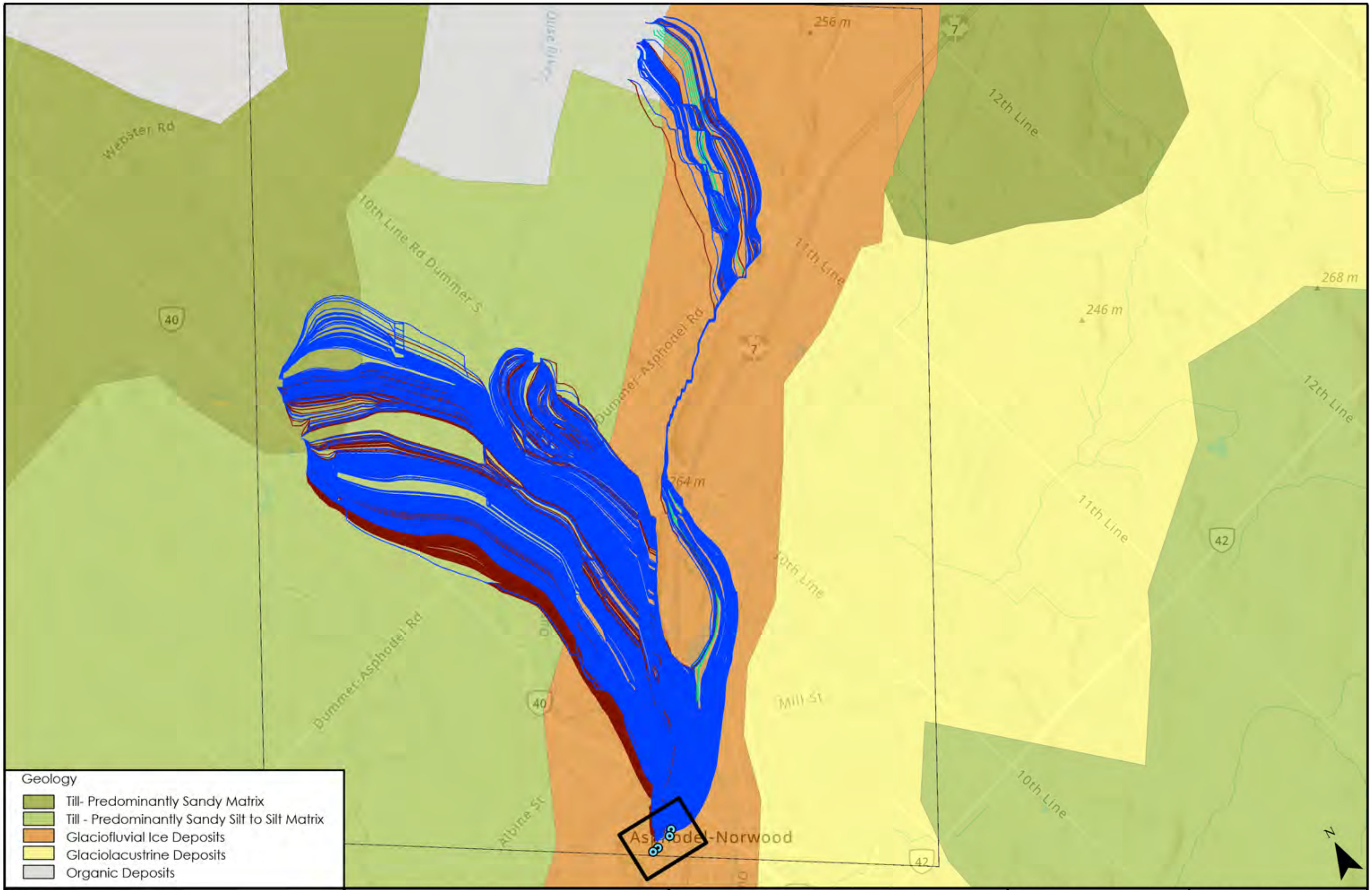
Project No. 21-7128	Drawing File No. Figure 6



Legend

◉ Municipal Wells

▭ Municipal Wellhead Area

Scene 1- 25 yr. Pathlines

Scene 2- 25 yr. Pathlines

Forward Tracking Pathlines 25 yr.

Composite Scenario 1 and 2 25 yr. Pathlines and Quaternary Geology

Norwood Well Field, Norwood Ontario

Figure 7

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Drawn By J Whalen

Checked D Ruttan

Project No. 7128

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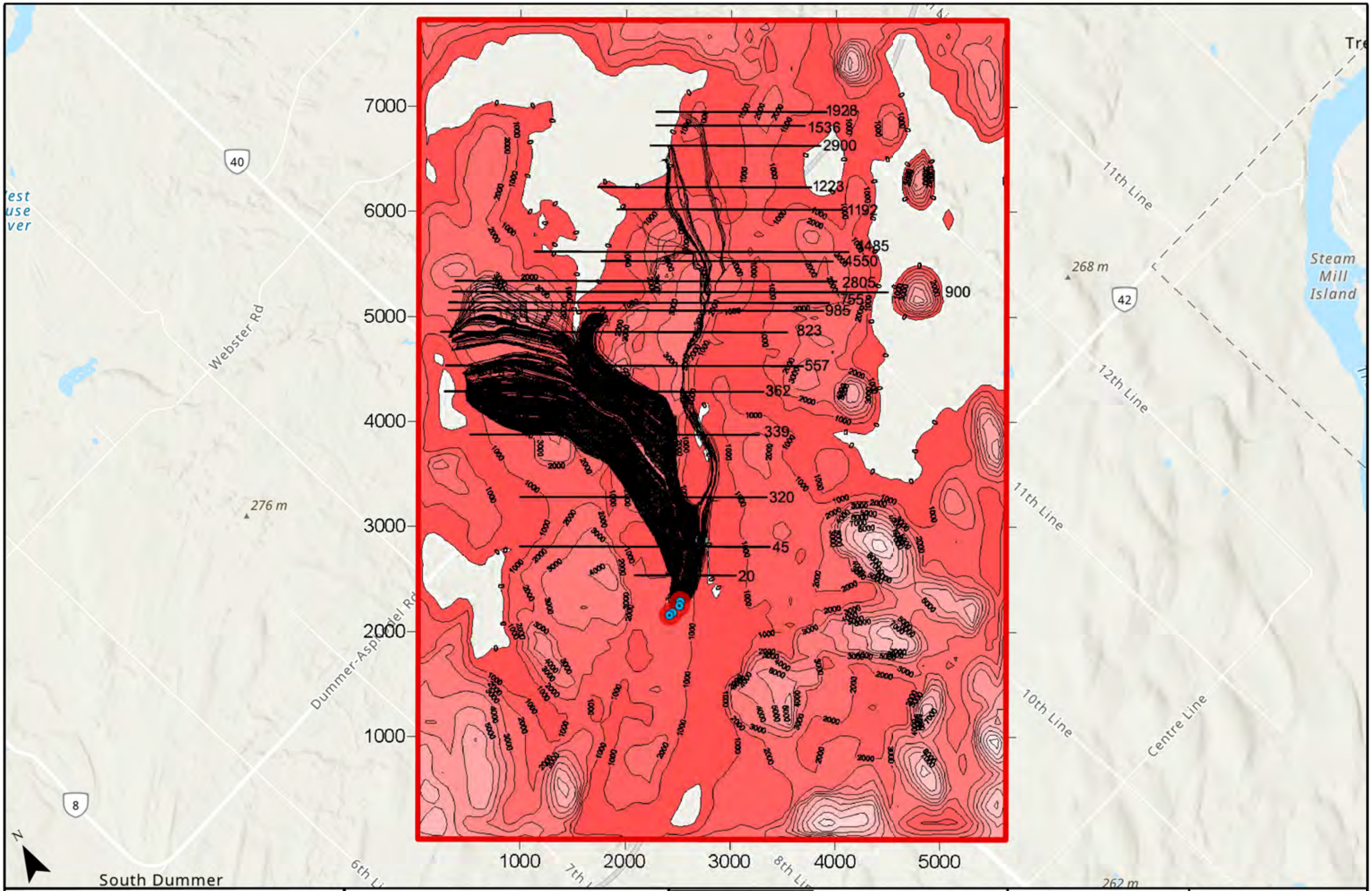

Legend

🟥 Model Grid Boundary

● Municipal Wells

—3000— Unsaturated Zone Vertical Travel Time (days)

—15 Minimum Travel Time in days to Municipal Well from Water Table

Source Credits:Esri, NASA, NGA, USGS, FEMA, Province of Ontario, Esri Canada, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, NRCan, Parks Canada

UZATs & Combined Scenario 1 and 2 WWATs'

Norwood Well Field, Norwood Ontario

Figure 8

WILLS

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Drawn By J Whalen

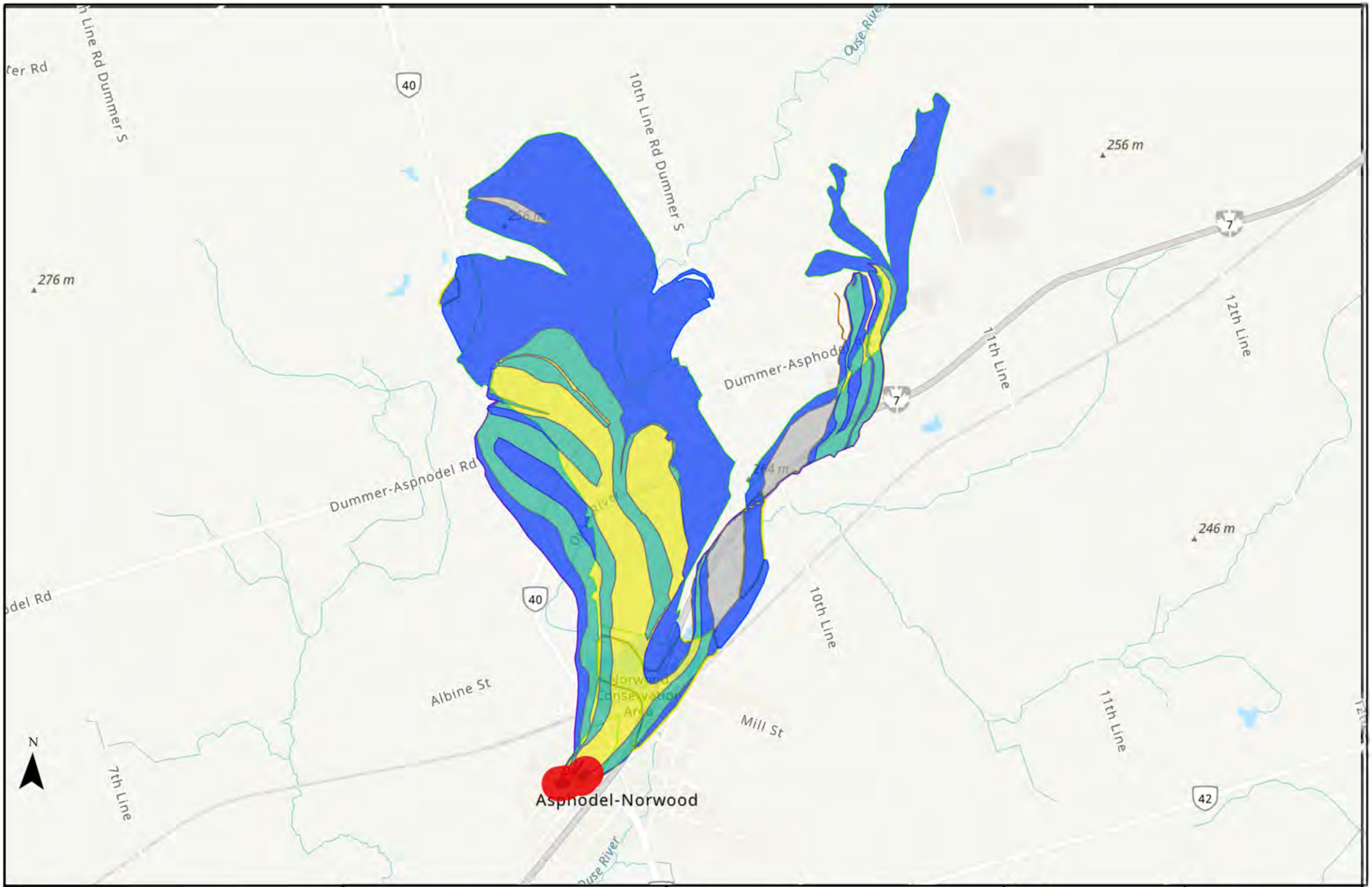
Checked D Ruttan

Project No. 7128

Scale Scale: 1:50,000

Date 2022-06-15 5:08 PM

Drawing File No. Name: 7128-WHPAFigs-



Vulnerability Score

- ⬜ 2
- 🟦 4
- 🟩 6
- 🟨 8
- 🟥 10

Vulnerability Score

Norwood Well Field, Norwood Ontario

Figure 9

W I L L S

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Drawn By J Whalen

Checked D Ruttan

Project No. 7128

Scale Scale: 1:30,000

Date 2022-06-15 6:19 PM

Drawing File No. Name: 7128-WHPAFigs-May2022

Legend

● Municipal Wells

🟥 WHPA -A100m Radius- Municipal Wells

WHPA-A

Norwood Well Field, Norwood Ontario

Figure 10

WILLS

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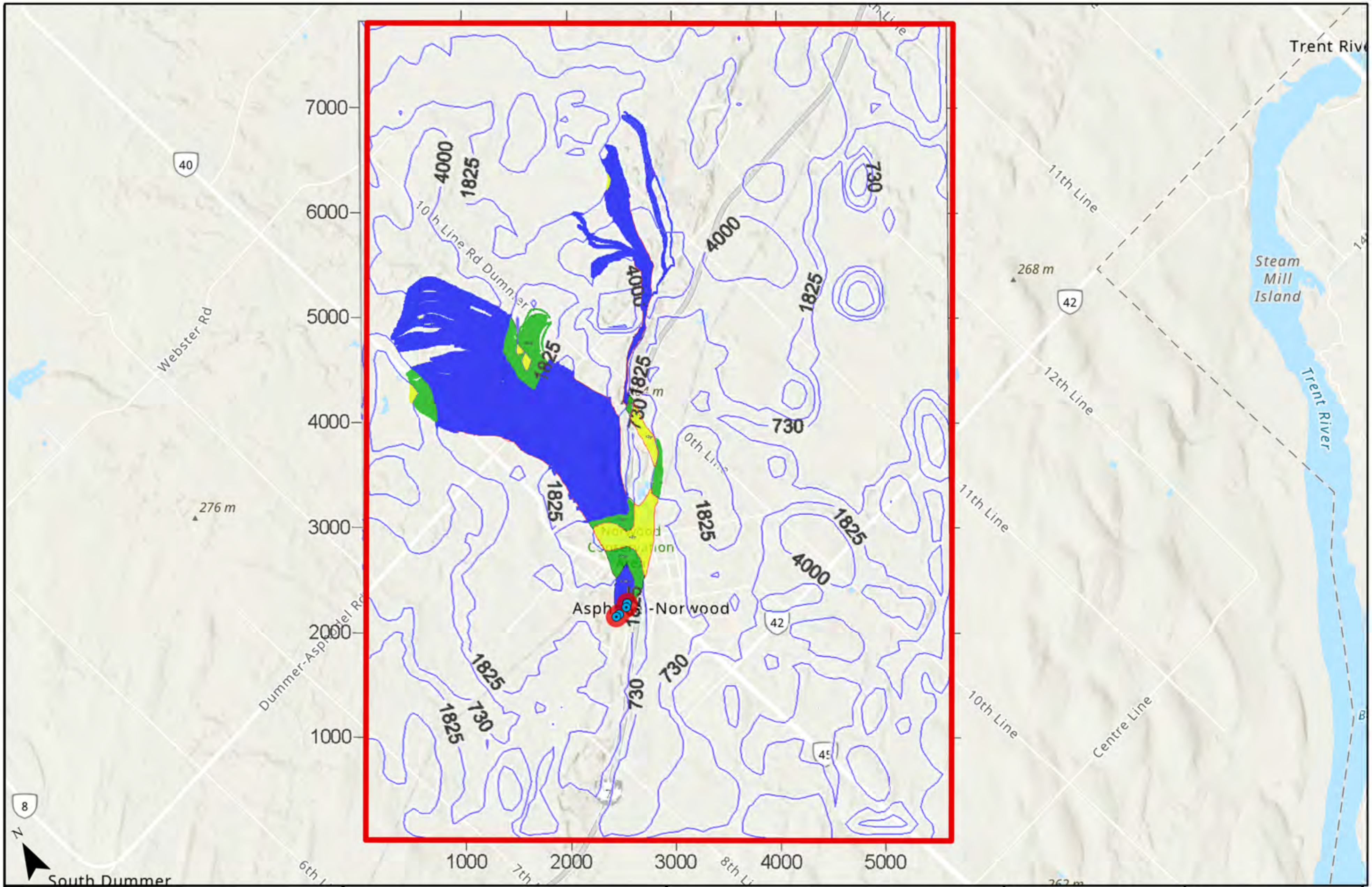
Drawn By J Whalen	**Scale** Scale: 1:1,708
Checked D Ruttan	**Date** 2022-06-15 5:37 PM
Project No. 7128	**Drawing File No.** Name: 7128-WHPAFigs-May2022



Legend

🟥 Model Grid Boundary

🟥 Zone A

🟨 Zone B < 2 Yr.

