# 5 Hydrogeology

LVM, a division of EnGlobe Corp. (Englobe) was retained by Sunvest Development Corp. through IBI Group to prepare a hydrogeology study report as part of the Erbsville South Environmental Study. The scope of work for this hydrogeology study included a review of available geological and hydrogeological information for the Study Area and adjacent lands, and a subsurface investigation within the Study Area. The subsurface investigation was performed to identify the subsoil stratigraphy and hydrogeological properties, groundwater conditions and hydraulic gradients, and the relationship between groundwater and surface water features. It also included continuous monitoring of groundwater levels in proximity to wetlands, a review of regional groundwater levels, calculation of a pre-development site water balance, assessment of the potential for infiltration under post-development conditions, and an assessment of the potential for chloride impacts to shallow groundwater and surface water features as a result of the proposed development.

The specific objectives were to:

- assess the geological and hydrogeological conditions beneath the Study Area;
- calculate a pre-development site water balance;
- identify water users and sensitive areas within the Study Area; and,
- identify potential impacts and provide suggested mitigation measures.

Please note that Section 5 of the Erbsville Environmental Study is excerpted from Englobe Report No. 160-P-0002619-0300-HD-R-0001-01 (January 2017 as revised December 2017). The full report including all appendices is available as a separate document.

## 5.1 Physical Setting of the Study Area

### 5.1.1 Topography and Physiography

The Study Area is situated within the Waterloo Moraine, a distinctive relief feature in the region. The area is more locally known as the Waterloo Sand Hills physiographic region of Southern Ontario, and is within the Kame Moraines physiographic landform (Chapman and Putnam, 1984). The overburden deposits of the Waterloo Moraine typically form a hummocky landscape. The high point of the Study Area (approx. 357 mASL) is marked by an undulating topography.

A series of Grand River Conservation Authority (GRCA) delineated wetlands are found in the Study Area and Extended Study Area (see Figure 5.1). The Study Area generally slopes gently towards the wetlands, Wideman Creek, and Laurel Creek. A swampy floodplain covers most of the Extended Study Area. North of Schnarr Street and east of Erbsville Road the wetland is confined into a narrow channelized area. The low-lying wetland areas have elevations of approximately 346 mASL,

Adjacent to Wideman Road, a wetland area exists in a depression with surface elevations between 349.0 and 349.5 mASL. A wetland pocket also exists in the southeastern corner of the Study Area.

### 5.1.2 Climate

Waterloo Region's climate is characterized by variable annual temperatures and less variable total monthly precipitation. The average annual temperature is approximately 7.0°C, and the average total precipitation is 916.5 mm/yr. Precipitation is typically lower in the fall and winter months, and late spring months experience higher amounts of runoff due to the effect of winter snow melt. Table 5.1 below lists monthly average precipitation and temperature data; from the Waterloo Wellington Airport station (Latitude: 43°27'00" N Longitude: 80°23'00" W; Elevation: 317.00 m).

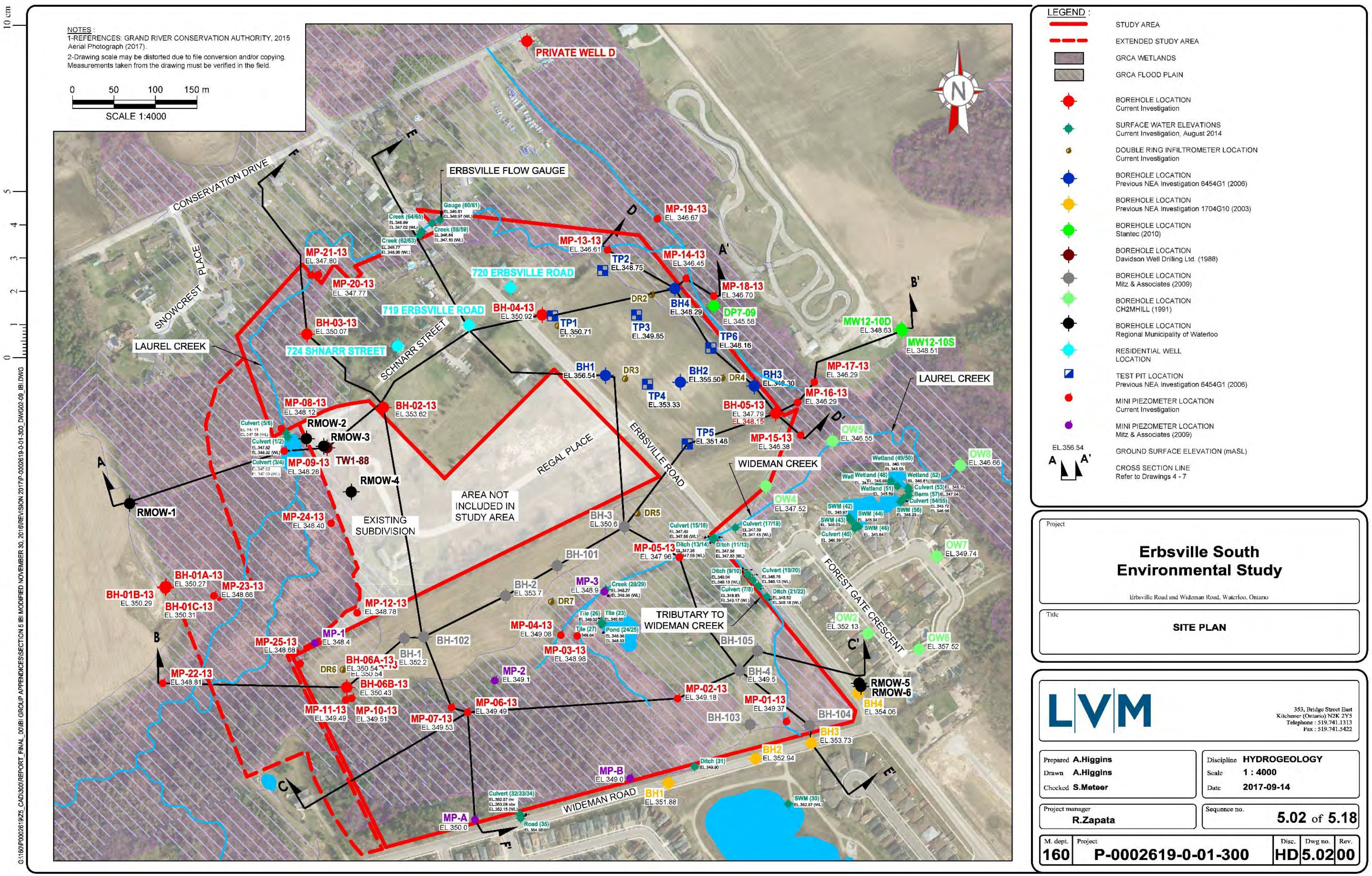


**Figure 5-1 Site Plan**

**Table 5.1 Monthly Climate Summary Data (1981 – 2010)**

| Month | Precipitation | Temperature |
|---|---|---|
| | (mm/year) | (deg. Celsius) |
| Jan | 65.2 | -6.5 |
| Feb | 54.9 | -5.5 |
| Mar | 61.0 | -1.0 |
| Apr | 74.5 | 6.2 |
| May | 82.3 | 12.5 |
| Jun | 82.4 | 17.6 |
| Jul | 98.6 | 20.0 |
| Aug | 83.9 | 18.9 |
| Sep | 87.8 | 14.5 |
| Oct | 67.4 | 8.2 |
| Nov | 87.1 | 2.5 |
| Dec | 71.2 | -3.3 |
| **Total** | 916.5 | -- |
| **Average** | -- | 7.0 |

### 5.1.3 Geology

#### *5.1.3.1 Overburden*

The Quaternary Geology Map of the Stratford Area (Karrow, 1993) indicates Maryhill Till and stratified ice-contact deposits are the most common overburden soils found within the Study Area, as depicted on the Figure 5.2. Organic deposits and Alluvium are found in association with wetland areas.

The Quaternary geology of the Study Area consists of interlobate moraine deposits which comprise the Waterloo Moraine. The materials were deposited during the Late Wisconsinan glacial episode, which ended 10,000 years ago. This episode corresponds to the last glacial period. The Waterloo Moraine was formed between the Huron-Georgian Bay and the Erie-Ontario ice lobes, as discussed by Karrow (1987), and Bajc and Shirota (2007).

These ice lobes made several advances and retreats during the Wisconsinan glaciation, which resulted in complex deposits of ice contact and glacial outwash sands and gravels separated by silt and clay rich tills.

The overburden deposits in the Study Area typically show discontinuous pinch-out layers at surface, as illustrated on the cross-sections on Figures 5.3 to 5.6, and are approximately 70 m thick.

The overburden consists of several lithostratigraphic units which are found regionally.
These units are described below in descending chronological order (starting with the youngest unit identified in the Study Area):

- Modern alluvial deposits and organic deposits associated with creeks and wetlands.
- Remnants of the Maryhill Till are found overlying the Upper Waterloo Moraine Deposits. This till is discontinuous, and is found in patches within the Study Area.
- The Upper Waterloo Moraine stratified sediments (and equivalents) are found overlying the Lower Maryhill Till. This deposit consists of mainly fine sands and sand and gravel deposits. Melt-waters from the glaciers built up large accumulations of gravel and sand, forming the Waterloo Sand Hills.
- The Lower Maryhill Till is found overlying the Catfish Creek Till, with intermittent Lower Waterloo Moraine stratified sediments (and equivalent). The Maryhill Till is a dense, dark brown, clayey silt to silty clay till.

