NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

MUNICIPALITY OF CENTRAL HURON, ONTARIO

APM-REP-06144-0128

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TERRAIN AND REMOTE SENSING STUDY

MUNICIPALITY OF CENTRAL HURON

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

FINAL REPORT

NWMO REPORT NUMBER: APM-REP-06144-0128

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EXECUTIVE SUMMARY

In July 2014, the Municipality of Central Huron (herein ‘the Municipality’) 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 Municipality for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening 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 assessment are reported in an integrated report (NWMO, 2015). The objective of the geoscientific desktop preliminary assessment is to determine whether the Municipality contains 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 Engineering Ltd., 2015) of the Municipality of Central Huron and its immediate periphery, referred to as the Central Huron area. 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 Canadian Digital Elevation Data. Additional information sources included several files on drainage features, watersheds, 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 Central Huron 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. The overburden is generally thick in this area, with values as high as

91 m and an average value of about 28 m. The largest area of thick (>40 m) drift is associated with the Wyoming Moraine, in the west part of the Municipality, while the thinnest overburden is found within river channels, where glacial meltwater and fluvial erosion have exposed bedrock locally, and along the eastern margin of the Municipality beneath the Stratford till plain.

Surficial deposits within the Municipality can be divided into four zones extending across the area from west to east. The westernmost zone, the zone of lowest elevation, is characterized by a discontinuous high permeability sand veneer draped over low permeability deposits of St. Joseph Till overlying glaciolacustrine silts and clays. The next zone eastward consists of the Wyoming Moraine and adjacent spillways. This zone of very thick drift (40 to 91 m) consists of low permeability St. Joseph Till forming till ridges and other topographic highs, while high permeability sand and gravel outwash deposits exist in spillways and other topographic lows. The third zone consists of the Wawanosh Moraine and adjacent spillways. In this zone, highly permeable and locally very thick ice-contact sand and gravel deposits form kames and other topographic highs, while outwash sand and gravel is exposed in spillways and other topographic lows. Low permeability Rannoch Till has been deposited over some of the ice-contact and outwash deposits, creating confined aquifers in some locations. The easternmost zone, the highest elevated of the four zones, is represented by the Stratford till plain. This is the largest area of low relief and the largest area of thin (0-20 m) drift within the Municipality, an area underlain largely by Rannoch Till, sporadic deposits of glaciolacustrine silts and clays and bounded to the east by the Mitchell Moraine.

The large-scale pattern of elevation across the Central Huron area controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from west (Lake Huron) to east is from 176 to 366 m, with the highest elevation associated with the Mitchell Moraine.

Apart from Lake Huron, the map area contains no large lakes, with waterbodies covering 11.0 km^2 or 0.8 % of the onshore portion of the map area. Several provincially significant wetland complexes are present and in total wetlands cover 78.4 km^2 or 5.6 % of the Central Huron area. The Hullett Marsh Complex (8.8 km^2), located in the southeast corner of the Municipality, is one of the largest wetland complexes in the area.

The shallow groundwater regime includes overburden aquifers that provide drinking water supplies to residences and shallow confined bedrock aquifers that provide water supplies to both municipalities and residences. Within the Central Huron area, all groundwater-based municipal drinking water supplies are sourced from shallow bedrock aquifers. 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 Central Huron area 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 neotectonic features could be identified in the Central Huron area using the information available in the current terrain study.

The Central Huron area contains a dense network of highways and local roads. The main accessibility constraints in the area represent areas of wet and swampy ground, and areas of high relief associated with river valleys, till ridges and kames.

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1 INTRODUCTION

In July 2014, the Municipality of Central Huron (the Municipality) 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 Municipality for safely hosting a deep geological repository (Step 3). 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 (NWMO, 2015).

This report presents the findings of a terrain and remote sensing assessment completed as part of the geoscientific desktop preliminary assessment (Geofirma Engineering Ltd., 2015) of the Municipality of Central Huron and its immediate periphery, referred to as the Central Huron area. The objective of the geoscientific desktop preliminary assessment is to determine whether the Municipality contains 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 Central Huron area 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, 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 Central Huron area using the data and methodology described in Section 1.3.