🟩 Zone C 2-5 yr.

🟦 Zone D 5-25 yr.

Composite Scenario 1 and 2
WHPAs and SWATs
Norwood Well Field, Norwood Ontario

Figure 11

WILLS

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Drawn By J Whalen	**Scale** Scale: 1:50,000
Checked D Ruttan	**Date** 2022-06-15 5:30 PM
Project No. 7128	**Drawing File No.** Name: 7128-WHPAFigs-

Appendix A

Regional Maps

Legend

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

Regional Physiography Map

Vulnerability Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

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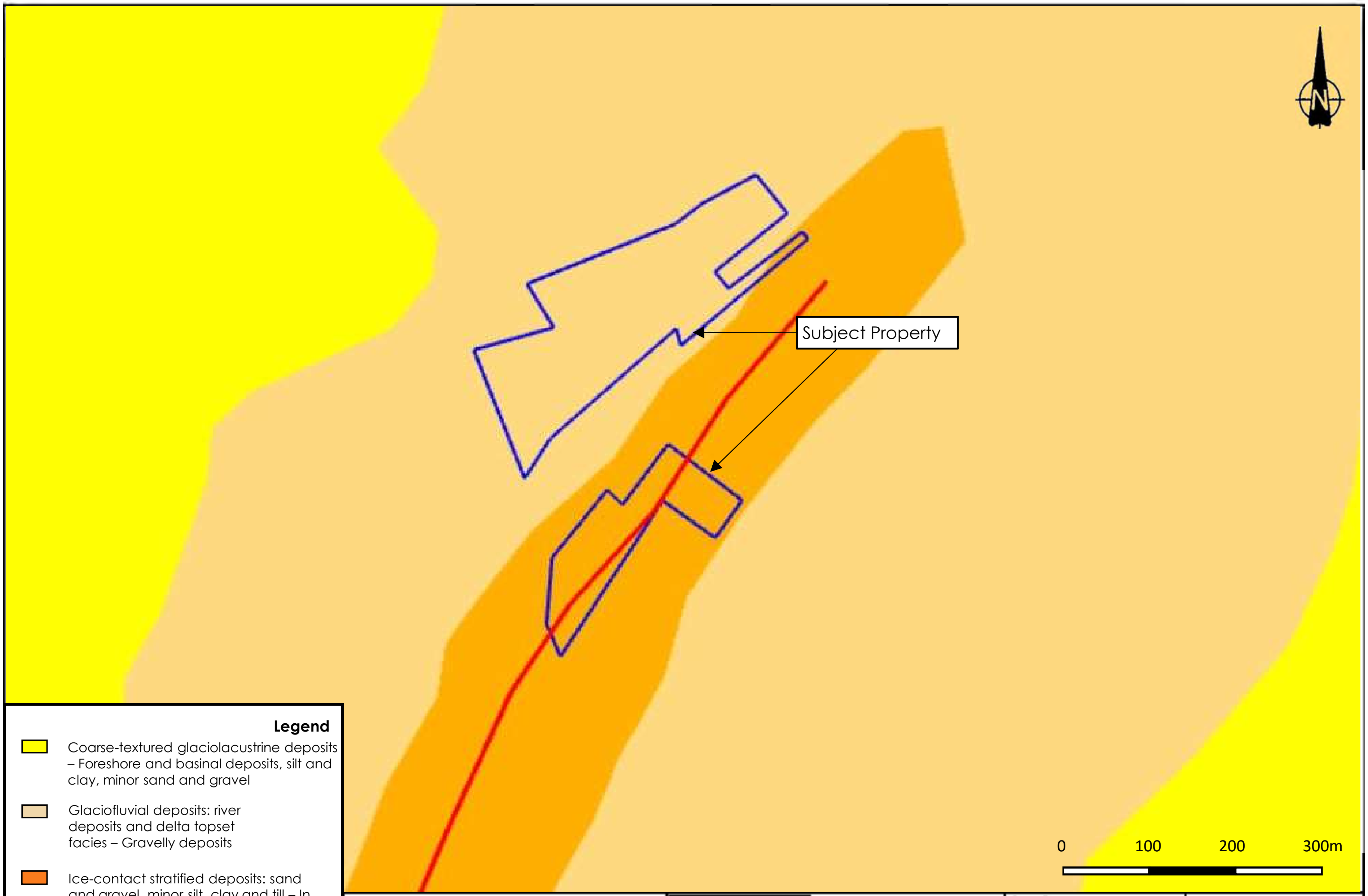
Drawn By	LT	**Scale**	See Scale Bar
Checked	IA	**Date**	May 2022
Project No.	21-7128	**Drawing File No.**	APP-A1



Legend

🟨	Coarse-textured glaciolacustrine deposits – Foreshore and basinal deposits, silt and clay, minor sand and gravel
🟫	Glaciofluvial deposits: river deposits and delta topset facies – Gravelly deposits
🟧	Ice-contact stratified deposits: sand and gravel, minor silt, clay and till – In moraines, eskers, kames and crevasse fills
—	Esker
—	Subject Property Boundary

Regional Surficial Geology Map

Vulnerability Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

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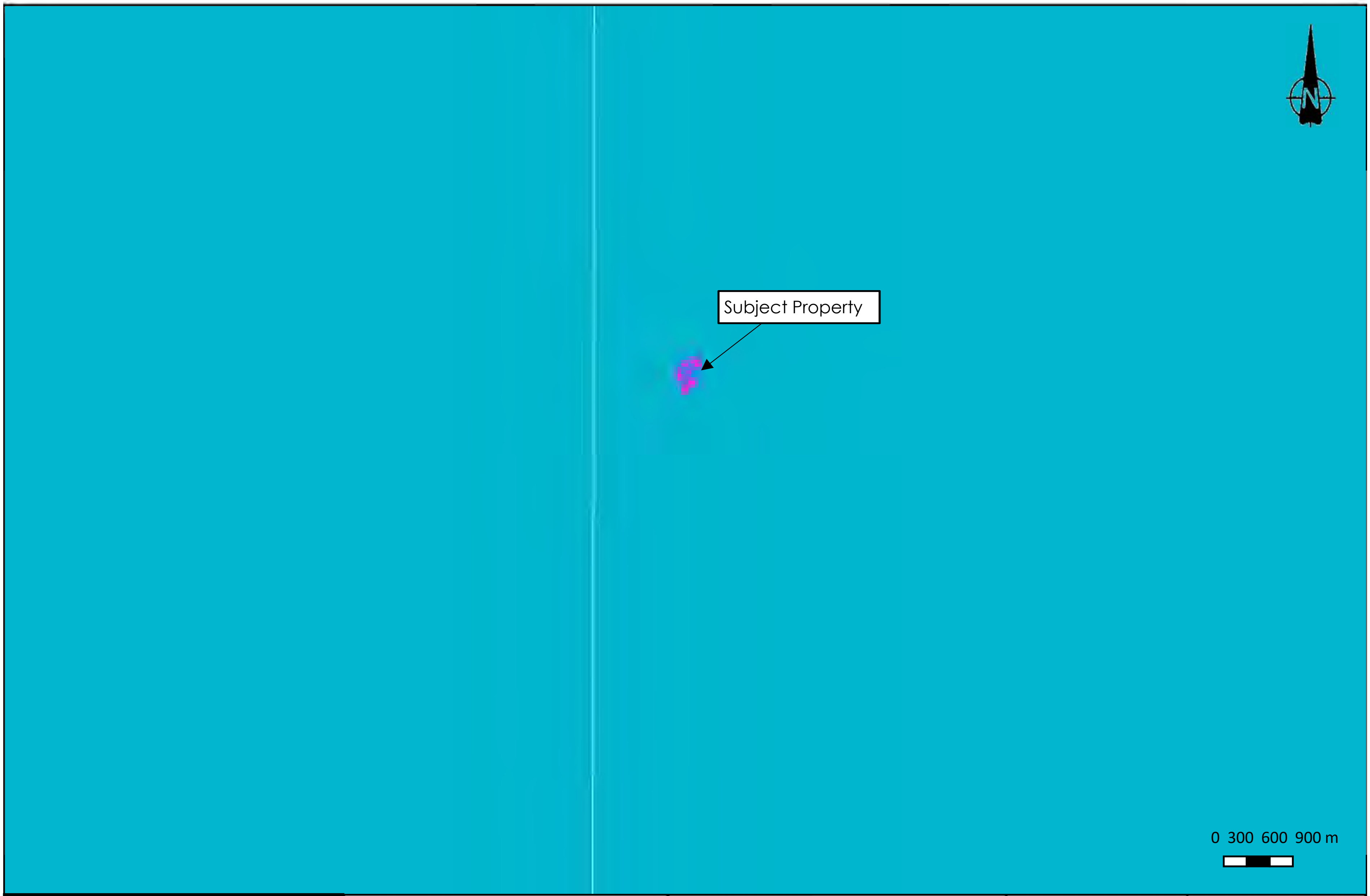
Drawn By	LT	**Scale**	See Scale Bar
Checked	IA	**Date**	May 2022
Project No.	21-7128	**Drawing File No.**	APP-A2



Legend

- 🟦 Middle Ordovician, Ottawa Group-Limestone, dolostone, shale, arkose, sandstone
- — Subject Property Boundary

Regional Bedrock Geology Map

Vulnerability Study
Norwood Municipal Well Field
Township of Asphodel-Norwood

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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: Dark brown silty sand topsoil, trace clay, rootlets, moist, loose	218.67
	■ SS-2	46	23			SILTY SAND: Brown silty sand, some gravel, trace clay, occasional cobble, moist, compact -trace gravel	
					3.05		215.67
	■ SS-3	17	15			GRAVEL: 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 -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: 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.

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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

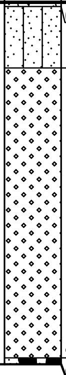
AT END OF DRILLING ---

NOTES

▼ **AFTER DRILLING** 4.06 m / Elev 198.17 m

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY %	N VALUE	REMARKS
	SS-1	50	3	Static Water Level 3.75 mbg Dec 3/21 GSA SS-5: Gravel - 0% Sand - 61% Silt - 35% Clay - 4%
	SS-2	67	28	
	SS-3	46	39	
5	SS-4	75	25	
	SS-5	87	18	
	SS-6	100	46	

GRAPHIC LOG



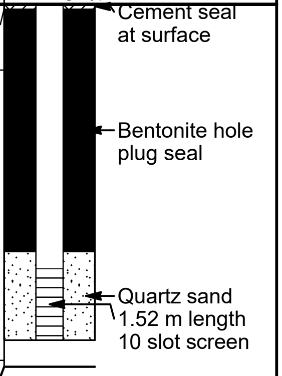
MATERIAL DESCRIPTION

0.10	TOPSOIL: Dark brown silty sand topsoil, trace clay, moist, loose	202.13
1.50	SILTY SAND: Medium brown silty sand, trace clay, moist, loose	200.73
	SAND: Brown sand, some silt, trace gravel, moist, dense ▼ -some gravel, occasional cobble -gravel and coarse sand, saturated, compact -trace gravel -interbedded coarse and fine grained sand, silty, no gravel	
8.10		194.13
8.25	GRAVEL AND SAND: 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



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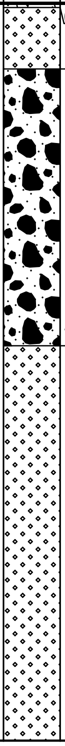
150 Jameson Drive
Peterborough, Ontario K9J 0B9

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	
10				Static Water Level 10.15 mbg Dec 3/21
	SS-8	56	26	
	SS-9	75	26	
	SS-10	83	20	
15	SS-11	87	30	GSA SS-11b: Gravel - 0% Sand- 70% Silt-25% Clay-5%
	SS-12	29	50+	



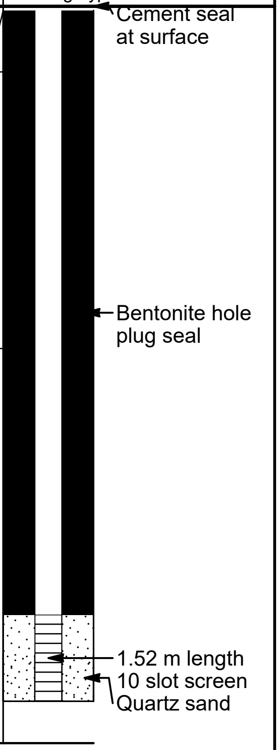
MATERIAL DESCRIPTION

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



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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+

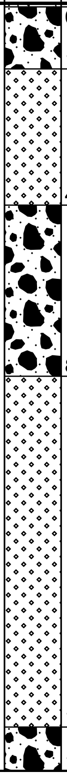
REMARKS

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



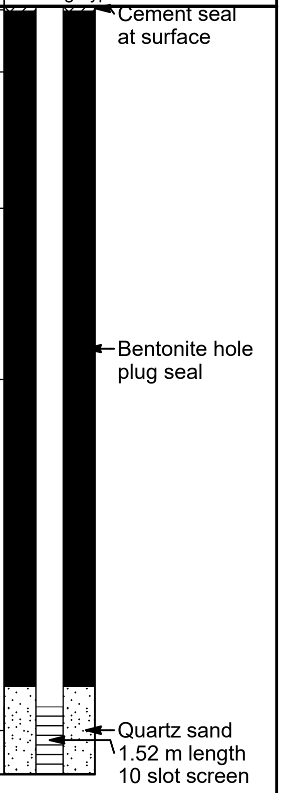
MATERIAL DESCRIPTION

Depth (m)	Material description	Elevation
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



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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
	SS-1	58	6	
	SS-2	56	4	
	SS-3	77	6	Static Water Level 3.48 mbg Dec 3/21
5	SS-4	79	11	
	SS-5	100	3	
	SS-6	100	11	
10	SS-7	100	16	GSA SS-8A: Gravel - 3% Sand- 83% Silt-11% Clay-3%
	SS-8	100	90	

GRAPHIC LOG

MATERIAL DESCRIPTION

0.10 TOPSOIL: 202.47
Dark brown silty sand topsoil, trace clay, rootlets, moist, compact

SAND:
Brown sand (medium grained), trace silt, trace clay, trace gravel, occasional cobble/boulder, loose
▽ -fine textured sand fraction, no gravel
-light brown

-brown, coarse textured sand fraction, trace gravel, wet, compact

-loose

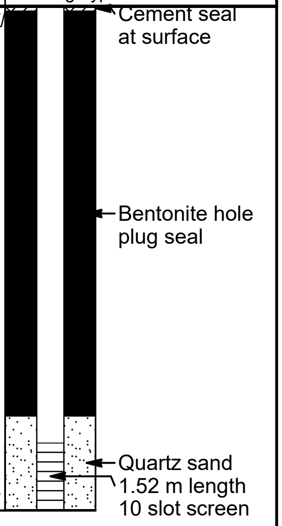
-grey brown, compact

11.50 -some silt, increasing cobble/boulder content, very dense 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



