NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment, Terrain and Remote Sensing Study

MUNICIPALITIES OF ARRAN-ELDERSLIE, BROCKTON AND SOUTH BRUCE, TOWNSHIP OF HURON-KINLOSS AND TOWN OF SAUGEEN SHORES, ONTARIO

APM-REP-06144-0109

JUNE 2014

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TERRAIN AND REMOTE SENSING STUDY

MUNICIPALITIES OF ARRAN-ELDERSLIE, BROCKTON AND SOUTH BRUCE, TOWNSHIP OF HURON-KINLOSS AND TOWN OF SAUGEEN SHORES

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

FINAL REPORT

June 2014

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EXECUTIVE SUMMARY

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) individually expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process, and requested that a preliminary assessment be conducted to assess the potential suitability of the Communities for safely hosting a deep geological repository (Step 3). This request followed the successful completion of initial screenings conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessments are reported in integrated reports (NWMO, 2014a; 2014b; 2014c; 2014d; 2014e). The objective of the geoscientific desktop preliminary assessment is to determine whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of a terrain and remote sensing assessment completed as part of the geoscientific desktop preliminary assessment (Geofirma, 2014) of the Communities and their immediate periphery, referred to as the Area of the Five Communities. This assessment does not include the portion of the Area of the Five Communities covered by Lake Huron. The main information sources relied on in this study are the Ontario Geological Survey (OGS) 1:50,000 scale surficial maps and reports, the physiographic information from Chapman and Putnam (2007), the OGS drift thickness data, and the CDED elevation model. Additional information sources included several files on drainage features, watersheds, lake depths, and roads obtained from Land Information Ontario (LIO). The assessment addresses the following seven objectives:

1. Evaluate the nature, areal extent and depth of overburden materials;
2. Delineate the areas of exposed bedrock or relatively thin overburden cover;
3. Identify features that may preserve evidence of neotectonics;
4. Establish the main site accessibility constraints;
5. Determine and/or confirm watershed and sub-catchment boundaries;
6. Infer groundwater recharge and discharge zones and divides; and
7. Infer regional and local groundwater and surface flow directions.

Surficial landforms and associated sediments within the Area of the Five Communities were deposited during the Late Wisconsinan by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet, 23,000 to 10,000 years ago. Morainal deposits are exposed at the surface over about 46 % of the Area of the Five Communities. Morainal deposits exposed at the surface in this area have been classified into four main till formations consisting of the Elma, St. Joseph, Dunkeld and Rannoch tills. Glaciofluvial deposits consisting primarily of sand or sand and gravel are exposed over 21.2 % of the area. Glaciolacustrine deposits are exposed over 23.7 % of the area, with about 58 % of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 42 % as coarse-grained deposits of sand or sand and gravel. The high permeability of glaciofluvial deposits and coarse-grained glaciolacustrine deposits results in them being recharge zones for overburden and shallow bedrock aquifers.

The overburden is generally thick in this area, with values as high as 104 m and an average value of about 30 m. The thickest overburden is associated with buried bedrock valleys and troughs. The Municipality of South Bruce contains the thinnest overburden, with an average thickness of 20 m, whereas overburden thickness in the other communities averages between 33 and 50 m.

The large-scale pattern of elevation across the Area of the Five Communities controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from east to west (Lake Huron) is from 400 to 176 m, with this elevation drop occurring over an approximate 70 km lateral distance. The municipalities of Arran-Elderslie, Brockton and South Bruce are located inland of Lake Huron, with minimum elevations ranging from 180 to 249 m. The Municipality of South Bruce has the highest elevation of the five Communities. The greatest relief in the area is associated with river valleys, such as the Saugeen River, and with drumlins and ancient shore bluffs.

Apart from Lake Huron, the Area of the Five Communities contains no large lakes, with Arran Lake (3.9 km^2) representing the largest lake and with waterbodies covering only 0.8 % of this area. Some of the larger provincially significant wetland complexes in the area include the Greenock Swamp Wetland Complex and the MacGregors Point Wetland Complex. In total, wetlands cover 14.3 % of this area. The Municipality of Brockton contains the largest areas covered by either wetland or forest, which is largely due to the presence of the Greenock Swamp Wetland Complex. The Area of the Five Communities is contained within the Great Lakes - St. Lawrence primary watershed, and surface flow is directed primarily to the west towards Lake Huron.

The shallow groundwater regime includes overburden aquifers and shallow bedrock aquifers that provide drinking water supplies to both municipalities and residences. Groundwater flow directions within shallow systems often mimic surface water flow directions with the groundwater table generally present as a subdued reflection of topography.

The Area of the Five Communities is located in a tectonically stable zone with no active fault zones. A previous study conducted in the region employing desktop and field-based methods to search for neotectonic features found no conclusive geomorphological or sedimentological evidence of neotectonic activity. No additional neotectonic features could be identified using the information available in the current terrain study.

The Area of the Five Communities contains a dense network of highways, local roads and other roads. The main accessibility constraints represent areas of wet and swampy ground and areas of high relief associated with river valleys, drumlins, raised shore bluffs and moraines.

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1 INTRODUCTION

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) individually expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Communities for safely hosting a deep geological repository (Step 3). The preliminary assessments are a multicomponent studies integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations (NWMO, 2014a; 2014b; 2014c; 2014d; 2014e).

This report presents the findings of a terrain and remote sensing assessment completed as part of the geoscientific desktop preliminary assessment (Geofirma, 2014) of the Communities and their immediate periphery, referred to as the Area of the Five Communities. This terrain assessment does not include the portion of the Area of the Five Communities covered by Lake Huron. The objective of the geoscientific desktop preliminary assessment is to determine whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

1.1 OBJECTIVES

This report presents an analysis of the terrain in the Area of the Five Communities using existing remote sensing and geoscientific information sources. The report provides information on the nature and distribution of overburden deposits in the area and it discusses the topography, physiography, surface drainage, and regional groundwater flow. The main information sources relied on in this terrain study are the Canadian Digital Elevation Data (CDED) elevation model, the maps and reports from the Ontario Geological Survey (OGS) 1:50,000 scale surficial geology mapping programs, and a drift thickness map constructed by the OGS from well data, geotechnical boreholes and geological observations. Additional data sources included several map files from the Ontario Ministry of Natural Resources (MNR), including files on drainage features, watersheds, lake depths, and roads. This study addresses the following seven objectives:

1. Evaluate the nature, areal extent and depth of overburden materials;

2. Delineate the areas of exposed bedrock or relatively thin overburden cover;
3. Identify features that may preserve evidence of neotectonics;
4. Establish the main site accessibility constraints;
5. Determine and/or confirm watershed and sub-catchment boundaries;
6. Infer groundwater recharge and discharge zones and divides; and
7. Infer regional and local groundwater and surface water flow directions.

These objectives were carried out for the Area of the Five Communities using the data and methodology described in Section 1.3.

1.2 AREA OF THE FIVE COMMUNITIES

The preliminary assessment focused on the area within the boundaries of the Communities (Municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores). Areas beyond the municipal boundaries of the five communities were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Communities and surrounding areas, referred to in this report as the Area of the Five Communities (Figure 1). Many of the summary statements in this report are reported as percentages of the portion of the Area of the Five Communities not covered by Lake Huron. For simplicity, the term "Area of the Five Communities" from herein refers to the portion of the area not covered by Lake Huron. The 87.1 km by 76.7 km rectangular area shown in most maps in this report is referred to as the "map area" in a few instances.

1.3 DATA AND METHODS

This section summarizes the remote sensing and geoscientific data sources that were used in this terrain assessment, including an evaluation of the quality of the data. The datasets are all publically available. Other data sources are described in appropriate sections.

1.3.1 OGS DATASETS

This section describes key datasets released by the Ontario Geological Survey (OGS) that were used in this study to characterize the nature, areal extent and thickness of overburden deposits throughout the Area of the Five Communities.

The surficial geology of southern Ontario has been mapped in detail. The OGS has digitized the available Quaternary geology maps and generated a seamless digital coverage showing the distribution and nature of surficial deposit types, material types, and geological features such as drumlins, eskers and raised shore bluffs (OGS, 2010). The paper maps used to generate this digital product represent primarily 1:50,000 scale surficial geology maps completed by the OGS and Geological Survey of Canada (GSC) over the past 40 years.

The "Physiography of Southern Ontario" by L.J. Chapman and D.F. Putnam was first published in 1951 and was republished and updated in 1966 and 1984. This historical publication was previously available only as a hardcopy book with colour maps. However, the map remains an important, highly used publication, which complements the 1:50,000 scale surficial mapping that covers most of southern Ontario. As a result, the Sedimentary Geoscience Section of the OGS has digitized the physiographic information and released it in the form of a geospatial dataset (Chapman and Putnam, 2007).

The OGS has developed a protocol or methodology to generate regional bedrock elevation and overburden thickness maps using water well, geotechnical and petroleum drill records as well as geological observations for southern Ontario. Gao et al. (2006) describe the methodology in detail, which is summarized below. Bedrock elevations were interpreted from water well records obtained from the Ministry of the Environment (MOE) Water Well Information System, from geotechnical borehole records obtained from the OGS Urban Geology Automated Information System, and from oil and gas well records obtained from the Ontario Oil, Gas and Salt Resources Library created by the MNR. The data were filtered for problematic records and then the filtered dataset was used to interpolate an initial bedrock elevation surface using ordinary kriging. Water wells reportedly not reaching bedrock but extending below the modelled bedrock surface elevation were identified and their depths were used to push the bedrock elevation surface down. The resulting digital model of bedrock topography had a 400 m cell size. The bedrock elevation grid was inspected at every stage to identify problems in the dataset. In areas of thin drift where overburden cover is known to be less than one metre thick, the bedrock elevation surface was created by subtracting the known drift deposit thickness from the surface digital elevation model. An overburden thickness map was created by subtracting the bedrock elevation grid from the surface digital elevation model. The primary source of digital elevation data was the provincial DEM produced by the MNR, with limited use of the Shuttle Radar Topography Mission (SRTM) topographic data generated by the National Aeronautics and Space Administration (NASA). Section 5.1 provides a description of the distribution of overburden thickness within the Area of the Five Communities, including a discussion of the buried bedrock valleys and troughs in the area, while Section 5.3 provides descriptions of drift thickness in each of the Communities.

1.3.2 DIGITAL ELEVATION MODEL

The Canadian Digital Elevation Data (CDED), 1:50,000 scale, 0.75 arc second (20 m) digital elevation model (DEM) (GeoBase, 2013) served as an important data source for analyzing and interpreting the terrain in the Area of the Five Communities. The DEM used for this study was constructed by Natural Resources Canada (NRCan) using data assembled through the Water Resources Information Program (WRIP) of the MNR. The source data were 1:10,000 scale topographic data generated through the Ontario Base Mapping (OBM) program, a major photogrammetric program conducted across Ontario between about 1978 and 1995. Four main datasets were used: OBM contours, OBM spot heights, WRIP stream network, and lake elevations derived using the OBM spot heights and OBM water features. CDED datasets are provided in geographic coordinates, referenced horizontally using NAD83 and vertically based on the Canadian Geodetic Vertical Datum 1928 (CGVD28). Ground elevations are recorded in metres relative to mean sea level.

The CDED generally provides a good quality representation of the land surface in high relief areas. However, relatively poor quality representation can be found in flat areas, where the elevation model is, in some instances, based on elevation values obtained from a single elevation contour, with large areas around the contour where elevation values must be interpolated. These areas display a distinct stair-step or terraced pattern in the DEM. Slope values are relatively steep along the margins of these steps, as the step represents an artificially abrupt shift in elevation.

The elevation matrices provided by GeoBase were converted from geographic coordinates to UTM projection using bilinear resampling, which assigns a value to each output cell based on a weighted average of the four nearest cells in the input raster. Compared with cubic convolution, bilinear resampling can sometimes produce a noticeably smoother surface, whereas cubic convolution can produce a sharper image. However, the differences between the two methods are generally trivial and the selection of bilinear resampling made here was arbitrary. After projection, each file was assembled into a single-band mosaic with a 20 m cell size.

Surface analyses were performed on the DEM in order to characterize slope and relief. Slope was calculated using the standard grid-based method employed in ArcGIS, which involves fitting a plane to the elevation values of a three by three neighbourhood centred on the processing cell. Slope is defined as the maximum slope of that plane, which can also be thought of as the dip of the plane, and aspect is equivalent to the dip direction. Relief was calculated in two ways. The first was by subtracting the average elevation within a radius from the elevation value in the processing cell; this was completed for two radii (20 km and 2 km). The second was defined as the range in elevation within a circular window. The first relief calculation represents a high pass filter.

Section 3.2 provides a detailed discussion of the topography in the Area of the Five Communities using the CDED digital elevation model as the representation of the landscape.

1.3.3 MNR DATASETS

Watercourse and waterbody map files have been obtained from Land Information Ontario (LIO, 2013). The files are associated with the Ontario Hydrographic Network (OHN). In southern Ontario, the watercourses and waterbodies have been mapped at the scale of 1:10,000. Due to the high level of detail in the creek and river mapping, a file that depicts only the watercourses designated as rivers was generated and plotted on all maps presented in this report. The best available watershed delineation in the area is that of the quaternary level watershed file produced by the MNR, which is described in Section 4.2.

Other LIO files used in this report include the roads file from the Ontario Road Network (Section 8), the Wetland Unit map file (Section 4.1), and several files depicting protected areas (e.g., Provincial Parks, federal protected land, conservation areas).

2 SUMMARY OF GEOLOGY

2.1 BEDROCK GEOLOGY

The bedrock geology of southern Ontario and the Area of the Five Communities is described in detail in Geofirma Engineering Ltd. (2014) and the following is a summary of that information.

2.1.1 GEOLOGICAL SETTING

The bedrock geology of southern Ontario consists of a thick Paleozoic sequence of sedimentary rocks ranging in age from Cambrian to Mississippian deposited between approximately 540 million and 323 million years ago (Johnson et al., 1992). This sedimentary sequence rests unconformably on an erosional surface of the Precambrian crystalline basement of the Grenville Province, the southeastern-most subdivision of the Canadian Shield. The Grenville Province comprises 2,690 million to 990 million year old metamorphic rocks deformed during orogenic events 1,210 million to 970 million years ago (Percival and Easton, 2007; White et al., 2000). The Grenville Province is considered to have been relatively tectonically stable for the past 970 million years (Williams et al., 1992).

Southern Ontario is underlain by two paleo-depositional centres referred to as the Michigan Basin and the Appalachian Basin. The Appalachian Basin is an elongate foreland basin that parallels the Appalachian orogen and comprises primarily siliciclastic sediments. The Michigan Basin is a broadly circular carbonate-dominated, evaporite-bearing intracratonic basin. These basins are separated by the northeast-trending Algonquin and Findlay arches which, along with the intervening east-southeast-trending Chatham Sag structural depression, define a regional basement high beneath southern Ontario and extending further southwestward into the northeastern United States.

The Paleozoic succession underlying the Area of the Five Communities was deposited within the Michigan Basin. Within the Michigan Basin, the thickness of Paleozoic rocks range from a maximum of about 4,800 m at the centre of the basin to approximately 450 m at the northeast corner of the Area of the Five Communities (OGSRL, 2013). The Paleozoic strata dip gently (3.5 to 12 m/km) to the west or southwest throughout the Ontario portion of the Michigan Basin (Armstrong and Carter, 2010).

Figure 2 shows the bedrock geological map for southern Ontario, and Figure 3 shows a vertically exaggerated cross-section constructed through the Area of the Five Communities. The location of the cross-section is shown on Figure 2. The geological cross-section (Figure 3) shows the west-southwesterly dip of the Paleozoic sedimentary formations from the Niagara Escarpment in the east to below Lake Huron in the west. The large vertical exaggeration of 50 times used in Figure 3 results in apparent moderate formation dips when, in reality, the sedimentary formations within the Area of the Five Communities are flat lying with dips of 1º or less. These moderate west-southwesterly dips result in outcrop or subcrop exposure of increasingly older sedimentary formations from west to east across southern Ontario, as shown on Figure 2.

2.1.2 Geological and Tectonic History

The structural and tectonic history of southern Ontario includes both Precambrian and Phanerozoic events. These events are described below and summarized in Table 1.

As mentioned above, the Paleozoic sedimentary sequence of southern Ontario lies unconformably on the Precambrian crystalline basement of the Grenville Province of the Canadian Shield. The Grenville Province is a complex orogenic belt that truncates several older geologic provinces. Basement rocks in southern Ontario have all been affected by an approximately 1,210 to 970 million year old orogenic event, the Grenville Orogeny. The Grenville Orogeny is generally interpreted to have involved northwest-directed thrusting and imbrication of the entire crust, presumably as a result of collision with another continental landmass originally located somewhere to the southeast. Older tectonic events including the approximately 2,700 million year old Kenoran Orogeny and the approximately 2,000-1,700 million year old Trans-Hudson/Penokean Orogen, built the proto-North American craton upon which Grenville deformation was imprinted (Easton, 1992). Post-Grenville extension associated with the initial opening of the Iapetus Ocean began approximately 970 million years ago (Thomas, 2006).

The deposition of the sedimentary rocks within the Michigan and Appalachian basins was largely dependent on two tectonic influences (Johnston et al., 1992). These were the orogenic activity at the eastern margin of North America, which provided clastic input to both the Appalachian and Michigan basins, and the resultant tectonic forces that controlled the positioning of the basins and arches separating the basins. The Algonquin Arch acted as a major structural control on depositional patterns, rising and falling with respect to the Michigan and Appalachian basins in response to epirogenic movements and horizontal tectonic forces during the course of several distinct Paleozoic orogenic episodes (Howell and van der Pluijm, 1999).

Table 1 Timetable of major tectonic events in Southern Ontario

Million Years Before Present	***Tectonic Activity***	***Reference***
1,210 – 1,180	Regional metamorphism in Central Metasedimentary Belt Boundary Zone (proto-Grenville)	Easton (1992), Lumbers et al. (1990), Hanmer and McEachern (1992)
1,109 – 1,087	Magmatism and formation of Midcontinent Rift	Van Schmus (1992)
1,030 – 970	Main phase of Grenville Orogeny	Carr et al. (2000), White et al. (2000)
970 – 530	Rifting and opening of the Iapetus Ocean	Thomas (2006)
530 – 320	Subsidence of Michigan Basin and uplift of Frontenac and Algonquin Arches (episodic)	Howell and van der Pluijm (1999), Sanford et al. (1985), Kesler and Carrigan(2002)
470 – 440	Taconic Orogeny • E-W to NW-SE compression, uplift in foreland (Frontenac and Algonquin Arches)	Quinlan and Beaumont (1984), Sloss (1982), McWilliams et al. (2007)
410 – 320	Caledonian/Acadian Orogeny • E-W to NW-SE compression, uplift (Frontenac and Algonquin Arches)	Gross et al. (1992), Marshak and Tabor (1989), Sutter et al. (1985), Kesler and Carrigan (2002)
300 – 250	Alleghenian Orogeny • E-W to NW-SE compression	Gross et al. (1992), Engelder and Geiser (1980)
200 – 50	• Opening of the Atlantic Ocean • St. Lawrence rift system created • Reactivation of Ottawa-Bonnechère Graben • NE-SW extension • Uplift	Kumarapeli (1976, 1985)
Pre-50 – Present	• NE-SW compression (from ridge push) • Post-glacial uplift	Barnett (1992)

Coincident with sediment deposition, the bedrock of southern Ontario was subject to a complex history of Paleozoic tectonism that included the Taconic (Ordovician), Caledonian/Acadian (Devonian) and Alleghenian (Carboniferous) orogenies (Howell and van der Pluijm, 1999). Subsequent events include the Mesozoic initiation of far field stresses associated with the opening of the Atlantic Ocean (Jurassic), compression from global-scale plate reorganization and ridge push (late Cretaceous-Eocene), and finally post-glacial uplift (Quaternary).

2.1.3 PRECAMBRIAN GEOLOGY

The geology of the Precambrian crystalline basement of the Grenville Province in southern Ontario has been well characterized by surface mapping north of the Paleozoic/Precambrian basement boundary, regional geophysical data (aeromagnetics and gravity), regional seismic reflection surveys and geochemical, geochronological and petrographic analyses of rock samples recovered from boreholes (O'Hara and Hinze, 1980; Green et al., 1988; Carr et al., 2000; Carter and Easton, 1990; Easton and Carter, 1995; Carter et al., 1996).

The Precambrian basement in southern Ontario has been grouped into two lithologic belts – the Central Gneiss Belt, located between the Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone, and the Central Metasedimentary Belt located southeast of the Central Metasedimentary Belt Boundary Zone. The Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone are major sub parallel shear zones several kilometres or more in width, characterized by strongly deformed rocks with northeast-trending, moderately to shallowly southeast-dipping tectonic layering and southeast plunging mineral lineations (Easton and Carter, 1995). Similar subparallel zones of intense deformation on a smaller scale form boundaries between lithotectonic terranes within both the Central Gneiss Belt and Central Metasedimentary Belt (Easton and Carter, 1995).

Major tectonic zones in southern Ontario are defined by extrapolation of the exposed basement structural boundaries beneath the Paleozoic cover. This process is aided by field mapping, borehole stratigraphic correlation, interpretation of seismic, aeromagnetic and gravity surveys (e.g., Boyce and Morris, 2002; Wallach et al., 1998), and by geochemical, geochronological and petrographic analyses of samples recovered from drill cuttings and core (Carter and Easton, 1990; Carter et al., 1996).

