APPENDIX A
Revised Tier 3 Water Budget and Local Area Risk Assessment, Long Point Region, Physical Characterization Report

REVISED

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT
LONG POINT REGION
PHYSICAL CHARACTERIZATION REPORT

Report Prepared for:
LAKE ERIE SOURCE PROTECTION REGION

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July 2013
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TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

LONG POINT REGION

PHYSICAL CHARACTERIZATION REPORT

Report prepared for Lake Erie Source Protection Region, July 2013

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DISCLAIMER

We certify that this report is accurate and complete and accords with the information available during the site investigation. Information obtained during the site investigation or provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care and diligence in assessing the information obtained during the preparation of this report.

This report was prepared for Lake Erie Source Protection Region. The report may not be relied upon by any other person or entity without our written consent and that of Lake Erie Source Protection Region. Any uses of this report by a third party, or any reliance on decisions made based on it, are the responsibility of that party. We are not responsible for damages or injuries incurred by any third party, as a result of decisions made or actions taken based on this report.

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1 INTRODUCTION

The Province of Ontario introduced the Clean Water Act (Bill 43; Ontario Ministry of Environment [MOE] 2006) to ensure that all residents have access to safe drinking water. Under the Clean Water Act, Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate any significant threats to either the quality or the quantity of drinking water supplies.

The Ministry of Environment released the Technical Rules: Assessment Report (MOE 2009) that describes the technical work required by municipalities to inventory the threats posed on their water supplies. With respect to water quantity, municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) to assess the water quantity risk placed on their groundwater or surface water sources. In instances where a municipality is predicted to be unable to meet their estimated future demands, the municipality will be required to identify the significant threats that may prevent them from meeting their future demands.

The Project Team for the Tier Three Assessment was directed by a technical team comprised of representatives from the Lake Erie Source Protection Authority, Norfolk County and the County of Oxford, Ministry of Natural Resources (MNR), and Ministry of the Environment (MOE). The Consultant Project Team responsible for the completion of the pilot project included AquaResource Inc. (AquaResource; Primary Consultant), Stantec Consulting Ltd., (Stantec), and Blackport and Associates (Blackport).

1.1 Clean Water Act Water Budgets

The Province's approach to completing water budgets and identifying drinking water quantity threats follows a three-tiered approach, whereby the studies begin at a Tier One Assessment and become progressively more detailed as outlined below:

1. Complete a Tier One Water Budget and Stress Assessment (Tier One Assessment) to identify subwatersheds that have a moderate or significant potential for stress.

2. Complete a Tier Two Water Budget and Subwatershed Stress Assessment (Tier Two Assessment) for the subwatersheds classified in the Tier One Assessment as having a moderate or significant potential for stress; and,

3. Conduct a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) for the municipal water supply systems present within subwatersheds classified as having a moderate or significant potential for stress in the Tier Two Assessment. As part this Tier Three Assessment, municipalities must delineate water quantity vulnerable areas for their drinking water systems,

estimate the water quantity risk level, and identify moderate or significant drinking water threats within these areas.

The primary objectives of the Tier One and Tier Two Assessments are to estimate the hydrologic stress that may exist within subwatersheds as a result of anthropogenic water takings. When following this process, the hydrologic stress is estimated based on a calculation of Percent Water Demand. Percent Water Demand is an estimate of the amount of water being consumed within a subwatershed, compared to the total amount of water available. The calculated Percent Water Demand of a subwatershed is then compared to threshold values published in the MOE Technical Rules (MOE 2009), and the subwatershed's hydrologic stress is classified (low, moderate, or significant).

Tier One Assessments are water budget studies that are developed using a GIS, or similar tool, to assess water budget components on a regional scale. Tier One Assessments classify the water quantity stress for each subwatershed in the Study Area as '*low*', '*moderate*', or '*significant*'. Subwatersheds classified in the Tier One Assessment as having a *moderate* or *significant* potential for stress require a Tier Two Water Budget and Subwatershed Stress Assessment. Subwatersheds classified in the Tier One as having a *low* potential for stress do not require additional studies at this time, as the studies found the availability of water far outweighs the demand and the Tier One Assessment is sufficient for local decision-making.

Tier Two Assessments are more detailed water budget studies than the Tier One Assessments. The Tier Two studies use three-dimensional groundwater flow models or continuous surface water flow models to examine the water budget components in the watershed and subwatersheds within the Study Area. Subwatersheds classified as having a *Moderate* or *Significant* potential for stress and contain a drinking water system identified in the Terms of Reference for that Source Protection Area, require a Tier Three Assessment. As above, the subwatersheds classified in the Tier Two as having a *Low* potential for stress do not require any additional studies at this time.

The Technical Rules: Assessment Report (MOE 2009) outlines the methodology and scenarios required for the Tier Three Assessment; in general, vulnerable areas (e.g. Local Areas) are delineated and a risk level is assigned based on the results of detailed water budget modelling. If the risk level for the vulnerable area is classified as *significant*, all consumptive water users will be classified as significant drinking water threats (details provided in MOE 2009).

The Tier Three Assessment uses detailed groundwater and/or surface water models. These models should be developed with the accuracy and refinement needed to evaluate hydrologic or hydrogeologic conditions within the local area and, whenever warranted by available data, should be refined from the Tier Two models. The models must be developed with sufficient spatial scale to evaluate the potential impacts of each demand on the water source. The scale of the model must also be sufficient to estimate the impact of future demands on the water supplies and other water users.

All numerical studies have a degree of uncertainty associated with the model inputs. The uncertainties with the model input parameters and their potential impact on the model results need to be acknowledged and quantified. As such, the uncertainties and model limitations, including the uncertainty associated major water balance components and primary study predictions will be discussed in the Tier Three Risk Assessment report.

1.1.1 Lake Erie Source Protection Region Water Budget Assessments

The Grand River Conservation Authority (GRCA), Long Point Region Conservation Authority (LPRCA), Catfish Creek Conservation Authority (CCCA), and Kettle Creek Conservation Authority (KCCA) together form the Lake Erie Source Protection Region. The Study Area (**Appendix A**, **Figure 1-1**) is defined by the Long Point Region, Catfish Creek and Kettle Creek Conservation Authority boundaries. Boundaries for each Conservation Authority are based on hydrologic boundaries (surface water divides). As part of the Clean Water Act, a Tier Two Water Budget and Subwatershed Stress Assessment (Tier Two Assessment) was completed for the Long Point Region, Catfish Creek, and Kettle Creek Conservation Authorities (**Figure 1-1**; AquaResource 2009a, 2009b). This Tier Two Assessment identified the following municipal supplies within subwatersheds that have a Moderate or Significant potential for hydrologic stress:

- Waterford (Groundwater), Simcoe (Groundwater), and Delhi (Groundwater and Surface Water) in Norfolk County
- Tillsonburg (Groundwater) in Oxford County

As a result, a Tier Three Water Budget and Local Area Risk Assessment for the Waterford, Simcoe, Delhi and Tillsonburg water supply systems is required to evaluate the likelihood that each of the communities may not be able to meet their current or planned water demands. If the risk level in the Local Area is classified as Moderate or Significant, water quantity threats located within the areas will be identified.

1.2 Study Area Description

The Tier Three Assessment Area (**Figure 1-1**) includes the Towns of Waterford, Simcoe, Delhi, and Tillsonburg, which are located within Norfolk and Oxford Counties. While the focus of this investigation is on the lands immediately surrounding these communities (Focus Area on **Figure 1-1**), portions of this report will include characterization for the entirety of Long Point Region, Catfish Creek and Kettle Creek Conservation Authorities (Watershed boundary on **Figure 1-1**).

The primary watercourses that are applicable to the Tier Three Focus Area include: Big Otter Creek which flows through the Town of Tillsonburg; Big Creek which flows through the Town of Delhi; Lynn River which flows through the Town of Simcoe; and Nanticoke Creek which flows through Waterford (**Figure 1-1;** GRCA 2011). Various tributaries feed these larger creeks and numerous wetland complexes can be found along the creek and river valleys.

Land use within the Study Area is predominantly agriculture-based, with additional minor occurrences of various natural heritage features (e.g. wetlands), forests, and urban areas (**Figure 1-2)**. While the 2006 population estimate of residents within the Long Point/Catfish/Kettle Creek watersheds is 112,971, the total population of Tillsonburg, Delhi, Simcoe, and Waterford, make up a third of this (GSP Group Inc. [GSP] 2010). The communities of Simcoe, Waterford and Tillsonburg are completely reliant upon groundwater for their municipal water supplies. The Town of Delhi relies on groundwater sources for approximately 90% of its annual supply, with the remainder supplied from a surface water intake from North Creek, a tributary of Big Creek.

1.3 Previous and Concurrent Studies

A number of regional- and local-scale groundwater studies have been carried out, or are currently underway, within the Study Area. These studies provided information on the geology and hydrogeology of the area and are summarized below.

1.3.1 Subwatershed Scale Water Resources Studies

The following list outlines some of the surface water and groundwater studies that have relevant input into the development of the conceptual geological and three-dimensional groundwater flow model:

- Watershed Characterization Reports completed for Catfish Creek (Lake Erie Source Protection Region Technical Team [Lake Erie SPRTT] 2008a), Kettle Creek (Lake Erie SPRTT 2008b) and the Long Point Region (Lake Erie SPRTT 2008c). These studies provide a conceptual overview of the important hydrogeologic and hydrologic features within the watersheds.

- Watershed Assessment Reports for the three watersheds (Lake Erie Region Source Protection Committee [Lake Erie Region SPC] 2010a, 2010b, 2011). These reports summarize water supply vulnerability, water quality threats, and water quantity threats.

- Water quality studies for the three watersheds (GRCA and Kettle Creek Conservation Authority [KCCA] 2006; GRCA 2007a, 2007b). These studies describe surface water quality in each watershed.

- Water use studies for the three watersheds (GRCA 2005a, 2005b, 2005c). These studies identify various water uses within each watershed.

- Tier Two Water budget study for the three larger watersheds (AquaResource 2009a) and the Big Creek Water Budget Study (Gamsby and Mannerow Inc. et al. 2002). These studies utilize various tools, including surface and groundwater flow models, to help quantify the various components of the hydrologic cycle.

- Norfolk Municipal Groundwater Study (Waterloo Hydrogeologic Inc. [WHI] et al. 2003). This study characterized the groundwater flow system, groundwater susceptibility, water use, contaminant threats, and capture zones to support groundwater protection and management in the Long Point Region Conservation Authority area.

- Norfolk Agricultural Water Assessment and Management Strategy (AMEC Earth and Environmental [AMEC] 2008). This report identified water demand and supply for irrigation purposes in four subwatersheds in the Big Creek Watershed and suggested management strategies.

- Oxford County Groundwater Protection Study: Phase II (Golder Associates Ltd. [Golder] 2001). This study characterized each well supply system in Oxford County including creation of wellhead protection areas, aquifer mapping, and identification of aquifer vulnerability, groundwater quality, contamination sources, and water use.

- Long Point Region Conservation Authority, Groundwater Resources Inventory Project (WHI 2004).

1.3.2 Local Scale Municipal Water Resources Studies

Various local studies have been commissioned to help manage groundwater supplies. These reports provide analyses and discussion on the local (hydro)geology and groundwater/surface water interactions:

- water system technical studies in Oxford County (County of Oxford 2009a, 2009b); these two studies detail the groundwater vulnerability and the water quality of water systems in Oxford County
- water resource studies for the Big Creek Drainage Basin (Yakutchik and Lammers 1970) and the Big Otter Creek Drainage Basin (Sibul 1969)
- Kent Creek Water Balance - Cedar Street Pumping Station Impoundment (Schroeter and Associates [Schroeter] 2008); preformed a water balance exercise for Kent Creek as it flows through the Simcoe Cedar St. Wellfield
- Water and Wastewater Master Plans - Norfolk County (Vallee and Hydromantis Inc. 2008)
- Water Supply Master Plan for Oxford South (R.J. Burnside Associates Ltd. [Burnside] and XCG Consultants Ltd. [XCG] 2010)
- Simcoe Water Supply EA (Banks, in progress)
- South Oxford Groundwater Investigation (Burnside and XCG 2010)
- County of Norfolk, Delhi Groundwater Investigation and Testing Program (International Water Consultants [IWC] 2010a)
- Engineers’ Report for the Delhi Water Works (MacViro Consultants Inc. [MacViro] 2001a)
- Engineers’ Report for the Simcoe Water Works (MacViro 2001b)
- Engineers’ Report for the Waterford Water Works (MacViro 2001c)
- Groundwater Under Direct Influence (GUDI) Hydrogeological Study for Delhi Municipal Water Supply System (MacViro 2002a)
- GUDI Hydrogeological Study for Simcoe Municipal Water Supply System (MacViro 2002b)

- Hydrogeological Study to Assess the Influence of Surface Water on the Tillsonburg Wells (Burnside 2002)
- Norfolk County, Waterford Municipal Well System Hydrogeologic Study (GUDI; Lotowater Ltd. [Lotowater] 2002)

1.3.3 Numerical Groundwater Modelling Studies

Several groundwater models have been developed within the Study Area with each model designed to improve the understanding of different portions of the groundwater system and/or the interaction between the groundwater flow system and surface water features. The following outlines the groundwater flow models completed within the Study Area:

- Oxford County Groundwater Protection Study: Phase II (Golder 2001). This study utilized a numerical groundwater flow model to delineate wellhead protection areas for each municipal water supply using MODFLOW and MODPATH.

- Big Creek Basin Water Budget Study *(*Gamsby and Mannerow et al. 2002). Study utilized GAWSER and data analysis to identified water management options to reduce impact of summertime water takings within Big Creek.

- GUDI Hydrogeological Study for Delhi Municipal Water Supply System (MacViro 2002a). A portion of this GUDI study involved utilizing MODFLOW to carry out a Well Head Protection Area Delineation and create capture zones for the area surrounding the municipal water supplies of the Town of Delhi.

- GUDI Hydrogeological Study for Simcoe Municipal Water Supply System (MacViro 2002b). Similar to the GUDI study of Delhi, this GUDI study the Town of Simcoe used the three-dimensional MODFLOW model to delineate Well Head Protection Areas and capture zones for the municipal wells.

- Norfolk Municipal Groundwater Study (WHI et al. 2003). This study modelled wellhead protection areas in the Long Point Region Conservation Authority area using FEFLOW.

- Catfish Creek (Schroeter 2006a), Kettle Creek (Schroeter 2006b) and Long Point Region (Schroeter 2006c) Watershed Hydrologic Models. These studies utilized GAWSER to develop a model of the hydrology of their respective watersheds.

- Extension of the Norfolk Groundwater Model (WHI 2007). The FEFLOW groundwater model developed for the Long Point Region was extended into the adjacent Catfish Creek and Kettle Creek watersheds.

- Water budget studies for the Catfish Creek, Kettle Creek, and Long Point Region watersheds (AquaResource 2009a) and the smaller watershed of Big Creek (Gamsby and Mannerow et al. 2002).

These studies utilize various tools, including GIS systems and surface water (GAWSER) and groundwater (FEFLOW) flow models, to help quantify the various components of the hydrologic cycle.

1.4 Report Organization

This report is organized into the following sections:

Section 1: Introduction - describes the framework for this study as well as the location, purpose and a brief review of relevant studies that have been undertaken, or are underway in the Study Area.

Section 2: Physical Setting - describes physical features of the Study Area such as topography, physiography, surface water systems.

Section 3: Geologic Setting - describes the geology of the Study Area. This includes descriptions of the bedrock geology and topography, Quaternary geology and local-scale geology.

Section 4: Hydrostratigraphic Setting - describes the hydrostratigraphic units, including properties of these units. A brief summary of the corehole drilling program undertaken as part of the Tier Three Assessment is also provided.

Section 5: Municipal Demands - describes the current municipal water demands within the Study Area. This section also outlines the Town of Tillsonburg, Waterford, Delhi, and Simcoe monitoring well networks within the Study Area. The water levels of these wells will be used as calibration targets in the groundwater flow model.

Section 6: Non-Agricultural Groundwater Demands - describes the permitted non-agricultural water demands within the Tier Three Focus Area that surrounds the communities of Simcoe, Delhi, Waterford and Tillsonburg.

Section 7: Summary

Section 8: References

2 PHYSICAL SETTING

2.1 Topography

Regionally throughout the three Conservation Authorities, the ground surface topography ranges from approximately 340 m above sea level (asl) along the crest of the St. Thomas Moraine found in the northern part of the Study Area, to a low of approximately 174 masl along the Lake Erie shoreline (**Figure 2-1**). Within the Tier Three Focus Area, ground surface topography varies from a high of 307 m asl on the St. Thomas Moraine in the northwest to a low of 190 m asl in the southern reaches of the Study Area along the valleys of Big Otter Creek, Big Creek, and Lynn River (**Figure 2-1**). Across much of the central portion of the Study Area, and the area in between moraines, the ground surface topography is relatively flat to gently rolling (Barnett 1982).

Regional topographic highs are associated with various moraines including the Westminster, St. Thomas and Norwich Moraines northwest of Tillsonburg, the Tillsonburg Moraine which trends southwest and northeast of Tillsonburg, the Courtland and Mabee Moraines south of Tillsonburg, the Paris Moraine northeast of Delhi, and the Galt and Moffat Moraine within and northwest of Waterford. These moraines are illustrated on **Figure 2-2.** Low lying areas along the shoreline of Lake Erie and incised valleys caused by Big Otter Creek (through Tillsonburg), Big Creek (through Delhi), Lynn River (through Simcoe), Catfish Creek, and Kettle Creek represent the main topographic lows within the Study Area.

2.2 Physiography

Portions of five physiographic areas are present within the three Conservation Authorities including: Norfolk Sand Plain; Mount Elgin Ridges; Horseshoe Moraines; Haldimand Clay Plain; and the Ekfrid Clay Plain (Chapman and Putnam, 1984). All of these regions except the Ekfrid Clay Plain are found in the Tier Three Focus Area. These physiographic regions are described in the following subsections and their distribution is illustrated on **Figure 2-2**.

2.2.1 Norfolk Sand Plain

The Towns of Tillsonburg, Delhi, Simcoe, and Waterford are found within the physiographic region known as The Norfolk Sand Plain which borders the Mount Elgin Ridges to the northwest, the Horseshoe Moraines to the northeast, the Haldimand Clay Plain to the east, and the Ekfrid Clay Plain to the west (Chapman and Putnam 1984). This region is characterized by relatively flat to undulating glaciolacustrine deltaic deposits of sands (up to 27 m thick) and silts which are observed to cover or partially cover the moraines in the area (Chapman and Putnam 1984; Barnett 1982). The moraines rise up to 23 m above the surrounding terrain, whereas the Big Otter and Big Creeks have incised into this plain up to 38 m (Chapman and Putnam 1984; Barnett 1982). While some finer-grained sands exist, the local soils are predominantly coarse-grained and both the coarse and fined grained sands have been historically well suited to the tobacco farming industry (Chapman and Putnam 1984). More recently, the type of crop planted is in a state of flux as acreage devoted to tobacco production has declined, with the acreage devoted to fruits, vegetables and ginseng increasing. Anecdotal evidence does suggest that the decline in tobacco acreage has ceased, and may have started to increase again.

2.2.2 Mount Elgin Ridges

The Mount Elgin Ridges physiographic region is located in the area north of Tillsonburg. This region is characterized by alternating ridges and valleys composed of Huron clay/silt loam soils and Perth silt loam soils respectively (Chapman and Putnam 1984). The ridges rise up to 37 m above the surrounding landscape, and represent various moraines, including the Ingersoll, Westminster, St. Thomas and Norwich (Barnett 1982). The St. Thomas and Norwich Moraines are found just to the west of the Tier Three Focus Area, and the orientation of their ridges follow the orientation of the modern Lake Erie shoreline (Barnett 1982). The valleys of the region are relatively flat-lying and represent glacial meltwater channels (Barnett 1982).

2.2.3 Horseshoe Moraines

The Horseshoe Moraines region represents the southward extent of the Galt and Paris Moraines. The Paris Moraine is located just to the east of Delhi, while the Galt Moraine is located to the west of Simcoe. This area is characterized by the irregular ridges of the Tillsonburg and Paris Moraines that rise out of the surrounding level outwash plains and mark retreating positions of the Erie-Ontario lobe of the Laurentide Ice Sheet of the most-recent glaciation (Barnett 1978). The moraines in this area are primarily composed of the Wentworth Till, but outwash deposits, glaciolacustrine deposits, and stratified drift also make up the structure of the ridges (Barnett 1978). Well-drained surficial soils, categorized as Huron clay loam, can be found both on and off the moraine (Chapman and Putnam 1984).

2.2.4 Haldimand Clay Plain

The Haldimand Clay Plain region is located in the eastern portion of Long Point Region, and along the eastern edge of the Focus Area near the Towns of Waterford and Simcoe where the terrain transitions to the Norfolk Sand Plain to the west. The region formed as a result of glaciolacustrine processes related to Lake Warren (Chapman and Putnam 1984) and, as the name implies, the region is dominated by clay and is relatively flat (Barnett 1978). In areas farther to the north where the clay deposits are among moraines and relief increases, the clay thins and is interbedded with till (Chapman and Putnam 1984). Soils of the region are predominantly fine-grained, which often prevents adequate drainage, but coarser grained soils are also locally present (Chapman and Putnam 1984).

2.2.5 Ekfrid Clay Plain

The Ekfrid Clay Plain region can be found in the western portion of Catfish and Kettle Creek Conservation authorities, bounded by the Norfolk Sand Plain and the Mount Elgin Ridges. This region is characterized by relatively flat, stratified clay deposits, but in the St. Thomas area, the deposit is thin and bouldery (Chapman and Putnam 1984). Soils in the Ekfrid Clay Plain region are fine-grained and do not readily drain (Chapman and Putnam 1984).

2.3 Surface Water Features

Surface water features (such as rivers, streams, wetlands and lakes) impact shallow groundwater flow and are an important part of the development of a conceptual model. The following sections outline the information that guided the development of the conceptual model of the groundwater and surface water interactions in the Tier Three Focus Area.

2.3.1 Rivers and Creeks

In the western portion of the Focus Area, Big Otter Creek and Cedar Creek are the primary surface water features which flow through and converge in the Town of Tillsonburg (**Figure 2-3**). Where Big Otter Creek enters the Town from the northeast after bisecting the Tillsonburg Moraine near Otterville, Cedar Creek enters the Town from the northwest and flows in a southeast direction through Tillsonburg. The confluence of the two creeks occurs in the southern part of Tillsonburg, before Big Otter Creek continues to the southwest and ultimately drains into Lake Erie. Over the course of its length, Big Otter Creek (with a total drainage area of 712 km^2; Sibul 1969) has an average gradient of 1.1 m/km and is deeply incised, with the river valley lying up to 40 m below the adjacent lands, south of Tillsonburg (Chapman and Putnam 1984).

Various smaller tributaries provide flow to Big Otter and Cedar Creeks and lie adjacent to some of the north-eastern municipal water supplies for the Town. A larger tributary of Big Otter Creek, Little Otter Creek (drainage area of 118 km^2; Lake Erie SPRTT 2008c), flows 2.3 km to the south of the southern-most municipal wells.

Big Creek is the main watercourse which flows into the central portion of the Focus Area from the north near Teeterville, between the Tillsonburg and Paris Moraines, through the western side of the Town of Delhi, and south out of the Focus Area where it ultimately enters Lake Erie (**Figure 2-3**). The Big Creek Watershed is the largest watershed in the Focus Area with a total drainage area of 750 km^2 (Lake Erie Region SPC 2011), containing 13 tributary streams (Yakutchik and Lammers 1970). Within Delhi, the Big Creek tributaries of North and South Creeks converge from the west and are dammed to form the Lehman Reservoir before entering Big Creek. Lehman Reservoir is a source of municipal water for the Town of Delhi, and is included in this Risk Assessment. On average, along its entire length, Big Creek has a gradient of 1.4 m/km and near Delhi, and has a narrow valley depth of 23 m (Chapman and Putnam 1984). At the southernmost portion of the Focus Area, the valley width increases forming a flood plain (Chapman and Putnam 1984). The groundwater municipal wells for Delhi, which lie several kilometers southwest of the Town, are located within approximately 500 m of Stony Creek, which enters Big Creek from the east.

In the eastern portion of the Focus Area (**Figure 2-3**), Nanticoke Creek flows southward into the Town of Waterford where it flows in and amongst the Waterford Ponds before taking a 90 degree turn to the east, across the Galt Moraine, before flowing towards and joining Lake Erie. Both of Waterford's municipal wells are located on the banks of the Waterford Ponds. In contrast to the creeks already described, the Nanticoke has a lower gradient of approximately 0.5 m/km (Barnett 1978). A number of other tributaries enter Nanticoke Creek from the southwest, via a series of online ponds formed by historical aggregate extraction activities. The municipal wells of Waterford lie immediately adjacent to these ponds.

South of Waterford, Patterson and Davis Creeks flow southward and converge in the northern part of the Town of Simcoe to form the Lynn River. The Lynn River then flows south for approximately 670 m where it is then joined by Kent Creek from the west. With an average gradient of 1.2 m/km (Barnett 1978), Lynn River continues through the Town of Simcoe before ultimately flowing to the southeast and into Lake Erie. Similar to the communities described above, tributaries of the larger Lynn River (i.e., Patterson and Kent Creeks) flow within 20 m of municipal groundwater wells.

2.3.2 Thermal Regimes

The thermal regime of a river or stream can provide a general indication of the groundwater and surface water interaction. Groundwater discharge is important to the watercourses within the Long Point Region as the upwelling areas are critical for fisheries spawning and also in maintaining a moderate temperature and flow in creeks and streams. The rate of groundwater discharge into the creeks and rivers depends on the elevation of the water table in the area surrounding the creek (which varies seasonally), as well as the hydraulic conductivity of the streambed materials. The thermal regimes (Aquatic Resource Area; LIO 2010) of the surface water features found in the Study Area can be found mapped on **Figure 2-3**.

Coldwater streams, which support coldwater fish communities such as brook and brown trout, are prevalent across the Tier Three Focus Area, especially in areas where coarser surficial sediments of the Norfolk Sand Plain are present at ground surface (Lake Erie SPRTT 2008c). Conversely, the majority of warm water streams, which support the fish species of bass, pike, perch, bullhead, and catfish are found where the terrain transitions to finer-grained tills in the north and the Haldimand Clay Plain in the east (**Figure 2-3**; Lake Erie SPRTT 2008c). In these areas, surface runoff will increase, resulting in lower infiltration and reduced discharge to streams (Lake Erie SPRTT 2008c).

In the western portion of the Focus Area (**Figure 2-3**), coldwater streams have been mapped along Big Otter Creek, both above, within, and below the Town of Tillsonburg. Similarly, the entire lengths of Cedar Creek and Little Otter Creek were observed to support coldwater fisheries. The only stream mapped as warmwater is an unnamed stream which enters the Town from the north, flows through the small Lake Lisgar, and enters Big Otter Creek just above the Cedar Creek confluence.

In the central portion of the Focus Area, coldwater stream conditions exist along the length of Big Creek and the majority of South Creek. Below the Town of Delhi, similar conditions exist along Stony Creek and its tributaries which are found approximately 450 m north of the Delhi municipal supply wells. Warmwater conditions have been mapped upstream of the Lehman Reservoir, in both the tributaries of North Creek and South Creek. Further upstream, near the Village of Teeterville, additional warmwater conditions have been recognized in the tributaries of Big Creek stemming from the eastern flanks of the

Tillsonburg Moraine. The only coolwater conditions in the Focus Area have been observed in portions of tributaries of North Creek, northwest of Delhi.

In the vicinity of the Town of Waterford, in the north-eastern portion of the Focus Area, a mix of cold and warmwater conditions exist as the terrain transitions from the Norfolk Sand Plain (to the west) to the Haldimand Clay Plain (to the east) (Lake Erie SPRTT 2008c). Except for minor warmwater tributaries north of Waterford, stream conditions entering the town from the north and south are predominately coldwater. Once Nanticoke Creek leaves the Waterford Ponds, and flows further downstream, it becomes a warmwater fishery.

Finally, in the south-eastern portion of the Focus Area, above the Town of Simcoe, tributaries of Lynn River (i.e., Patterson and Davis Creeks) have been mapped as containing exclusively coldwater groundwater discharge areas. West of Simcoe, the headwaters of Kent Creek have been observed to support warmwater fish communities. However, it transitions to coldwater fisheries approximately 2 km upstream of the municipal supply wells, on the western edge of town. Other than the small, warmwater, tributary headwaters of Spring Creek, the Lynn River leaves the Focus Area as a coldwater stream below Simcoe.

2.3.3 Reservoirs

While there are many water control structures within the Tier Three Focus Area, very few of these actively control the release of water. The water control structures, and associated reservoirs are typically run-of-river structures that use overflow weirs (fixed elevation or stop-logs) to control the upstream water level. Due to the design of such outlet structures, outflow typically equals inflow on a daily basis, and cannot be used to release stored water during dry periods to augment low flows. Examples of such structures include the Teeterville Reservoir in Teeterville (along Big Creek), Mill Pond in Otterville (along Big Otter Creek), and Crystal Lake in Simcoe (along Lynn River; Lake Erie SPRTT 2008c).

The exception to these passive structures is the Lehman Dam Reservoir, which was constructed in 1963 and is located west of the Town of Delhi (AECOM Canada Ltd. [AECOM] 2010). This 5 hectare reservoir was formed by damming South Creek and North Creek and it supplies part of the drinking water supply for the Town of Delhi (AECOM 2010). With a maximum depth of 5 m, the water from the reservoir is blended with the groundwater-derived water supply, and subsequently delivered to the population as a single system (AECOM 2010). In addition to the municipal water supply source, the reservoir also regulates stream flow for recreational fishing (Lake Erie SPRTT 2008c; AECOM 2010). As coldwater fish communities have been recognized to spawn upstream of the dam, the Lehman Dam is also equipped with a fishway to facilitate trout movement in that direction (Lake Erie SPRTT 2008c).

The normal lake elevation of the reservoir is 215.3 m asl, with a maximum pool elevation of 217.3 m asl. The reservoir storage at an elevation of 215.3 m asl is 89,400 m^3. In addition to the fishway, there are three potential outflows from the reservoir. These include: the drinking water intake; an overflow structure (215.27 m asl); and a spillway (crest elevation 215.5 m asl). The drinking water intake has two controlled openings, at elevations of 212.77 and 211.8 m asl. The lower intake is not in regular operation (AECOM 2010). Included as part of the overflow structure, is a submerged gate that could be used to draw down the lake elevation to 210.7 m asl. It is not known the last time this gate was operated.

2.3.4 Lakes and Ponds

A cluster of small surface water bodies, known as the Waterford Ponds, exists on the western edge of the Town of Waterford. These bodies represent former gravel pits which are now used for recreation (Chapman and Putnam 1984). The ponds/lakes have coarse-grained subsurface materials and are located in close proximity to the municipal groundwater wells whose pumping is thought to cause surface water infiltration (Lake Erie SPRTT 2008c). Similarly in the Northwest Well Field of the Town of Simcoe, the municipal supply wells lie within 10 m of former sand and gravel pits which have since infilled with groundwater and lie adjacent to the upper reaches of Patterson Creek.

Additional small ponds can be found in the town of Tillsonburg (Lake Lisgar found along a tributary of Big Otter Creek) and in Simcoe (Sutton's Pond found along the southern reaches of Patterson Creek).

Irrigation ponds are a common source of water for the area's agricultural irrigators. This has resulted in a large number of constructed ponds within the Norfolk Sand Plain. Due to the shallow water table throughout much of this physiographic area, most irrigation ponds are depressions that have been excavated to such a depth that the water table is intersected. Typically these constructed ponds are disconnected from the surface water drainage system, and are maintained by groundwater inflows.

2.3.5 Significant Wetland Complexes

In addition to streams and reservoirs, groundwater discharge also supports a number of local wetlands (**Figure 2-4**). Small bogs and swamps of varying thickness can be found in the Study Area within glacially-derived depressions of kettle holes (up to 6 m thick), lake plains (up to 2 m thick), flutings (up to 2 m thick), and meltwater channels (up to 2 m thick) (Barnett 1978; 1982). Wetlands classified as "Provincially Significant" make up the bulk of the Wetlands found in the Tier Three Focus Area (**Figure 2-4**). In the western portion of the Focus Area, two groups of Provincially Significant Wetlands exist north of the Town of Tillsonburg. To the northwest (approximately 4 km), the Dereham Wetland exists in the lowlands in between the Norwich and St. Thomas Moraines. To the northeast of Tillsonburg (~1.3 km), a wetland known as Hughes Tract can be found just north of the Tillsonburg Moraine, in the upper reaches of Plumb Creek (a small tributary of Big Otter Creek). To the southeast of Tillsonburg, located just north of the Village of Courtland, and at the northern tip of the Courtland Moraine, a group of small pockets of Provincially Significant and other mapped wetland complexes (Lake Erie SPRTT 2008c) are present amongst small tributaries and drains of Little Otter Creek. Additional Provincially Significant Wetlands (Courtland Swamp Complex) are located on the southern side of the Courtland Moraine, south of Little Otter Creek (Lake Erie SPRTT 2008c).

In the central portion of the Focus Area, small areas of Provincially Significant Wetlands can be found along the entire length of Big Creek including a small area found 180 m east of the Lehman Reservoir surface water Intake in the Town of Delhi. The closest Provincially Significant Wetlands to Delhi's municipal wells are located 1.3 km north (Nixon Ellaton Wetlands), 1.7 km east (Kent Creek Complex) and 2 km west along Stony Creek. An additional wetland (BC26) was mapped approximately 1.4 km to the southeast.

The municipal groundwater wells found in the eastern portion of the Focus Area are exclusively surrounded by Provincially Significant Wetlands. These wetland complexes follow the Nanticoke Creek and its southern tributaries into the Town of Waterford, where they border and surround the surface water features of the Waterford Ponds and the Waterford municipal wells.

In the south-eastern part of the Focus Area, named and unnamed significant wetland complexes follow the Patterson, Davis, and Kent (Kent Creek Complex) Creeks, past, and even encompassing, the majority of the municipal production wells on their way into the Town of Simcoe.

3 GEOLOGIC SETTING

An understanding of the regional and local geologic environment provides a sound basis for investigation of the groundwater flow conditions and the interaction between the groundwater system and surface water features. Bedrock formations, lithology and bedrock topography are described below, followed by a discussion of the Quaternary overburden deposits, their distribution, and thickness within the Long Point Region, Catfish and Kettle Creek Conservation Authorities (Regional Area).

3.1 Paleozoic Bedrock

The Regional Area is underlain by a series of gently dipping Paleozoic sedimentary rocks consisting of deep-water shales interbedded with shallow water carbonate rocks (dolostone and limestone) and sandstone. These rocks are overlain by a variable thickness of overburden sediments that were laid down since the Nissouri Stade glacial period of the Late Wisconsinan (starting approximately 25,000 years ago; Barnett 1992). Paleozoic rocks outcrop in only a few areas in the east near Hagersville; however, in the remainder of the Study Area these rocks are buried beneath a thick veneer of Quaternary-aged (2,000,000 years to 10,000 years ago) and Holocene (10,000 years to present) sediments. Dolostone and limestone of the Dundee, Lucas, Amherstburg, Onondaga, Bois Blanc, Bass Islands/Bertie, and Salina Formations underlie the area, with shales of the Marcellus Formation subcropping areas along the north shore of Lake Erie.

Due to the thick accumulations of sand and gravel near the surface, the domestic water wells within the Study Area are typically shallow and completed in the upper 10 to 30 m of the overburden. In the eastern portions of the Long Point Region where the Haldimand Clay Plain (**Figure 2-2**) commonly extends from ground surface to top of rock, the upper portions of the Dundee Formation bedrock are commonly used for domestic water supplies (WHI et al. 2003).

In the Norwich area, northeast of Tillsonburg (**Figure 1-1**), the Norwich municipal wells are completed in the bedrock of the Detroit River Group, which consists of the Lucas Formation, a microcrystalline limestone, and the underlying Amherstburg Formation, a crinoidal limestone and dolostone (Johnson et al., 1992). The bedrock geology of the Study Area was assembled by the Ontario Ministry of Northern Development and Mines (MNDM) in 2007 (MNDM 2007), and this mapping is presented on **Figure 3-1** and listed in **Table 1** below (youngest formations listed at the top of the table and the oldest deposits at the bottom), and is followed by more detailed descriptions of each formation. It is noted that several other bedrock formations underlie the Salina and are excluded from **Table 1**, notably the units associated with the Guelph Formation, the Lockport Formation, the Clinton-Cataract Group and the Queenston Formation. These units subcrop far to the east of the Study Area, and once within the Study Area are at a significant depth below ground surface. As a result, it is assumed they are not part of the active groundwater flow system and not discussed further. This approach of excluding deeper bedrock units follows the Long Point Tier 2 Water Budget and Stress Assessment (AquaResource, 2009b).

Table 1 Bedrock Geology Underlying the Regional Area

Formation	Group	Lithology	Approx. Thickness[1] (m)
Marcellus		Black, organic-rich shales, interbedded with grey shales and carbonates. Interbeds are very fine to medium grained and fossiliferous (limestone), and somewhat calcareous (shale).	Up to 12
Dundee		Light brown-grey, fossiliferous limestone and minor dolostones. Medium to thickly bedded and microcrystalline.	35 - 45
Lucas	Detroit River Group	The Anderdon Member of the Lucas Formation consists of an upper medium-grained, fossiliferous sandy limestone, and a lower fine-grained locally fossiliferous limestone.	0 - 47
Amherstburg		Brown limestone and dolostone. Commonly fossiliferous, bituminous, and cherty	Up to 60
Onondaga		Cherty, fossiliferous limestones	?
Bois Blanc		Grey-Brown, crystalline, cherty, fossiliferous limestones and dolostones. Often thin- to medium-bedded and fine- to medium-grained	3 to 50
Bass Islands / Bertie		Brown-grey, dolostones and minor shales. Often argillaceous, bituminous, crystalline, variably laminated, and contains minor fossil content.	10 to 90
Salina		Brown-buff-grey, characterized by evaporites (i.e. halite, gypsum, and anhydrite), shales, and carbonates (dolostone and limestone)	?

[1] Estimated thicknesses from Armstrong and Carter 2010

(Yakutchik and Lammers 1970; Barnett 1982; Armstrong and Carter 2010)

3.1.1 Marcellus Formation

The Marcellus Formation subcrops within the Catfish and Kettle Creek Conservation Authorities, just south of Alymer and St. Thomas (**Figure 3-1**). The formation is characterized by black organic-rich shales interbedded with grey calcareous shales and very fine- to medium-grained and fossiliferous limestone (Armstrong and Carter 2010).