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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
	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
15			
	SS-11	73	60
	SS-12	99	65
	SS-13	42	50+
20	SS-14	75	113
	SS-15	62	50+

REMARKS

GSA SS-10:
Gravel - 40%
Sand- 46%
Silt-11%
Clay-3%

Static Water Level
19.63 mbg
Dec 6/21

GSA SS-15:
Gravel - 3%
Sand- 83%
Silt-11%
Clay-3%

GRAPHIC LOG

MATERIAL DESCRIPTION

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

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

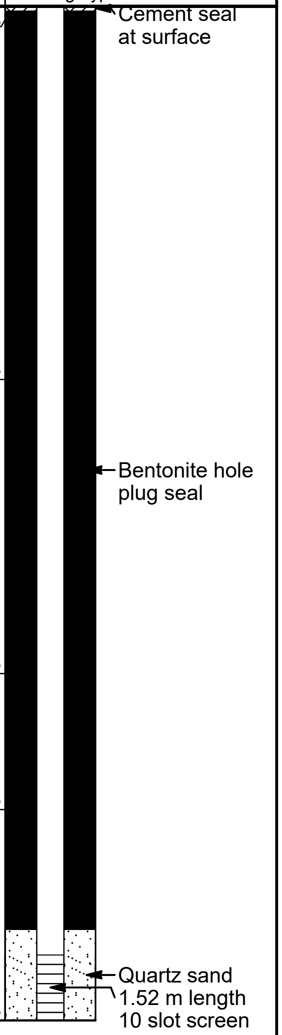
SANDY GRAVEL: Grey brown sandy gravel, some silt, trace clay, occasional cobble/boulder
- fine grained sand bed (0.3 m thick), some silt, trace clay, trace gravel
- increasing cobble/boulder content, very dense

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



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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

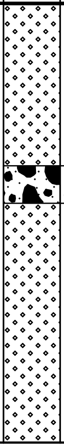
AT END OF DRILLING ---

NOTES

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

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY %	N VALUE	REMARKS
	SS-1	42	2	
	SS-2	25	4	
	SS-3	58	14	Static Water Level 3.54 mbg Dec 3/21
5	SS-4	96	8	
	SS-5	56	16	
	SS-6	75	24	GSA SS-7: Gravel - 3% Sand- 76% Silt-17% Clay-4%
10	SS-7	100	13	

GRAPHIC LOG

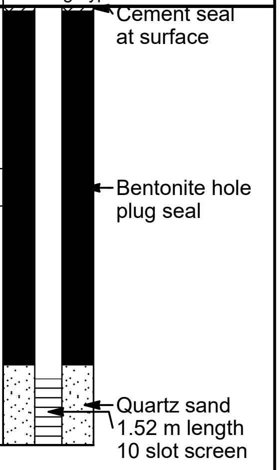


	MATERIAL DESCRIPTION	
0.03	TOPSOIL: Dark brown silty sand topsoil, trace clay, moist, loose	202.18
3.70 ▽	SAND: Brown sand, some gravel, trace silt, moist, loose -some silt, occasional cobble	198.51
4.55	SILTY SAND AND GRAVEL: Grey brown silty sand and gravel, wet, occasional cobble, compact	197.66
10.00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



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150 Jameson Drive
Peterborough, Ontario K9J 0B9

WELL NUMBER MW21-07

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 11/24/21 **COMPLETED** 11/26/21

UTM EASTING 262375.3874 **NORTHING** 4918656.8643

DRILLING CONTRACTOR Canadian Environmental Drilling & Contractors Inc.

GROUND ELEVATION 216.47 masl

DRILLING METHOD Mud Rotary with Split Spoons

GROUNDWATER LEVELS:

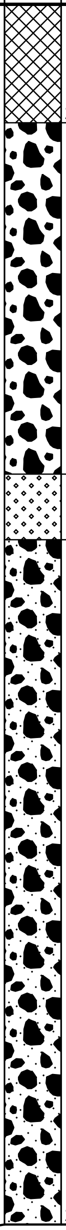
LOGGED BY LT **CHECKED BY** IA

AT END OF DRILLING ---

NOTES

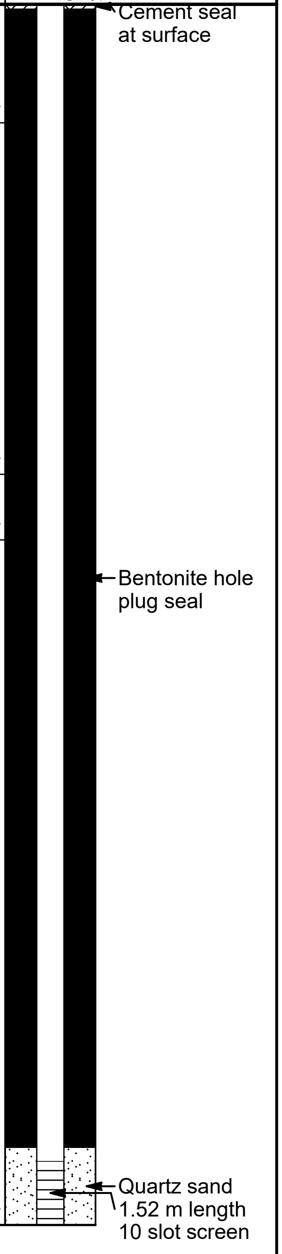
AFTER DRILLING 19.12 m / Elev 197.35 m

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY %	N VALUE	REMARKS	GRAPHIC LOG	MATERIAL DESCRIPTION	
						Augered through 2.74 m thick drill pad (granular fill)	
					2.70		213.77
	SS-1	38	68			GRAVEL: Grey brown gravel, some sand (coarse grained), trace silt, trace clay, very dense	
5	SS-2	54	16			sandy, some silt, compact	
	SS-3	42	48			-some sand, trace silt, occasional cobble, dense	
	SS-4	50	44				
10	SS-5	33	40				
					10.70		205.77
	SS-6	58	23			SAND: Brown sand (fine grained), trace silt, trace clay, compact	
					12.20		204.27
	SS-7	27	50+			GRAVEL AND SAND: Grey brown gravel and sand, some silt, trace clay, occasional cobble/boulder, very dense	
15							
	SS-8	50	48			-dense	
	SS-9	46	87	Static Water Level 19.12 mbg Dec 3/21		-very dense	
20							
	SS-10	54	59				
25	SS-11	48	46			-dense -silty sand bed (0.05 m thick)	
				GSA SS-12: Gravel - 44% Sand- 40% Silt-13% Clay-3%		-increasing cobble/boulder content -very dense	
	SS-12	96	50+		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



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150 Jameson Drive
Peterborough, Ontario K9J 0B9

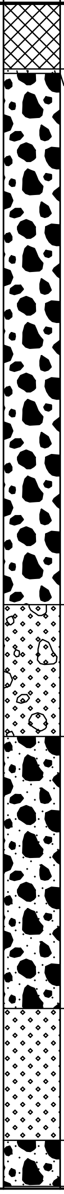
WELL NUMBER MW21-08

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

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY %	N VALUE	REMARKS
	SS-1	75	26	
5	SS-2	23	14	
	SS-3	42	19	
10	SS-4	71	36	
15	SS-5	62	36	
	SS-6	58	53	GSA SS-6: Gravel - 57% Sand- 28% Silt-12% Clay-3%
20	SS-7	54	80	Static Water Level 20.59 mbg Dec 6/21
	SS-8	58	28	
25	SS-9	42	50+	GSA SS-9: Gravel - 45% Sand- 35% Silt-16% Clay-4%

GRAPHIC LOG



MATERIAL DESCRIPTION

Augered through 1.50 m thick drill pad (granular fill)

1.50 216.39

1.60 216.29

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

GRAVEL:
Grey brown gravel, some sand, trace silt, trace clay, occasional cobble

-medium grained sand fraction

-sand and gravel, coarse grained sand fraction

-sandy

13.70 204.19

GRAVELLY SAND:
Grey brown gravelly sand, trace silt, trace clay, occasional cobble

16.70 201.19

SANDY GRAVEL:
Grey brown sandy gravel, some silt, trace clay, occasional cobble, very dense

▽

22.90 194.99

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

25.90 191.99

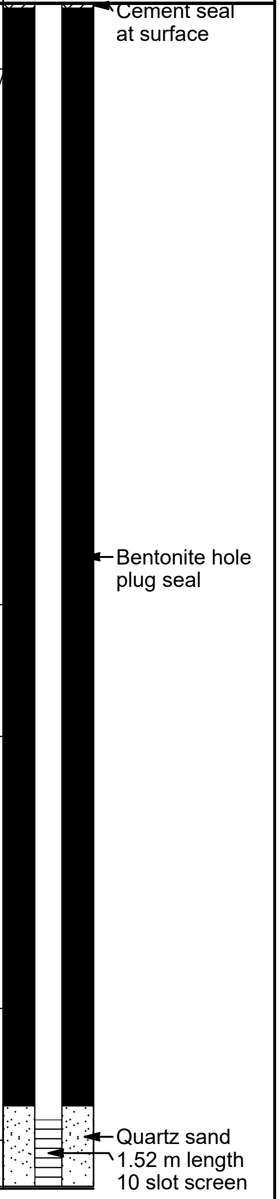
GRAVEL AND SAND:
Grey brown gravel and sand, some silt, trace clay, occasional cobble/boulder, very dense

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



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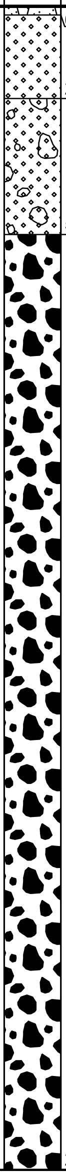
WELL NUMBER MW21-09

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 11/29/21 **COMPLETED** 12/1/21
UTM EASTING 262418.6275 **NORTHING** 4918723.8931
DRILLING CONTRACTOR Insitu Contractors Inc.
GROUND ELEVATION 216.54 masl
DRILLING METHOD Sonic Drilling with Continuous Sampling
GROUNDWATER LEVELS:
LOGGED BY LT **CHECKED BY** IA
AT END OF DRILLING ---
NOTES
▽ **AFTER DRILLING** 19.20 m / Elev 197.34 m

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

GRAPHIC LOG



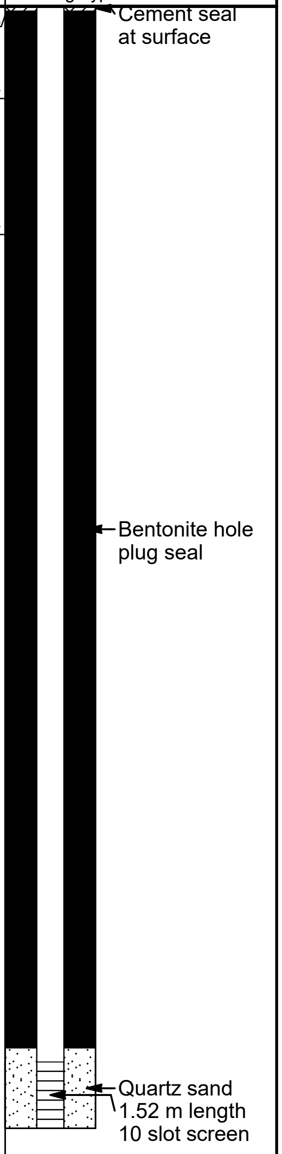
MATERIAL DESCRIPTION

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



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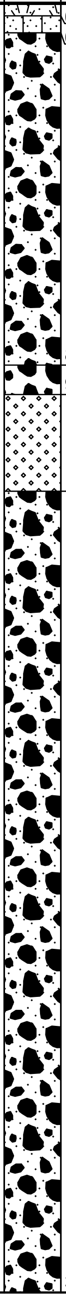
WELL NUMBER MW21-10

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: Gravel - 34% Sand- 38% Silt - 22% Clay-6%
	ST-8	57	Static Water Level 22.31 mbg Dec 6/21
25	ST-9	100	
30	ST-10	85	GSA ST-10: Gravel - 53% Sand- 35% Silt-7% Clay-5%

GRAPHIC LOG



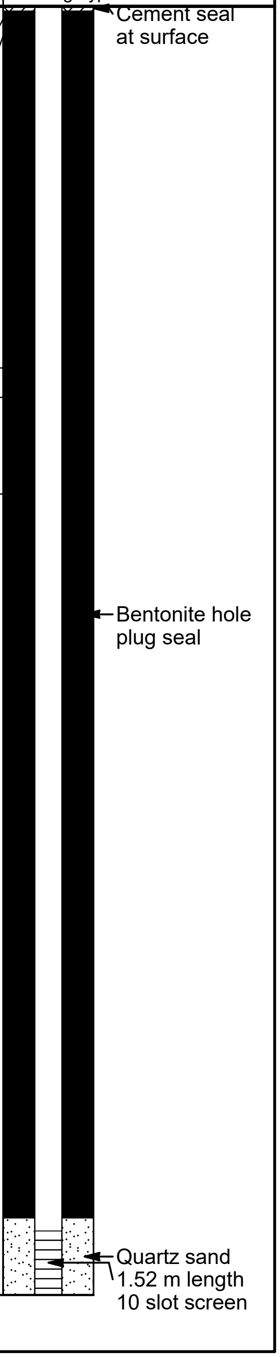
MATERIAL DESCRIPTION

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

Borehole terminated at 30.65 m in gravel and sand.

WELL DIAGRAM

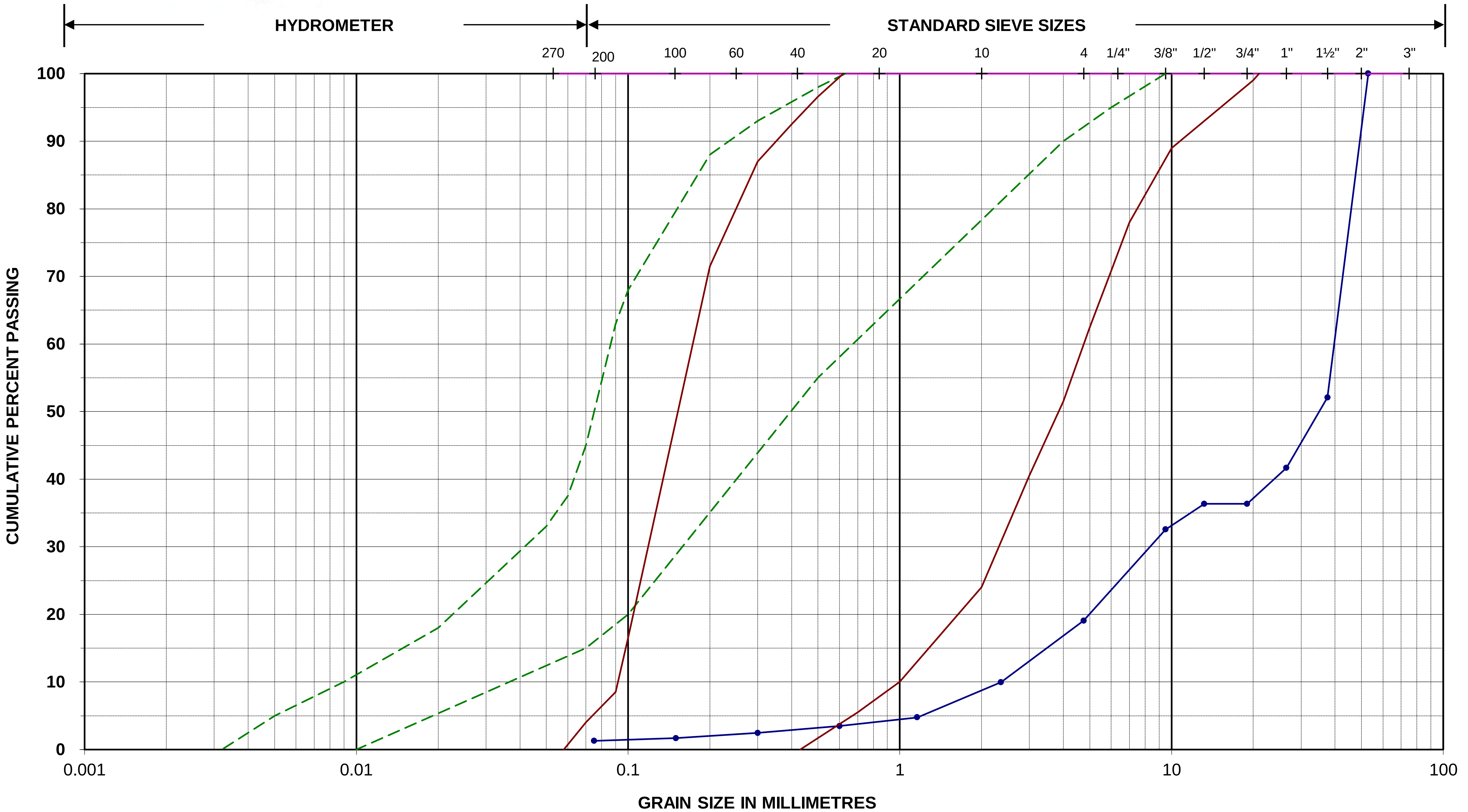
Casing Top Elev: 220.61 (m)
Casing Type: Monument