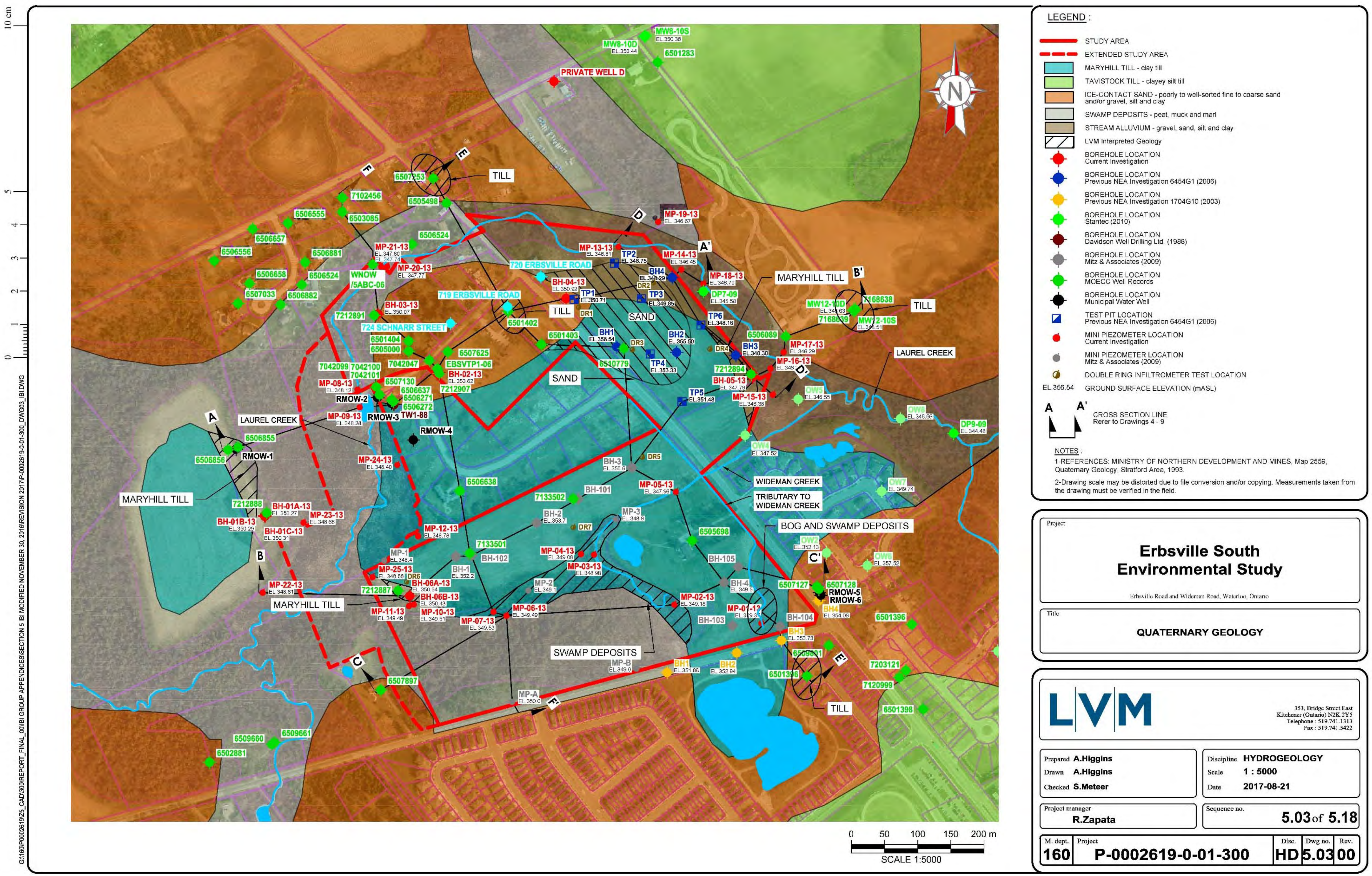


**Figure 5-2 Quaternary Geology**

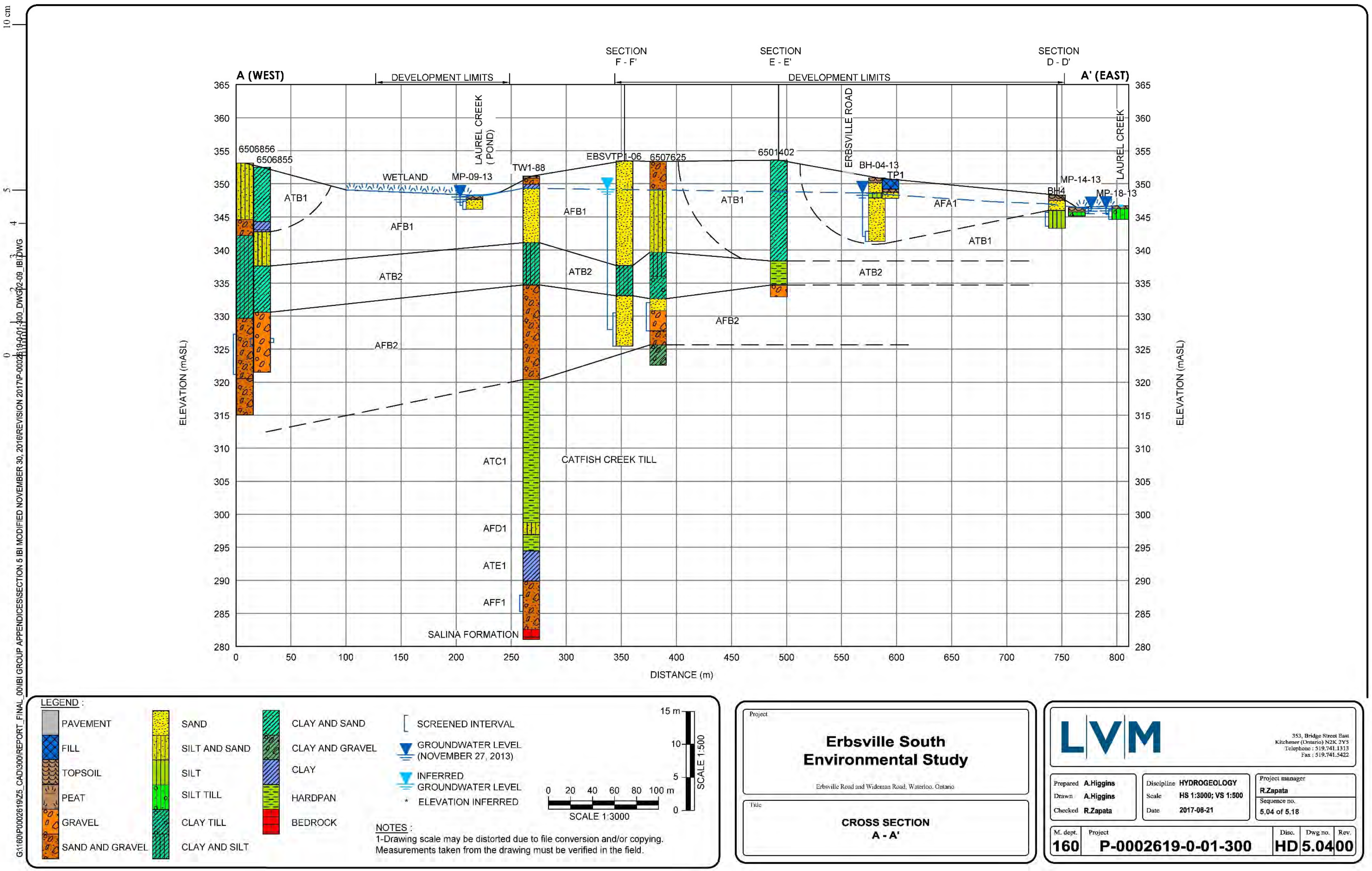


**Figure 5-3 Cross Section A-A'**

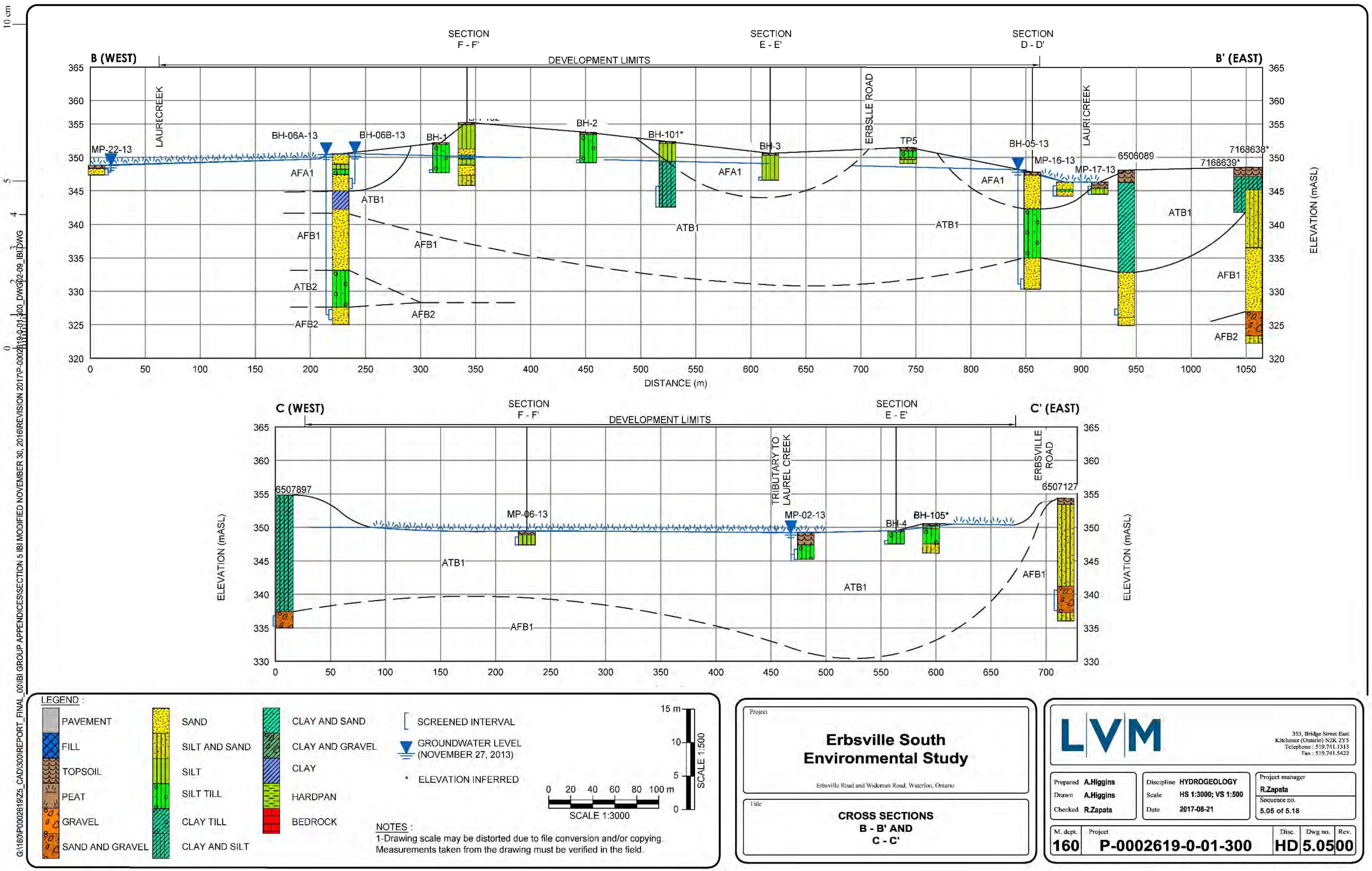


**Figure 5-4 Cross Sections B-B' and C-C'**

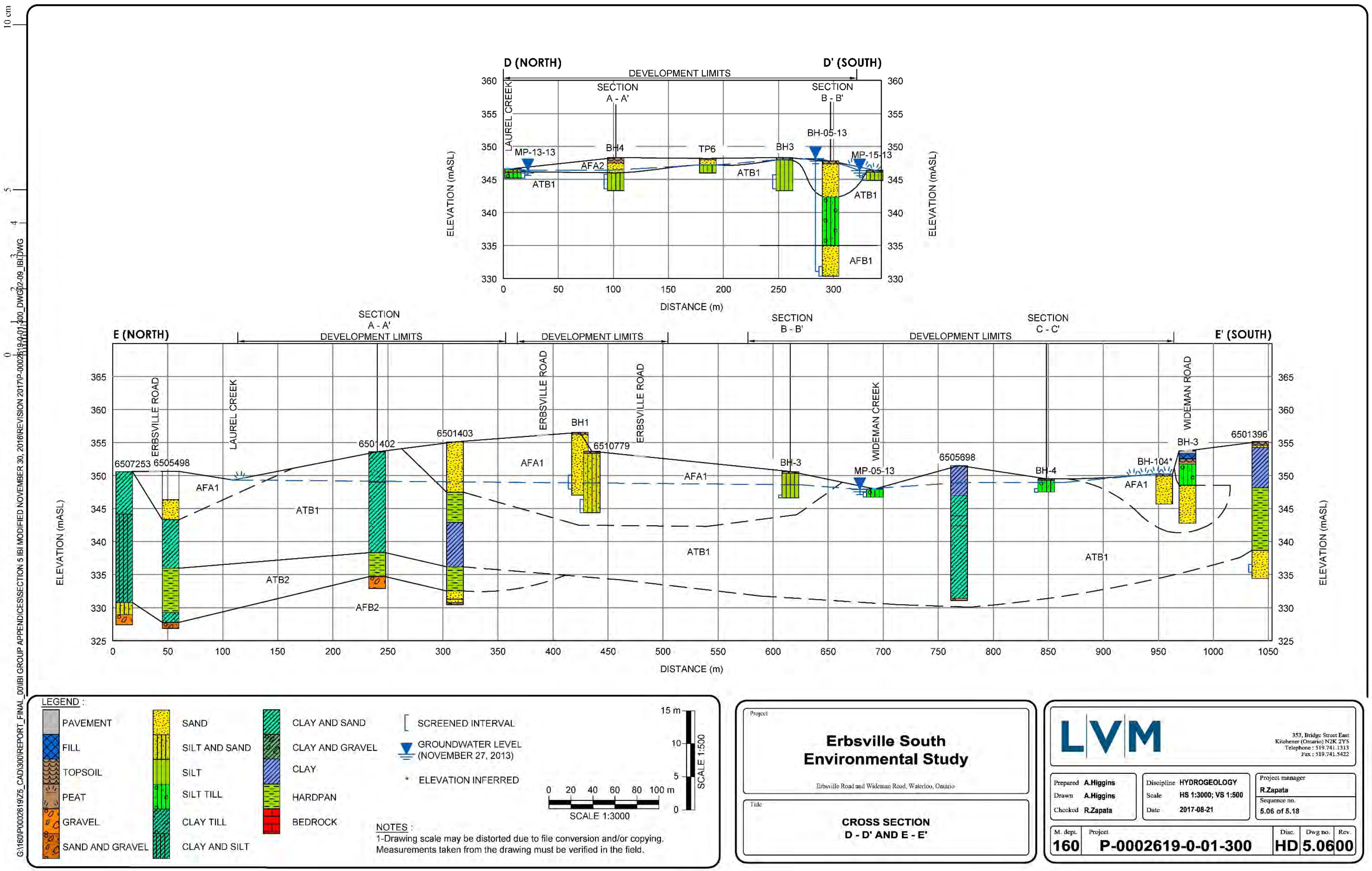


**Figure 5-5 Cross Section D-D' and E-E'**

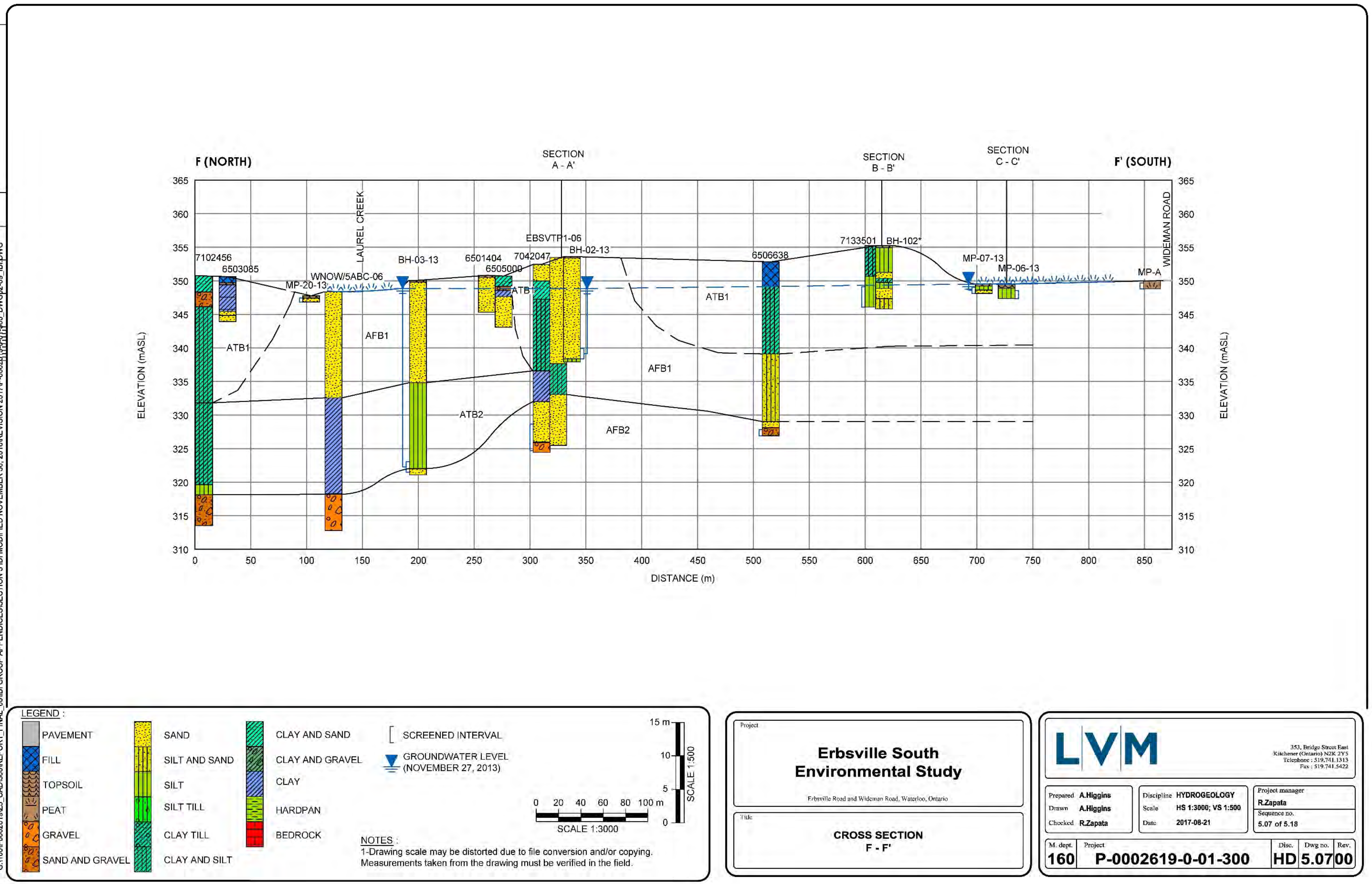


**Figure 5-6 Cross Section F-F'**

- The Catfish Creek Till is found overlying older Pre-Catfish Tills and bedrock, and is interpreted to be the first major stratigraphic marker throughout the moraine. The Catfish Creek Till is an extremely dense, stony, sandy silt to silt till. This till is commonly referred to as ''hardpan'' by drillers on well records. The Catfish Creek Till was laid down by a strong ice advance about 18,000 years ago.

#### *5.1.3.2 Bedrock*

The overburden is underlain by a major carbonate bedrock formation, the Salina Formation, which consists of grey-brown dolomite, grey and red shale, minor limestone, gypsum, anhydrite, and salt. The evaporite minerals indicate the Salina Formation was formed in shallow sea waters. The bedrock formation dates from the Upper Silurian Period, approximately 400 million years ago.

The Salina Formation is generally unlikely to be subject to karstification. Karstification is a process of limestone dissolution over time which increases the overall permeability of a limestone, and of a dolostone to a lesser extent.

### 5.1.4 Overburden Aquifer System

The regional hydrogeological context consists of stratified shallow and deep overburden aquifers overlying bedrock aquifers. In all aquifers, groundwater flow is generally towards the Grand River; however, adjacent to surface watercourses shallow (near surface) groundwater generally flows towards the watercourses; and in proximity to wellfields groundwater flows radially towards the pumping wells.

The hydrostratigraphy of the overburden soils is based on the conceptual hydrogeological model of the Waterloo Moraine developed by Bajc and Shirota (2007). This conceptual geological model consists of a sequence of eighteen overburden layers. Most layers are discontinuous and a few are found only at certain locations within the Waterloo Moraine. In the Study Area, six of the eighteen layers were identified, as shown on the cross sections on Figures 5.3 to 5.6.

Bajc and Shirota (2007) introduced a new naming convention for identifying these layers using acronyms: AT for aquitards and AF for aquifers. These acronyms are then followed by a sequential letter and a number as described hereafter.

The hydrostratigraphic units found within the Waterloo Moraine are listed in Table 5.2. It is noted that these eighteen hydrostratigraphic units are identified on a regional scale and only a subset are interpreted by Englobe and other consultants to exist within the Study Area.

**Table 5.2 OGS Regional Hydrostratigraphy**

| OGS Layer Name | Lithological Description | Predominant Materials | Hydrogeologic Classification |
|---|---|---|---|
| ATA1 | Whittlesey Clay | Silt and Clay | Aquitard |
| **AFA1** | **Recent alluvial deposits (originally described as Whittlesey Sand)** | **Very Fine to coarse sand** | **Aquifer** |
| ATA2 | Wentworth Till | Stoney, Sandy till | Aquifer/Aquitard |
| **AFA2** | **Outwash deposits** | **Sand** | **Aquifer** |
| ATA3 | Fine-grained Deposits | Sandy Silt and Silt | Aquitard |
| **ATB1** | **Tavistock Till**<br>**Upper Maryhill Till** | **Silty to Clayey Till**<br>**Silty to Clayey Till** | **Good Aquitard** |
| **AFB1** | **Upper Waterloo Moraine stratified sediments and Equivalents** | **Mainly fine Sand, some Gravel** | **Good Aquifer** |
| **ATB2** | **Middle Maryhill Till and Equivalents** | **Silty to Clayey Till, Silt, Clay** | **Poor Aquitard** |
| **AFB2** | **Middle Waterloo Moraine stratified sediments and Equivalents** | **Mainly fine Sand, some Gravel** | **Good Aquifer** |
| ATB3 | Lower Maryhill Till | Silty to Clayey Till | Good Aquitard |
| AFB3 | Lower Waterloo Moraine stratified sediments or Catfish Creek Outwash | Layered Gravel Sand or Silt | Poor to Good Aquifer |
| **ATC1** | **Upper/Main Catfish Creek Till** | **Stoney, silty to sandy Till** | **Good Aquitard** |
| AFC1 | Catfish stratified deposits | Stoney, silty to sandy Till | Good Aquitard |
| ATC2 | Lower Catfish Creek Till | Stoney, silty to sandy Till | Good Aquitard |
| **AFD1** | **Pre-Catfish Creek Sand and Gravel** | **Sand and Gravel** | **Good Aquifer** |

| OGS Layer Name | Lithological Description | Predominant Materials | Hydrogeologic Classification |
|---|---|---|---|
| **ATE1** | **Canning Drift (Pre-Catfish Creek Till)** | **Silty to Clayey Till, Silt, Clay** | **Good Aquitard** |
| **AFF1** | **Pre-Canning coarse-textured glaciofluvial / glaciolacustrine sediments** | **Sand and Gravel** | **Aquifer** |
| ATG1 | Pre-Canning coarse-textured Till | Stoney, silty to sandy Till | Aquitard |

Note: Bajc, A.F. and Shirota, J. 2007. *Three-dimensional mapping of surficial deposits in the Regional Municipality of Waterloo, Southwestern Ontario*; report. Ontario Geological Survey, Groundwater Resources Study 3, 42p.

The absence of certain hydrostratigraphic units within the Study Area could be due to some units forming localized deposits, or some units being eroded away after deposition, and potentially misidentification of some units within the Study Area during field reconnaissance.

The hydrostratigraphic units listed below from youngest to oldest are interpreted to be represented within the Study Area:

- **Aquifer – AFA1:** AFA 1 corresponds to rent alluvial deposits consisting of sand and silt. This unit is discontinuous within the Study Area, as shown on Figures 5.3 to 5.6.
- **Aquitard 1 – ATB1:** The Maryhill Till is identified as ATB1, an aquitard consisting of low permeability soils. This aquitard is laterally discontinuous, as shown on Figures 5.3 to 5.6.
- **Aquifer 1 – AFB1:** This deposit corresponds to the Upper Waterloo Moraine stratified sediments and equivalents. It represents the shallow overburden aquifer found within the Study Area, and consists of layered silty sand and sand deposits. This Shallow Overburden Aquifer is generally unconfined, and exposed at the ground surface in some areas, as shown on Figures 5.3 and 5.6.
- **Aquitard 2 – ATB2:** This unit corresponds to the Middle Maryhill Till and equivalents, as shown on Figures 5.3 to 5.6. The Middle Maryhill Till represents a confining unit that separates Shallow from Deep Overburden Aquifer. This aquitard bisects the Waterloo Moraine stratified sediments into an upper AFB1 and a middle AFB2 aquifer unit. Hydraulic windows between AFB1 and AFB2 are possible where ATB2 is discontinuous.
- **Aquifer 2 – AFB2:** This deposit corresponds to the Lower Waterloo Moraine stratified sediments and equivalents. It represents the Deep Overburden Aquifer found within the Study Area, and also consists of layered silty sand and sand deposits. This overburden aquifer is not exposed at the ground surface, as shown on Figures 5.3 to 5.6. The Deep Overburden Aquifer is confined.
- **Aquitard 3 – ATC1:** This regional aquitard corresponds to the Catfish Creek Till, as shown on Figure 5.3.

When considered on a larger scale, the Study Area hydrostratigraphy generally consists of an overburden system of aquitards (till deposits) interbedded with aquifers (comprised of mainly sand deposits). This overburden system overlies bedrock.

Within the Study Area, shallow groundwater generally flows towards Laurel Creek and discharges into the creek. Recharge of the shallow groundwater (through infiltration of precipitation) occurs more intensely within an identified sand pocket around Schnarr Street. A portion of infiltrated recharge seeps downwards to the deep overburden aquifer, while some recharge becomes part of the shallow groundwater table and flows laterally towards more localized discharge points. Groundwater flow in the shallow overburden is shown on the groundwater contour plan on Figure 5.7, as well as on cross sections on Figures 5.3 to 5.6. Groundwater levels in mini-piezometers were used to support the interpretation of the inferred groundwater table. The soils below the inferred froundwater table are assumed to be continuously saturated; no present field observations indicate otherwise. Figure 5.8 shows the composite groundwater contour high for the highest measured water levels measured on different dates between November 2013 and November 2014.

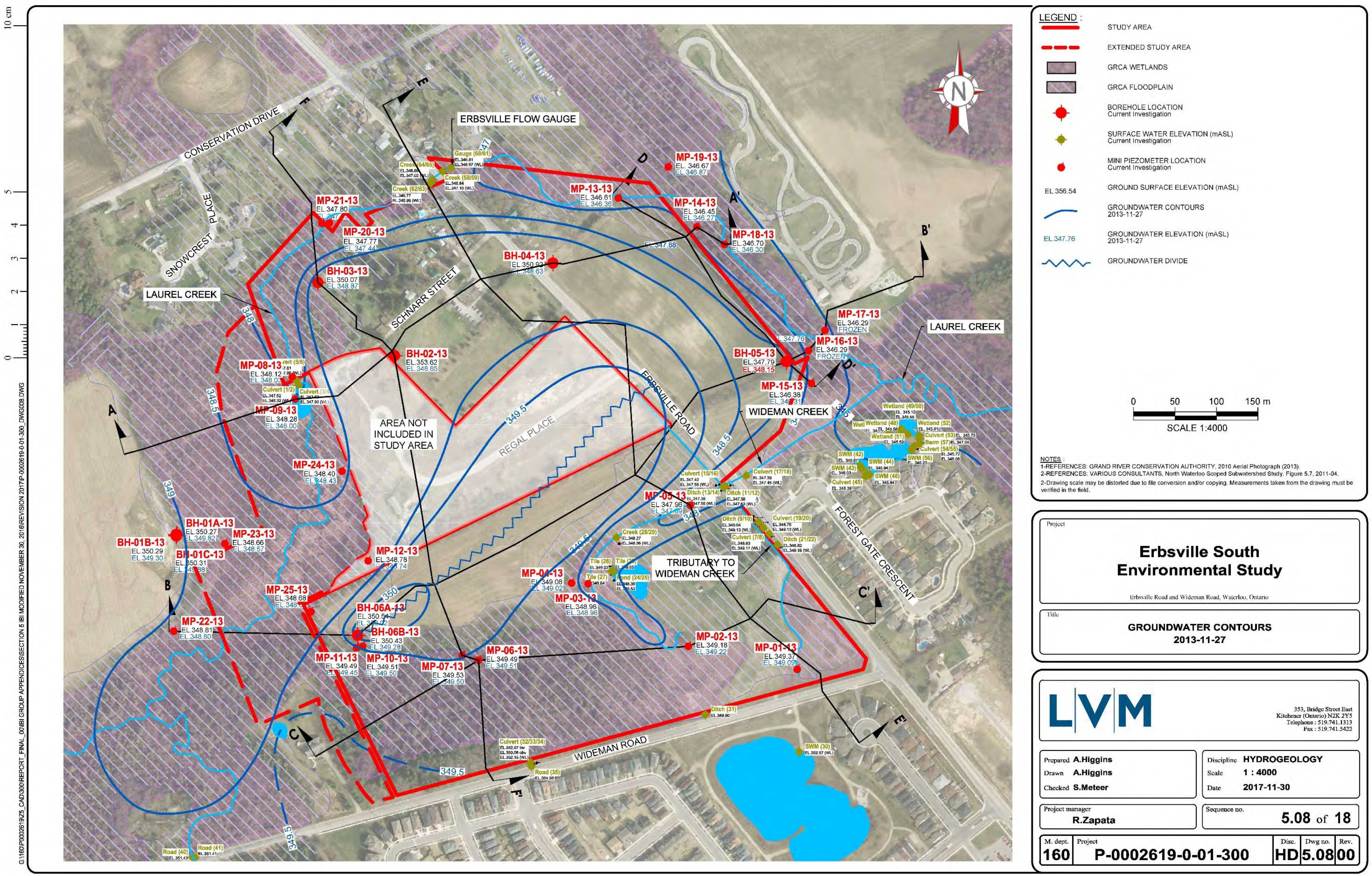


Figure 5-7 Groundwater Contours

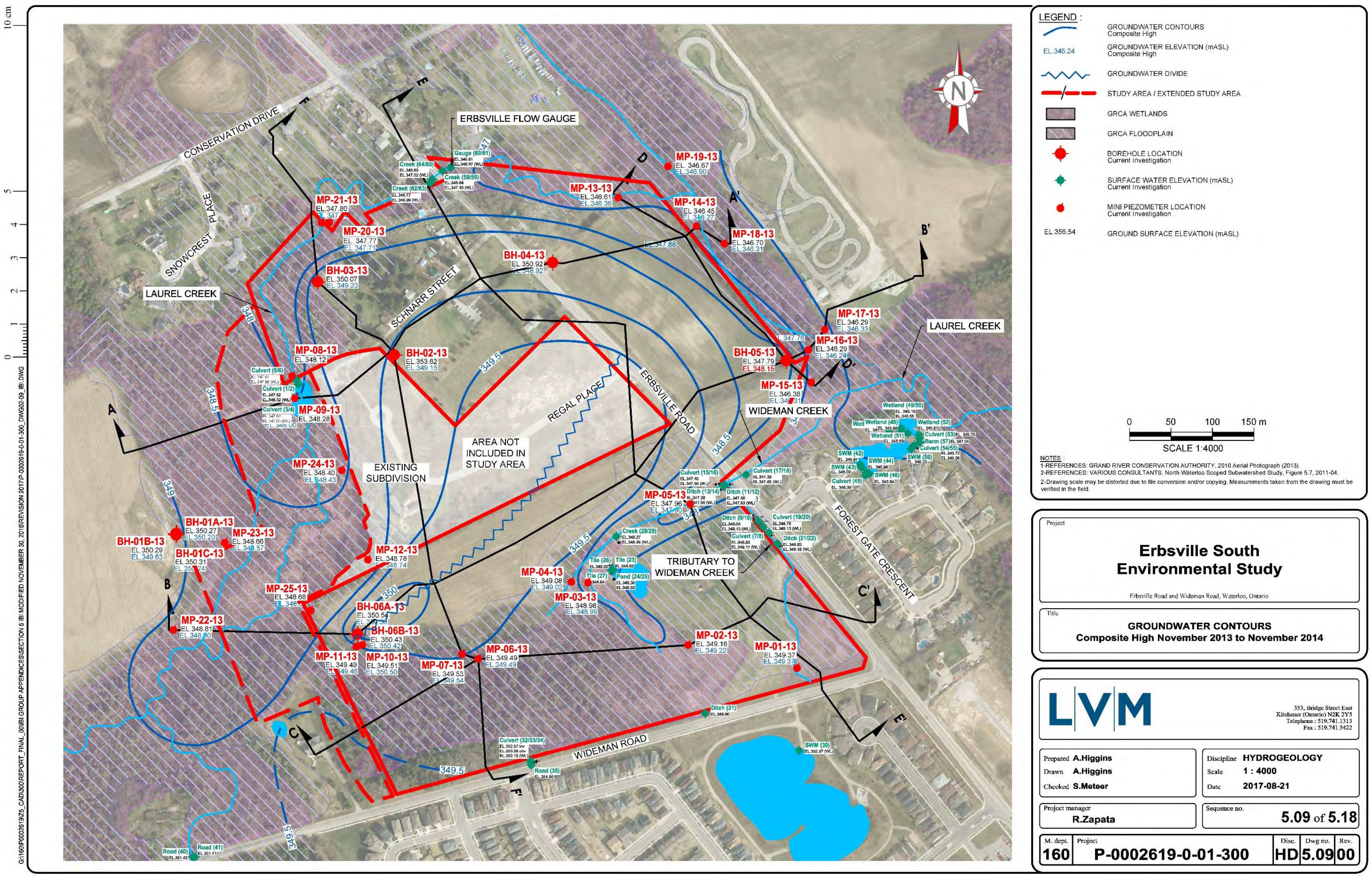


**Figure 5-8 Groundwater Contours – Composite High**

### 5.1.5 Watershed

The Laurel Creek watershed has an area of approximately 74 $km^2$ within the Regional Municipality of Waterloo, and is characterized by many land use types. Urban land use consists of a broad range of types including high to low density residential, industrial, commercial and institutional. An upper portion of the watershed consists mostly of agricultural land use, with considerable woodlots and wetlands. The majority of the Laurel Creek watershed is located within the City of Waterloo, but it also reaches into the Townships of Wellesley, Wilmot, and Woolwich, and the City of Kitchener (GRCA, 2004).