3.1.2 Dundee Formation

The Dundee Formation is the youngest formation that occurs from the southeast to the northwest in the Tier Three Focus Area, and is found to subcrop beneath the Towns of Tillsonburg, Delhi, and the southern half of the Town of Simcoe (**Figure 3-1**). The formation is comprised predominantly of limestones, and to a lesser extent dolostones, which are medium- to thickly-bedded (Armstrong and Carter 2010). The formation is 35 to 45 m thick in Ontario, and is found close to surface (7 m below ground surface [bgs]) approximately 4.5 km upstream of Tillsonburg, along Big Otter Creek (Armstrong and Carter 2010; Barnett 1982).

3.1.3 Lucas Formation (Detroit River Group)

The Lucas Formation is the youngest unit of the Detroit River Group that is subcrops in the Tier Three Focus Area near the Town of Simcoe (**Figure 3-1**). The Lucas Formation is characterized by brown, microcrystalline limestones and dolostones that are often sandy and contain evaporite beds (Barnett 1982; Armstrong and Carter 2010). Just northwest of the Focus Area, near Ingersoll, the Lucas Formation was identified in a quarry and further refined into the Anderdon Member limestone and the Anderdon Member sandy limestone (Armstrong and Carter 2010). Where the Anderdon Member limestone is fine-grained with thin to medium bedding, the Anderdon Member sandy limestone is notably sandier and coarser grained with thicker bedding (Armstrong and Carter 2010). Near Ingersoll the formation is 47 m thick, and in Norfolk County the unit pinches out completely (Armstrong and Carter 2010).

3.1.4 Amherstburg Formation (Detroit River Group) and Onondaga Formation

The Amherstburg and Onondaga Formations are laterally equivalent to each other (Armstrong and Carter 2010) and thus are discussed together. The transition from the Onondaga in the east/southeast to the Amherstburg in the north/northwest occurs under the northern portion of the Tillsonburg Moraine in the Focus Area. In the area beneath the Town of Waterford and the northern part of the Town of Simcoe, only the Onondaga Formation is observed to subcrop. While the Amherstburg is composed of limestones and dolostones, the Onondaga is primarily composed of limestones (Armstrong and Carter 2010). Both formations are cherty and fossiliferous, but the Amherstburg is described as bituminous with a fine- to coarse-grained texture and the Onondaga is characterized as argillaceous (contains clay sediments) in some areas (Armstrong and Carter 2010).

3.1.5 Bois Blanc Formation

The Bois Blanc Formation subcrops in the north-eastern part of the Focus Area, north of Waterford (**Figure 3-1**). This unit is characterized by limestones and dolostones which are grey-brown, cherty, and fossiliferous (Barnett 1982; Armstrong and Carter 2010). The formation is fine to medium grained and thin to medium bedded (Armstrong and Carter 2010). Locally, the formation ranges from 38 m thick in Ingersoll to 3 m thick at Innerkip (Cowen 1975).

3.1.6 Bass Islands Formation and Bertie Formation

The Bass Islands/Bertie Formations subcrop in the northeastern portion of the Focus Area, north of Waterford (**Figure 3-1**). The two formations are thought to be laterally equivalent and thus are discussed together. These formations are comprised predominantly of dolostone and, to a lesser extent, shales with the Bertie Formation (Armstrong and Carter 2010). Both formations are characterized as brown to grey, bituminous, argillaceous (containing clay sediments), very fine to fine crystalline with minor fossil content (Armstrong and Carter 2010). The formations are known to reach thicknesses of 90 m and locally reach up to 150 m thick (Armstrong and Carter 2010).

3.1.7 Salina Formation

The Salina Formation subcrops north of Waterford (**Figure 3-1**). The formation is comprised predominantly of evaporites (i.e. halite, gypsum, and anhydrite), shales, and carbonates and reaches a thickness of 420 m near Sarnia (Armstrong and Carter 2010). The shallow units of the formation change from carbonate-dominated to evaporite-dominated and the relative proportion of shale increases as well (Armstrong and Carter 2010).

3.2 Bedrock Surface Topography

A major unconformity separates Paleozoic bedrock formations from overlying Quaternary overburden deposits across Ontario. This unconformity represents the period between the deposition of the Paleozoic bedrock and the deposition of overlying Quaternary sediments, approximately 200 million years later. During this period, the Paleozoic bedrock surface was exposed and extensively eroded (Johnson et al. 1992). The bedrock topographic surface reflects the erosion and drainage patterns that were established during that time period.

The bedrock surface elevation mapping of Southern Ontario was developed by the Ontario Geological Survey (OGS) in 2006 (Gao et. al. 2006), and this mapping is presented on **Figure 3-2**. Across the Regional Area the bedrock topography ranges from a high of approximately 265 m asl in the northern portions, to a low of 50 m asl in areas along the Lake Erie shoreline (**Figure 3-2**). More specifically in the Tier Three Focus Area, bedrock topography varies from a high of 235 m asl in the north-western portion of the Focus Area to approximately 150 m asl along the southern boundary of the Focus Area (**Figure 3-2**). The bedrock surface generally slopes fairly uniformly to the south towards Lake Erie, without any evidence of significant buried bedrock valleys.

3.3 Quaternary Geology

3.3.1 Regional Glacial History

The sedimentary record of southern Ontario provides a record of historic climate change and sediment deposition throughout the Quaternary Period (last 2,000,000 years). Glacial deposits laid down prior to the Nissouri Stadial (commencing approximately 25,000 years ago) of the Late Wisconsinan Glacial Stage (starting ~115,000 and ending ~10,000 years before present), were not mapped to exist within the Regional Area and therefore, the following sections focus on the most recent Late Wisconsinan sediments. Till plains are generally the most continuous and extensive glacial sediments in an area and they offer the most information when reconstructing the glacial history of an area. In general, subglacial till sheets (commonly aquitards) are laterally extensive across regional areas, whereas glaciofluvial sands or kame deposits (aquifers) may be deposited on a smaller scale in more isolated areas. In this area, glaciolacustrine sands and clays were deposited on a fairly regional scale and represent local and regional aquifers (sand plains) and aquitards (clay plains).

During the Late Wisconsinan, the Laurentide Ice Sheet advanced southward through southern Ontario into Ohio and Indiana in the United States as a large continental-scale ice sheet (Barnett 1992). The ice front advanced forward during cold periods (glacial stades) and retreated when the climate temporarily warmed (glacial interstades) leaving behind a complex subsurface sedimentological record. As the Laurentide advanced over southern Ontario, it scoured the Paleozoic bedrock surface and reworked the vast majority of pre-existing glacial and interglacial sediments. The Late Wisconsinan lasted from 115,000 years ago (115 ka) to 10,000 years ago (10 ka; Dreimanis and Goldthwait 1973). This period is divided into several different stades and interstades, and it was during this period that the Laurentide Ice Sheet reached its most southerly extent, advancing through Ontario extending into the United States. It was also during the Late Wisconsinan that the Laurentide thinned and formed a series of lobes, each moving independently of one another at different rates, and in different directions.

Overburden within the Regional Area was predominately deposited by the Erie lobe, or at times by the Ontario-Erie lobe, when the two lobes temporarily coalesced. The discussion of Quaternary deposits found within the Regional Area progresses chronologically from oldest to youngest deposits, with a summary timeline including the glacial substages, stades/ interstades and deposits listed in **Table 2**. Surficial geology for the Regional Area is presented on **Figure 3-3** (OGS 2003) and was mapped and compiled by the Ontario Geological Survey.

Table 2 Summary of Late Wisconsinan Deposits Identified in the Regional Area

Age (years before present)	Glacial Period	Associated Deposit
12,500 - present	Post-glacial	Modern alluvium, organic deposits, Long Point spit, eolian sand dunes
13,500 - 13,000	Port Huron Stade	Wentworth Till, Norfolk Sand Plain, Haldimand Clay Plain and intervening coarse-grained sediments
14,000 - 13,500	Mackinaw Interstade	Paris/ Galt Moraines
15,500 - 14,000	Port Bruce Stade	Port Stanley Till, fine-grained glaciolacustrine deposits, coarse-grained intervening deposits, several end moraines (e.g., St. Thomas, Norwich, Ingersoll, Westminster, Tillsonburg, Courtland and Mabee Moraines)
16,500 - 15,500	Erie Interstade	Fine and coarse-grained glaciolacustrine deposits
25,000 - 18,000	Nissouri Stade	Catfish Creek Till

(After Barnett 1992)

3.3.1.1 Nissouri Stade and Sedimentary Deposits

The onset of the Nissouri Stade (25,000 to 18,000 years ago; Barnett 1992) marked the initial advance of the Laurentide Ice Sheet southward through Ontario into the United States (Dreimanis and Goldthwait 1973; Barnett 1992). This ice advance deposited the stoney Catfish Creek Till within the Regional Area. The Catfish Creek Drift is mapped as stacked layers of lodgement till, stratified glaciofluvial and glaciolacustrine sediment, and supraglacial till (deVries and Dreimanis 1960; Dreimanis 1982; Barnett 1978, 1992). The sandy silt till reaches a total thickness of up to 23 m (Barnett 1982, 1992) and overlies bedrock in the Study Area. The till is often described as “hardpan” in driller’s logs due to its high stone content and hardness.

The till occurs primarily as a buried till plain across the Long Point, Catfish and Kettle Creek Conservation Authority jurisdictions (jurisdictions shown on **Figure 1-1**) and thins in the eastern areas of the Regional Area (**Figure 3-3**; Barnett 1978, 1982). Catfish Creek Till was noted in the high quality coreholes, especially in the northernmost coreholes, but thickness was minimal (< 3 m).

At the end of the Nissouri Stade, the continental-scale ice sheet began to thin and break up forming a series of lobes that were focused within the Lake Huron, Erie, Ontario and Simcoe basins.

3.3.1.2 Erie Interstade and Sedimentary Deposits

The climate warmed during the Erie Interstade, a period that was estimated to have taken place between 16,500 and 15,500 years ago (Barnett 1992). It was during this period that the ice margin of the Erie-Ontario lobe retreated eastward to the Niagara Escarpment (Dreimanis and Goldthwait 1973) leading to the formation of a series of large ice contact lakes at the southern ends of Lakes Michigan, Erie and Huron (Barnett 1992).

Elevated lake levels in the Lake Erie basin caused portions of the Regional Area to be inundated, and a blanket of fine-grained silts and clays was deposited on top of the Catfish Creek Till (Barnett 1982, 1992). Although subsequent ice advances may have removed substantial portions of the Erie Interstade sediment record, the fine-grained nature of the overlying tills (e.g., Port Stanley Till) suggests the ice lobes were overpassing and reworking previously deposited glaciolacustrine mud (Barnett 1993).

Within the Catfish Creek and Kettle Creek watersheds, the Catfish Creek Till and the overlying Port Stanley Till are separated by a discontinuous layer of glaciolacustrine sediments that are up to 4 m thick and texturally vary from well-sorted sand to clay (Schwartz 1974). These sediments are interpreted to have been laid down during the Erie Interstadial.

3.3.1.3 Port Bruce Stade and Sedimentary Deposits

The climate cooled following the Erie Interstade and this led to the onset of the Port Bruce Stade (approximately 14,800 years ago; Barnett, 1992) and the second advance of the Laurentide Ice Sheet into the United States during the Late Wisconsinan. In the early stages of the Port Bruce Stade, the southward advancing Laurentide Ice Sheet blocked the drainage outlet for the Lake Erie basin leading to the formation of a large glacial lake (Lake Leverett) in the Erie basin. This led to the deposition of glaciolacustrine silts and clays in some portions of the Regional Area including the town of Bayham located approximately 15 km south of Tillsonburg (**Figure 3-3**; Barnett 1982). As the ice continued to advance southward, the Ontario and Erie ice lobes coalesced and overrode (and incorporated) fine-grained glaciolacustrine sediments deposited during the Erie Interstade. This led to the subglacial deposition of the Port Stanley Drift as the ice sheet moved radially outward from the centre of the Lake Erie basin across the Study Area (Barnett 1982, 1992).

Port Stanley Drift is mapped as interbedded glaciolacustrine sediment and fine-grained subglacial till (Barnett 1982, 1992). Within the Regional Area, the `till complex' consists of up to 5 layers of subglacial till separated by glaciolacustrine sediments resulting from lake level fluctuations within the Lake Erie basin (Barnett 1982; 1992). Further inland, the Port Stanley Till consists of only one layer of subglacial till with associated glaciofluvial sediments (Barnett 1992). The Port Stanley Till is buried beneath younger glaciolacustrine sediments across most of the Long Point Region; however, it outcrops north of Tillsonburg (Barnett and Girard 1982) and forms the core of several of the recessional (end) moraines in the Study Area including (from oldest to youngest) the St. Thomas, Norwich, Tillsonburg, Courtland and Mabee Moraines (**Figure 3-3**; Barnett 1993). These moraines are interpreted to have been formed as the Erie-Ontario ice lobe advanced from southeast to northwest towards the Ingersoll Moraine (northwest of the Study Area; Barnett 1982, 1993). Fluctuations and minor standstills in the ice advance led to the formation of each of the moraines at different times throughout the Port Bruce Stade. Also at this time it is interpreted that glacial meltwater ponded between the front of the glacier and the recently constructed end moraines. This led to the deposition of the fine-grained glaciolacustrine sediments on top of the Port Stanley Till in the northwest portions of the Study Area (Barnett 1982).

The recession of the Erie lobe toward the southeast into the Lake Erie and Ontario basins also formed the end moraines present in the Catfish Creek and Kettle Creek Watersheds including the Ingersoll, Westminster, St. Thomas, Norwich and Tillsonburg Moraines (**Figure 3-3**). These moraines mark either positions of standstill or minor re-advances of the ice margin.

Within the northern portions of the Catfish Creek Watershed, the Port Stanley Till is the dominant surficial unit. The older, basal portion of the Port Stanley Till was deposited during the initial advances of the Erie Lobe. Previously deposited glaciofluvial sand and gravel and bedrock clasts were incorporated into the till. The younger overlying till units were deposited during retreat cycles of the Erie ice lobe. This generated a depositional environment of subaquatic flow in glaciolacustrine conditions and produced lacustrine silt and sand interbeds within the Port Stanley Till (Dillon Consulting Ltd. and Golder Associates Ltd. 2004).

3.3.1.4 Mackinaw Interstade and Sedimentary Deposits

The climate warmed at the end of the Port Bruce Stade and the Mackinaw Interstade (13,500 to 14,000 years ago; Barnett 1992) saw the rapid retreat of glacial ice out of southern Ontario. The Ontario-Erie ice lobe retreated into the Ontario basin east of Toronto (Dreimanis and Goldthwait 1973) and this blocked the drainage outlet for Lake Erie and Ontario forming a large lake within the Lake Erie basin with lake levels significantly higher than those seen today. The first glacial lake was termed Glacial Lake Maumee, and it was followed by Glacial Lake Arkona (Barnett 1992). There are very few sediments preserved that are associated with Glacial Lake Maumee and none on record within the Study Area for Glacial Lake Arkona, likely due to reworking by subsequent subglacial or glaciolacustrine processes (Barnett 1982).

3.3.1.5 Port Huron Stade and Sedimentary Deposits

The Port Huron Stade took place from approximately 13,000 to 13,500 years ago, when the Laurentide Ice Sheet advanced for the last time through southern Ontario depositing the Wentworth Till and the Paris and Galt Moraines. The Wentworth Till is the youngest till located in the Study Area, and is commonly buried beneath glaciolacustrine sediments (Barnett 1982); however, it outcrops in some areas northeast of Delhi along the Paris Moraine, in areas approximately 3 km north of Port Rowan, and in drumlins north of Hagersville (**Figure 3-3**; Barnett 1978). The Paris Moraine marks the maximum south-western extent of the Port Huron ice (and the Wentworth Till), and therefore this till is restricted to areas east of the Paris Moraine. Within the Regional Area, the Wentworth Till is described as a stoney, silt till that coarsens inland, as the ice lobe overrode and incorporated fine-grained glaciolacustrine sediments of the Lake Erie basin before advancing westward (Barnett 1992, 1993). As mentioned earlier, the Paris and Galt Moraines are not well exposed in the Study Area as younger glaciolacustrine sediments have largely buried these two features.

As the ice sheet began to withdraw from the Study Area, large glacial lakes were formed in the Lake Erie basin, with water levels much higher than the present day elevation of Lake Erie. Glacial Lake Whittlesey was formed, followed by Glacial Lake Warren, each flooding a large portion of the Study Area throughout the Port Huron Stade (Barnett 1992). At the base of these lakes, the Haldimand Clay and Norfolk Sand Plains were deposited (**Figure 3-3**; Barnett 1982).

The Haldimand Clay Plain was deposited in the east as fine-grained silts and clays settled to the bottom of the deep lake basin. Similarly, in the west, the Ekfrid Clay Plain (**Figure 3-3**) was laid down under calm conditions as the fine-grained suspended sediment settled out onto the lake floor.

The sandy Norfolk Sand Plain was laid down when the sediment-laden Grand River (historic alignment) emptied into deep glacial lakes (i.e., Whittlesey and Warren), depositing a deltaic sequence of sands and silts throughout the central portion of the Study Area and in front of the eastward retreating ice front (Chapman and Putnam, 1984). Sands of the Norfolk Sand Plain are described as fine to medium-grained, ranging in thickness from less than 1 m to roughly 27 m (although this estimate may include deeper, and older sands; Barnett, 1982). As the levels in Lake Whittlesey were much higher than the present day, the moraines evident in the (north)western portions of the Regional Area acted as ‘islands' in an otherwise flooded terrain. The extent of Lake Whittlesey can essentially be mapped by the presence or absence of surficial sand deposits. Where sand exists, the land was inundated by water, and where sand does not exist (such as the crests of the local end moraines) these areas remained above water.

Within the Catfish and Kettle Creek Watersheds (**Figure 1-1**), the Norfolk Sand Plain is located across the southern portions of the region and it continues northward along the eastern boundary of the Catfish Creek watershed (**Figure 3-3**). As noted above, the Norfolk Sand Plain forms an important aquifer across the area and is extensively used for private groundwater supply.

As the water elevation in the Lake Erie basin dropped from the level of Lake Warren, new glacial lakes formed in the basin, each with a different shoreline and associated deposits (Barnett 1992). Although the high waters of several of the glacial lakes are believed to have covered up to half of the Study Area, post-Whittlesey and Warren shoreline features are rare (Barnett 1982).

3.3.1.6 Post-Glacial Period

Following the Port Bruce Stade, glacial ice began to melt and the ice margin retreated northward out of the Study Area. Postglacial and erosional processes during the Holocene continued to work to shape the landscape within the Long Point Region. The 40 km Long Point Spit (**Figure 3-3**) began to form in Lake Erie roughly 7,600 years ago when coarse-grained sediments were carried by long shore currents from the west, and this process has continued ever since (Stenson 1993; Davidson-Arnott and Van Heyningen 2003).

In the Tillsonburg area, portions of the Norfolk Sand Plain have been modified by the wind as it forms large dunes up to 6 m high (Barnett 1982). In addition, modern alluvial deposits are scattered throughout the Study Area and are associated with Big Creek, Big Otter Creek and the Grand River (**Figure 3-3**; Barnett 1993).

3.3.2 Alternate Conceptual Geologic Model

Numerous studies have been completed to characterize the overburden stratigraphy in the Study Area based on the available hydrogeologic information (e.g. deVries and Dremanis 1960; Yakutchik and Lammers 1970; Novakovic and Farvolden 1974; Barnett 1978, 1979, 1982, 1987, 1998; Dreimanis 1966, 1982, 1987, 1995; Hicock 1992; Banks et al. 2007; Bajc 2008). Due to the limited amount of subsurface data, an alternative conceptualization exists to the complex geological model described above (initially proposed by Barnett 1978, 1982, 1987, 1993, 1998). In the alternate simplified hydrogeological model, Yakutchik and Lammers (1970) conceptualized the Quaternary overburden system as flat-lying, relatively continuous layers of alternating fine-grained silt, clay and diamict and discontinuous coarse-grained deposits. All deposits were interpreted to have been laid down either subglacially or under a glaciolacustrine depositional environment (**Figure 3-4**). This interpretation was based on surficial geology mapping, borehole data, and hydrogeologic data. The flat-lying conceptualization was later adopted by Novakovic and Farvolden (1974) in an investigation of groundwater flow systems in Norfolk and Oxford Counties. The key difference between this earlier interpretation and that adopted in this study is that the earlier model conceptualizes the deeper municipal production aquifers as discontinuous, and confined aquifers that are isolated from ground surface and the overlying shallow aquifer groundwater flow system. In many cases, this representation is sufficient. It becomes problematic along the north-western margin of the recessional Paris and Galt Moraines, where intervening fine-grained material is limited or absent (as related to the maximum advance of glacial ice to the moraine). These moraine margins align with the communities of Delhi (Paris Moraine), Simcoe, and Waterford (Galt Moraine).

The complex geologic model, in contrast, suggests that there is a connection between the shallow and deeper aquifers (Barnett 1978, 1982, 1987, 1993, 1998). Barnett (1982) hypothesized that the Tillsonburg, Courtland, and Mabee Moraines were formed during advances of a fluctuating ice margin fronted by a glacial lake (Port Huron Stade; Section 2.1.5). Barnett states that there are subsurface wedge-shaped bodies of deltaic and glaciolacustrine sands that are overlain by the flat-lying Norfolk Sand Plain, and the high quality cores drilled as part of the Tier Three field program support this conceptual model. In some areas, the deeper aquifer units are interpreted to be connected to the shallow groundwater flow system and potentially to surface water features. Barnett's model was developed based on sediment exposed along the Lake Erie shoreline, surficial mapping, and corehole/ borehole data (Barnett 1993). The sections below outline the interpreted stratigraphy within the well field areas and is based on the Barnett (1993) conceptual model of wedge-shaped sand aquifers that are deeply confined in some areas, and unconfined in others. **Figure 3-5** illustrates a cross-section through the Norfolk Sand Plain, from the St. Thomas Moraine in the northwest, to the Tillsonburg and Paris Moraines in the centre, and the Galt Moraine, the Haldimand Clay Plain and Lake Erie bluffs in the southeast. The wedge-shaped dipping units of sand and gravel are apparent on this section.

3.4 Local-Scale Well Field Geology

As noted above, the Tier Three Assessment requires detailed interpretation of the geologic and hydrogeologic conditions within the municipal well field areas under investigation. In this study, these well fields include the communities of Waterford, Simcoe, Delhi and Tillsonburg.

3.4.1 Waterford

The Waterford municipal water system consists of two wells located approximately one kilometre west of Waterford (**Figure 3-6**). Waterford lies between the Norfolk Sand Plain in the west and the Haldimand Clay Plain in the east. **Figure 3-7** illustrates an east-west cross-section that runs from the sand plain in the west to the clay plain in the east. The shallow overburden in this area consists of glaciolacustrine silt and clay underlain by a discontinuous unit of sand and gravel corresponding to the Norfolk Sand Plain, along the crest and western flank of the buried Galt Moraine (located on **Figure 3-3**). The majority of boreholes in the vicinity of the Waterford municipal well field are completed in the Norfolk Sand Plain. Underlying the Norfolk Sand Plain is a thick unit of Wentworth Till and associated fine-grained material that lies east of the buried moraine, and north of the municipal supply wells (**Figure 3-7**).

The Waterford municipal wells are completed in a sand unit that extends beneath the western flank of the buried Galt Moraine. This sand unit is approximately 6 m thick in Waterford, thins north and south of the municipal well field, and pinches out to the west where Wentworth Drift thickens (**Figure 3-7**). It is overlain by Wentworth Till and directly underlain by a 15-m thick package of laminated silty clay to sand with clasts (interpreted to be ice rafted debris) and interbedded clay-rich diamict interpreted to be the Port Stanley Till (**Figures 3-7** and **3-8**). East of the municipal wells, this lower till unit is underlain by a discontinuous layer of medium sand and fine gravel and a thin unit of laminated fine-grained sediment overlying bedrock. This lowermost unit is interpreted to be associated with Port Stanley and Catfish Creek Drift.

3.4.2 Simcoe

The municipal water supply system in the community of Simcoe consists of three well fields: 1) Northwest Well Field, 2) Cedar Street Well Field, and 3) Chapel Street Well Field (**Figure 3-9**) that lie at the transition zone between the Norfolk Sand Plain in the west and the Haldimand Clay Plain in the east. Overburden stratigraphy in the Simcoe area consists of layers of sand, silt, clay, and diamict. The majority of the subsurface units dip towards the southeast towards the Lake Erie basin, except for the flat-lying surficial sand and gravel unit.

3.4.2.1 Simcoe: Northwest Well Field

Fine- to medium-grained sand associated with the Norfolk Sand Plain lies at surface south of the Northwest Well Field area (**Figure 3-10**), and is not present at Northwest Well 2. At surface across much of this area is a thin (< 2 m) discontinuous layer of interbedded clay, silt, and silty fine-grained sand interpreted to be Wentworth Drift (**Figure 3-10)**. Underlying the Wentworth Drift in the Northwest Well

Field area is a thick (14 m) unit of fine- to medium-grained sand with variable gravel and silt content (**Figure 3-10**). This coarse-grained unit is interpreted to be an outwash deposit laid down during the Mackinaw Interstade. This unit extends to bedrock at Northwest Well 1 (not illustrated on cross-section).

This sand unit is underlain by a relatively continuous package of interbedded clay, silt, and sand with clasts interpreted as a combination of Wentworth Drift and Port Stanley Drift. Differentiating between the two units was not possible using low quality water well logs. In this area, Wentworth Drift and Port Stanley Drift were deposited at the base of a large glacial lake during the Port Huron and Port Bruce Stades (Barnett 1998). This fine-grained unit has an average thickness of approximately 10 m across the well field area, and reaches a maximum thickness of 24 m along the western margin of the well field area. It is absent at Northwest Well 1 where the overlying sand unit is in contact with the bedrock.

Underlying the Port Stanley and Wentworth Drift unit lies a deep, discontinuous, fine- to medium-grained sand unit (**Figure 3-10**), that reaches up to 20 m in one high quality deep borehole on the south side of the cross-section (LP-MW-09-10). The lateral continuity of this deeper sand unit is poorly understood as the remaining wells in the area are shallow and do not penetrate through the uppermost sand unit. This lower sand unit is underlain by a discontinuous unit of fine-grained material (interbedded clay, silt, and sand with trace gravel), interpreted to be Port Stanley Drift, Catfish Creek Drift and/or older fine-grained sediment (**Figure 3-10**).

3.4.2.2 Simcoe: Cedar Street Well Field

Similar to the Northwest Well Field, fine- to coarse-grained sands associated with the Norfolk Sand Plain lie at surface in the Cedar Street Well Field. Where present, this unit averages approximately 6 m in thickness, and up to a maximum of 12 m southwest of the Cedar Street Well Field (**Figure 3-11**). Underlying this surficial sand unit is a discontinuous fine-grained unit of interbedded clay, silt, and silty fine-grained sand (**Figure 3-11**), interpreted to be Wentworth Drift and associated glaciolacustrine deposits. This unit is absent beneath the Cedar Street Well 1A, the Cedar Street infiltration gallery, and areas west of Cedar Street Wells 2A and 3 (**Figure 3-11**). Where the Wentworth Drift is absent, the Norfolk Sand Plain unit is in direct contact with an underlying fine- to coarse-grained sand with variable gravel and silt content. It averages 4.6 m in thickness where present and reaches a maximum thickness of 11.5 at the municipal wells and infiltration gallery (**Figure 3-11**).

A thick package of interbedded clay, silt, and fine-grained sand with variable coarse-grained sand and gravel content underlies the above noted sand unit that the Cedar Street municipal wells are completed within (**Figure 3-11**). This lower fine-grained unit is interpreted to be the Wentworth and Port Stanley Drift packages, and is underlain by a unit of fine- to medium-grained sand with trace silt. While not illustrated on the cross-section, this unit is generally less than 3 m in thickness where present, but thickens to approximately 10 m south of the well field (**Figure 3-11**). Due to the limited deep borehole data in this area, the spatial extent of this deep coarse-grained unit is poorly understood.

Overlying bedrock at the base of the overburden is a continuous layer of clay-rich diamict and laminated clay and silt interpreted to be Port Stanley and Catfish Creek Drift, and associated fine-grained glaciolacustrine sediment.

3.4.2.3 Simcoe: Chapel Street Well 3

Chapel Street Well 3 is located on the Galt Moraine, where clay-rich diamict and laminated clay and silt outcrop at surface. This surficial unit (Wentworth Till) is continuous across the well field area with an average and maximum thickness of approximately 11 and 19 m, respectively (**Figure 3-12**). Chapel Street Well 3 is screened across a sand unit that has an average thickness of 10 m. Based on borehole lithology records, the unit is texturally heterogeneous and consists of fine- to medium grained sand with variable silt content. Beds (up to 5 m thick) of laminated clay, silt, and silty very fine-grained sand and clay-rich diamict are frequently reported. A fining upward trend is observed in the coarse-grained unit in several borehole logs (e.g., Chapel Street well 3 and TW4-59); a 0.5 to 2 m thick bed of gravel is observed at the base of the unit and fines upward into sand to silty sand at the top. This unit is underlain by a package of interbedded clay, silt and sand with variable gravel content interpreted to be the clay-rich diamict and associated fine-grained glaciolacustrine sediment associated with the Wentworth and Port Stanley Drift. The aquitard is continuous across the Chapel Street well field and reaches a maximum thickness of approximately 19 m south of Chapel Street Well 3 (**Figure 3-12**). Underlying the Wentworth and Port Stanley Drift is a discontinuous, thin (< 3 m) coarse-grained unit, and an underlying layer of fine-grained glaciolacustrine sediment with occasional clay-rich diamict beds that overlies bedrock (**Figure 3-12**).

3.4.3 Delhi

The Delhi well field consists of two wells plus a test well located approximately 4 km east of the community of Delhi (**Figure 3-13;** MacViro 2002a) on the Norfolk Sand Plain. The Norfolk Sand Plain in this area consists of fine- to medium-grained sand with minor gravel as well as thin (< 3 m thick) interbeds of clay reported in borehole and corehole logs. The beds appear to be discontinuous and could not be tracked between boreholes located 100 m apart (**Figures 3-14** and **3-15**). This surficial sand unit is 18 m thick on average and reaches a maximum thickness of 30 m southwest of the Delhi municipal supply wells (**Figure 3-14**).

The surficial sand unit is underlain by a package of fine-grained sediments (beds of clay and silt with minor sand and gravel) that pinches out north and south of the Delhi municipal wells (**Figures 3-14** and **3-15**). The fine-grained unit is interpreted to be Wentworth Drift and associated glaciolacustrine deposits. Where present, the unit averages 7 m in thickness across the Delhi municipal well field area and reaches a maximum thickness of 17 m at the municipal wells (**Figures 3-14** and **3-15**). As illustrated on **Figure 3-15**, the fine-grained unit has been eroded completely in some portions of this area.

Beneath this fine-grained unit is a continuous sand unit with an average and maximum thickness of 11 and 20 m, respectively within the Delhi municipal well field area (**Figures 3-14** and **3-15**). This unit consists of fine- to coarse-grained sand with variable silt and gravel content, and it is underlain by a fine-grained unit of interbedded clay, silt, and very fine- to fine-grained sand with clay-rich diamict interpreted as the Wentworth Drift, Port Stanley Drift and associated fine-grained glaciolacustrine sediment. A thin (< 2 m) sand unit underlies the fine-grained Wentworth and Port Stanley Drift, and is underlain by a fine-grained glaciolacustrine unit that overlies bedrock (**Figures 3-14** and **3-15**).

3.4.4 Tillsonburg

The Tillsonburg water supply system consists of ten groundwater municipal water supply wells subdivided spatially into the Northwest and Southeast Well Field areas. The well fields lie along the transition between the Norfolk Sand Plain in the east and Port Stanley Till Plain in the west (**Figure 3-3**). Similar to the community of Simcoe, this area is geologically complex reflecting a dynamic depositional environment along the north-western margin of the Tillsonburg Moraine.

3.4.4.1 Tillsonburg: Northwest Well Field

Isolated patches of surficial outwash material lie at surface along the river valleys in the Tillsonburg Northwest Well Field area (**Figures 3-16A, 3-17** and **3-18**). These glaciofluvial outwash deposits primarily consist of medium-grained sand underlain by a thick unit (16 m on average) of laminated clay and sandy silt, silt sand diamict and silt, interpreted to be Port Stanley Drift. The Port Stanley Drift was eroded from the larger modern day river networks, and is absent at Tillsonburg Well 5. The Drift reaches a maximum thickness of approximately 37 m at municipal Well 6A along the core of the Norwich Moraine (**Figure 3-18**).

Underlying the Port Stanley Drift is a silty fine-grained sand, very fine- to coarse-grained sand, and sandy pebble gravel that is 3 m on average but reaches up to 14 m in thickness at Well 6A. This unit lies at ground surface east and south of Tillsonburg Well 5 (**Figures 3-17** and **3-19**).

Underlying this sand unit is a unit of fine-grained sediment interpreted as the Port Stanley Drift, fine-grained glaciolacustrine sediment, Catfish Creek Drift and/or older sediment. It was not possible to differentiate these units using water well logs so they were grouped based on their similar geologic properties. The unit has an average and maximum thickness of 12 and 30 m, respectively (**Figures 3-17**, **3-18** and **3-19**).

3.4.4.2 Tillsonburg: Southeast Well Field

The Norfolk Sand Plain is the uppermost unit across much of the Tillsonburg Southeast Well Field and consists of silty fine- to coarse-grained sand with variable gravel content. Where present, the unit is approximately 8 m thick and reaches a maximum thickness of 25 m west of Well 12 (**Figures 3-20** to **3-23**). A thin (< 3 m) isolated area of sandy-clay outcrops at surface around Wells 1A and 2 (**Figure 3-20**) and may represent localized ponding that occurred within the Norfolk Sand Plain.

Clay-rich diamict, interbedded clay and silt, and silty sand diamict interpreted to be the Port Stanley and Catfish Creek Drift underlie the Norfolk Sand Plain in this area. This fine-grained unit has an average thickness of 7 m, and reaches a maximum thickness of 30 m at Well 11 (**Figure 3-21**). This unit is not present east of Wells 1A and 2 (**Figure 3-20**), northwest and northeast of Wells 9 and 10 (not shown on cross-section).

The Tillsonburg Southeast wells are completed in a sand unit underlying the Port Stanley and Catfish Creek Drift deposits that consists of fine- to medium-grained sand with variable silt and gravel content. The unit is approximately 8 m thick on average and thickens to the northwest (**Figures 3-20** to **3-23**). It is underlain by a thick (approximately 28 m) package of clay-rich and silty-sand diamict with interbeds of laminated clay, silt, and sand (interpreted to be Catfish Creek Drift and older sediment) that overlies bedrock.

4 HYDROSTRATIGRAPHIC SETTING

To a large extent, the regional groundwater flow system in the Long Point Region, Catfish and Kettle Creek Conservation Authorities is a reflection of the ground surface topography. Groundwater moves from areas of high hydraulic head to areas of low hydraulic head, generally following topographic relief, unless it is impeded by geologic conditions, or local changes in relief such as stream valleys that intersect the water table. In areas where rivers, streams or wetlands intersect the water table, groundwater discharges into the stream or river and contributes baseflow to the surface water feature. Understanding the movement of groundwater through the subsurface, and through interactions with surface water features requires an understanding of the three-dimensional geometry of aquifers (water bearing units) and aquitards (confining units) as well as the location of significant recharge areas.

4.1 Regional Hydrostratigraphic Units

Conceptual hydrostratigraphic models provide a technical basis for the development of numerical groundwater flow models. Hydrogeologic characterization involves understanding the lateral and vertical extent, and subsequent interconnection of the aquifer and aquitard units along with their representative hydrogeologic characteristics. The extent and interconnection, or lack thereof, of the aquifer units can be a significant factor in determining the availability of groundwater for anthropogenic use and potential impacts from withdrawal. The conceptual hydrostratigraphy developed for this assessment was based primarily on the glacial history of the area alongside high-quality corehole data collected as part of the Tier Three Assessment (**Section 4.6** and **Appendix B**). The abundant lower-quality water well data and supplemental data such as water quality data was also used to guide the interpretation of the hydrostratigraphic units.

Based on analysis of drill core collected in the field program, the Barnett (1982) conceptual model was carried forward for adaptation in this Assessment. Regional- and local-scale cross-sections were generated and interpreted to extend through various depositional and erosional landforms and a total of eleven overburden hydrostratigraphic layers that represent hydrostratigraphic units within the Regional Area (**Table 3**). Due to the limited high quality borehole data within the Regional Area, it was difficult to differentiate the Port Stanley Drift and Catfish Creek Drift as they are lithologically similar. In some instances, the continuously-cored holes provided additional insight into the local stratigraphy; however, as the two were laid down under similar depositional environments, a hydrostratigraphic approach to creating model layers was taken rather than a purely geologic model approach.

As noted in Table 3 below, the hydrostratigraphic framework within the three Conservation Authorities consists of a stacked assemblage of aquifers and aquitards. As discussed in the previous sections, the depositional environments under which the overburden units were laid down were complex, and often contain interbedded units of fine and coarse-grained material. While many of the units outlined in Table 3 are regional in extent, many of them are spatially restricted within the Regional Area; one example is the Haldimand Clay Plain, which is only present in the far eastern portion of the Long Point Region. Consequently, several of the units listed in Table 3 may not be present at all locations within the Regional Area.

Table 3 Hydrostratigraphic Units within the Regional Area

No.	Geologic Unit	Glacial Period	Aquifer/ Aquitard
1	Haldimald Clay Plain/ Surficial Clay	Holocene	Aquitard
2	Norfolk Sand Plain/ Interstadial Sediment	Mackinaw Interstade / Port Huron Stade	Aquifer
3	Wentworth Drift		Aquitard
4	Coarse-grained Interstadial Sediment (Sand, Gravel)		Aquifer
5	Wentworth Drift		Aquitard
6	Coarse-grained Interstadial Sediment (Sand, Gravel)		Aquifer
7	Port Stanley Drift	Port Bruce Stade	Aquitard
8	Coarse-grained Interstadial Sediment (Sand, Gravel)		Aquifer
9	Port Stanley Drift		Aquitard
10	Coarse-grained Interstadial Sediments (Sand, Gravel)	Erie Interstade	Aquifer
11	Catfish Creek Drift	Nissouri Stade	Aquitard
12	Paleozoic Bedrock		Aquifer/ Aquitard

4.1.1 Regional Overburden Aquifers

Overburden aquifers in the Regional Area are abundant and include coarse-grained interstadial outwash and glaciolacustrine deposits. These deposits lie between till layers (Table 3) which create a complex aquifer system, especially in the central morainal portions of the Regional Area. The Norfolk Sand Plain is the most spatially extensive aquifer within the Regional Area and lies within the Long Point Region. The aquifer is unconfined and lies at surface across much of the central portion of the Regional Area and the thickness of the sands exceeds 20 m in some areas including Delhi (**Figure 3-14**). The unit is primarily fine- to medium-grained sand with some silt and gravel in areas.