Based on aeromagnetic data and borehole samples, the Precambrian basement below the sedimentary rock cover has been subdivided into several lithotectonic domains and boundary zones similar in scale and form to those found where the Precambrian bedrock of the Grenville Province is exposed (Carter and Easton, 1990). Much of southern Ontario, including the Area of the Five Communities, is underlain by Precambrian crystalline basement of the Central Gneiss Belt and consists mainly of quartzofeldspathic gneissic rocks which have generally been metamorphosed to upper amphibolite facies, and locally to granulite facies. Most of these gneisses are believed to be plutonic in origin, with subordinate amounts of metasedimentary gneiss.

The Huron Domain is a lithotectonic domain within the Central Gneiss Belt, and underlies most of the Area of the Five Communities. The Huron Domain acted as single crustal block during the Paleozoic. It is defined by Carter and Easton (1990), Easton and Carter (1995) and Carter et al. (1996) based on lithologic data from boreholes and published aeromagnetic maps.

2.1.4 PALEOZOIC STRATIGRAPHY

Table 2 illustrates the Paleozoic bedrock stratigraphy for the Area of the Five Communities as presented by Geofirma Engineering Ltd. (2014). The Paleozoic stratigraphic nomenclature has evolved over time and a recent compilation by Armstrong and Carter (2010) provides the current standard for usage. Two key stratigraphic designations have recently been revised. Firstly, strata traditionally referred to as Middle Ordovician, i.e., Black River and Trenton groups (from Armstrong and Carter, 2006), are now considered part of the Upper Ordovician. Secondly, the formal term Middle Silurian (from Armstrong and Carter, 2006) has been abandoned so all strata have been re-assigned to either the Lower or Upper Silurian.

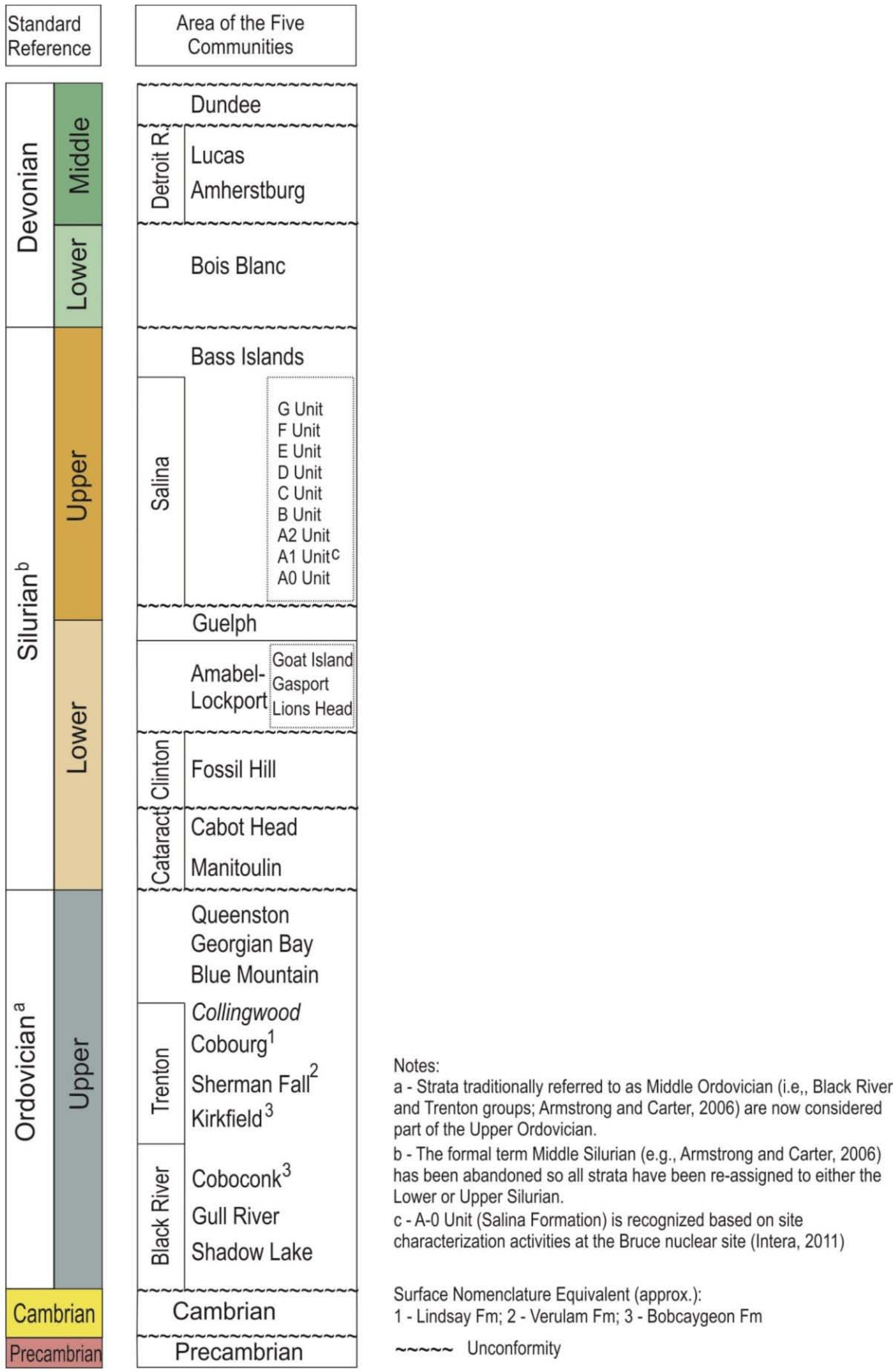
In addition, the stratigraphic nomenclature in Table 2 and Figure 3 adopts the subsurface nomenclature of Armstrong and Carter (2010), while geological mapping as shown in Figures 2 and 4 uses an outcrop nomenclature. This distinction primarily applies to the Trenton and Black River groups, where the Bobcaygeon Formation (outcrop) is equivalent to the Coboconk and Kirkfield formations (subsurface), and the Verulam and Lindsay formations (outcrop) are approximately equivalent to the Sherman Fall and Cobourg formations (subsurface), respectively.

The Paleozoic stratigraphy includes shale, carbonate and evaporite units formed predominantly from marine sediments that were deposited when this portion of eastern North America was located at tropical latitudes and intermittently covered by shallow seas (Johnson et al., 1992; Armstrong and Carter, 2010).

2.1.4.1 Cambrian

The Cambrian bedrock geology in southern Ontario is dominated by white to grey quartzose sandstone with regional lithological variations that include fine to medium crystalline dolostone, sandy dolostone, and argillaceous dolostone to fine to coarse quartzose sandstone (Hamblin, 1999). Cambrian sedimentary rocks unconformably overlie the Precambrian basement. These sedimentary rocks are generally characterized as a succession of clastic and carbonate rocks resulting from transgressive Cambrian seas that flooded across the broad platform of the Algonquin Arch and into the subsiding Michigan and Appalachian basins (Hamblin, 1999). The

Table 2 Stratigraphy of the Area of the Five Communities (after Armstrong and Carter, 2010)



Cambrian units are largely absent over the Algonquin Arch as the result of a pre-Ordovician regional-scale unconformity (Bailey Geological Services Ltd. and Cochrane, 1984a). The Cambrian unit is interpreted to pinch out eastwards, near the western boundaries of the municipalities of Arran-Elderslie, Brockton and South Bruce (Bailey Geological Services Ltd. and Cochrane, 1984a), and thus is expected to be absent beneath the eastern and central parts of the Area of the Five Communities. There are no surface exposures of the Cambrian unit in southern Ontario.

2.1.4.2 Upper Ordovician

Unconformably overlying the Cambrian unit is a thick sequence of Upper Ordovician sedimentary units with a distinctly bimodal composition consisting of a carbonate-rich lower unit and a shale-rich upper unit. The lower unit was deposited during a major marine transgression (Coniglio et al., 1990) prior to the westward inundation of the carbonate platform by the upper shale-dominated sediments (Hamblin, 1999). The Upper Ordovician carbonates subcrop in the northeastern part of southern Ontario around Lake Ontario and Lake Simcoe, and the Upper Ordovician shales subcrop east of the Niagara Escarpment between Owen Sound and Niagara Falls (Figure 2).

The lower carbonate unit of the Upper Ordovician succession is a thick sequence of predominantly limestone formations (carbonate and argillaceous carbonate sedimentary rocks), which include, from bottom to top: the Shadow Lake, Gull River and Coboconk formations of the Black River Group; and the Kirkfield, Sherman Fall, and Cobourg (including the Collingwood Member) formations of the Trenton Group (Table 2). These rocks range in character from coarse-grained bioclastic carbonates to carbonate mudstone with interbedded calcareous and non-calcareous shales. The Shadow Lake Formation, at the base of the Black River Group, is characterized by poorly sorted, red and green sandy shales, argillaceous and arkosic sandstones, minor sandy argillaceous dolostones and rare basal arkosic conglomerate. The lower part of the overlying Gull River Formation consists mainly of light grey to dark brown limestones and the upper part of the formation is very fine grained with thin shale beds and partings. The Coboconk Formation, at the top of the Black River Group, is composed of light grey-tan to brown-grey, medium to very thick bedded, fine to medium grained bioclastic limestones (Armstrong and Carter, 2010).

The Kirkfield Formation, at the base of the Trenton Group, is characterized by fossiliferous limestones with shaley partings and locally significant thin shale interbeds. The overlying Sherman Fall Formation ranges in lithology from dark grey argillaceous limestones interbedded with calcareous shales, found lower in the formation, to grey to tan bioclastic, fossiliferous limestones that characterize the upper portions of the formation. The overlying Cobourg Formation is described regionally as a grey, fine-grained limestone to argillaceous limestone with coarse-grained fossiliferous beds and a nodular texture. The Cobourg Formation is also subdivided to include an upper Collingwood Member that consists of dark grey to black, calcareous shales with increased organic content and distinctive fossiliferous limestone interbeds (Hamblin, 2003; Armstrong and Carter, 2010).

The upper unit of the Upper Ordovician succession is characterized by a thick sequence of predominantly shale sedimentary rocks, which comprise from base to top: the Blue Mountain, Georgian Bay and Queenston formations. The Blue Mountain Formation is characterized by uniform soft and laminated grey non-calcareous shale with minor siltstone and minor impure carbonate (Johnson et al., 1992; Hamblin, 1999). In the lower part of the Blue Mountain Formation there is downward gradation from grey to greenish-grey shales to a very dark grey to black shale (Armstrong and Carter, 2010). This lower part of the Blue Mountain Formation was historically named the Rouge River Member (Russell and Telford, 1983). The overlying Georgian Bay Formation is composed of blue-grey shale with intermittent centimetre-scale siltstone and limestone interbeds. The Queenston Formation is characterized by maroon, with lesser green, shale and siltstone with varying amounts of carbonate. The top of the Queenston Formation is marked by a regional erosional unconformity (Table 2; Armstrong and Carter, 2010).

2.1.4.3 Lower Silurian

The Lower Silurian units, including the Cataract and Clinton groups and the Amabel-Lockport and Guelph formations, unconformably overlie the Upper Ordovician shales (Table 2). A major marine transgression at the top of the Clinton Group marks the transition to deposition of the extensive carbonate-dominated Amabel and Guelph formations. These Lower Silurian units form the cap-rock of the Niagara Escarpment in outcrop. The Lower to Upper Silurian boundary occurs within the Guelph Formation (Table 2; Brunton and Dodge, 2008).

The Cataract Group unconformably overlies the Upper Ordovician Queenston Formation and includes a lower unit of grey argillaceous dolostone and minor grey-green shale, and an upper clastic unit which consists of grey to green to maroon noncalcareous shales with minor sandstone and carbonate interbeds. The Clinton Group is composed of thin- to medium-bedded, very fine- to coarse-grained fossiliferous dolostone.

The Amabel-Lockport Formation includes a lower unit of light grey to grey-brown, finely crystalline, thin- to medium-bedded, sparingly fossiliferous dolostone with minor chert nodules. It also includes an upper unit of blue-grey, fine- to coarse-grained, thick bedded to massive dolostone, which locally contains minor dolomitic limestone.

The Guelph Formation lithology varies from reefal to inter-reefal dolostones and dolo-mudstones (Armstrong and Goodman, 1990). Reefal facies represent pinnacle, patch and barrier reefs and their distribution defines the key aspects of the paleogeography during deposition. The widespread inter-reefal dolostones are typically sucrosic, dark brown to black dolo-mudstones with pebble-size fragments lithologically similar to the underlying Goat Island unit (Armstrong and Carter, 2006). Within the Area of the Five Communities, the Guelph Formation is characterized by facies deposited between the basinward pinnacle reef belt found along the eastern shore of Lake Huron, the patch reefs found in the central parts of the Area of the Five Communities, and the basin margin reef complex typically located in the eastern part of the Area of Five Communities (Johnson et al., 1992).

2.1.4.4 Upper Silurian

The Upper Silurian units include the evaporite and evaporite-related sedimentary rocks of the Salina Group, and overlying dolostones and minor evaporites of the Bass Islands Formation (Table 2). The Upper Silurian units subcrop in a northwest trending belt that extends from south of Niagara Falls to west of Owen Sound (Figure 4). The Salina Group is characterized by repeated, cyclical deposition of carbonate, evaporite and argillaceous sedimentary rocks, comprising Units A through G. Parts of the Silurian salt beds (i.e., B, D, E and F Unit salts) have been dissolved resulting in the collapse structure within the overlying uppermost Silurian and Devonian strata (Sanford, 1993; 1976).

A change to less-restricted depositional conditions was responsible for deposition of the Bass Islands Formation, which is a microcrystalline, commonly bituminous dolostone containing evaporite mineral clasts. The contact with the overlying Devonian carbonates marks a major unconformity characterized by subaerial exposure (Uyeno et al., 1982).

2.1.4.5 Lower and Middle Devonian

The Lower and Middle Devonian units unconformably overlie the Upper Silurian Bass Islands Formation and are dominated by carbonate sedimentary rocks of the Bois Blanc Formation, the Detroit River Group consisting of the Amherstburg and Lucas formations. The Bois Blanc Formation consists of cherty, fossiliferous limestones and argillaceous dolostones that unconformably overlie Silurian strata. The Lucas Formation is fine-crystalline, fossiliferous dolostone and limestone. The Amherstburg Formation is a bituminous bioclastic fossiliferous limestone and dolostone (Table 2). The Dundee Formation, which does not subcrop within the Communities, comprises sparsely fossiliferous limestones and minor dolostones that unconformably overly the Detroit River Group.

The Detroit River Group rocks represent the subcropping bedrock within western and central parts of the municipalities of Brockton and South Bruce and all of the Township of Huron-Kinloss (Figure 4). Devonian rocks are not present beneath the Municipality of Arran-Elderslie (Figure 4). The Devonian carbonates are found southwest of the Municipality and crop out along the shoreline of Lake Huron and north shoreline of Lake Erie.

2.1.5 Faulting of the Paleozoic Strata

Figures 2 and 4 show basement-seated faults that displace the Paleozoic strata in southern Ontario and the Area of the Five Communities, respectively. These faults were compiled from several sources by the Ontario Geological Survey (Armstrong and Carter, 2010) and given relative ages based on the youngest geological unit that is offset: i) Shadow Lake/Precambrian, ii) Trenton Group and iii) Rochester Formation (Silurian-aged). These faults are interpreted based on vertical displacements of key unit-top surfaces in the Paleozoic strata, based on earlier compilation and assessment work completed by Brigham (1971) and Bailey Geological Services Ltd. and Cochrane (1984a; 1984b). Vertical displacement of unit top surfaces was identified based primarily on hand contouring and interpretation of formation top data in the Petroleum Wells Subsurface Database (OGSRL, 2013). Where these data are numerous, such as in the southwestern corner of southern Ontario, the faults are identified with a high degree of confidence, and are often named (e.g., Dawn Fault and Electric Fault). In areas where oil and gas exploration wells are widely spaced, such as in the Area of the Five Communities, faults are identified with a low degree of confidence.

2.2 QUATERNARY GEOLOGY

Quaternary glaciations have played a major role in shaping and creating the landscape of southern Ontario (Barnett, 1992). Glacial landforms and associated sediments within the Area of the Five Communities were deposited by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet during the most recent glacial event, the Late Wisconsinan glacial episode, dated 23,000 to 10,000 years ago. Exposures of older deposits are rare as they are mostly buried beneath the Late Wisconsinan sediments and can only be seen in such places as riverbank exposures, lake bluffs or man-made exposures in quarries and pits (Barnett, 1992).

The overburden is generally thick in southern Ontario, with thicknesses that can exceed 200 m and common values of 30 to 60 m (Karrow, 1989). As shown on Figure 5, the surficial deposits in the Area of the Five Communities are mapped in considerable detail, and they are responsible for shaping many of the landforms mapped throughout the area, including moraines, drumlins, and raised beaches (Figure 6). In addition to defining many of the surface landforms, the surficial deposits also play an important role in controlling the location and extent of surficial aquifers, groundwater discharge and recharge areas, and aggregate deposits. About half of the Area of the Five Communities is covered by till, shown as 'morainal' deposits on Figure 5, which is typically characterized by low permeability (Figure 5, inset B) due to its fine-grained texture. Fine-grained glaciolacustrine deposits of generally low permeability are also common in the area. In contrast, zones of high permeability are present where sandy glaciolacustrine deposits or glaciofluvial deposits associated with kame moraines and spillways are found at the surface.

The following sections describe the major episodes of ice advancement across the region and the glacial and post-glacial lakes that have left important landforms and surface deposits. Section 5 summarizes the distribution of surficial deposits within the Area of the Five Communities.

2.2.1 LATE WISCONSINAN ICE ADVANCES

The Late Wisconsinan glacial episode featured three significant periods of advancement of the Laurentide Ice Sheet in this part of southern Ontario: the Nissouri (23,000 to 18,000 years ago), Port Bruce (15,200 to 13,800 years ago), and Port Huron (13,100 to 12,300 years ago) stades (Barnett, 1992). Two periods of climatic amelioration were responsible for driving ice-marginal recession during the Late Wisconsinan (Barnett, 1992): the Erie (16,500 to 15,500 years ago) and

Mackinaw (14,000 to 13,000 years ago) interstades. Table 3 summarizes the Quaternary deposits and events that have shaped the Area of the Five Communities to accompany the maps of surficial deposits and landforms presented in Figure 5 and Figure 6, respectively.

Table 3 Summary of Quaternary deposits and events in the Area of the Five Communities.

Age (ka)	Glacial period	Deposit or event	Landform
10 to present	Holocene	Organic deposits	Wetlands
		Fluvial deposits	River and floodplain landforms
		Glacial Lake Nipissing deposits	Raised beaches and bluffs
12 to 11.8	Two Creeks Interstade	Glacial Lake Algonquin deposits	Raised shorebluffs, sand sheets deposited within Huron fringe
		Glaciofluvial deposits	Outwash and ice-contact landforms
13.1 to 12.3	Port Huron Stade	Glacial Lake Warren deposits	Saugeen clay plain, Warren beaches
		St. Joseph Till	Wyoming, Banks and Williscroft moraines
14 to 13	Mackinaw Interstade	Glaciolacustrine deposits	Clay plains
15.2 to 13.8	Port Bruce Stade	Glaciofluvial deposits	Outwash and ice-contact landforms
		Dunkeld Till	Walkerton Moraine
		Rannoch Till	Wawanosh Moraine
		Elma Till	Teeswater and Arran drumlin fields, Singhampton Moraine
16.5 to 15.5	Erie Interstade	Glaciolacustrine deposits	Buried
23 to 18	Nissouri Stade	Catfish Creek Till	Buried

Compiled after Barnett (1992)

Initial ice advancement during the Late Wisconsinan occurred during the Nissouri Stade, at which time the Laurentide Ice Sheet advanced to the Niagara Escarpment by approximately 23,000 years ago (Hobson and Terasmae, 1969) and to its southernmost limit in Ohio and Indiana by about 20,000 to 18,000 years ago (Dreimanis and Goldthwait, 1973). During the Nissouri Stade, the advance of the Laurentide Ice Sheet deposited the Catfish Creek Till, which is widespread in the subsurface throughout southern Ontario (Barnett, 1992). Only during the maximum Nissouri advance was ice sheet movement controlled regionally, whereas the early and late movements were controlled by the orientation of the Great Lakes basins (Cowan, 1975).

Following the Erie Interstade, the Laurentide Ice Sheet advanced during the Port Bruce Stade across southern Ontario and extended well into the United States (Barnett, 1992). Ice flow was controlled by the morphology of the Great Lakes basins, with movement radiating outward from each basin. Glaciolacustrine sediments deposited during the Erie Interstade were overridden.

Early in the Port Bruce Stade, a combined ice sheet extending from the Georgian Bay and Lake Huron basins deposited the Stirton, Tavistock, Mornington, Stratford and Wartburg tills to the south and east of the Area of the Five Communities (Karrow, 1974, 1989).

Later in the Port Bruce Stade, the Huron and Georgian Bay lobes separated and deposited the Elma Till (Georgian Bay lobe) and the Rannoch Till (Huron lobe) (Figure 5, inset A). The Elma Till is the most widely distributed till in the Area of the Five Communities. It occurs as a stony, sandy silt till in ground moraine and in drumlins of the Teeswater and Arran drumlin fields (Figure 6, inset A) and is associated with the Singhampton Moraine (Barnett, 1992). The Rannoch Till is a silt till that occurs as ground moraine and in several end moraines including the Wawanosh Moraine (Cowan and Pinch, 1986; Figure 6). The Dunkeld Till was deposited during a minor re-advance of the Georgian Bay lobe into a proglacial lake (Cowan and Pinch, 1986), forming ground moraine in the Saugeen Valley near Paisley and forming the core of the Walkerton Moraine (Figure 6). The Dunkeld Till is dominantly a silt till comprising reconstituted glaciolacustrine silt (Cowan and Pinch, 1986).