Appendix C

Certificates of Analysis - Soil

PARTICLE SIZE DISTRIBUTION



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

---------------------- sm envelope T = 8 - 20 min/cm

———————— sp envelope T = 2 - 8 min/cm

Estimated T = 7 min/cm

GRAVEL	**81**	**%**
SAND	**18**	**%**
SILT	**1**	**%**
CLAY	**----**	**%**

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-09	**Sample No./Depth:**	ST-4A

Sieve Size	% Passing Coarse	**Sieve Size**	% Passing Fine
37.5 mm	52.1	**2.36 mm**	10.0
26.5 mm	41.7	**1.16 mm**	4.8
19.0 mm	36.4	**0.60 mm**	3.5
13.2 mm	36.4	**0.30 mm**	2.5
9.5 mm	32.6	**0.15 mm**	1.7
4.75 mm	19.1	**0.075 mm**	1.3

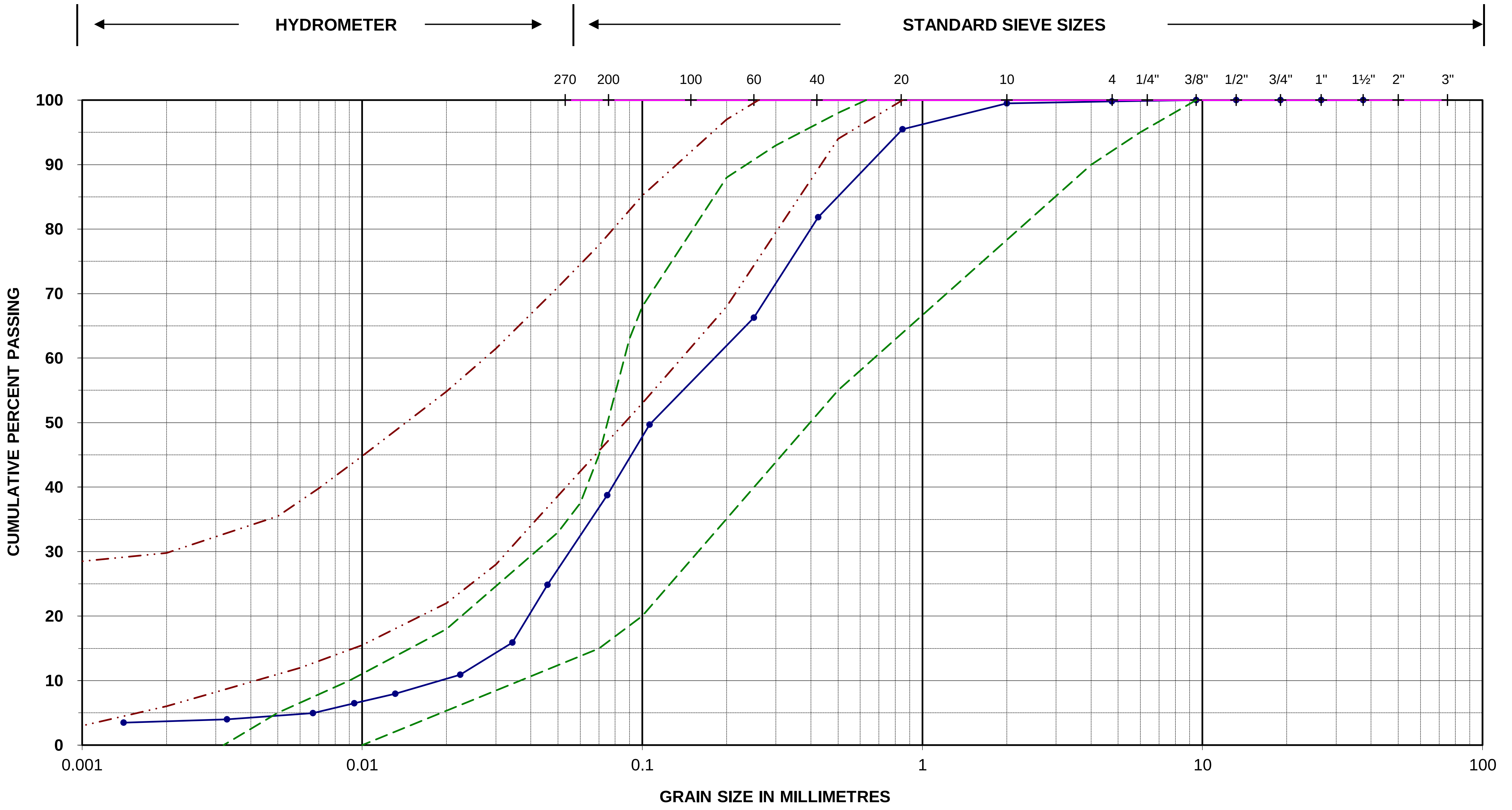
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 20-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**0**	**%**
SAND	**61**	**%**
SILT	**35**	**%**
CLAY	**4**	**%**

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - - ml envelope T = 20 - 50 min/cm

Estimated T = 18 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-01	**Sample No./Depth:**	SS-5

Sieve Size	% Passing Coarse	**Sieve Size**	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	99.51	**0.046**	24.8
26.5 mm	100.0	**0.850 mm**	95.5	**0.022**	10.9
19.0 mm	100.0	**0.425 mm**	81.8	**0.009**	6.5
13.2 mm	100.0	**0.250 mm**	66.2	**0.003**	4.0
9.50 mm	100.0	**0.106 mm**	49.7	**0.001**	3.5
4.75 mm	99.8	**0.075 mm**	38.7		

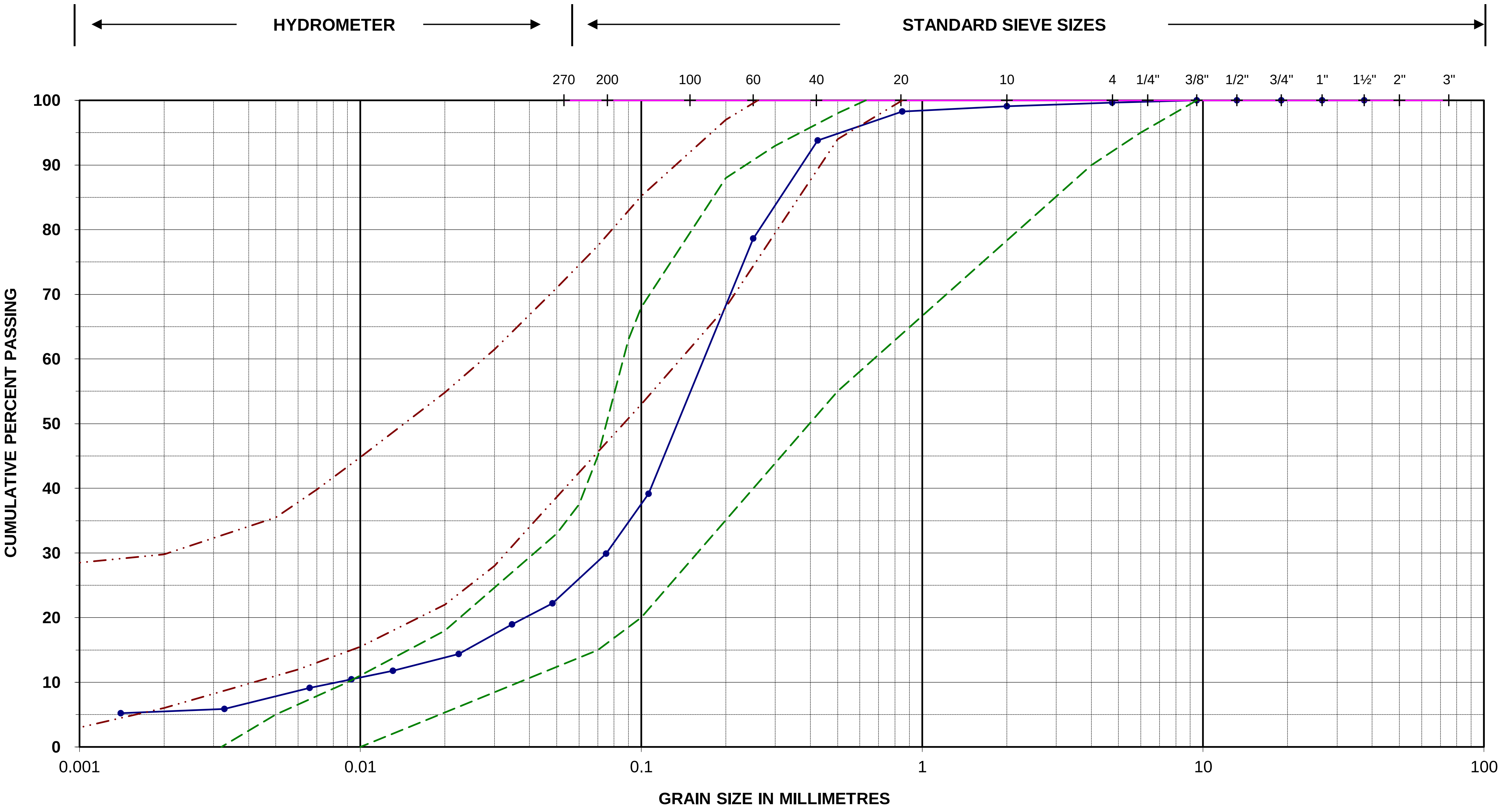
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**0 %**
SAND	**70 %**
SILT	**25 %**
CLAY	**5 %**

----------------------- sm envelope T = 8 - 20 min/cm

- - - — - - — - — ml envelope T = 20 - 50 min/cm

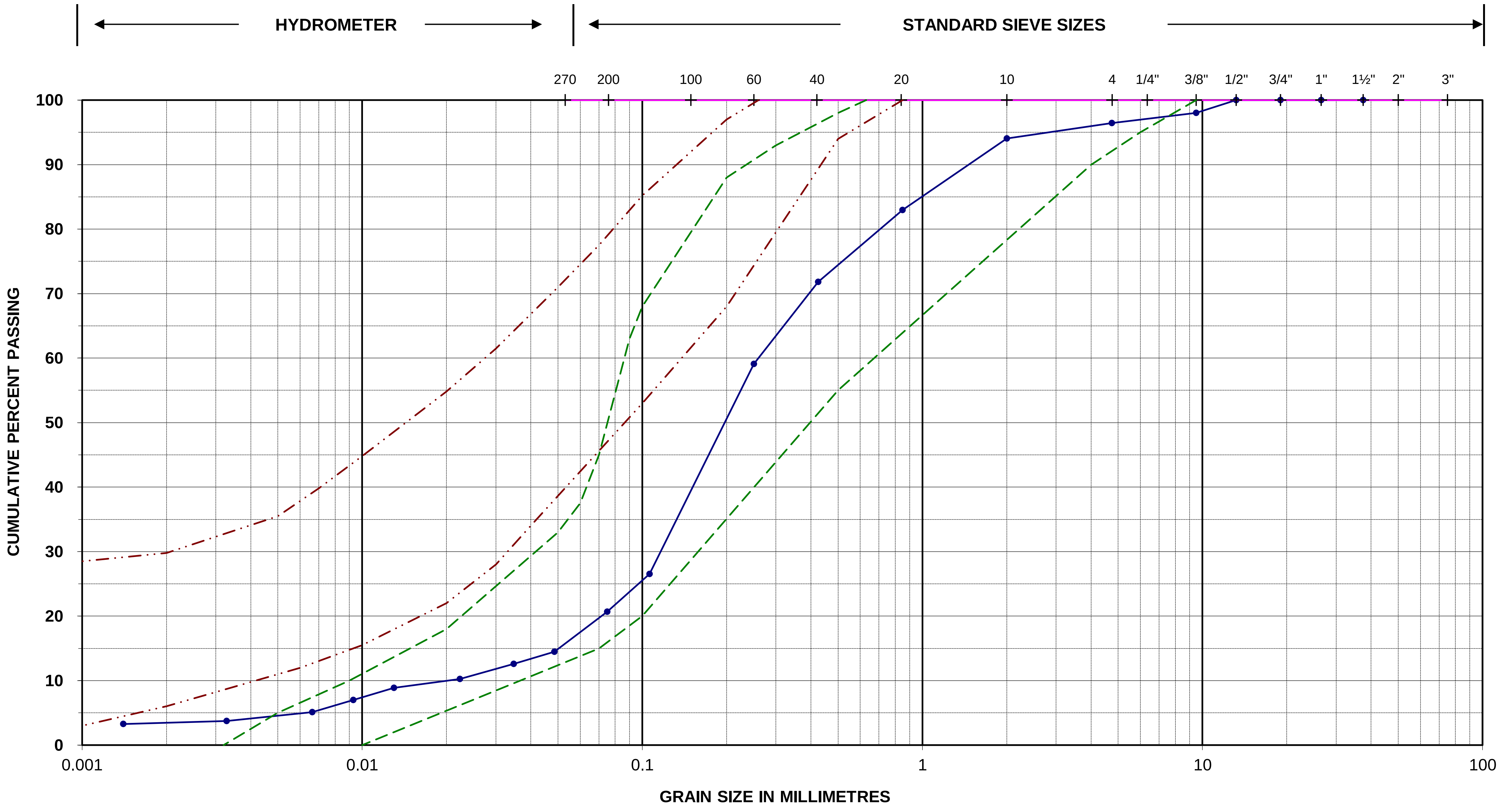
Estimated T = 20 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-02	**Sample No./Depth:**	SS-11B

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	99.07	**0.048**	22.2
26.5 mm	100.0	**0.850 mm**	98.3	**0.022**	14.4
19.0 mm	100.0	**0.425 mm**	93.8	**0.009**	10.4
13.2 mm	100.0	**0.250 mm**	78.6	**0.003**	5.9
9.50 mm	100.0	**0.106 mm**	39.1	**0.001**	5.2
4.75 mm	99.6	**0.075 mm**	29.9		

Note: More information is available upon request. Tested by: NLO Reviewed by: Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**3**	**%**
SAND	**76**	**%**
SILT	**17**	**%**
CLAY	**4**	**%**

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — - — ml envelope T = 20 - 50 min/cm

Estimated T = 19 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-03	**Sample No./Depth:**	SS-7

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	94.06	**0.049**	14.5
26.5 mm	100.0	**0.850 mm**	82.9	**0.022**	10.3
19.0 mm	100.0	**0.425 mm**	71.8	**0.009**	7.0
13.2 mm	100.0	**0.250 mm**	59.1	**0.003**	3.7
9.50 mm	98.0	**0.106 mm**	26.5	**0.001**	3.3
4.75 mm	96.4	**0.075 mm**	20.7		

Note: More information is available upon request.