Beneath the upper Norfolk Sand Plain aquifer is an intermediate aquifer that is commonly confined by either fine-grained Wentworth or Port Stanley Till in the central portions of the Regional Area. The fine- to medium-grained sand aquifer pinches out in the eastern portions of the Long Point Region where the Haldimand Clay Plain is mapped at surface. There are no interpreted overburden aquifers within the eastern portions of the Regional Area beneath the clay plain.

Deeper sand aquifers may exist within the Regional Area; however, due to the highly transmissive nature of the shallow and intermediate aquifers, few boreholes penetrate to depth and there is little information regarding the spatial extent of these aquifers, or the associated water quality within them. Additional deep borehole data collected in the Tier Three field program suggests these deeper aquifers are thin and limited in spatial extent and as such, are unlikely to transmit large volumes of water.

4.1.2 Regional Bedrock Aquifers

Bedrock aquifers are seldom used in the western and central portions of the Regional Area where overburden aquifers are thick and transmissive. In the eastern portions of the Long Point Region where the Haldimand Clay Plain lies at surface, the uppermost aquifers, consisting of limestone and dolostone units of the Dundee and Onondaga Formations, are used for domestic water supply. The Dundee Formation lies south of Tillsonburg and is a productive aquifer, although water quality is sulphurous (Armstrong and Carter 2010). The Lucas Formation of the Detroit River Group is a productive bedrock aquifer due to the presence of fractures or karst-related porosity (Armstrong and Carter 2010). Similar to the Dundee Formation, the Lucas and Amherstburg Formations can contain elevated concentrations of sulphur (Armstrong and Carter 2010).

4.2 Regional Groundwater Flow

The Regional Area contains both overburden and bedrock aquifers that are used for water supply. Overburden aquifers that lie at depth tend to be localized, while those that lie at or close to ground surface (such as the Norfolk Sand Plain) extend across much of the Focus Area. Fractured bedrock aquifers are more regional in scale; however, due to the abundance of overburden aquifers within the area, the bedrock aquifers are not often used for municipal water supply, and are not used at all by any of the towns examined in detail in the Tier Three Assessment.

To help visualize the groundwater flow directions within the Regional and Focus Areas, a map of the shallow (**Figure 4-1**) and deeper (**Figure 4-2**) water levels was created at a regional scale. Static water levels reported in MOE water well records (for wells with location reliability less than 200 m) and higher quality observation wells were interpolated across the Regional Area to create these maps. The water levels in the MOE water well database correspond to water levels measured and recorded by water well drillers after drilling a well. These static water levels were collected over decades and may represent pre-pumping water level conditions that are not indicative of present day levels, which can be influenced by localized pumping (municipal or otherwise). Despite the limitations, the data used to create the water level maps (**Figures 4-1** and **4-2**) are the best available, and the maps are considered a reasonable representation of regional groundwater flow conditions at the scale applied.

The map of shallow groundwater levels (**Figure 4-1**) was created by kriging all wells in the MOE Water Well Information System (WWIS) database with a depth less than 15 m bgs and a location reliability code indicating a less than 200 m. The surface was kriged at a 50 m resolution across the model domain, and then was constrained to the 10 m DEM of the Regional Area. Constraining the surface in this manner ensures that the kriged water level map does not extend above ground surface. This is particularly useful within river valleys, where a lack of water wells would otherwise create a flat water level surface. The deeper water level surface was created in the same fashion using wells that are completed at depths greater than 15 m bgs. A lake elevation of 174 m asl was also used to constrain the elevation of the shallow water level surface along the Lake Erie shoreline.

The shallow water levels reach a high of 305 m asl in the north-western portions of the Regional Area beneath the Ingersoll and St. Thomas Moraines. Water levels decline to the south and southeast towards the Lake Erie shoreline to a low of 174 masl at the lake (**Figure 4-1**). Shallow groundwater is interpreted to flow towards and discharge into the deeply incised surface water features such as Big Creek, which runs through Teeterville and Delhi, Big Otter Creek, which runs through Tillsonburg and the Lynne River that runs through Simcoe.

The deeper water levels show a similar pattern to the shallow water levels with the highest water level elevations occurring in the northwest and the lowest along the deeply incised surface water features and the Lake Erie shoreline (**Figure 4-2**).

4.3 Local Hydrostratigraphic Units

The following sections outline the hydrostratigraphic units present within each of the four communities being examined in the Tier Three Assessment.

4.3.1 Waterford

The Waterford municipal water system consists of two wells located approximately one kilometre west of Waterford (**Figure 3-6**). The wells are screened from 7.6 to 10.1 m bgs, and are classified as GUDI of surface water as they are interpreted to obtain a portion of their water from the two nearby Waterford Ponds. The ponds were formed as remnants of a below the water table aggregate extraction operation.

The Waterford municipal wells are completed in an intermediate aquifer that is approximately 6 m thick in Waterford, thins north and south of the municipal well field, and pinches out to the west where Wentworth Drift thickens (**Figure 3-7**). The municipal aquifer is mainly overlain by Wentworth Till; however, a window in the Wentworth Till exists just west of the municipal wells where the intermediate production aquifer is in contact with the upper Norfolk Sand Plain aquifer. It is at this location where there is an interpreted hydraulic connection between the production aquifer and the nearby Waterford Ponds (see well 4402623; **Figures 3-7** and **3-8**), which give the municipal wells their GUDI designation.

4.3.2 Simcoe

The community of Simcoe is serviced by three well fields: 1) Northwest Well Field, 2) Cedar Street Well Field, and 3) Chapel Street Well Field (**Figure 3-9**). These three well fields lie at the transition zone between the Norfolk Sand Plain in the west and the Haldimand Clay Plain in the east, which lead to a complex interfingering of aquifers and aquitards in this area.

4.3.2.1 Simcoe: Northwest Well Field

The Northwest well field contains three water supply wells that lie in close proximity to a below the water table sand and gravel extraction operation. The extraction of sand and gravel left behind three large ponds that lie less than 10 m from the current municipal wells. The wells are screened at depths ranging from 18.3 to 26.2 m bgs and are classified as GUDI.

At the well field the ground surface is blanketed by a very thin (< 2m) discontinuous layer of fine-grained interbedded clay, silt, and silty sand (Wentworth Drift; **Figure 3-10)**. This unit does not exist south of Northwest Well 2, and the fine- to medium-grained sand aquifer (Norfolk Sand Plain) is present at surface (**Figure 3-10**). The municipal production aquifer is a thick (14 m) unit of fine- to medium-grained sand with variable gravel and silt content (**Figure 3-10**), and this unit was likely the granular deposit targeted by the aggregate extraction operation responsible for the formation of the large ponds located adjacent to the municipal wells. The municipal aquifer thins to the south toward the Chapel Street Well Field and extends to bedrock at Northwest Well 1 (not illustrated on cross-section). The surficial confining unit (i.e., Wentworth Till) is interpreted to be discontinuous and windows in this till are interpreted to lead to a direct connection between the shallow surface water features and the deeper municipal production wells in this well field area.

4.3.2.2 Simcoe: Cedar Street Well Field

The Cedar Street Well Field consists of five individual groundwater wells and one shallow infiltration gallery and all are classified as GUDI. Well 1 was abandoned in 1999 and replaced with Well 1A (both wells are illustrated on **Figure 3-11**). The wells are screened with top depths ranging 6.7 to 11.9 m bgs. Four of the five municipal wells are located within 50 m of Kent Creek, a tributary of the Lynn River (**Figure 3-9**). The infiltration gallery consists of a series of lateral pipes that lie adjacent to Kent Creek and are connected to a central pumping station.

Fine- to coarse-grained sand associated with the Norfolk Sand Plain lies at surface in the Cedar Street Well Field and is underlain by a discontinuous fine-grained unit of Wentworth Drift, which is pinches out beneath the Cedar Street Well 1A, the Cedar Street infiltration gallery, and areas west of Cedar Street Wells 2A and 3 (**Figure 3-11**). Where the aquitard is absent, the surficial aquifer is in contact with the underlying fine- to coarse-grained sand municipal production aquifer. As noted on the cross-section, there is uncertainty regarding the spatial size and extent of the window between these two aquifers.

There is also a deeper aquifer in the well field area; however, due to the limited deep borehole data in this area, the spatial extent of the aquifer is poorly understood (**Figure 3-11**).

4.3.2.3 Simcoe: Chapel Street Well 3

Chapel Street Well 3 is located within the heavily urbanized sector of Simcoe far from sensitive surface water features (**Figure 3-9**). The well is screened from 19.1 to 22.1 m bgs and supplies approximately 30% of the water demand for the community of Simcoe.

Overlying the production aquifer in this area is fine-grained Wentworth Drift (**Figure 3-12**). Based on borehole lithology records, the municipal production aquifer consists with interbeds of fine-grained material that reach thicknesses of up to 5 m, which may lead to an elevated horizontal to vertical anisotropy ratio. As noted earlier, the production aquifer fines upward and contains a 0.5 to 2 m thick discontinuous bed of gravel at the base of the unit and fine sand to silty sand at the top. A test well was drilled approximately 10 m southeast of Chapel Street Well 3 as part of recent water supply exploration efforts, and despite being screened at the base of the same aquifer the test well could not produce a yield comparable to Chapel Street Well 3 (Banks Groundwater Engineering Ltd. and Gerrits Drilling and Engineering Ltd. [Banks and Gerrits] 2010). The test well was screened in a silty fine-grained sand, and the gravel bed present at Chapel Street Well 3 was not present at the test well, which may explain the poor well yield. Drilling of test wells in the Chapel Street area was being undertaken, with the aim of finding an eventual replacement well for Chapel Street Well 3. However, recent rehabilitation works on Chapel Street Well 3 have shown that this well can continue producing the required volumes of water into the future.

4.3.3 Delhi

The Delhi well field consists of two GUDI wells located approximately 4 km east of the community of Delhi (**Figure 3-13;** MacViro 2002a). Delhi Well 1 is screened from 31.1 to 38.6 m bgs and Delhi Well 2 is screened from 33 to 39 m bgs. In addition, a test well is located approximately 465 m southeast of the existing municipal wells and is screened 39 to 48.8 m bgs within the same intermediate municipal supply aquifer. This test well will eventually be brought into production as Delhi Well 3.

The Delhi well field obtains its water from an intermediate fine- to coarse-grained sand aquifer that is overlain by Wentworth Drift and a thick unit (18 m on average) of sand and gravel at surface (**Figures 3-14** and **3-15**). The Wentworth Drift pinches out north and south of the Delhi municipal wells, but reaches thicknesses of up to 17 m at the municipal wells (**Figures 3-14** and **3-15**). As illustrated on **Figure 3-15**, windows exist through this aquitard unit where there is the potential for interactions between the municipal production aquifer and the shallow surficial aquifer.

4.3.4 Tillsonburg

Approximately 15,000 residents are serviced by the Tillsonburg water system, which consists of ten groundwater municipal water supply wells subdivided spatially into the Northwest and Southeast Well Field areas.

4.3.4.1 Tillsonburg: Northwest Well Field

Four wells are located in the Northwest Well Field (Wells 4, 5, 6A, and 7), and these wells are screened 18 to 35 m bgs in a sand aquifer. Wells 4, 5, and 7 are located in proximity to Cedar Creek, a tributary of Big Otter Creek (**Figure 3-16A**) and are classified as GUDI wells.

The Tillsonburg Northwest municipal supply aquifer consists of silty fine-grained to pebbly gravel. It is thin (3 m on average) but reaches up to 14 m thick at Well 6A. The municipal supply aquifer outcrops at ground surface east and south of Tillsonburg Well 5 and is likely hydraulically connected to the nearby surface water features (**Figures 3-17** and **3-19**).

4.3.4.2 Tillsonburg: Southeast Well Field

The Tillsonburg Southeast Well Field is comprised of six wells; four GUDI wells (Wells 1A, 2, 9, and 10) and two non-GUDI wells (Wells 11 and 12). The well field is located southeast of Tillsonburg and northwest of the Town of Courtland (**Figure 3-16B)**.

A thick unit (8 m on average) of sand (Norfolk Sand Plain; **Figures 3-20** to **3-22**) lies at surface and is underlain by fine -grained aquitard materials associate with the Port Stanley and Catfish Creek Drift. Windows have been identified within this aquitard unit east of Wells 1A and 2 (**Figure 3-20**), and northwest and northeast of Wells 9 and 10 (not shown on cross-section), which form a hydraulic connection between the shallow aquifer and the underlying semi-confined municipal production aquifer. The production aquifer consists of fine- to medium-grained sand and is approximately 8 m thick on average, and thickens to the northwest (**Figures 3-20** to **3-22**).

4.4 Development of Numerical Model Layers from Hydrostratigraphic Layers

Eleven hydrostratigraphic units were interpreted as outlined in Table 3 above. Due to several of the hydrostratigraphic units not being present across the entire Regional Area, it was possible to reduce the number of model layers, at any one point within the model domain, from eleven to seven. For example, the Haldimand Clay Plain exists in the eastern portion of the Regional Area, but does not exist in the central or western portions. Similarly, the Catfish Creek Till exists in the west and central portions of the Regional Area but does not exist in the east.

To facilitate the reduction of numeric layers from eleven to seven, the Study Area was subdivided into three geological zones that represent the three distinct geological depositional environments. From west to east, these zones consist of the Port Stanley Till Plain (west), Norfolk Sand Plain (centre) and the

Haldimand Clay Plain (east). Table 4 below summarizes the layers that exist within each of the three geologic zones.

Table 4 Hydrostratigraphic Framework

Layer	Geologic Unit	Glacial Period	Aquifer/ Aquitard
ZONE 1: Haldimand Clay Plain Zone (zone extends approximately from the Galt Moraine in the west across the Haldimand Clay Plain to the eastern model boundary).			
1	Haldimald Clay Plain / Surficial Clay	Holocene	Aquitard
2	Norfolk Sand Plain / Interstadial Sediment	Mackinaw	Aquifer
3	Wentworth Drift	Interstade / Port Huron Stade	Aquitard
4	Interstadial Sediment (Sand, Gravel)		Aquifer
5	Wentworth Drift		Aquitard
6	Interstadial Sediment (Sand, Gravel)		Aquifer
7	Port Stanley Drift	Port Bruce Stade	Aquitard
8	Paleozoic Bedrock	Paleozoic	Aquifer / Aquitard
ZONE 2: Norfolk Sand Plain Zone (zone extends approximately from the Tillsonburg Moraine in the west, to the Galt Moraine in the east)			
Layer	Geologic Unit	Glacial Period	Aquifer/ Aquitard
1	Surficial Clay	Holocene	Aquitard
2	Norfolk Sand Plain / Interstadial Sediment	Mackinaw	Aquifer
3	Wentworth Drift	Interstade / Port Huron Stade	Aquitard
4	Interstadial Sediment (Sand, Gravel)		Aquifer
5	Port Stanley Drift	Port Bruce Stade	Aquitard
6	Interstadial Sediment (Sand, Gravel)		Aquifer
7	Port Stanley Drift		Aquitard
8	Paleozoic Bedrock	Paleozoic	Aquifer / Aquitard
ZONE 3: Port Stanley Till Plain (extending from the Study Area boundary in the west approximately to the Tillsonburg Moraine in the east)			
Layer	Geologic Unit	Glacial Period	Aquifer/ Aquitard
1	Surficial Clay	Holocene	Aquitard
2	Surficial Interstadial Sediment (Sand, Gravel)	Mackinaw Interstade	Aquifer
3	Port Stanley Drift	Port Bruce Stade	Aquitard
4	Interstadial Sediment (Sand, Gravel)		Aquifer
5	Port Stanley Drift		Aquitard
6	Interstadial Sediment (Sand, Gravel)	Erie Interstade	Aquifer
7	Catfish Creek Drift	Nissouri Stade	Aquitard
8	Paleozoic Bedrock	Paleozoic	Aquifer / Aquitard

Across the model domain, Layer 1 was used to represent fine-grained clay-rich deposits, including the Haldimand Clay Plain in the east, and other localized fine-grained deposits in the west such as the Ekfrid Clay Plain. Layer 2 represents sand and gravel deposits underlying the fine-grained clays; however, geologically, this layer represents different units spatially within the Study Area. For example, Layer 2 represents the shallow aquifer of the Norfolk Sand Plain in the central portions of the Study Area (Zone 2), but represents a deeper confined sand unit in the Haldimand Clay Plain area (Zone 1). **Figure 4-3a** illustrates the relationship between the hydrostratigraphic layers (**Figure 4-3a**) and the numerical model layers (**Figure 4-3b**). Layer 1 is not included in **Figure 4-3a** or **Figure 4-3b** as Layer 1 is only present in the far eastern portion of the Study Area, outside the area being shown in the figures. In general, all model layers that deform in one zone to represent a different geologic unit in another zone were picked such that the geologic layer pinches out completely before deforming to represent a new unit. This methodology ensures that the model layers do not create artificial hydraulic connections where they should not exist (**Figure 4-3b**). In many areas of Ontario this methodology would not be possible; however, as the stratigraphy is dominated by wedge-shaped sand deposits that pinch out at depth beneath till moraines and at the ground surface it was seen as a methodology that could effectively be used to simplify the groundwater flow modelling. A summary of borehole picks is provided in **Appendix C**. The points used to interpolate the surfaces and the kriging semi-variograms are contained in **Appendix D**. **Appendix E** contains maps of the individual constrained surfaces. **Appendix F** contains isopach maps for the resulting overburden model layers, and technical details on surface development and constraints used to develop the model layers are contained in **Appendix G**. Figure 4.4 shows the division of the Tier 3 Focus Area into the three zones described above.

4.5 Hydrogeologic Properties

Hydraulic conductivity and storage values are the two main hydrogeologic properties assigned within cells or elements of a numerical groundwater flow model domain. Hydraulic conductivity is a property of sediment or rock that describes the relative ease with which water can move through pore spaces or fractures. Hydraulic conductivities can have a significant impact on the model-calculated hydraulic-head distribution.

4.5.1 Hydraulic Conductivities

When developing a numerical groundwater flow model, the initial estimates of hydraulic conductivity are specified and subsequently altered through the calibration process to achieve an acceptable fit to observed data. Initial conductivity estimates are based on the conceptual understanding of the geologic/ hydrostratigraphic units and their hydrogeologic properties. Where data exist, pumping tests or slug tests help to constrain the conductivity estimates within particular geologic formations. When such data are not readily available, conductivity values are often estimated from literature values for materials with a similar lithological description, or from previous studies conducted in the area. In this study, both site specific, measured hydraulic conductivities and estimates from literature were applied.

Hydraulic conductivity and transmissivity estimates for the overburden and bedrock units will be extrapolated from field-based, local-scale values to other areas of the Regional Area. Average field measured values will then be used as initial estimates of hydraulic conductivity in the groundwater flow model, and the values will be altered within the range of field measured conductivities through the model calibration process. This methodology will produce a homogeneous distribution of hydraulic conductivities within hydrostratigraphic layers with heterogeneities in model layer hydraulic conductivity values representing spatial changes in lithology. Details regarding the hydraulic conductivity values will be provided with a future water budget modelling report.

4.5.2 Storage

In transient models, specific yield and specific storage values are used to represent the release of water from storage due to dewatering of pores or the reduction in pressure head within aquifers of interest. Within the groundwater flow model, estimates of specific yield and specific storage will be obtained from analysis of hydraulic testing data and literature values (Anderson and Woessner 2002). Storativity and specific storage values cited in hydrogeologic studies within the Regional Area will be compiled and used to guide the application of these parameters within the groundwater flow model. As noted above, the storage values used in the calibrated groundwater model will be discussed in a future water budget modelling report.

4.6 Field Data Collection

As part of the Tier Two Assessment (AquaResource 2009a), several data gaps were identified that limited the development of conceptual hydrologic and hydrostratigraphic models within the Waterford, Simcoe, Delhi and Tillsonburg areas, particularly in the vicinity of the municipal groundwater wells. The data gaps included a lack of deep borehole data, lack of surface water flow data and similar data. As a result, the Lake Erie Source Protection Region implemented a field program that included an extensive coring (drilling) program, monitoring of groundwater levels, and spot flow monitoring.

4.6.1 Geologic Data Collection

Approximately 70% of the wells (7,258 of 10,327) in the MOE provincial water well database that are located within the Regional Area extend to a depth less than 20 m bgs. This is due to the presence of a thick sand and gravel aquifer that lies at or near ground surface (Norfolk Sand Plain) across the central portions of the Regional Area. To enhance the geologic characterization, continuous PQ core (8.5 cm diameter core) was obtained from 26 locations (**Figure 4-4**). At each location, core was extracted from ground surface to the top of bedrock and subsequently logged. Locations were chosen where the density of data was low and/or where was little deep borehole data available to characterize the lateral continuity of subsurface aquifers and aquitards. Additional data were collected where the continuity of intermediate and deep aquifer units were uncertain or where the connection between the deeper municipal aquifers and the upper sand plain were poorly defined due to lack of data. Twenty-two wells were drilled around the communities of Delhi, Waterford and Simcoe, two wells were drilled to investigate the lateral continuity of an intermediate aquifer observed between Delhi and Tillsonburg, and two additional wells were drilled to examine the potential connection between deeper aquifers and surface water features near Tillsonburg.

A total of 1278 m of sediment were drilled at the 26 drilling sites, with over 80% recovery (1064 m of core). The core was logged at each borehole, and grain size (texture), sorting and fabric, clast characteristics, sedimentary structures, nature of bounding surfaces, and bed geometry were recorded. **Appendix B** contains the borehole logs for all wells drilled and logged as part of this study.

4.6.2 Hydrogeological Data Collection

Multi-level wells were installed at most of the corehole locations to record hydraulic head measurements. Depending on the hydrostratigraphy encountered at drilling locations, monitoring wells were installed in one to three different aquifers. Water chemistry was also collected to determine the potential interconnection between the surface and underlying shallow and deeper aquifer units.

In addition to the high-quality boreholes drilled in this study, high-quality borehole logs were also drilled and logged under separate study and used in the characterization of this study (**Figure 4-5**). Wells were drilled at one site between Delhi and Tillsonburg (Barnett 2008), at multiple sites near Simcoe and Port Rowan (Banks and Gerrits 2010), and five sites near Tillsonburg (Burnside 2009). The locations of these wells are illustrated on **Figure 4-5.**

All of the above noted high-quality borehole (corehole) data were used alongside available geochemical and hydrogeologic data, surficial geology mapping, previous geologic interpretations, and an understanding of the Quaternary depositional history of the area to interpret the spatial distribution of subsurface geologic units. Together, these data helped improve the interpretation of the lateral distribution of subsurface aquifers and aquitards within the Regional Area along a series of intersecting cross-sections that bisected the Regional Area (**Figure 4-6**). **Figure 4-6** illustrates the cross sections considered during interpretation, as well as the picked boreholes and added control points. The majority of picked boreholes are MOE water wells, which are not surveyed or logged by a professional geoscientist. Control points are hydrostratigraphic picks made along each cross section, but are not at a borehole location. These points are selected during cross section analysis to better control the interpreted distribution of subsurface units during the interpolation process.

5 MUNICIPAL SYSTEMS AND WATER DEMANDS

Other than the Town of Delhi, which uses a mix of surface water and groundwater for a potable water supply, the towns of Tillsonburg, Waterford, and Simcoe rely exclusively on groundwater to meet their municipal demands. The following sections outline the municipal systems and associated wells or intakes, being investigated as part of the Tier Three Assessment. This section also presents the volume of water produced from each municipal production well. Due to variations in data availability between municipal systems, the time period for which water taking data is presented also varies between municipal systems.

It is noted that additional well details (i.e., safe available drawdown) will be required to complete the Risk Assessment, and will be collected prior to preforming the Risk Assessment.

5.1 Town of Tillsonburg

The Town of Tillsonburg is located along the southern border of Oxford County and is bounded by Norfolk County to the southeast and Elgin County to the southwest (**Figures 3-16A** and **3-16B**). Tillsonburg relies solely on groundwater to supply potable water for its estimated 15,000 customers, and it obtains this water from ten municipal wells located in two general well field areas (Table 5). Seven of the 10 wells (1A, 2, 4, 5, 7, 9, and 10) are designated as GUDI (of surface water) wells (County of Oxford 2009b).

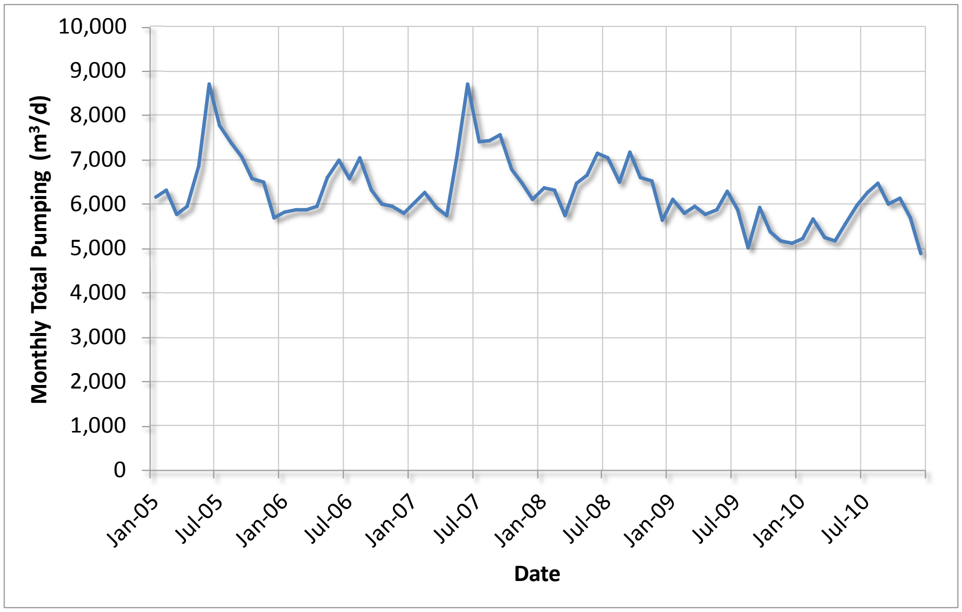
Table 5 Town of Tillsonburg Water Supply Wells

Well Field	Well Name	Permit Number	Permitted Capacity (m^3/day)	2010 Average Annual Taking (m^3/day)
Southeast	Well 1A	7665-79KMNT (exp. 12/31/2018)	2,290	1,002
	Well 2		1,310	227
	Well 9		1,310	798
	Well 10		1,310	1,019
	Well 11		1,310	887
	Well 12		1,310	328
Northwest	Well 4		1,454	782
	Well 5		2,995	749
	Well 6A		2,002	352
	Well 7		1,310	378
Total			**16,600**	**6,522**

Figures 3-16A and 3-16B illustrate the location of the municipal supply wells listed in Table 5. All of the wells operate under one consolidated permit (7665-79KMNT), which expires at the end of 2018. The total permitted taking for the Town is 16,600 m^3/day; however, the actual average annual taking for the well field in 2010 was 6,520 m^3/day.

Municipal water demands for the Tillsonburg system seem to be declining, as is shown in **Chart 1**. **Chart 1** displays the monthly total pumping for the Tillsonburg system from 2005-2010, with a downward trend apparent. It is noted that both the summertime (peak) demands, as well as the winter (baseline) demands seem to have been reduced.

Chart 1 **Tillsonburg Monthly Total Pumping 2005-2010**



5.1.1 Southeast Well Field

Tillsonburg Wells 1A and 2 lie along the south and north sides, respectively, of Mall Road, near the intersection with Jackson Side Road, just outside the southeast corner of Tillsonburg (**Figure 3-16B**). With the exception of a shopping plaza found approximately 400 m to the southwest, the land use surrounding the wells is primarily agricultural. The nearest surface water feature is a small tributary of Big Otter Creek found 370 m north of Well 2. Well 1A was drilled in 1974 to a total depth of 23.8 m (78 feet) with a 610-mm diameter steel outer casing extended to a depth of 18.3 m and a 254-mm steel inner casing extended to a depth of 19.8 m. The well is screened in a sand and gravel layer from 19.8 to 23.3 m bgs and overburden deposits above the aquifer include an assortment of clay and sand and gravel deposits (Appendix H).

Well 2 was completed 7 years later in 1981 to a total depth of 25.1 m (82.5 feet). The topmost casing is 635 mm in diameter and extends down 0.91 m within a 660-mm diameter copper bearing steel outer casing which extends down to 18.9 m. A 254-mm diameter steel inner casing was installed to a depth of 20.4 m, after which the well is screened in sand and silt to the bottom of the hole. Sand and silt make up the bulk of the stratigraphic profile above this, with minor occurrences of sand and gravel, and sandy clay (Appendix H).

Tillsonburg Wells 9, 10, and 11 are located southwest of Wells 1A and 2, on the east side of Bell Mill Side Road, approximately 615 m south (Wells 9 and 10) and 1 km south (Well 11) of the intersection with Rokeby Side Road. Agricultural lands are the dominant land use in the areas surrounding the wells and the closest surface water feature is a small tributary of Big Otter Creek found 520 m to the east of Wells 9 and 10. While Wells 9 and 10 were both completed in 1988 to depths of 24.7 m (81 feet), Well 11 was drilled in 1991 to a total depth of 23.8 m (78 feet). The construction of Wells 9 and 10 were also very similar with 15.2 m of 508-mm diameter steel outer casings and 20.1 m long, 254-mm diameter, steel inner casings. On the other hand, Well 11 was made with a 508-mm diameter, 20.4-m long steel outer casing, followed by a 20.5-m long, 254-mm diameter steel inner casing. All three wells are screened to the bottom of the borehole, within a fine- to medium-grained sand and fine-grained gravel aquifer. Overlying overburden deposits consist of primarily sand with some clay and gravel (Appendix H).

Well 12 is the southernmost well in the Southeast Well Field in Tillsonburg. This well is located approximately 1.3 km east of Well 11, on Rokeby Sideroad and is surrounded by agricultural lands. The nearest surface water features are small tributaries of Big Otter Creek which can be found approximately 700 m to the north and 860 m to the southwest. The well was installed in 1994, with a total drill depth of 25.60 m (84 feet). A 500-mm diameter outer steel casing was installed to a depth of 17.18 m and sealed with cement grout, followed by the installation of a 250-mm diameter inner steel casing, installed to a depth of 20.27 m. The well screen was installed from 20.27 to 24.99 m bgs, within an aquifer of fine to medium sand and some gravel. The stratigraphic profile above this layer consisted of materials ranging from medium to silty sands with some fine gravel and minor clay (Appendix H).

5.1.2 Northwest Well Field

Wells 4 and 5 lie 70 m apart, along the south side of Brownsville Road, on the edge of the northwest side of Tillsonburg amongst agricultural lands, approximately 470 m west of Woodland Crescent. Well 4 lies adjacent to a small tributary of Cedar Creek and Well 5 lies 45 m from this tributary and 240 m west of a second tributary feeding this same creek. Both wells were constructed in 1962 to total depths of 21.3 m (70 feet; Well 4) and 23.3 m (76.6 feet; Well 5) and are screened in the bottom 3 m within a sand and gravel aquifer. Furthermore, Wells 4 and 5 were installed with 660 mm diameter outer casings that are 10.1 and 11.6 m long, respectively, and, 406 mm diameter inner casings that are 18.3 and 20.3 m long, respectively. Overburden deposits consisted predominately of fine to medium sand, gravel, and clay (Appendix H).

Well 6A is the northernmost municipal well in Tillsonburg, and is located along the west side of Plank Line, 90 m south of Keswick Road, and amongst agricultural fields. The closest surface water feature lies approximately 900 m to the southeast, at a tributary of Cedar Creek. The borehole was completed in 1990, to a total depth of 36.3 m (119 feet), and the 6.1 m long screen was installed from 29.0 to 35.1 m bgs, within a sand and gravel overburden aquifer. Overlying materials were considerably finer and consisted of sandy silty clay, with some gravel. The well was constructed with a 203-mm diameter, 29 m long outer casing, which was subsequently cemented from 0.3 to 7.0 m bgs (Appendix H).

Well 7 is the final municipal well found in the Town of Tillsonburg. The well is located in a residential area of Tillsonburg, on the west side of Broadway Street, at the intersection with Christie Street and adjacent to a tributary of Cedar Creek. The well was drilled in 1977 to a total depth of 22.9 m (75 feet). It was constructed with 508 mm diameter steel outer casing that was extended to a depth of 13.7 m and cemented to 4.9 m, followed by a 254-mm diameter, 19.8 m long, steel inner casing. The bottom 3.0 m of the well consisted of a screen installed within a gravel and sand aquifer, which was found beneath predominantly gravel and clay (Appendix H).

5.2 Town of Delhi

The Town of Delhi is located within the centre of the Study Focus Area, within Norfolk County (**Figure 3-13**). The Town of Delhi has an estimated population of 5,550 (GSP 2010) and rely on surface water from the Lehman Reservoir as well as groundwater from two GUDI wells for its municipal water supply demands (Table 6). The wells and surface water intake also supply water to the nearby community of Courtland.

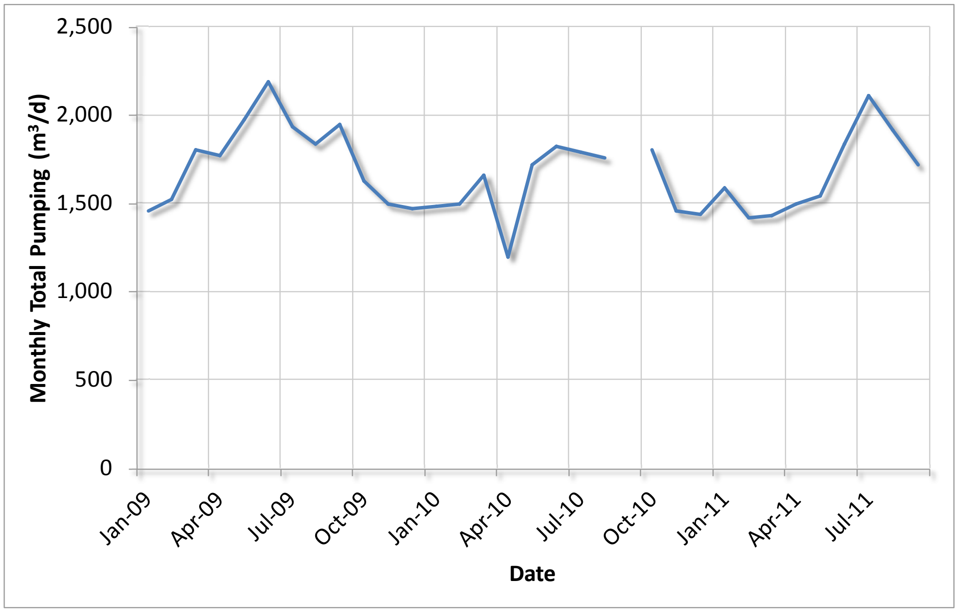
Table 6 Town of Delhi Water Supply Wells/Intakes

Well Name	Permit Number	Permitted Capacity (m^3/day)	2009 Average Annual Taking (m^3/day)
Well 1	7760-6MYTDD (exp. 3/31/2013)	2,300	613
Well 2		2,300	940
Lehman Reservoir	*8735-67NL7Y (exp.* 31/10/2010)	6,815	217
Total		**11,415**	**1,770**

The total permitted capacity of the two groundwater wells and the Lehman Reservoir intake is approximately 11,400 m^3/day. The 2009 average withdrawals from all three sources was 1,770 m^3/day, which suggests that the municipal system has sufficient capacity to accommodate future growth. However, it should be noted that almost 60% of the permitted capacity is derived from the Lehman Reservoir intake. Due to high water treatment costs, Norfolk County is considering abandoning the reservoir as a source of water and replacing it with additional groundwater wells. As such, the available capacity for the Delhi system may be less than currently indicated. From Table 6, it does not appear that the loss of the capacity associated with the Lehman Reservoir would significantly affect the municipality’s ability to meet demand.

As is shown in **Chart 2**, total pumping for the Delhi system is relatively stable from 2009 to September 2011. Monthly variations are shown, with summer peak months being approximately 30% higher than winter baseline months.

Chart 2 Delhi Monthly Total Pumping 2009 to September 2011



5.2.1 Groundwater Supply Wells

Wells 1 and 2 lie approximately 340 m away from one another, along the west side of Windham West Quarter Line Road, approximately 4 km southeast of Delhi (**Figure 3-13**). The wells are located in a rural landscape of primarily agricultural land and the nearest surface water sources are small tributaries of Stony Creek located approximately 1.3 km to the west and 300 m north of Well 1. Well 1 was completed in 1994 to a total depth of 39.32 m (129 feet), and Well 2 was constructed in 2002 to a total depth of 40.84 m (134 feet). Well 1 was constructed with a 24.38-m long, 610-mm diameter outer steel casing which was subsequently sealed with cement grout. The steel inner casing was 305 mm in diameter and extended down to 38.10 m bgs, followed by 7.62 m of screen completed in fine to medium sand. Well 2 was constructed similarly with a 31.7-m long, 610-mm diameter steel outer casing and a 305-mm diameter, 32.77-m long steel inner casing. The 6.24 m long screen was completed within a layer of fine sand. The stratigraphic profile above the screened interval consisted primarily of sand with some gravel and trace clay for Well 1 and the same with slightly more gravel for Well 2 (Appendix H).

The two wells are operated under permit number 7760-6MYTDD, which is due to expire at the end of 2013. Each well is permitted to pump at a rate of 2,300 m^3/day. In 2009 the average annual water taking from Well 1 was 613 m^3/day with a peak daily taking of 1,941 m^3 occurring in June 2009. The average annual withdrawal in 2009 from Well 2 was 940 m^3/day with a peak daily production of 2,278 m^3 (IWC 2010a). The total average annual municipal demand for 2009 was 1,553 m^3/day, which is slightly lower than the demand in 2008 (1,616 m^3/day), 2007 (1,812 m^3/day) and 2006 (2,036 m^3/day; IWC 2010a).

As a requirement of Delhi's groundwater Permit to Take Water, a detailed annual groundwater and surface water monitoring program must be carried out for the lands immediately surrounding the Delhi

Well Field (IWC 2010b). The program includes the monitoring of water withdrawals in the two production wells, monitoring local precipitation amount, and recording water levels (manually by hand and automatically using pressure transducers) in streams, ponds, shallow monitoring wells, deep test wells, and production wells (IWC 2010b). The monitoring is completed most heavily within 1.5 km of the production wells (IWC 2010b) and overall the Town monitors water levels in approximately 45 locations.