Following the Mackinaw Interstadial, the Laurentide Ice Sheet advanced during the Port Huron Stade across the region, depositing the St. Joseph Till and forming the Wyoming, Banks and Williscroft moraines, which parallel the Lake Huron and Georgian Bay shorelines (Barnett, 1992; Figure 6). The St. Joseph Till contains an abundance of silt and silty clay due to extensive incorporation and deformation of glaciolacustrine sediments deposited during the Port Bruce Stade and Mackinaw Interstade.

2.2.2 Glacial and Postglacial Lakes

Following the retreat of the Laurentide Ice Sheet from the Huron basin, several ice-contact and proglacial lakes occupied the Huron basin during Late Wisconsinan and Holocene times (Figure 6, inset B), leaving several important deposits and landforms in the Area of the Five Communities. Descriptions of the available evidence for pre-Late Wisconsinan glacial lakes can be found in Barnett (1992) and Eschman and Karrow (1985). Glacial and postglacial lake level changes within the Huron basin are an important aspect of Late Wisconsinan and Holocene environmental change in this area.

2.2.2.1 Lake Warren

The oldest known proglacial lake to inundate the Area of the Five Communities during the Late Wisconsinan was glacial Lake Warren, which extended into parts of each of the Communities except the Municipality of South Bruce (Figure 6, inset B). Landforms associated with Lake Warren are present within the zone adjacent to the Lake Huron shoreline described in Section 3.1.5 as the Huron slope (Figure 6, inset A). Generally, there are two abandoned beaches associated with Lake Warren (Chapman and Putnam, 2007). In the southernmost part of the Area of the Five Communities, the Warren beaches are located along the west edge of the Wyoming Moraine about 8 km east of the Lake Huron shoreline. Further north, the beaches extend 12 to 16 km east of the Lake Huron shoreline in the Township of Huron-Kinloss (Figure 6). Deep stratified silts and clays were deposited in a bay within Lake Warren, forming the Saugeen clay plain (Section 3.1.4), which covers the respective northern and southern halves of the municipalities of Arran-Elderslie and Brockton (Figure 6, insets).

2.2.2.2 Lake Algonquin

Glacial Lake Algonquin was a proglacial lake that occupied portions of the Lake Huron and Michigan basins between 12,500 and 10,600 years ago (Eschman and Karrow, 1985). Erosional and depositional landforms associated with glacial Lake Algonquin are abundant within the narrow zone adjacent to the Lake Huron shoreline described in Section 3.1.6 as the Huron fringe (Figure 6, insets). Glacial Lake Algonquin deposits consist of well-sorted, medium to coarse sands deposited as beach ridges and glaciolacustrine plains several metres in thickness. Wave erosion along glacial Lake Algonquin formed a prominent 30 m high bluff formed in St. Joseph Till, known as the Algonquin bluff (Figure 6), along the Lake Huron shoreline. Sediment eroded from the St. Joseph Till was subsequently deposited on a sand plain adjacent to Lake Huron.

2.2.2.3 Nipissing Transgression

Isostatic rebound about 5,000 years ago resulted in an increase in the elevation of the northern outlet of Lake Huron to an elevation the same as that of outlets at the south ends of Lake Huron and Lake Michigan (Eschman and Karrow, 1985). This resulted in the Nipissing Great Lakes or the Nipissing Transgression. Glacial Lake Nipissing was the first lake to form within this transgression, forming beach ridges and bluffs along the Lake Huron shoreline within the Huron fringe (Section 3.1.6; Figure 6). For example, between Kincardine and Southampton the

Nipissing bluff is 4 to 5 m high and is located usually less than one kilometre from the current Lake Huron shoreline (Cowan, 1977; Sharpe and Edwards, 1979).

3 PHYSIOGRAPHY AND TOPOGRAPHY

Several landforms and landform complexes resulting from events associated with the advance and retreat of the Laurentide Ice Sheet across the region during the Late Wisconsinan glaciation have been classified by Chapman and Putnam (2007) and are described in Section 3.1. These landforms provide a map of the glacial and postglacial events that were largely responsible for producing the detailed topography of the Area of the Five Communities. Many of these landforms are visible in images generated from the digital elevation model presented in Section 3.2. These landforms and the topography in general are important because they play a role in controlling surface water and shallow groundwater flow directions and should be considered when planning site characterization and construction activities.

3.1 PHYSIOGRAPHY

The physiography of the Area of the Five Communities can be classified into a set of ten physiographic units (Figure 6, inset A) based on the presence of distinct landforms such as valleys, drumlin fields, escarpments and till plains. Table 4 summarizes the extent of the six specific physiographic units that extend into the Communities, and these units are described in the sub-sections below, which are based on Chapman and Putnam (2007) except where stated otherwise.

Table 4 Extent of physiographic units within the Communities (in percent).

	Physiographic unit					
Community	Arran drumlin field	Horseshoe moraines	Huron fringe	Huron slope	Saugeen clay plain	Teeswater drumlin field
Municipality of Arran-Elderslie	55	0	3	1	41	0
Municipality of Brockton	0	62	0	2	33	3
Municipality of South Bruce	0	41	0	0	0	59
Township of Huron-Kinloss	0	36	2	59	0	3
Town of Saugeen Shores	3	0	54	38	5	0

3.1.1 HORSESHOE MORAINES

The elaborate array of moraines and spillways extending northeast to southwest across a large part of the Area of the Five Communities is part of what is described as the Horseshoe moraines (Figure 6, inset A). The moraines within this belt are known as the Port Huron moraine system. The belt is about 13 km wide where it extends parallel with the Lake Huron shoreline at the southern edge of the Area of the Five Communities. The Horseshoe moraines physiographic unit widens considerably towards the east. The two chief landform complexes in the Horseshoe moraines are the till and kame moraines and the generally pitted sand and gravel terraces within swampy valley floors.

3.1.2 TEESWATER DRUMLIN FIELD

The Teeswater drumlin field covers the southeastern half of the Municipality of South Bruce (Figure 6, inset A) and includes more than 380 drumlins. Drumlin orientation varies from southerly in the Wingham and Teeswater areas to southeasterly in the area near Harriston. The drumlins are characterized as low, broad, oval hills with gentle slopes. The till (Elma Till, Figure 5, inset A) is moderately compact, highly calcareous, and pale brown or yellowish brown in colour after the soft, pale brown limestone from which the till was derived.

The drumlin field was cut by meltwater streams draining ice fronts to the north and west. The meltwater channels now carry branches of the Saugeen and Maitland rivers. Most of these valleys were cut in till, and only in a few cases have the channels incised into the underlying bedrock. Broad terraces of sand and gravel are found in most of these valleys, occupying much of the low ground between drumlins, producing a “drumlin and gravel flat” landform pattern. The drumlin field is interrupted in a few places by the presence of kames and associated outwash. Drainage is usually good on drumlins, gravel terraces, kames and moraines. However, the Teeswater drumlin field, like most others, contains many areas of swampy land.

3.1.3 ARRAN DRUMLIN FIELD

The Arran drumlin field extends over the northern half of the Municipality of Arran-Elderslie (Figure 6, inset A) and includes about 300 long narrow drumlins in an area between Southampton and Owen Sound. Glaciolacustrine clay occurs between drumlins in some areas, particularly in the southern part of the field. The drumlins are oriented southwest, having been formed by the advance of the Georgian Bay ice lobe. Eight to ten narrow, east-west trending recessional moraines near Tara record the intermittent retreat of the ice lobe from this area (Figure 6).

The southern margin of the drumlin field is clearly defined by two morainal strands composed of St. Joseph Till (Figure 5, inset A) located near Dobbinton. The western margin of the field is marked clearly by a steep bluff associated with glacial Lake Algonquin (Figure 6). Wave action within glacial Lake Algonquin eroded all drumlins west of the Algonquin shoreline, leaving only bouldery patches on the old lake floor as evidence of former drumlins.

The till in this field is highly calcareous and contains many stones and boulders of both dolostone of the Amabel Formation and Precambrian rocks. The ground moraine is not particularly thick, and many of the drumlins, particularly in the northeast, stand isolated on the dolostone bedrock. Many of the inter-drumlin areas are occupied by swamps, and a few lakes are present in the lows between drumlins.

3.1.4 SAUGEEN CLAY PLAIN

The Saugeen clay plain is located in the watershed of the Saugeen River north of the Walkerton Moraine (Figure 6). It covers the southern and northern half of the municipalities of Arran-Elderslie and Brockton, respectively (Figure 6, inset A). The area contains a deep stratified glaciolacustrine clay deposit formed in a bay of glacial Lake Warren.

The clay in this area is pale brown in colour and highly calcareous and was derived from local limestones and dolostones. The clay was transported in meltwater channels now occupied by branches of the Saugeen River. The largest area of thick lacustrine clay is located in the topographic low between the moraines at Walkerton and Chesley. Several modern streams, such as the Saugeen and Teeswater rivers, have cut deep valleys into the clay deposits.

A delta in glacial Lake Warren formed a sand plain at what is now the junction of the Saugeen and Teeswater rivers. Kames can also be found locally in this area. The southern portion of the clay plain is generally well drained due to stream dissection, whereas the northern part has some areas of poor drainage.

3.1.5 HURON SLOPE

The Huron slope occupies the section of land along the east shore of Lake Huron between the Algonquin bluff and the Wyoming Moraine, and covers the western half of the Township of Huron-Kinloss (Figure 6). The land slopes gently across this feature from about 180 to 260 or 275 m elevation. The area is characterized by a clay plain containing a narrow strip of sand and the twin beaches of glacial Lake Warren.

Below the Warren beach, the till surface has been subdued by the deposition of a veneer of glaciolacustrine clay less than a metre thick. Exposures of till occur at the surface in many locations where the clays are absent. Above the glacial Lake Warren beaches, the till surface has not been subdued by the deposition of glaciolacustrine clays. The till sheet is formed of a brown calcareous clay (St. Joseph Till, Figure 5, inset A) and is generally only 2 to 3 m thick and rests on stratified clay of the same colour. The material in the till sheet almost certainly represents reworked glaciolacustrine material similar to that found in the beds below.

3.1.6 HURON FRINGE

Wave-cut terraces of glacial Lake Algonquin and glacial Lake Nipissing, with their boulders, gravel bars and sand dunes are located within a narrow fringe of land extending along the Lake Huron shoreline (Figure 6, inset A). The Huron fringe covers a small part of the Township of Huron-Kinloss and a portion of the Town of Saugeen Shores. South of Port Elgin, the Huron fringe is bordered by a cliff 15 to 30 m high. South of Point Clark there is little or no terrace below this bluff and there are only a few strips of sandy beach.

3.2 TOPOGRAPHY

Topography is an important aspect of the terrain, as it plays a role in controlling surface water and shallow groundwater flow directions and should be considered when planning site characterization and construction activities. The large-scale topography in the Area of the Five Communities is controlled by bedrock topography whereas the detailed topography is often controlled by surficial landforms. The following descriptions of topography rely heavily on the representation of the landscape by the CDED digital elevation model.

3.2.1 ELEVATION

The large-scale pattern of elevation across the Area of the Five Communities (Figure 7) controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from east to west (Lake Huron) is from 400 to 176 m, with this elevation drop occurring over an approximate 70 km lateral distance. The elevation minimum is defined by the surface of Lake Huron, with a chart datum of 176 m. The highest points in the area, with elevations of 400 m, are located in the southeast corner of the Area of the Five Communities, about 3 km southeast and east of Harriston (Figure 7).

The municipalities of Arran-Elderslie, Brockton and South Bruce are located inland of Lake Huron, with minimum elevations ranging from 180 to 249 m (Table 5). The Municipality of South Bruce has the highest elevation of the Communities. Due to its high elevation, this municipality was the only one of the Communities that was above the elevation of glacial Lake Warren. The Town of Saugeen Shores has the lowest elevation of the Communities and this land area was therefore almost entirely inundated by glacial Lake Warren. Spot heights showing the minimum and maximum elevations of the Communities have been added to Figure 7 for reference.

Table 5 Elevation statistics for the Communities.

Community	Minimum (m)	Maximum (m)	Range (m)	Mean (m)
Municipality of Arran-Elderslie	180	302	122	244
Municipality of Brockton	210	335	125	272
Municipality of South Bruce	249	396	147	316
Township of Huron-Kinloss	176	336	160	259
Town of Saugeen Shores	176	266	90	215

3.2.2 RELIEF

As described in Section 1.3.2, relief within a given radius was calculated as the range in elevation and as the departure from the average elevation. As described in Section 3.2.1, the total range in elevation across the Area of the Five Communities is approximately 224 m. The calculation of relief at different spatial scales results in a more precise description of the topography.

A map of departures from the average elevation within a 20 km radius (Figure 8) provides definition of high and low ground within the area beyond that shown by the raw elevation map (Figure 7). For instance, the heavily entrenched aspect of the Saugeen River is more apparent in Figure 8 than Figure 7. Figure 8 also shows broad areas of topographic prominence. For example, the inset map provided on Figure 8 shows the areas that are at least 10 m higher than average at this scale of calculation.

Topographic prominence calculated at a local scale is a variable that can provide a detailed image of drumlins, moraines, raised shore bluffs, and river and creek valleys. Figure 9 shows the departure in elevation from the mean elevation calculated within a 2 km radius. Several of the surficial landforms shown on Figure 6 are labelled on Figure 9 for reference. Most of the relief shown on Figure 9 is associated with surficial landforms, not bedrock.

A map showing the range in elevation within a 250 m radius (Figure 10) provides a further indication of the location and extent of high and low relief zones within the Area of the Five Communities. The inset map in Figure 10 shows the areas with at least 15 m and 25 m of relief calculated at this scale. The Township of Huron-Kinloss is the flattest of the Communities, with the lowest maximum and mean relief calculated at this scale (Table 6). The greatest relief in the area is associated with river valleys, such as the Saugeen River, and with drumlins and ancient shore bluffs.

Table 6 Range in elevation within a 250 m radius for the Communities.

Community	Maximum (m)	Mean (m)
Municipality of Arran-Elderslie	45	11
Municipality of Brockton	60	11
Municipality of South Bruce	52	13
Township of Huron-Kinloss	43	9
Town of Saugeen Shores	55	13

3.2.3 SLOPE

Steep slopes in the Area of the Five Communities are associated with drumlins, river valleys, spillways, moraines, and raised shore bluffs (Figure 11). Areas with slopes of at least 6° are rare in this landscape, with only 3.2 % of the area covered by slopes of such magnitude.

The average slope of the Township of Huron-Kinloss is 1.3°, whereas that of the other communities ranges from 1.6 to 1.9°. This further illustrates the relative flatness of the Township of Huron-Kinloss. The relative flatness is partly associated with the presence of clay plains, sand plains and till plains over much of the Township, and the relatively small size of the rivers in that community, as compared with the bigger rivers extending through the other communities, such as the Saugeen River. Many of the flattest areas are associated with poor drainage and the presence of wetlands and small waterbodies.

4 DRAINAGE

Drainage and the distribution of surface water are important factors to consider in the preliminary assessment. Drainage is a useful indicator of groundwater flow at shallow depth and the distribution of wetlands and watercourses would need to be considered as a component of accessibility. Section 4.1 provides information on the size, distribution and depth of lakes and wetlands in the Area of the Five Communities. Section 4.2 describes the existing watershed map file, and Section 4.3 describes surface drainage within the area.

4.1 WATERBODIES AND WETLANDS

Waterbodies cover 38.7 km^2 or 0.8 % of the Area of the Five Communities. The largest lake in the Area of the Five Communities is Arran Lake, which is located in the northern part of the Municipality of Arran-Elderslie and covers an area of 3.9 km^2 (Figure 12 and Table 7). Chesley Lake is the next largest lake, located about 5 km north of the north tip of Arran Lake. The largest lakes in the other communities range from 0.04 km^2 (unnamed lake) in the Town of Saugeen Shores to 0.6 km^2 (Silver Lake) in the Township of Huron-Kinloss. Lake Rosalind (0.4 km^2) is the largest lake in the Municipality of Brockton, while McGlinn Lake (0.09 km^2) is the largest lake in the Municipality of South Bruce (Figure 12).

Table 7 Size of nine largest lakes in the Area of the Five Communities.

Lake[1]	Perimeter (km)	Area (km^2)
Clam Lake	5.1	0.4
Town Line Lake	2.7	0.4
Lakelet Lake	10.2	0.4
Lake Rosalind	6.8	0.4
McCullough Lake	6.2	0.5
Williams Lake	6.1	0.6
Silver Lake	4.7	0.6
Chesley Lake	9.7	2.1
Arran Lake	23.5	3.9

[1]Metrics obtained from LIO OHN Waterbody file

Within the map area (Figure 12), the floor of Lake Huron reaches a minimum elevation of 13 m below sea level, equivalent to a maximum depth of 189 m. Apart from Lake Huron, there is little information on the depths of other lakes within the area. The MNR completed depth surveys of selected lakes in the late 1960s and early 1970s. The resulting bathymetry maps consist of contour plots based on soundings, with summary information in the map margin, such as maximum and mean depth. The greatest known lake depth is 19.8 m, which was measured in Silver Lake (Table 8).

Table 8 Maximum and mean depths of lakes within the Area of the Five Communities.

Lake[1]	Area (km^2)	Max depth (m)	Mean depth (m)
McCullough Lake	0.5	16.5	5.9
Silver Lake	0.6	19.8	7.3

[1]Area from LIO OHN Waterbody file; depth values from MNR depth maps

Wetlands depicted on Figure 12 are from the Wetland Unit map file produced by the MNR. The smaller wetlands are generally clustered into lines following property boundaries. Provincially significant wetlands are those areas identified by the province as being the most valuable, as determined by a science-based ranking system known as the Ontario Wetland Evaluation System (Glooschenko, 1983). Some of the larger provincially significant wetland complexes in the Area of the Five Communities include the Greenock Swamp Wetland Complex and the MacGregors Point Wetland Complex, which cover parts of the Municipality of Brockton and Town of Saugeen Shores, respectively (Figure 12). The Greenock Swamp Wetland Complex is the largest forested wetland in southern Ontario. There is also a large provincially significant wetland complex surrounding Arran Lake, the Arran Lake Wetland Complex, located within the northern part of the Municipality of Arran-Elderslie. Many of the wetland complexes are situated in topographic lows between drumlins or in glacial spillways.

In total, wetlands cover 671.8 km^2 (14.3 %) of the Area of the Five Communities, while wooded areas cover 1,182.4 km^2 (25.2 %). Note that there is significant overlap between the areas mapped as wetland and those mapped as forest, as shown in the inset maps of Figure 12. Table 9 summarizes the extent of wetlands and forest cover within the Communities. The Municipality of Brockton contains the largest areas covered by either wetland or forest, which is largely due to the presence of the Greenock Swamp Wetland Complex. The Township of Huron-Kinloss contains the lowest percentage of area covered by forest and a low percentage of wetland cover.

Table 9 Extent of wetlands and forest cover in the Communities.

Community	Extent of wetlands		Extent of forest	
	km^2	%	km^2	%
Municipality of Arran-Elderslie	50	10.7	80	17.1
Municipality of Brockton	121	21.3	163	28.5
Municipality of South Bruce	77	15.8	112	23.0
Township of Huron-Kinloss	44	9.8	66	15.0
Town of Saugeen Shores	16	9.2	45	26.3

4.2 WATERSHEDS

A watershed, also known as a catchment, basin or drainage area, includes all of the land drained by a watercourse and its tributaries. The best available watershed delineation for the Area of the Five Communities is the quaternary watershed file produced by the MNR (Figure 13). The delineation of drainage divides can be useful for determining drainage directions and contributing to an initial understanding of the shallow groundwater flow system.

According to the metadata for the MNR quaternary watershed file, a quaternary watershed is a polygon feature that identifies a subdivision of a tertiary watershed (MNR tertiary watersheds are generally equivalent to the sub-sub-division of drainage areas produced by the Water Survey of Canada). The boundaries of the quaternary watersheds were created based on the Provincial DEM and Enhanced Flow Direction products released between 2006 and 2008. The watershed boundaries are generally consistent with the regional hydrology available for Ontario. The horizontal positional accuracy of the quaternary watershed boundaries is variable depending on the nature and spatial distribution of the raw DEM information, and thus cannot be quantified without on-site investigation and verification. In general, positional accuracy in southern Ontario is within 100 m, but there is no statistical level of confidence available.

4.3 SURFACE FLOW

The Area of the Five Communities is contained entirely within the Great Lakes - St. Lawrence primary watershed, which drains towards the Atlantic Ocean through the St. Lawrence River. The Great Lakes - St. Lawrence watershed covers parts of the provinces of Ontario and Quebec, and the states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Vermont and Wisconsin. The main rivers draining the Area of the Five Communities flow towards Georgian Bay in the north or Lake Huron to the west. Watersheds and surface water flow directions for the area are shown on Figure 13.

4.3.1 GEORGIAN BAY DRAINAGE

The Pottawatami and Sydenham rivers are the larger rivers in the portion of the Southwest Georgian Bay tertiary watershed within the Area of the Five Communities (Figure 13). The Bighead River also drains a portion of this watershed in the northeast corner of the Area of the Five Communities, but this river is mostly located northeast of the area.

The Pottawatami and Sydenham rivers empty into Owen Sound, draining areas of 213 and 112 km^2, respectively (Figure 13), parts of which are outside of the Area of the Five Communities. Much of the drainage areas are rocky or swampy with much forest cover. The incision of deep valleys by these rivers has been prevented by the presence of bedrock near the surface, which has resulted in numerous swamps in the watershed (Figure 12).

4.3.2 LAKE HURON DRAINAGE

Surface flow over the vast majority of the Area of the Five Communities is directed to the west towards Lake Huron (Figure 13). Much of the flow into Lake Huron is associated with the Saugeen and Penetangore watersheds, and to a lesser extent by the Maitland and Bruce Peninsula watersheds.