#### *5.1.5.1 Laurel Creek*

Laurel Creek drains the Waterloo Moraine from west to east, and discharges into the Grand River in Bridgeport after having passed a series of surface water bodies (Laurel Creek Reservoir, Columbia Lake, Laurel Lake, and Silver Lake). The Creek drains most of the lands within the City of Waterloo, and much of the watershed is highly urbanized (GRCA, 2004). Laurel Creek and its tributaries have a total length of approximately 47 km. The Grand River is located approximately 9.5 km east of the Study Area.

At the headwaters of Laurel Creek and west of the Study Area is Sunfish Lake, which is a small kettle lake (25 hectare), and the principal source of Laurel Creek at approximately 357 mASL.

Laurel Creek enters forested and wetland areas of the Extended Study Area at approximately 349 mASL. Then it flows within a well-defined channel feature across the Extended Study Area, and along the northern and northeastern Study Area border with an approximate average gradient of 0.24%. Forested and wetland areas surround the Creek. The stream exits the Study Area at approximately 345 mASL. Wideman Creek drains a wetland south of the Study Area before discharging into Laurel Creek, east and beyond the Study Area.

Laurel Creek is a stream of low gradient downstream of the Erbsville flow gauge. The Creek flows predominantly through woodlands, and is heavily influenced by large woody debris. The Creek channel was modified at the Erbsville Road culvert (2.4m x 5m). Beaver dams creating backwater have been identified along the reach between Erbsville Road and the merging point between Laurel Creek and Wideman Creek (reach LC-1 in Parish, 2011). A Rapid Geomorphological Assessment (RGA) indicated that the reach between Erbsville Road and the merging point between Laurel Creek and Wideman Creek is either “Transitional or Stressed”. This means that the channel morphology is within the range of variance for streams of similar hydrographic characteristics but the evidence of instability is frequent.

A Rapid Stream Assessment Technique (RSAT) survey indicated that reaches within the Study Area are in a moderate condition in terms of overall stream health (channel stability, erosion/deposition, in-stream habitat, water quality, riparian condition, and biological indicators).

Downstream of the Study Area, Laurel Creek discharges into Laurel Creek Reservoir that controls seasonal flows within the watershed. The emergency spillway elevation of Laurel Creek Reservoir is 343.2 mASL. Throughout the late spring and summer months the Laurel Creek Reservoir is maintained at the constant regulated water level of 342.4 mASL (GRCA, 2004).

#### *5.1.5.2 Baseflow*

Flow in a watercourse is comprised of direct runoff and baseflow. Direct runoff corresponds to surface water drainage resulting from precipitation events. Baseflow corresponds to groundwater discharge to the watercourse, and is more constant in terms of flow rate than direct runoff peaks. It is important to consider; however, that not all groundwater discharges as baseflow to any particular watercourse, and a portion of groundwater may never discharge to the ground surface. This lateral and/or vertical component of groundwater flow maintains saturation of the aquifer(s) beneath the ground surface.

During periods of precipitation, the proportion of direct runoff to baseflow in a watercourse increases temporarily as the pulse of precipitation runoff migrates into the watercourse.

Within the Study Area, the larger portion of recharge is expected to become local baseflow. Regional baseflow contributions originated west of the Study Area are inferred to be a small quantity. A quantitative assessment would require monitoring water levels in multi-level wells and baseflow measurements along the creeks.

Continuous flow is measured at the Erbsville flow gauge by the GRCA. Flow measured on January 24, 2014 (interpreted to represent baseflow) was 430 L/sec (GRCA provisional online data).

Both Laurel Creek and Wideman Creek are classified as cold water streams. The reach immediately downstream of the Study Area (and upstream of the reservoir) has been identified as a source for groundwater discharge, supplying baseflow to the Creek and its associated wetland features (City of Waterloo & Grand River Conservation Authority, 1993).

#### *5.1.5.3 Wetlands*

Figure 5.1 shows GRCA delineated wetland areas on, and in proximity to, the Study Area. A total of 13.9 hectares of GRCA delineated wetlands are found within the Study Area and the Extended Study Area, comprising roughly 39.4 % of their total area. Approximately 29.4% of the Study Area and 88.3% of the Extended Study Area are comprised of forested and wetlands areas. The wetlands are sustained by runoff and shallow groundwater discharge. The wetlands within the Study Area form part of the Sunfish Lake – Laurel Creek Provincially Significant Wetland Complex.

Four main wetland areas are differentiated as follows:

- Swampy floodplain influenced by Laurel Creek, often during the spring melt period, covers most of the Extended Study Area. This wetland locally recharges to the Shallow Overburden Aquifer;
- Wetland confined into a narrow channelized area, north of Schnarr Street and east of Erbsville Road;
- Swampy wetland in a low-lying area, in the southern portion of the Study Area and adjacent to Wideman Creek; and,
- A small wetland pocket next to Wideman Creek Tributary in the southeastern corner of the Study Area.

The last three wetlands are considered discharging wetlands, supported by discharge from the Shallow Overburden Aquifer and by runoff. The delineated wetlands lie within the GRCA floodplain as expected, and as shown on Figure 5.1.

## 5.2 Hydrogeological Study Methodology

The study methodology involved a number of tasks, which included:

- review of topographic, geological, and hydrogeological reports for the area; Region of Waterloo groundwater monitoring data; the Ontario Ministry of the Environment and Climate Change (MOECC) Water Well Record (WWR) database; and GRCA information and data;
- drilling of nine boreholes, completed as 50 mm monitoring wells, for investigation of subsurface stratigraphy and hydrogeology;
- installation of twenty-five mini-piezometers around the wetland areas within and in proximity to the Study Area;
- collection of soil samples for moisture content analysis, and for particle size distribution analysis;
- performance of single response in-situ (slug) tests in the monitoring wells to determine hydraulic conductivity values of the water-bearing deposits;
- measurement of groundwater levels to establish the horizontal gradient and flow direction; and,
- performance of double-ring infiltration tests.

### 5.2.1 Review of Previous Studies

The review of previous studies for the Erbsville Study Area included the following reports:

- CH2M HILL Engineering Ltd. 1991. Detailed Hydrogeological Investigation – Beechwood West, Neighbourhood Four, Waterloo. Final Report.
- Ecoplans, MHBC & Stantec. 2013. North Waterloo – Scoped Subwatershed Study.

- Golder. 2011. Waterloo North Water Supply Class Environmental Assessment - Hydrogeological and Natural Environment Report.
- Mitz & Associates Inc. Hydrogeological Study Report - Michael Property; Waterloo, Ontario.
- Naylor Engineering Associates. 2003. Wideman Road Sanitary Sewer – Wideman Road and Erbsville Road, Waterloo, Ontario. Project Number 1704G10.
- Naylor Engineering Associates. 2006. Simpson Lands Residential Subdivision – 720 Erbsville Road, Waterloo, Ontario. Project Number 6454G1.

### 5.2.2 Field Program

#### *5.2.2.1 Borehole Drilling*

The current field program involved the advancement of nine boreholes (Boreholes BH-01A-13, BH-01B-13, BH-01C-13, and BH-02-13 to BH-05-13, BH-06A-13, and BH-06B-13) to depths ranging from 4.57 to 26.36 m to identify the subsurface soil and groundwater conditions at the locations shown on Figure 5.1. It is noted that several boreholes are “nested” as they are drilled to different depths at the same location. The boreholes were advanced between October 18 and November 18, 2013 by Geo-Environmental Drilling Inc. under the full-time observation of a senior technician from LVM using a CME-75 track-mounted drill-rig equipped with continuous flight hollow stem augers.

Soil samples were recovered from the boreholes at regular 0.75 and 1.50 m depth intervals using a 50 mm diameter split-spoon sampler in accordance with the Standard Penetration Test (SPT) procedure (ASTM D1586). Soil samples obtained from the boreholes were submitted for moisture content analysis and physical testing. The laboratory results for moisture content are included on the borehole logs in Appendix 5.1.

#### *5.2.2.2 Surveying*

The borehole, mini piezometer, and ground surface elevations were surveyed by IBI Group and supplied to LVM in CAD format. It is understood that the elevations are related to a geodetic datum. A series of surface water elevations and hydraulically relevant locations were surveyed by LVM, and are depicted on Figures 5.1 and 5.8. Table 5.3 contains the complete list of surveyed locations.

#### *5.2.2.3 Monitoring Well and Mini-Piezometer Installations*

During the borehole drilling program, monitoring wells were installed in the boreholes for measurement of groundwater levels and saturated soil hydrogeological parameters.

The 50 mm diameter monitoring wells were constructed by inserting slotted, Schedule 40 PVC well screen and riser pipe into the open auger holes. Sand was added in order to place a filter pack around the screen, until the level of the sand was approximately 300 mm above the top of the screen. Bentonite seals were then placed above the sand pack to prevent the infiltration of surface water. The tops of all the well riser pipes were vented to allow accurate measurement of stabilized groundwater levels, and protective steel casings with lockable covers were concreted in place to house each of the monitoring wells. Details of the monitoring well installations and soil and groundwater conditions encountered are provided on the borehole logs included in Appendix 5.1. Test pit logs from previous LVM reports are also included in Appendix 5.1 for reference.

## Table 5.3 Measured Groundwater Elevations

| Borehole Name | Ground Surface Elevation (mASL) | Top of Pipe Elevation (mASL) | Stickup (m) | 27-Nov-13 | | | 27-Feb-14 | | | 20-May-14 | | | 15-Aug-14 | | | 14-Nov-14 | | | MAXIMUM RECORDED VALUES | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Depth to WL (mBTOP) | WL Elev. (mBGS) | WL Elev. (mASL) | Depth to WL (mBTOP) | WL Elev. (mBGS) | WL Elev. (mASL) | Depth to WL (mBTOP) | WL Elev. (mBGS) | WL Elev. (mASL) | Depth to WL (mBTOP) | WL Elev. (mBGS) | WL Elev. (mASL) | Depth to WL (mBTOP) | WL Elev. (mBGS) | WL Elev. (mASL) | High Groundwater Elevation (Manual) | Date Measured | High Groundwater Elevation (Datalogger) | Date Measured |
| BH-01A-13 | 350.27 | 351.22 | 0.95 | 1.40 | 0.45 | 349.82 | 1.71 | 0.76 | 349.51 | 1.31 | 0.36 | 349.91 | 1.57 | 0.62 | 349.65 | 1.48 | 0.53 | 349.74 | 349.91 | 20-May-14 | 350.20 | 15-Apr-14 |
| BH-01B-13 | 350.29 | 351.29 | 1.00 | 1.99 | 0.99 | 349.30 | 2.23 | 1.23 | 349.06 | 1.84 | 0.84 | 349.45 | 2.00 | 1.00 | 349.29 | 2.02 | 1.02 | 349.27 | 349.45 | 20-May-14 | 349.63 | 8-Apr-14 |
| BH-01C-13 | 350.31 | 351.11 | 0.80 | 1.23 | 0.43 | 349.88 | 1.56 | 0.76 | 349.55 | 1.15 | 0.35 | 349.96 | 1.42 | 0.62 | 349.69 | 1.33 | 0.53 | 349.78 | 349.96 | 20-May-14 | 350.24 | 15-Apr-14 |
| BH-02-13 | 353.62 | 354.37 | 0.75 | 5.52 | 4.77 | 348.85 | 5.92 | 5.17 | 348.45 | 5.42 | 4.67 | 348.95 | 5.78 | 5.03 | 348.59 | 5.76 | 5.01 | 348.61 | 348.95 | 20-May-14 | 349.15 | 20-Apr-14 |
| BH-03-13 | 350.07 | 351.05 | 0.98 | 2.18 | 1.20 | 348.87 | 2.45 | 1.47 | 348.60 | 2.04 | 1.06 | 349.01 | no access | no access | no access | 2.26 | 1.28 | 348.79 | 349.01 | 20-May-14 | 349.23 | 8-Apr-14 |
| BH-04-13 | 350.92 | 351.63 | 0.71 | 3.00 | 2.29 | 348.63 | 3.60 | 2.89 | 348.03 | 3.04 | 2.33 | 348.59 | 3.38 | 2.67 | 348.25 | 3.25 | 2.54 | 348.38 | 348.63 | 27-Nov-13 | 348.92 | 8-Apr-14 |
| BH-05-13 | 347.79 | 348.43 | 0.64 | 0.28 | -0.36 | 348.15 | 0.18 (Ice) | Ice | Ice | 0.16 | -0.48 | 348.27 | 0.33 | -0.31 | 348.10 | 0.28 | -0.36 | 348.15 | 348.27 | 20-May-14 | 348.46 | 1-Apr-14 |
| BH-06A-13 | 350.54 | 351.19 | 0.65 | 1.17 | 0.52 | 350.02 | 1.47 | 0.82 | 349.72 | 1.05 | 0.40 | 350.14 | 1.20 | 0.55 | 349.99 | 1.25 | 0.60 | 349.94 | 350.14 | 20-May-14 | 350.36 | 14-Apr-14 |
| BH-06B-13 | 350.43 | 351.53 | 1.10 | 2.25 | 1.15 | 349.28 | 2.46 | 1.36 | 349.07 | 2.12 | 1.02 | 349.41 | 2.50 | 1.40 | 349.03 | 2.39 | 1.29 | 349.14 | 349.41 | 20-May-14 | 350.42 | 8-Apr-14 |
| MP-01-13 IN | 349.37 | 351.07 | 1.70 | 1.98 | 0.28 | 349.09 | 1.28 (Ice) | Ice | Ice | 1.87 | 0.17 | 349.20 | 2.00 | 0.30 | 349.07 | 2.03 mud | dry | dry | 349.20 | 20-May-14 | -- | -- |
| MP-01-13 OUT | 349.37 | 351.07 | 1.70 | Snow | Snow | Snow | Snow | Snow | Snow | 1.70 | 0.00 | 349.37 | dry | dry | dry | dry | dry | dry | 349.37 | 20-May-14 | -- | -- |
| MP-02-13 IN | 349.18 | 350.94 | 1.76 | 1.72 | -0.04 | 349.22 | 1.60 (Ice) | Ice | Ice | 1.76 | 0.00 | 349.18 | 1.75 | -0.01 | 349.19 | 1.76 | 0.00 | 349.18 | 349.22 | 14-Nov-14 | -- | -- |
| MP-02-13 OUT | 349.18 | 350.94 | 1.76 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-03-13 IN | 348.98 | 350.69 | 1.71 | 1.71 | 0.00 | 348.98 | 1.13 (Ice) | Ice | Ice | 1.71 | 0.00 | 348.98 | 1.70 | -0.01 | 348.99 | 1.79 | 0.08 | 348.90 | 348.99 | 14-Nov-14 | -- | -- |
| MP-03-13 OUT | 348.98 | 350.69 | 1.71 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-04-13 IN | 349.08 | 350.91 | 1.83 | 1.89 | 0.06 | 349.02 | 1.94 | 0.11 | 348.97 | 1.90 | 0.07 | 349.01 | 2.10 | 0.27 | 348.81 | 1.89 | 0.06 | 349.02 | 349.02 | 14-Nov-14 | -- | -- |
| MP-04-13 OUT | 349.08 | 350.91 | 1.83 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | 1.83 | 0.00 | 349.08 | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-05-13 IN | 347.96 | 349.80 | 1.84 | 1.91 | 0.07 | 347.89 | 1.90 | 0.06 | 347.90 | 1.92 | 0.08 | 347.88 | 1.97 | 0.13 | 347.83 | 1.90 | 0.06 | 347.90 | 347.90 | 14-Nov-14 | -- | -- |
| MP-05-13 OUT | 347.96 | 349.80 | 1.84 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-06-13 IN | 349.49 | 350.42 | 0.93 | 0.91 (Ice) | Ice | Ice | 0.60 (Ice) | Ice | Ice | 0.93 | 0.00 | 349.49 | 0.97 | 0.04 | 349.45 | blocked | blocked | blocked | 349.49 | 20-May-14 | -- | -- |
| MP-06-13 OUT | 349.49 | 350.42 | 0.93 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | 0.94 | 0.01 | 349.48 | -- | -- | -- | -- |
| MP-07-13 IN | 349.53 | 351.22 | 1.69 | 1.72 | 0.03 | 349.50 | 1.86 | 0.17 | 349.36 | 1.70 | 0.01 | 349.52 | 1.73 | 0.04 | 349.49 | 1.68 | -0.01 | 349.54 | 349.54 | 14-Nov-14 | -- | -- |
| MP-07-13 OUT | 349.53 | 351.22 | 1.69 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dy | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-08-13 IN | 348.12 | 349.32 | 1.20 | 1.29 | 0.09 | 348.03 | 1.11 (Ice) | Ice | Ice | 1.32 | 0.12 | 348.00 | 1.39 | 0.19 | 347.93 | 1.36 | 0.16 | 347.96 | 348.03 | 14-Nov-14 | -- | -- |
| MP-08-13 OUT | 348.12 | 349.32 | 1.20 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-09-13 IN | 348.28 | 349.30 | 1.02 | 1.30 | 0.28 | 348.00 | 1.02 (Ice) | Ice | Ice | 1.30 | 0.28 | 348.00 | 1.36 | 0.34 | 347.94 | 1.37 | 0.35 | 347.93 | 348.00 | 14-Nov-14 | -- | -- |
| MP-09-13 OUT | 348.28 | 349.30 | 1.02 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-10-13 IN | 349.51 | 351.20 | 1.69 | 1.70 | 0.01 | 349.50 | 0.70 | -0.99 | 350.50 | 1.72 | 0.03 | 349.48 | 1.70 | 0.01 | 349.50 | 1.71 | 0.02 | 349.49 | 350.50 | 14-Nov-14 | -- | -- |
| MP-10-13 OUT | 349.51 | 351.20 | 1.69 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-11-13 IN | 349.49 | 351.29 | 1.80 | 1.84 | 0.04 | 349.45 | 1.29 (Ice) | Ice | Ice | 1.83 | 0.03 | 349.46 | 1.84 | 0.04 | 349.45 | 1.91 | 0.11 | 349.38 | 349.46 | 14-Nov-14 | -- | -- |
| MP-11-13 OUT | 349.49 | 351.29 | 1.80 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-12-13 IN | 348.78 | 350.59 | 1.81 | 1.85 | 0.04 | 348.74 | 0.78 (Ice) | Ice | Ice | 1.86 | 0.05 | 348.73 | destroyed | destroyed | destroyed | destroyed | destroyed | destroyed | 348.74 | 27-Nov-13 | -- | -- |
| MP-12-13 OUT | 348.78 | 350.59 | 1.81 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | destroyed | destroyed | destroyed | destroyed | destroyed | destroyed | -- | -- | -- | -- |
| MP-13-13 IN | 346.61 | 348.24 | 1.63 | 1.88 | 0.25 | 346.36 | 1.36 (Ice) | Ice | Ice | 2.02 | 0.39 | 346.22 | 2.04 | 0.41 | 346.20 | 1.96 | 0.33 | 346.28 | 346.36 | 14-Nov-14 | -- | -- |
| MP-13-13 OUT | 346.61 | 348.24 | 1.63 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-14-13 IN | 346.45 | 348.19 | 1.74 | 1.92 | 0.18 | 346.27 | 2.10 (Ice) | Ice | Ice | 2.06 | 0.32 | 346.13 | 2.13 | 0.39 | 346.06 | -- | -- | -- | 346.27 | 27-Nov-13 | -- | -- |
| MP-14-13 OUT | 346.45 | 348.19 | 1.74 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | -- | -- | -- | -- | -- | -- | -- |
| MP-15-13 IN | 346.38 | 347.88 | 1.50 | 1.57 | 0.07 | 346.31 | 0.63 (Ice) | Ice | Ice | 1.67 | 0.17 | 346.21 | 1.72 | 0.22 | 346.16 | 1.76 | 0.26 | 346.12 | 346.31 | 14-Nov-14 | -- | -- |
| MP-15-13 OUT | 346.38 | 347.88 | 1.50 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-16-13 IN | 346.29 | 348.13 | 1.84 | 1.77 (Ice) | Ice | Ice | 1.92 | 0.08 | 346.21 | 1.89 | 0.05 | 346.24 | 1.91 | 0.07 | 346.22 | 1.89 | 0.05 | 346.24 | 346.24 | 14-Nov-14 | -- | -- |
| MP-16-13 OUT | 346.29 | 348.13 | 1.84 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-17-13 IN | 346.29 | 347.53 | 1.24 | 1.16 (Ice) | Ice | Ice | 1.37 | 0.13 | 346.16 | 1.21 | -0.03 | 346.32 | 1.20 | -0.04 | 346.33 | 1.21 | -0.03 | 346.32 | 346.33 | 14-Nov-14 | -- | -- |
| MP-17-13 OUT | 346.29 | 347.53 | 1.24 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-18-13 IN | 346.70 | 348.18 | 1.48 | 1.88 | 0.40 | 346.30 | 2.08 | 0.60 | 346.10 | 1.95 | 0.47 | 346.23 | no access | no access | no access | 2.04 | 0.56 | 346.14 | 346.30 | 14-Nov-14 | -- | -- |
| MP-18-13 OUT | 346.70 | 348.18 | 1.48 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | no access | no access | no access | 1.87 | 0.39 | 346.31 | 346.31 | 14-Nov-14 | -- | -- |
| MP-19-13 IN | 346.67 | 348.48 | 1.81 | 1.61 | -0.20 | 346.87 | 1.78 | -0.03 | 346.70 | 1.58 | -0.23 | 346.90 | no access | no access | no access | 1.60 | -0.21 | 346.88 | 346.90 | 14-Nov-14 | -- | -- |
| MP-19-13 OUT | 346.67 | 348.48 | 1.81 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | no access | no access | no access | dry | dry | dry | -- | -- | -- | -- |
| MP-20-13 IN | 347.76 | 349.88 | 2.12 | 2.14 | 0.02 | 347.74 | 2.20 (Ice) | Ice | Ice | 2.17 | 0.05 | 347.71 | 2.23 | 0.11 | 347.65 | 2.20 | 0.08 | 347.68 | 347.74 | 14-Nov-14 | -- | -- |
| MP-20-13 OUT | 347.76 | 349.88 | 2.12 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-21-13 IN | 347.79 | 349.39 | 1.60 | 1.76 | 0.16 | 347.63 | 2.00 (Ice) | Ice | Ice | 1.75 | 0.15 | 347.64 | 1.81 | 0.21 | 347.58 | 1.81 | 0.21 | 347.58 | 347.64 | 14-Nov-14 | -- | -- |
| MP-21-13 OUT | 347.79 | 349.39 | 1.60 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-22-13 IN | 348.81 | 350.38 | 1.57 | 1.58 | 0.01 | 348.80 | 1.23 (Ice) | Ice | Ice | 1.64 | 0.07 | 348.74 | 1.68 | 0.11 | 348.70 | 1.66 | 0.09 | 348.72 | 348.80 | 14-Nov-14 | -- | -- |
| MP-22-13 OUT | 348.81 | 350.38 | 1.57 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-23-13 IN | 348.66 | 350.19 | 1.53 | 1.62 | 0.09 | 348.57 | 1.48 (Ice) | Ice | Ice | 1.68 | 0.15 | 348.51 | 1.89 | 0.36 | 348.30 | 1.82 | 0.29 | 348.37 | 348.57 | 14-Nov-14 | -- | -- |
| MP-23-13 OUT | 348.66 | 350.19 | 1.53 | Frozen Ground | Frozen Ground | Frozen Ground | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-24-13 IN | 348.40 | 349.90 | 1.50 | 1.47 | -0.03 | 348.43 | 1.38 (Ice) | Ice | Ice | 1.51 | 0.01 | 348.39 | 1.57 | 0.07 | 348.33 | 1.55 | 0.05 | 348.35 | 348.43 | 14-Nov-14 | -- | -- |
| MP-24-13 OUT | 348.40 | 349.90 | 1.50 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| MP-25-13 IN | 348.68 | 350.18 | 1.50 | 1.52 | 0.02 | 348.66 | 1.43 (Ice) | Ice | Ice | 1.56 | 0.06 | 348.62 | 1.64 | 0.14 | 348.54 | 1.60 | 0.10 | 348.58 | 348.66 | 14-Nov-14 | -- | -- |
| MP-25-13 OUT | 348.68 | 350.18 | 1.50 | Snow | Snow | Snow | Snow | Snow | Snow | Dry | Dry | Dry | dry | dry | dry | dry | dry | dry | -- | -- | -- | -- |
| BH3 | 348.30 | 348.93 | 0.63 | 1.17 | 0.54 | 347.76 | 1.34 | 0.71 | 347.59 | 1.28 | 0.65 | 347.65 | dry | dry | dry | 1.27 | 0.64 | 347.66 | 347.76 | 14-Nov-14 | -- | -- |
| BH4 | 348.29 | 348.94 | 0.65 | 1.06 | 0.41 | 347.88 | -- | -- | -- | 1.17 | 0.52 | 347.77 | -- | -- | -- | 1.12 | 0.47 | 347.82 | 347.88 | 14-Nov-14 | -- | -- |
| BH101 - A090736 | -- | -- | 0.86 | 6.17 | 5.31 | -- | 5.41 | 4.55 | -- | 4.76 | 3.90 | -- | 5.22 | 4.36 | -- | 5.06 | 4.20 | -- | -- | -- | -- | -- |
| BH102 - A090705 | -- | -- | 0.95 | 3.66 | 2.71 | -- | 4.02 | 3.07 | -- | 3.59 | 2.64 | -- | 3.86 | 2.91 | -- | 3.79 | 2.84 | -- | -- | -- | -- | -- |