In 2009, a groundwater investigation and testing study (IWC 2010a) was conducted to attempt to locate additional water supplies for the Town. Three test wells were drilled less than 1 km south of Well 2 and hydraulic tests were conducted on the wells (IWC 2010a). One well was found to have more favourable conditions and it was recommended that if additional supplies are needed that two larger diameter wells be drilled at the site approximately 15 to 20 m apart (IWC 2010a). To our knowledge, larger diameter test wells have not been drilled and an Environmental Assessment has not been completed so these wells will not be classified as Planned System wells by definition in the Clean Water Act (MOE 2006).

5.2.2 Surface Water Intake

In addition to the two groundwater wells, the Town of Delhi relies upon Lehman Reservoir for a portion of its water supply. The surface water source is typically used in times of high demand and for fire flow and makes up 14% of the total supply in 2009 (Table 6).

Lehman Reservoir, which reaches depths up to 5 m and spans an area of 5 hectares, is located in the north-western portion of Delhi, at the confluence of North and South Creeks (**Figure 3-13**) and was built in 1963 (AECOM 2010). While land use surrounding the reservoir is primarily agricultural to the south and west, residential housing can be found to the north, along Hillside Avenue (AECOM 2010). The surface water intake is located 16.75 m from the upstream dam face, in the eastern part of the reservoir, approximately 70 m north of Old Mill Road and 120 m southwest of Hillside Avenue (**Figure 3-13**). The intake is designed so that water can be collected via gravity from depths of 0.73 m (regularly used) and 1.7 m below the normal surface water level (AECOM 2010). The water collected from the reservoir is mixed with that from groundwater sources and delivered to the population via a single distribution system (AECOM 2010). Other infrastructure found at the reservoir includes the dam, a fish ladder, an overflow structure, a spillway, and a water treatment facility located just downstream of the dam (AECOM 2010).

5.3 Town of Waterford

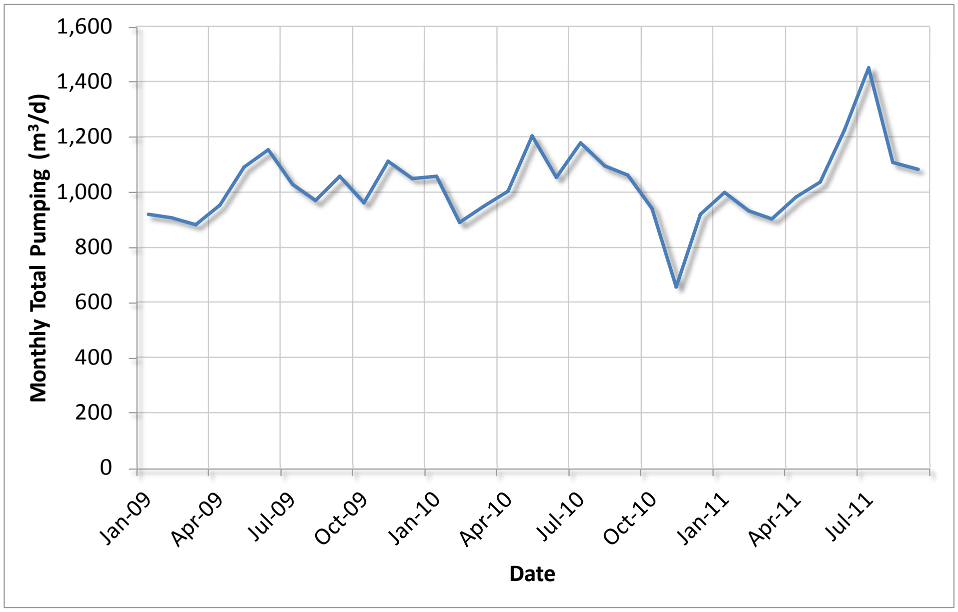
The Town of Waterford is located within the northeastern part of the Focus Area, within Norfolk County (**Figure 3-6**). The Town of Waterford and its estimated 3,730 residents (GSP 2010), rely on groundwater from two GUDI wells for their municipal water supply demands (**Table 7**).

Table 7 Town of Waterford Water Supply Wells

Well Name	Alternate Name	Permit Number	Permitted Capacity (m^3/day)	2009 Average Annual Taking (m^3/day)
Well 3	Thompson Road Well 3	0356-79SPVH (exp. 5/31/2017)	2,946	487
Well 4	Thompson Road Well 4		3,270	518
Total			6,216	1,005

Monthly pumping rates for both wells combined are shown in Chart 3 for the January 2009 to September 2011 time period. Pumping rates over this time period are fairly stable, with the exception of July 2011, which is significantly higher than other months.

Chart 3 Waterford Monthly Total Pumping January 2009 to September 2011



Wells 3 and 4 lie within 100 m of each other, approximately 400 m north of Thompson Road West, and 1 km west of the Town of Waterford. The wells are located in a rural landscape of primarily agricultural land, but immediately surrounding the wells are the surface water features of the Waterford Ponds and southern tributaries of Nanticoke Creek. While Well 3 was completed in 1964 to a total depth of 10.7 m (35 feet), Well 4 was drilled in 1976 to a total depth of 13.1 m (43 feet). The construction of Well 3 consisted of 5.5 m of 762-mm diameter outer casing and 7.6 m of 406-mm diameter inner casing. Below this, the screen extends to the bottom of the hole, within a gravel and sand aquifer. The construction of Well 4, on the other hand, consists of a 610-mm diameter steel outer casing, extended to a depth of 4.9-m, and an inner steel casing, 10.1 m long and 406 mm in diameter. Below the inner casing, the screen extended to the bottom of the hole, within a gravel and sand aquifer. Above the aquifer, overburden materials are noticeably finer with sandy clay and silt (Appendix H).

Figure 3-6 illustrates the location of the municipal supply wells listed in **Table 7**. The two wells are permitted to pump under permit 0356-79SPVH, with a total permitted rate of 6,216 m^3/day; this is considerably higher than the 2009 average annual taking of 487 and 518 m^3/day from Wells 3 and 4, respectively.

5.4 Town of Simcoe

The Town of Simcoe is located in the south-eastern portion of the Focus Area, within Norfolk County (**Figure 3-9**), and has an estimated population of 17,860 residents (GSP 2010). The town relies on groundwater for its municipal water supply demands, and obtains this water from nine municipal groundwater wells and one shallow infiltration gallery located in three well fields (**Table 8**). The infiltration gallery and the wells of the Northwest and Cedar Street Well Fields are designated as GUDI.

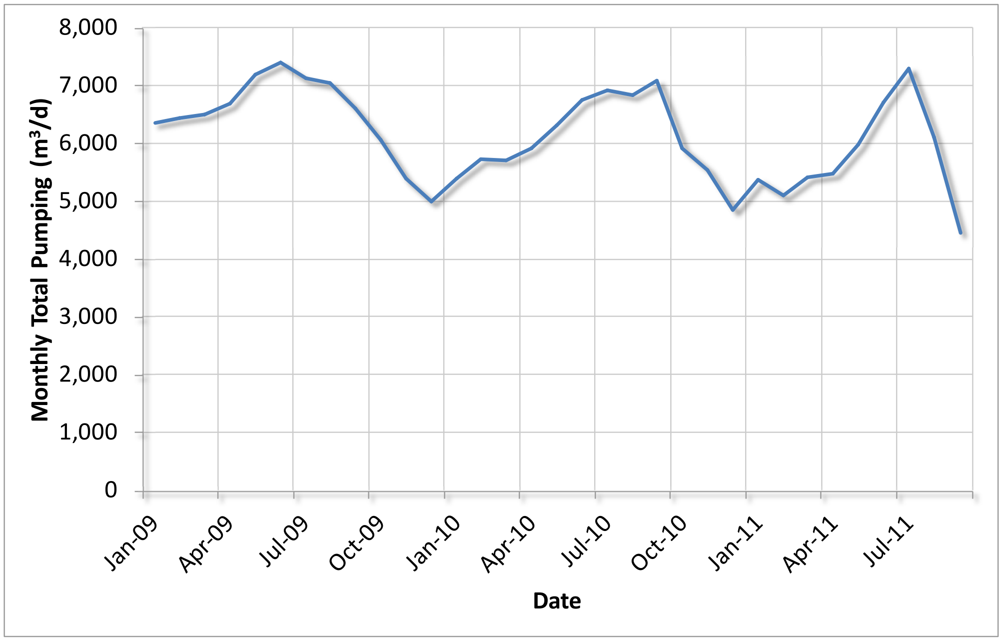
Table 8 Town of Simcoe Water Supply Wells

Well Field	Well Name	Permit Number	Permitted Capacity (m^3/day)	2009 Average Annual Taking (m^3/day)
Northwest	Northwest Well 1	80-P-2005 (exp. 3/31/2010)	2,292	78
	Northwest Well 2	92-P-2013 (exp. 3/31/2010)	2,292	931
	Northwest Well 3	2316-6Y8PQD (exp. 12/31/2016)	2,292	1,217
Cedar Street	Cedar Street Well 1A	8003-5XCR4H (exp. 3/31/2014)	6,819	466
	Cedar Street Well 2A			302
	Cedar Street Well 3			521
	Cedar Street Well 4			305
	Cedar Street Well 5			359
	Infiltration Gallery	4813-64CQPC (exp. 6/30/2009)	5,236	595
Chapel Street	Chapel St. Well 3	02-P-2040 (exp. 3/31/2012)	3,437	1,703
Total			**22,368**	**6,478**

Figure 3-9 illustrates the location of the municipal supply wells listed in **Table 8**. Most wells are permitted under individual permits as listed in **Table 8**; however, the Cedar Street Wells have a combined well field permit (8003-5XCR4H). The total permitted capacity for all of the Simcoe wells is 22,368 m^3/day, and the average annual taking for all wells in 2009 was 6,478 m^3/day (**Table 8**).

Monthly pumping rates for both wells combined are shown in Chart 4 for the January 2009 to September 2011 time period. Pumping rates seem to show a declining trend in winter (baseline) demands, with seasonal increases in demand during the warm months clearly evident.

Chart 4 Simcoe Monthly Total Pumping January 2009 to September 2011



5.4.1 Northwest Well Field

The Northwest Well Field is located approximately 1 km northwest of the Town of Simcoe. The three water supply wells (NW Wells 1, 2 and 3) lie less than 10 m away from either watercourses, or ponds which represent former sand and gravel extraction sites that have infilled with groundwater (**Figure 3-9**).

Northwest Well 1 is approximately 200 m north of 14 Street West. While, the original borehole was drilled in 1979 to a total depth of 27.4 m (90 feet), the well was installed to a depth of 26.2 m (86.1 feet). A 508-mm diameter steel outer casing was installed to a depth of 14.0 m, followed by a 254-mm diameter steel inner casing, which was installed to the top of the screen at 20.0 m bgs. The well screen was installed to a depth of 26.2 m, within a medium grained sand aquifer. Above the well screen, the overburden consisted primarily of fine sand, with gravel and clay in the upper parts of the profile (Appendix H).

Northwest Well 2 is located approximately 615 m west of Northwest Well 1 and was drilled in 1989. The borehole was drilled to a total depth of 26.5 m (87 ft.), while the well installation was completed to a depth of 25.3 m (83 feet). A 15.2-m long, 489-mm diameter inner casing was installed and grouted to 10.4 m bgs, followed by a 19.2-m long, 254-mm diameter steel outer casing. A 6.1 m long well screen was placed below the inner casing, within a fine sand aquifer. Overburden materials overlying the fine sand, consisted of more sand and some gravel and clay (Appendix H).

Northwest Well 3 is located approximately 340 m north of Northwest Well 2. This well was completed in 1996, to a total depth of 23.8 m (78 feet). A 610-mm diameter outer casing was extended to a depth of 14.6 m and sealed with cement grout. A 305 mm diameter steel inner casing was subsequently installed to the top of the well screen at 18.3 m bgs. At this depth potable water is extracted from a medium grained sand aquifer, which makes up the bulk of the stratigraphic profile. Upper layers consist of sand with minor occurrences of gravel and clay (Appendix H).

5.4.2 Cedar Street Well Field

The Cedar Street Well Field is located in the northwest corner of Simcoe, and consists of five groundwater wells (Cedar St. Wells 1A, 2A, 3, 4, and 5), which lie 10 m to 170 m away from Kent Creek, and one shallow infiltration gallery immediately adjacent to Kent Creek (**Figure 3-9**). Additionally, four wells (1A, 2A, 3, and 5) lie within the Kent Creek Complex Wetland.

Cedar Street Well 1A is located approximately 130 m south of Cedar Street, 400 m north of Sunset Drive, and replaced Well 1, which was installed in 1963 and abandoned in 1999. Well 1A was completed in 1999, to a total depth of 14.9 m (49 feet). The well was constructed with a 470-mm diameter steel casing which extends to a depth of 11.9 m, followed by 3.0 m of well screen. The well casing was sealed with cement grout to a depth of 5.8 m bgs, followed by bentonite to a depth of 7.0 m bgs. The stratigraphic profile of the material surrounding the well consists predominantly of sand, with minor amounts of gravel throughout the middle of the profile, and 1.2 m of clay below the well (Appendix H).

Similarly to Cedar Street Well 1A, Cedar Street Well 2A was installed as a replacement for Well 2, which was drilled in 1963 and abandoned in 2002. Well 2A is located approximately 155 m south of Well 1A and 250 m north of Sunset Drive, and was installed in 1997 to a total depth of 10.7 m (35 feet). The well was constructed with a 250-mm diameter steel casing which was extended to a depth of 7.6 m and sealed with cement grout to 4.28 m bgs, followed by bentonite seal to 4.9 m bgs. The well screen was constructed from 7.6 to 10.7 m bgs, within a fine to medium grained sand aquifer. Sediment above this unit consists of medium- to coarse-grained sand and silt (Appendix H). Both Wells 1 and 2 were replaced and abandoned due to decreasing yields caused by siltation and iron encrustation. In both cases the replacement wells were located approximately 4 metres from the original well location.

The original Cedar Street Well 3 that was installed in 1963 to a total depth of 9.8 m (32 feet) still exists today. The well is located 100 m south of Well 2A and 155 m north of Sunset Drive. A 660-mm diameter outer casing was installed to a depth of 2.4 m, followed by a 405-mm diameter inner casing installed to a depth of 6.7 m. Finally, a 3.0 m long well screen was installed in medium to coarse-grained sand and completes the well. The stratigraphic profile above this unit consists of silt, sand and some gravel (Appendix H).

Approximately 120 m east of Cedar Street Well 3, Cedar Street Well 4 is located just outside (70 m) the Kent Creek Wetland Complex and 110 m north of Holden Avenue. The well was originally completed in 1963 and rebuilt in 1993 (International Water Supply Ltd. [IWS] 2010). The well was constructed to a total depth of 10.1 m (33 feet). A 660-mm diameter outer casing was installed to a depth of 3.7 m, followed by a 406-mm diameter inner casing extended to a depth of 7.0 m. The well screen, which immediately follows the inner casing to the bottom of the hole, is completed within a medium to fine-grained sand aquifer. Medium to coarse-grained sand exists above this unit, along with minor amounts of silt (Appendix H).

The final groundwater well in the Cedar Street Well Field, Well 5, is located 45 m west of Well 3 and approximately 145 m north of Sunset Drive. This well was also installed in 1963 to a depth of 9.4 m (31 feet). A 660-mm diameter outer casing was extended 4.0 m below grade, followed by a 406-mm inner casing constructed to a depth of 6.4 m. At the terminus of the inner casing, the well screen begins and continues to the bottom of the hole, within a coarse sand and gravel aquifer. Material above this unit is comprised of coarse sand, gravel, silt, and some clay, while material in the bottom 0.3 m of the profile is composed of clay and sand (Appendix H).

The infiltration gallery is located immediately east of Cedar Street Well 4, beginning just 80 m north of Holden Avenue and 100 m northwest of Warren Road. A series of shallow (< 3 m bgs) perforated pipes have been installed within the sandy sediment along Kent Creek to collect and convey water to a central pumping station. The perforated pipes are connected through nine manholes as is shown on **Figure 5.1**. Water is pumped from the infiltration gallery on a reoccurring, but variable, basis as the infiltration gallery becomes flooded via inflows.

5.4.3 Chapel Street Well 3 Well Field

Chapel Street Well 3 is located in an urbanized, residential area of Simcoe, 100 m south of Chapel Street, and approximately 60 m east of Brook Street (**Figure 3-9**). The well was installed in 1939, to a total depth of 23.0 m (75.5 feet). Further, the well was constructed with a 660-mm diameter, 16.8-m long, copper-bearing steel outer casing, followed by a 356-mm diameter, 19.1-m long copper-bearing steel inner casing. The well screen was completed below the inner casing to a depth of 22.1 m bgs, within a sand and gravel aquifer. Immediately above the screen interval, the overburden materials consist of sand, gravel, followed by a thick unit (10.4 m) of clay near the surface (Appendix H).

6 NON-AGRICULTURAL WATER DEMANDS

The Long Point, Catfish and Kettle Creek Conservation Authorities are recognized by the Province as an area of High Water Use (AquaResource 2004). This designation is largely due to the high concentration of Permits to Take Water related to agricultural irrigation within the Norfolk Sand Plain. Within the drainage areas that comprise the Focus Area for the Risk Assessment, Big Creek (Delhi) contains approximately 1,200 permitted water takings; Big Otter (Tillsonburg) contains approximately 430 permitted water takings; Lynn River (Simcoe) contains 260 permits to take water; and Nanticoke Creek (Waterford) contains approximately 200 permits to take water (Lake Erie Region SPC 2011).

Characterizing and quantifying the amount of water these permitted water takings remove from area watercourses and aquifers is a critical step in assessing the reliability of the municipal supplies.

Municipal water withdrawals for Tillsonburg, Simcoe, Waterford and Delhi have been described and quantified in Section 5. Demand associated with agricultural irrigation will be estimated using the numerical models yet to be developed, and will be documented as part of the numerical modelling report. The following section summarizes the development of a dataset of reported and estimated water takings for the non-agricultural water takers within the Tier Three Focus Area that surrounds the towns of Simcoe, Delhi, Waterford and Tillsonburg (**Figure 1-1**).

6.1 Data Sources

There are two main data sources available for estimating non-municipal, non-agricultural water demands. The two data sources are the Provincial Permit To Take Water Database and the Provincial Water Taking and Reporting System Database. The databases and how they were utilized to develop estimates of consumptive water use are described in the following sections. The definition of consumptive water use is the amount of water withdrawn from a particular source (e.g., watercourse or aquifer) and not returned to that same source in a reasonable period of time.

6.1.1 Permit to Take Water Database

All persons or organizations withdrawing water at a rate greater than 50,000 L/day, must apply for, and be granted, a Permit To Take Water (PTTW) from the Ministry of Environment. Information regarding each PTTW is stored within the PTTW database, including such information as: name of the person/organization; maximum amount of water that can be withdrawn; coordinates of taking; and the purpose of the water withdrawal.

From a water management perspective, a major shortcoming of this database is that it does not contain records on actual pumping records. Typically, actual pumping is significantly less than the maximum amount of withdrawals permitted. The Grand River Conservation Authority provided their PTTW database for use in this study in 2010. This PTTW database was first received by the Grand River Conservation Authority in 2008, after which the Grand River Conservation Authority has been adding new permits as they are circulated. As a result, the PTTW database used in this analysis represents permitted water takings as of 2010.

To verify the data contained within the PTTW database, every permit that was located within 500 m of the Focus Area was downloaded from the Environmental Registry (www.ebr.gov.on.ca) and reviewed. Data contained within the actual permit was referenced to the corresponding record in the PTTW database. Missing data fields were populated, the relationship between the permitted volume and multiple points of taking was noted, and the nature of takings was examined. Temporary permits (permits active for one year or less), including those for pumping tests or temporary construction were removed from this assessment.

For those PTTWs that did not have reported values associated with them (as discussed below in Section 6.2), estimates were developed to represent consumptive water demands. This was done by combining maximum permitted withdrawal rates with the number of days each taking was permitted to withdrawn for. This volume was distributed across the months in which the taking would be active, and resulted in an estimate of the amount of water withdrawn. Consumptive use factors, from a document prepared for the Ontario Ministry of Natural Resources (Kinkead Consulting and AquaResource 2009), were then applied to the volume withdrawn to generate consumptive estimates.

6.1.2 Water Taking and Reporting System

In January 2005, the Water Taking Regulation came into effect. This regulation modified the Permit To Take Water program by requiring, among other things, mandatory monitoring and reporting of water takings by all permit holders. The monitoring and reporting requirements were phased in over a three year period, with all water users captured under this requirement in 2008.

In the Focus Area, 41 out of 70 water takings had reported pumping rates contained within the 2008 Water Taking Reporting System (WTRS). The daily reported rates were averaged over the month to obtain monthly pumping rates, and those were averaged over the year to obtain annual average pumping rates; both datasets will be used in the Tier Three Assessment modelling efforts.

Data contained within the WTRS database are reported directly by permit holders, and as such data entry errors associated with incorrect units (e.g. gallons per day versus litres per day), inaccurate measurement practices, or number keying issues are common. To identify sources of error, the maximum daily reported rate was queried from the WTRS dataset and compared to the maximum daily permitted rate. If the maximum daily reported rate was significantly larger than the maximum daily permitted rate, the reported data for that source was manually inspected and corrected.

The WTRS dataset contains actual daily pumping rates; however, not all water withdrawn from an aquifer is consumed. The Water Budget Framework as part of the Clean Water Act considers the consumptive demand at each water taking, which is the volume of water withdrawn that is not returned to its original source. To calculate the consumptive use of WTRS reported takings, a consumptive factor related to the purpose of the taking was applied. The consumptive use factors applied were obtained from a document prepared for the Ontario Ministry of Natural Resources (Kinkead Consulting and AquaResource 2009).

6.2 Estimated Consumptive Demands

Figure 6-1 illustrates the location of the 70 permitted, non-agricultural water takings wells that will be included in the groundwater flow model, and **Figure 6-2** is a thematic map of the calculated consumptive water takings. **Tables 9** and **10** provide a summary of this information and includes the maximum permitted rate, percentage of total permitted takings, and average annual consumptive demand by specific purpose for groundwater and surface water takings, respectively. This summary lists the consumptive use estimates using values listed in the WTRS and those derived from the PTTW database where reported rates were not available.

Table 9 Summary of Permitted Rates and Consumptive Demands of Groundwater Takings in the Focus Area

Specific Purpose	No. of Sources (Wells, Ponds, Sand Points)	Maximum Daily Permitted Rate (m^3/day)	% of Total Permitted	Average Annual Consumptive Rate (m^3/day)
Aquaculture	29	23,599	58%	16,439
Golf Course Irrigation	6	7,557	19%	531
Municipal	7	5,779	14%	717
Other - Commercial	3	1,382	3%	54
Other - Miscellaneo us	2	1,092	3%	26
Other - Industrial	3	487	1%	485
Aesthetics	4	360	1%	360
Campgrounds	3	355	1%	249
Aggregate Washing	1	109	0%	-

Table 10 Summary of Permitted Rates and Consumptive Demands of Surface Water Takings in the Focus Area

Specific Purpose	No. of Sources (Streams, Online Ponds)	Maximum Daily Permitted Rate (m^3/day)	% of Total Permitted	Average Annual Consumptive Rate (m^3/day)
Dams and Reservoirs	1	14,343	56%	-
Wildlife Conservation	5	5,596	22%	-
Golf Course Irrigation	4	3,312	13%	331
Aquaculture	1	1,968	8%	-
Other - Recreational	1	364	1%	149

Consumptive use estimates are lower than the maximum permitted pumping rates listed in the PTTW database, as they represent more realistic estimates than those estimated by simply summing the permitted volumes. This highlights the need for effective understanding and assessment of demand volumes and rates.

7 SUMMARY

The Regional Area is covered by a thick blanket of Quaternary-aged sediment deposited during the Late Wisconsinan as glacial ice lobes advanced and retreated across the area and were impacted by fluctuating lake levels in the Lake Erie basin. The glacial history of the area was examined in detail to help reconstruct the overburden hydrostratigraphy on a regional and local-scale.

Due to the presence of a thick and productive surficial aquifer, deep water well data across the Regional Area that can be used to characterize and interpret the distribution of subsurface hydrostratigraphic units is scarce. Water-well logs fail to provide insight into the aquifer and aquitard relationships. As such, a field program was undertaken as part of the Tier Three Assessment to provide additional, high-quality data to aid in the characterization of the regional- and local-scale hydrogeology of Norfolk and Oxford Counties, especially within the municipal well field areas of Delhi, Simcoe, Waterford and Tillsonburg.

Analysis of core collected from 26 coreholes in the Regional Area and the generation and interpretation of 118 cross-sections within the Regional Area facilitated the creation of a three-dimensional geologic model across the Lake Erie Source Protection Area. The developed geologic model consists of dipping strata, and is consistent with the stratigraphic framework presented by Barnett (1978, 1982, 1987, 1993, 1998). It will be used to form the basis for a numerical groundwater flow model to evaluate the long-term reliability of water supplies in the communities of Delhi, Simcoe, Waterford and Tillsonburg.

Characterization efforts completed as part of the Tier Three Assessment provide enhanced understanding of the regional and local geology and hydrostratigraphy, particularly where there are connections between the municipal aquifers and nearby surface water features. The surfaces that form the basis of the three-dimensional geologic model represent the most current interpretation of the hydrostratigraphic units within the Lake Erie Source Protection Area and incorporate all of the field data and available glacial understanding of the area. The refined surfaces have been constrained to be applied as continuous surfaces for application in the Tier Three Assessment numerical model, and provide the enhanced hydrogeologic structure needed to support the detailed modeling evaluations of the Tier Three Assessment.

Of the 95 total non-agricultural PTTW locations, 23 locations are associated with a municipal production well. In addition, there is one municipal surface water intake (Delhi) and an infiltration gallery (Simcoe). Only 13 of the 95 withdrawal locations take water from surface water sources, the remainder rely on groundwater for their supply. More than half of the non-agricultural water withdrawals have reported water withdrawal volumes within the Provincial Water Taking and Reporting System, which were used for this study. Volumes for takings without records in the Water Taking and Reporting System were estimated using the maximum permitted rates and maximum allowable days of pumping from the PTTW database.

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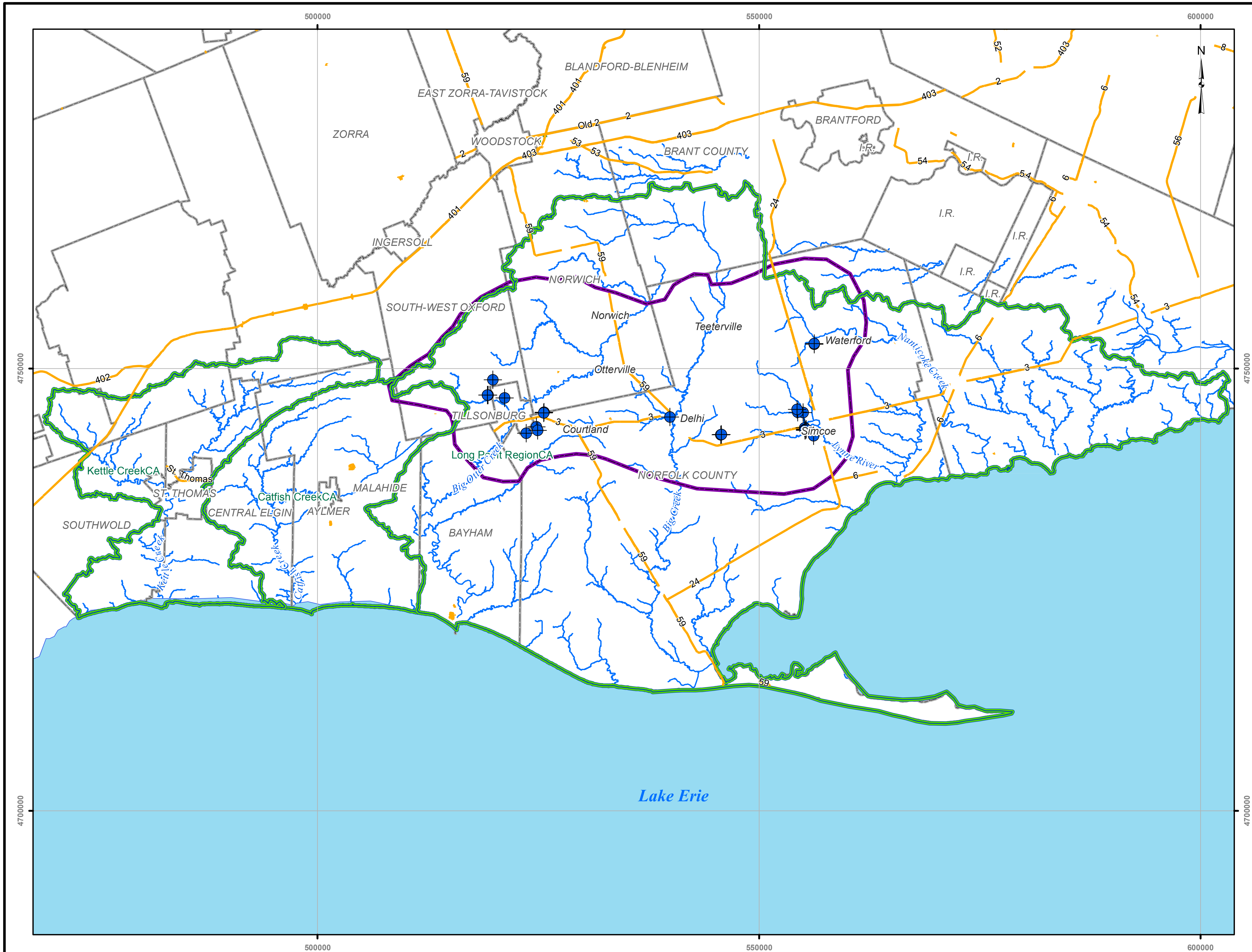
Appendix A

Figures



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Highway / Expressway
- Drainage
- Open Water
- Conservation Authority Boundary, Watershed Boundary
- Tier Three Focus Area
- Municipal Boundaries

Scale 1:425,000

0 5 10 15

Kilometres

REFERENCES

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Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 05-Aug-2011; Created By: LH

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Figure 1-1.
Study Area

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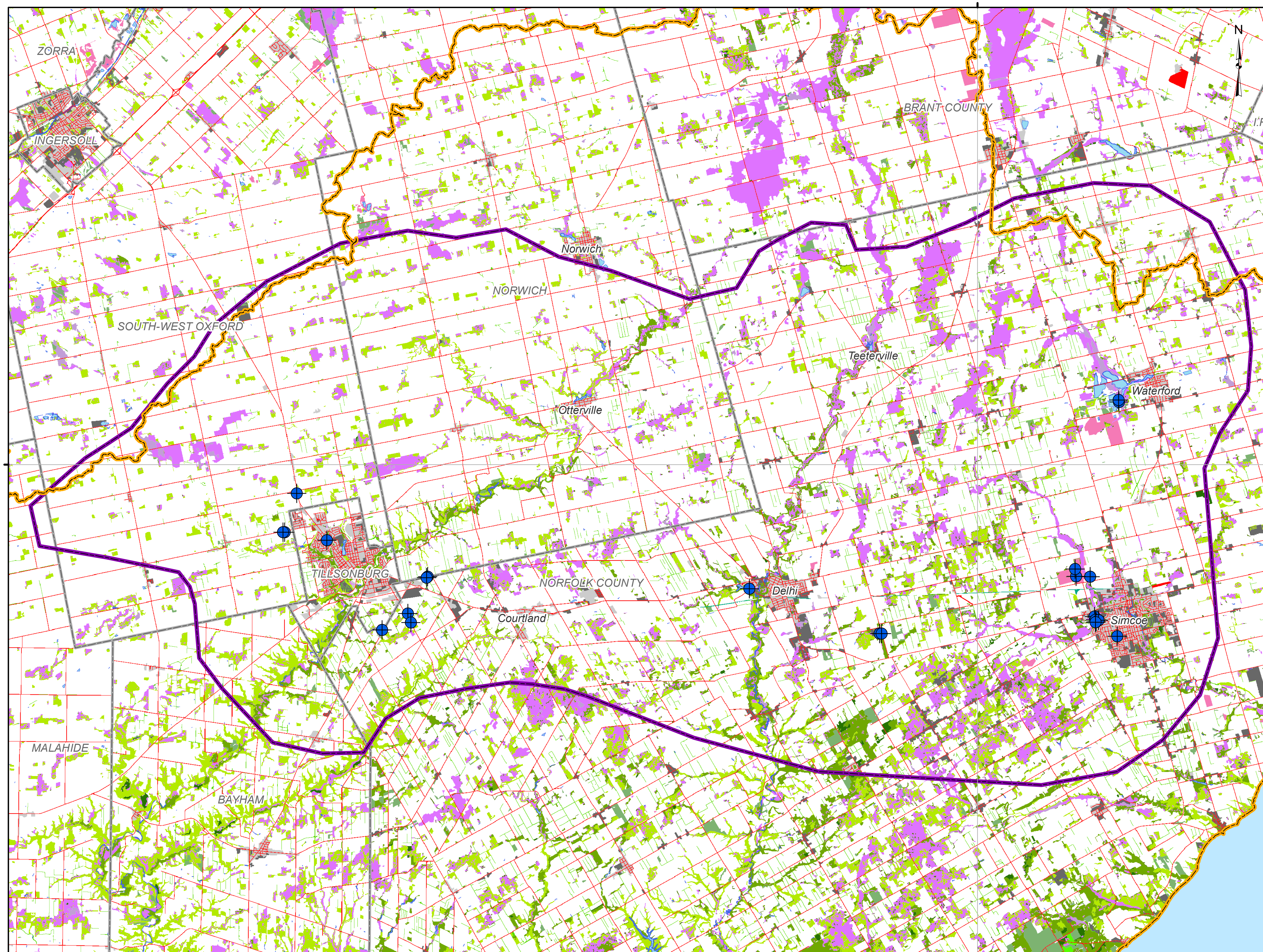
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries
- Open Cliff and Talus
- Alvar
- Shoreline, Open Shoreline
- Open Sand Barren and Dune
- Treed Sand Barren and Dune
- Open Tallgrass Prairie
- Tallgrass Savannah
- Tallgrass Woodland
- Forest
- Coniferous Forest
- Mixed Forest
- Deciduous Forest
- Plantations - Tree Cultivated
- Hedge Rows
- Transportation
- Extraction
- Built-Up Area (Pervious)
- Built-Up Area (Impervious)
- Swamp
- Fen
- Bog
- Marsh
- Open Water
- Agriculture

Scale 1:175,000

0 2 4 6

Kilometres

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Southern Ontario Land Resource Information System (2000-2002). Ministry of Natural Resources.
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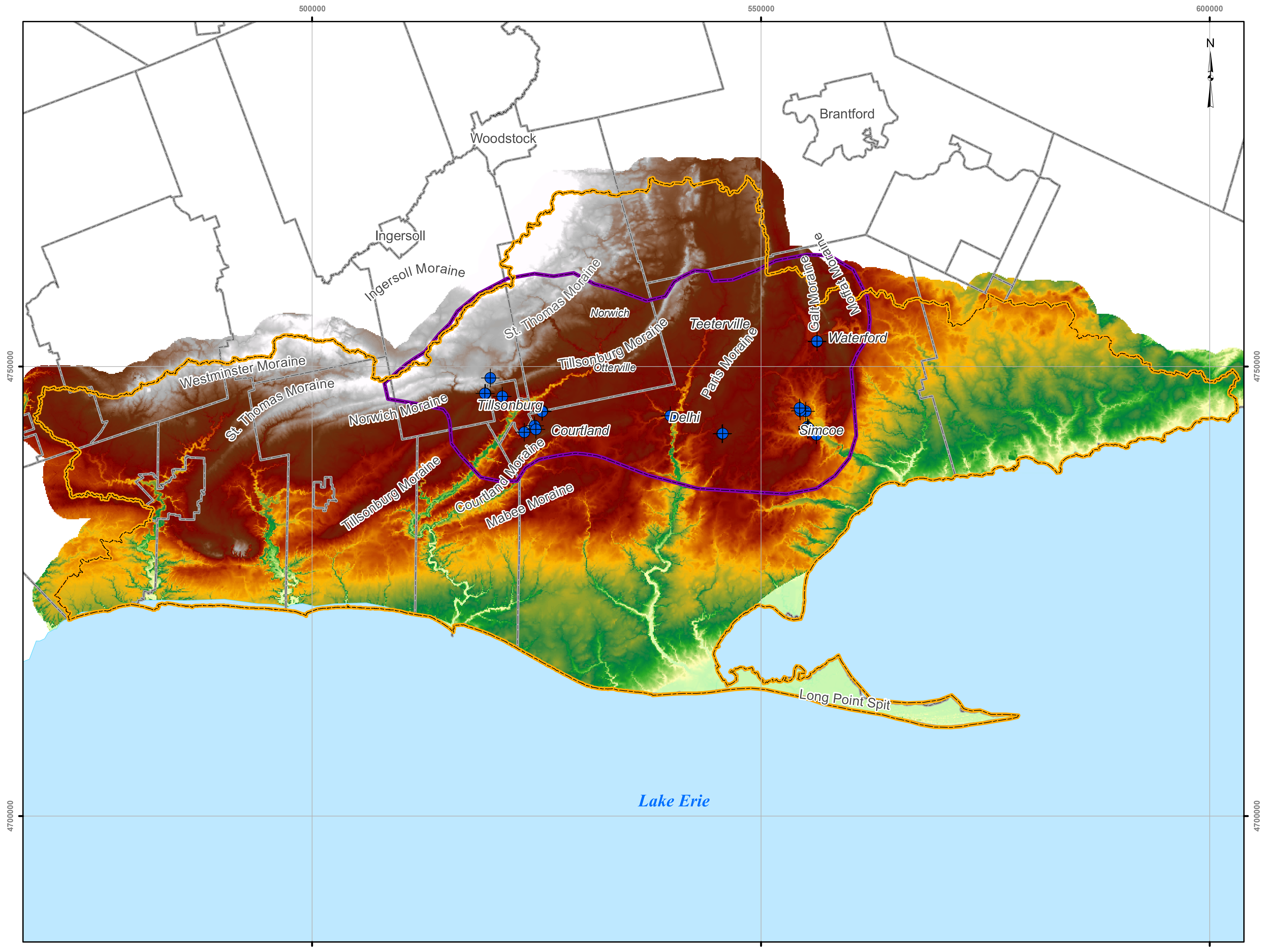
Figure 1-2.
Land Cover (SOLRIS)

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_LandCover.mxd

Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Elevation (mASL)

High : 340

Low : 160

Scale 1:425,000

0 5 10 15

Kilometres

Projection: NAD 1983 UTM Zone 17N
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Figure 2-1.
Ground Surface Topography