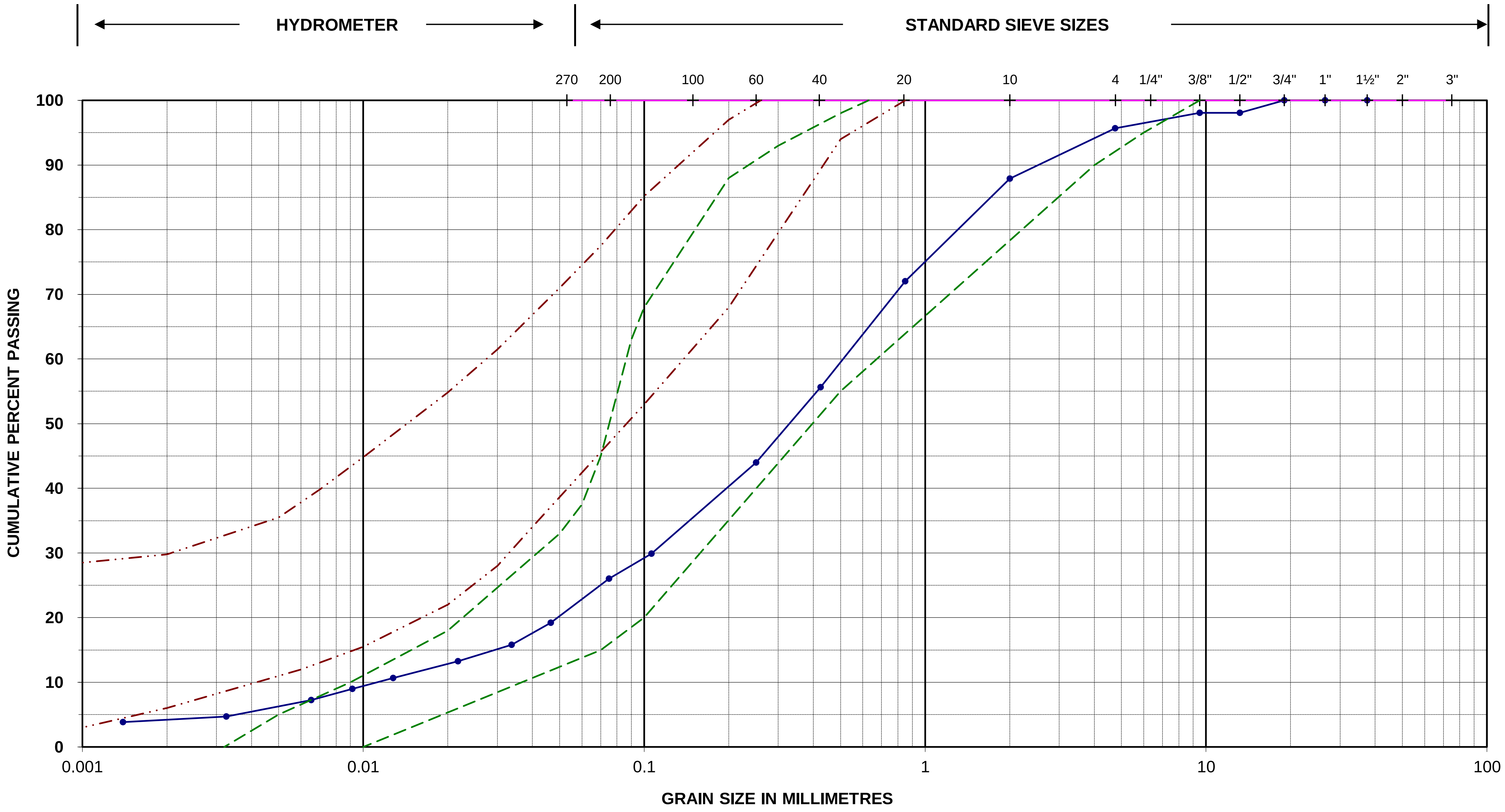
Tested by: NLO

Reviewed by:

Date: 20-Jan-22

CERTIFIED BY CCIL
Canadian Council of Independent Laboratories
For specific tests as listed at www.ccil.com

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - – ml envelope T = 20 - 50 min/cm

Estimated T = 20 min/cm

GRAVEL	**4**	**%**
SAND	**70**	**%**
SILT	**22**	**%**
CLAY	**4**	**%**

Project Name: Norwood Wells
Location ID.: BH21-03
Project No.: 201-07253-00 (7128)
Sample No./Depth: SS-11

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	87.90	**0.046**	19.2
26.5 mm	100.0	**0.850 mm**	72.0	**0.022**	13.2
19.0 mm	100.0	**0.425 mm**	55.6	**0.009**	9.0
13.2 mm	98.1	**0.250 mm**	44.0	**0.003**	4.7
9.50 mm	98.1	**0.106 mm**	29.9	**0.001**	3.8
4.75 mm	95.7	**0.075 mm**	26.0		

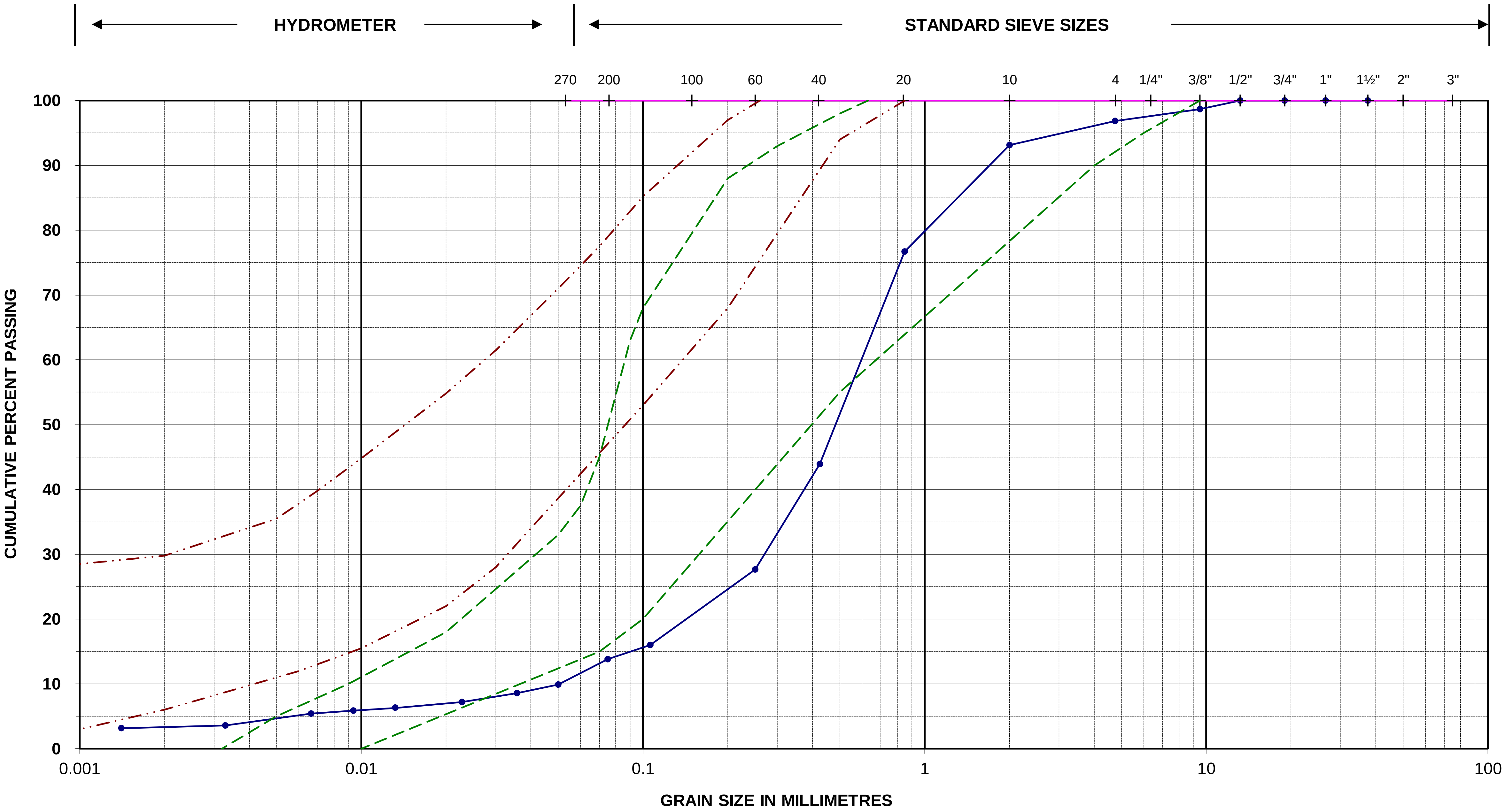
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**3 %**
SAND	**83 %**
SILT	**11 %**
CLAY	**3 %**

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — - — ml envelope T = 20 - 50 min/cm

Estimated T = 17 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-04	**Sample No./Depth:**	SS-8A

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	93.11	**0.050**	9.9
26.5 mm	100.0	**0.850 mm**	76.7	**0.023**	7.2
19.0 mm	100.0	**0.425 mm**	43.9	**0.009**	5.9
13.2 mm	100.0	**0.250 mm**	27.6	**0.003**	3.6
9.50 mm	98.7	**0.106 mm**	16.0	**0.001**	3.2
4.75 mm	96.8	**0.075 mm**	13.8		

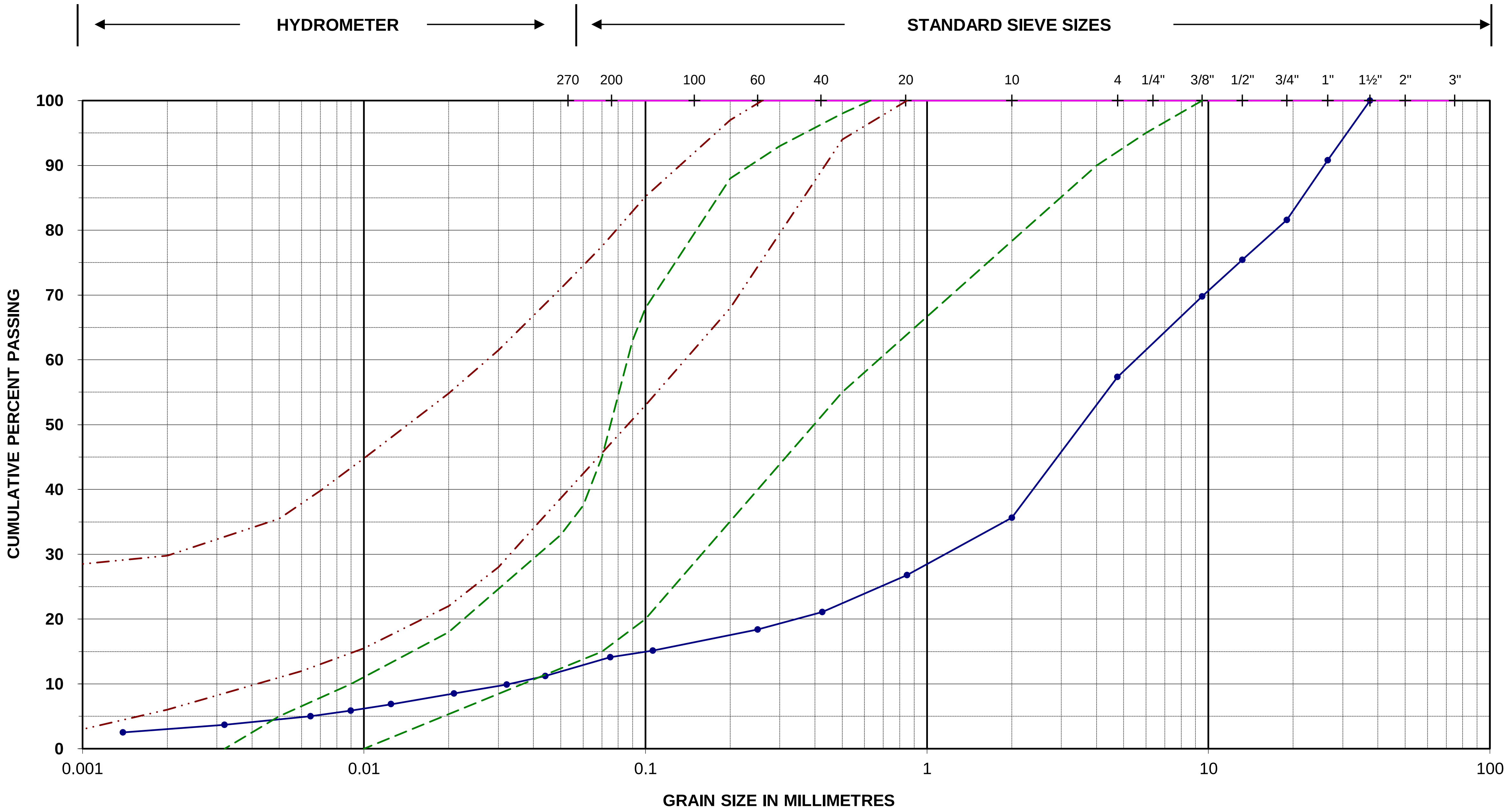
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**40**	**%**
SAND	**46**	**%**
SILT	**11**	**%**
CLAY	**3**	**%**

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — - - — ml envelope T = 20 - 50 min/cm

Estimated T = 18 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-05	**Sample No./Depth:**	SS-10

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	35.63	**0.044**	11.2
26.5 mm	90.8	**0.850 mm**	26.8	**0.021**	8.5
19.0 mm	81.6	**0.425 mm**	21.1	**0.009**	5.9
13.2 mm	75.4	**0.250 mm**	18.4	**0.003**	3.7
9.50 mm	69.8	**0.106 mm**	15.1	**0.001**	2.5
4.75 mm	57.3	**0.075 mm**	14.1		

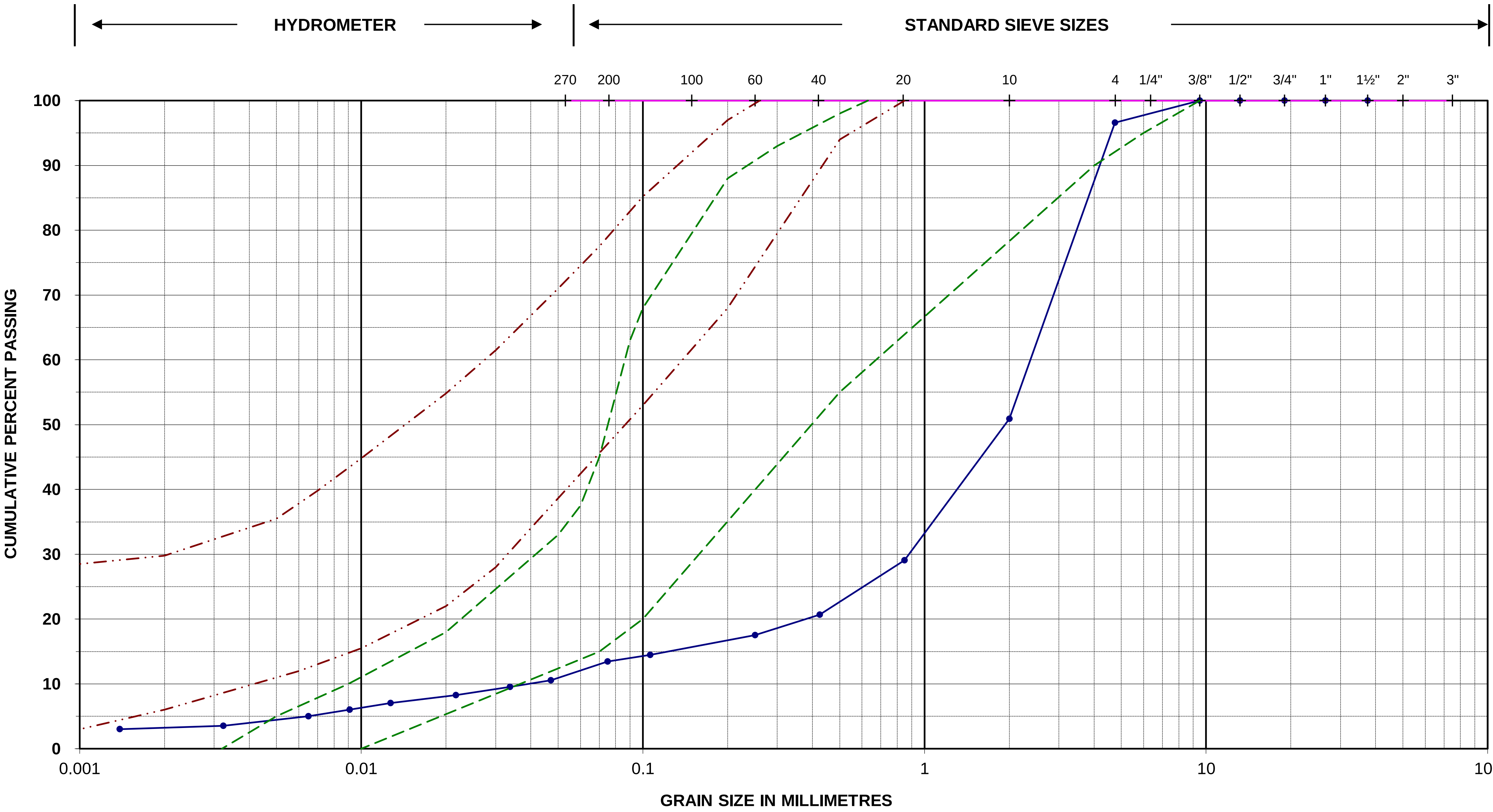
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 20-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	3	%
SAND	83	%
SILT	11	%
CLAY	3	%