Notes:

1. mBTOP = meters below top of pipe
2. mBGS = meters below ground surface
3. MASL = metres above sea level
4. Highlighted text indicates water levels above ground surface.
5. Highlighted text identifies manual water level measurements that do not correlate with datalogger data
6. Elevation data not available

All of the monitoring wells were constructed in accordance with Ontario Regulation 903 (as amended) as administered by the MOECC. Well records were submitted to the MOECC based on the cluster system whereby one well record can be submitted on behalf of an entire property. Provincial Site Cluster Tag Identification Numbers were placed on the boreholes listed in Table 5.4.

**Table 5.4 Boreholes with Provincial Site Cluster Tag Identification Numbers**

| Borehole | Provincial Site Cluster Tag Identification Number |
|---|---|
| BH-01A-13 | A146705 |
| BH-02-13 | A146700 |
| BH-03-13 | A146699 |
| BH-05-13 | A146708 |
| BH-06A-13 | A146701 |

At Boreholes BH-01-13 and BH-06-13, multiple monitoring wells were installed to enable measurement of vertical gradients between the saturated units encountered during drilling.

Additionally, mini-piezometers were installed in selected locations adjacent to wetland features using a hand auger to advance a hole. The piezometers were constructed using 19 mm diameter PVC piping with hand-fabricated screens. Descriptions of the mini-piezometer completion depths, screen lengths, and stratigraphies encountered are included on the logs in Appendix 5.1.

Manual measurements of stabilized groundwater levels in the monitoring wells and mini-piezometers on site were collected between November 20 and 27, 2013; and February 27, May 20, August 15, and November 14, 2014 with measurements summarized in Table 5.3.

Continuous groundwater monitoring is currently being conducted using electronic pressure transducers (dataloggers) installed in the nine monitoring wells, and a barologger has been installed in BH-01A-13 to continuously record barometric pressure fluctuations. All datalogger data has been barometrically compensated.

### 5.2.3 Laboratory Soil Testing

All soil samples obtained during borehole drilling were returned to LVM laboratory facilities for visual examination, with selected samples undergoing physical testing. The soil moisture content test results obtained from borehole samples are plotted on the appended borehole logs, and grain size analyses are plotted on Figures 5.1 and 5.2 in Appendix 5.5.

#### *5.2.3.1 Hydraulic Conductivity Testing*

Hydraulic conductivity estimates for the site soils were determined using two methods.

The first method is applicable to saturated soils at depth, and involves single response in-situ hydraulic (slug) tests at monitoring wells.

The second method involves a calculated estimation of hydraulic conductivity based on soil sample grain size analysis using the Beyer, Hazen, Kozeny-Carman, and Kaubisch formulae where appropriate. The two methods used for this study are described in the following subsections.

##### 5.2.3.1.1 Slug Testing

Hydraulic conductivity estimates were determined for the saturated soils at depth using single response slug tests for eight monitoring wells within and in proximity to the Study Area.

Each monitoring well was developed prior to slug testing. Well purging was implemented to remove silt and sand introduced into the well during construction, and to remove fine particles from the coarse sand pack placed around the outside of the well screen during construction.

The slug test procedure employs the hydrostatic time-lag method for groundwater recovery following the introduction of a slug of known volume into a monitoring well, and makes use of the theory of Hvorslev (1951), as described in Freeze and Cherry (1979). Hvorslev's method is expressed by the following equation:

$$K = \frac{r^2 \ln (L/R)}{2LT_0}$$

where:

| | | |
|---|---|---|
| K | = | hydraulic conductivity of the tested material (m/sec) |
| r | = | inner radius of the well riser pipe (m) |
| R | = | outer radius of the well riser pipe (m) |
| L | = | length of screen and sand pack (m) |
| $T_o$ | = | time lag (sec), where $(H\text{-}h)/(H\text{-}H_o) = 0.37$ |
| h | = | water level at each time of measurement (m) |
| $H_o$ | = | initial water level (m, start of test) |
| H | = | stabilized water level prior to introducing slug (m) |

The time lag, $T_0$, is defined as the time required for the water level to recover to the stabilized level if the initial flow rate into the well is maintained. This time lag is determined graphically as the time for which (H-h) divided by $(H\text{-}H_o)$ is equal to 0.37.

Slug test data was analyzed using MS Excel 2010 software. A summary of the hydraulic conductivity estimates is provided in Table 5.5, and graphed results of the slug tests completed for the monitoring wells are included in Appendix 5.2.

**Table 5.5 Hydraulic Conductivity Estimates**

| Borehole Name / Location | Ground Surface Elevation (MASL) | Grain Size Analyses | | | | |
|---|---|---|---|---|---|---|
| | | Soil Description | Sampled Interval (mBGS) | Hydraulic Conductivity (m/sec) | Method | OGS Layer Name |
| **BH-01A-13** | 350.27 | Sand, some silt, trace clay | 12.19-2.65 SS-8 | $3.2 \times 10^{-5}$ | Beyer %P=4 | AFB1 |
| **BH-01B-13** | 350.29 | Silty clayey sand, trace gravel | 24.38-4.84 SS-4 | * | Kaubisch %P=43 | AFB2 |
| **BH-01C-13** | 350.31 | Sand, some silt and gravel, trace clay | 0.76-1.22 SS-1 | $8.6 \times 10^{-6}$ | Kaubisch** %P=14 | AFB1 |
| **BH-02-13** | 353.62 | Silty sand, trace clay and gravel | 1.52-1.98 SS-2 | * | Kozeny-Carman $C_u$ =14 $D_{10}$ = 0.010 $D_{60}$ = 0.137 | AFB1 |
| **BH-03-13** | 350.07 | Sand, trace silt | 1.52-1.98 SS-2 | $3.4 \times 10^{-5}$ | Beyer %P=5 | AFB1 |
| **BH-04-13** | 350.92 | Sand, some silt, trace clay and gravel | 9.14-9.60 SS-7 | $3.4 \times 10^{-5}$ | Beyer %P=4 | AFA1 |
| **BH-05-13** | 347.79 | Sand, some silt, trace clay | 1.52-1.98 SS-2 | $3.5 \times 10^{-5}$ | Beyer %P=4 | AFA1 |
| **BH-05-13** | 347.79 | Sandy silty gravel, trace clay | 12.85-16.31 SS-8 | * | Kozeny-Carman $C_u$ =450.3 $D_{10}$ = 0.009 $D_{60}$ = 3.873 | AFB1 |
| **BH-06A-13** | 350.54 | Sand and silt, trace clay | 0.76-1.52 SS-1 | $1.8 \times 10^{-5}$ | Kozeny-Carman $C_u$ =2.6 $D_{10}$ = 0.039 $D_{60}$ = 0.104 | AFA1 |

| Borehole Name / Location | Ground Surface Elevation (MASL) | Slug Tests | | | | |
|---|---|---|---|---|---|---|
| | | Soil Description | Sampled Interval (mBGS) | Hydraulic Conductivity (m/sec) | Method | OGS Layer Name |
| **BH-01A-13** | 350.27 | Silty sand, trace gravel | 12.19-13.72 | $2.0 \times 10^{-5}$ | Falling Head | AFB1 |
| **BH-01B-13** | 350.29 | Silty sand, trace gravel | 24.38-25.91 | $3.4 \times 10^{-5}$ | Rising Head | AFB2 |
| **BH-01C-13** | 350.31 | Silty sand, trace gravel | 3.05-4.57 | $1.0 \times 10^{-5}$ | Rising Head | AFB1 |
| **BH-03-13** | 350.07 | Sand, trace gravel and silt | 26.97-28.50 | $1.7 \times 10^{-4}$ | Falling Head | AFB2 |
| **BH-04-13** | 350.92 | Silty sand | 7.62-9.14 | $3.8 \times 10^{-5}$ | Rising Head | AFA1 |
| **BH-05-13** | 347.79 | Silty sand, some gravel | 15.85-17.37 | $5.7 \times 10^{-5}$ | Rising Head | AFB1 |
| **BH-06A-13** | 350.54 | Sand, some silt and gravel | 23.47-24.99 | $3.3 \times 10^{-5}$ | Falling Head | AFA1 |
| **BH-06B-13** | 350.43 | Silty sand | 3.66-5.18 | $2.3 \times 10^{-5}$ | Rising Head | AFB2 |

Notes:

1. MASL – Metres Above Sea Level
2. *Could not calculate Hydraulic Conductivity as $C_u$ outside range for formula or $D_{10}$ value is too low
3. **Deemed to be most realistic value although P<20%
4. Hydraulic conductivities values for BH-02-13 (SS-8), BH-03-13 (SS-12), BH-04-13 (SS-2), BH-06A-13 (SS-11) could not be obtained as hydrometer testing was not completed on these samples

#### 5.2.3.1.2 Grain Size Analyses

Hydraulic conductivity values of near-surface soil samples were derived empirically using the particle size distribution test and the Kozeny-Carman, Beyer, and Kaubisch formulae where the grain size analyses met the appropriate formulae criteria.

The particle size distribution analysis graphs are shown on Figures 5.01 and 5.02 in Appendix 5.3, and the calculated conductivity values for the samples from the boreholes are listed in Table 5.5.

### *5.2.3.2 Double Ring Infiltrometer Tests*

Seven Double-Ring Infiltrometer tests (employing falling hydraulic heads) were performed to assessing the infiltration capacity of the soils within the development area. The locations are depicted on Figure 5.1. The vertical hydraulic conductivities $K_z$ were obtained with a variably saturated flow model and a linear model type. The model flow was built with FEFLOW 6.2, and PEST 13.0 was used for the parameter estimation. The test results are presented in Table 5.6 below.

**Table 5.6 Infiltration Test Results**

| Infiltration Test | Vertical Hydraulic Conductivity $K_z$ (M/SEC) | Lithology | Infiltration Rate (MM/HOUR) | Approx. Depth to High Water Table (M) |
|---|---|---|---|---|
| DR1 | $6.0 \times 10^{-6}$ | sand (AFA1) | 65.0 | 2.5 |
| DR2 | $4.0 \times 10^{-6}$ | sand (AFA1) | 61.0 | < 1.0 |
| DR3 | $3.9 \times 10^{-6}$ | Sand (AFA1) | 60.5 | 4.3 |
| DR4 | $2.1 \times 10^{-6}$ | Sand (AFA1/ATB1) | 55.0 | < 0.5 |
| DR6 | $4.3 \times 10^{-6}$ | Sand (AFA1) | 62.0 | < 0.4 |
| Geom. Mean | | | 60.7 | |
| DR5 | $< 3.0 \times 10^{-8}$ (estimated) | till (Maryhill) | < 14.0 (estimated) | 1.1 |
| DR7 | $3.5 \times 10^{-6}$ | till (Maryhill) | 60.0* | 1.5 |

*High rate likely due to leaky double-ring.

Due to the high groundwater table, the infiltration locations appear to be suited for at-source low impact development (LID) stormwater management solutions measures but not for end-of-pipe measures, e.g. infiltration galleries.

The infiltration rates in Table 5.6 are not design infiltration rates. As stated in Table C2 of Appendix C (CVC & TRCA, 2010), a safety correction factor of at least 2.5 applies for calculating design infiltration rates. Therefore, the design infiltration rate would become 24.3 mm/hour (=60.7 mm/hour /2.5).

### 5.2.4 Groundwater Chemistry Testing

Samples of groundwater were obtained from five on-site monitoring wells on November 21 and 22, 2013 and January 14, 2014; from the residential wells at 724 Schnarr Street and 719 Erbsville Road on January 24, 2014; and from the residential well at 720 Erbsville Road on January 27, 2014 and submitted to ALS Laboratories in Waterloo, Ontario for analysis of general chemistry parameters. Analysis results are summarized in Tables 5.7 and 5.8 with comparison to the Ontario Drinking Water Standards (ODWS), and the laboratory Certificates of Analysis are included in Appendix 5.4. Additional four (4) samples were taken on August 15, 2015 for Sodium and Chloride analyses. Analysis results are summarized in Table 5.9.

## 5.3 Hydrogeological Investigation Results

### 5.3.1 Subsoils

The borehole logs indicated that soil composition varies across the Study Area. As shown in the cross sections on Figures 5.3 to 5.6, the outcropping granular deposits vary considerably in extension and thickness across the Study Area. The sediments of the Study Area consist of sand and silty sand deposits within intermittent layers of silt, silt till, and clay.

The interpretation of the local hydrogeology was set in the context of the regional hydrostratigraphy as described in Blackport Hydrogeology Inc. (2012) and Bajc and Shirota (2007).

Depending on the location, topsoil is underlain by a layer of clay (ATB1), or silt/sand (AFA1 and AFB1). The granular deposits are less extensive in the Study Area and are typically saturated; forming the shallow overburden aquifer (OGS layers AFA1 and AFB1). The granular deposits are underlain at depth by deposits of silt, silt till, clay, and silt/sand (OGS layers ATB1 and ATB2).

### 5.3.2 Hydraulic Conductivity

Hydraulic conductivity estimates determined by the various testing methods are summarized in Table 5.5, with graphical analyses of slug test data included in Appendix 5.2, and particle size distribution graphs on Figures 5.01 and 5.02 in Appendix 5.3.

The analyzed soil types varied from sand to silty sand. Table 5.10 below shows the range of calculated hydraulic conductivity values and geometric mean values for the OGS layers.

**Table 5.7 Groundwater Chemistry Results**

| Parameter | ODWS Standards | Type of Standard | BH-01A-13 21-NOV-13 | BH-01B-13 21-NOV-13 | BH-01C-13 21-NOV-13 | BH-02-13 15-Jan-14 | BH-03-13 21-NOV-13 | BH-04-13 22-NOV-13 | BH-05-13 22-NOV-13 | BH-06A-13 21-NOV-13 | BH-06B-13 21-NOV-13 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color, Apparent | 5 TCU | AO | **37.2** | **40.8** | **34.2** | **15.0** | **72.2** | **103** | **90.0** | **77.4** | **54.3** |
| Conductivity | -- | -- | 533 | 489 | 506 | 943 | 667 | 1030 | 767 | 753 | 553 |
| Hardness (as CaCO3) | 80-100 | OG | **401** | **512** | **373** | **448** | **770** | **2020** | **1120** | **3150** | **511** |
| pH | 6.5-8.5 | OG | 7.94 | 7.96 | 7.84 | 7.90 | 7.99 | 7.84 | 7.90 | 8.18 | 7.94 |
| Total Dissolved Solids | 500 | AO | 306 | 289 | 276 | 569 | 406 | **615** | 453 | 322 | 319 |
| Turbidity | 5 NTU | AO | **9.98** | **8.53** | **8.47** | **36** | **17.4** | **52.0** | **24.0** | **950** | **13.5** |
| Alkalinity, Total (as CaCO3) | 30-500 mg/L | OG | 240 | 224 | 288 | 277 | 251 | 264 | 265 | 283 | 253 |
| Ammonia, Total (as N) | -- | -- | 0.067 | 0.060 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.100 | 0.067 |
| Chloride | 250 mg/L | AO | 11.7 | 3.4 | <2.0 | 84.8 | 23.5 | 165 | 56.6 | 6.3 | 16.2 |
| Fluoride | 1.5 mg/L | MAC | 0.18 | 0.10 | <0.10 | 0.13 | 0.10 | <0.10 | <0.10 | 0.20 | <0.10 |
| Nitrate-N | 10 mg/L | MAC | <0.10 | <0.10 | 0.20 | <0.10 | 0.30 | 0.66 | 1.18 | 0.92 | <0.10 |
| Nitrite-N | 1 mg/L | MAC | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | 0.25 | <0.10 |
| Phosphate-P (ortho) | -- | -- | 0.0054 | 0.0054 | <0.0030 | <0.0030 | 0.0055 | 0.0041 | 0.0049 | 0.0143 | 0.0037 |
| Sulphate | 500 mg/L | AO | 36.9 | 40.5 | 2.2 | 113.0 | 78.3 | 17.2 | 57.9 | 124 | 35.6 |
| Aluminum (Al)-Total | 0.1 mg/L | OG | **2.03** | **10.3** | **2.89** | **6.63** | **13.7** | **27.5** | **15.5** | **115** | **6.91** |
| Barium-Total | 1 mg/L | MAC | 0.113 | 0.217 | 0.041 | 0.27 | 0.323 | 0.297 | 0.355 | **1.840** | 0.192 |
| Chromium-Total | 0.05 mg/L | MAC | <0.0050 | 00.0097 | <0.000090 | 0.01 | 00.0124 | 00.0394 | 00.0169 | **0.110** | 0.0100 |
| Iron (Fe)-Total | 0.3 mg/L | AO | **3.32** | **14.4** | **4.71** | **6.73** | **21.8** | **59.4** | **24.8** | **189** | **12.7** |
| Lead (Pb)-Total | 0.01 mg/L | MAC | 0.0094 | **0.0209** | **0.0126** | **0.0131** | **0.0470** | **0.157** | **0.0392** | **0.324** | **0.0146** |
| Magnesium (Mg)-Total | -- | -- | 34.3 | 36.5 | 24.3 | 36.20 | 58.5 | 139 | 84.0 | 207 | 37.0 |
| Manganese (Mn)-Total | 0.05 mg/L | AO | **0.329** | **1.06** | **0.283** | **0.26** | **1.67** | **2.85** | **1.93** | **14.8** | **0.616** |
| Nickel (Ni)-Total | -- | -- | <0.010 | 0.013 | <0.010 | 0.02 | 0.019 | 0.059 | 0.021 | 0.15 | 0.012 |
| Sodium (Na)-Total | 20-500 mg/L | AO | 18.0 | 12.8 | <5.0 | 88.4 | 52.1 | 35.5 | 26.9 | 181 | 6.0 |
| Zinc (Zn)-Total | 5.0 mg/L | AO | 0.041 | 0.077 | 0.103 | 0.05 | 0.127 | 0.612 | 0.138 | 1.21 | 0.067 |
| Aluminum (Al)-Dissolved | 0.1 mg/L | OG | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Barium-Dissolved | 1 mg/L | MAC | 0.086 | 0.079 | 0.019 | 0.171 | 0.093 | 0.084 | 0.143 | 0.062 | 0.094 |
| Chromium-Dissolved | 0.05 mg/L | MAC | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 |
| Iron (Fe)-Dissolved | 0.3 mg/L | AO | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lead (Pb)-Dissolved | 0.01 mg/L | MAC | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 |
| Magnesium (Mg)-Dissolved | | | 21.6 | 20.5 | 17.3 | 25.0 | 20.1 | 28.9 | 27.3 | 8.40 | 21.9 |
| Manganese (Mn)-Dissolved | 0.05 mg/L | AO | 0.0728 | 0.0309 | 0.0109 | 0.0443 | 0.0343 | 0.129 | 0.0606 | 0.0325 | 0.0791 |
| Nickel (Ni)-Dissolved | -- | -- | <0.0020 | <0.0020 | <0.0020 | 0.0066 | <0.0020 | 0.0021 | <0.0020 | <0.0020 | <0.0020 |
| Sodium (Na)-Dissolved | 20-500 mg/L | AO | 16.7 | 11.4 | 1.27 | 83.0 | 49.6 | 35.0 | 26.1 | 123 | 5.69 |
| Zinc (Zn)-Dissolved | | | <0.0030 | <0.0030 | <0.0030 | <0.0030 | <0.0030 | <0.0030 | <0.0030 | <0.0030 | <0.0030 |

MAC – Maximum Acceptable Concentration (health related).