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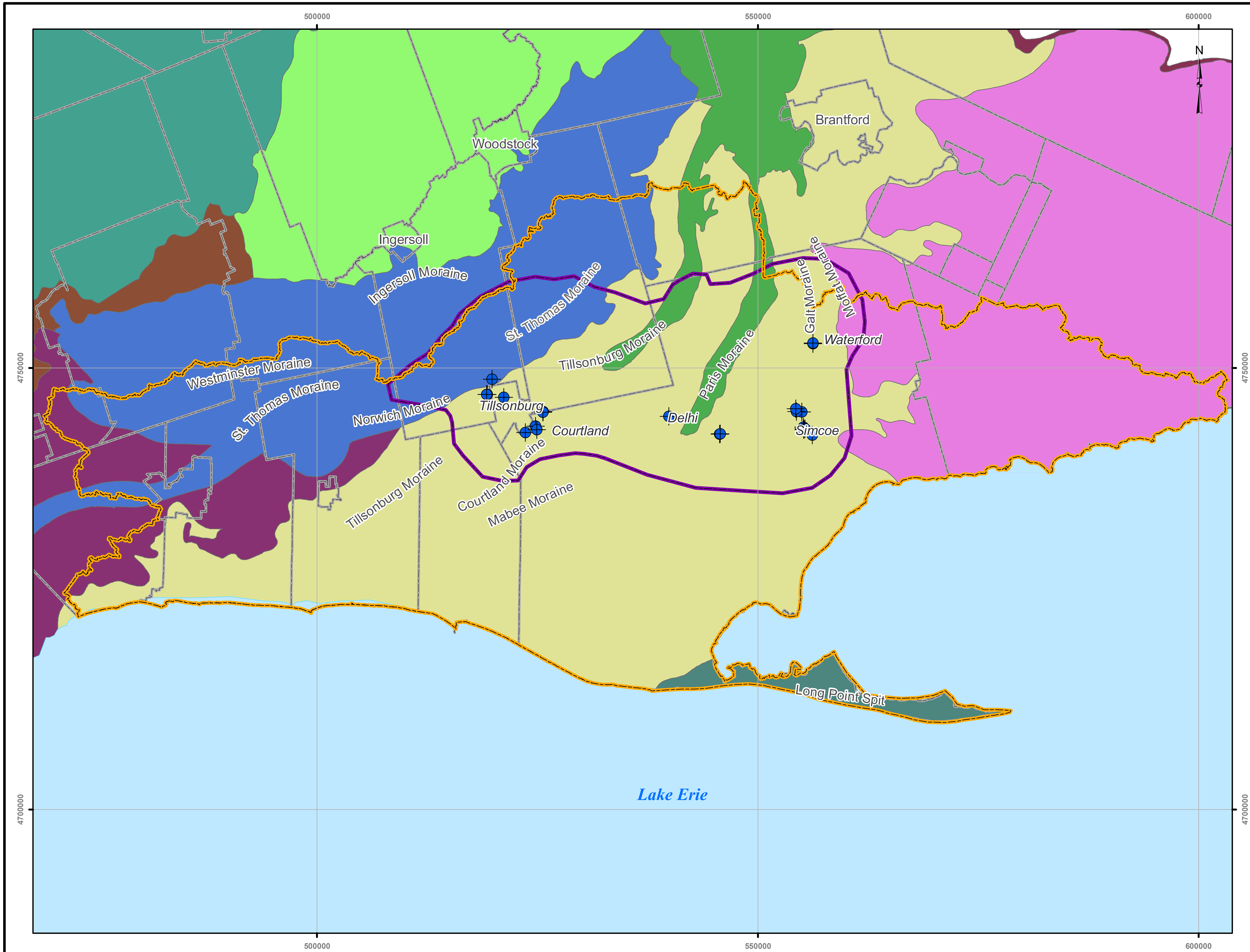
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries
- Niagara Escarpment
- Horseshoe Moraines
- Stratford Till Plain
- Oxford Till Plain
- Mount Elgin Ridges
- Caradoc Sand Plains
- Ekfrid Clay Plain
- Erie Spits
- Norfolk Sand Plain
- Haldimand Clay Plain

Scale 1:425,000

0 5 10 15

Kilometres

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Chapman, L.J. and Putnam, D.F. 2007. Physiography of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 228 ISBN 978-1-4249-5158-1

Projection: NAD 1983 UTM Zone 17N

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Figure 2-2.
Physiographic Regions

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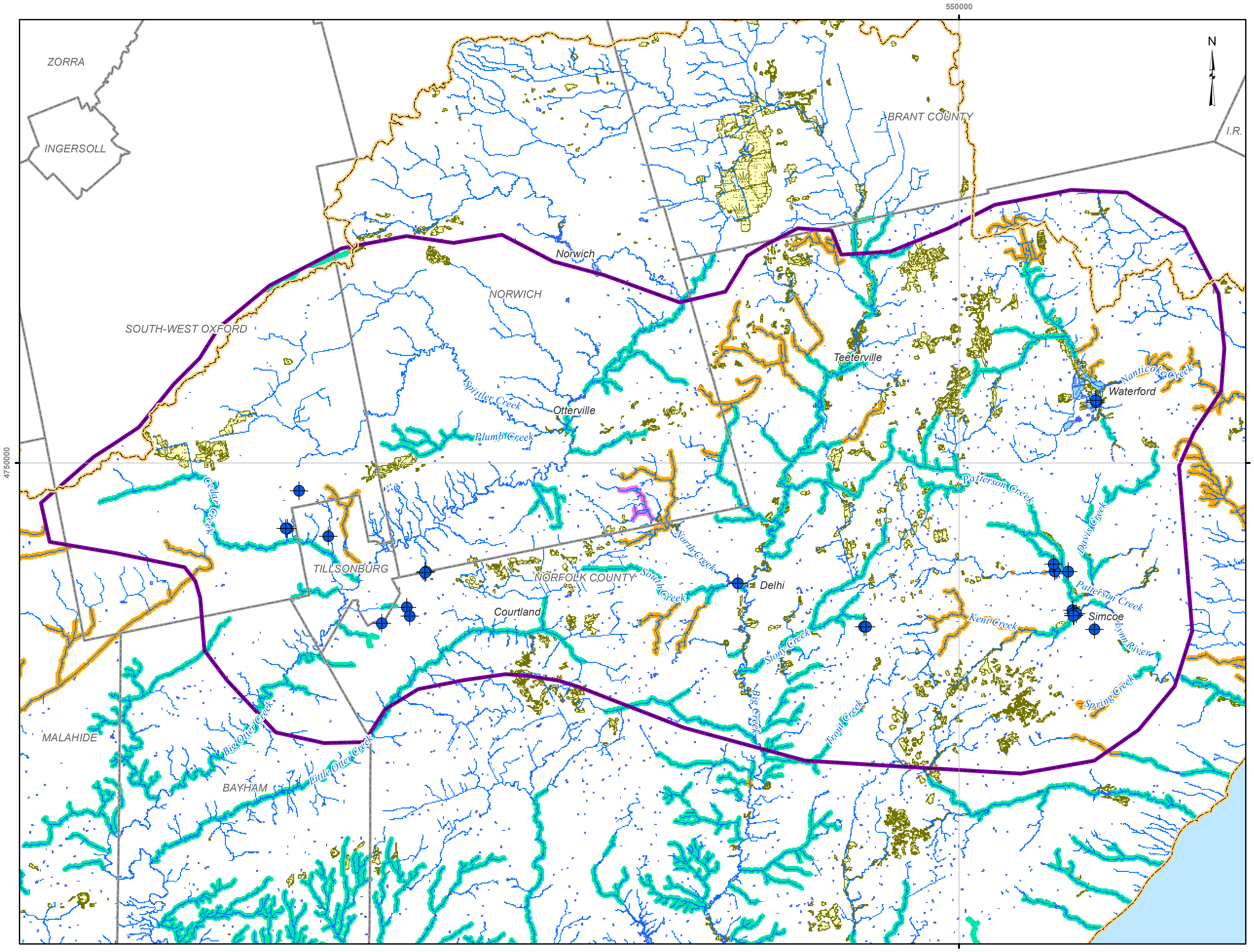
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Drainage
- Thermal Regime
  - Warm Water
  - Cool Water
  - Cold Water
- Open Water
- Wetland
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Scale 1:175,000

0 2 4 6

Kilometres

Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 05-Aug-2011; Created By: LH

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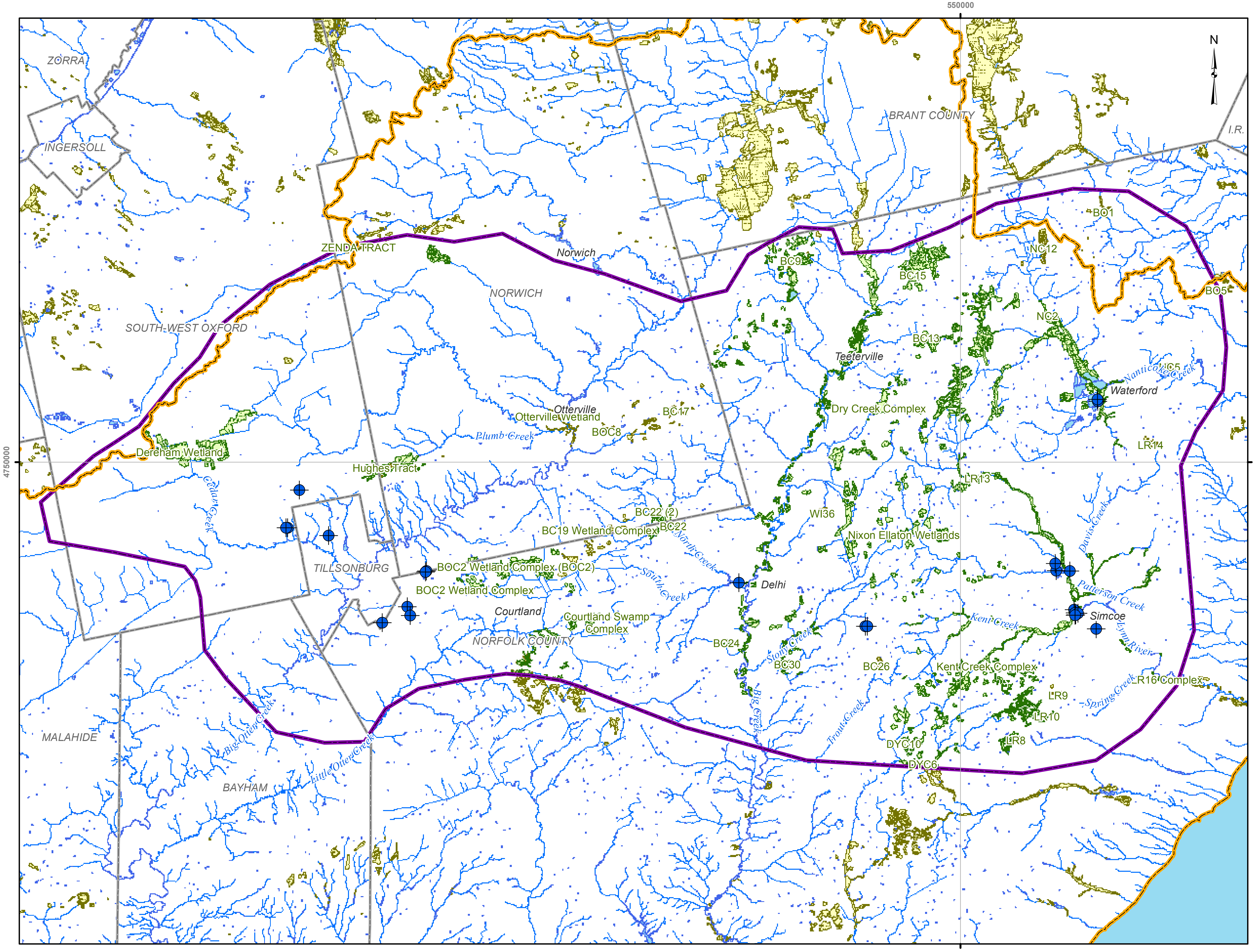
Figure 2-3.
Surface Water Features and Thermal Regimes



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Provincially Significant Wetland
- Wetland
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Scale 1:175,000

0 2 4 6

Kilometres

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Land Information Ontario, Aquatic Resource Area (2010).
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Figure 2-4.
Wetland Complexes

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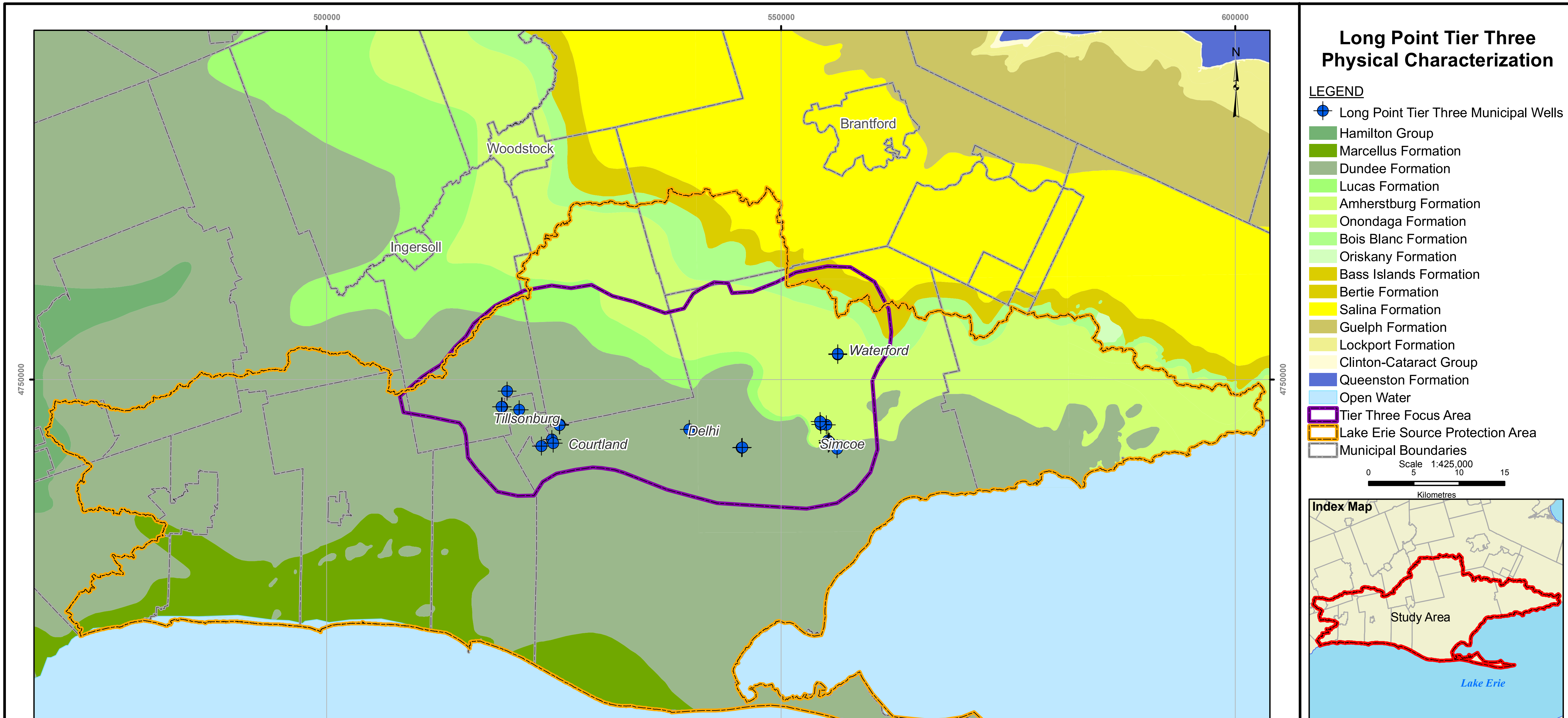
Project: 2010015_LongPointT3

Long Point Tier Three Physical Characterization



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Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 219. ISBN 978-1-4249-4526-9
Projection: NAD 1983 UTM Zone 17N
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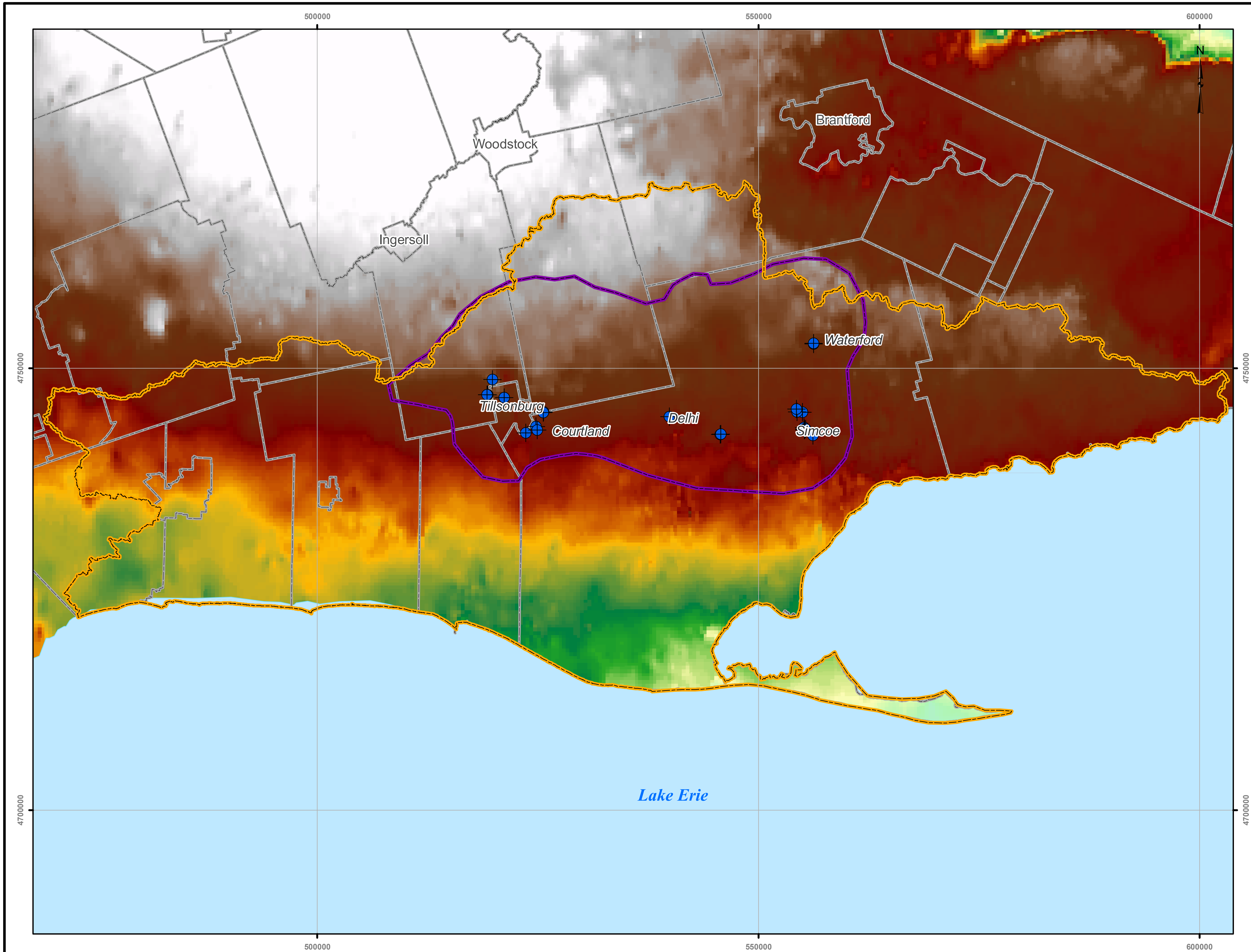
Figure 3-1.
Bedrock Geology

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_BdrkGeol.mxd

Project: 2010015_LongPointT3

Long Point Tier Three Physical Characterization



LEGEND

- Long Point Tier Three Municipal Wells
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Elevation (mASL)

High : 265

Low : 50

Scale 1:425,000

0 5 10 15 Kilometres

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Gao, C., Shirota, J., Kelly, R. I., Brunton, F.R., van Haaften, S. 2006. Bedrock topography and overburden thickness mapping, southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 207. ISBN 1-4249-2550-9
Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 05-Aug-2011; Created By: LH

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Figure 3-2.
Bedrock Topography

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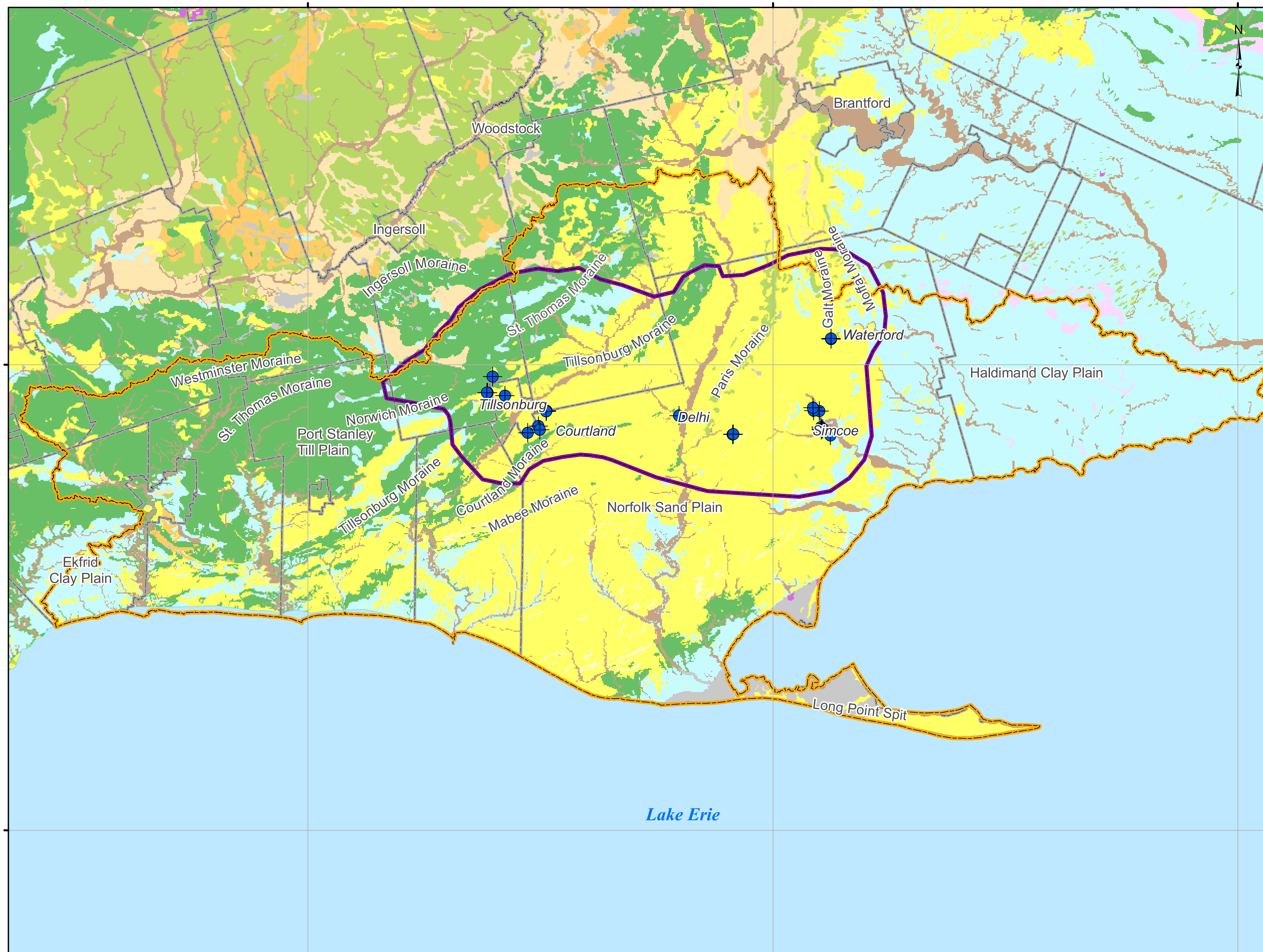
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Paleozoic bedrock
- Stone-poor, carbonate-derived silty to sandy till
- Glaciolacustrine-derived silty to clayey till
- Ice-contact stratified deposits
- Glaciofluvial deposits
- Fine-textured glaciolacustrine deposits
- Coarse-textured glaciolacustrine deposits
- Alluvial deposits
- Eolian deposits
- Organic deposits
- Man-made deposits
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Scale 1:425,000

0 5 10 15

Kilometres

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Ontario Geological Survey 2010. Surficial geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 128-REV ISBN 978-1-4435-2483-4 [DVD] ISBN 978-1-4435-2482-7 [zip file]

Projection: NAD 1983 UTM Zone 17N

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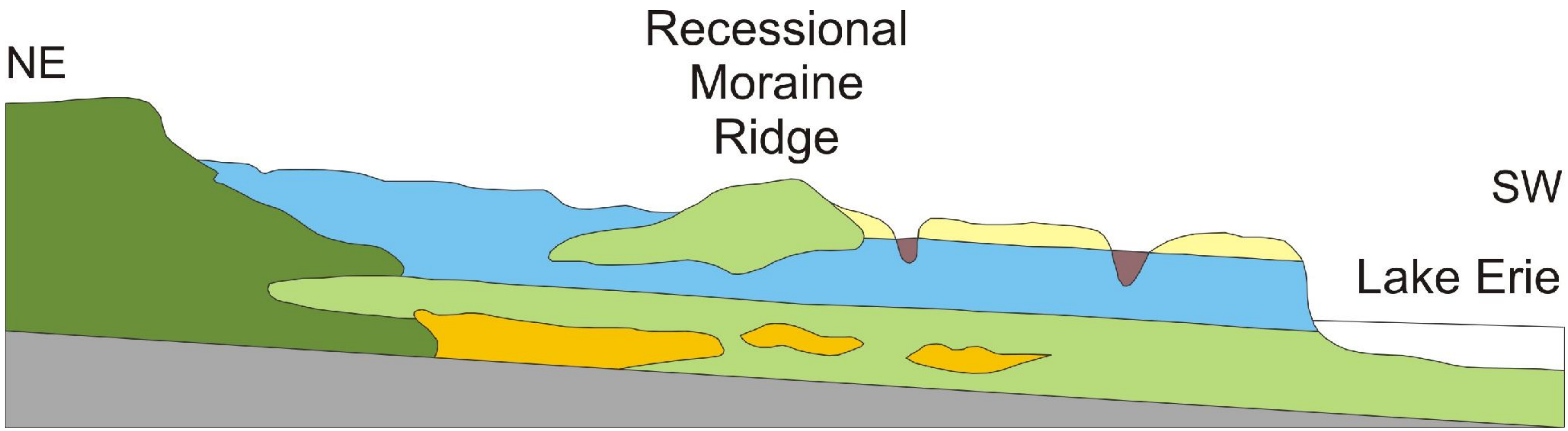
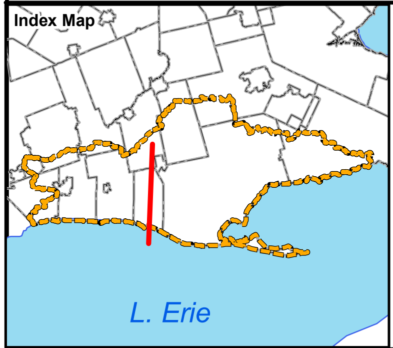
Figure 3-3.

Surficial Geology

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_SurfGeol.mxd

Project: 2010015_LongPointT3





LEGEND

- Bedrock
- (Glacio)Lacustrine Sediment
- Diamict (Till) Complex
- Surficial Sand
- Buried Sand and Gravel
- Recent Alluvium

Long Point Tier Three: Physical Characterization

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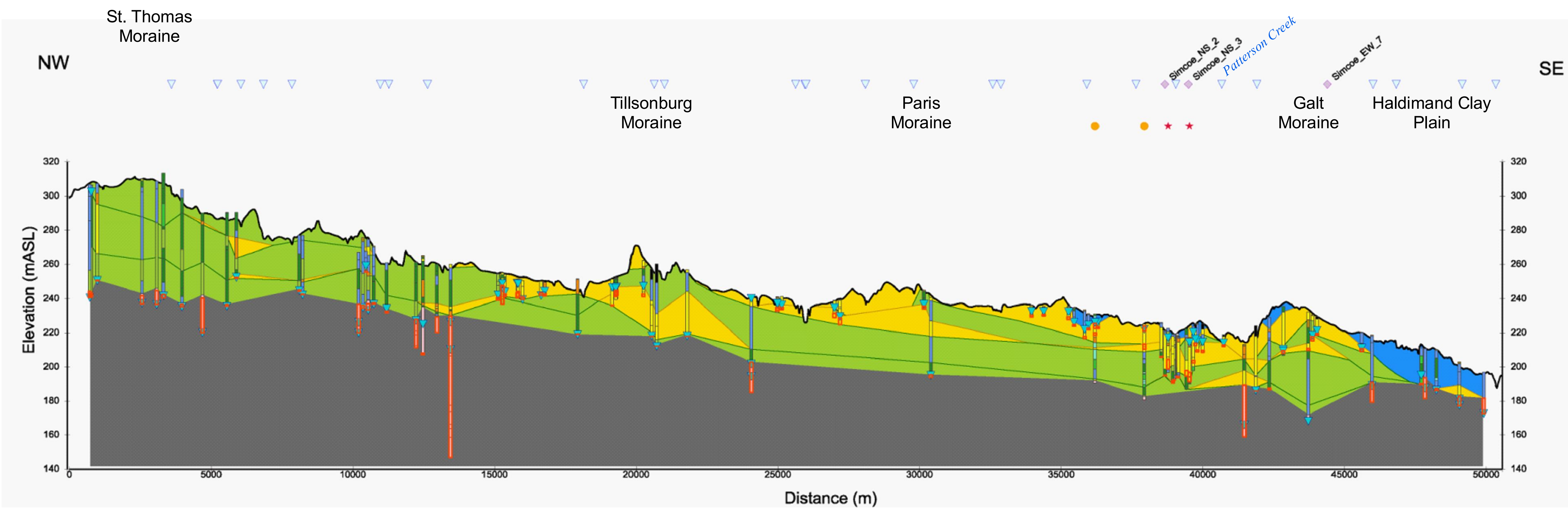
Figure 3-4.

Alternate Conceptual Geologic Model

REFERENCES
Novakovic and Farvolden (1974)
Map Version: 1; Map Date: 05-2011-08; Created By: LH



Vertical Exaggeration: 60x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Layer Structure

- Haldimand Clay Plain, Aquitard
- Coarse-textured sediment, Aquifer
- Fine-textured sediment, Aquitard
- Bedrock
- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

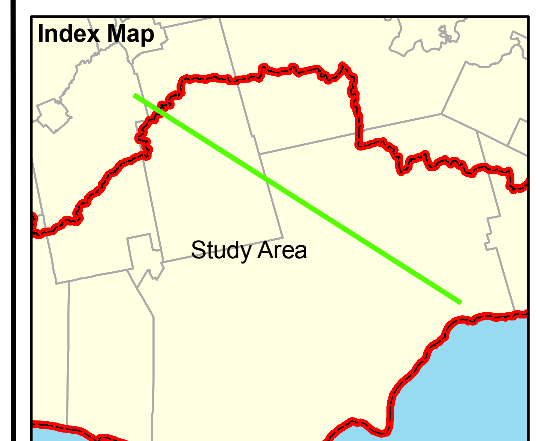


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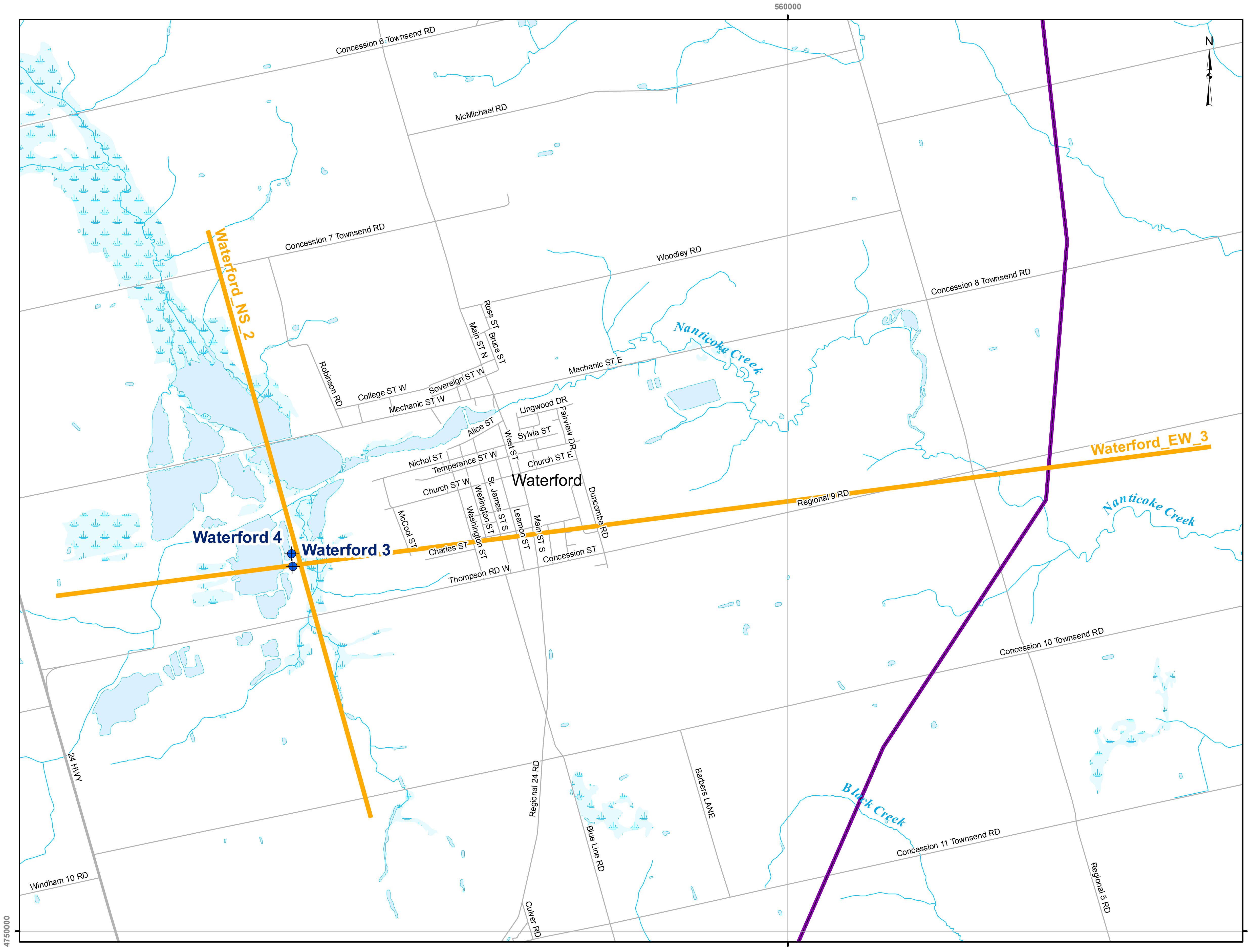
Figure 3-5.

Norfolk Sand Plain Cross-section: NSP_Moraines_NWSE_4

Long Point Tier Three Physical Characterization



LEGEND

- Long Point Tier Three Municipal Wells
- Cross Section Locations
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas
- Tier Three Focus Area

Scale 1:29,000

0 0.5 1 1.5

Kilometres

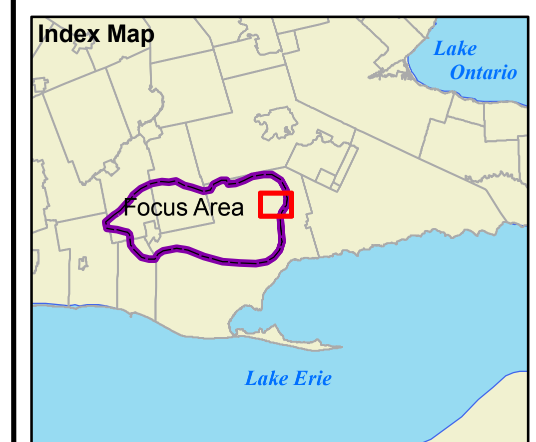


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Figure 3-6.
Waterford Well Field Area

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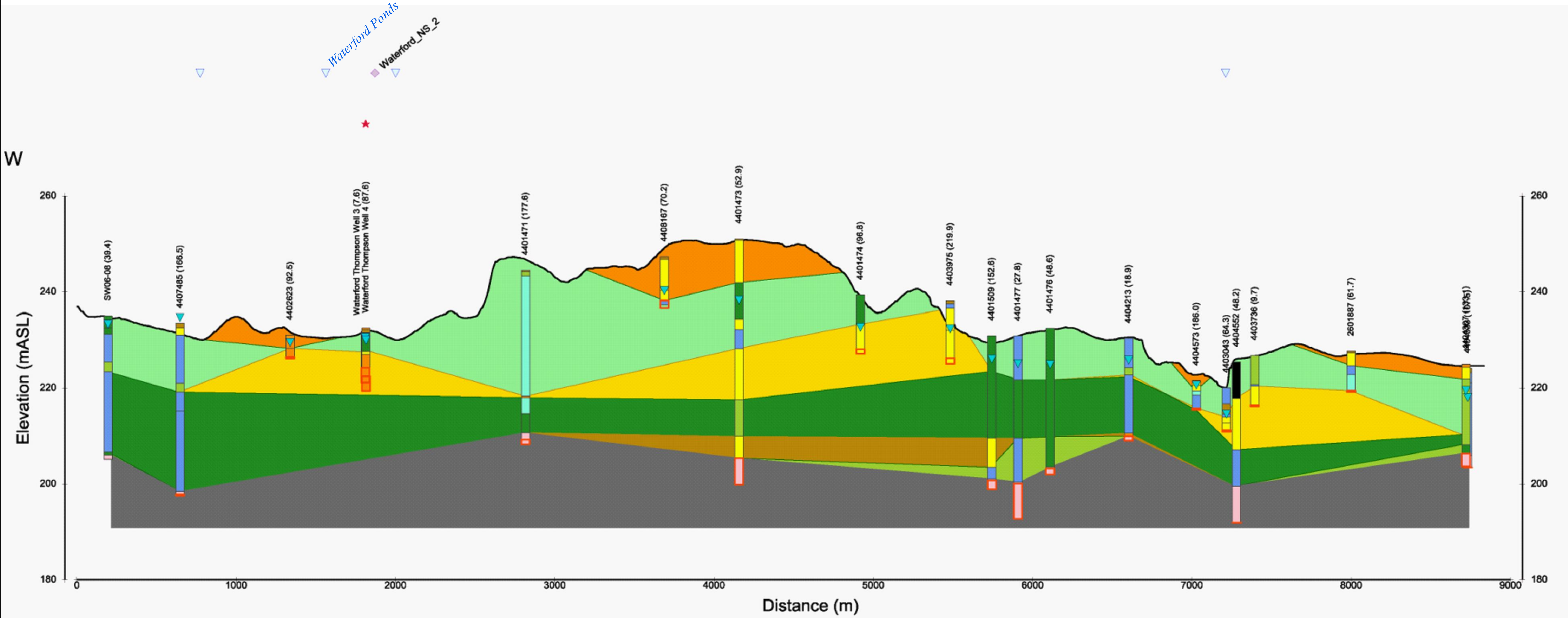
Project: 2010015_LongPointT3

Long Point Tier Three Physical Characterization



Vertical Exaggeration: 30x

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Wentworth Drift, Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

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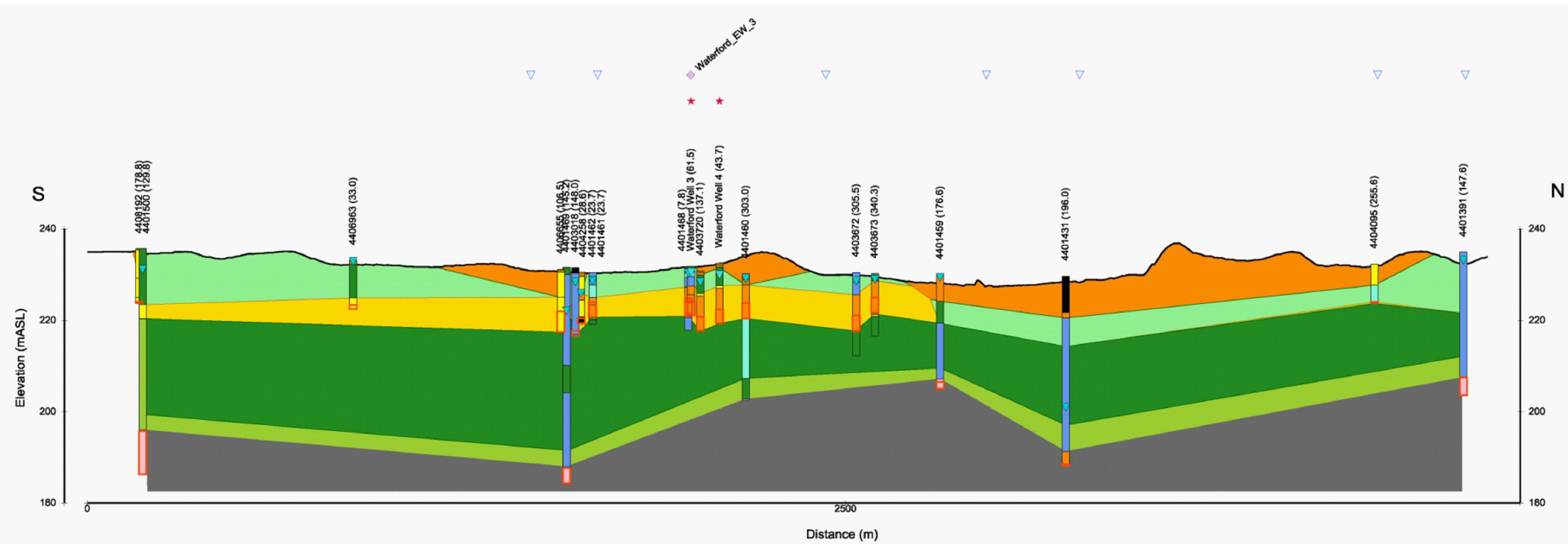
Figure 3-7.