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - – ml envelope T = 20 - 50 min/cm

Estimated T = 18 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-05	**Sample No./Depth:**	SS-15

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	50.89	**0.047**	10.5
26.5 mm	100.0	**0.850 mm**	29.1	**0.022**	8.3
19.0 mm	100.0	**0.425 mm**	20.7	**0.009**	6.0
13.2 mm	100.0	**0.250 mm**	17.5	**0.003**	3.5
9.50 mm	100.0	**0.106 mm**	14.5	**0.001**	3.0
4.75 mm	96.6	**0.075 mm**	13.5		

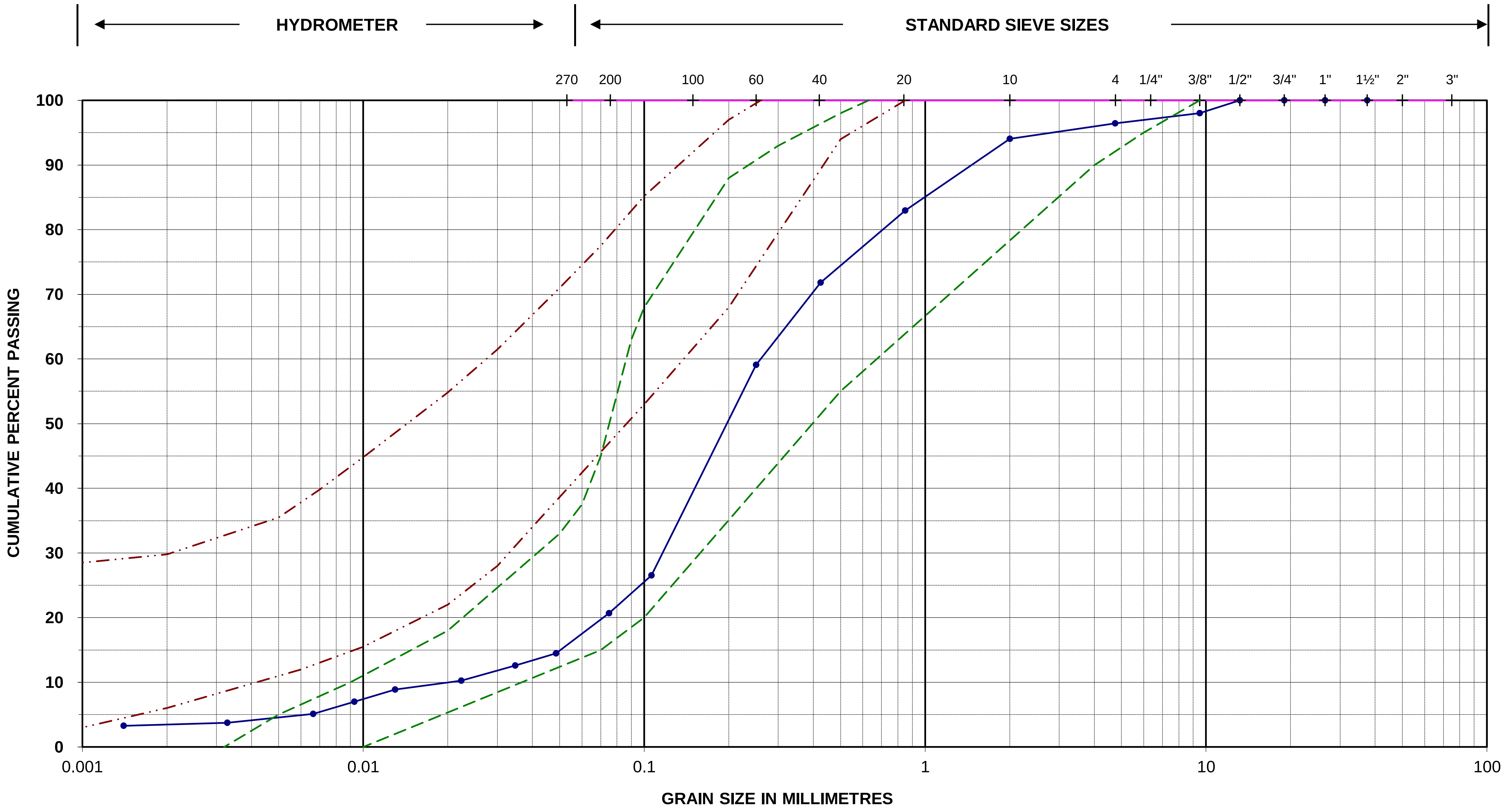
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	3	%
SAND	76	%
SILT	17	%
CLAY	4	%

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - - ml envelope T = 20 - 50 min/cm

Estimated T = 19 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-06	**Sample No./Depth:**	SS-7

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	94.06	**0.049**	14.5
26.5 mm	100.0	**0.850 mm**	82.9	**0.022**	10.3
19.0 mm	100.0	**0.425 mm**	71.8	**0.009**	7.0
13.2 mm	100.0	**0.250 mm**	59.1	**0.003**	3.7
9.50 mm	98.0	**0.106 mm**	26.5	**0.001**	3.3
4.75 mm	96.4	**0.075 mm**	20.7		

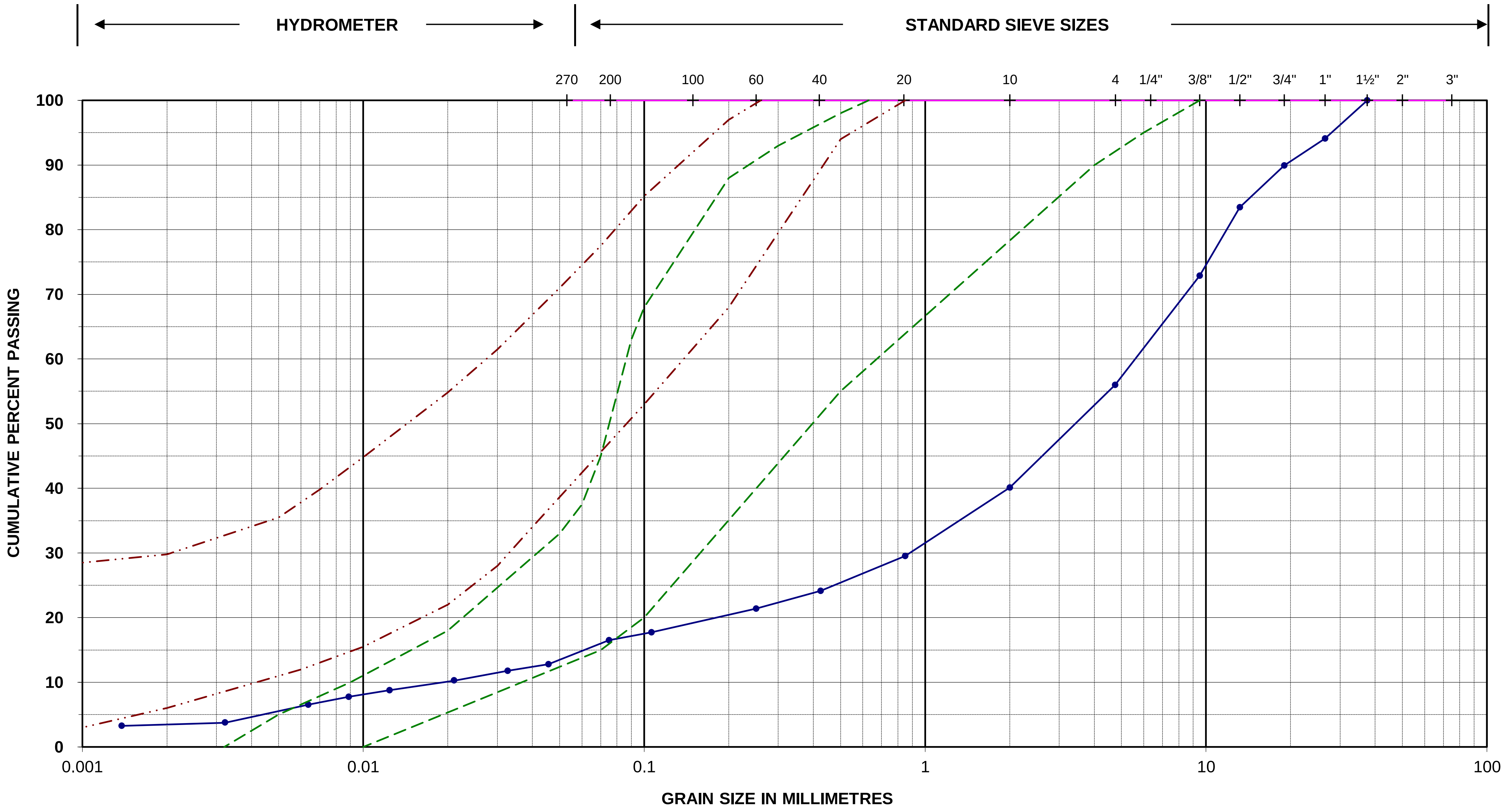
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 20-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — ml envelope T = 20 - 50 min/cm

Estimated T = 19 min/cm

GRAVEL	**44**	**%**
SAND	**40**	**%**
SILT	**13**	**%**
CLAY	**3**	**%**

Project Name: Norwood Wells

Location ID.: BH21-07

Project No.: 201-07253-00 (7128)

Sample No./Depth: SS-12

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	40.12	**0.046**	12.8
26.5 mm	94.1	**0.850 mm**	29.5	**0.021**	10.3
19.0 mm	89.9	**0.425 mm**	24.2	**0.009**	7.8
13.2 mm	83.4	**0.250 mm**	21.4	**0.003**	3.8
9.50 mm	72.9	**0.106 mm**	17.7	**0.001**	3.3
4.75 mm	56.0	**0.075 mm**	16.5		

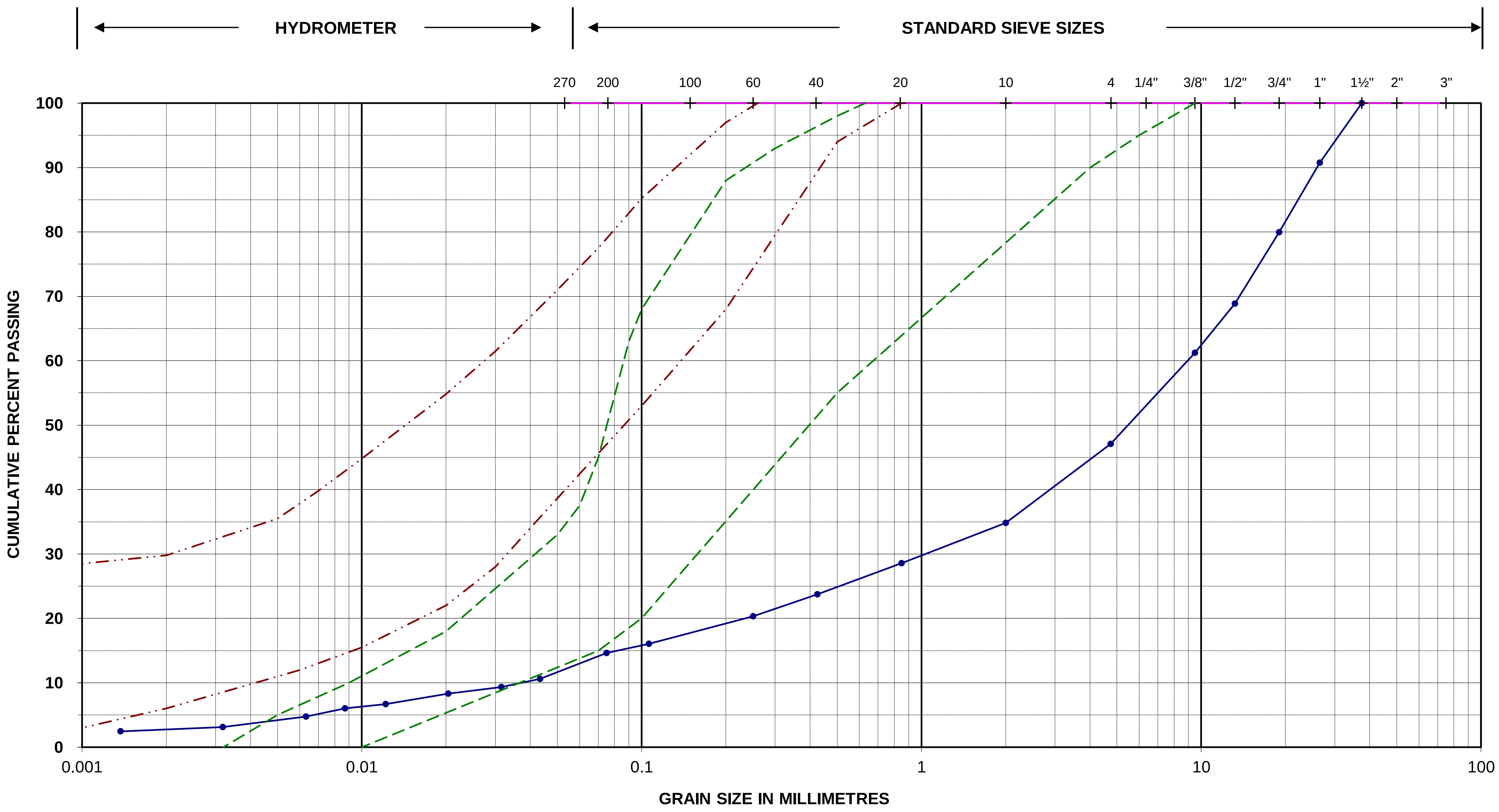
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — - — ml envelope T = 20 - 50 min/cm

Estimated T = 19 min/cm

GRAVEL	57	%
SAND	28	%
SILT	12	%
CLAY	3	%

Project Name: Norwood Wells
Location ID.: BH21-08
Project No.: 201-07253-00 (7128)
Sample No./Depth: SS-6

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	34.82	**0.043**	10.6
26.5 mm	90.7	**0.850 mm**	28.5	**0.020**	8.3
19.0 mm	80.0	**0.425 mm**	23.8	**0.009**	6.0
13.2 mm	68.8	**0.250 mm**	20.3	**0.003**	3.1
9.50 mm	61.3	**0.106 mm**	16.1	**0.001**	2.4
4.75 mm	47.1	**0.075 mm**	14.6		