OG - Operational Guideline

AO – Aesthetic Objective.

TCU – True Colour Units.

NTU – Nephelometric Turbidity Units.

Notes:

1. Criteria from *Ontario Drinking Water Standards* (MOE, 2007).
2. Tests carried out at ALS Laboratories (Waterloo).
3. Measurements in **bold and highlighted** text exceed ODWS criteria limits.

a. Where nitrate and nitrite are present, the total of the two should not exceed 10 mg/L.
b. The aesthetic objective for sodium in drinking water is 200 mg/L. The local Medical officer of Health should be notified when the sodium concentration exceeds 20 mg/L so that this information may be communicated to local physicians for their use with patients on sodium restricted diets.

**Table 5.8 Groundwater Chemistry Results – Residential Wells**

| Parameter | ODWS Standards | Type of Standard | 724 Schnarr | 719 Erbsville | 720 Erbsville |
|---|---|---|---|---|---|
| | | | 24-Jan-14 | 24-Jan-14 | 27-Jan-14 |
| Color, Apparent | 5 TCU | AO | <1.0 | 27.0 | <1.0 |
| Conductivity | -- | -- | 567 | 769 | 637 |
| Hardness (as CaCO3) | 80-100 | OG | **272** | **348** | **281** |
| pH | 6.5-8.5 | OG | 7.79 | 7.79 | 7.75 |
| Total Dissolved Solids | 500 | AO | 313 | 437 | 371 |
| E.Coli | 0 | MAC | 0 | 0 | 0 |
| Total Coliforms | 0 CFU | MAC | **1** | 0 | 0 |
| Turbidity | 5 NTU | AO | 0.24 | 3.41 | 0.23 |
| Alkalinity, Total (as CaCO3) | 30-500 mg/L | OG | 257 | 278 | 206 |
| Ammonia, Total (as N) | -- | -- | <0.050 | 0.100 | 0.064 |
| Chloride | 250 mg/L | AO | 26.5 | 59.2 | 36 |
| Fluoride | 1.5 mg/L | MAC | <0.10 | <0.10 | 0.34 |
| Nitrate-N | 10 mg/L | MAC | 0.95 | <0.10 | <0.10 |
| Nitrite-N | 1 mg/L | MAC | <0.10 | <0.10 | <0.10 |
| Phosphate-P (ortho) | -- | -- | 0.0050 | <0.0030 | 0.003 |
| Sulphate | 500 mg/L | AO | 08.5 | 48.6 | 53.2 |
| Aluminum (Al)-Total | 0.1 mg/L | OG | <0.010 | <0.010 | <0.010 |
| Barium-Total | 1 mg/L | MAC | 0.016 | 0.143 | 0.037 |
| Chromium-Total | 0.05 mg/L | MAC | 0.00053 | <0.00050 | <0.00050 |
| Iron (Fe)-Total | 0.3 mg/L | AO | <0.050 | **0.651** | <0.050 |
| Lead (Pb)-Total | 0.01 mg/L | MAC | <0.0010 | <0.0010 | <0.0010 |
| Magnesium (Mg)-Total | -- | -- | 19.3 | 31.1 | 24.6 |
| Manganese (Mn)-Total | 0.05 mg/L | AO | 0.0011 | 0.0194 | <0.0010 |
| Nickel (Ni)-Total | -- | -- | <0.0020 | <0.0020 | <0.0020 |
| Sodium (Na)-Total | 20-500 mg/L | AO | 11.4 | 26.0 | 11.8 |
| Zinc (Zn)-Total | 5.0 mg/L | AO | 0.493 | 0.0068 | 0.0139 |

MAC – Maximum Acceptable Concentration (health related).
OG – Operational Guideline
AO – Aesthetic Objective
TCU – True Colour Units
NTU – Nephelometric Turbidity Units

a. Where nitrate and nitrite are present, the total of the two should not exceed 10 mg/L.
b. The aesthetic objective for sodium in drinking water is 200 mg/L. The local Medical officer of Health should be notified when the sodium concentration exceeds 20 mg/L so that this information may be communicated to local physicians for their use with patients on sodium restricted diets.

**Table 5.9 Supplementary Sodium and Chloride Analysis Results**

| Parameter | 15-Aug-14 | | | |
|---|---|---|---|---|
| | BH-02-13 | BH-04-13 | BH-05-13 | BH-06B-13 |
| Chloride (Cl) | 60.6 | 288 | 55.2 | 15.7 |
| Sodium (Na)-Total | 82.5 | 90.3 | 24.2 | <5.0 |
| Sodium (Na)-Dissolved | 80.0 | 92.8 | 23.6 | 4.43 |

Notes:
1. Analysis performed by ALS Laboratories in Waterloo, Ontario
2. Dissolved metals sample filtered by ALS Laboratories
3. * Indicates Detection Limit Adjusted due to sample matrix effects.

**Table 5.10 Range of Hydraulic Conductivity Values in OGS Layers**

| OGS Layer Name | Soil Type | Hydraulic Conductivity (m/sec) | | |
|---|---|---|---|---|
| | | Number of Values | Range | Geometric Mean |
| AFA1 | Sand and Silty Sand Deposits | 5 | $1.8 \times 10^{-5}$ to $3.8 \times 10^{-5}$ | $3.1 \times 10^{-5}$ |
| AFB1 | Sand and Silty Sand Deposits | 6 | $8.6 \times 10^{-6}$ to $3.4 \times 10^{-5}$ | $1.8 \times 10^{-5}$ |
| AFB2 | Sand and Silty Sand Deposits | 3 | $2.3 \times 10^{-5}$ to $1.7 \times 10^{-4}$ | $5.1 \times 10^{-5}$ |

### 5.3.3 Groundwater Elevations and Flow Direction

Groundwater is typically found within the granular deposits beneath the Study Area. The granular deposits occurring at varying depths across the Study Area are interpreted to be hydraulically connected.

Across the Study Area, groundwater in the overburden aquifers flows towards Laurel Creek and Wideman Creek, driven by the topography and surface drainage features. The general flow gradient slopes towards Laurel Creek. Groundwater contours converging towards Laurel Creek are shown on Figure 5.7. The depicted groundwater levels were measured on November 20 and 27, 2013.

A localized 450 m long SW-NE groundwater divide is identified on Figure 5.7, with groundwater radially flowing outwards on either side of this divide. It is expected the groundwater divide may shift on a seasonal/annual basis depending on groundwater levels and recharge conditions.

Beneath the Study Area an aquitard separates an unconfined Shallow Overburden Aquifer from the generally confined Deep Overburden Aquifer. The aquitard plays an important role in the protection of groundwater resources in the area.

Enhanced groundwater recharge occurs in a small area of near-surface granular deposits around Schnarr Street, as shown on Figure 5.2.

The observed depth to water table in the boreholes varies across the site from slightly above ground surface to more than 5 mBGS. In proximity to active wells the hydraulic gradients in the Overburden Aquifer can be affected by pumping; for example, water levels measured at BH-02-13 may be influenced by pumping in municipal well ERSVTP1-06. ERSVTP1-06 appeared to be inactive during the monitoring program from November 2013 to November 2014.

Perched water is occasionally encountered in areas of stratified granular deposits with near surface silt layers located within the first two metres below ground surface; however, the shallow groundwater table was generally encountered within the first five metres below the ground surface.

Groundwater discharging conditions occur along the banks of Laurel Creek and Wideman Creek, as shown in the pattern of groundwater contours on Figure 5.7.

A cluster of monitoring wells were installed in the Extended Study Area. The clustered (nested) wells enable measurement of the downward vertical gradient between the upper (BH-01C-13) and lower (BH-01A-13) portions of the Shallow Overburden Aquifer, and the confined Deep Overburden Aquifer (BH-01B-13) in an area where the aquifer is inter-bedded with a low permeability layer. The groundwater elevations from the nested wells show a downwards gradient within the granular deposits of the overburden aquifer, indicating recharging conditions.

In contrast, groundwater behaviour at the clustered (nested) monitoring wells BH-06A-13 and BH-06B-13 indicates a slightly upwards gradient.

At the confluence of Laurel Creek and Wideman Creek, an upwards gradient indicates discharge to Laurel Creek. Artesian conditions encountered in wells BH-05-13 at the edge of an Upper Maryhill Till deposit (ATB1), as shown on Cross Section B-B' on Figure 5.4, indicate seasonally discharging conditions.

Within the Study Area the Deep Overburden Aquifer is confined, as observed in BH-01B-13 and BH-06A-13, implying varying infiltration conditions from recharging to discharging along the wetlands associated with Laurel Creek. Hence the Study Area is concluded to be located within a transition zone.

Mini-piezometers were installed near the wetlands in order to assess the connection between shallow groundwater and surface water. In proximity to wetland areas, groundwater levels range from slightly above to slightly below the ground surface, indicating variability between recharging and discharging conditions. Groundwater levels above ground surface occur in the wetlands along the Laurel Creek valley (MP-24-13, and MP-19-13), and in the wetland associated with Wideman Creek (MP-02-13).

### 5.3.4 Municipal Test Production Well EBSVTP1-06

Municipal test production well EBSVTP1-06, a 250 mm diameter well, is 25.04 m deep and is screened in granular soils of the intermediate aquifer (AFB2). It is currently idle as it may have insufficient capacity to meet the Region’s long-term water supply needs (Don Corbett, September 14, 2016, pers. comm.). The Waterloo North Water Supply Class Environmental Assessment (Regional Municipality of Waterloo, 2011) concluded after pumping the test production well for 25 days at a constant rate of 39.5 L/s that there was inherent uncertainty regarding the sustainability of EBSVTP1-06.

According to Golder Associates Ltd. (2011): “In response to groundwater pumping from EBSVTP1-06 at a rate of 39.5 L/s, groundwater levels were drawn down throughout the intermediate aquifer with responses observed over an area of about 2 to 3 $km^2$. Groundwater levels drew down at a consistent rate and did not stabilize during the 25 days of pumping indicating the rate of recharge to the intermediate aquifer [AFB2] is less than the pumping rate of 39.5 L/s. In some monitoring wells, groundwater levels did not fully recover in 25 days after pumping had ceased. Groundwater levels in the deep aquifer did not respond to pumping from EBSVTP1-06. Except for one shallow overburden well (Private Well D), shallow overburden monitoring locations and surface water monitor stations showed no obvious response to EBSVTP1-06 pumping. Collectively, these results indicate some hydraulic connection to the overlying shallow aquifer system [AFA1/AFB1] from which it is inferred that the bulk of the recharge to the intermediate aquifer is derived.”

Golder Associates Ltd. (2011) states in the summary of Waterloo North pumping test interpretation that “The lack of water level response in shallow overburden monitoring wells and surface water stations would typically indicate that drainage from the surface catchment area is relatively low. Since the intermediate aquifer [AFB2] is interpreted to form part of the shallow groundwater flow system [AFA1/AFB1] and a direct hydraulic response to EBSVTP1-06 pumping is noted in a shallow overburden monitoring well (Private Well D), it is possible that pumped groundwater was predominantly derived from water storage within the shallow groundwater flow system, i.e., the intermediate and shallow aquifers. Continuous pumping over the long-term could deplete the water storage. The sustainable pumping rate for EBSVTP1-06 must therefore be evaluated over the long term, as steady state groundwater flow is established. The quality of groundwater pumped from EBSVTP1-06 is good, meeting all health-related ODWS.”

“Private Well D (depicted on Figure 5-1) showed an immediate response to EBSVTP1-06 pumping, indicating that the intermediate aquifer [AFB2] is directly connected to the shallow aquifer [AFA1/AFB1] within a limited area around Private Well D (Golder Associates Ltd., 2011).” Private Well D is a 4 m deep dug well and is located at 685 Conservation Drive outside of the Study and Extended Study Areas.

The extent of a local sand deposit (shallow aquifer) is depicted on Figure 5-2. It is also shown on cross sections A-A’ (Figure 5-3), E-E’ (Figure 5-5), and F-F’ (Figure 5-6). No drawdown was evidenced in monitoring wells of the shallow aquifer AFA1/AFB1 during pumping tests of EBSVTP1-06 in 2006 (6 days of pumping) and 2009 (25 days of pumping), see Blackport Hydrology Inc. (2012) and Golder Associates Ltd. (2011), respectively. Hence, the contribution to regional recharge (inflow to intermediate and deep aquifer) is deemed small. The contribution to local recharge into the shallow aquifer AFA1/AFB1 is estimated to be about 55% of the total recharge volume (=24435.0/44696.2), as outlined in Table 5.11.

The “infiltration weight” in Table 5.11 should not be mistaken for the ‘infiltration factor” from the MOE (2003) Stormwater Management Planning and Design Manual.

**Table 5.11 Areal Recharge**

| No. | Name | Area | Soil Type | Area $m^2$ | % | Infiltration Weight | Volume $m^3$ | Recharge mm |
|---|---|---|---|---|---|---|---|---|
| 1 | 1A | Study Area | | 70981 | 19.3 | | | |
| 2 | 1B | Study Area | | 2430 | 0.7 | | | |
| 3 | 1C | Study Area | | 16540 | 4.5 | | | |
| 4 | 5 | Extended Area | | 51710 | 14.0 | | | |
| | | | *Swamp (wetland)* | *141661* | *38.5* | *0* | *0.0* | *0* |
| 5 | 4 | Study Area | | 18409 | 5.0 | | | |
| | | | *Alluvium* | *18409* | *5.0* | *0.75* | *2391.4* | *130* |
| 6 | 2A | Study Area | | 117661 | 32.0 | | | |
| 7 | 2B | Study Area | | 6598 | 1.8 | | | |
| 8 | 2C | Study Area | | 2429 | 0.7 | | | |
| 9 | 6 | Extended Area | | 10876 | 3.0 | | | |
| | | | *Till* | *137564* | *37.4* | *0.75* | *17869.8* | *130* |
| 10 | 3A | Study Area | | 66589 | 18.1 | | | |
| 11 | 3B | Study Area | | 1838 | 0.5 | | | |
| 12 | 7 | Extended Area | | 2112 | 0.6 | | | |
| | | | *Sand* | *70539* | *19.2* | *2* | *24435.0* | *346* |
| | | TOTAL | | 368173 | 100.0 | | 44696.2 | 121.4 |

### 5.3.5 Seasonal Fluctuation of Groundwater Elevations

The groundwater monitoring program shows the seasonal fluctuations in the groundwater table. Hydrographs compiling manual measurements of groundwater levels in the on-site monitoring wells are shown in Figures 1 through 9 in Appendix 5.6. Data was collected on a quarterly basis, and datalogger readings were compared to manual readings. Responses to precipitation events, and seasonal highs during the spring and lows at the end of the fall and the beginning of winter, are observed in the hydrographs as expected. The evolution of hydraulic heads in monitoring wells BH-01A-13, BH-01B-13, BH-01C-13, BH-02-13, BH-03-13, BH-04-13, BH-05-13, BH-06A-13, and BH-06B-13, between November 2013 and November 2014 is shown on Figure 1, appended. The 2014 spring high water levels are unambiguously depicted in all monitoring wells.

The hydraulic heads of monitoring wells screened in hydrostratigraphic unit AFB1 are depicted on Figure 2. The wells BH-01C-13 and BH-01A-13 are hydraulically connected, and the evolution of hydraulic heads of both wells is well correlated. The hydraulic heads of BH-02-13 are approximately 1 m lower than the heads recorded in

BH-01A-13 or in BH-01C-13 as this well is located downstream of the other two wells. The groundwater levels in monitoring well BH-02-13 did not show any impact from pumping at the nearby municipal well ERSVTP1-06, which was apparently inactive during the monitoring program.

The monitoring wells BH-06B-13 and BH-04-13 are screened in the hydrostratigraphic unit AFA1. The hydraulic heads of the wells are depicted on Figure 3. The hydraulic heads of BH-06B-13 are slightly higher than the heads observed in BH-04-13 due to its position upstream of BH-04-13. The curve of monitoring well BH-06B-13 has the highest monitored water level and a sharp peak at approximately 350.4 mASL.

The hydraulic heads of monitoring wells screened in hydrostratigraphic unit AFB2 are depicted on Figure 4. These are BH-06A-13 (deep screen), BH-01B-13, BH-03-13, and BH-05-13, listed in order of decreasing hydraulic heads which reflects the decreasing ground surface elevation from the first to the last well. The hydrographs of these monitoring wells are very well aligned. Most of the time an upwards gradient exists between BH-06A-13 (deep screen) and BH-06B-13 (shallow screen), as the hydraulic head in BH-06A-13 is higher than in BH-06B-13. A downwards gradient between BH-06A-13 (deep screen) and BH-06B-13 (top screen) was observed only during the Spring 2014 monitoring event.

The field program included multi-level wells BH-01A-13 (intermediate), BH-01B-13 (deep), BH-01C-13 (shallow), BH-06A-13 (deep), and BH-06B-13 (shallow). Except for a few days, during the monitoring period (end November 2013 to mid-November 2014) water levels of BH-06A-13 (deep) were about 0.5 m higher than in BH-06B-13 (shallow). The prevalent upward gradient is interpreted to lead to local discharge from the intermediate aquifer AFB2 into the shallow aquifer AFA1 and into the wetland between Laurel Creek and Wideman Creek.

Throughout the monitoring period, water levels in BH-01B-13 (deep) were consistently about 0.4 m lower than in BH-01C-13 (shallow) or BH-01A-13 (intermediate) suggesting recharging conditions from the shallow aquifer AFA1 into the intermediate aquifer AFB2 in the zone west of the Extended Study Area.

Although no additional multi-level wells were installed beside the streams, it is judged, that within the Study Area recharging conditions from the intermediate AFB2 into the shallow AFA1 aquifer prevail along Laurel Creek and Wideman Creek. On higher grounds, recharge from the shallow aquifer AFA1 into the intermediate aquifer AFB2 is deemed insignificant.

The manually recorded measurements are “snapshots in time”, and generally confirm the correctness of the continuous recorded datalogger measurements of groundwater levels. It is noted; however, that the manual measurements from February 2014 show an anomalous behavior. In one case, freezing conditions prevented obtaining manual measurements.

The precipitation data retrieved from the weather station at the University of Waterloo and the flow rate of Laurel Creek at Erbsville Road (Flow Gauge # 8785042) are shown on Figure 5 for the monitoring period from November 27, 2013 to November 12, 2014. During summer 2014 precipitation and flow rate peaks correlate very well. Snow melt in spring 2014 lead to a larger flow volume. The average flow rate was about 0.444 m3/day and base flow during summer time was roughly 0.150 m3/day.

Figure 6 depicts the flow rate of Laurel Creek at Erbsville Road (Flow Gauge # 8785042) and the hydrographs in the shallow monitoring wells at the margin of wetland upstream and downstream of the study area and extended study area (BH-01C-13 and BH-05-13). Water levels collected in mini-piezometers along Laurel Creek are also shown on the hydrograph. The water levels in mini-piezometers around BH-01C-13 (shallow) and BH-05-13 appeared to be 1.2 to 1.8 m lower than in the shallow monitoring wells suggesting discharge conditions to the wetland during the discrete measurement events. The water levels in the mini-piezometers decrease with lower topographic elevations.

Discontinuous groundwater levels collected in mini-piezometers along Wideman Creek are illustrated on Figure 7. No flow rate measurements were recorded from Wideman Creek. Again, as expected, the water levels in the mini-piezometers decrease with lower topographic elevations.

Figure 8 shows the flow rate of Laurel Creek at Erbsville Road (Flow Gauge #8785042) and the hydrograph in monitoring well BH-06B-13 (shallow) at the margin of the wetland between Laurel Creek and Wideman Creek. The discontinuous water levels determined in the mini-piezometers line up with the continuous water levels measured in monitoring well BH-06B-13 (shallow).

Only one mini-piezometer (MP-01-13) was installed along the tributary to Wideman Creek. The discrete water levels are shown on Figure 9. Flow rates from the tributary to Wideman Creek were not measured.

Continuous recording of water levels is proposed for the long-term monitoring program in Section 5.6 Groundwater and Surface Water Monitoring Requirements. This will allow for the confirmation of prevalent discharge conditions in the wetlands and fix the shortcomings of sparse data.

### 5.3.6 Groundwater Chemistry

Groundwater samples were obtained from the nine new monitoring wells on November 21 and 22, 2013, and on January 15, 2014. Water samples were also obtained from the residential wells located at 724 Schnarr Street and 719 Erbsville Road on January 24, 2014, and at 720 Erbsville Road on January 27, 2014.

#### *5.3.6.1 Monitoring Well Water Chemistry*

It is important to note that while used for comparative purposes, the ODWS is intended for drinking water samples. None of the monitoring wells are used to supply drinking water.

As shown on Table 5.7, a number of samples had measured exceedances of Apparent Colour, Hardness, Total Dissolved Solids, Turbidity, Aluminum, Iron, and Manganese. In each case, these parameters are not health related, pertaining to aesthetic qualities or the effectiveness of water treatment systems. The unusally high total concentrations for iron and lead is is thought to be attached to suspended matter as all samples were turbid (> 5 NTU), and dissolved iron and lead was below detection limit in all samples. No filtration was proposed for mobile metals determination.

Samples from Boreholes BH-01B-13, BH-01C-13, BH-02-13, BH-03-13, BH-04-13, BH-05-13, BH-06A-13, and BH-06B-13, had measured exceedances of the ODWS Maximum Acceptable Criteria (MAC) limit for total Lead; and samples from Borehole BH-06A-13 had measured exceedances of the ODWS MAC limit for total Barium and Chromium. It is important to consider the measured exceedances in the shallow groundwater samples from on-site monitoring wells is likely related to the adsorption of metals onto suspended soil particles which are not field filtered from the samples (per ODWS Guidelines). As shown on Table 5.8, the concentration of all dissolved metals, including Barium, Chromium, and Lead, is significantly lower and below the ODWS criteria threshold; therefore, it is concluded that the shallow groundwater meets all ODWS criteria for metals.