Waterford Cross-section: Waterford_EW_3



Vertical Exaggeration: 15x

Long Point Tier Three Physical Characterization

LEGEND

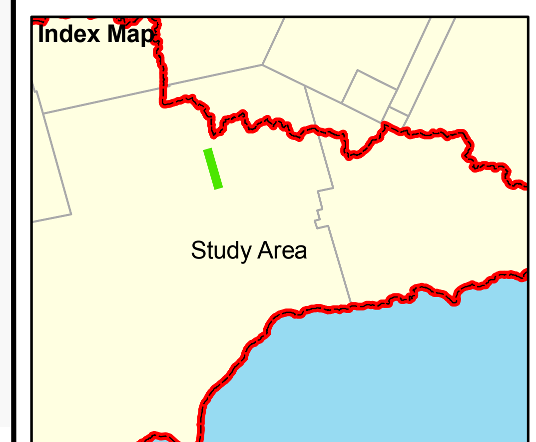
Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Wentworth Drift, Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log



REFERENCES

Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 06-Aug-2011; Created By: LH

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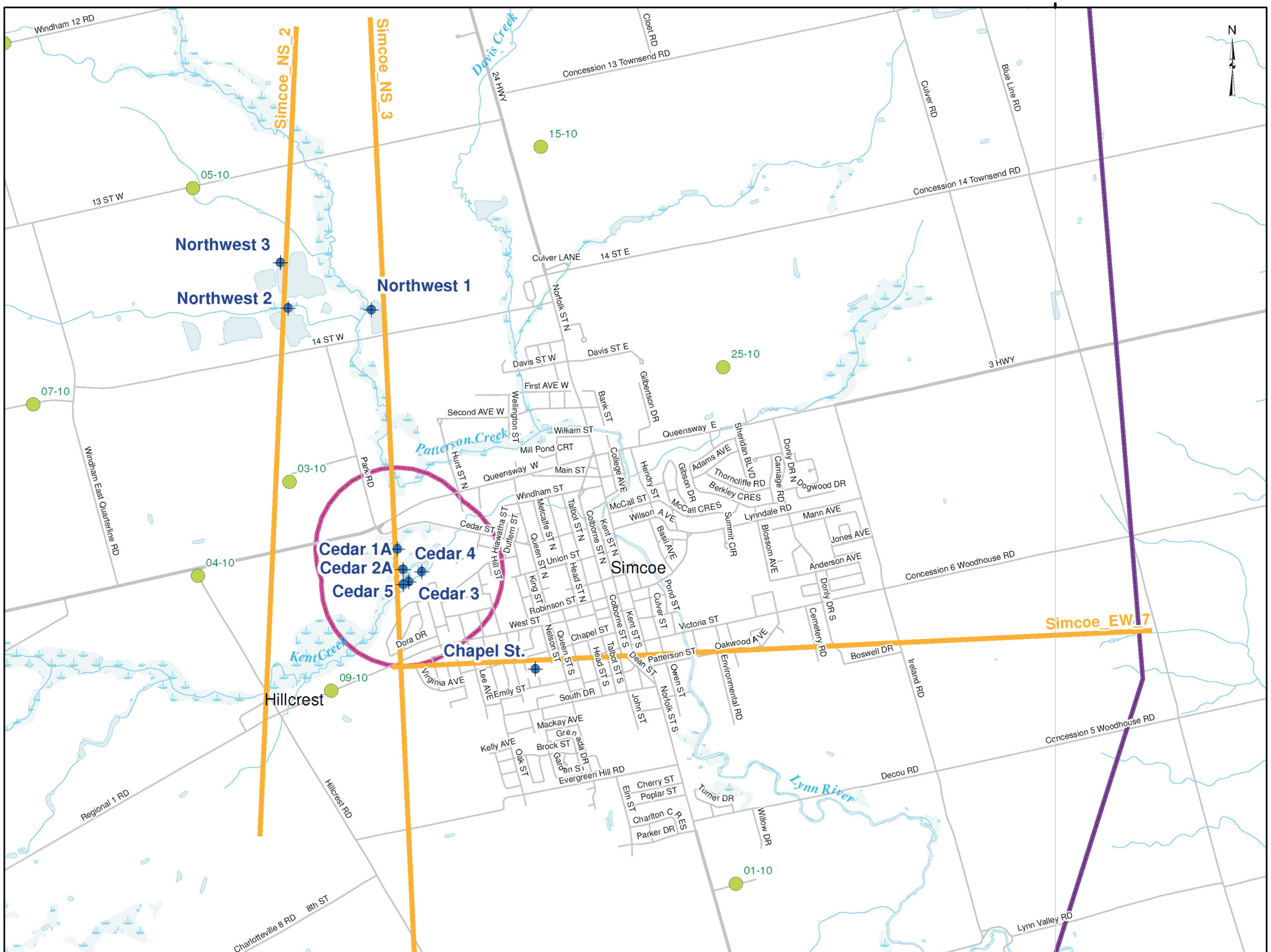
Figure 3-8.

Waterford Cross-section: Waterford_NS_2



Long Point Tier Three Physical Characterization

LEGEND

- Tier Three Field Program Drilling Site
- Long Point Tier Three Municipal Wells
- Cross Section Locations
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas
- Tier Three Focus Area
- 600 m Buffer around Cedar Street Municipal Supply Wells

Scale 1:29,000

0 0.5 1 1.5

Kilometres

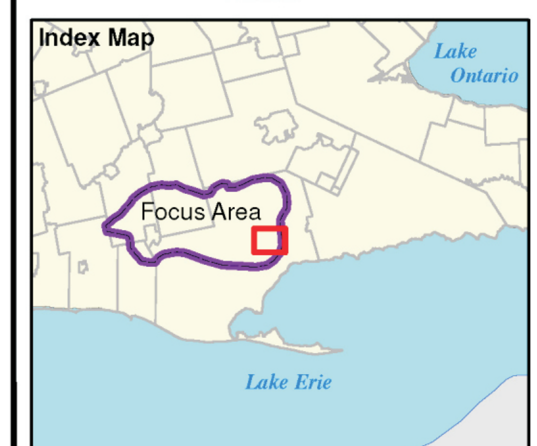


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Figure 3-9.
Simcoe Well Field Area

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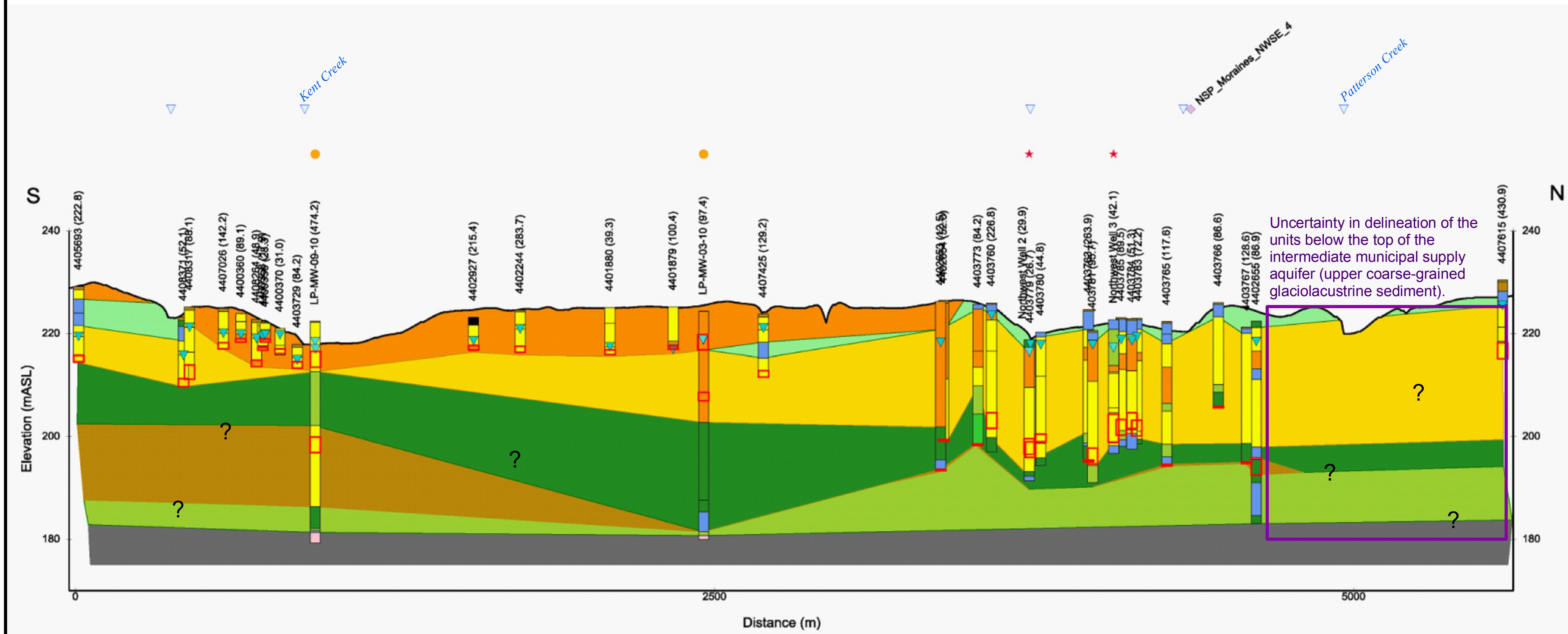
Project: 2010015_LongPointT3



Vertical Exaggeration: 20x

Long Point Tier Three Physical Characterization

LEGEND

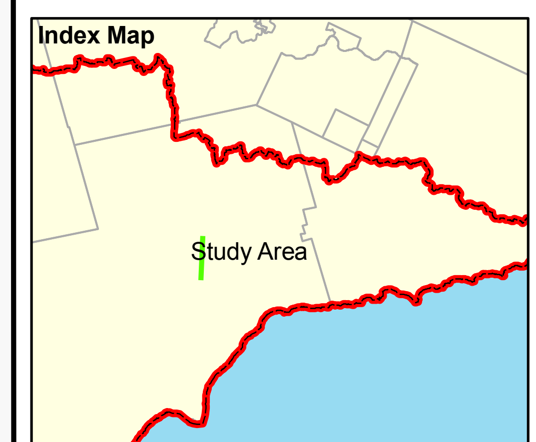
Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Wentworth Drift, Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log



Projection: NAD 1983 UTM Zone 17N
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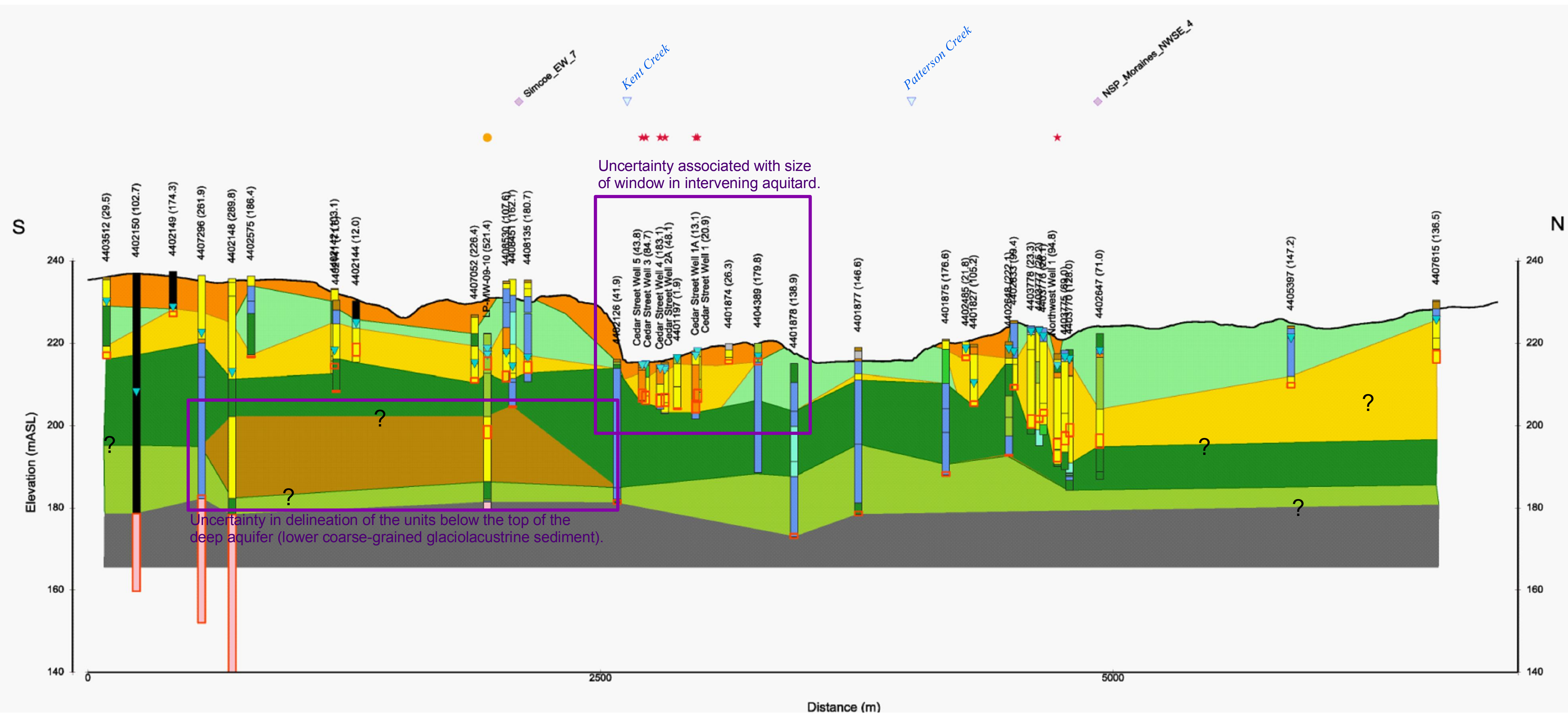
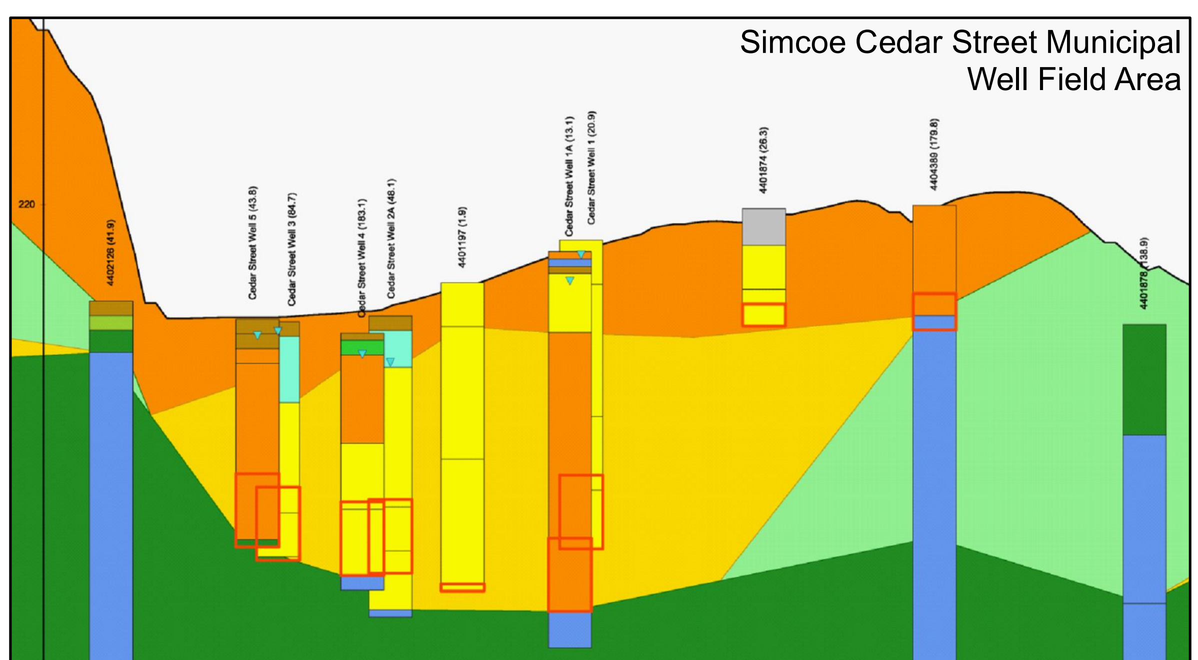
Figure 3-10.

Simcoe, Northwest Well Field
Cross-section: Simcoe_NS_2



Vertical Exaggeration: 20x



Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Wentworth Drift, Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

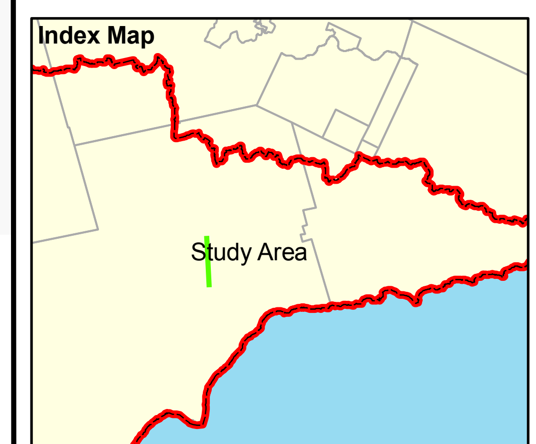


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Figure 3-11.
Simcoe, Cedar Street Well Field
Cross-section: Simcoe_NS_3

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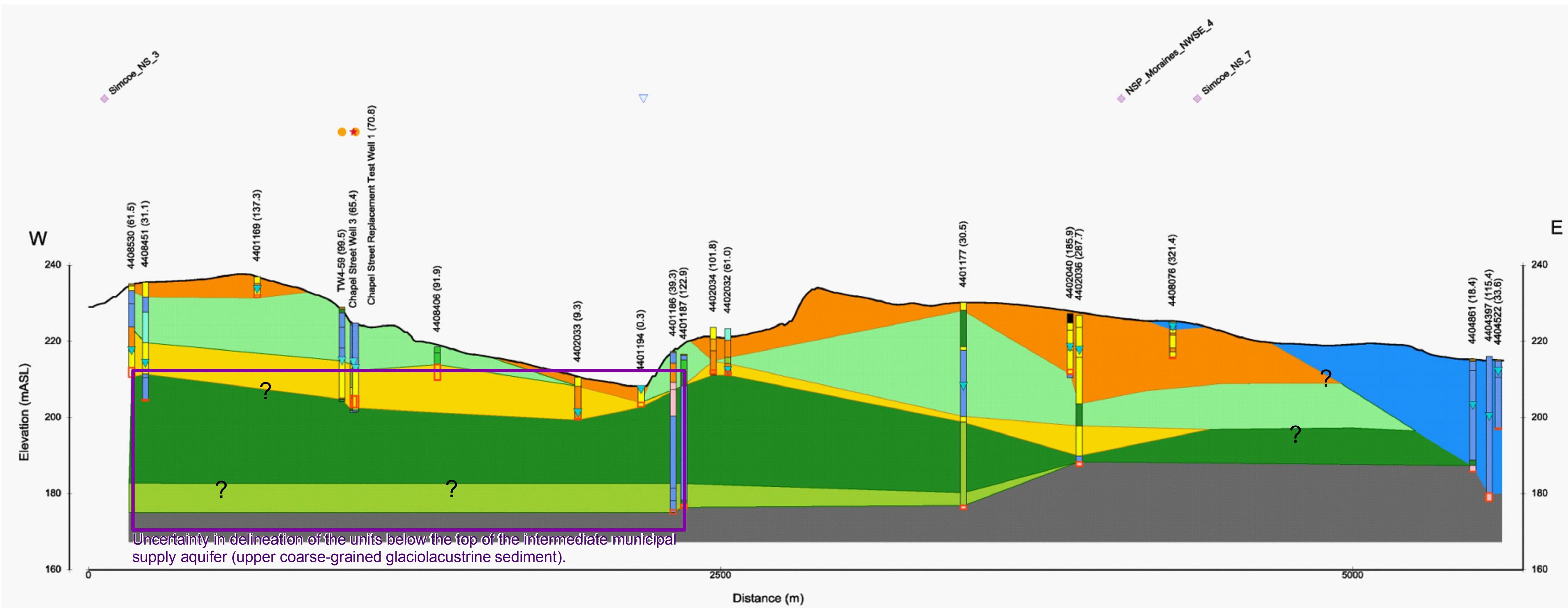
Project: 2010015_LongPointT3



Vertical Exaggeration: 20x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Clay, Haldimald Clay Plain
- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Wentworth Drift, Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock
- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

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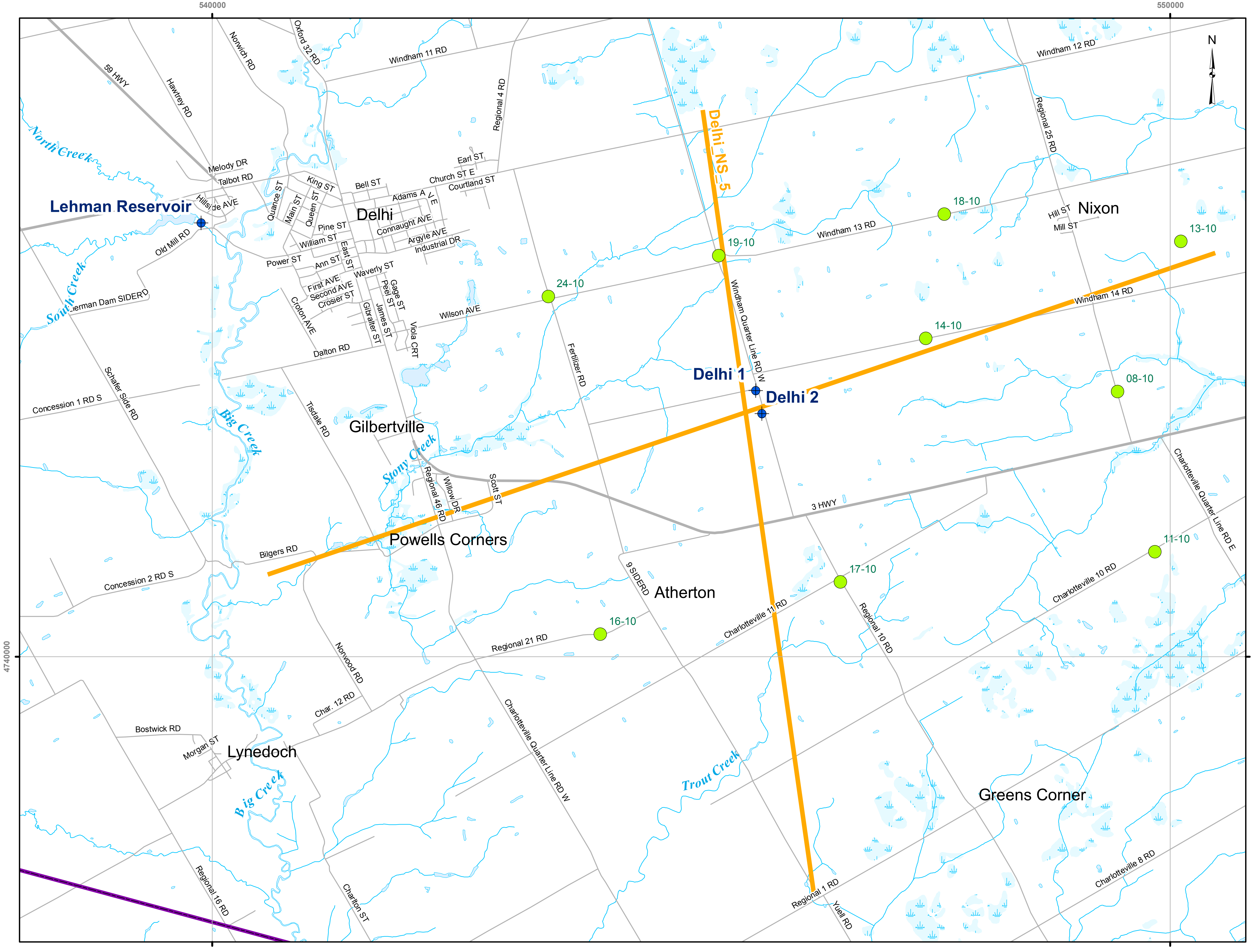
Figure 3-12.

Simcoe, Chapel Street Well 3
Cross-section: Simcoe_EW_7



Long Point Tier Three Physical Characterization

LEGEND
- Tier Three Field Program Drilling Site
- Long Point Tier Three Municipal Wells
- Cross Section Locations
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas
- Tier Three Focus Area

Scale 1:40,000

0 0.5 1 1.5

Kilometres

Index Map

Lake Ontario

Focus Area

Lake Erie

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Figure 3-13.
Delhi Well Field Area

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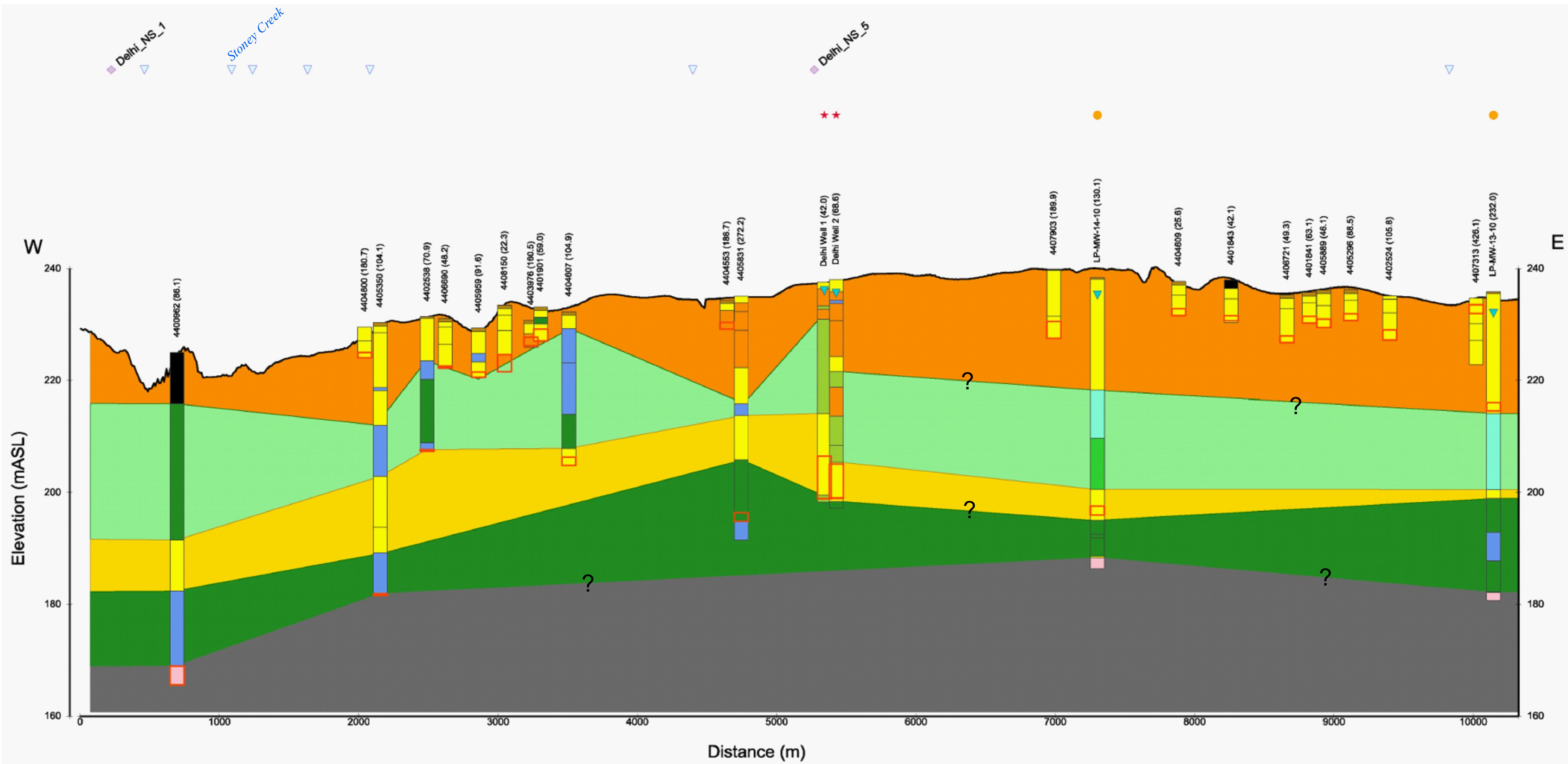
Project: 2010015_LongPointT3



Vertical Exaggeration: 40x

Long Point Tier Three Physical Characterization

LEGEND

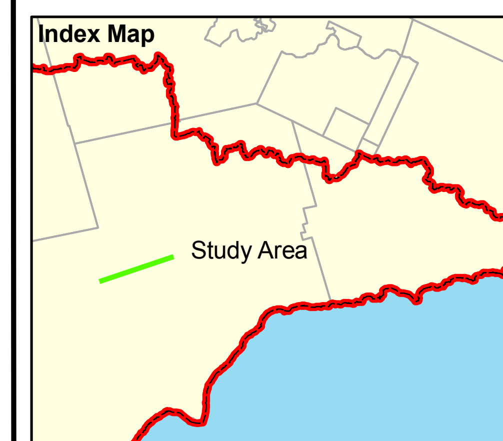
Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log



REFERENCES

Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 06-Aug-2011; Created By: LH

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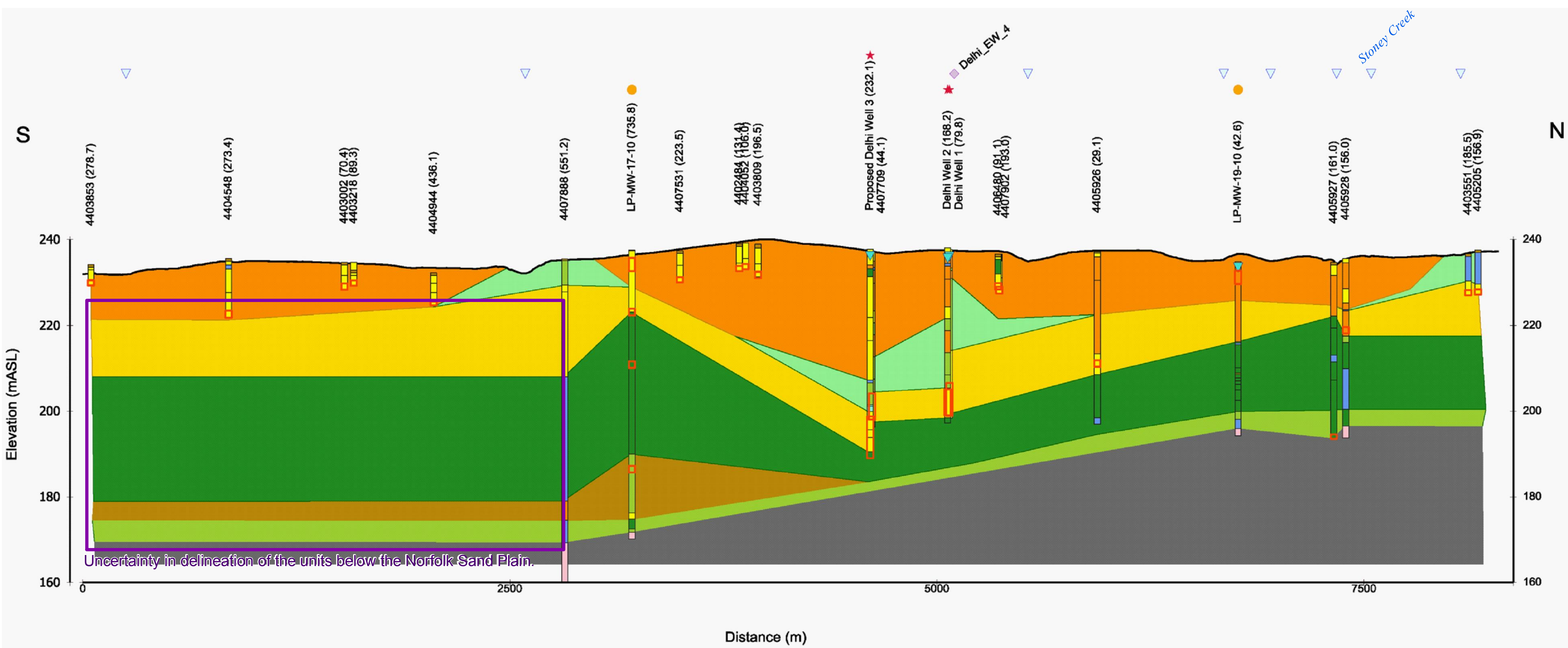
Figure 3-14.

Delhi Cross-section: Delhi_EW_4



Vertical Exaggeration: 25x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

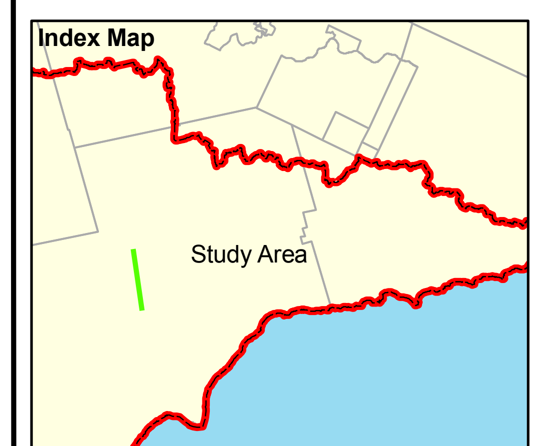


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Figure 3-15.