The Bruce Peninsula tertiary watershed drains an area of about 2,115 km^2, most of which is located north of the Area of the Five Communities. The northern part of the Municipality of Arran-Elderslie is within this watershed. The primary drainage feature is the Sauble River. The actual drainage area is difficult to estimate due to the presence of disappearing streams on the Bruce Peninsula.

The Saugeen tertiary watershed drains an area of 4,025 km^2 (Figure 13), part of which extends east of the Area of the Five Communities. Parts of the Town of Saugeen Shores and the Municipality of Arran-Elderslie are contained within this watershed. The municipalities of Brockton and South Bruce are almost entirely contained within the Saugeen tertiary watershed. The primary drainage feature is the Saugeen River with its main tributaries being the Teeswater, South Saugeen, Beatty Saugeen, Rocky Saugeen and North Saugeen rivers. The Teeswater drains the Greenock Swamp Wetland Complex, which results in a uniform summer flow. Upstream of Walkerton, the branches of the Saugeen River flow in old spillways associated with the Horseshoe moraines (Section 3.1.1). At Walkerton, the Saugeen changes its course northward through the Walkerton Moraine (Figure 6) extending across a sand plain formed as a delta in glacial Lake Warren. In this area, the river meanders widely, shifting its course occasionally. The watershed is considerably dissected between Walkerton and Paisley due to the erodible sands in this area.

Most of the Township of Huron-Kinloss is contained within the Penetangore tertiary watershed, a watershed that drains an area of 1,235 km^2, part of which is located south of the Area of the Five Communities. Streams draining the east shore of Lake Huron within the Penetangore watershed include the Penetangore, North Penetangore, Pine and South Pine rivers, Eighteen Mile River and Nine Mile River (Figure 13).

The Maitland tertiary watershed covers an area of 2,646 km^2 (Figure 13) and is located along the southern margin of the Area of the Five Communities. The primary drainage feature is the Maitland River, which empties into Lake Huron at Goderich (located 14 km south of the area). The Maitland River extends through Harrison and Wingham before flowing south of the Area of the Five Communities.

5 SURFICIAL DEPOSITS

Overburden deposits are generally thick in southern Ontario, with common values of 30 to 60 m and thicknesses that can exceed 200 m (Karrow, 1989). The surficial deposits in the Area of the Five Communities have been mapped at the scale of 1:50,000 by Cowan (1977), Cowan et al. (1986), Cowan and Pinch (1986), Feenstra (1994), Sharpe and Broster (1977), Sharpe and Edwards (1979) and Sharpe and Jamieson (1982). The Ontario Geological Survey has compiled these maps into a seamless surficial geology map (OGS, 2010), which was used to generate the surficial deposit map shown on Figure 5. A map showing surficial landforms, such as moraines, raised beaches and drumlins, is presented on Figure 6 based on the work of Chapman and Putnam (2007). Section 2.2 introduced the surficial deposits and landforms in the Area of the Five Communities and placed these features into the context of the Late Wisconsinan ice advances and the main glacial and postglacial lakes. This section provides more detail on overburden thickness in the Area of the Five Communities, including a brief description of buried valley complexes, and it provides more detail on the distribution of surficial deposits within each of the Communities.

5.1 DRIFT THICKNESS

Gao et al. (2006) compiled data from approximately 253,000 data points (including outcrop mapping, oil and gas well records, geotechnical drill records and 180,000 domestic water wells records) to establish the depth to the top of the bedrock surface. Drift thickness in the Area of the Five Communities ranges from zero up to about 104 m (Figure 14), with an average thickness of approximately 30 m. The Municipality of South Bruce contains the thinnest drift, with an average thickness of 20 m, whereas the other communities average between 33 and 50 m (Section 5.2). The thickest drift in the area is associated with buried bedrock lows such as troughs and valleys, some of which are outlined on Figure 14.

The broadest of the buried bedrock lows in the Area of the Five Communities is the Walkerton trough, extending from Southampton to Hanover (Figure 14). The Onondaga Escarpment bounds the Walkerton trough to the south (Gao, 2011), with a complex of re-entrant valleys extending into the escarpment near Walkerton (Figure 14). Wingham marks the junction of two buried valleys: the Wingham valley extending from the east, and the Hutton Heights valley extending from the south. The other buried valleys highlighted by Gao (2011) in this area are a north-trending unnamed valley east of Teeswater and a valley extending north from Silver Lake (Figure 14). Drift thickness generally exceeds 60 m within these buried valley structures.

5.2 SURFICIAL DEPOSITS WITHIN THE AREA OF THE FIVE COMMUNITIES

Table 10 provides a summary in percentages of the areal extent of the different surficial deposits mapped within the Area of the Five Communities and within each of the Communities (Figure 5). The percentages presented in Table 10 were queried from the digital surficial geology map (OGS, 2010).

Morainal deposits (Table 10, 'M') occur extensively throughout the Area of the Five Communities (Figure 5), covering about 46 % of area. Morainal deposits exposed at the surface in this area have been classified into four main till formations, as shown on Figure 5 (inset A). The Elma Till is the most abundant till, mapped over 23 % of the area. The St. Joseph Till is the next most common till formation, covering 20 % of the area. The Dunkeld and Rannoch tills each cover about 1 % of the area. These morainal deposits generally have low to low-medium permeability, as shown on Figure 5 (inset B), with the relatively high sand content of the Elma Till resulting in a slightly higher permeability rating than the other three till formations ('low-medium' rather than 'low'). Many of the locations where Elma Till is exposed at the surface (Figure 5, inset A) are the areas of thinnest drift cover as shown on Figure 14 (inset). In fact, the average overburden thickness where Elma Till is mapped within the Area of the Five Communities is 21 m, whereas it is 44 m in areas where St. Joseph Till is mapped, and about 32 m for the other two till formations. The high carbonate content and many stones and boulders in the Elma Till are indicative of having been derived from the underlying rock formations, whereas the other till formations in the area were derived from underlying glaciolacustrine deposits.

Glaciofluvial deposits (Table 10, 'GF') consisting primarily of sand or sand and gravel are exposed over 21.2 % of the Area of the Five Communities (Figure 5). Glaciofluvial deposits associated with moraines and eskers have been classified as ice-contact deposits on Figure 5, while deposits associated with channel fill, outwash plain and deltaic topset facies have been classified as outwash. The high permeability of glaciofluvial deposits in this area (Figure 5, inset B) results in them being important surficial recharge zones for groundwater.

Table 10 Extent of surficial deposits based on primary genesis of deposit.

	Primary genesis[1] (expressed as % area)								
	C	**AE**	**F**	**M**	**GF**	**GL**	**L**	**O**	**R**
Municipality of Arran-Elderslie	0.0	0.0	3.2	45.6	8.2	39.4	0.0	3.4	0.1
Municipality of Brockton	0.0	0.0	6.3	20.3	14.1	54.5	0.0	4.7	0.2
Municipality of South Bruce	0.0	0.0	4.9	35.9	44.6	9.7	0.0	4.6	0.3
Township of Huron-Kinloss	0.0	0.0	5.0	63.5	18.0	9.9	1.3	2.3	0.0
Town of Saugeen Shores	1.4	0.6	8.2	26.7	0.7	61.9	0.5	0.0	0.0
Area of the Five Communities	0.1	0.0	3.8	45.6	21.2	23.7	0.2	4.4	1.0

[1]C = colluvium; AE = Aeolian; F = Fluvial; M = Morainal; GF = Glaciofluvial; GL = Glaciolacustrine; L = Lacustrine; O = Organic; R = Bedrock

Glaciolacustrine deposits are exposed over 23.7 % of the Area of the Five Communities, with about 58 % of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 42 % as coarse-grained deposits of sand or sand and gravel. The largest fine-grained glaciolacustrine deposit mapped in the area (Figure 5) is represented by the Saugeen clay plain (Figure 6, inset A), located north of Walkerton, which Sharpe and Edwards (1979) describe as a thick deposit of massive to faintly laminated clay. Two of the larger coarse-grained glaciolacustrine deposits in the area are located beneath the Greenock Swamp Wetland Complex (Figure 12) and near Port Elgin. However, a test hole in the centre of the Greenock Swamp Wetland Complex revealed 26 m of primarily weakly laminated silts and rhythmically bedded silts and clays before penetrating coarse sand under considerable hydraulic pressure (Cowan and Pinch, 1986). Despite the large subsurface thickness of silts and clays, this deposit is mapped on Figure 5 as coarse-grained glaciolacustrine sediments merely due to the presence of fine sands at the top of the sequence. The offshore deposits mapped near Port Elgin dominantly represent deposits of glacial Lake Algonquin and consist mainly of well-sorted sand several metres thick (Sharpe and Edwards, 1979). Littoral and foreshore deposits are composed of sand and gravel, and are represented by features such as beaches, bars and spits located in the western part of the area.

Other surficial deposits in the Area of the Five Communities include colluvial, aeolian, fluvial, lacustrine and organic deposits (Figure 5). Fluvial deposits, make up 3.8 % of the area, and are represented by the modern and abandoned floodplains of the major rivers and creeks in the area. These deposits are primarily composed of silt, sand and gravel. Lacustrine deposits of sand and gravel consisting of beaches, bars and spits have been mapped along the shores of Lake Huron and Georgian Bay, covering only 0.2 % of the area. Organic deposits of peat and muck have been mapped over 4.4 % of the area, with many of the deposits located within spillways and other topographic lows within till plains or on rocky plains of the Bruce Peninsula in the northeast margin of the area. Mapped colluvial deposits are primarily associated with the Algonquin bluff (Figure 6). Aeolian deposits cover a very small portion of the Area of the Five Communities and are located near Port Elgin and Southampton.

Areas of exposed bedrock or thin drift with sporadic bedrock exposures make up only 1.0 % of the area (Figure 5). Fine-grained dolostone and interbedded limestone of the Lucas Formation is exposed along the Lake Huron shoreline at Douglas Point (Sharpe and Edwards, 1979), representing one of the larger exposures of bedrock in the area. The other major exposure of bedrock in the area is located south and west of Owen Sound (Figure 3).

Table 11 presents a summary of the permeability of the various surficial deposits mapped within the Area of the Five Communities and within each of the Communities. These permeabilities were derived from the surficial geology map (OGS, 2010) based on the primary texture of the sediments. A permeability map is presented on Figure 5 (inset B).

Table 11 Texture-derived permeability of surficial deposits.

	Texture-derived permeability[1] (expressed as % of area)				
	Low	Low-medium	Medium-high	High	Variable
Municipality of Arran-Elderslie	45.9	32.2	0.0	18.5	3.4
Municipality of Brockton	43.5	7.2	0.0	42.9	6.4
Municipality of South Bruce	5.4	33.9	0.0	55.5	5.2
Township of Huron-Kinloss	67.4	0.0	0.0	27.6	5.0
Town of Saugeen Shores	42.3	8.3	0.6	39.3	9.6
Area of the Five Communities	36.4	23.0	0.0	35.7	4.8

[1]Permeability based on OGS (2010)

5.3 SURFICIAL DEPOSITS WITHIN THE COMMUNITIES

5.3.1 MUNICIPALITY OF ARRAN-ELDERSLIE

Drift thickness in the Municipality of Arran-Elderslie ranges from zero to 89 m, with an average of 37 m and the thickest drift occurs in the western part of the community in association with the Walkerton trough (Figure 14). The thinnest drift occurs along the eastern margin of the community between Tara and Chesley.

The Arran drumlin field extends over the northern half of the community (Figure 6, inset A), where patchy deposits of glaciolacustrine clay up to 5 m thick occur between drumlins (Sharpe and Edwards, 1979; Figure 5). Several east-west trending recessional moraines near Tara record the intermittent retreat of the ice lobe from this area (Figure 6). The till in this area (Elma Till) rests on bedrock, as indicated by boreholes and field observations (Sharpe and Edwards, 1979). The Williscroft Moraine (Figure 6) defines the southern margin of the drumlin field.

The Saugeen clay plain covers the southern half of the community (Figure 6, inset A). The clay plain represents a deep stratified glaciolacustrine clay deposit formed in a bay of glacial Lake Warren. The Saugeen, North Saugeen and Teeswater rivers have cut deep valleys into the clay deposits. Raised beach deposits of sand and gravel can be found locally along the Williscroft and Banks moraines but are generally poorly formed in this area (Sharpe and Edwards, 1979).

The surficial deposits in the northern half of the community are generally of higher permeability than those in the southern half (Figure 5, inset B). The fine-grained glaciolacustrine deposits and clayey silt textured St. Joseph Till found in the southern half of the community have low permeability. In the north, the sandy silt textured Elma Till has a low-medium permeability and the ice-contact and coarse-grained glaciolacustrine deposits have high permeabilities (Figure 5).

Exposed bedrock is mapped in 0.1 % of the community, some of which is found on the bed and banks of the Sauble River.

5.3.2 MUNICIPALITY OF BROCKTON

Drift thickness in the Municipality of Brockton ranges from zero to 104 m, with an average of 33 m, and the thickest drift occurs in the east and west margins of the community in association with buried bedrock valleys (Figure 14). The Walkerton trough and Onondaga Escarpment extend through the eastern half of the community, with several small re-entrant valleys extending southward into the escarpment near Hanover and Walkerton.

The Walkerton Moraine extends through the central part of the community, forming a boundary between the Saugeen clay plain and Horseshoe moraines physiographic units (Figure 6, inset A) to the north and south, respectively. The Walkerton Moraine was formed by a north-south re-advance over glaciolacustrine sediments deposited in the Saugeen basin in front of the Georgian Bay ice lobe. As a result, the Dunkeld Till forming the moraine is a silt till comprising reconstituted glaciolacustrine silt for the most part (Cowan and Pinch, 1986). Ice-contact deposits of sand with local pockets of gravel occur along the Walkerton Moraine (Cowan and Pinch, 1986), as shown on Figure 5.

The northern part of the community is dominated by the Saugeen clay plain (Figure 6, inset A). The area contains a deep stratified glaciolacustrine silt and clay deposit that is dissected by the

Saugeen and Teeswater rivers (Figure 5). Glaciolacustrine deposits that occur extensively along the Saugeen River in this area, and in small patches elsewhere within the clay plain, are composed of sands.

South of the Walkerton Moraine, surface materials are dominated by glaciolacustrine deposits in the southwest and southeast corners of the community (Figure 5), with Elma Till exposed in the south-central part of the community. The Greenock Swamp Wetland Complex covers the western portion of the community. The swamp is formed over a sequence of silts and clays at least 25 m thick with sand and some silt near the top of the sequence (Cowan and Pinch, 1986).

Fluvial deposits are associated with the floodplains of the Saugeen and Teeswater rivers and their tributaries. Fluvial deposits forming terraces above the modern stream flood levels dominantly represent sand and gravel (Cowan and Pinch, 1986). Higher-level terraces have been mapped as glaciofluvial outwash (Figure 5).

The fine-grained glaciolacustrine deposits forming the Saugeen clay plain and the Dunkeld Till forming the Walkerton Moraine have been rated as having low permeability (Figure 5). Surface deposits of high permeability have been mapped throughout the community.

Exposed bedrock is mapped in 0.2 % of the community, nearly all of which is found on the beds and banks of rivers, such as the Saugeen River.

5.3.3 MUNICIPALITY OF SOUTH BRUCE

Drift thickness in the Municipality of South Bruce ranges from zero to 73 m, with an average of 20 m, and the thickest drift occurs along the western boundary and in the northeast corner of the community in association with buried bedrock valleys (Figure 14).

Glaciofluvial deposits are abundant in this community. Ice-contact stratified drift occurs dominantly in association with the Wawanosh and Singhampton moraines (Figure 5), which extend through the western and eastern margins of the community, respectively (Figure 6). The Wawanosh Moraine is an interlobate ice-contact delta composed dominantly of fine sand with lesser amounts of gravel, silt and clay (Cowan et al., 1986). The Singhampton Moraine in this community is represented by a broad north-south trending zone of ice stagnation deposits (Figure 5) consisting dominantly of sand (Cowan et al., 1986). Outwash sand and gravel occurs extensively along meltwater channels and as sheet deposits fronting the Wawanosh and Singhampton moraines (Figure 5). The outwash occurs in the form of terrace and fill deposits related to a network of channels that are particularly well developed between Teeswater and Mildmay.

Elma Till is the dominant surface till exposed in the community, with lesser amounts of Dunkeld and Rannoch tills exposed locally (Figure 5, inset A). Elma Till occurs as ground moraine, fluted ground moraine and drumlins in this area (Cowan et al., 1986).

Glaciolacustrine deposits are scarce in this community, distributed in small patches over less than 10 % of the area (Figure 5; Table 10). Organic deposits are found in patches throughout the community, covering less than 5 % of the area (Table 10), with a notable concentration of deposits in the northwest corner of the community (Figure 5). The organic deposits consist of peat and muck 1 to 3 m thick (Cowan et al., 1986). Bedrock is exposed locally within river and creek beds, such as along the Teeswater River.

This community contains the highest percentages of low-medium and high permeability surface deposits of the Communities (Figure 5, inset B; Table 11). This is mainly due to the abundance of glaciofluvial deposits and Elma Till and to the lack of fine-grained glaciolacustrine deposits or silt-dominated till formations.

5.3.4 TOWNSHIP OF HURON-KINLOSS

Drift thickness in the Township of Huron-Kinloss ranges from 9 to 91 m, with an average of 39 m, and the thickest drift occurs in the western margin of the community near the Lake Huron shoreline (Figure 14). Another area of thick drift is located in the northern tip of the community near Silver Lake in association with a buried bedrock valley (Figure 14).

The Township of Huron-Kinloss contains the greatest proportion of morainal deposits and one of the smallest proportions of glaciolacustrine deposits of the Communities (Figure 5; Table 10). The morainal sediments are represented by an extensive plain of St. Joseph Till interrupted by a narrow strip of sand and the twin beaches of glacial Lake Warren. The till sheet is formed of brown calcareous clay and is generally only 2 to 3 m thick and rests on stratified clay of the same colour (Chapman and Putnam, 2007). The St. Joseph Till also forms the Wyoming Moraine.

The Wawanosh Moraine (Figure 6) represents the main area mapped as glaciofluvial sediment in this community. The Wawanosh Moraine is composed dominantly of fine sand with lesser amounts of gravel, silt and clay (Cowan et al., 1986). Outwash sand and gravel occurs extensively as sheet deposits fronting the Wawanosh Moraine (Figure 5).

The permeability of surface deposits in this community is low over the western two thirds of the area due to the clayey silt texture of the St. Joseph Till, and permeability is high in the eastern third in association with the Wawanosh Moraine (Figure 5, inset B).

5.3.5 TOWN OF SAUGEEN SHORES

Drift thickness in the Town of Saugeen Shores ranges from 2 to 86 m, with an average of 50 m, and the thickest drift is associated with the Walkerton trough, which extends through the northern half of the community (Figure 14). This community has the highest average overburden thickness of any of the Communities.

Glaciolacustrine sediments are the most common surface deposit type mapped in this community (Figure 5; Table 10). A massive glacial Lake Algonquin beach (or spit) was built across the Saugeen River a short distance inland of Port Elgin (Figure 6). This feature is composed of gravels up to 10 m thick (Sharpe and Edwards, 1979). Fine-grained glaciolacustrine sediments can be found above this Algonquin beach (Figure 6). Below the Algonquin beach, delta sands extend from the beach down to a distinct bluff about 800 m from the present shore, below which gravel bars built by glacial Lake Nipissing rib the terrace surface (Chapman and Putnam, 2007).

Most of the till exposed in the area is St. Joseph Till, with Elma Till exposed locally. The surface materials exposed below the Algonquin beach in this community are dominantly of high permeability, whereas those exposed above this beach are of low permeability (Figure 5, inset B).

6 GROUNDWATER

A detailed discussion of the hydrogeology of the Area of the Five Communities is provided by Geofirma Engineering Ltd. (2014). Only a brief summary of the shallow groundwater regime including overburden and shallow bedrock aquifers and aquitards, recharge and discharge conditions and local and regional groundwater flows based on available information and terrain characteristics is provided here.

The shallow groundwater regime includes overburden aquifers and shallow bedrock aquifers that typically extend to depths of less than 60 m and provide drinking water supplies to both municipalities and residences (Waterloo Hydrogeologic Inc., 2003). Groundwater flow directions within shallow systems often mimic surface water flow directions with the groundwater table generally present as a subdued reflection of topography. Shallow groundwater flow will be directed from areas of higher hydraulic head, such as highlands and drainage divides, to areas of lower hydraulic head such as valleys, depressions, and surface waters. The extent of such shallow flow systems will be defined by local, topography-controlled, drainage divides across which groundwater flow will not readily occur. Generally, for such shallow systems groundwater divides will coincide with surface water drainage divides.

Information on the shallow overburden and bedrock groundwater flow systems within the Area of the Five Communities is provided in the Provincial Source Water Protection Assessment Reports (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region, 2011a; 2011b). Information on surficial deposits (Figure 5) and landforms (Figure 6), and subsurface overburden and bedrock occurrence from MOE water well records have been compiled and interpreted in these studies to broadly map the spatial distribution of overburden aquifers and aquitards within the Area of the Five Communities. This information has been compiled and incorporated into watershed-scale, calibrated 3-D groundwater flow models for the purposes of addressing Provincial Source Water Protection needs (Waterloo Hydrogeologic Inc., 2003). The available hydrogeologic information for the overburden system is often limited compared to that for the shallow bedrock due to the preference for drillers to access the shallow bedrock as a reliable aquifer for water supply (Waterloo Hydrogeologic Inc., 2003).

Figure 5 shows that the major glacial overburden deposits in the Area of the Five Communities predominantly include a widespread low permeability morainal till which is locally overlain by more permeable glaciofluvial deposits and less permeable glaciolacustrine deposits (Waterloo

Hydrogeologic Inc., 2003). The more permeable glaciofluvial deposits which are exposed at surface in the southeastern part of the Township of Huron-Kinloss, throughout large parts of the Municipality of South Bruce and sporadically within the municipalities of Brockton and Arran-Elderslie, often form unconfined shallow overburden aquifers. These shallow variable thickness aquifers are locally important sources of drinking water and are essential for their contribution to surface waters and ultimately recharge to the shallow bedrock aquifers.