#### *5.3.6.2 Residential Well Water Chemistry*

As shown on Table 5.8, in addition to measured exceedances of Hardness (all three wells) and Iron (719 Erbsville), both non health-related parameters, the residential well on 724 Schnarr Street had an exceedance of the Maximum Acceptable Criteria (health related) for Total Coliforms. All homeowners have been notified of their well water chemistry analysis results.

## 5.4 Pre-Development Water Balance

The water balance accounts for all water in- and out-flows in the hydrologic cycle. Precipitation (P) falls as rain and snow. Then it can run off towards wetlands, ponds, lakes, and streams (R), infiltrate to the groundwater table (I), or evaporate from surface water and vegetation (ET). When long-term average values of P, R, I, and ET are used there is minimal or no net change to groundwater storage ($\Delta S$).

The annual water balance can be stated as:

$$P = ET + R + I + \Delta S$$

where:

**P** = Precipitation (mm/year)
**ET** = Evapo-transpiration (mm/year)
**R** = Runoff (mm/year)
**I** = Infiltration (mm/year)

**ΔS** = Change in groundwater storage (taken as zero) (mm/year)

A monthly water balance is provided to take into account short (seasonal) and long-term (annual) effects. The monthly calculations of potential evapotranspiration, actual evapotranspiration and surplus are based on the Thornthwaite's model, McCabe & Markstrom (2007). Table 5.12 presents the monthly water balance.

**Table 5.12 Monthly Water Balance**

| Month | $T_{ave}$ | P | PET | AET | SS | $RO_{tot}$ | P-PET | SM | Surplus |
|---|---|---|---|---|---|---|---|---|---|
| Jan | -6.5 | 65.2 | 8.5 | 8.5 | 33.5 | 9.6 | 22.7 | 150 | 22.7 |
| Feb | -5.5 | 54.9 | 10.2 | 10.2 | 50.6 | 13 | 27.1 | 150 | 27.1 |
| Mar | -1 | 61 | 19.2 | 19.2 | 43.4 | 20.2 | 48.2 | 150 | 48.2 |
| Apr | 6.2 | 74.5 | 37 | 37 | 21.7 | 28.1 | 57.7 | 150 | 57.7 |
| May | 12.5 | 82.3 | 67.7 | 67.7 | 10.8 | 27.7 | 23.8 | 150 | 23.8 |
| Jun | 17.6 | 82.4 | 98.3 | 98.3 | 5.4 | 22.8 | -12.1 | 137.9 | 0 |
| Jul | 20 | 98.6 | 113 | 112.1 | 0 | 19.1 | -11 | 127.8 | 0 |
| Aug | 18.9 | 83.9 | 90.2 | 89 | 0 | 15.5 | -8 | 121 | 0 |
| Sep | 14.5 | 87.8 | 52.9 | 52.9 | 0 | 13.8 | 33.2 | 150 | 4.2 |
| Oct | 8.2 | 67.4 | 28.6 | 28.6 | 0 | 18.2 | 37.4 | 150 | 37.4 |
| Nov | 2.5 | 87.1 | 15.1 | 15.1 | 0 | 28.7 | 70.4 | 150 | 70.4 |
| Dec | -3.3 | 71.2 | 9.5 | 9.5 | 21.7 | 30.1 | 39.2 | 150 | 39.2 |
| Annual | | 916.3 | 550.2 | 548.1 | 187.1 | 246.8 | | | 330.7 |

Average Temperature $T_{avg}$ in ºC, Precipitation (P), Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Snow Storage (SS), Total Runoff ($RO_{tot}$), Precipitation minus Potential Evapotranspiration (P-PET), Soil Moisture Storage Capacity (SM), and Surplus (mm).

A new Figure 5-9 Annual Groundwater Recharge has been created to reflect the revised water balance and the revised Geology Map. The previously issued recharge map has been renamed Figure 5-10.

The pre-development recharge/infiltration rates from the GRCA dataset (shown on Figure 5-9) indicate rates ranging from < 50 mm/year to > 400 mm/year across the Study Area and surrounding lands. The average infiltration rate for the entire Study Area is estimated to be approximately 120 mm/year.

It is important to consider that the localized infiltration rates vary widely. Similarly, the infiltration capacity of soils under post-development conditions will also fluctuate considerably.

### 5.4.1 Precipitation and Evapotranspiration

The average annual precipitation[1] for the study area is taken as 916 mm/yr, and is used for the purposes of the predevelopment water budget.

An estimated evapotranspiration rate of 548 mm/yr was estimated for this site. Applying these figures to the pre-development water budget for the subject property gives a water surplus of 368 mm/year (precipitation minus evapotranspiration), which then becomes the infiltration and runoff components of the budget.

[1] **Canadian Climate Centre Normals, 1981-2010 for Waterloo Wellington Airport.**

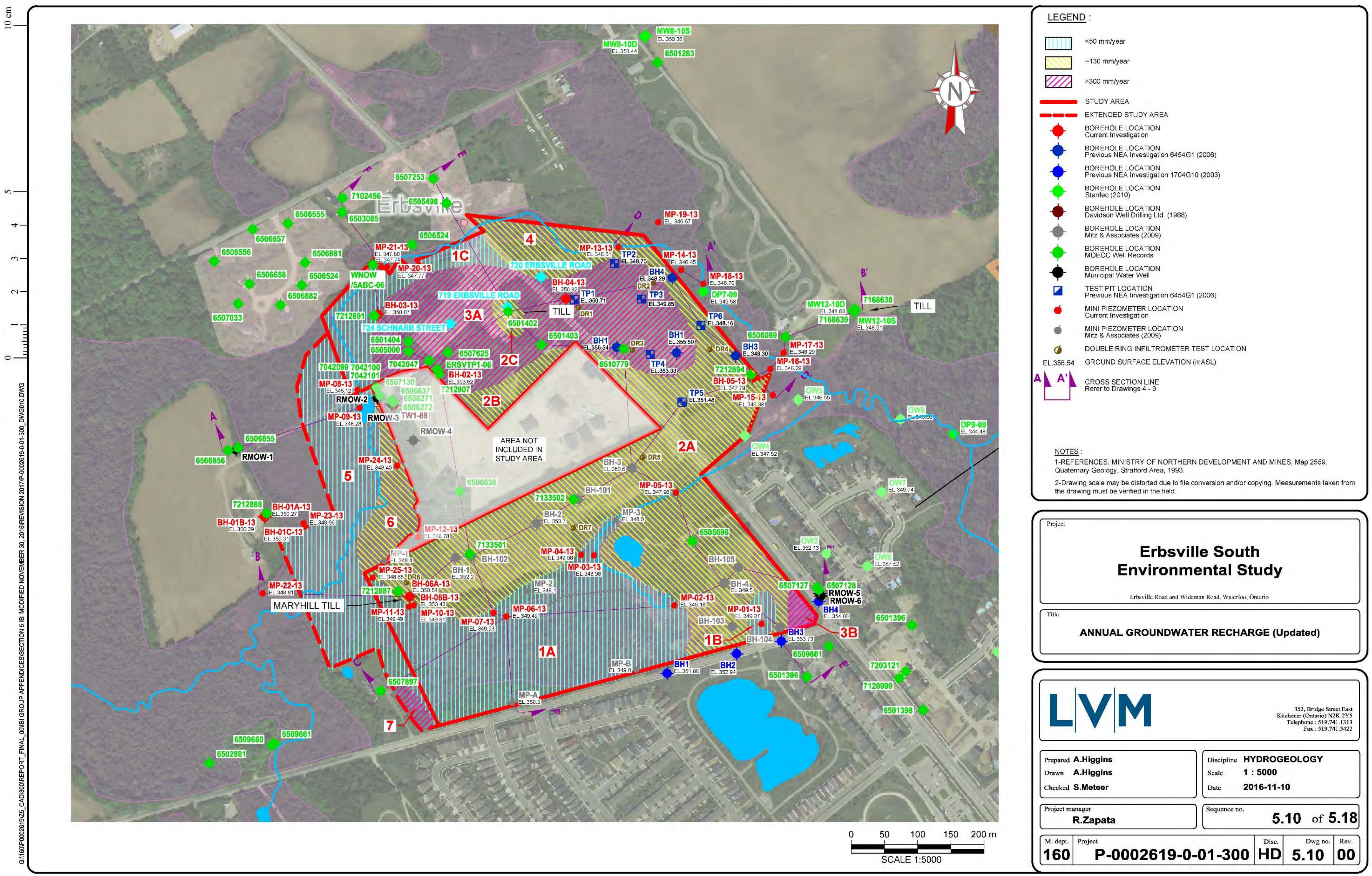


**Figure 5-9 Annual Groundwater Recharge**

#### *5.4.1.1 Infiltration and Runoff*

The rate of infiltration across the site is expected to vary, based on a number of factors to be considered in any infiltration model. The most important variables include the saturated hydraulic conductivity of surface soils, land slope, rainfall intensity, relative soil moisture at the start of a rainfall event, and vegetative cover of the ground surface. Table 5.13 presents the annual pre-development water balance for the Study Area (SA) and Extended Study Area (ESA). The estimated annual infiltration rate is 121 mm.

**Table 5.13 Pre-Development Water Balance for the Study Area (SA) and Extended Study Area (ESA)**

| Hydrologic Component | SA and ESA (mm/year) |
|---|---|
| Total Precipitation | 916 |
| Evapotranspiration | 548 |
| Runoff | 247 |
| Infiltration | 121 |

Estimated recharge (presented in Table 5.14) is consistent with the simulated GAWSER values provided in Blackport Hydrogeology Inc. (2012).

**Table 5.14 Estimated and Simulated Recharge**

| | ESTIMATED RECHARGE MM/YEAR (ENGLOBE 2016) | SIMULATED RECHARGE (GAWSER) MM/YEAR (BLACKPORT HYDROGEOLOGY INC. 2012) |
|---|---|---|
| Wetland | 0 | 0 |
| Alluvium | 130 | 75 - 125 |
| Till | 130 | 50 - 125 |
| Sand | 346 | 200 - 350 |

It is noted that the overall runoff component of the Study Area is relatively high, and the infiltration rate is relatively low. These runoff and infiltration values are a result of the poorly draining soils contributing increased runoff to the water balance.

The areal recharge based on the annual infiltration rate of 121 mm/year and is presented in Table 5.11 in Section 5.3.4 (Municipal Test Production Well EBSVTP1-06).

Groundwater recharge and infiltration are treated as equivalent in this context.

### 5.4.2 Infiltration of Precipitation

Hydraulic conductivity values of sub-surface soils within the study area were calculated using a variety of methods. Based on the borehole stratigraphies, near-surface soils are typically sandy with a low to moderate silty component resulting in a relatively low to moderate permeability; however, interlayering of sandy soils with Maryhill Till soils results in an overall soil stratigraphic profile that has a relatively low permeability. It is important to consider that the site infiltration rate calculated previously represents an average of the soil types encountered across the study area. Variation in infiltration on a sub-catchment level would be expected, depending on the specific near-surface soil types encountered within each sub-catchment.

At-source infiltration of precipitation from rooftops and other impervious surfaces, or infiltration under roadways, will be dependent on the native soil types exposed by grading and/or the physical characteristics of fill placed; along with the thickness of unsaturated soils above the shallow groundwater table. In areas where low permeability (silt/till) soils are present near the post-grading ground surface and/or groundwater exists close to the post-grading ground surface, localized infiltration capacities will be limited.

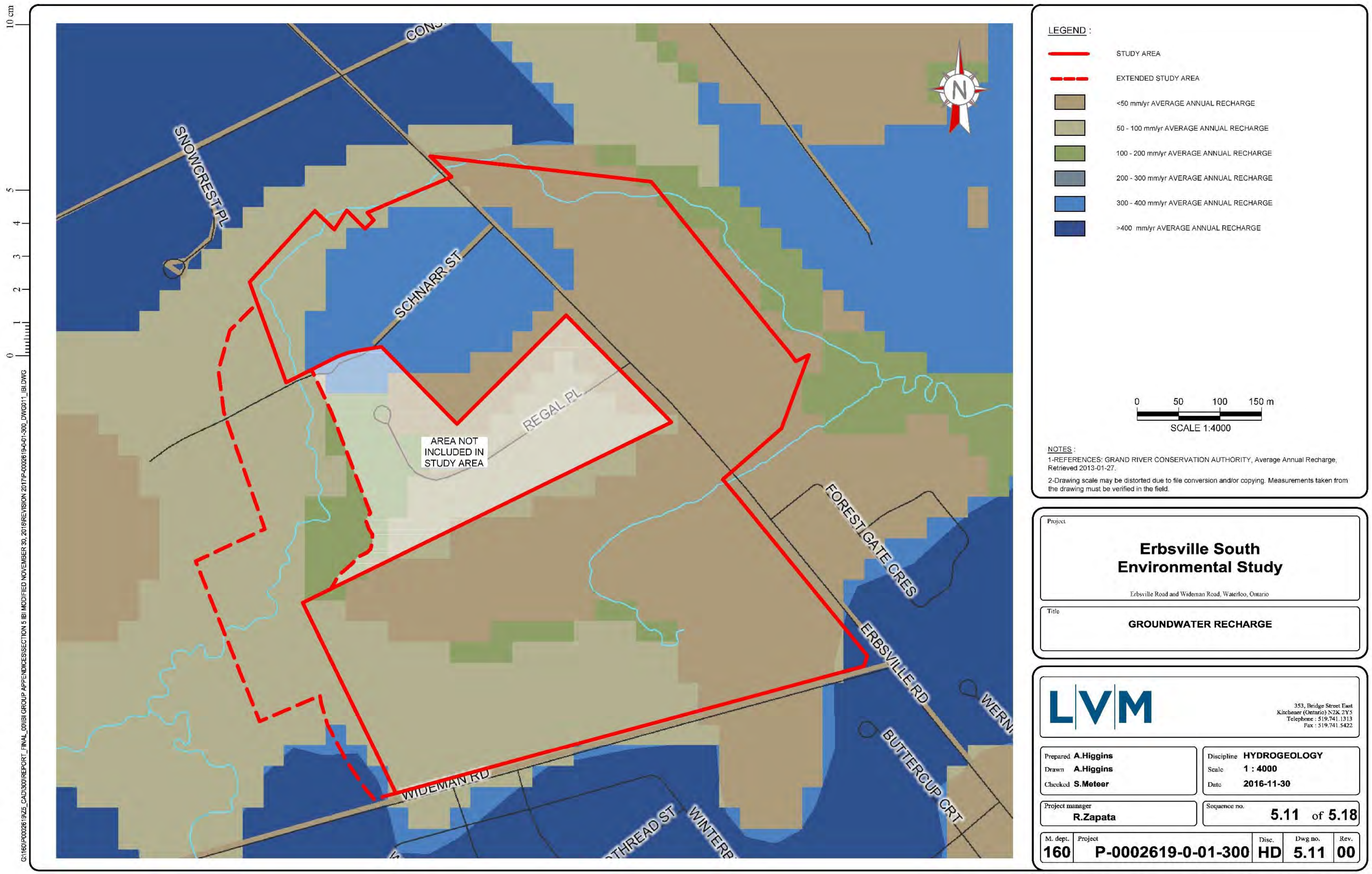


**Figure 5-10 GRCA Recharge Rates**

As the pre-development infiltration rate is relatively low, and the wetland areas are supported in part by surface water runoff, measures to maintain runoff volumes and direct them towards the wetland areas will be important to maintain the function of the wetlands. Depression-focused infiltration within the wetland areas will be maintained by maintaining runoff rates to the wetlands.

It is noted that the rates presented in Table 5.13 above take into account the area included within the Study Area and ESA only, and do not account for additional infiltration resulting from runoff from the Study Area and ESA infiltrating within adjacent wetlands located outside of the Study Area and ESA. Under post-development conditions, maintenance of infiltration rates within the Study Area and ESA and runoff contributions from the Study Area and ESA to adjacent areas will be necessary to ensure the overall water balance within and outside of the Study Area and ESA is maintained.

It is noted that the estimated water balance reflects past meteorological conditions and cannot take into consideration possible changes to these conditions in the future. However, by developing the Study Area in such a way that infiltration rates and spatial distribution of infiltration are maintained, and that seasonal runoff volumes to wetlands are maintained, changes in meteorological conditions will not adversely impact recharge/runoff rates across the study any differently than if the land remained undeveloped.

### 5.4.3 Post-Development Water Balance Considerations

It is important to consider that cutting and filling during grading operations may result in different soil types being exposed at the ground surface, which would be expected to result in changes to soil infiltration rates.

Design of grading must consider shallow groundwater elevations as well as subsurface soil types to avoid the potential of localized groundwater mounding from at-source infiltration impacting footings and foundations.

As a large portion of groundwater and runoff discharges to the wetlands and creeks, levels of salt and other contaminants in the water being infiltrated must be considered. Mitigation measures such as salt management plans, potential winter by-pass of stormwater infiltration facilities, use of bioswales, and other contaminant reduction strategies should be evaluated for their applicability to the project. A combination of at-source contaminant reduction plus education of the public will help to minimize the introduction of contaminants into the natural environment.

Post-development site infiltration should be designed to attempt to match pre-development rates within the Study Area through methods such as at-source infiltration from rooftops connected to soakaway pits, where feasible. Under post-development conditions, runoff contributions from the Study Area to adjacent wetlands and other catchments should also match pre-development rates.

### 5.4.4 Post-Development Water Quality Considerations

As a large portion of groundwater and runoff discharges to the wetlands and creeks, levels of salt and other contaminants in the water being infiltrated must be considered. Mitigation measures such as salt management plans, potential winter by-pass of stormwater infiltration facilities, use of bioswales, and other contaminant reduction strategies should be evaluated for their applicability to the project. A combination of at-source contaminant reduction plus education of the public will help to minimize the introduction of contaminants into the natural environment.

Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Existing recourses such as Snow Clearing/De-Icing Guidelines which focus on the reduction in the application of de-icing salts and therefore limit their release into the environment should be used as primary strategy for managing chloride threats. This guidance is illustrated in Table 5.15 below.

**Table 5.15 Example Educational Resources – Snow Clearing / De-icing Guidelines (Aquafor Beech Ltd., 2013)**

| | RECOMMENDED APPROACH | | |
|---|---|---|---|
| OUTDOOR TEMPERATURE | RAIN/ FREEZING RAIN | SNOWING | DRIFTING SNOW |
| Greater than 0ºC | Monitor weather forecast – if temperature is forecast to rise or stay above 0ºC de-icer (salt) application is not required. | | |
| 0ºC to -10ºC | Treat slippery surfaces only. Apply de-icer (salt) sparingly, wait for ice to melt through and remove mechanically. | Remove accumulated snow. Treat slippery surfaces only with de-icer (salt). Apply aggregate for traction. | Remove accumulated snow. Do not apply de-icer (salt) as it may cause snow to stick. |
| Below -10ºC | Remove accumulated snow only. Salt is not effective at these temperatures. Apply aggregate for traction if required or use alternative de-icing compound effective at these temperatures. | | |

Table referenced from the East Side Lands (Stage 1) Master Environmental Servicing Plan and Community Plan, Final (Aquafor Beech Ltd., 2013).

Consider limiting salt use on side roads, parking lots, driveways and sidewalks to freezing rain conditions only, and remove snow mechanically. Preclude snow disposal in the vicinity of wetlands. Only sources of clean water (roof drainage, rain collection systems etc.) should be allowed to enter sensitive wetlands. Low impact development (LID) practices located where high salt (chloride) loadings are anticipated can be designed with additional safety features such as the impermeable liner (bioswale facilities with an impermeable liner) and/or inlet gates which can be closed in the winter.

By ensuring the water balance is maintained and that the water chemistry of infiltrated water is not significantly degraded, the potential impacts to the shallow overburden aquifer and on-site Guelph Northeast Provincially Significant Wetland Complex will be mitigated.

## 5.5 Potential Impacts of Land Development

### 5.5.1 Water Users

Well Records from the MOECC Water Well Record (WWR) Database were reviewed to determine the number of wells present. As shown on Figure 5.11, one-hundred-and-six wells are located within an approximate radius of 500 m from the Study Area according to the MOECC WWR database, with eighty-three wells completed in overburden soils, four wells completed in bedrock, and nineteen wells with unknown completion details. A summary of the Water Well records is included in Appendix 5.5.

It is noted that some wells on Figure 5.11 are located in areas where the actual existence of a well is unlikely (they may be associated with nearby residences or monitoring well clusters), and some residences (outside of the municipally serviced urban boundary) shown on the aerial imagery do not have a well associated with them; however, the MOECC WWR coordinate data has been used in the absence of more reliable information. It is important to consider that the subdivisions shown on Figure 5.11 are municipally serviced with water; therefore, no water supply wells would be anticipated within the subdivisions.

Of the wells listed on the appended summary, twenty-seven are identified as having a diameter of 50 mm or less indicating they are monitoring wells rather than supply wells. Additionally, three are listed as not being used and fifteen wells drilled since 2003 have no completion details. These forty-five wells have been excluded from further consideration.

Of the remaining sixty-one wells, fifty-eight wells are completed in overburden soils at depths between 4.6 and 76.5 m, and three wells are completed in bedrock at depths between 30.5 to 80.2 m.