Delhi Cross-section: Delhi_NS_5

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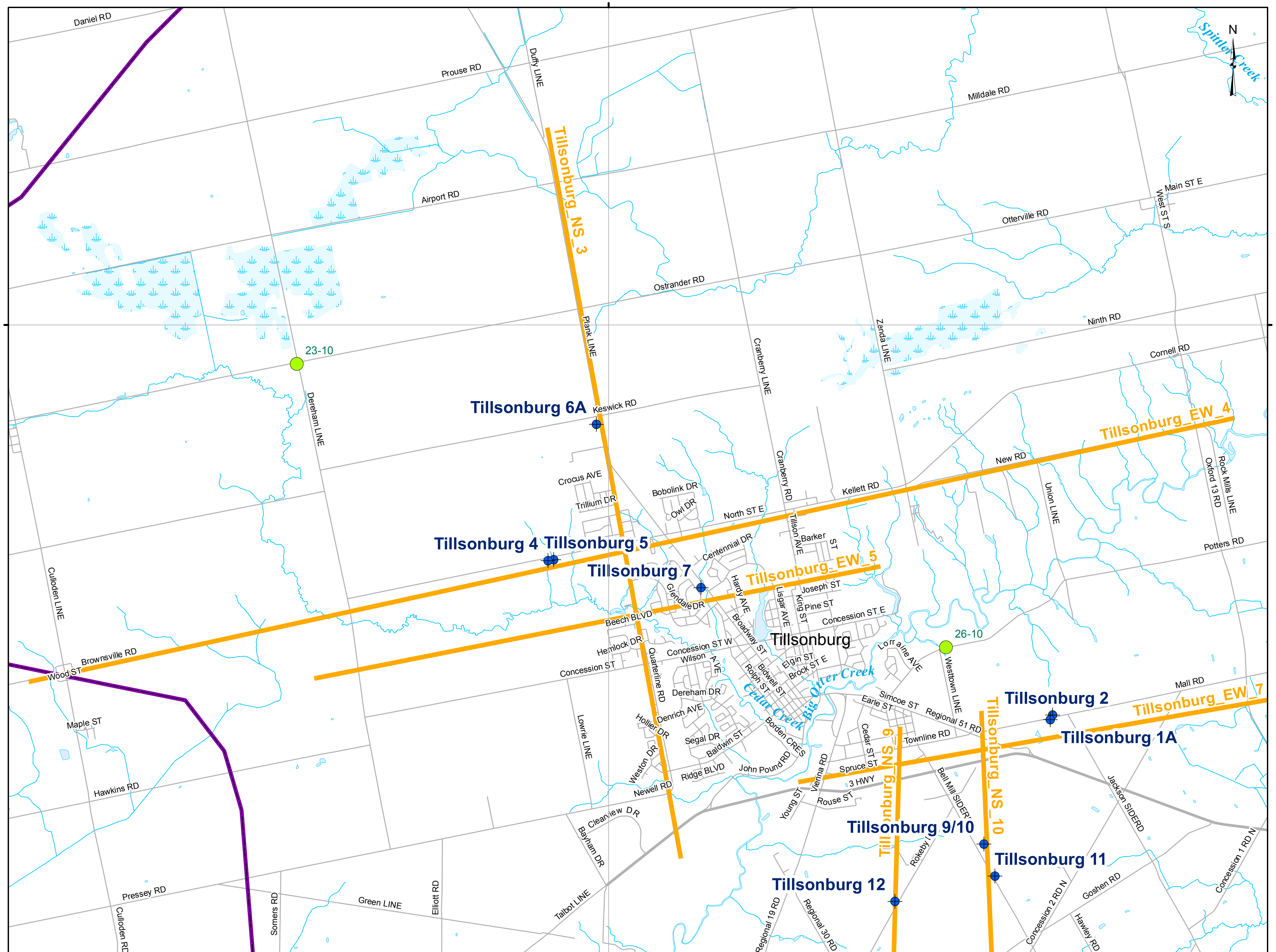
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Tier Three Field Program Drilling Site
- Long Point Tier Three Municipal Wells
- Cross Section Locations
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas
- Tier Three Focus Area

Scale 1:50,000

0 0.5 1 1.5

Kilometres

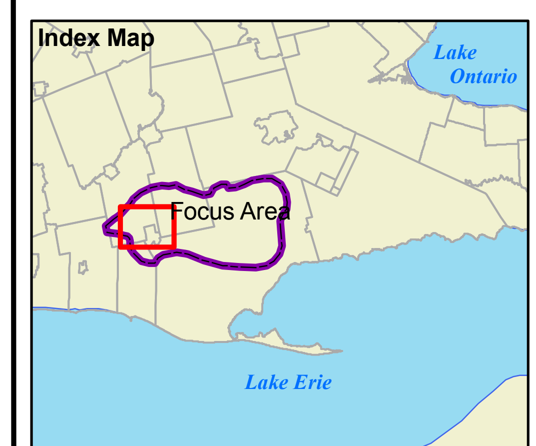


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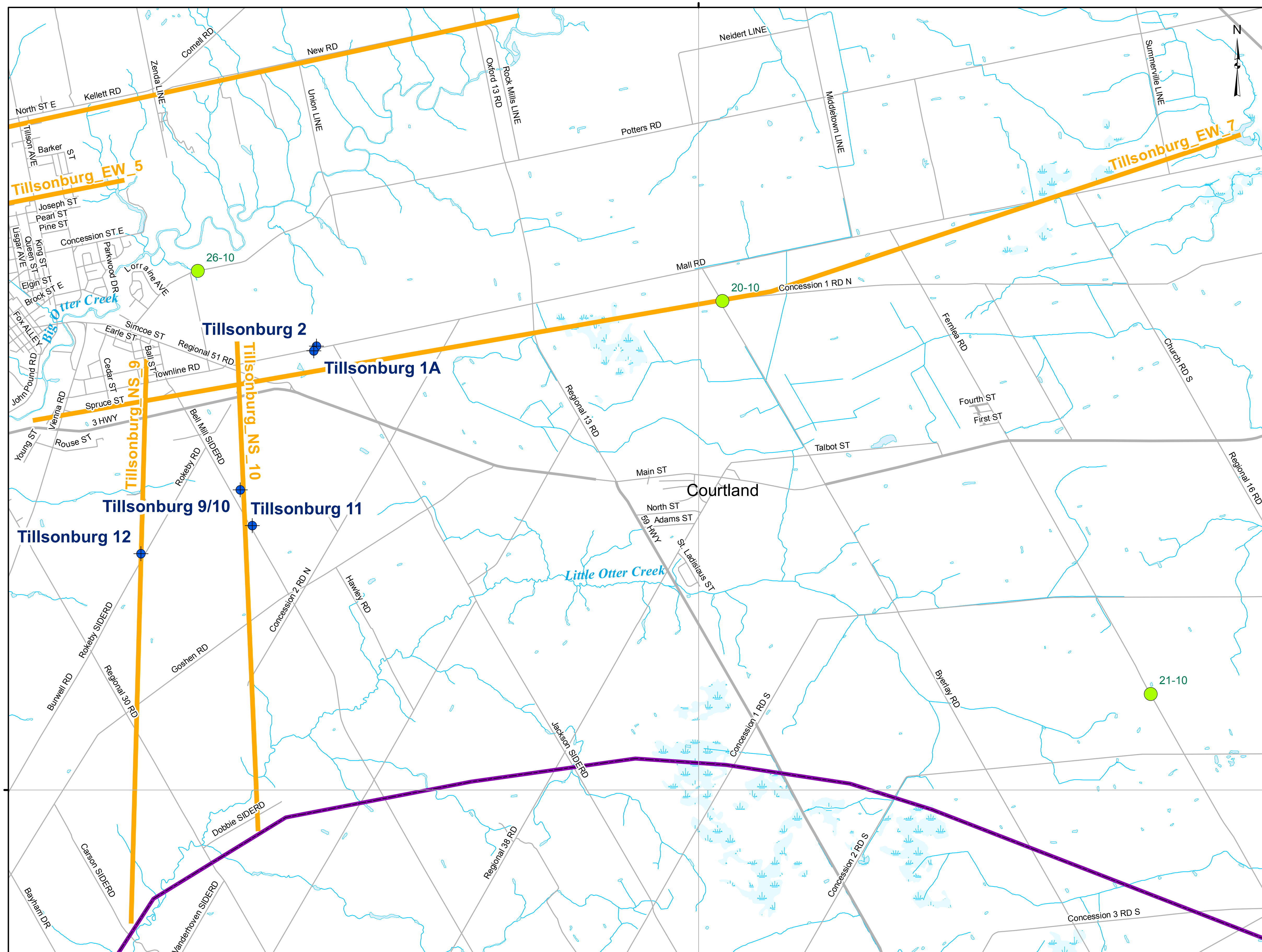
Figure 3-16A.
Tillsonburg Well Field Area (Northwest)

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_TillsonburgNorth_WF.mxd

Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Tier Three Field Program Drilling Site
- Long Point Tier Three Municipal Wells
- Cross Section Locations
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas
- Tier Three Focus Area

Scale 1:45,000

0 0.5 1 1.5

Kilometres

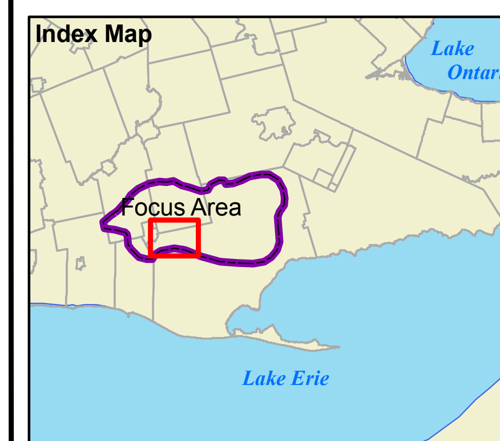


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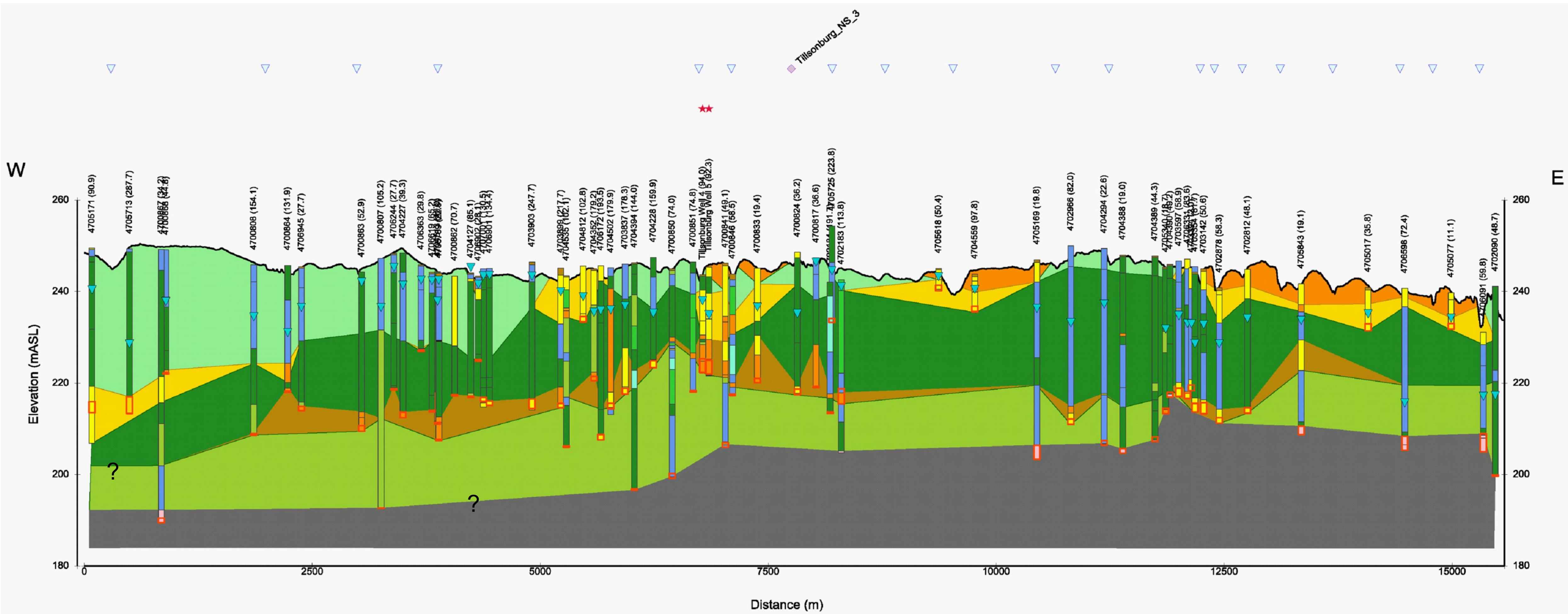
Figure 3-16B.
Tillsonburg Well Field Area (Southeast)

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_TillsonburgSouth_WF.mxd

Project: 2010015_LongPointT3



Vertical Exaggeration: 50x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

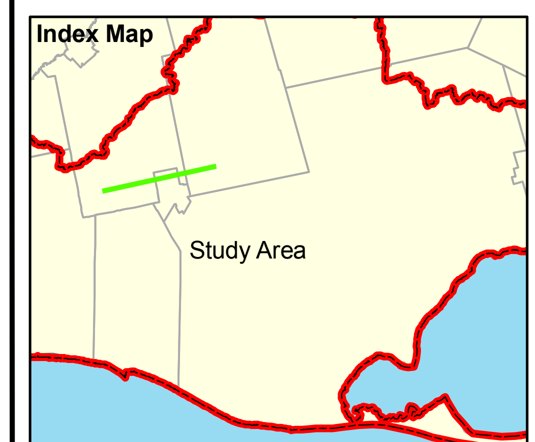
- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Outwash, Norfolk Sand Plain
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

Index Map



Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 06-Aug-2011; Created By: LH

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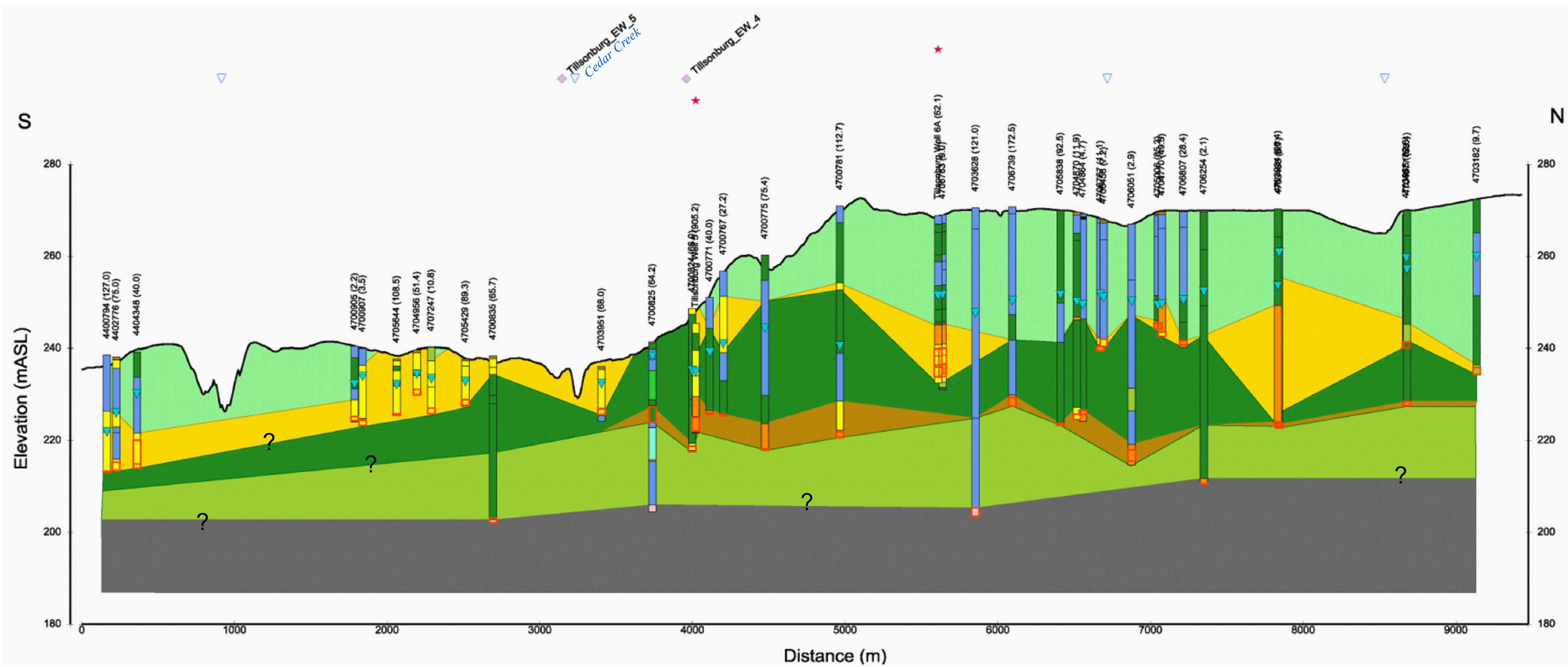
Figure 3-17.

Tillsonburg, Northwest Well Field
Cross-section: Tillsonburg_EW_4



Vertical Exaggeration: 30x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Outwash
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

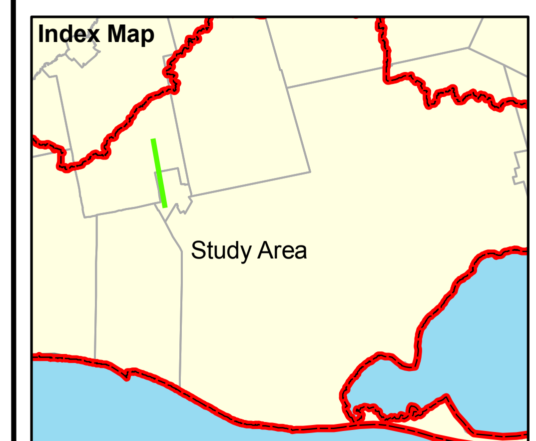


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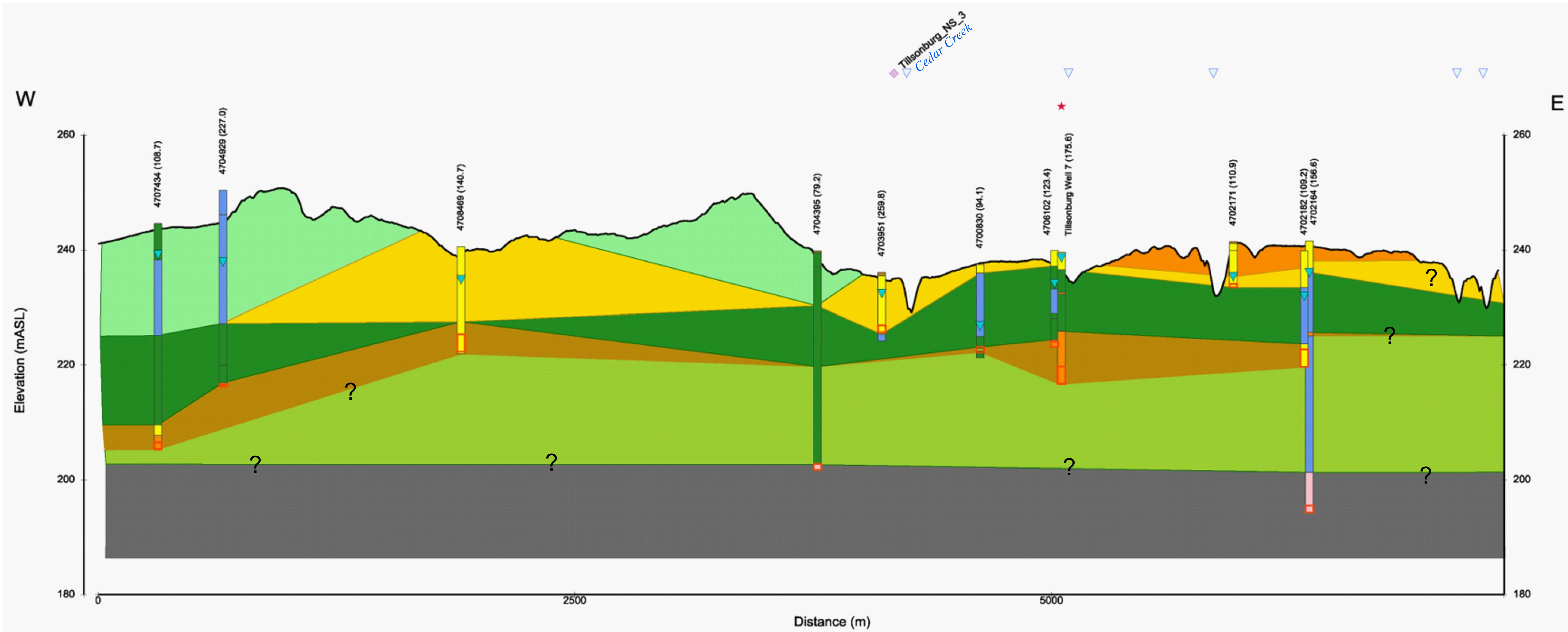
Figure 3-18.

Tillsonburg, Northwest Well Field
Cross-section: Tillsonburg_NS_3



Vertical Exaggeration: 25x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Outwash, Norfolk Sand Plain
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

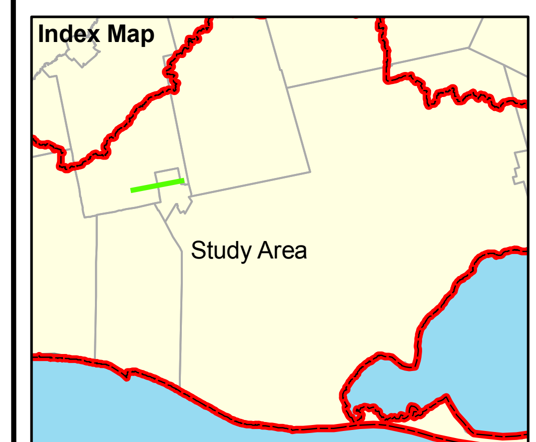


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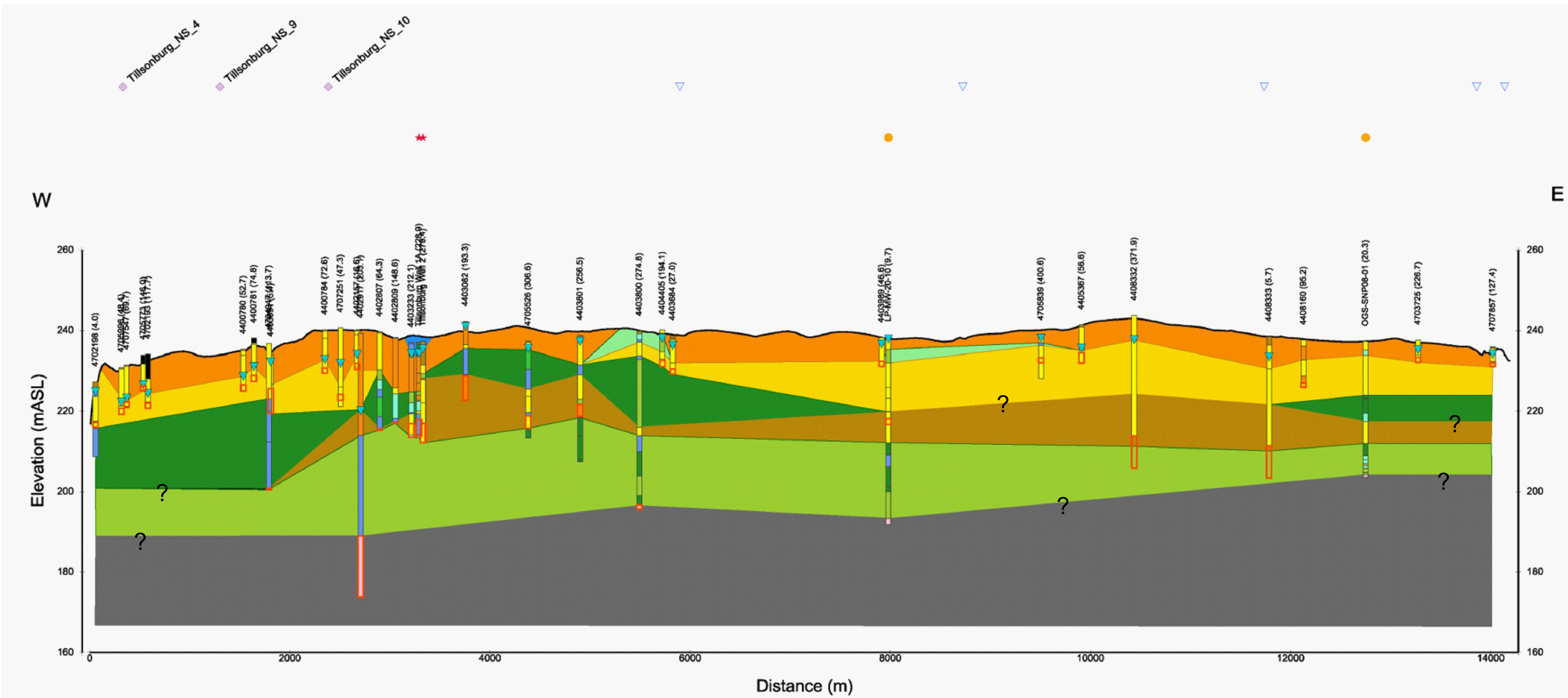
Figure 3-19.

Tillsonburg, Northwest Well Field
Cross-section: Tillsonburg_EW_5



Vertical Exaggeration: 40x

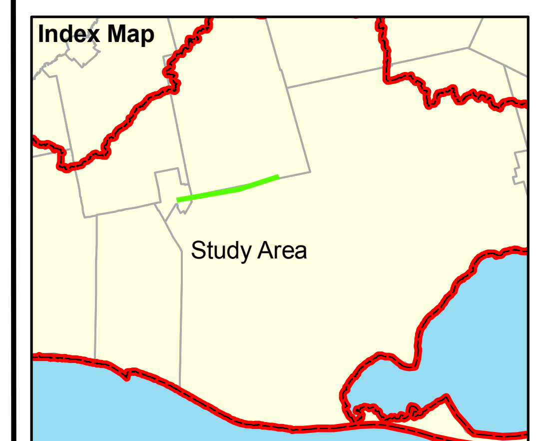
Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology
- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation
- Surficial Clay / Silt
- Surficial Outwash, Norfolk Sand Plain
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log



Projection: NAD 1983 UTM Zone 17N
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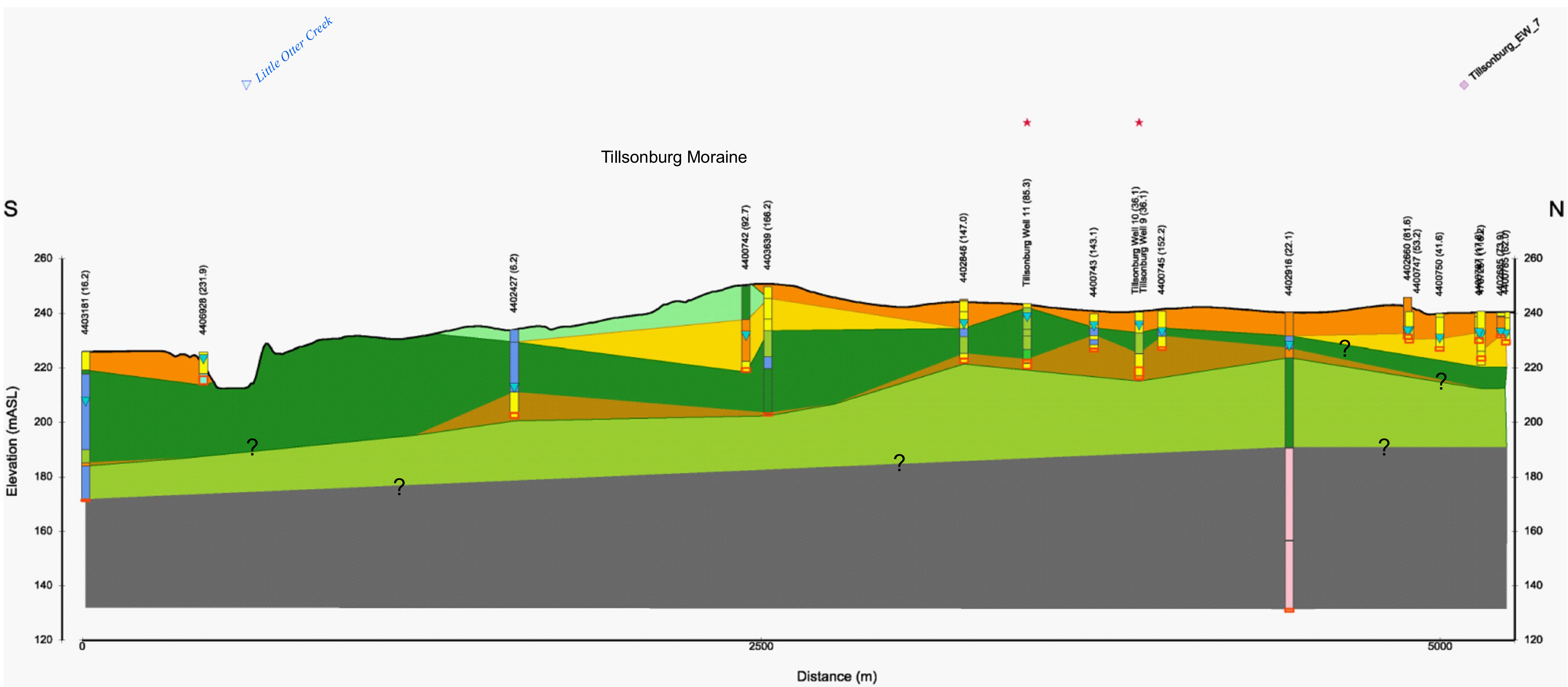
Figure 3-20.

Tillsonburg, Southeast Well Field
Cross-section: Tillsonburg_EW_7



Vertical Exaggeration: 10x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Outwash, Norfolk Sand Plain
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 06-Aug-2011; Created By: LH

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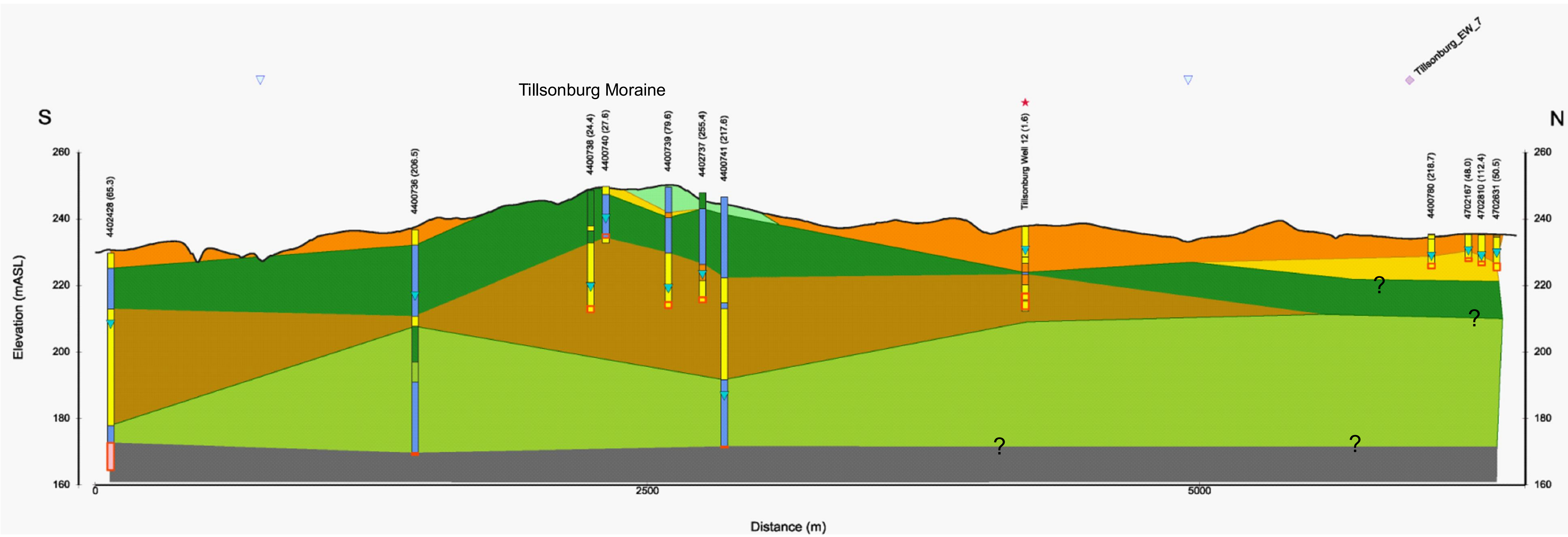
Figure 3-21.

Tillsonburg, Southeast Well Field
Cross-section: Tillsonburg_NS_10

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_XS_Tillsonburg_NS_10.mxd

Project: 2010015_LongPointT3



Vertical Exaggeration: 15x

Long Point Tier Three Physical Characterization

LEGEND

Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Surficial Outwash, Norfolk Sand Plain
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log

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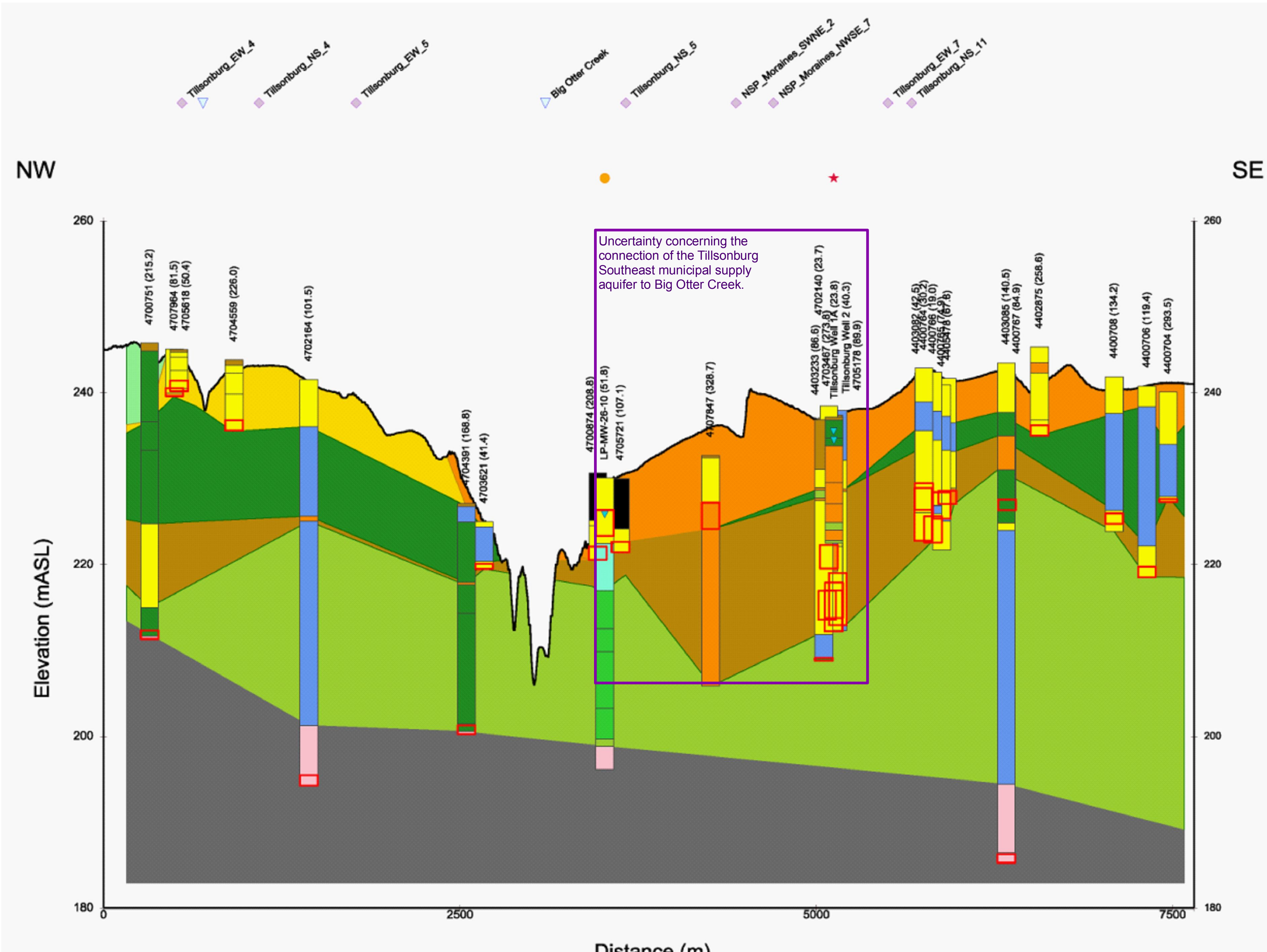
Figure 3-22.