Contour maps of the groundwater table surface within the shallow bedrock aquifers of the Area of the Five Communities have been prepared in the Provincial Source Water Protection Assessment Reports based on the large number of water wells that access the shallow bedrock for water supply. These potentiometric surface maps show that shallow bedrock groundwater within the municipalities of Brockton and South Bruce, the Town of Saugeen Shores and the southwest portion of the Municipality of Arran-Elderslie flows broadly to the northwest from the highland areas along the eastern edge of the area (Figure 7) towards Lake Huron, similar to surface water flow within the Saugeen watershed (Figure 13). Within the Township of Huron-Kinloss, shallow groundwater flows northwest and southwest toward Lake Huron similar to surface water flow within the Penetangore watershed. In the northeast half of the Municipality of Arran-Elderslie, shallow groundwater flows north and northwest towards Lake Huron, similar to surface water flow in the Bruce Peninsula watershed.

Local and regional distortions of these general shallow groundwater flow patterns that are developed assuming relatively homogeneous hydraulic properties will occur where there are major changes in the spatial distribution of permeable overburden and shallow bedrock units. An important regional shallow groundwater flow distortion, noted within the Saugeen Valley Source Protection Area Assessment Report (2011b), occurs where the Salina Formation subcrops in bedrock valleys below the Saugeen River within the municipalities of Brockton and Arran-Elderslie and the Town of Saugeen Shores from Walkerton to Southampton (Figures 4 and 14). This area of buried bedrock valleys is referred to as the Walkerton trough (Gao, 2011). In these areas, the glacially eroded Salina Group has led to the development of large bedrock valleys that are infilled with permeable coarse sands and gravels that preferentially concentrate groundwater flow from the surrounding shallow bedrock into the bedrock valleys and eventually upward into the Saugeen River and Lake Huron (Waterloo Hydrogeologic Inc., 2003; Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region, 2011b).

7 NEOTECTONIC FEATURES

The Area of the Five Communities is located in a tectonically stable zone with no active fault zones (Slattery, 2011). High horizontal stresses are present in the bedrock in southern Ontario as indicated by features such as elongated compressional ridges or pop-up structures (White et al., 1973; White and Russell, 1982; Gorrell, 1988), and faulted and striated bedrock surfaces (Gorrell, 1988; Barnett and Kelley, 1987). Two main theories are used to explain the occurrence of stress-release features: 1) a response to glacial unloading (Adams, 1988), and 2) regional tectonic forces (White and Russell, 1982).

Knowledge of the history of seismic activity associated with glacial unloading or regional tectonic forces can be acquired through field investigations, such as studies of seismically induced deformation of liquefaction-prone sediments and seismically induced landforms such as sand volcanoes, lateral spreads or offset landforms. For example, paleoliquefaction studies have been used to estimate the timing and magnitude of Holocene-age earthquakes (Obermeier, 1996).

Work by Slattery (2011) represents the best available neotectonic investigation completed within the Area of the Five Communities. The study used desktop and field-based methods to search for evidence of paleoseismicity within Quaternary deposits within 50 km of the Bruce nuclear site. The investigation involved reviewing existing information sources (e.g., papers, reports, maps, etc.), interpreting air photos and a LiDAR digital elevation model, and searching for liquefaction structures displayed in sediment exposures in the field. No conclusive geomorphological or sedimentological evidence of neotectonic activity was found in the area.

No additional neotectonic features have been identified during the current desktop study using the available remote sensing data.

8 ACCESSIBILITY CONSTRAINTS

The Area of the Five Communities contains a dense network of highways, local roads and other roads (Figure 15). The main roads shown on all figures in this report represent the paved arterial roads and highways of the Ontario Road Network (ORN). The ORN represents the authoritative source of roads data for Ontario. Local roads shown on Figure 15 represent all roads other than the main roads, including streets, resource roads, collectors, and other service roads. As shown on this figure, the density of roads in the Area of the Five Communities is high and is generally uniform excepting some local areas of lower density.

The main accessibility constraints in the area represent areas of wet and swampy ground (or wetlands), areas of relatively high relief associated with river valleys, and areas of higher relief associated with drumlins, raised shore bluffs, and moraines. One of the larger areas devoid of existing roads is the Greenock Swamp Wetland Complex, located on the western side of the Municipality of Brockton (Figure 12). Other less accessible areas include the area around Arran Lake and the Arran Lake Wetland Complex in the Municipality of Arran-Elderslie.

Apart from the local areas of swampy ground or high relief associated with river valleys, the minimum distance to the nearest road is generally in the order of 275 to 375 m in the Communities.

9 SUMMARY

This report presents an assessment of the terrain in a 87.1 km by 76.7 km region around the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Area of the Five Communities) using available remote sensing and geoscientific information sources. This terrain assessment does not include the portion of the Area of the Five Communities covered by Lake Huron. The main information sources relied on in this study are the 1:50,000 scale surficial mapping by the OGS (2010), the physiographic information from Chapman and Putnam (2007), the OGS drift thickness data (Gao et al., 2006), and the CDED elevation model (GeoBase, 2013). Additional information sources included several files on drainage features, lake depths, and roads obtained from Land Information Ontario (LIO).

Quaternary glaciations have played a major role in shaping and creating the landscape of the Area of the Five Communities. Surficial landforms and associated sediments within the area were deposited during the Late Wisconsinan by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet 23,000 to 10,000 years ago. Exposures of older deposits are rare as they are mostly buried beneath the Late Wisconsinan sediments and can only be seen in such places as riverbank exposures, lake bluffs or man-made exposures in quarries and pits.

The thickness and distribution of the various surficial deposits and associated physiographic units were reviewed for each of the Communities. The overburden is generally thick in the Area of the Five Communities, with values as high as 104 m and an average value of about 30 m. The thickest drift is associated with buried bedrock valleys and troughs, such as the Walkerton trough, which extends from Southampton to Hanover (Gao, 2011). Drift thickness generally exceeds 60 m within these buried valley structures. The Municipality of South Bruce contains the thinnest drift, with an average thickness of 20 m, whereas the other communities average between 33 and 50 m (Section 5.2).

Morainal deposits occur extensively throughout the area and are exposed at the surface over about 46 % of the Area of the Five Communities. Morainal deposits exposed at the surface in this area have been classified into four main till formations. The Elma Till is the most abundant till in the area, mapped over 23 % of the area. The St. Joseph Till is the next most common till formation, covering 20 % of the area. The Dunkeld and Rannoch tills each cover about 1 % of the area. These morainal deposits generally have low to low-medium permeability, with the relatively high sand content of the Elma Till resulting in a slightly higher permeability rating than the other three till formations.

Glaciofluvial deposits consisting primarily of sand or sand and gravel are exposed over 21.2 % of the Area of the Five Communities. Glaciofluvial deposits associated with moraines and eskers have been classified as ice-contact deposits, while deposits associated with channel fill, outwash plain and deltaic topset facies have been classified as outwash. Glaciolacustrine deposits are exposed over 23.7 % of the area, with about 58 % of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 42 % as coarse-grained deposits of sand or sand and gravel. The high permeability of glaciofluvial deposits and coarse-grained glaciolacustrine deposits results in them being important surficial recharge zones for groundwater.

The large-scale pattern of elevation across the Area of the Five Communities controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from east to west (Lake Huron) is from 400 to 176 m, with this elevation drop occurring over an approximate 70 km lateral distance. The municipalities of Arran-Elderslie, Brockton and South Bruce are located inland of Lake Huron, with minimum elevations ranging from 180 to 249 m. The Municipality of South Bruce has the highest elevation of the Communities. Due to its high elevation, this municipality was the only one of the Communities to be above the elevation of glacial Lake Warren.

Relief within a given radius was calculated as the range in elevation and as the departure from the average elevation. Elevation departures calculated within a 2 km radius provided a detailed image of drumlins, moraines, raised shore bluffs, and river and creek valleys. A map showing the range in elevation within a 250 m radius further defined the location and extent of high and low relief zones within the Area of the Five Communities. The greatest relief in the area is associated with river valleys, such as the Saugeen River, and with drumlins and ancient shore bluffs. The Township of Huron-Kinloss is the flattest of the Communities, with the lowest maximum and mean relief calculated at this scale.

Apart from Lake Huron, the Area of the Five Communities contains no large lakes, with Arran Lake (3.9 km^2) representing the largest lake and with waterbodies covering 38.7 km^2 or 0.8 % of the area. The bottom of Lake Huron reaches a maximum depth of 189 m within the map area. Apart from Lake Huron, there is little information on lake depths within the area, and the greatest known lake depth is 19.8 m (Silver Lake). Some of the larger provincially significant wetland complexes in the Area of the Five Communities include the Greenock Swamp Wetland Complex and the MacGregors Point Wetland Complex, which cover parts of the Municipality of Brockton and the Town of Saugeen Shores, respectively. The Greenock Swamp Wetland Complex is the largest forested wetland in southern Ontario. In total, wetlands cover 671.8 km^2 or 14.3 % of the Area of the Five Communities. The Municipality of Brockton contains the largest areas covered by either wetland or forest, which is largely due to the presence of the Greenock Swamp Wetland Complex. The Township of Huron-Kinloss contains the lowest percentage of area covered by forest and a low percentage of wetland cover.

Surface flow within the drainage basins delineated in the provincial quaternary watershed file produced by the Ministry of Natural Resources was described. All of the surface flow within the Area of the Five Communities is contained within the Great Lakes - St. Lawrence primary watershed, which drains toward the Atlantic Ocean through the St. Lawrence River. The main rivers draining the area flow north toward Georgian Bay and west toward Lake Huron. Surface flow over the vast majority of the Area of the Five Communities is directed to the west through the Saugeen River and through several rivers in the Penetangore watershed.

A brief summary was provided of the shallow groundwater regime including overburden and shallow bedrock aquifers and aquitards, recharge and discharge conditions and local and regional groundwater flows based on available information and terrain characteristics. The shallow groundwater regime includes overburden aquifers and shallow bedrock aquifers that typically extend to depths of less than 60 m and provide drinking water supplies to both municipalities and residences. Groundwater flow directions within shallow systems often mimic surface water flow directions with the groundwater table generally present as a subdued reflection of topography. Till deposits are exposed over about half of the Area of the Five Communities and represent deposits of low permeability. Glaciofluvial deposits and coarse-grained glaciolacustrine deposits have high permeabilities and these deposits are exposed over about a third of the Area of the Five Communities, often forming unconfined shallow overburden aquifers that are locally important sources of drinking water.

Although the Area of the Five Communities is located in a tectonically stable zone with no active fault zones, high horizontal stresses are present in the bedrock in southern Ontario, as indicated by features such as elongated compressional ridges or pop-up structures and faulted and striated bedrock surfaces. A previous neotectonic study conducted in the area used desktop and field-based methods to search for evidence of paleoseismicity in Quaternary deposits within 50 km of the Bruce nuclear site. No conclusive geomorphological or sedimentological evidence of neotectonic activity was found in the area. No additional neotectonic features could be identified using the information available in the current terrain study.

The Area of the Five Communities contains a dense network of highways, local roads and other roads that could be used to gain access for site characterization. The main accessibility constraints in the area represent areas of wet and swampy ground, and areas of high relief associated with river valleys, drumlins, raised shore bluffs and moraines. One of the larger areas devoid of existing roads is the Greenock Swamp Wetland Complex, located on the western side of the Municipality of Brockton.

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REPORT SIGNATURE PAGE

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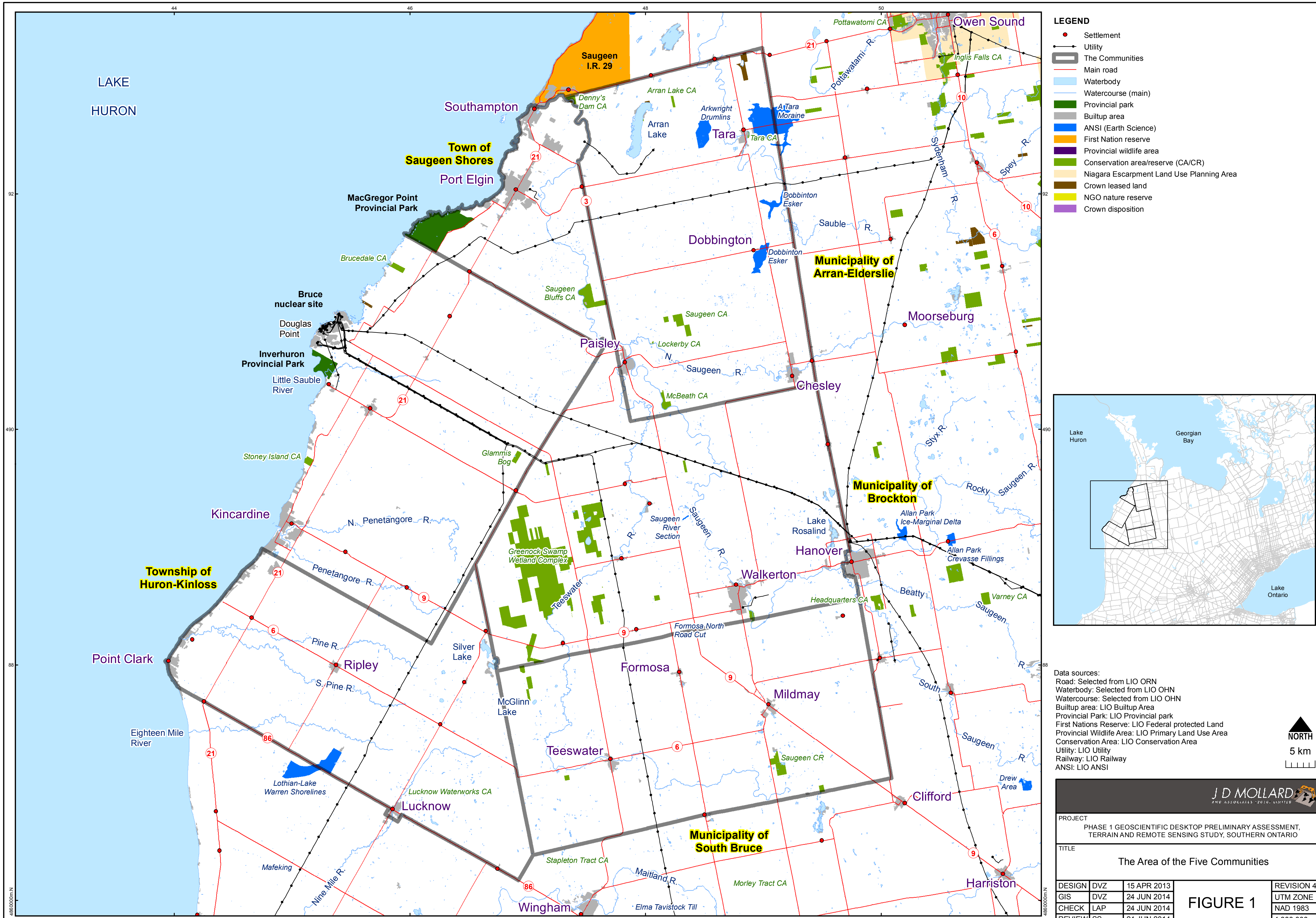
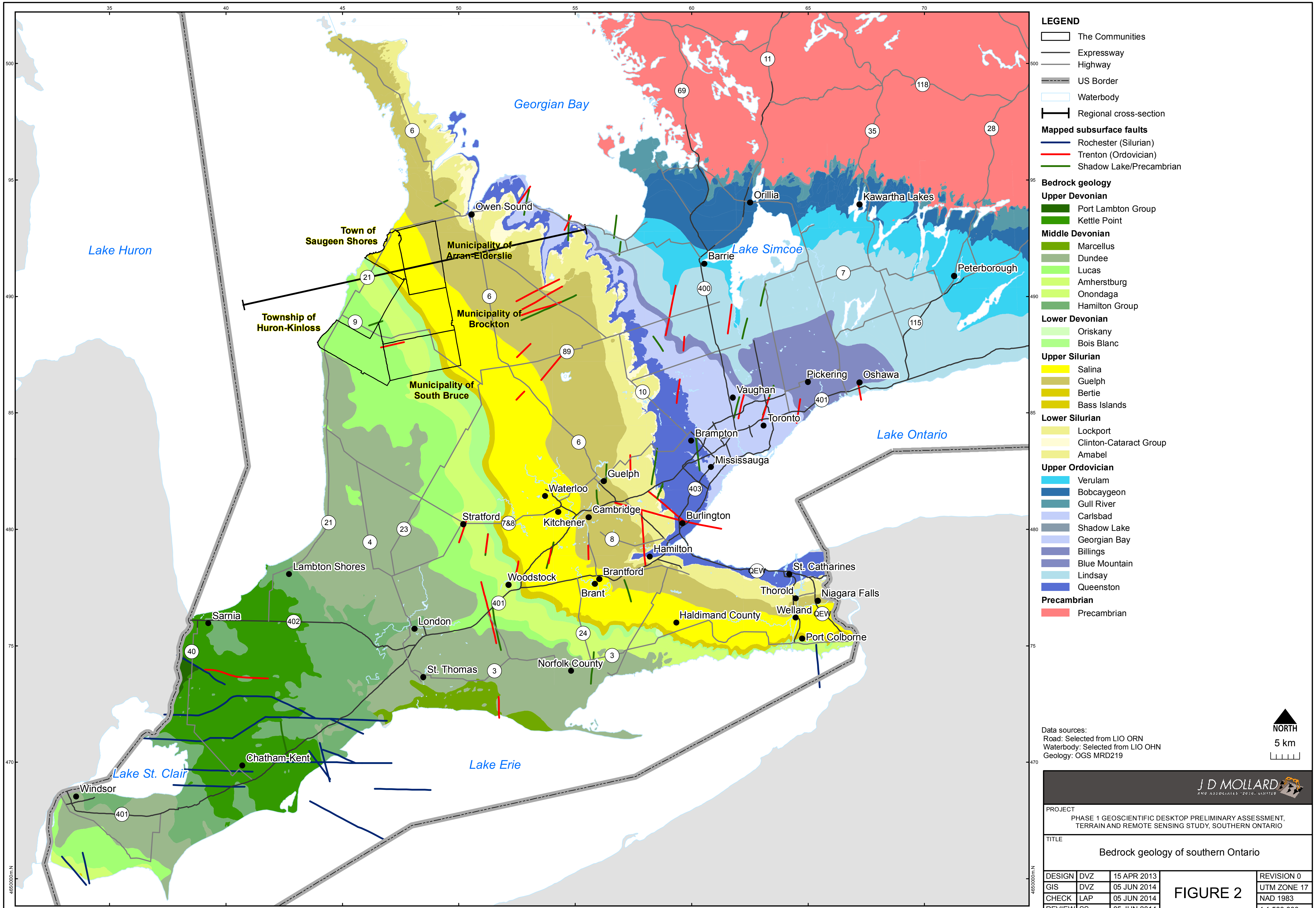
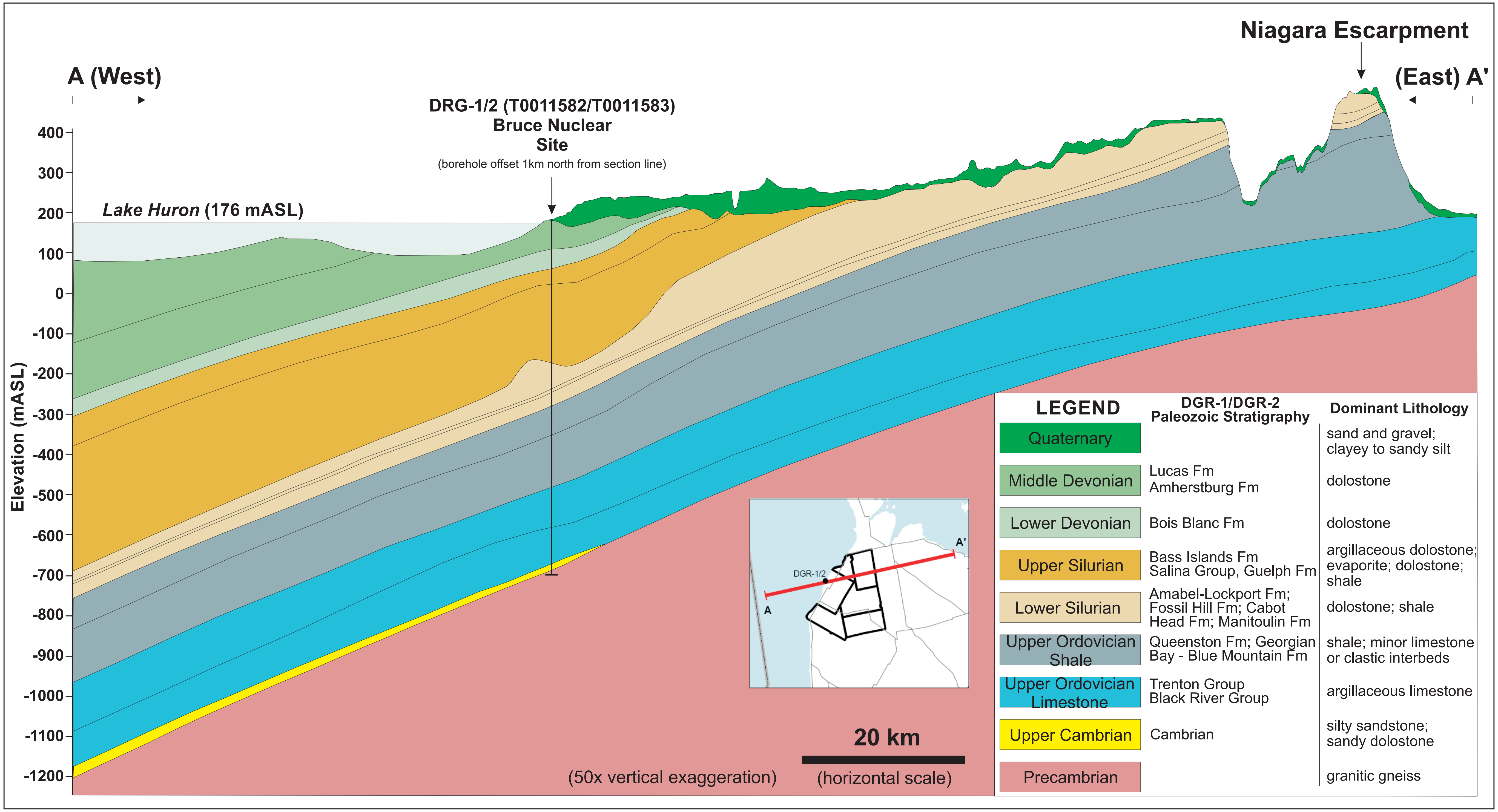
FIGURES