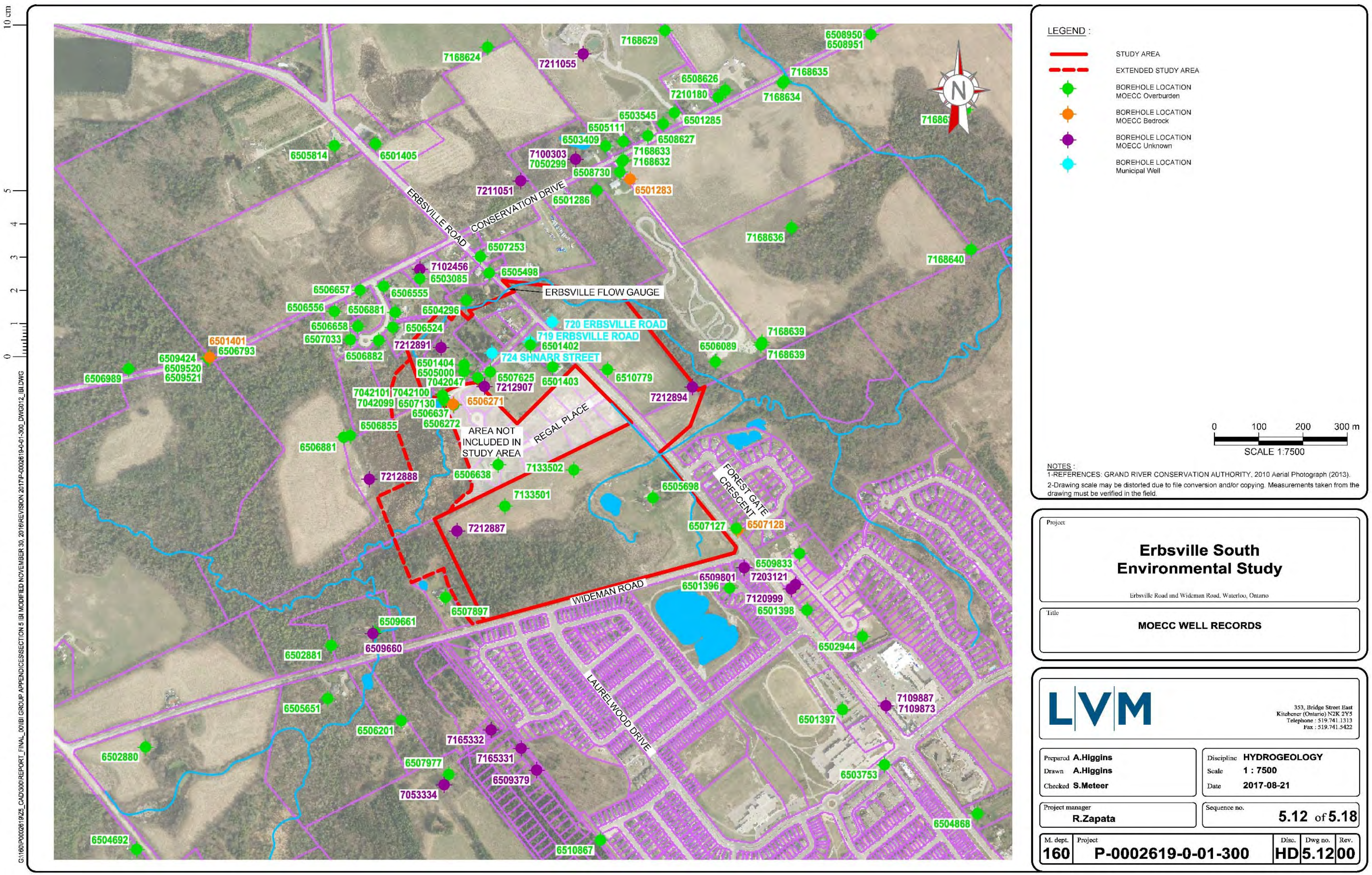


**Figure 5-11 MOECC Well Records**

It is noted the well record summary includes two municipal wells (WWR Numbers 6506637 and 7042047) located along Schnarr Street.

Maintaining the distribution of pre-development infiltration rates across the Study Area will help to preserve recharge to the Shallow Overburden Aquifer; therefore, no impacts to shallow overburden water supply wells would be expected. Wells screened in deeper overburden and bedrock aquifers are principally supplied by precipitation that infiltrates over a much broader area, and are not reliant upon infiltration within the Study Area.

As discussed in Section 5.4.2, the post-development water balance should be designed with the intention to match pre-development conditions.

### 5.5.2 Waterloo North Wellfield

In their assessment report (2012) the Lake Erie Region Source Protection Committee describes that:

> "…the water supply for the Waterloo North well field is obtained from Production Wells W5 and W10. The Region ceased full-time production at W5 in the mid to late 70's due to water quality concerns – mainly elevated TDS, hardness, iron and sulphate – and the well was physically disconnected from the IUS in 2000. An Environmental Assessment is currently underway to look at options for bringing W5 back into production. Production well W5 is screened within the Deep Overburden Aquifer at a depth of approximately 33 m BGS to 37 m BGS. Production well W10 is screened within the Shallow Overburden Aquifer at a depth of approximately 9 m to 18 m BGS, and is classified as Groundwater under the Direct Influence (GUDI) of surface water with effective filtration. These two aquifer systems are separated by a confining aquitard corresponding to the Maryhill and Catfish Creek Tills."

#### *5.5.2.1 Wellhead Protection Areas (WHPAs)*

The Grand River Source Protection Area (GRSPA) Approved Assessment Report (2012) defines Wellhead Protection Areas (WHPAs) for the studied wellfields. WHPAs correspond to the travel time of groundwater flowing through an aquifer to a municipal well. The GRSPA identifies WHPA classes as follows:

- WHPA-A: 100 m radius from a municipal supply well;
- WHPA-B: between 100 m and the 2 year travel time;
- WHPA-C: Between the 2 year and 5 year travel time;
- WHPA-D: Between the 5 year and 25 year travel time;

As shown on Figure 5.12, the development area lies within WHPA-D of W5 located within the Waterloo North municipal wellfield. It is noted that the WHPA corresponds to travel times for municipal well W5 (a deep overburden well), which is not currently active. Wellhead protection areas for municipal well ERSVTP1-06 have not been delineated as of the issue of this report.

According to the Regional Official Plan 2031 (Regional Municipality of Waterloo, 2015) the study area and the extended study area are located within a Wellhead Protection Sensitivity Area (WPSA-8), see Figure 5.13. WPSA-8 delineates the area outside the ten (10) year time of travel to the limit of the total land area contributing water to a municipal drinking-water supply well.

#### *5.5.2.2 Aquifer Adjusted Intrinsic Vulnerability*

Mapping of the intrinsic vulnerability within WHPAs is based on the Intrinsic Susceptibility Index (ISI). The ISI is intended to reflect the intrinsic degree of protection of an aquifer based on the thickness and properties of the materials overlying the aquifer, which is analogous to the vertical travel time of a contaminant to the given aquifer.

Figure 5.14 depicts the adjusted intrinsic vulnerability mapping (GRCA, 2013) of the overburden aquifer, indicating that the Study Area mostly overlaps an area of low to medium intrinsic vulnerability. The area of medium intrinsic vulnerability corresponds to a high density of private wells at this location.

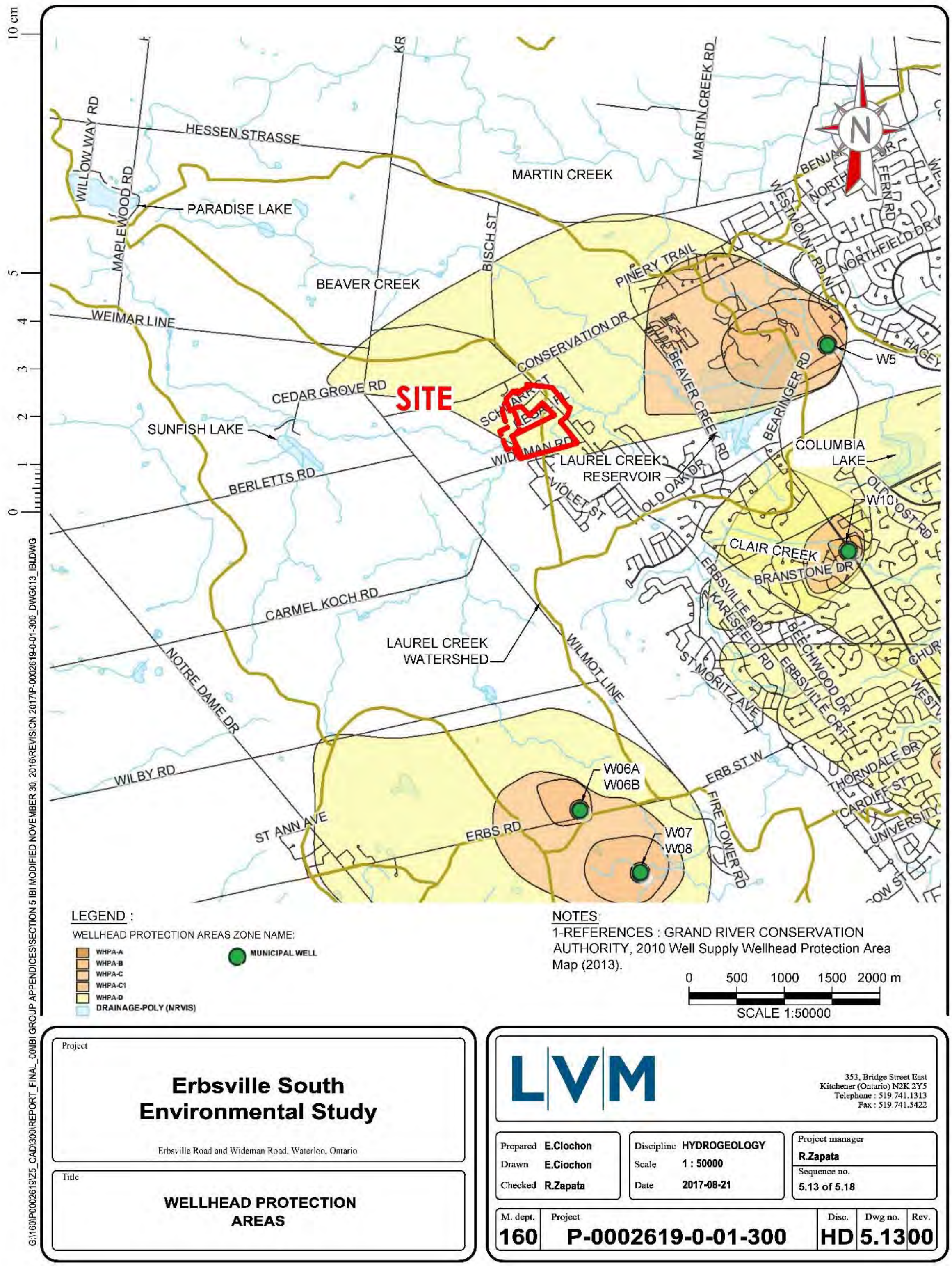


**Figure 5-12 Wellhead Protection Area**

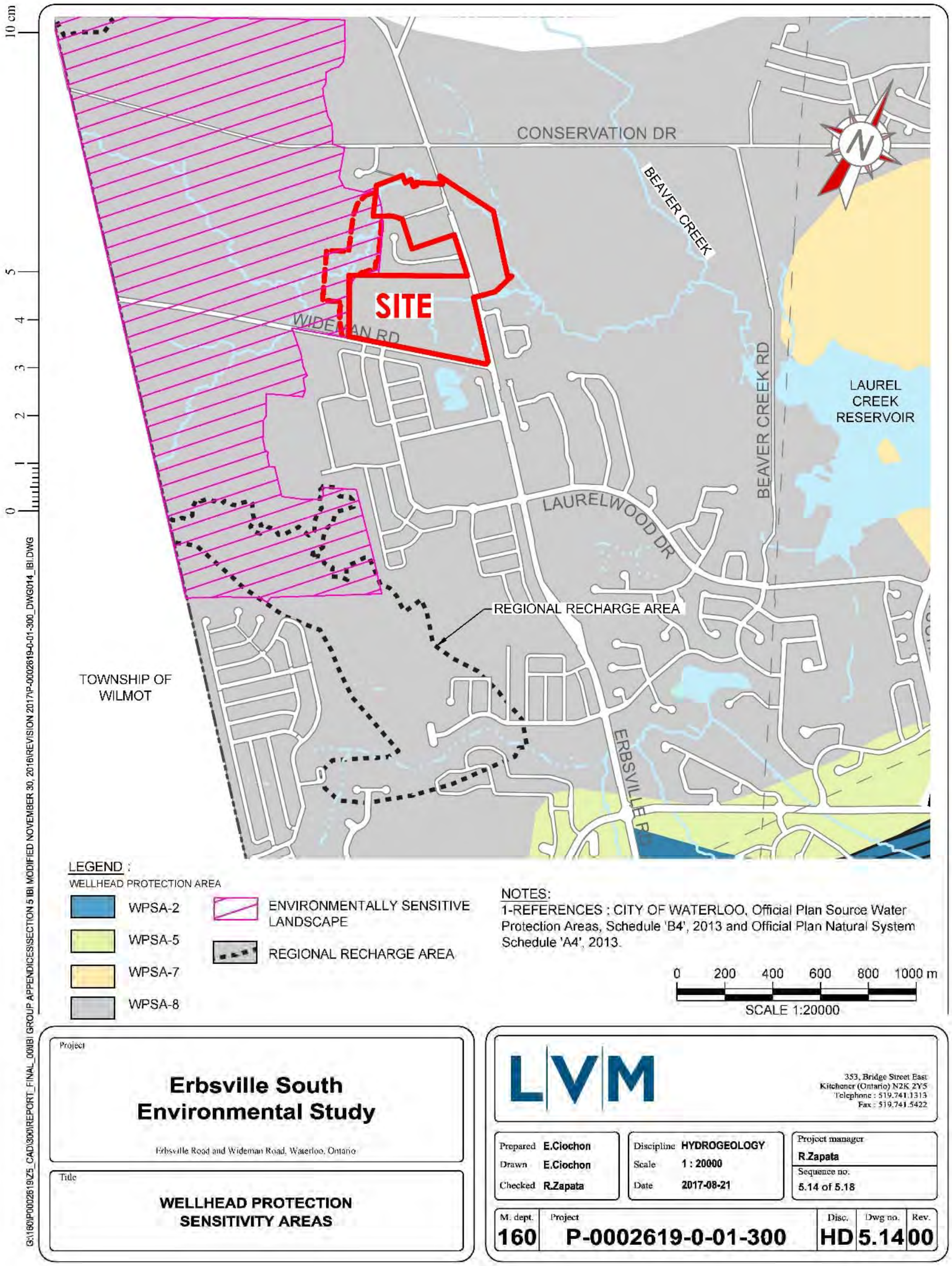


**Figure 5-13  Wellhead Protection Sensitivity Areas**

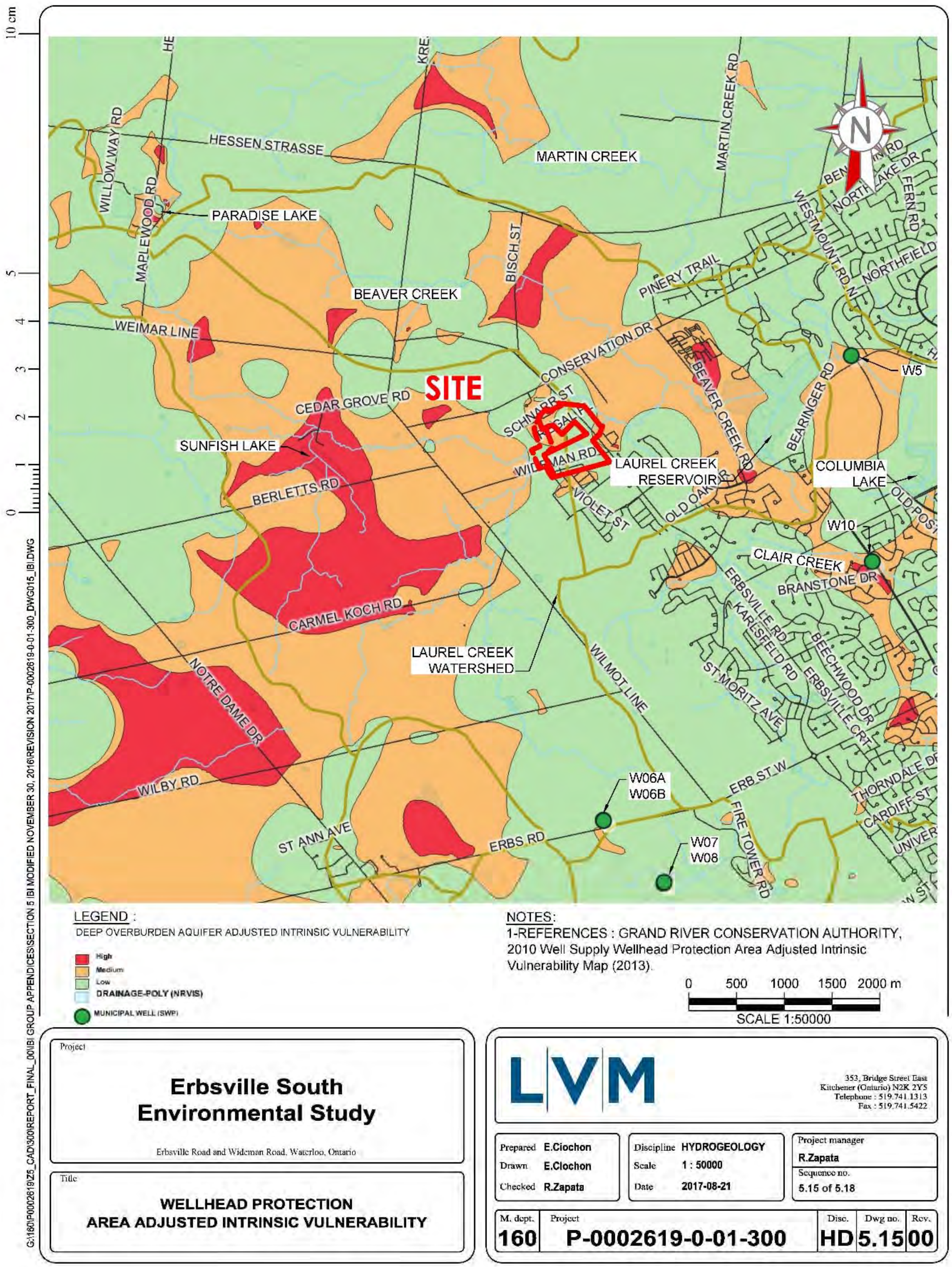


**Figure 5-14 Wellhead Protection Area Adjusted Intrinsic Vulnerability**

#### *5.5.2.3 WHPA Adjusted Vulnerability Scoring*

Wellhead Protection Area adjusted vulnerability scoring mapping combines the WHPA and the intrinsic vulnerability to provide vulnerability scoring inside the WHPA. The adjusted vulnerability score for a WHPA accounts for both the rate of vertical and horizontal movement of water to the well and range from 2 to 10, with 10 being the highest score. Generally, vulnerability scores increase in proximity to a supply well. Figure 5.15 shows the Study Area within the areas with adjusted vulnerability scores up to 4.

#### *5.5.2.4 Aquifer Vulnerability Mapping*

Figure 5.16 illustrates aquifer vulnerability designations for Significant Groundwater Recharge Areas (SGRAs) surrounding the Study Area. SGRAs correspond to areas where recharge is greater than or equal to 115% of the average recharge rate within a watershed. It is noted that no Highly Vulnerable Aquifer (HVA) areas with a score of 6 are mapped in the vicinity of the Study Area.

### 5.5.3 Other Policy Areas

Laurel Creek Headwaters, an environmentally sensitive landscape according to the Official Plan (City of Waterloo, 2014) and the Regional Official Plan 2031 (Regional Municipality of Waterloo, 2015), is shown on Figure 5.17. An outline of the regional recharge area from the Official Plan (City of Waterloo, 2014) and the Regional Official Plan 2031 (Regional Municipality of Waterloo, 2015) is also delineated on Figure 5.13. The study area and the extended study area are situated outside of the regional recharge area.

Neither the study area nor the extended study area is or would be subject to the Source Protection Plan policies as presented in Lake Erie Region Source Protection Committee (2015b) and as shown on Figure 5.17.

### 5.5.4 Chloride Impact Assessment

Groundwater chemistry may be impacted by the change in land use within the Study Area. Currently, the land use is primarily low density residential and agricultural. The development of the Study Area into residential subdivisions will reduce agricultural inputs on the lands such as fertilizers, insecticides, and pesticides. However, road salting in the winter will increase the concentration of Chlorides across the Study Area.