Tillsonburg, Southeast Well Field
Cross-section: Tillsonburg_NS_9



Vertical Exaggeration: 60x

Long Point Tier Three Physical Characterization

LEGEND

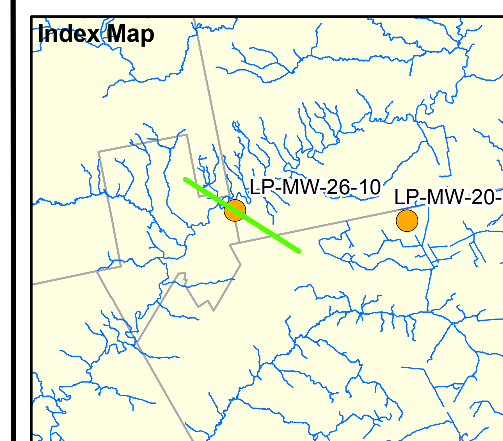
Borehole Lithology

- Clay, silty clay
- Silt, clay-rich silt, sandy silt
- Diamict
- Sand, silty sand
- Gravel, gravelly sand
- Bedrock
- Fill
- Organic
- Unknown
- Well Screen
- Static Water Level

Geologic Interpretation

- Norfolk Sand Plain Sediment
- Wentworth Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift
- Coarse-grained Interstadial Sediment
- Port Stanley Drift, Catfish Creek Drift
- Bedrock

- Cross-section Intersection
- Drainage Intersection
- Municipal Well
- High Quality Log



Projection: NAD 1983 UTM Zone 17N
Map Version: 1; Map Date: 06-Aug-2011; Created By: LH

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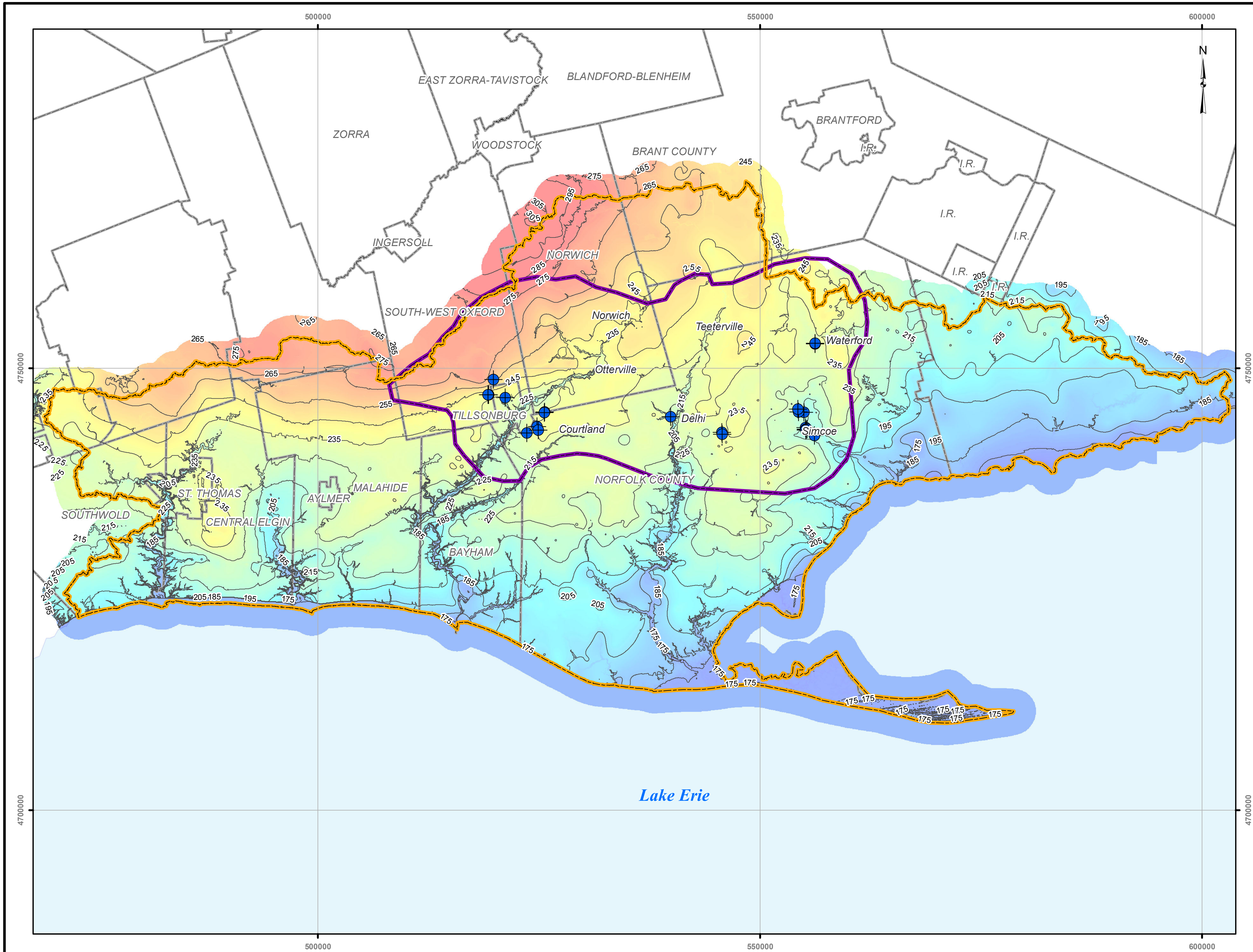
Figure 3-23.
Cross-section: Tillsonburg, Big Otter Creek / LP-MW-26



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Contours (10 m Intervals)
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Shallow Water Levels (mASL)
High : 315
Low : 174

Scale 1:425,000
0 5 10 15
Kilometres

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Figure 4-1.
Shallow Water Level Elevation (Bottom of Screen less than 15 mBGS)

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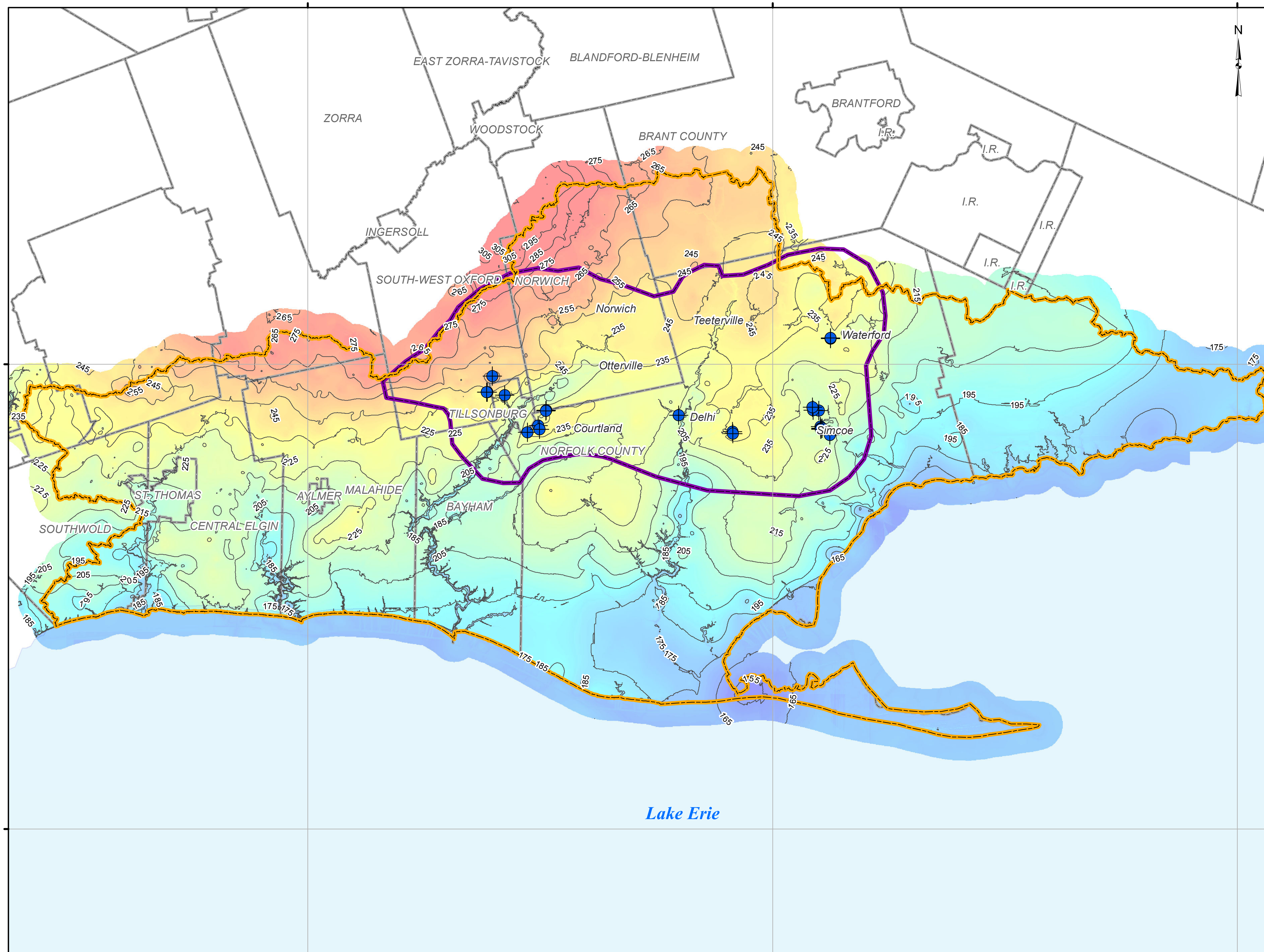
Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Contours (10 m Intervals)
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Deep Water Levels (mASL)

High : 320

Low : 145

Scale 1:425,000

0 5 10 15

Kilometres

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Map Version: 1; Map Date: 04-Nov-2011; Created By: LH

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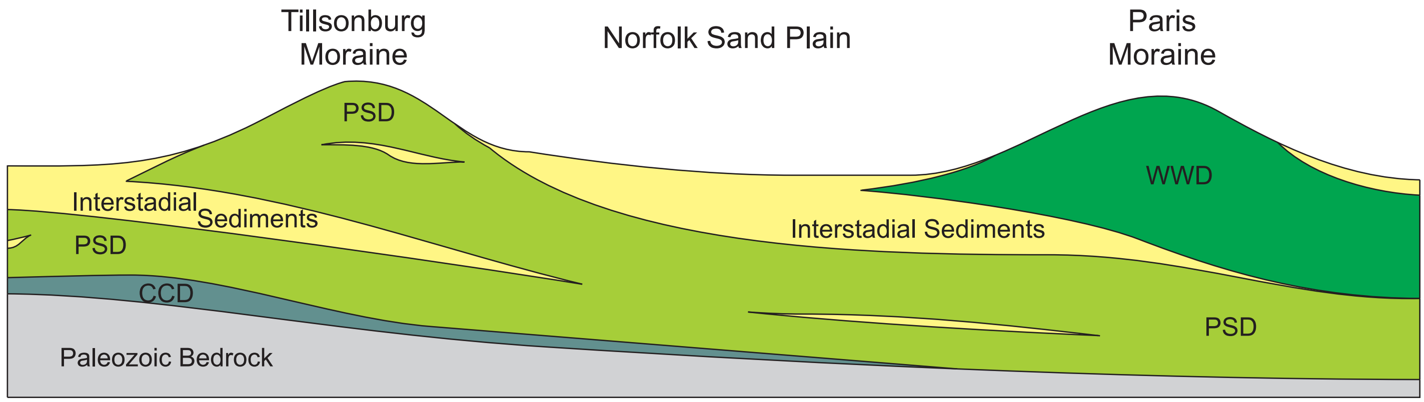
Figure 4-2.
Deep Water Level Elevation (Bottom of Screen more than 15 mBGS)

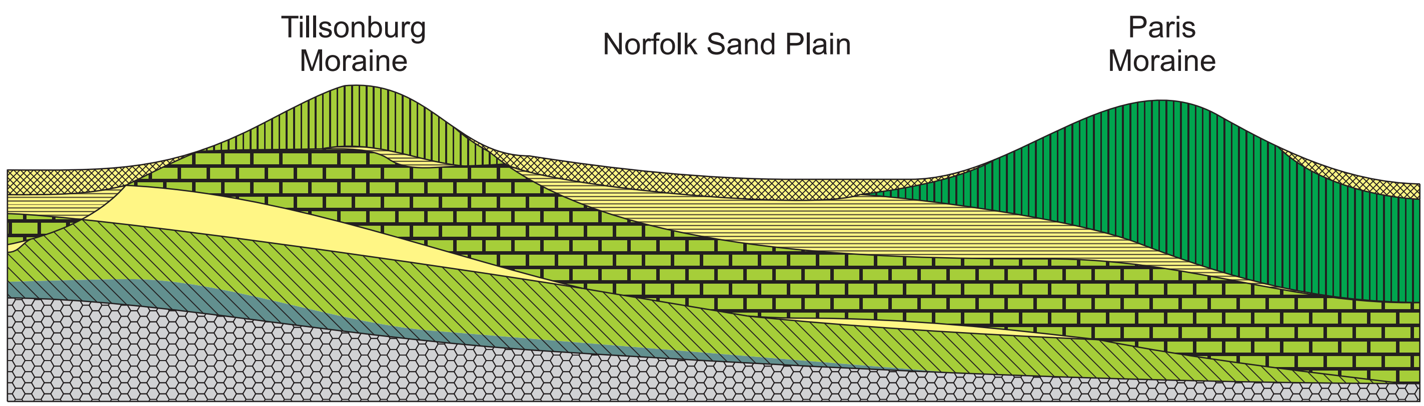
S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_Hydrostrat_6Aug2011\LPT3_DeepWaterLevels.mxd

Project: 2010015_LongPointT3

A
Conceptual Hydrostratigraphic Layers



B
Numerical Model Layers



LEGEND

- Sand, gravel, silt
- Wentworth Drift (WWD)
- Port Stanley Drift (PSD)
- Catfish Creek Drift (CCD)
- Paleozoic Bedrock
- Numerical Model Layer 2
- Numerical Model Layer 3
- Numerical Model Layer 4
- Numerical Model Layer 5
- Numerical Model Layer 6
- Numerical Model Layer 7
- Numerical Model Layer 8

Long Point Tier Three Physical Characterization

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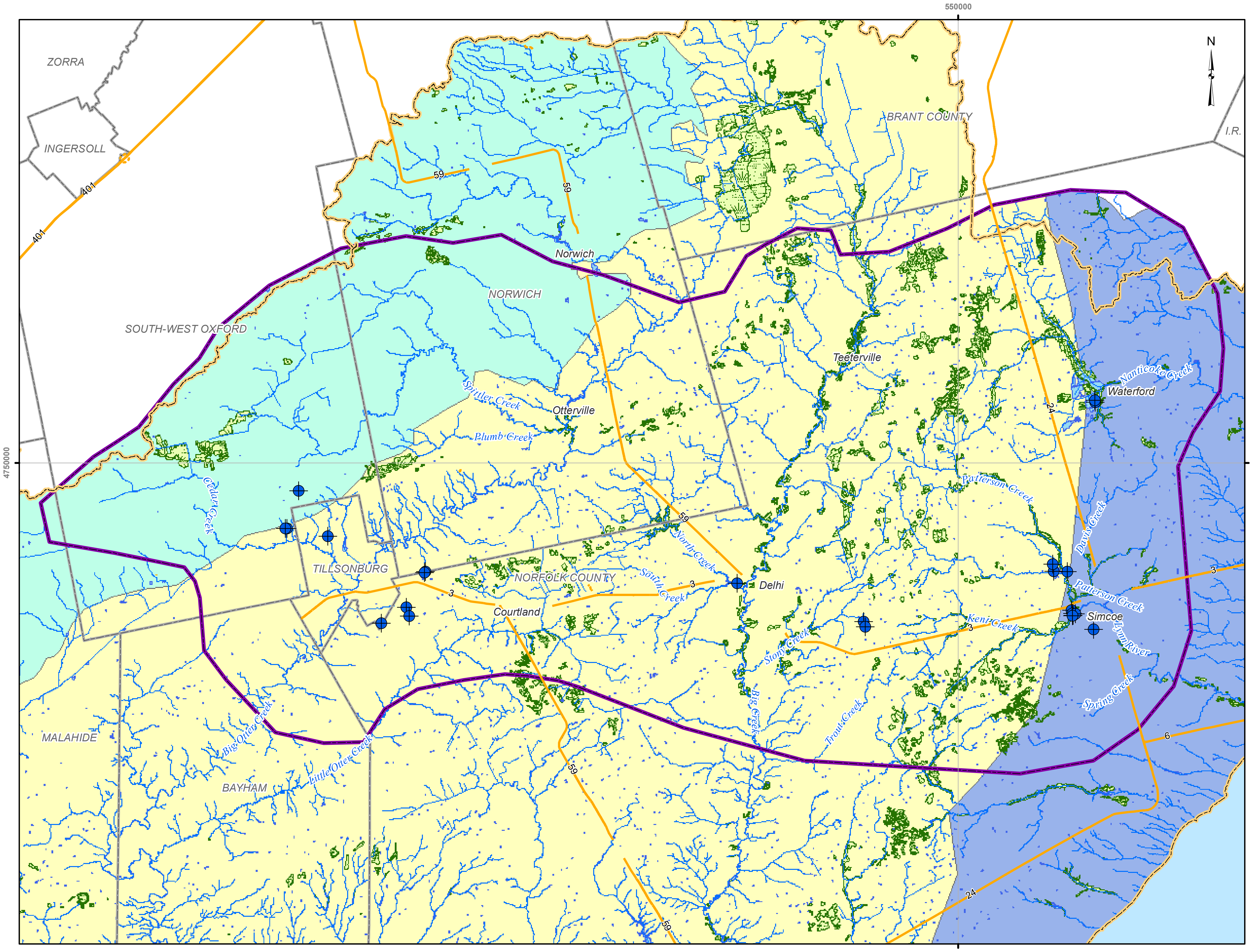
Figure 4-3.
Numerical Respresentation of Discontinuous Geologic Units

REFERENCES
Map Version: 1; Map Date: 08-2011-15; Created By: LH

Long Point Tier Three Physical Characterization



LEGEND

- Long Point Tier Three Municipal Wells
- Highway / Expressway
- Drainage
- Open Water
- Wetland
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries
- Zone 1: Haldimand Clay Plain
- Zone 2: Norfolk Sand Plain
- Zone 3: Port Stanley Till Plain

Scale 1:175,000

0 2 4 6

Kilometres

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Figure 4-4.
Hydrostratigraphic Model Zonation

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Project: 2010015_LongPointT3

Long Point Tier Three Physical Characterization

LEGEND
- Long Point Tier Three Municipal Wells
- Tier Three Field Program Drilling Site
- OGS Corehole
- Simcoe / Waterford Groundwater Investigation Test Well
- Burnside Test Well
- Water Well Record
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Note: Drilling site names have been truncated for clarity. All well names are prefaced with "LP-MW" in Appendix B

Scale 1:150,000
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Kilometres

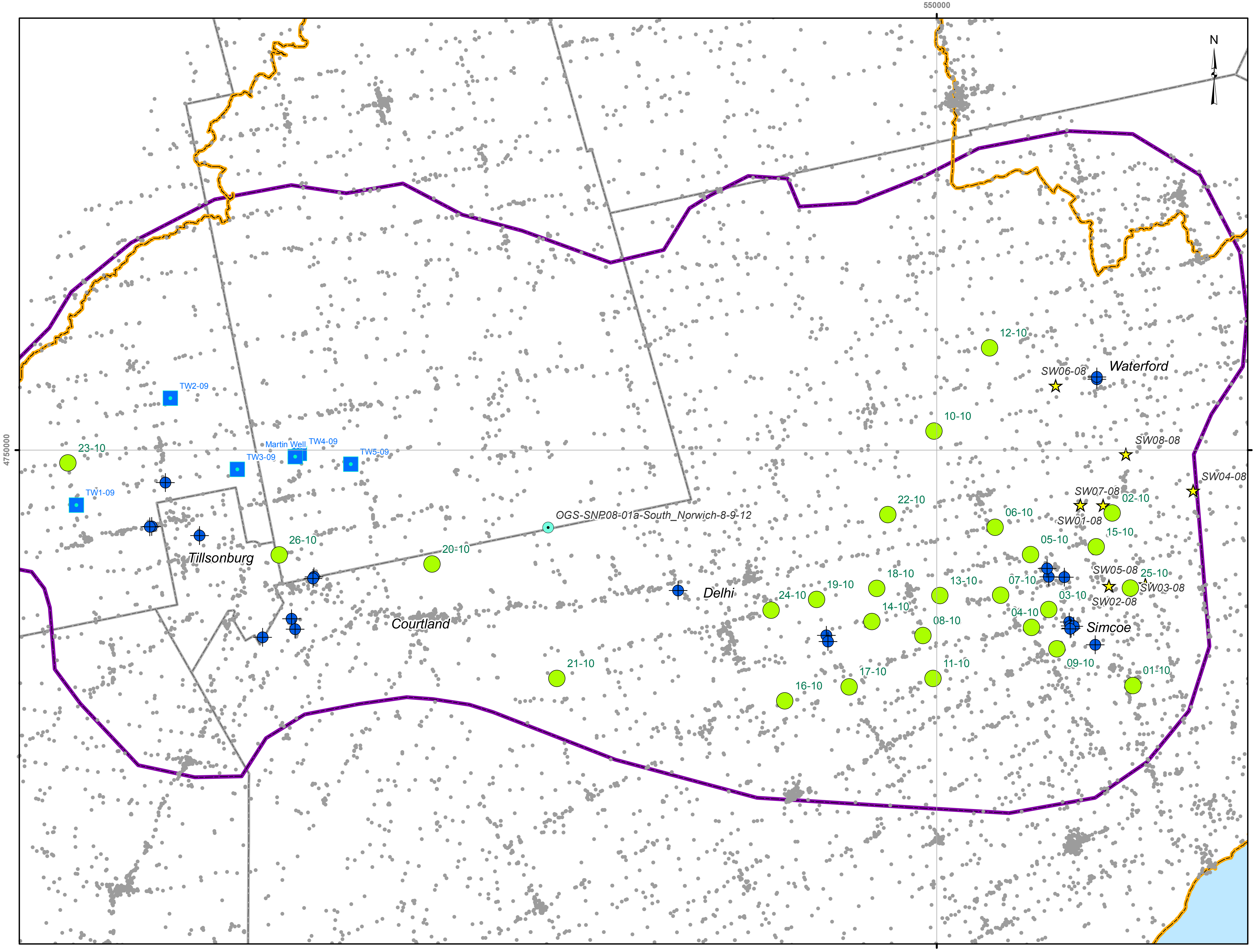

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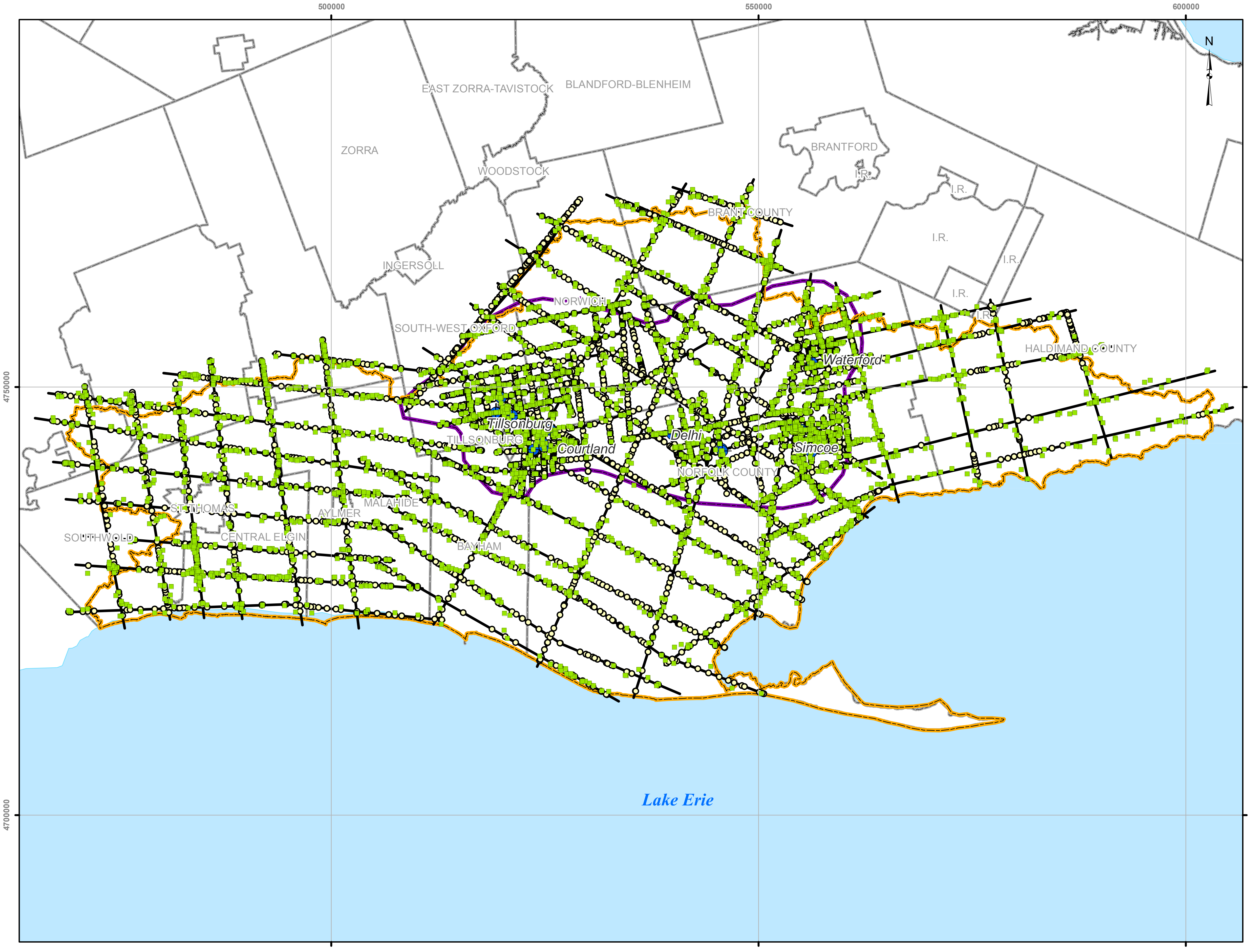
Figure 4-5.
High Quality Borehole Locations



Long Point Tier Three Physical Characterization

LEGEND

- Long Point Tier Three Municipal Wells
- Picked Borehole
- Control Point
- Tier Three Cross-section
- Open Water
- Tier Three Focus Area
- Lake Erie Source Protection Area
- Municipal Boundaries

Scale 1:447,500

0 5 10 15

Kilometres

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Figure 4-6.
All Cross-section Locations, Hydrostratigraphic Pick Locations

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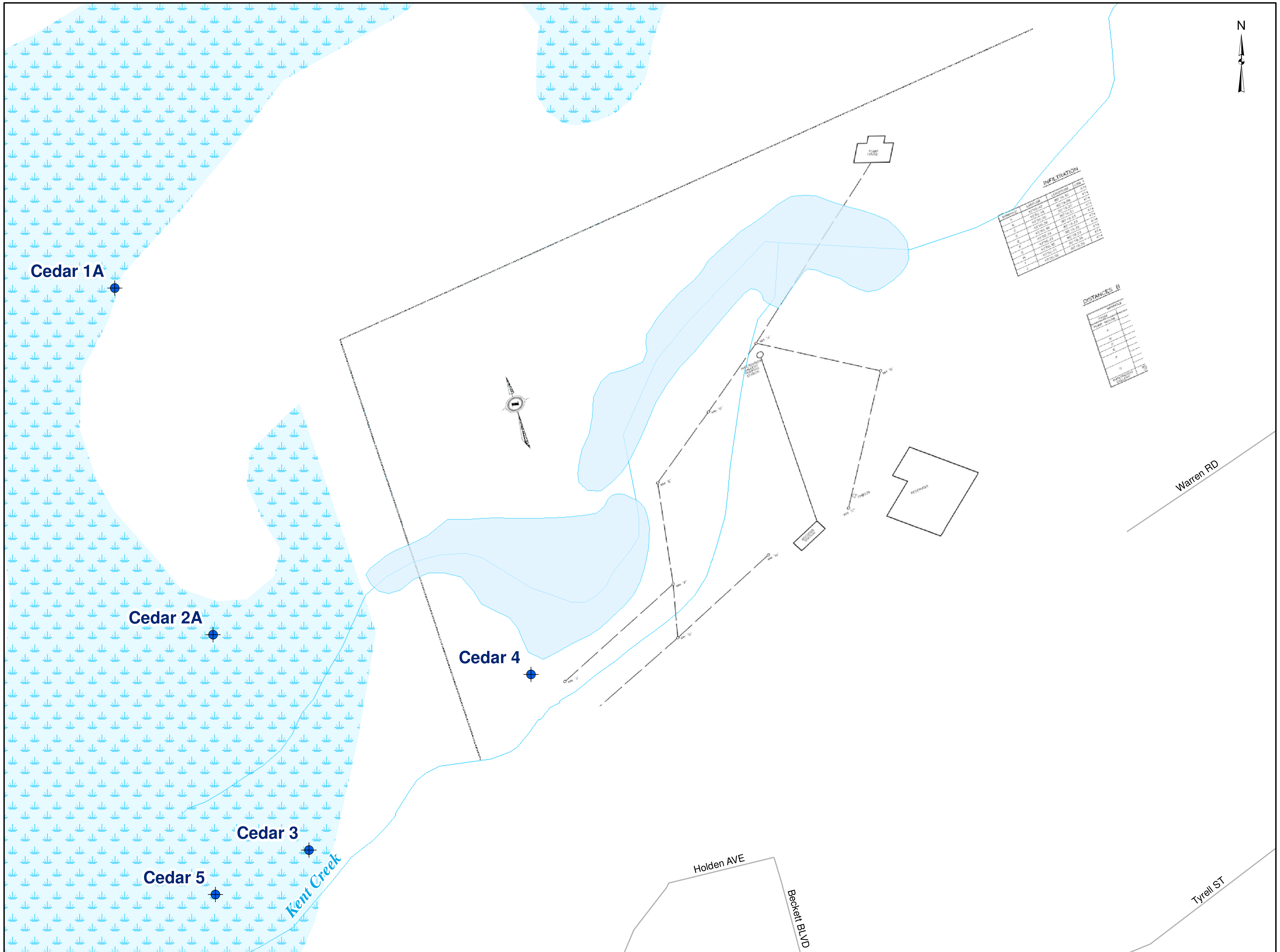
Project: 2010015_LongPointT3

Long Point Tier Three Physical Characterization



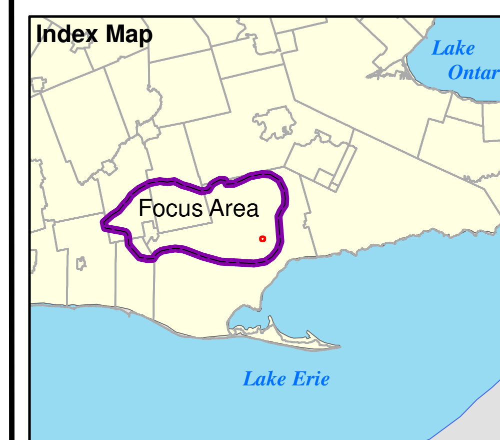
LEGEND

- Long Point Tier Three Municipal Wells
- Road
- Expressway / Highway
- Drainage
- Ponds
- Wetland Areas

Scale 1:1,700

0 25 50 75

Metres



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Map Version: 1; Map Date: 04-Aug-2011; Created By: christinec

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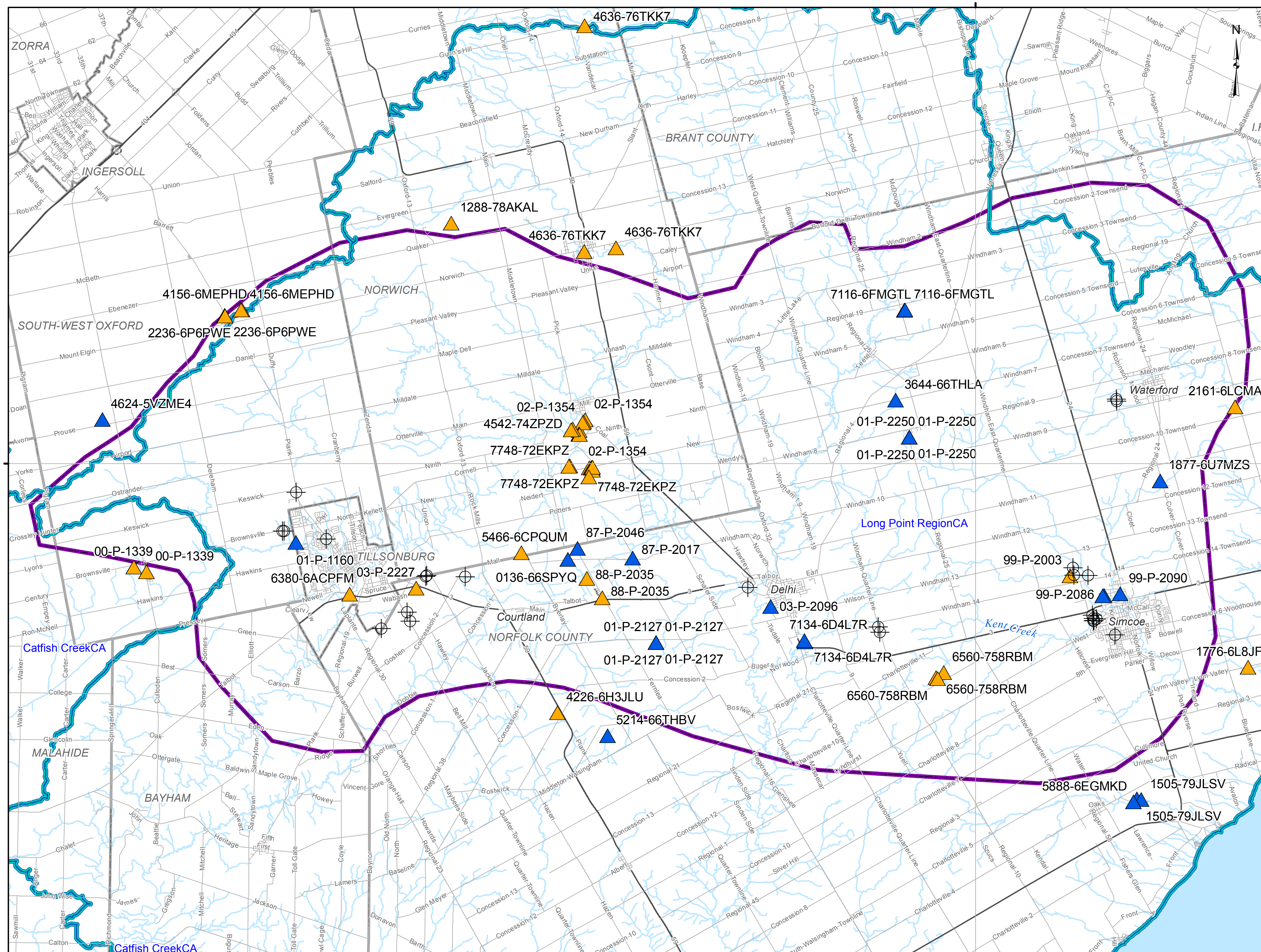
Figure 5-1.

Cedar Street Infiltration Gallery Layout

C:\Projects\2010015_LongPointT3\GIS\ArcView\MXDs\Wellfields\Figure5.1_CedarStreetInfiltrationGallery.mxd

Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

Reported Pumping Rates: Data Source

- 2008 WTRS
- No Reported Rates Available
- Long Point Tier Three Municipal Wells
- Road
- Highway / Expressway
- Drainage
- Open Water
- Conservation Authority Boundary, Watershed Boundary
- Tier Three Focus Area
- Municipal Boundaries

Scale 1:175,000

0 2.5 5 7.5

Kilometres

Index Map

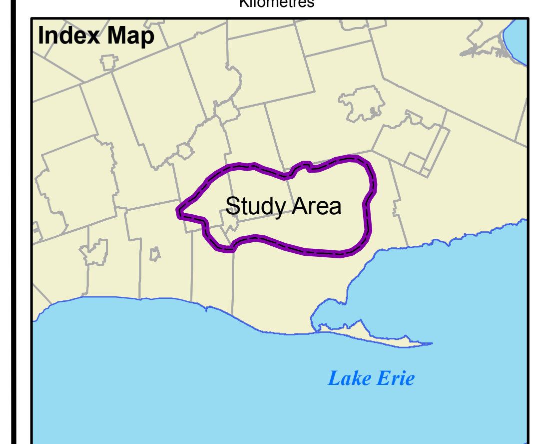


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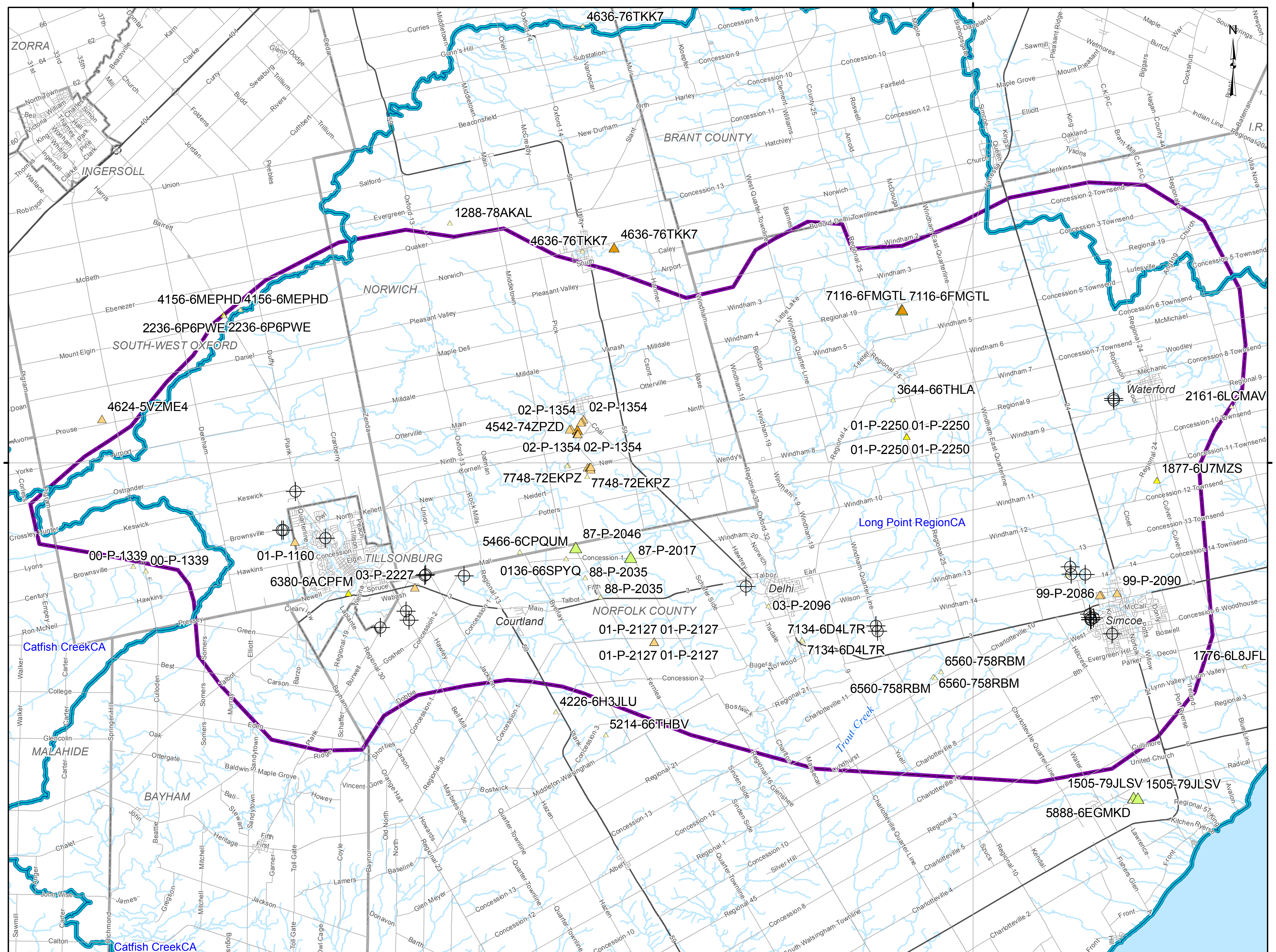
Figure 6-1.
Location of Permits to Take Water

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_NonAgricPTTWs\LPT3_PTTWs_Location.mxd

Project: 2010015_LongPointT3



Long Point Tier Three Physical Characterization

LEGEND

Consumptive Rate (m3/d)

- <50
- 50...100
- 100...500
- 500...1000
- 1000...5000
- >5000
- Long Point Tier Three Municipal Wells
- Road
- Highway / Expressway
- Drainage
- Open Water
- Conservation Authority Boundary, Watershed Boundary
- Tier Three Focus Area
- Municipal Boundaries

Scale 1:175,000

0 2.5 5 7.5

Kilometres

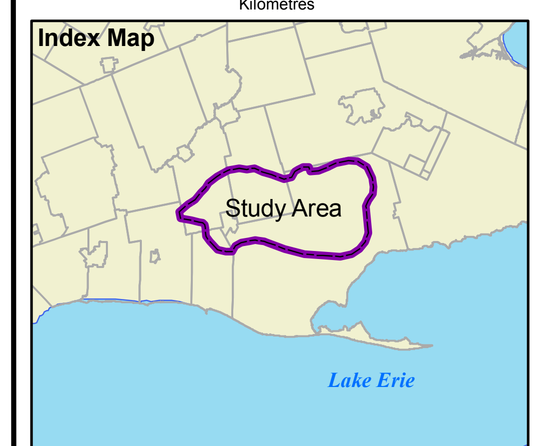


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Figure 6-2.
Consumptive Rates for Permits to Take Water

S:\Shared\2010015_LongPointT3\GIS\ArcView\MXDs\MdlMemo_NonAgricPTTWs\LPT3_PTTWs_ConRate.mxd

Project: 2010015_LongPointT3