1.2 CENTRAL HURON AREA

The geoscientific desktop preliminary assessment (Geofirma Engineering Ltd., 2015) focuses on the area within the Municipality of Central Huron. For the purpose of the assessment, geoscientific information was collected and interpreted for the Municipality and surrounding areas, referred to in this report as the Central Huron area (Figure 1). Many of the summary statements in this report are reported as percentages of the portion of the Central Huron area not covered by Lake Huron. For simplicity, the term "Central Huron area" from herein refers to the portion of the area not covered by Lake Huron. The 44 km by 35 km rectangular area shown in most maps in this report, which includes a portion of Lake Huron, is referred to as the "map area" in a few instances. The north, south, east and west boundaries of the map area, in Universal Transverse Mercator projection (using North American Datum 1983), are 4,852,150, 4,816,950, 437,825 and 481,822 m, respectively. Settlements within the Municipality include Clinton, Holmesville, Kinburn and Londesborough (Figure 1).

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 Central Huron area.

The surficial geology of southern Ontario has been mapped in detail. The OGS digitized the available Quaternary geology maps, and generated a seamless digital coverage showing the distribution and nature of surficial deposits 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 Ontario Ministry of Natural Resources (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. Limited use was also made 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 Central Huron area, including a discussion of the buried bedrock valleys in the area, while Section 5.3 describes drift thickness in the Municipality.

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 Central Huron area. 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 provide 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 (2013) 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 Central Huron area 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, 2014). 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, except for the surface drainage map and the watershed map, where all watercourses are shown. The best available watershed delineation in the area is that of the quaternary 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 Central Huron area is described in detail in Geofirma Engineering Ltd. (2015) 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 and 323 million years ago (Johnson et al., 1992). This sedimentary sequence rests unconformably on the Precambrian crystalline basement rocks of the Grenville Province, which is the southeastern-most subdivision of the Canadian Shield. The Grenville Province comprises 2,690 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. These arches, along with the east-southeast-trending Chatham Sag structural depression, define a regional basement high beneath southern Ontario that extends further southwestward into the northeastern United States.

The Paleozoic succession underlying the Central Huron area was deposited within the Michigan Basin. The Paleozoic rocks have a maximum thickness of about 4,800 m at the centre of the Michigan basin; at the northeast corner of the Central Huron area the thickness is about 900 m (OGSRL, 2014). 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 representative regional cross-section constructed approximately east-west about 50 km north of the Central Huron area. 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 along the cross-section and within the Central Huron area 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 been affected by approximately 1,210 to 970 million year old orogenic events, referred to generally as 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 Orogeny, built the proto-North American craton upon which Grenville deformation was imprinted (Easton, 1992). Post-Grenville extension associated with rifting prior to 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 subparallel shear zones several kilometres or more in width that are generally assumed to be related to the approximately 1 billion year old Grenville Orogeny (Easton, 1992). These shear zones are 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 Central Huron area, is underlain by Precambrian crystalline basement of the Central Gneiss Belt and consists mainly of quartzofeldspathic gneissic rocks that 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 the Central Huron area. The Huron Domain acted as a 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. Geofirma Engineering Ltd. (2015) provides additional information and mapping outlining the Huron Domain and tectonic boundary zones.

2.1.4 PALEOZOIC STRATIGRAPHY

Table 2 illustrates the Paleozoic bedrock stratigraphy for the Central Huron area as presented by Geofirma Engineering Ltd. (2015). 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.

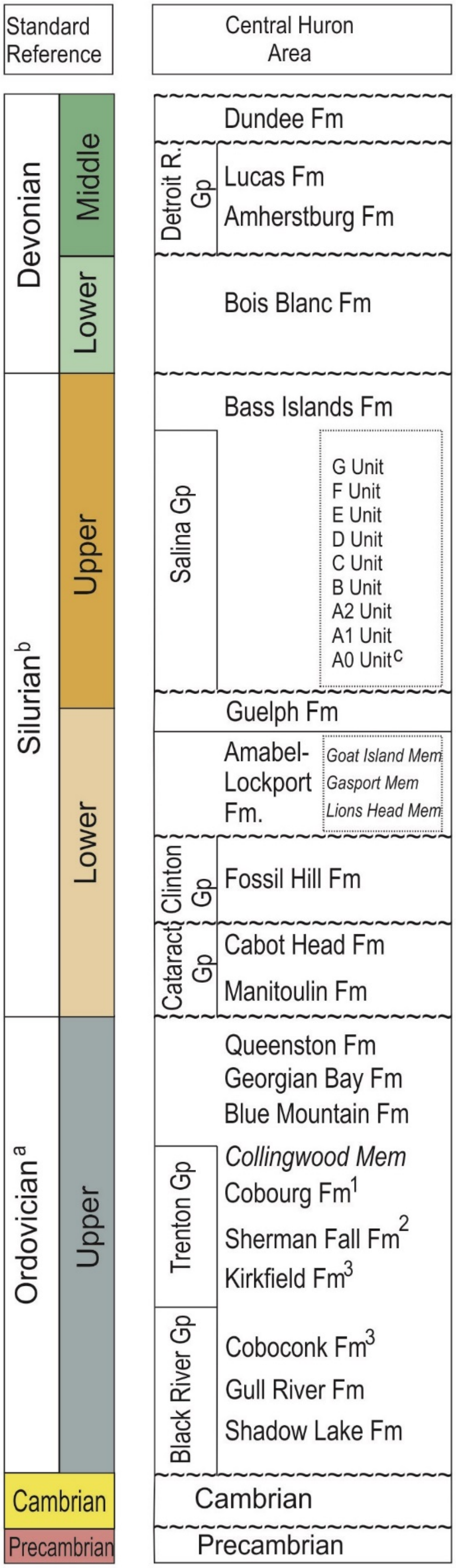
In addition, the stratigraphic nomenclature in Table 2 and Figure 3 adopts the subsurface nomenclature of Armstrong and Carter (2010), while geological mapping as shown in Figures 2 and 4 uses an outcrop nomenclature. This distinction primarily applies to the Trenton and Black River groups, where the 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 in the Central Huron area 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