LAKE
HURON
Saugeen I.R. 29
Southampton
Town of Saugeen Shores
Port Elgin
MacGregor Point Provincial Park
Brucedale CA
Bruce nuclear site
Douglas Point
Inverhuron Provincial Park
Little Sauble River
Stoney Island CA
Kincardine
Township of Huron-Kinloss
Point Clark
Eighteen Mile River
Lothian-Lake Warren Shorelines
Mafeking
Nine Mile R.
Lucknow
Lucknow Waterworks CA
Ripley
Pine R.
S. Pine R.
Penetangore R.
N. Penetangore R.
Silver Lake
McGlinn Lake
Glammis Bog
Greenock Swamp Wetland Complex
Teeswater
Teeswater R.
Formosa
Formosa North Road Cut
Stapleton Tract CA
Wingham
Maitland R.
Elma Tavistock Till
Morley Tract CA
Municipality of South Bruce
Mildmay
Saugeen CR
Clifford
Harriston
Drew Area
Walkerton
Headquarters CA
Hanover
Lake Rosalind
Saugeen River Section
Saugeen R.
Municipality of Brockton
Allan Park Ice-Marginal Delta
Allan Park Crevasse Fillings
Beatty Saugeen
Varney CA
South Saugeen R.
Rocky Saugeen R.
Styx R.
Moorseburg
Municipality of Arran-Elderslie
Chesley
McBeath CA
N. Saugeen R.
Lockerby CA
Paisley
Saugeen CA
Saugeen Bluffs CA
Dobbington
Dobbinton Esker
Sauble R.
Tara
Tara CA
Arkwright Drumlins
Arran Lake
Arran Lake CA
Denny's Dam CA
Tara Moraine
Pottawatomi CA
Pottawatomi R.
Sydenham R.
Spey R.
Inglis Falls CA
Owen Sound
LEGEND
Settlement
Utility
The Communities
Main road
Waterbody
Watercourse (main)
Provincial park
Builtup area
ANSI (Earth Science)
First Nation reserve
Provincial wildlife area
Conservation area/reserve (CA/CR)
Niagara Escarpment Land Use Planning Area
Crown leased land
NGO nature reserve
Crown disposition
Lake Huron
Georgian Bay
Lake Ontario
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
Builtup area: LIO Builtup Area
Provincial Park: LIO Provincial park
First Nations Reserve: LIO Federal protected Land
Provincial Wildlife Area: LIO Primary Land Use Area
Conservation Area: LIO Conservation Area
Utility: LIO Utility
Railway: LIO Railway
ANSI: LIO ANSI
NORTH
5 km
J D MOLLARD AND ASSOCIATES (2010) LIMITED
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO
TITLE
The Area of the Five Communities
DESIGN DVZ 15 APR 2013
GIS DVZ 24 JUN 2014
CHECK LAP 24 JUN 2014
REVIEW SS 24 JUN 2014
FIGURE 1
REVISION 4
UTM ZONE 17
NAD 1983
1:300,000



LEGEND
The Communities
Expressway
Highway
US Border
Waterbody
Regional cross-section
Mapped subsurface faults
Rochester (Silurian)
Trenton (Ordovician)
Shadow Lake/Precambrian
Bedrock geology
Upper Devonian
Port Lambton Group
Kettle Point
Middle Devonian
Marcellus
Dundee
Lucas
Amherstburg
Onondaga
Hamilton Group
Lower Devonian
Oriskany
Bois Blanc
Upper Silurian
Salina
Guelph
Bertie
Bass Islands
Lower Silurian
Lockport
Clinton-Cataract Group
Amabel
Upper Ordovician
Verulam
Bobcaygeon
Gull River
Carlsbad
Shadow Lake
Georgian Bay
Billings
Blue Mountain
Lindsay
Queenston
Precambrian
Precambrian
Georgian Bay
Lake Huron
Lake Simcoe
Lake Ontario
Lake Erie
Lake St. Clair
Town of Saugeen Shores
Municipality of Arran-Elderslie
Township of Huron-Kinloss
Municipality of Brockton
Municipality of South Bruce
Owen Sound
Orillia
Kawartha Lakes
Barrie
Peterborough
Pickering
Oshawa
Vaughan
Toronto
Brampton
Mississauga
Guelph
Waterloo
Kitchener
Cambridge
Burlington
Stratford
Hamilton
Lambton Shores
Woodstock
Brantford
Brant
St. Catharines
Thorold
Niagara Falls
Welland
Haldimand County
Port Colborne
Sarnia
London
St. Thomas
Norfolk County
Chatham-Kent
Windsor
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Geology: OGS MRD219
NORTH
5 km
J D MOLLARD AND ASSOCIATES (2010) LIMITED
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO
TITLE
Bedrock geology of southern Ontario
DESIGN DVZ 15 APR 2013
GIS DVZ 05 JUN 2014
CHECK LAP 05 JUN 2014
REVIEW SS 05 JUN 2014
FIGURE 2
REVISION 0
UTM ZONE 17
NAD 1983
1:1,500,000



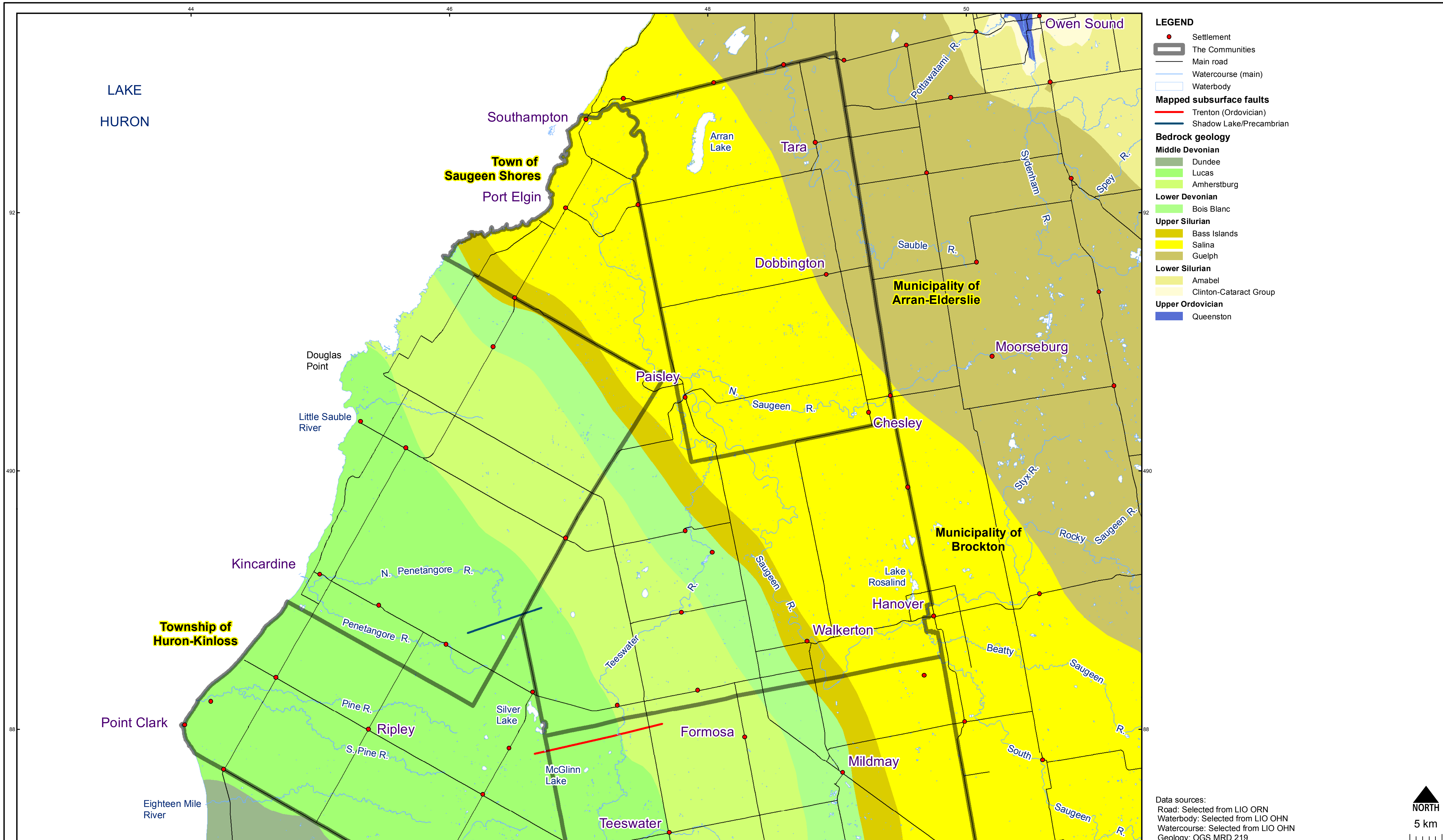
Data source: NWMO, 2011

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Regional geological cross-section of the eastern flank of the Michigan Basin

DESIGN	NMP	15 APR 2013	FIGURE 3	REVISION 1
GIS	DVZ	24 JUN 2014		
REVIEW	LAP	24 JUN 2014		



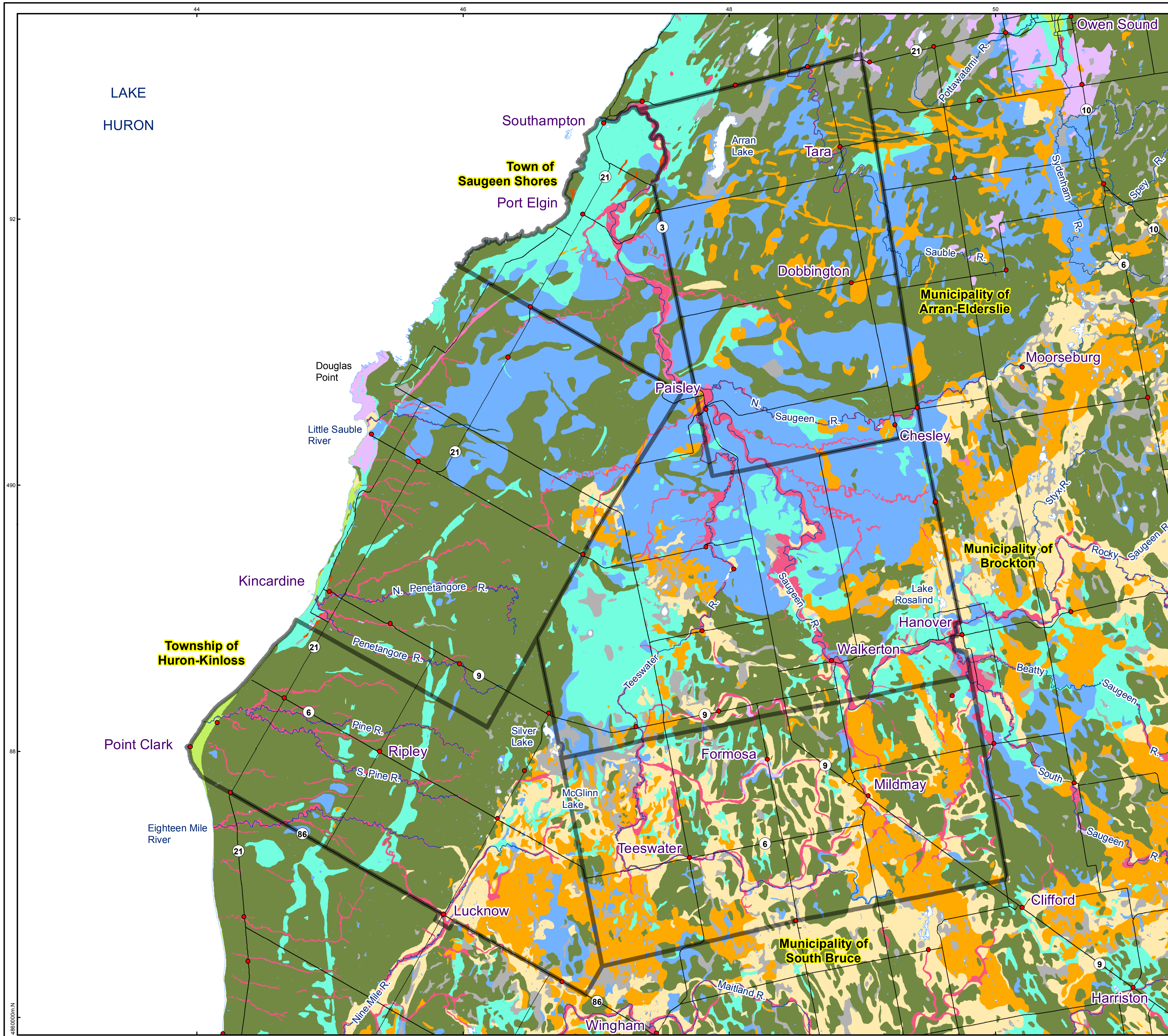
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
Geology: OGS MRD 219

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Bedrock geology of the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 4	REVISION 3
GIS	DVZ	05 JUN 2014		UTM ZONE 17
CHECK	LAP	05 JUN 2014		NAD 1983
REVIEW	SS	05 JUN 2014		1:300,000



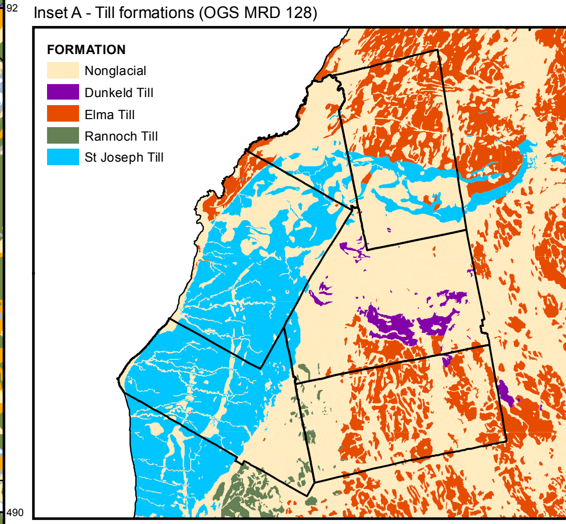
LEGEND

Surficial deposit

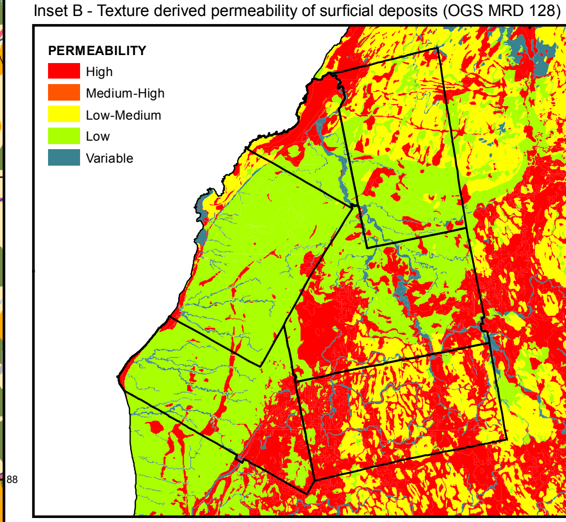
- Wetland
- Colluvial
- Lacustrine
- Fluvial
- Aeolian
- Glaciolacustrine (coarse)
- Glaciolacustrine (fine)
- Glaciofluvial (ice-contact)
- Glaciofluvial (outwash)
- Glacial (morainal)
- Bedrock-drift complex

- Settlement
- The Communities
- Main road
- Waterbody
- Watercourse (main)

Inset A - Till formations (OGS MRD 128)



Inset B - Texture derived permeability of surficial deposits (OGS MRD 128)



Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
Geology: OGS MRD128 1:50,000

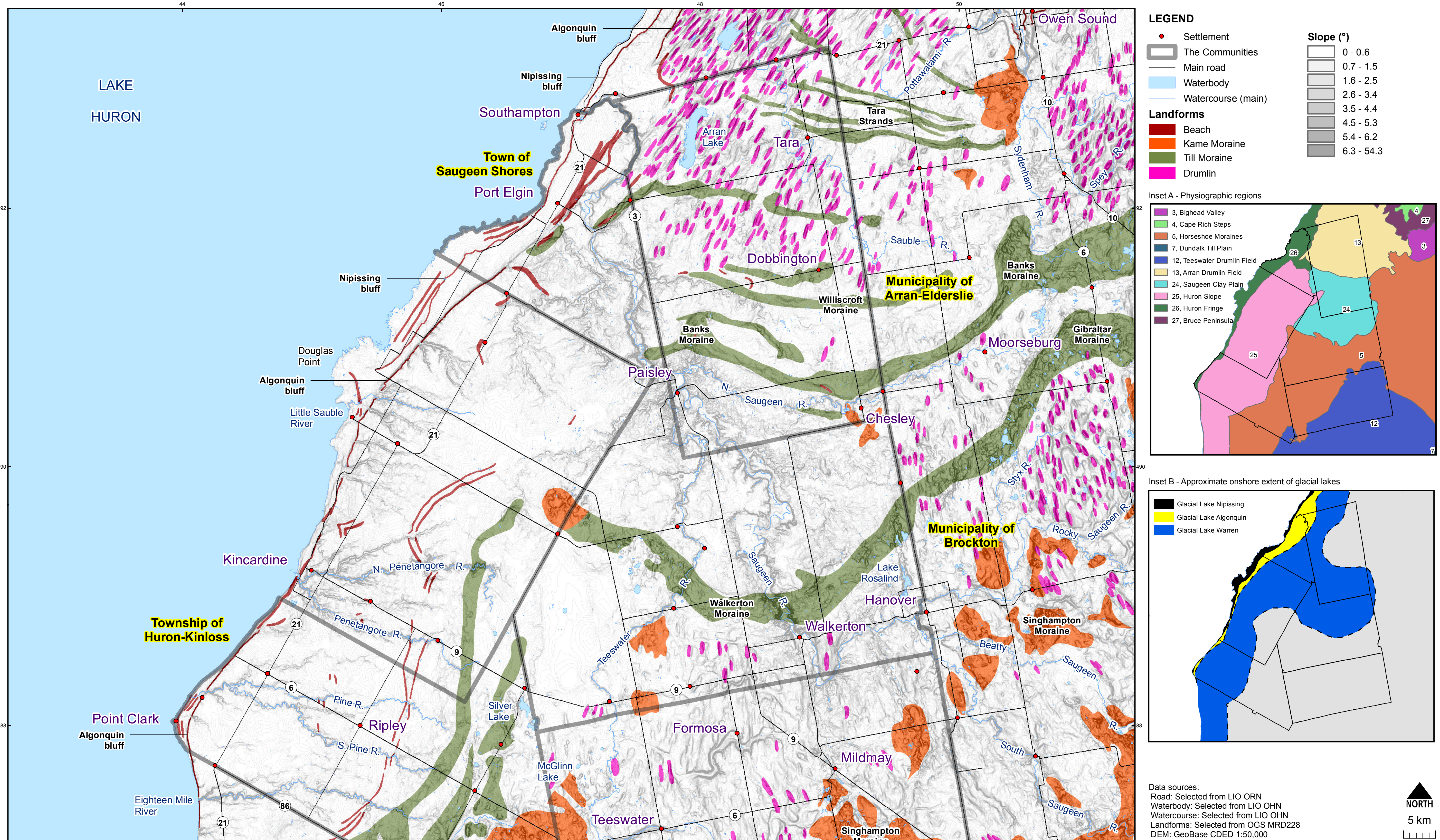
NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Surficial geology of the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 5	REVISION 3
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000