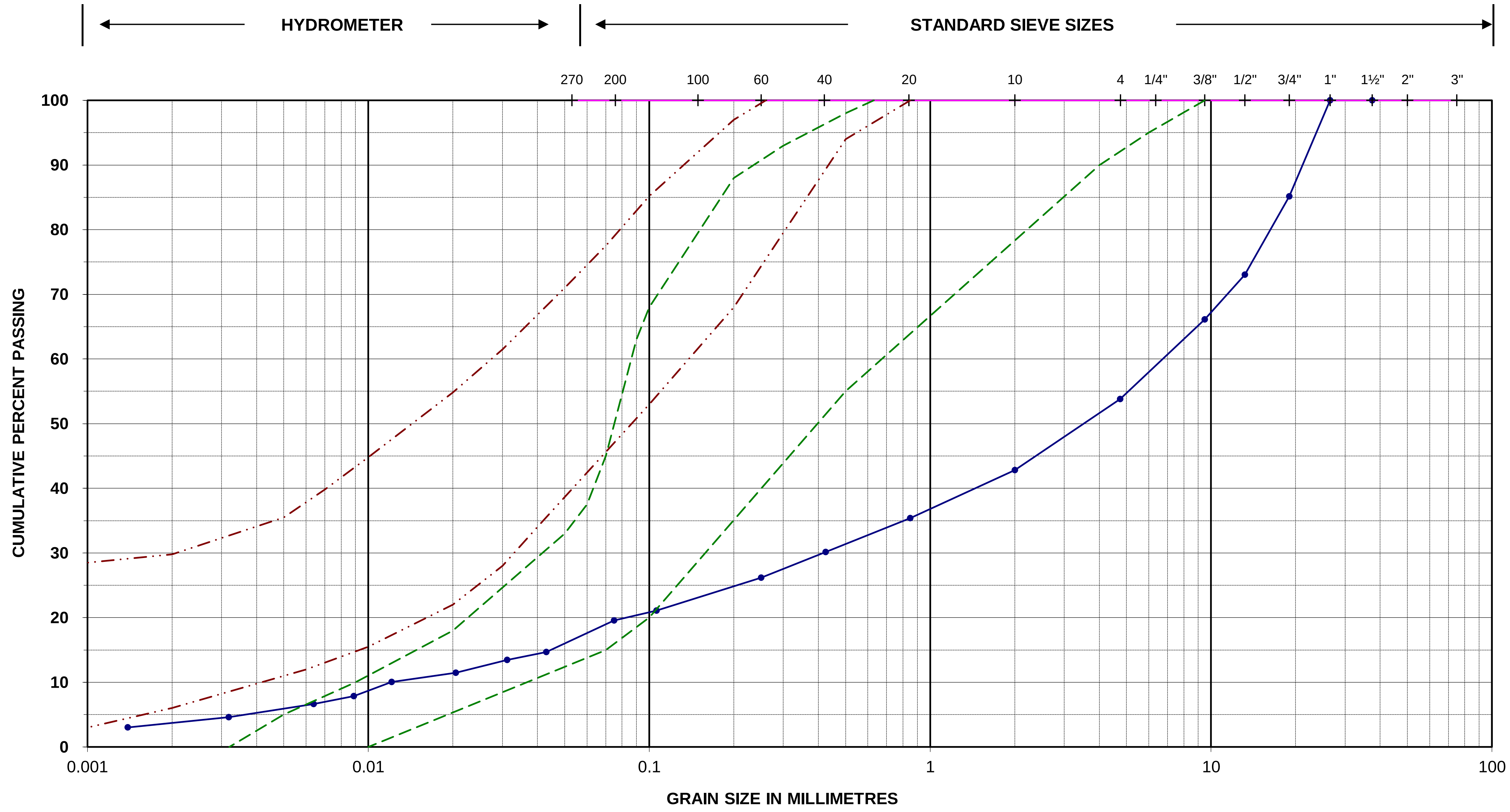
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**45**	**%**
SAND	**35**	**%**
SILT	**16**	**%**
CLAY	**4**	**%**

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - – ml envelope T = 20 - 50 min/cm

Estimated T = 19 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-08	**Sample No./Depth:**	SS-9

Sieve Size	% Passing Coarse	**Sieve Size**	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	42.79	**0.043**	14.7
26.5 mm	100.0	**0.850 mm**	35.4	**0.020**	11.4
19.0 mm	85.2	**0.425 mm**	30.2	**0.009**	7.8
13.2 mm	73.0	**0.250 mm**	26.2	**0.003**	4.6
9.50 mm	66.1	**0.106 mm**	21.1	**0.001**	3.0
4.75 mm	53.8	**0.075 mm**	19.6		

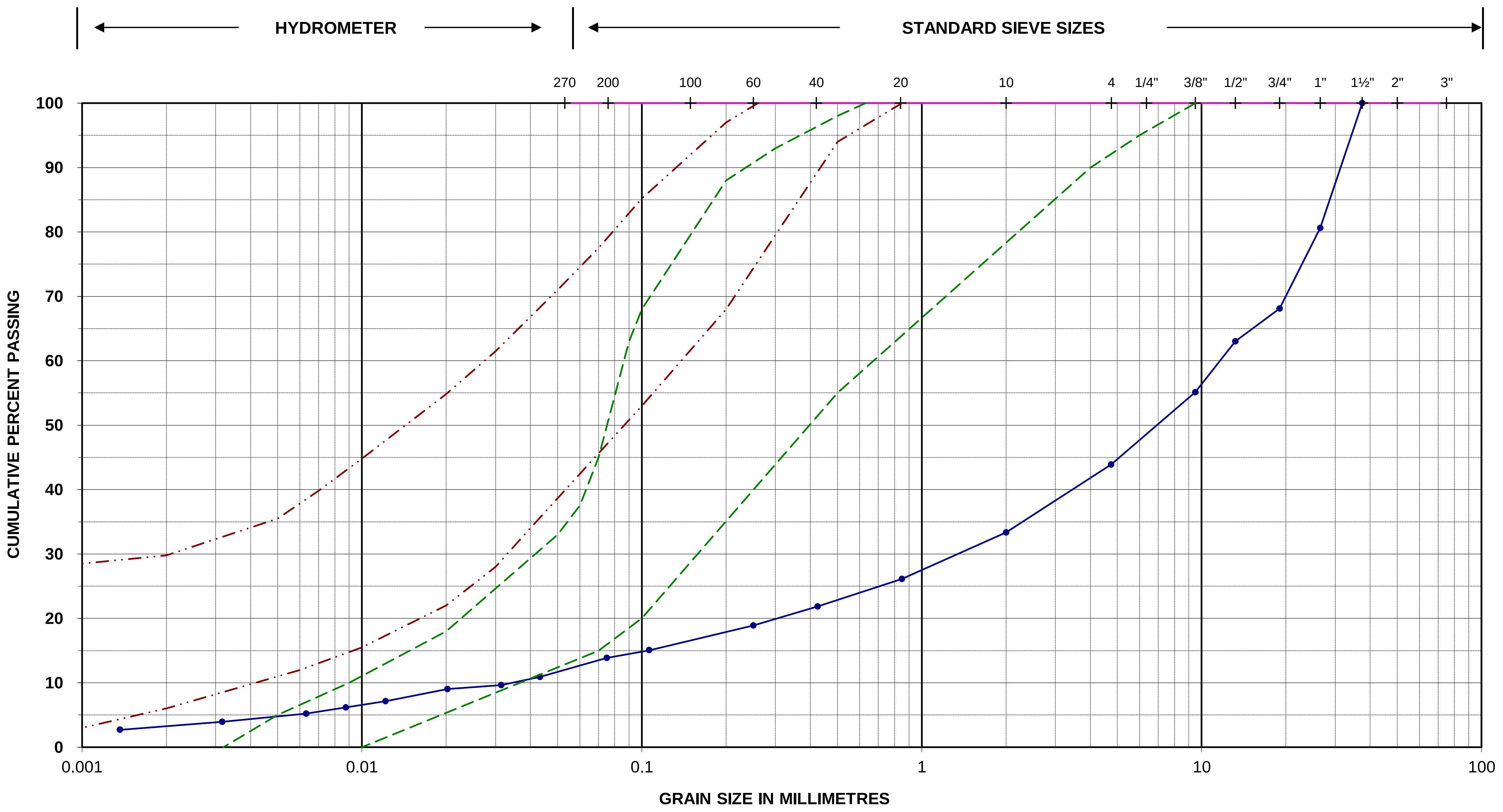
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 20-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	56	%
SAND	30	%
SILT	11	%
CLAY	3	%

------------------------ sm envelope T = 8 - 20 min/cm

— - - — - - — - — - ml envelope T = 20 - 50 min/cm

Estimated T = 20 min/cm

Project Name: Norwood Wells

Location ID.: BH21-09

Project No.: 201-07253-00 (7128)

Sample No./Depth: ST-9

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	33.36	**0.043**	10.9
26.5 mm	80.6	**0.850 mm**	26.1	**0.020**	9.0
19.0 mm	68.1	**0.425 mm**	21.8	**0.009**	6.2
13.2 mm	63.0	**0.250 mm**	18.9	**0.003**	4.0
9.50 mm	55.1	**0.106 mm**	15.1	**0.001**	2.7
4.75 mm	43.9	**0.075 mm**	13.8		

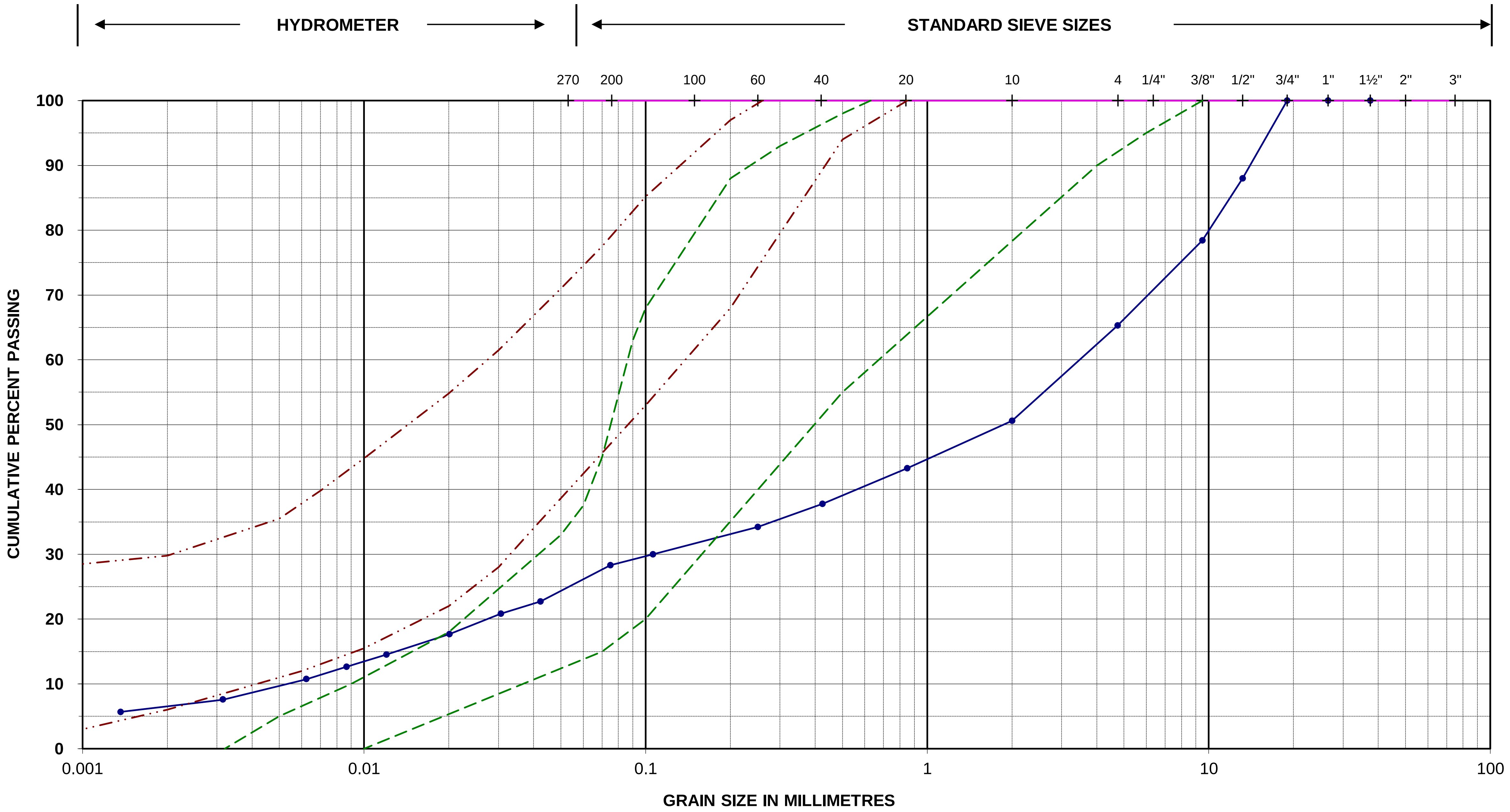
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 20-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	**34**	**%**
SAND	**38**	**%**
SILT	**22**	**%**
CLAY	**6**	**%**

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - – ml envelope T = 20 - 50 min/cm

Estimated T = 20 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-10	**Sample No./Depth:**	ST-7B

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	100.0	**2.00 mm**	50.60	**0.042**	22.7
26.5 mm	100.0	**0.850 mm**	43.3	**0.020**	17.7
19.0 mm	100.0	**0.425 mm**	37.8	**0.009**	12.6
13.2 mm	88.0	**0.250 mm**	34.2	**0.003**	7.6
9.50 mm	78.4	**0.106 mm**	30.0	**0.001**	5.7
4.75 mm	65.3	**0.075 mm**	28.3		

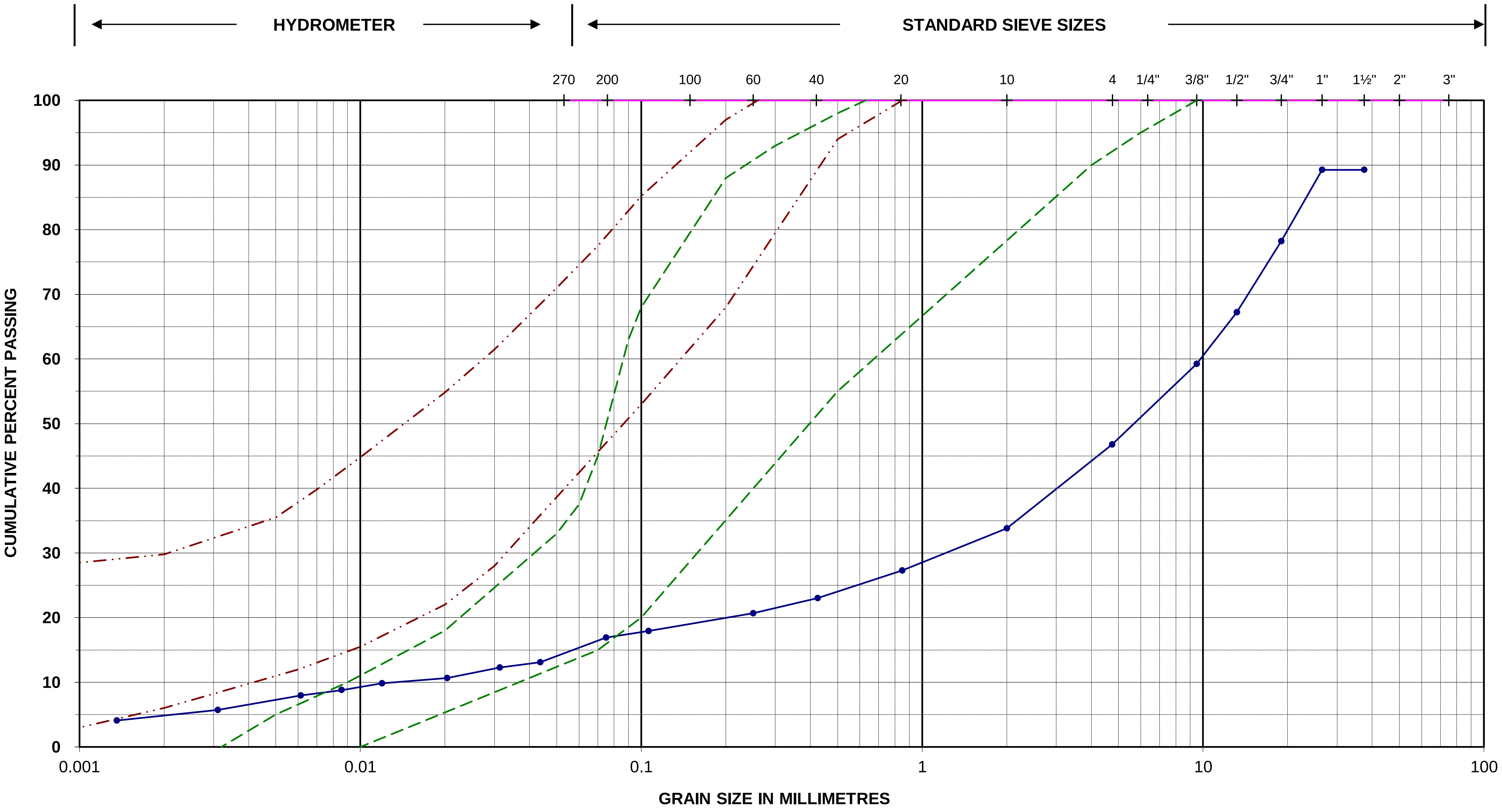
Note: More information is available upon request.