Table 2 Stratigraphy of the Central Huron area (after Armstrong and Carter, 2010)



Notes:
Gp - Group
Fm - Formation
Mem - Member
a - Strata traditionally referred to as Middle Ordovician (i.e,, Black River and Trenton groups; Armstrong and Carter, 2006) are now considered part of the Upper Ordovician.
b - The formal term Middle Silurian (e.g., Armstrong and Carter, 2006) has been abandoned so all strata have been re-assigned to either the Lower or Upper Silurian.
c - A-0 Unit (Salina Formation) is recognized based on site characterization activities at the Bruce nuclear site (Intera, 2011)
The Rochester Fm and Reynales Fm are Southwestern Ontario - Lake Erie equivalents of the Lion's Head Mem (Amabel Gp) and Fossil Hill Fm

Surface Nomenclature Equivalent (approx.):
1 - Lindsay Fm; 2 - Verulam Fm; 3 - Bobcaygeon Fm

~~ Unconformity ~~

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 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 about 5 to 10 km east of Lake Huron (Bailey Geological Services Ltd. and Cochrane, 1984a), and thus is expected to be absent beneath the eastern and central parts of the Central Huron area. 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 Central Huron area, 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 eastern parts of the Central Huron area, and the basin margin reef complex typically located east of the Central Huron area (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 2). The Salina Group is characterized by repeated, cyclical deposition of carbonate, evaporite and argillaceous sedimentary rocks, comprising Units A through G. Silurian salt beds (i.e., A-2, B, D, E and F Unit salts) are present in the Central Huron area, thinning and pinching out eastward from Lake Huron (Sanford, 1993; 1977). Underground excavation mining of salt at the Goderich Mine is from the Salina A2 Unit salt at a depth of about 550 m (Hewitt, 1962). In areas where salt has been removed by dissolution, collapse structures are present within the overlying uppermost Silurian and Devonian strata

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, and the Dundee Formation (Table 2). The Bois Blanc Formation consists of cherty, fossiliferous limestones and argillaceous dolostones that unconformably overlie Silurian strata. The Amherstburg Formation is a bituminous bioclastic fossiliferous limestone and dolostone. The Lucas Formation is fine-crystalline, fossiliferous dolostone and limestone, and subcrops in the northeast and north-central parts of the Central Huron area, mostly outside of the Municipality. The Dundee Formation, which is the dominant subcropping bedrock formation within the Municipality of Central Huron (Figure 4), comprises sparsely fossiliferous limestones and minor dolostones that unconformably overly the Detroit River Group.

2.1.5 Faulting of the Paleozoic Strata

Figure 2 shows basement-seated faults that displace the Paleozoic strata in southern Ontario. 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, 2014). 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, faults are identified with a low degree of confidence. As shown in Figure 4, there are no OGS mapped faults within the Central Huron area.

2.2 QUATERNARY GEOLOGY

Quaternary glaciations have played a major role in shaping the landscape of southern Ontario (Barnett, 1992). Glacial landforms and associated sediments within the Central Huron area were formed and 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 Central Huron area are mapped in considerable detail, and they are responsible for shaping many of the landforms mapped throughout the area, including moraines, drumlins, eskers 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 Central Huron area 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 in detail the distribution of surficial deposits within the Central Huron area and within the Municipality.

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 Central Huron area 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 Central Huron area.