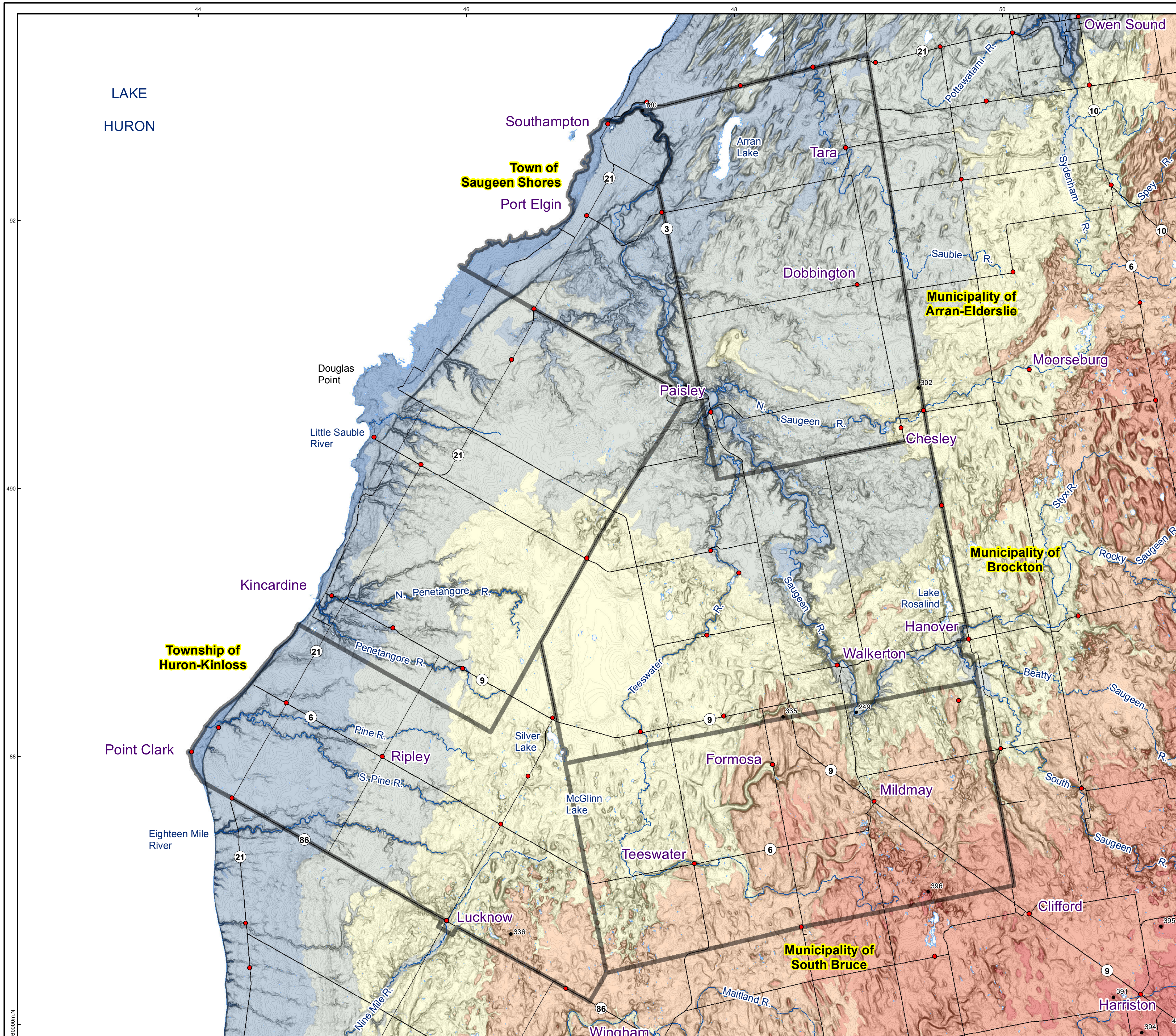


J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Surficial landforms of the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 6	REVISION 4
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000



LEGEND

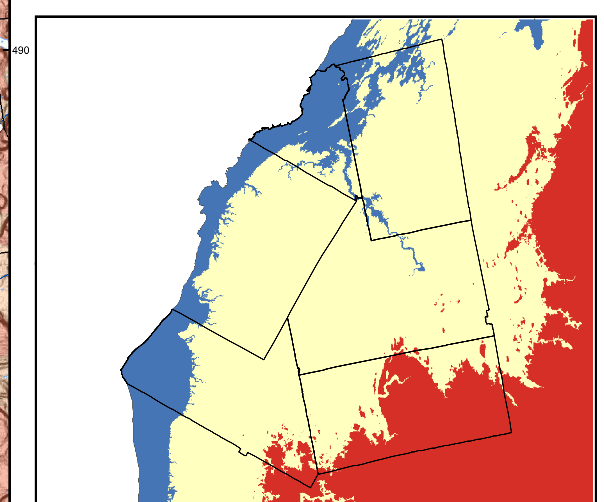
- Settlement
- Spot height (m)
- The Communities
- Main road
- Waterbody
- Watercourse (main)

Slope (°)

- 0 - 0.6
- 0.7 - 1.5
- 1.6 - 2.5
- 2.6 - 3.4
- 3.5 - 4.4
- 4.5 - 5.3
- 5.4 - 6.2
- 6.3 - 54.3

Elevation (m)

- 176 - 193
- 194 - 231
- 232 - 269
- 270 - 307
- 308 - 344
- 345 - 382
- 383 - 400



Elevation (m)

- 176 - 225
- 226 - 310
- 311 - 400

Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
DEM: GeoBase CDED 1:50,000

NORTH

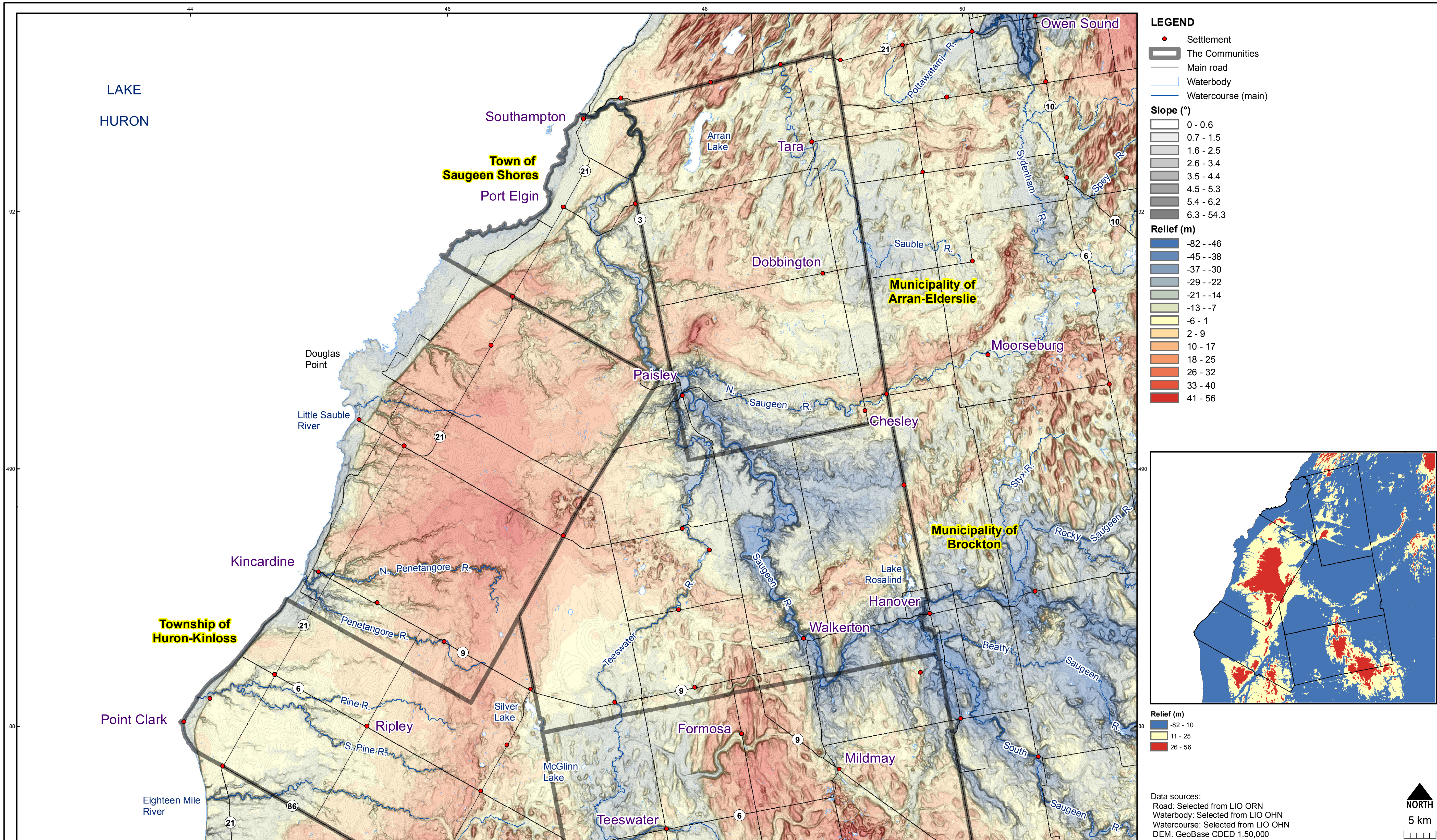
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Elevation within the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 7	REVISION 3
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000



J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Elevation departure within 20 km radius

DESIGN	DVZ	15 APR 2013	FIGURE 8	REVISION 3
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000

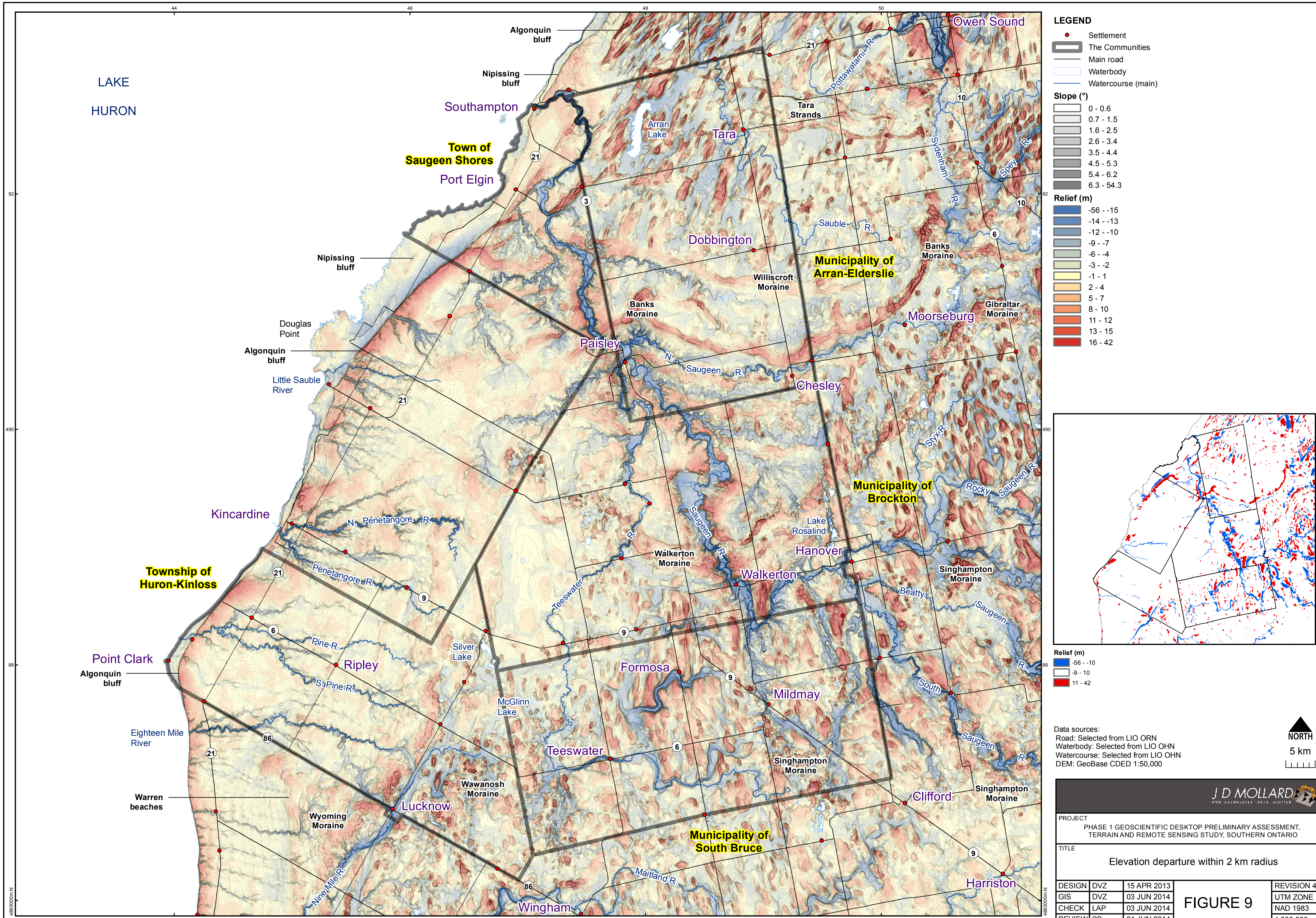
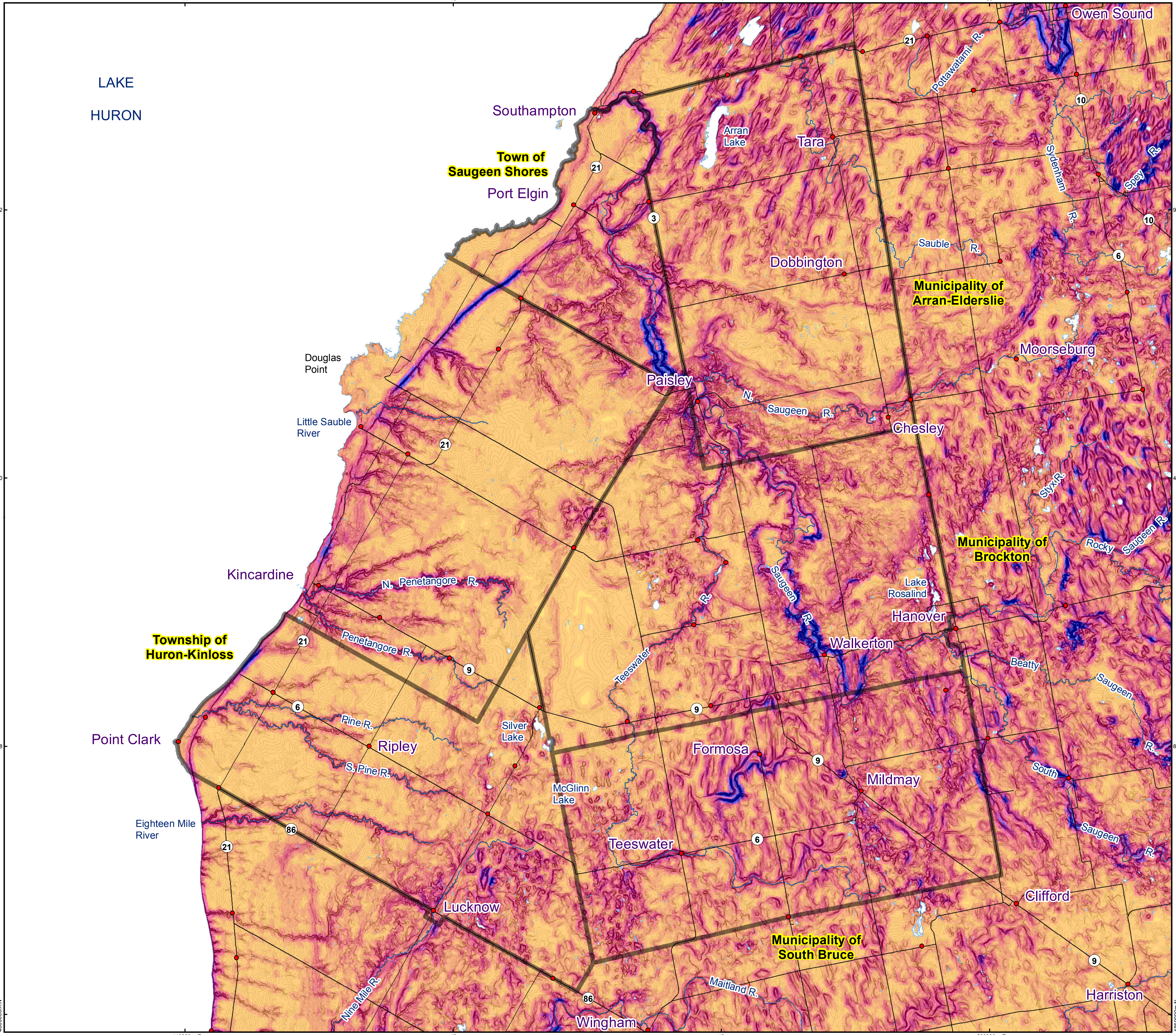

LAKE
HURON
Algonquin bluff
Nipissing bluff
Southampton
Town of Saugeen Shores
Port Elgin
Nipissing bluff
Douglas Point
Algonquin bluff
Little Sauble River
Kincardine
Township of Huron-Kinloss
Point Clark
Algonquin bluff
Eighteen Mile River
Warren beaches
Wyoming Moraine
Wawanosh Moraine
Lucknow
Ripley
Pine R.
S. Pine R.
N. Penetangore R.
Penetangore R.
Silver Lake
McGlinn Lake
Teeswater
Teeswater R.
Nine Mile R.
Wingham
Maitland R.
Municipality of South Bruce
Formosa
Mildmay
Singhampton Moraine
Clifford
Harriston
Walkerton
Walkerton Moraine
Saugeen R.
Lake Rosalind
Hanover
Municipality of Brockton
Paisley
Banks Moraine
N. Saugeen R.
Chesley
Dobbington
Williscroft Moraine
Municipality of Arran-Elderslie
Arran Lake
Tara
Tara Strands
Pottawatami R.
Owen Sound
Sydenham R.
Spey R.
Sauble R.
Banks Moraine
Moorseburg
Gibraltar Moraine
Styx R.
Rocky Saugeen R.
Singhampton Moraine
Beatty Saugeen R.
South Saugeen R.
Singhampton Moraine
21
3
10
6
9
86
44
46
48
50
92
490
88
440000m.E
500000m.E
4860000m.N
LEGEND
Settlement
The Communities
Main road
Waterbody
Watercourse (main)
Slope (°)
0 - 0.6
0.7 - 1.5
1.6 - 2.5
2.6 - 3.4
3.5 - 4.4
4.5 - 5.3
5.4 - 6.2
6.3 - 54.3
Relief (m)
-56 - -15
-14 - -13
-12 - -10
-9 - -7
-6 - -4
-3 - -2
-1 - 1
2 - 4
5 - 7
8 - 10
11 - 12
13 - 15
16 - 42
Relief (m)
-56 - -10
-9 - 10
11 - 42
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
DEM: GeoBase CDED 1:50,000
NORTH
5 km
J D MOLLARD AND ASSOCIATES (2010) LIMITED
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO
TITLE
Elevation departure within 2 km radius
DESIGN DVZ 15 APR 2013
GIS DVZ 03 JUN 2014
CHECK LAP 03 JUN 2014
REVIEW SS 04 JUN 2014
REVISION 4
UTM ZONE 17
NAD 1983
1:300,000

FIGURE 9



LEGEND

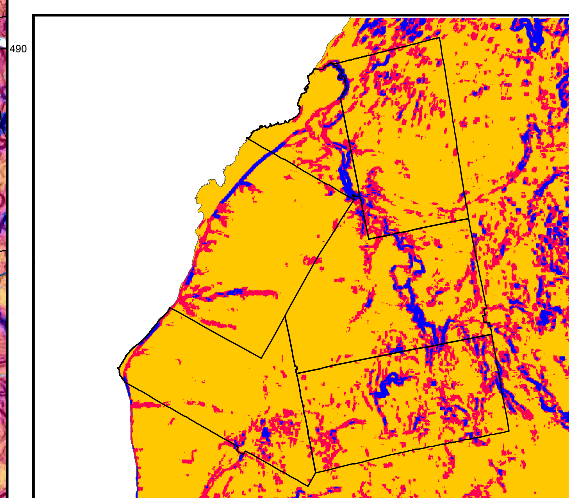
- Settlement
- The Communities
- Main road
- Waterbody
- Watercourse (main)

Slope (°)

- 0 - 0.6
- 0.7 - 1.5
- 1.6 - 2.5
- 2.6 - 3.4
- 3.5 - 4.4
- 4.5 - 5.3
- 5.4 - 6.2
- 6.3 - 54.3

Relief (m)

- 0 - 0
- 1 - 5
- 6 - 11
- 12 - 16
- 17 - 22
- 23 - 27
- 28 - 32
- 33 - 38
- 39 - 186



Relief (m)