Tested by: NLO

Reviewed by:

Date: 19-Jan-22

PARTICLE SIZE DISTRIBUTION LS702/ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL

GRAVEL	53	%
SAND	35	%
SILT	7	%
CLAY	5	%

------------------------ sm envelope T = 8 - 20 min/cm

– - - – - - – - – ml envelope T = 20 - 50 min/cm

Estimated T = 20 min/cm

Project Name:	Norwood Wells	**Project No.:**	201-07253-00 (7128)
Location ID.:	BH21-10	**Sample No./Depth:**	ST-10

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
37.5 mm	89.2	**2.00 mm**	33.80	**0.044**	13.1
26.5 mm	89.2	**0.850 mm**	27.3	**0.020**	10.6
19.0 mm	78.2	**0.425 mm**	23.0	**0.009**	8.8
13.2 mm	67.2	**0.250 mm**	20.7	**0.003**	5.7
9.50 mm	59.3	**0.106 mm**	17.9	**0.001**	4.1
4.75 mm	46.8	**0.075 mm**	16.9		

Note: More information is available upon request.

Tested by: NLO Reviewed by: Date: 19-Jan-22

Appendix D

Geologic Cross-Sections

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

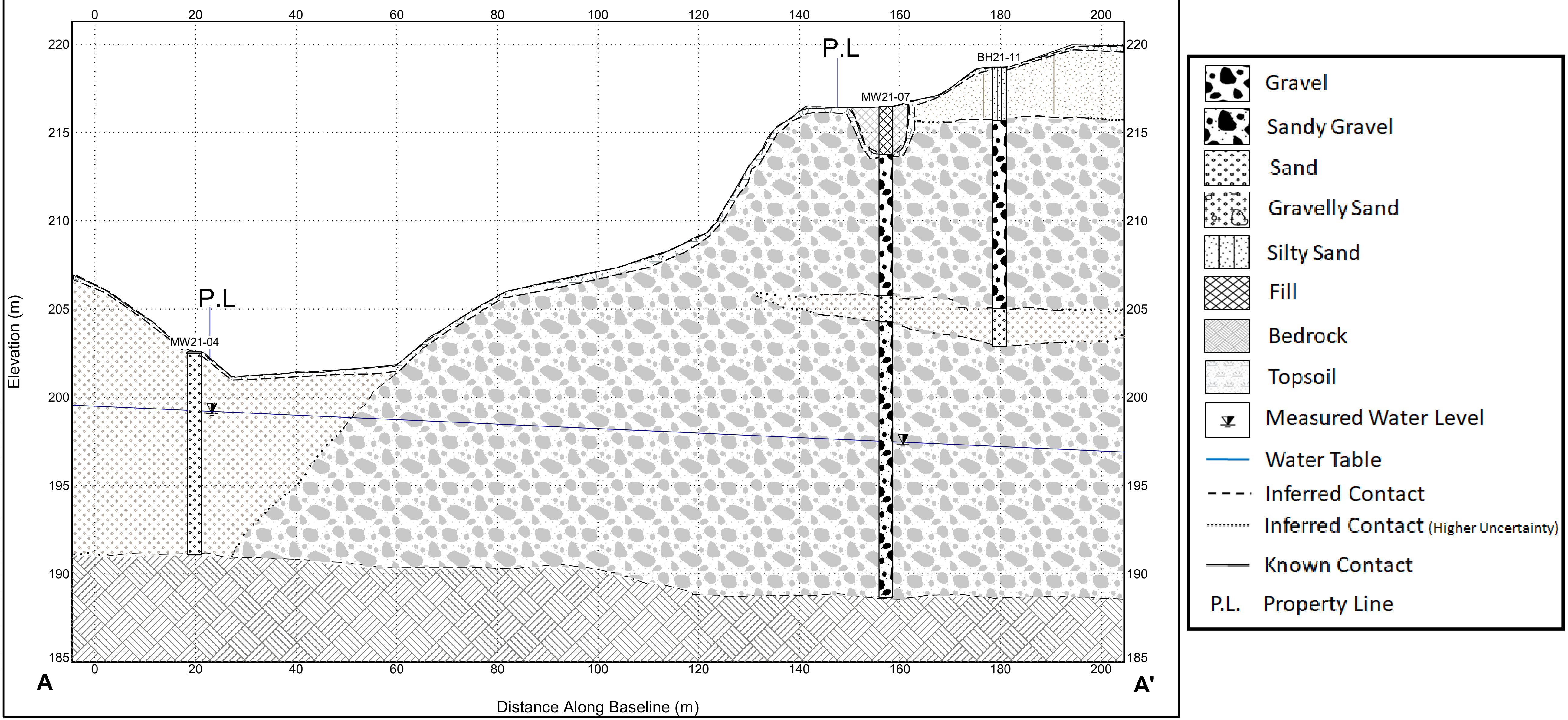
Cross Section A - A'

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

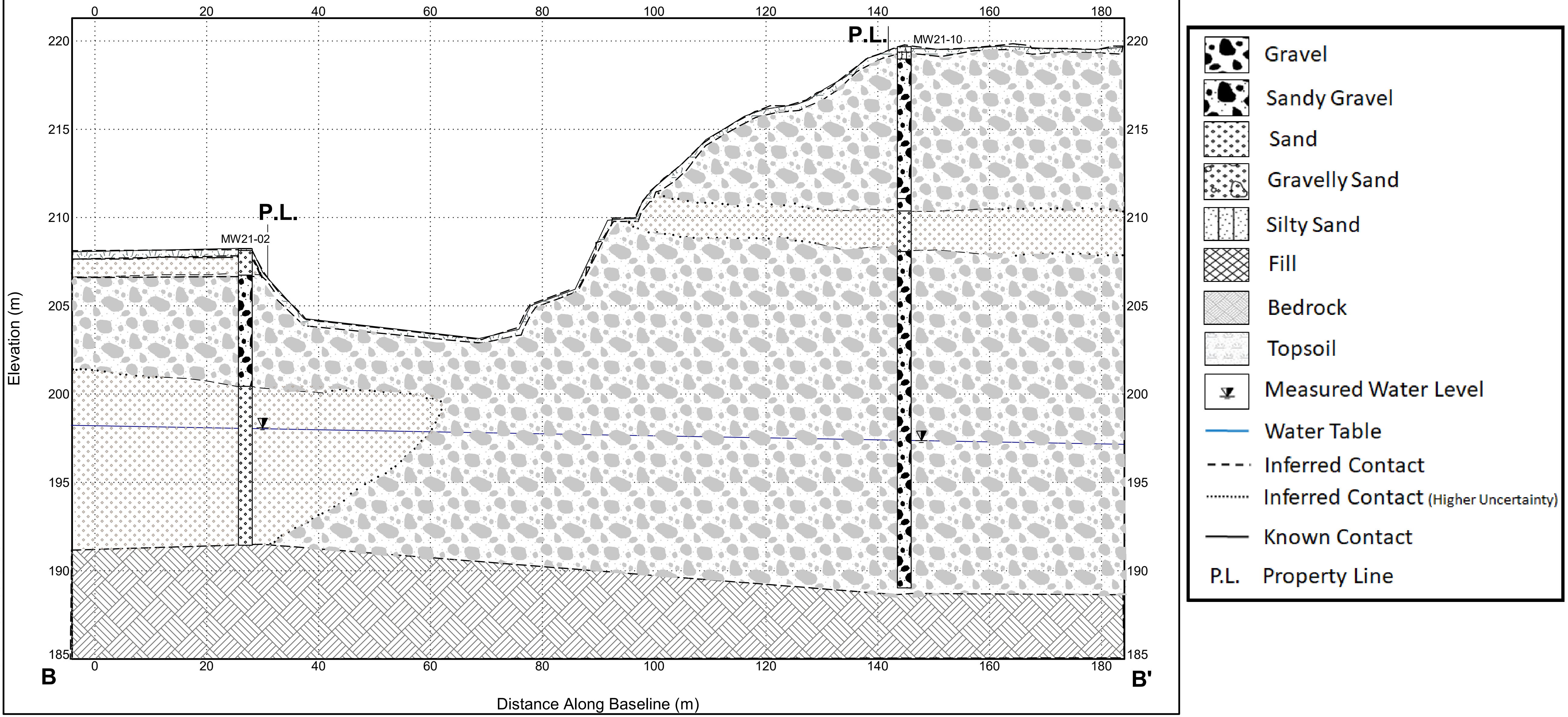
Cross Section B-B'

CLIENT Township of Asphodel-Norwood

PROJECT NUMBER 21-7128

PROJECT NAME Norwood Aquifer Capacity and Vulnerability

PROJECT LOCATION Norwood, Ontario



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

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

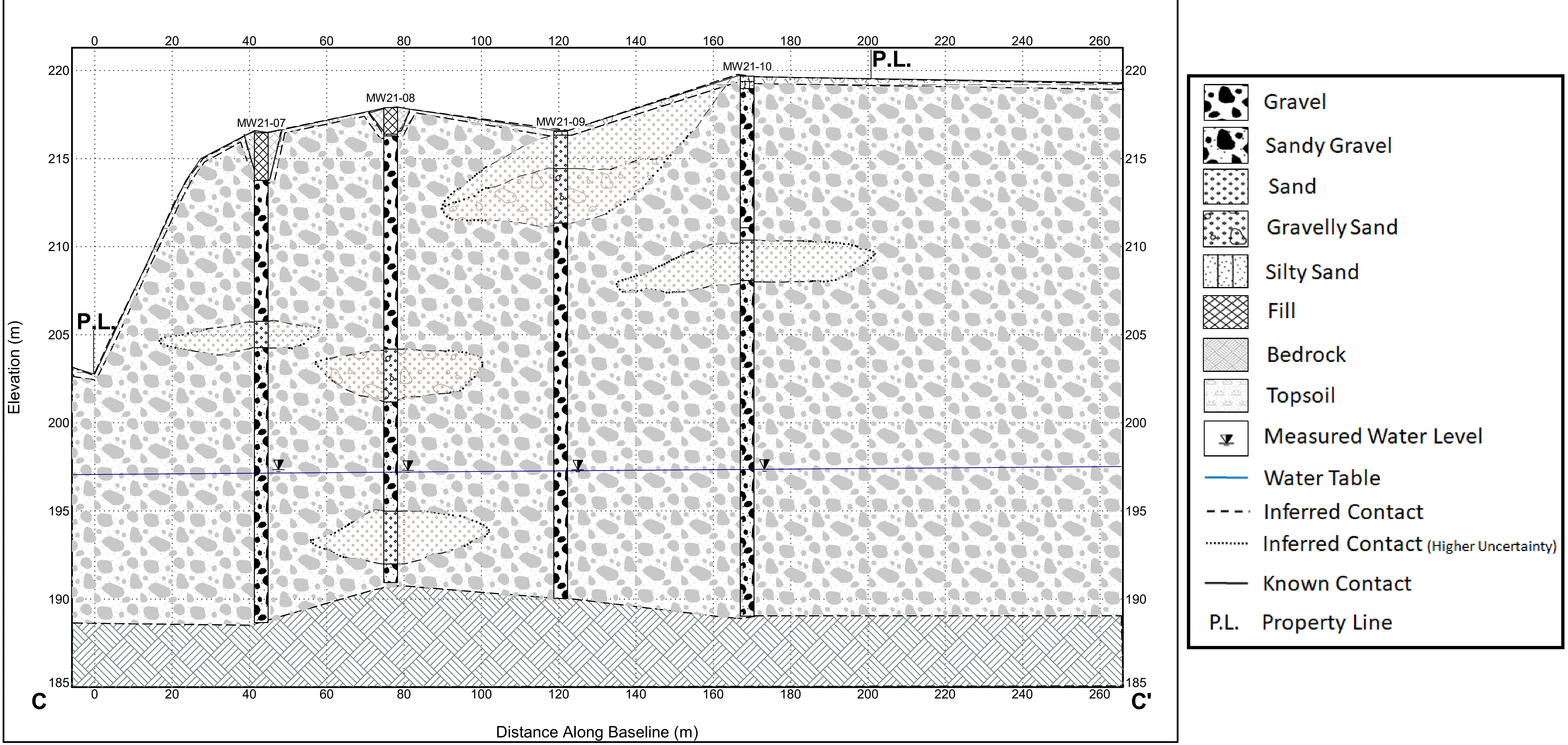
Cross Section C-C'

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 E

Pumping Tests – Observation Well Details

Appendix E - 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 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 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 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 F

Aquifer Parameter Results for Well 3 & Well 4

Appendix F - 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

Appendix G

Scope of Work – Proposed Development Lands Investigation

Appendix G

Scope of Work for Additional Investigation Requirements

Proposed Development Lands

- Review existing reports and maps, proposed subdivision detailed design drawings and material removal plans. Make informed predictions about the location of the flank/core contact.
- Site three boreholes to investigate the subsurface environment underlying the Proposed Development, and to facilitate the installation of monitor wells. Boreholes should be located to straddle the flank/core contact, more or less perpendicular to that contact, and should be terminated on the underlying bedrock (approx. 23 m to 30 m deep). Boreholes should be in locations that can be accessed by Municipal personnel or their consultants and maintained during the construction period and made available for long term water sampling.
- During drilling, collect soil samples for grain size analysis (every 1.5 m) using split spoon samplers and perform detailed logging of the borehole by an experienced professional.
- Install three 51 mm diameter PVC monitor wells consisting of a riser pipe and machine slotted screen within the saturated portion of the aquifer. Install tamper- proof, lockable protective casings and protective devices around the monitor wells if located in proposed vehicular traffic areas or in danger of being destroyed during construction. Develop the monitor wells by recognized methods and conduct hydraulic conductivity tests (either rising or falling head tests). If the water level rises or falls too fast to time accurately, perform constant head tests. Constant head tests will likely be required in the core deposits.
- Collect three water samples (spring, summer, and fall) from the individual monitor wells for chemical analysis. Water samples should be analyzed by an accredited laboratory for general chemistry parameters, petroleum hydrocarbons, and bacteria.
- Advance three boreholes in locations to be determined, to sample the surficial deposits and collect samples for grain size analyses, determine the location of the water table and the top of bedrock. Measure water levels

on the completion of drilling, abandon the boreholes by filling with bentonite.

- Survey the tops of monitor well casings and ground surface for accurate elevations and locations.
- Calculate hydraulic conductivities from grain size analyses and hydraulic testing.
- Prepare detailed logs for monitor wells and boreholes.
- Measure groundwater levels in the new monitor wells and in Municipal Water Supply Wells on the same day with each sampling event.
- Assess climate factors such a precipitation, infiltration evapotranspiration and runoff. Assess the effects of infiltration on the subsurface groundwater regime, including seasonal effects.
- Prepare a map of the piezometric surface showing groundwater flow directions.
- Prepare a map of the contact between the flank and core deposits, if these can be clearly defined. Prepare cross-sections across the Proposed Development and across the esker.
- Determine whether the Proposed Development is underlain by the flank or core deposits or both. If the flank/core contact is not found, complete the field program assuming the Proposed Development overlies the core of the esker.
- Enter the new data in the groundwater model and regenerate the WHPAs.
- If the Proposed Development is mostly over the flank deposits, prepare a report showing the results of the field investigations, calculations of hydraulic conductivity, interpreted subsurface geology, and the location of the Proposed Development in relation to the esker flank/core contact.
- If much of the Proposed Development overlies the core deposits of the esker, calculate unsaturated zone travel time (UZAT) and vulnerability zones for the Proposed Development after construction.