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	Warren beaches and bluffs
		St. Joseph Till	Wyoming Moraine
14 to 13	Mackinaw Interstade	Glaciolacustrine deposits	Clay plains
15.2 to 13.8	Port Bruce Stade	Glaciofluvial deposits	Outwash and ice-contact landforms
		Rannoch Till	Wawanosh Moraine, Stratford till plain
		Elma Till	Teeswater and Dundalk drumlin fields, Wawanosh 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 Central Huron area (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 Rannoch Till (Huron lobe) (Figure 5, inset A; Table 4). The Georgian Bay lobe advanced southward, whereas the Huron lobe advanced eastward across the map area. The Elma Till is distributed on the surface in the northeast corner of the Central Huron area, mostly outside of the Municipality, and beneath the Rannoch Till to the south and west (Cooper et al., 1977). It occurs as a stony silt, sandy silt and clayey silt till in ground moraine and in drumlins of the Teeswater drumlin field (Figure 6, inset A) (Barnett, 1992). The Rannoch Till is a silt to silty clay till that occurs as the surface till east of the Wyoming Moraine and it occurs in several moraines including the Mitchell, Dublin, Seaforth and Wawanosh moraines (Cowan and Pinch, 1986; Figure 6; Table 4).

Table 4 Characteristics of tills in the Central Huron area.

Elma Till	Rannoch Till	St. Joseph Till
Georgian Bay lobe	Huron lobe	Huron lobe
Strongly calcareous	Strongly calcareous	Strongly calcareous
Carbonate content 45-55%	Carbonate content 50-60%	Carbonate content 45%
Silt, sandy silt and clayey silt till	Silt to silty clay till	Silt to silty clay till
Non-plastic to low plasticity	Low plasticity	Low plasticity
More clayey southward	Finer grained westward	Fine grained southward
Fissile structure	Blocky structure, non-stratified	Block structure, columnar jointing
Clast content 5-25%	Clast content < 2%	Clast content 1-2%
Low-medium permeability	Low permeability	Low permeability

Compiled largely after Barnett (1992, p. 1045, 1048)

Following the Mackinaw Interstadial, the Laurentide Ice Sheet advanced during the Port Huron Stade eastward across the region, depositing the St. Joseph Till and forming the Wyoming Moraine, which parallels the Lake Huron shoreline (Barnett, 1992; Figure 6). The St. Joseph Till, found in the west part of the Central Huron area (Figure 5, inset A), contains an abundance of silt and silty clay (Broster, 1982) 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 Central Huron area. 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 Central Huron area during the Late Wisconsinan was glacial Lake Warren, which extended into the western part of the area approximately 12,500 years ago (Figure 6, inset B). Landforms associated with Lake Warren are present within the zone adjacent to the Lake Huron shoreline described in Section 3.1.3 as the Huron slope (Figure 6, inset A). Generally, there are two abandoned beaches associated with Lake Warren (Chapman and Putnam, 2007). In the Central Huron area, the Warren beaches are located along the west edge of the Wyoming Moraine about 2.5 to 3.5 km east of the Lake Huron shoreline (Figure 6). West of the intermittently developed Warren beaches, Lake Warren is well represented in the western part of the Central Huron area by a bevelled till plain with shallow linear deposits of sand, silt and clay (Cooper and Fitzgerald, 1977) (Figure 6).

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). Outside of the Central Huron area, erosional and depositional landforms associated with glacial Lake Algonquin are generally abundant within the narrow zone adjacent to the Lake Huron shoreline described in Section 3.1.4 as the Huron fringe (Figure 6, insets). However, recent shore erosion has obliterated the Lake Algonquin shoreline within the Central Huron area, with the exception of a number of terrace features present on the creeks flowing into Lake Huron (Cooper and Fitzgerald, 1977).

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. Outside the Central Huron area, glacial Lake Nipissing has formed beach ridges and bluffs along the Lake Huron shoreline within the Huron fringe (Section 3.1.4; Figure 6). However, in the Central Huron area, any landforms associated with glacial Lake Nipissing have been eroded by recent shore erosion (Cooper and Fitzgerald, 1977).

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 Central Huron area. 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 play a role in controlling surface water and shallow groundwater flow directions.

3.1 PHYSIOGRAPHY

The physiography of the Central Huron area can be classified into a set of six physiographic units (Figure 6, inset A) based on the presence of distinct landforms such as valleys, drumlin fields, escarpments and till plains. Table 5 summarizes the extent of the five specific physiographic units that extend into the Municipality, and four of these units are described in the sub-sections below, which are based on Chapman and Putnam (2007) except where stated otherwise. The Teeswater drumlin field is not described below as it makes up only 0.01% of the Municipality. The Dundalk Till Plain is similarly not described, as it is found outside of the Municipality.