- 0 - 15
- 16 - 25
- 26 - 186

Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
DEM: GeoBase CDED 1:50,000

NORTH

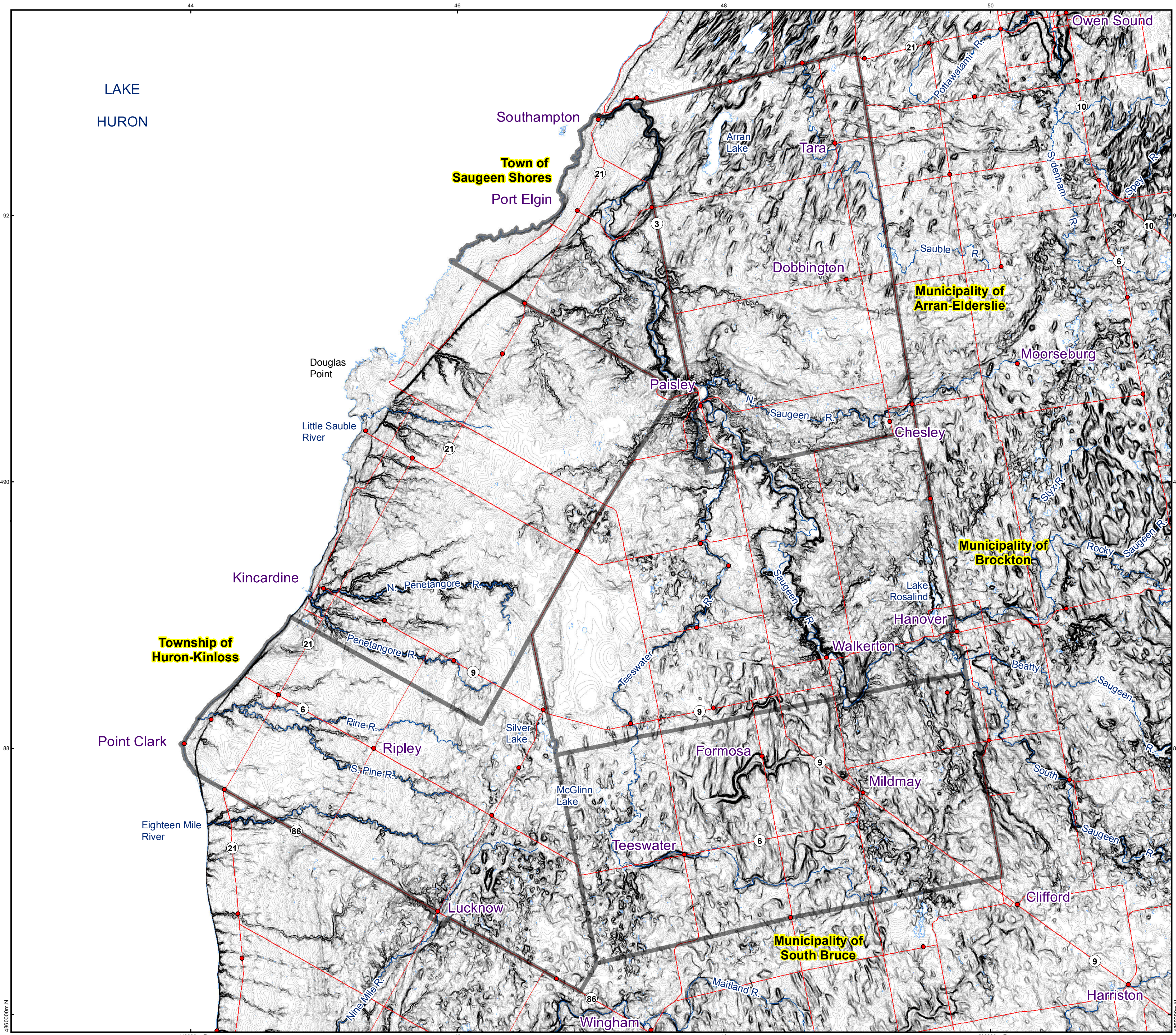
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Range in elevation within 250 m

DESIGN	DVZ	15 APR 2013	FIGURE 10	REVISION 3
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000

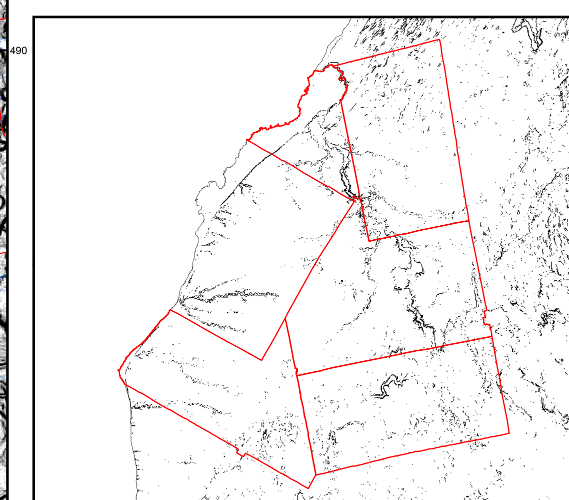


LEGEND

- Settlement
- The Communities
- Main road
- Waterbody
- Watercourse (main)

Slope (°)

- 0 - 0.7
- 0.8 - 1.5
- 1.6 - 2.4
- 2.5 - 3.3
- 3.4 - 4.1
- 4.2 - 5
- 5.1 - 5.9
- 6 - 26.7



Slope (°)

- 0 - 6
- 6.1 - 54.3

Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
DEM: GeoBase CDED 1:50,000

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

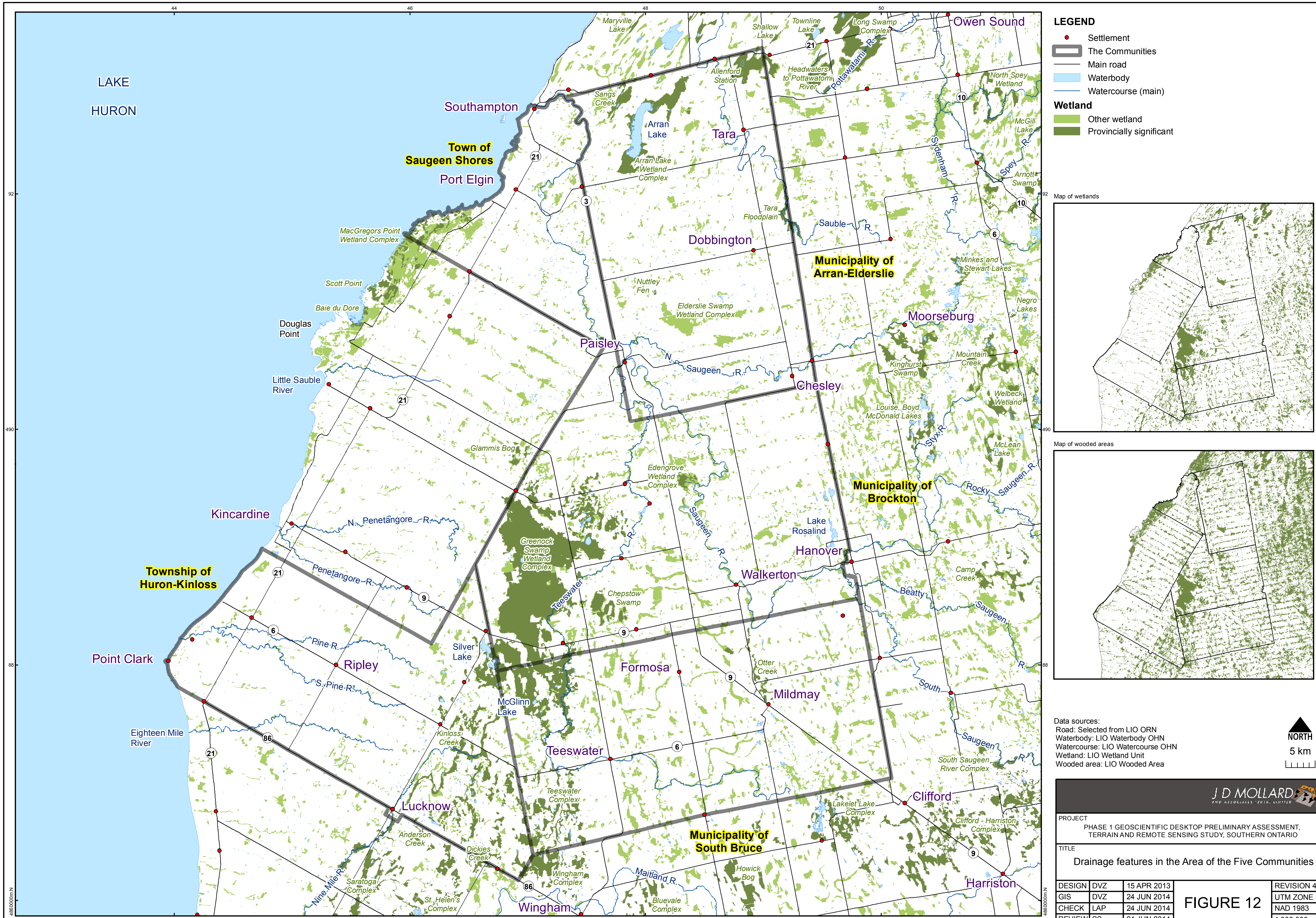
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

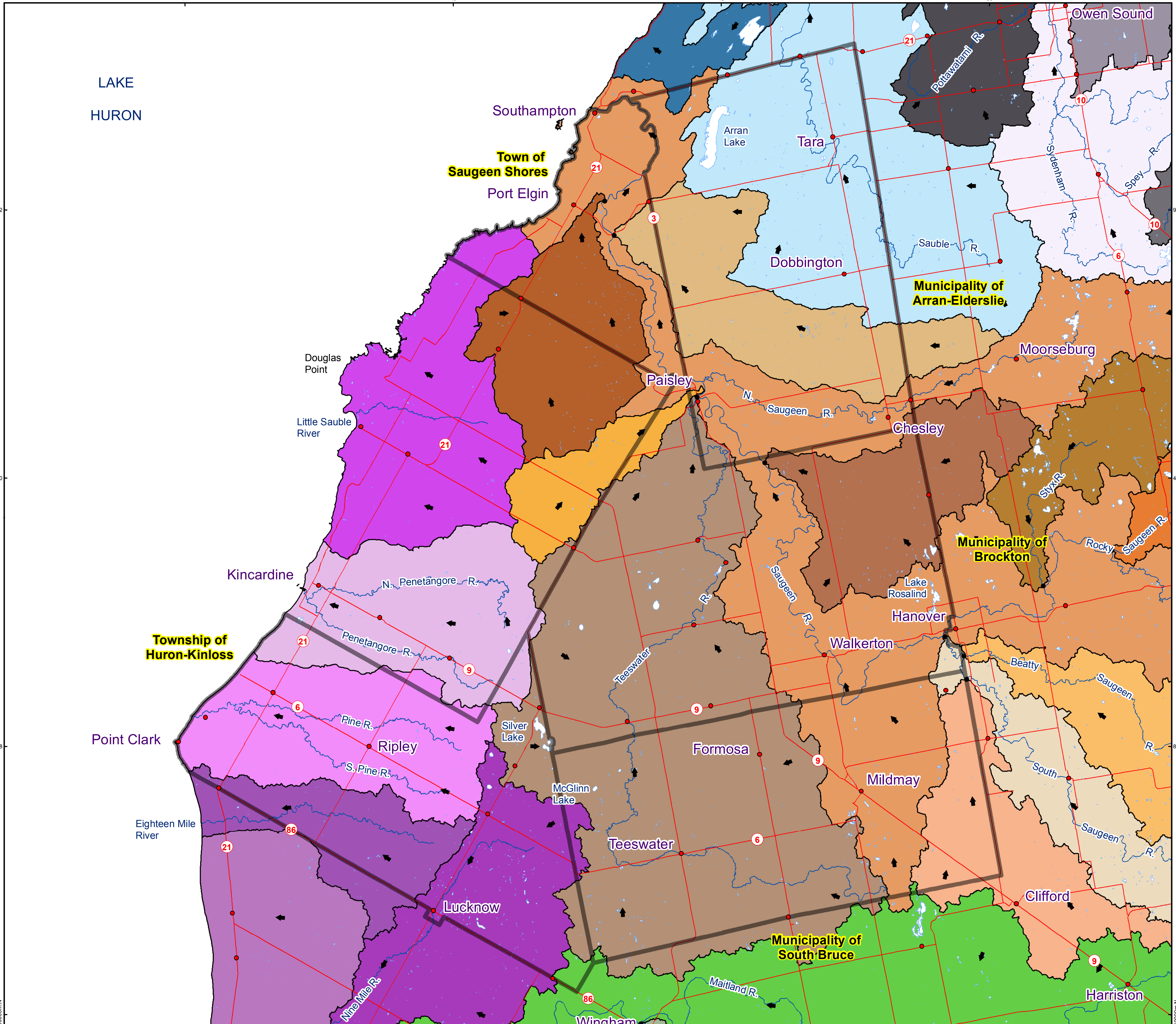
TITLE

Slope within the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 11	REVISION 2
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000

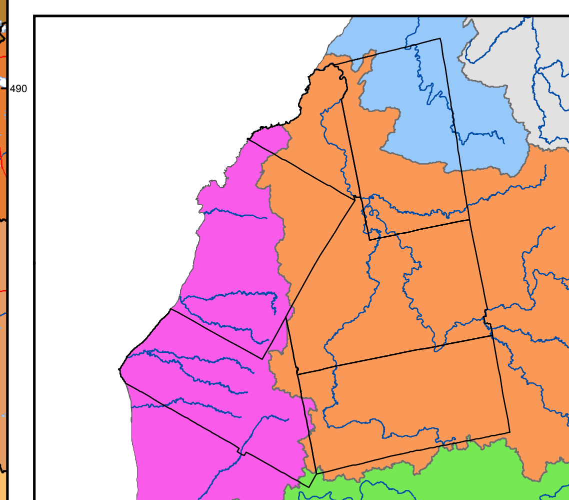


LEGEND
Settlement
The Communities
Main road
Waterbody
Watercourse (main)
Wetland
Other wetland
Provincially significant
Map of wetlands
Map of wooded areas
LAKE HURON
Southampton
Town of Saugeen Shores
Port Elgin
MacGregors Point Wetland Complex
Scott Point
Baie du Dore
Douglas Point
Little Sauble River
Kincardine
Township of Huron-Kinloss
Point Clark
Ripley
Eighteen Mile River
Lucknow
Paisley
Tara
Arran Lake
Arran Lake Wetland Complex
Allenford Station
Sangs Creek
Dobbington
Tara Floodplain
Nuttley Fen
Elderslie Swamp Wetland Complex
Municipality of Arran-Elderslie
Chesley
N. Saugeen R.
Owen Sound
Maryville Lake
Shallow Lake
Townline Lake
Long Swamp Complex
Headwaters to Pottawatomi River
Pottawatomi R.
North Spey Wetland
McGill Lake
Spey R.
Arnott Swamp
Sydenham R.
Sauble R.
Minkes and Stewart Lakes
Negro Lakes
Moorseburg
Kinghurst Swamp
Mountain Creek
Welbeck Wetland
Louise, Boyd McDonald Lakes
Styx R.
McLean Lake
Rocky Saugeen R.
Municipality of Brockton
Lake Rosalind
Hanover
Walkerton
Camp Creek
Beatty Saugeen R.
Glammis Bog
Edengrove Wetland Complex
Greenock Swamp Wetland Complex
Chepstow Swamp
Teeswater R.
Saugeen R.
N. Penetangore R.
Penetangore R.
Pine R.
S. Pine R.
Silver Lake
McGlinn Lake
Formosa
Otter Creek
Mildmay
South Saugeen R.
South Saugeen River Complex
Kinloss Creek
Teeswater
Teeswater Complex
Anderson Creek
Dickies Creek
Municipality of South Bruce
Lakelet Lake Complex
Clifford
Clifford - Harriston Complex
Harriston
Saratoga Complex
Nine Mile R.
St. Helen's Complex
Wingham
Wingham Complex
Maitland R.
Howick Bog
Bluevale Complex
440000m.E
500000m.E
4860000m.N
Data sources:
Road: Selected from LIO ORN
Waterbody: LIO Waterbody OHN
Watercourse: LIO Watercourse OHN
Wetland: LIO Wetland Unit
Wooded area: LIO Wooded Area
NORTH
5 km
J D MOLLARD
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO
TITLE
Drainage features in the Area of the Five Communities
DESIGN DVZ 15 APR 2013
GIS DVZ 24 JUN 2014
CHECK LAP 24 JUN 2014
REVIEW SS 24 JUN 2014
FIGURE 12
REVISION 4
UTM ZONE 17
NAD 1983
1:300,000



LEGEND

- Settlement
- Surface flow
- Watershed outlet
- The Communities
- Main road
- Quaternary watershed
- Waterbody
- Watercourse (main)



Tertiary watershed

- Bruce Peninsula
- Maitland
- Penetangore
- Saugeen
- Southwest Georgian Bay

Data sources:
Road: Selected from LIO ORN
Waterbody: LIO Waterbody OHN
Watercourse: LIO Watercourse OHN
Watershed: LIO Quaternary Watershed

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

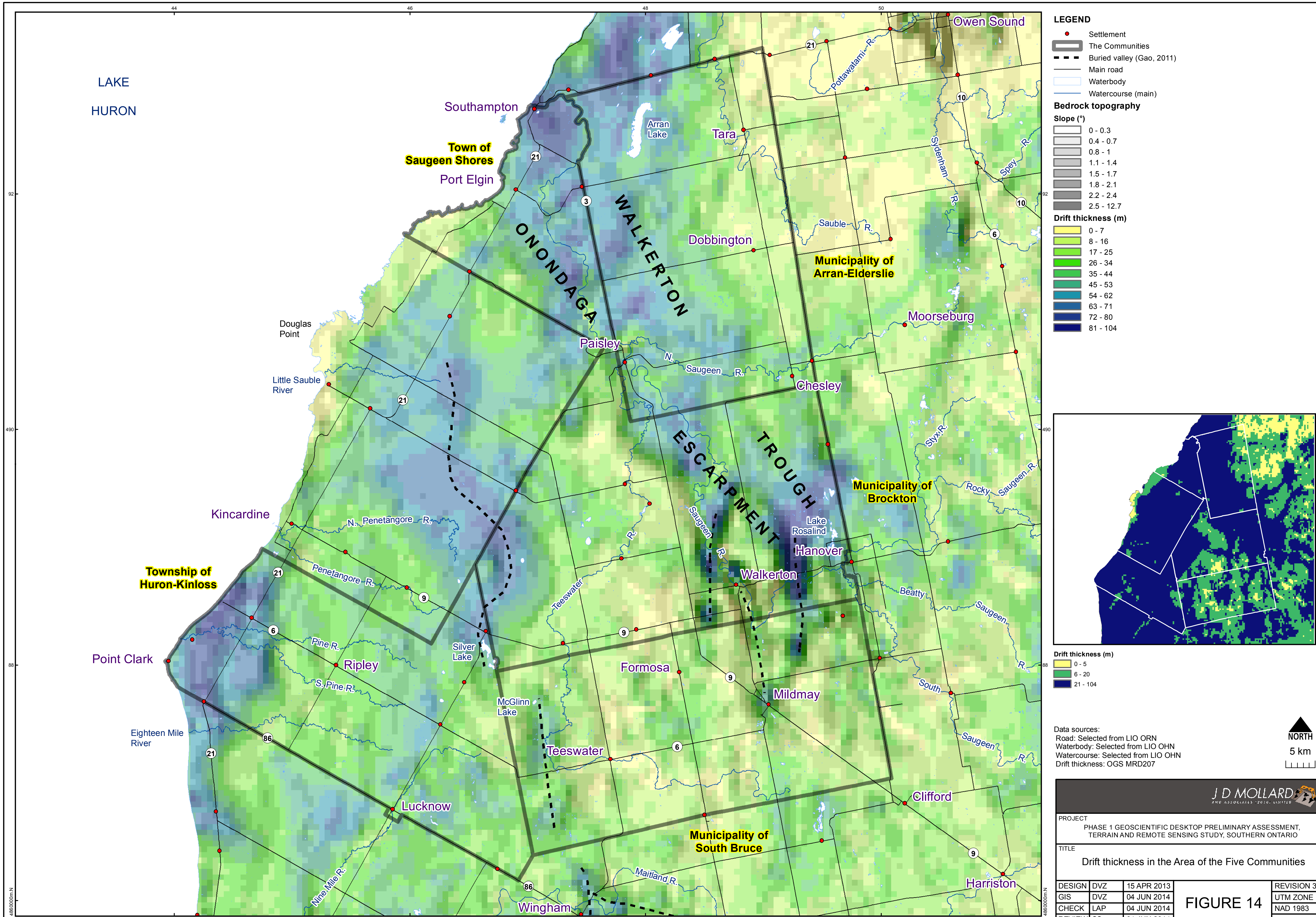
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE

Watersheds within the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 13	REVISION 3
GIS	DVZ	03 JUN 2014		UTM ZONE 17
CHECK	LAP	03 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000


LAKE
HURON
Southampton
Town of
Saugeen Shores
Port Elgin
Arran
Lake
Tara
Owen Sound
Pottawatami R.
Sydenham R.
Spey R.
ONONDAGA
WALKERTON
Dobbington
Sauble R.
Municipality of
Arran-Elderslie
Moorseburg
Douglas
Point
Paisley
N. Saugeen R.
Chesley
Little Sauble
River
ESCARPMENT
TROUGH
Styx R.
Municipality of
Brockton
Rocky Saugeen R.
Kincardine
N. Penetangore R.
Lake
Rosalind
Hanover
Saugeen R.
Walkerton
Township of
Huron-Kinloss
Penetangore R.
Teeswater R.
Beatty Saugeen
Pine R.
Ripley
Silver
Lake
Point Clark
Formosa
S. Pine R.
McGlinn
Lake
Mildmay
South Saugeen R.
Eighteen Mile
River
Teeswater
Lucknow
Clifford
Municipality of
South Bruce
Nine Mile R.
Maitland R.
Harriston
Wingham
LEGEND
Settlement
The Communities
Buried valley (Gao, 2011)
Main road
Waterbody
Watercourse (main)
Bedrock topography
Slope (°)
0 - 0.3
0.4 - 0.7
0.8 - 1
1.1 - 1.4
1.5 - 1.7
1.8 - 2.1
2.2 - 2.4
2.5 - 12.7
Drift thickness (m)
0 - 7
8 - 16
17 - 25
26 - 34
35 - 44
45 - 53
54 - 62
63 - 71
72 - 80
81 - 104
Drift thickness (m)
0 - 5
6 - 20
21 - 104
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
Drift thickness: OGS MRD207
NORTH
5 km
J D MOLLARD
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO
TITLE
Drift thickness in the Area of the Five Communities
DESIGN DVZ 15 APR 2013
GIS DVZ 04 JUN 2014
CHECK LAP 04 JUN 2014
REVIEW SS 04 JUN 2014
FIGURE 14
REVISION 3
UTM ZONE 17
NAD 1983
1:300,000

LEGEND

- Settlement
- Main road
- Local road
- The Communities
- Waterbody
- Watercourse (main)

Data sources:
Roads: LIO ORN
Waterbody: LIO Waterbody OHN
Watercourse: LIO Watercourse OHN

NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, SOUTHERN ONTARIO

TITLE
Roads within the Area of the Five Communities

DESIGN	DVZ	15 APR 2013	FIGURE 15	REVISION 1
GIS	DVZ	04 JUN 2014		UTM ZONE 17
CHECK	LAP	04 JUN 2014		NAD 1983
REVIEW	SS	04 JUN 2014		1:300,000