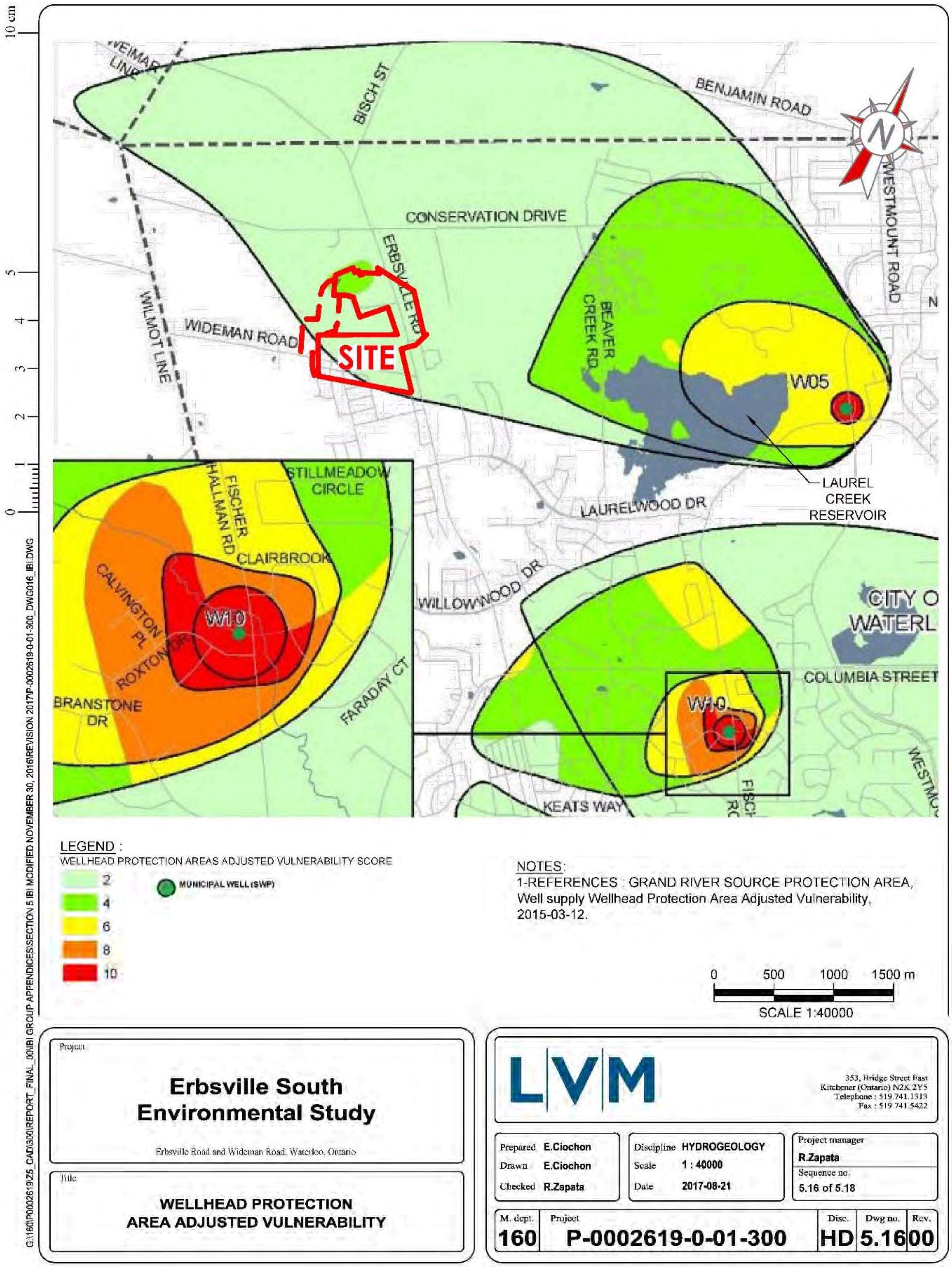


**Figure 5-15 Wellhead Protection Area Adjusted Vulnerability**

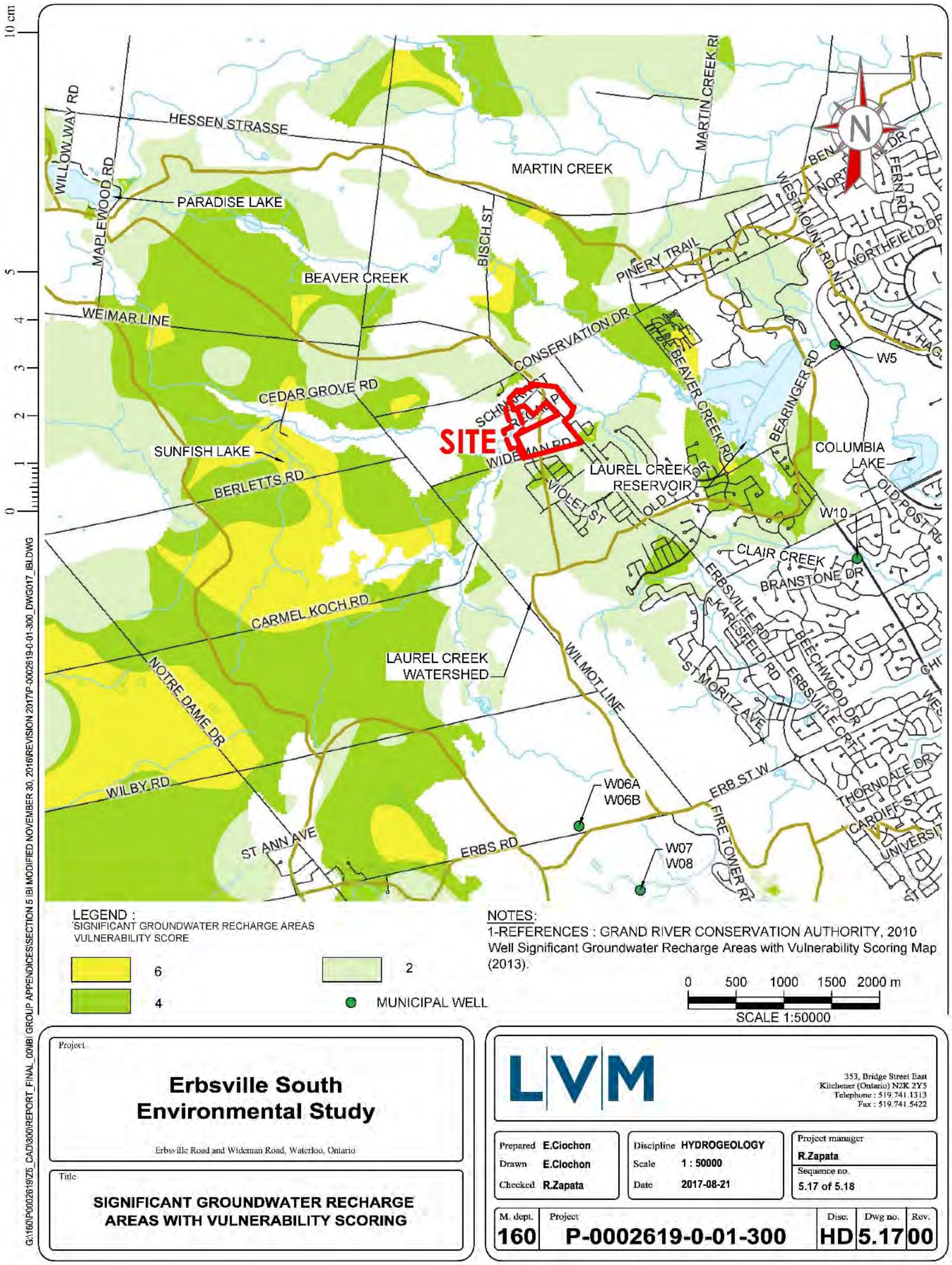


**Figure 5-16 Significant Groundwater Recharge Areas with Vulnerability Scoring**

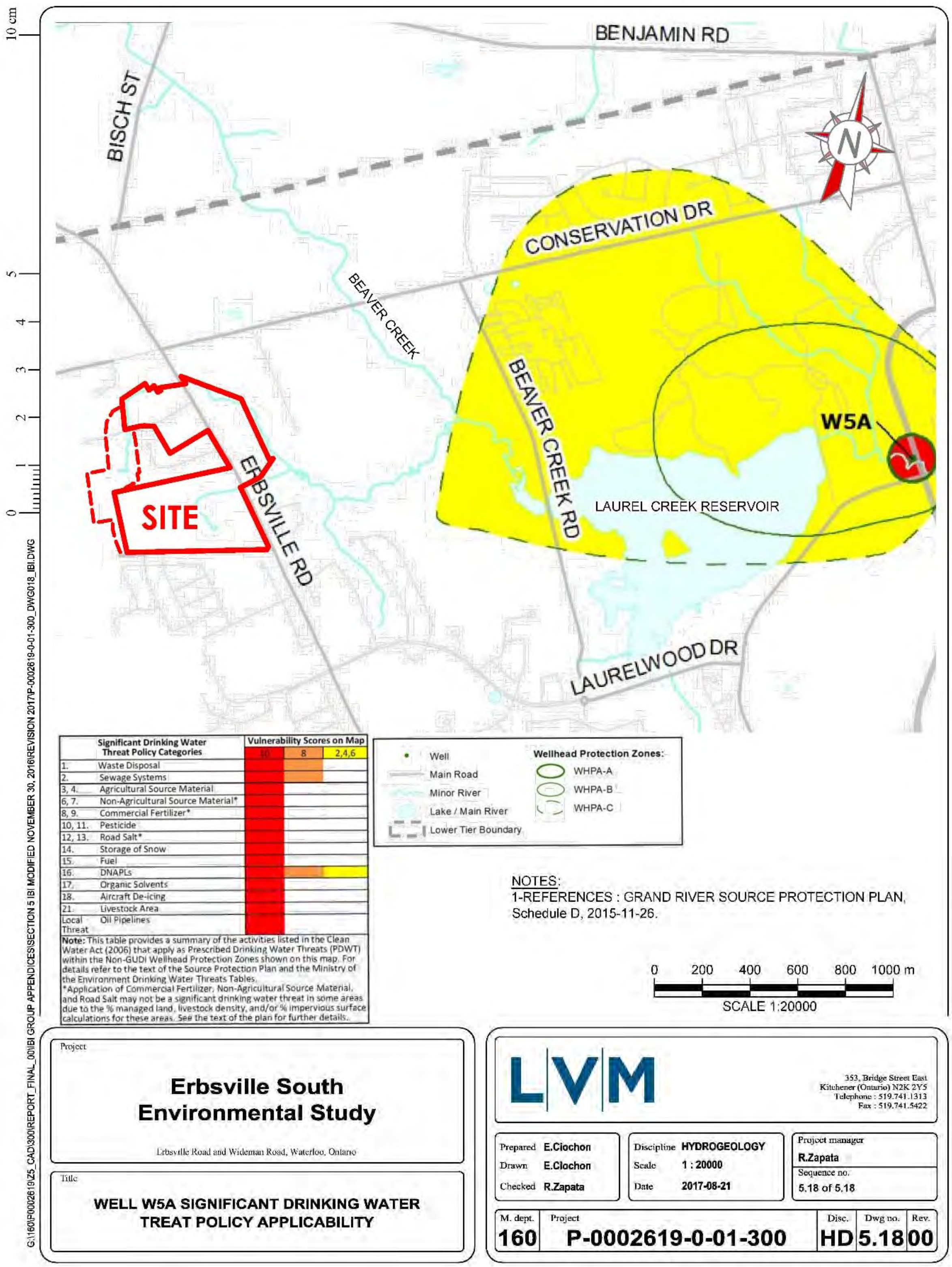


**Figure 5-17 Well WSA Significant Drinking Water Threat Policy**

#### *5.5.4.1 Sources of Chloride in Groundwater*

Chloride can be found naturally in groundwater as a result of the weathering and leaching of sedimentary rocks and soils, and the dissolution of salt deposits. Chloride may also arise in groundwater from anthropogenic sources such as leachate from dumps or landfills, water softener backwash, sewage contamination, fertilizer application, and road salt application. Chloride salts are composed of approximately 60% Chloride, and 40% positive ions such as Sodium (Na+).

The chloride to sodium ratio of dissolved salt (NaCl) is used as an indicator of the potential source. The ratio is equivalent to the ratio of their molar masses (1.54 = 35.45 g/22.99 g).

Ecoplans Ltd. carried out an impact assessment and mitigation study of the Brookville Operations Centre in Milton and surrounding lands for road salt that is stored at this location (Ecoplans Ltd., 2007). At the site, adjacent to the salt/sand storage dome (source), chloride to sodium ratios were determined to be between 1.31 and 1.74 in monitoring wells MW07-1S and MW07-1D. These values lie within the 10% concentration variability range (1.26 and 1.88) and are taken as reference.

**Table 5.16 Chloride: Sodium Ratios at Brookville Operations Centre, Milton**

| Monitoring Well | Cl mg/L | Na mg/L | Cl:Na Ratio | Date |
|---|---|---|---|---|
| MW07-1S | 2120 | 1600 | 1.33 | 30-Jul-07 |
| MW07-1S | 2169 | 1430 | 1.52 | 30-Jul-07 |
| MW07-1D | 2050 | 1570 | 1.31 | 29-Aug-07 |
| MW07-1D | 3295 | 1890 | 1.74 | 29-Aug-07 |

In proximity to the Study Area, the silt/silt till, silty sand, and sand and gravel overburden deposits are not anticipated to be significant sources of Chlorides. Additionally, in proximity to the Study Area there are no known dumps or landfills.

The application of road salt along Erbsville Road, throughout the nearby residential subdivisions, and in church and shopping centre parking lots is a possible source of Chloride impacts. Additionally, salts and metals may be used in agricultural fertilizers that are applied to the fields within and adjacent to the Study Area.

Groundwater samples were obtained from nine on-site monitoring wells on November 21 and 22, 2013/January 15, 2014, and August 15, 2014 and submitted to the ALS Environmental Laboratory in Waterloo, Ontario for analysis of general chemistry parameters including Sodium and Chloride. It is important to note that some samples were obtained from nested monitoring wells; therefore, the nine samples represent water chemistry of multiple water-bearing deposits at varying depths.

As shown on Tables 5.7 and 5.9, measured Chloride concentrations ranged between non-detectable levels and 288 mg/L over the sampling period; however, only one location (Borehole BH-04-13, November 2013 and August 2014 samples) was above 84.8 mg/L. Similarly, measured Total Sodium concentrations ranged between non-detectable levels and 181 mg/L; however, only Borehole BH-06A-13 (November 2013 sample) was above 88.4 mg/L.

Borehole BH-04-13 is located in the north-central portion of the property, directly adjacent to Erbsville Road. The borehole stratigraphy indicates a relatively continuous deposit of silty sand saturated below 2 mBGS. This near-surface groundwater could certainly be impacted by road salting operations.

Borehole BH-06A-13 is screened more than 23 mBGS, and appears to exhibit sub-artesian (confined) conditions. Borehole BH-06B-13 is screened approximately 5 mBGS, and exhibits similar sub-artesian conditions; however, the water chemistry analysis results from Borehole BH-06A-13 and BH-06B-13 show markedly different chemical compositions. It is concluded the groundwater encountered in the two wells is isolated by the approximately 5 m of this silt till layer shown in the borehole log, and that the two aquifers are hydrologically distinct.

Road salt used in de-icing operations typically results in an approximate ratio of Chloride to Sodium of 3:2 (or 1.5) by weight in groundwater. Table 5.17 below, shows the approximate ratio in the nine analyzed samples.

**Table 5.17 Chloride:Sodium Ratios**

| Borehole | DATE | $Cl^-$ [mg/L] | Total $Na^+$ [mg/L] | Cl:Na Ratio |
|---|---|---|---|---|
| BH-01A-13 | 21-Nov-13 | 11.7 | 18.0 | 0.65 |
| BH-01B-13 | 21-Nov-13 | 3.4 | 12.8 | 0.27 |
| BH-01C-13 | 21-Nov-13 | <2.0 | <5.0 | n/c |
| BH-02-13 | 15-Jan-14 | 84.8 | 88.4 | 0.96 |
| | 15-Aug-14 | 60.6 | 82.5 | 0.73 |
| BH-03-13 | 21-Nov-13 | 23.5 | 52.1 | 0.45 |
| BH-04-13 | 21-Nov-13 | 165.0 | 35.5 | 4.65 |
| | 15-Aug-14 | 288.0 | 90.3 | 3.19 |
| BH-05-13 | 21-Nov-13 | 56.6 | 26.9 | 2.10 |
| | 15-Aug-14 | 55.2 | 24.2 | 2.28 |
| BH-06A-13 | 21-Nov-13 | 6.3 | 181 | 0.03 |
| BH-06B-13 | 21-Nov-13 | 16.2 | 6.0 | 2.70 |
| | 15-Aug-14 | 15.7 | <5.0 | >3.00 |
| 724 Schnarr | 24-Jan-14 | 26.5 | 11.4 | 2.32 |
| 719 Erbsville | 24-Jan-14 | 59.2 | 26.0 | 2.28 |
| 720 Erbsville | 27-Jan-14 | 36.0 | 11.8 | 3.05 |

n/c – not calculated, as sodium and chloride concentrations were below detectable limits

The widely varying ratios indicates that road salting is likely not the sole source of Sodium and Chloride in the groundwater at the monitoring wells. In the opinion of the Region of Waterloo (written communication), winter road salting has already impacted the water resources in the Study Area to some degree, although the chloride levels are relatively low and not unprecedented compared to other rural-suburban mixed settings within the Region. Agricultural fertilizers (Sodium Nitrate, Calcium Chloride, and Potassium Chloride) are considered a minor source for salt.

#### *5.5.4.2 Calculated Groundwater Chemistry Impacts from Road Salt Application*

In order to evaluate the potential for road salt application to impact groundwater, the MOECC Reasonable Use Policy (Guideline B-7) can be applied to calculate the maximum allowable concentration of Chloride in groundwater at the property boundary.

Reasonable Use Guideline B-7 establishes limits on discharge of contaminants to groundwater, with considerations for existing or potential down-gradient use. The Guideline takes into account the parameter of concern; being Chloride in this case, its background concentration in shallow groundwater, whether the parameter is health related or of aesthetic concern, and the Ontario Drinking Water Standard (ODWS) for that parameter (i.e., 250 mg/L for Chloride).

The Chloride concentration limit in shallow groundwater at the down-gradient subject property boundary can be calculated using the following formula from the Reasonable Use Guideline:

$$C_m = C_b + x[C_r - C_b]$$

where:

$C_m$ – maximum acceptable concentration of contaminant in shallow groundwater at the down-gradient property boundary (mg/L).

$C_b$ – background concentration of contaminant in shallow groundwater (taken as 84.8 mg/L for Chloride at BH-02-13, the second-highest measured concentration on site, as BH-04-13 is considered anomalous).
This assumption is a conservative measure, as it results in a lower calculated acceptable Chloride concentration.

$C_r$ – ODWS criteria limit (250 mg/L for Chloride).

x – constant; 0.5 for non-health-related parameters.

Using the formula above, the calculated maximum acceptable concentration of Chloride ($C_m$) at the down-gradient property boundary is 167.4 mg/L.

The measured chloride concentrations in BH-04-13 were 165 and 288 mg/L. Chloride in BH-04-13 likely reflects unnaturally high concentrations affected by road salting operations rather than a reasonably high natural background concentration. Accepting a high value of 288 mg/L as background concentration of contaminant in shallow groundwater $C_b$ would lead to a higher (less conservative) value of 269 mg/L for the maximum acceptable contaminant concentration in shallow groundwater at the down gradient property boundary $C_m$.

The projected future impact of salt applications can be estimated once road layouts and lengths are provided.

### 5.5.5 Sensitive Areas

#### *5.5.5.1 Wetlands*

Wetlands are sensitive to changes in seasonal runoff volumes, and changes in shallow groundwater elevations. Runoff, coupled with groundwater inputs from the Shallow Overburden Aquifer, increases the surface area of the wetlands.

Based on the general shallow groundwater flow direction and elevation, and the groundwater contours converging towards Laurel Creek, it is concluded that Laurel Creek and its associated wetlands are partially dependent on groundwater flowing from (and discharging from) the Study Area. The groundwater contours on Figure 5.7 indicate that a portion of groundwater discharges into the Creek.

As a result, any detrimental changes to the pre-development water balance, causing a reduction in the volume of runoff to the wetlands or lowering of groundwater levels in the Shallow Overburden Aquifer, would adversely impact this ecosystem and result in a reduction in size of this habitat, due to the gentle slope of the ground surface within and in proximity to the wetlands.

#### *5.5.5.2 Streams*

Post-development runoff from the Study Area is not expected to drain directly into surface water features. Wetlands on and in proximity to the Study Area will likely receive runoff treated by SWM facilities, plus clean runoff from naturalized areas. The proposed at-source infiltration infrastructure and SWM facilities across the Study Area will mitigate the potential for impacts to streams (and wetlands) by matching pre-development infiltration and runoff rates.

## 5.6 Groundwater and Surface Water Monitoring Requirements

A long-term monitoring program is proposed for the study area, including the extended study area during pre-development (2 years in advance of grading as per the City of Waterloo), construction, and guarantee period (minimum of 2 years). Monitoring comprises continuous recording of groundwater and surface water levels. It involves manual measurements of groundwater table depths, estimating stream flows, and sampling for water quality analyses in well installations, including mini-piezometers installed in wetlands, streambeds and in projected stormwater ponds.

Pre-construction monitoring will assist in determining a baseline for the study area, including the extended study area. Monitoring of the stormwater management practices implemented for the site will be included into the monitoring program during the construction stage. Corrective measures will be employed as required in the event of operation and function change. After substantial completion of the development the monitoring program intervals will continue in a reduced form (post-construction monitoring) and will be adjusted to any constructed mitigative measures placed on-site.

The final monitoring protocol, including locations and the monitoring frequency, will be determined in consultation with GRCA and Region and City of Waterloo staff. The proposed monitoring parameters and frequency are listed in Tables 5.18 and 5.19. A dual sampling approach (filtered and unfiltered) in selected wells is recommended for comparison purposes (Puls & Barcelona, 1989). Well installations removed during construction or destroyed need to be replaced, e.g. BH1 was destroyed. The results of the monitoring program (pre-, during, and post-construction) will be reported on an annual basis.

**Table 5.18 Monitored Parameters**

| WATER BODY | PARAMETERS |
|---|---|
| Groundwater (GW) | Manual measurements of groundwater table depths in all well installations and continuous groundwater level recording with data-loggers in selected well installations |
| | Sampling and analysis of chemical parameters Na, Cl, Br, $NO_3$, P, dissolved $O_2$ and pH; physical parameters T, TDS, TSS, turbidity and E.C.; and biological parameters E. coli |
| Wetland | Manual measurements of groundwater table depths in all mini-piezometers and continuous groundwater level recording with data-loggers in selected mini-piezometers |
| Surface Water (SW): Laurel Creek, Wideman Creek and tributary to Wideman Creek | Manual measurements of surface water levels in all streambed mini-piezometers and continuous surface water level recording with data-loggers in selected streambed mini-piezometers, including data of Erbsville flow gauge from GRCA (No. 8785042) |
| | Sampling (upstream, in stream and downstream locations) and analysis of chemical parameters Cl, P, dissolved $O_2$; physical parameter TSS |
| | Flow and baseflow rate measurements at selected locations within various stream reaches |
| Stormwater Management Ponds (SWMP) | Manual measurements of surface water levels in all stormwater management pond mini-piezometers and continuous surface water level recording with data-loggers in selected in-pond mini-piezometers |
| | Sampling at inlet and outlet locations and analysis of chemical parameters Cl, P, dissolved $O_2$; physical parameter TSS |
| | Flow rate measurements at discharge locations of stormwater management ponds |

**Table 5.19 Proposed Monitoring Frequency**

| | ITEM | PRE-CONSTRUCTION | DURING CONSTRUCTION | POST-CONSTRUCTION |
|---|---|---|---|---|
| GW | Level | Quarterly | Quarterly | Quarterly |
| | Chemistry | Bi-annual | Bi-annual | Bi-annual |
| Wetland | Level | Quarterly | Quarterly | Quarterly |
| SW | Level | Quarterly | Quarterly | Quarterly |
| | Chemistry | Monthly (March to November), 1 rainfall event within 24 hours (flush) 3 dry weather events (low flow conditions) | Monthly (March to November), 1 rainfall event within 24 hours (flush) 3 dry weather event (low flow conditions) | 1 rainfall event within 24 hours (flush) and 1 dry weather event (low flow conditions) per season |
| | Flow Rate | Monthly (March to November), 1 rainfall event 3 dry weather events | Monthly (March to November), 1 rainfall event 3 dry weather events | 1 rainfall event and 1 dry weather event per season |
| SWM Ponds | Level | na | Quarterly | Quarterly |
| | Chemistry | na | Monthly (March to November), 1 rainfall event 3 dry weather events | 1 rainfall event and 1 dry weather event per season |
| | Flow Rate | na | Monthly (March to November), 1 rainfall event 3 dry weather events | 1 rainfall event and 1 dry weather event per season |