Table 5 Extent of physiographic units within the Municipality.

	Area (m^2)	Area (%)
Teeswater drumlin field	52,927	0.01%
Huron fringe	5,526,632	1.2%
Huron slope	64,427,331	14.1%
Stratford till plain	93,899,738	20.6%
Horseshoe moraines	292,837,856	64.1%

3.1.1 STRATFORD TILL PLAIN

The Stratford till plain, covering the easternmost 20.6 % of the Municipality, represents an area of low relief largely underlain by Rannoch Till and sporadic glaciolacustrine deposits (Figure 6, inset A). Within the Central Huron area, the Stratford till plain extends between the Mitchell and Seaforth moraines and is interrupted by the Dublin Moraine (Figure 6).

3.1.2 HORSESHOE MORAINES

The Horseshoe Moraines, covering 64.1 % of the Municipality, represent an elaborate array of moraines and spillways extending north-south across the central part of the Central Huron area (Figure 6, inset A). The belt is about 16 km wide within the Municipality. The western boundary of the Horseshoe moraines is marked by the low gravel beaches of glacial Lake Warren, whereas the eastern flank is marked largely by the Seaforth Moraine (Figure 6). The central part of the Horseshoe moraines in this area comprises the Wawanosh Moraine, the Wyoming Moraine and a network of adjacent spillways.

3.1.3 HURON SLOPE

The Huron slope, covering 14.1 % of the Municipality, occupies the section of land along the east shore of Lake Huron between the east edge of the Huron fringe and the west edge of the Wyoming Moraine. It covers a strip of land 2.7 to 5 km in width that extends along the western part of the Municipality (Figure 6, inset A). The land slopes gently across this feature from about 180 to 245 m elevation. The area is characterized by a sand plain and bevelled till plain bounded to the east by the twin beaches of glacial Lake Warren (Figure 6).

West of the Warren beaches, the till surface has been subdued by the deposition of a veneer of glaciolacustrine gravelly sand. Exposures of till occur at the surface in many locations where the sand and gravel are absent. The till sheet is formed of brown silt to silty 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.

3.1.4 HURON FRINGE

Outside of the Central Huron area, the Huron fringe is characterized by wave-cut terraces of glacial Lake Algonquin and glacial Lake Nipissing, with their boulders, gravel bars and sand dunes located within a narrow fringe of land extending along the Lake Huron shoreline (Figure 6, inset A). However, in the Central Huron area recent shoreline erosion has eliminated most of the landforms and deposits associated with glacial lakes Algonquin and Nipissing. The Huron fringe in this area is typically only 200 to 400 m wide.

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. The large-scale topography in the Central Huron area is controlled by bedrock topography whereas the detailed topography is almost entirely 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 Central Huron area (Figure 7) controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from west (Lake Huron) to east in the Central Huron area is from 176 to 366 m, with this elevation increase occurring over an approximate 35 km lateral distance. The elevation minimum is defined by the surface of Lake Huron, which has a chart datum of 176 m. The highest points in the area, with elevations of 366 m, are located along the Mitchell Moraine at the east edge of the Central Huron area (Figure 7). Similar to the pattern across the Central Huron area, elevation within the Municipality increases to the west.

The elevation of 245 m outlines the approximate extent of glacial Lake Warren in the Central Huron area (Figure 7, inset). The lower approximately 15 % of the Municipality was submerged beneath this glacial lake approximately 12,500 years ago.

3.2.2 Relief

As described in Section 3.2.1, the total range in elevation across the Central Huron area is approximately 190 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 beyond that shown by the raw elevation map (Figure 7). Most of the positive relief shown on Figure 8 is associated with relatively thick surficial deposits. The broad topographic highs along the Wyoming Moraine, where parts of the moraine stand 25 to 50 m above the surrounding terrain, are well expressed in Figure 8, and a slope profile has been drawn (Figure 8, inset B) to illustrate the increase in overburden thickness associated with the positive relief of the Wyoming Moraine. The slope profile also shows the major spillway on the east margin of the Wyoming Moraine and the high water level reached by glacial Lake Warren on the west edge of the moraine. Another major topographic high, situated in the north-central part of the area, is associated with thick ice-contact and outwash deposits within the northeast extension of the Wawanosh Moraine in this area. This figure also highlights some of the extensive topographic lows present in the map area, such as the oval depression that supports the Hullett Marsh about 6 km east of Clinton.

Topographic prominence calculated at a local scale is a variable that provides a detailed image of drumlins, till ridges, kames, and river and creek valleys. Figure 9 shows the departure in elevation from the mean elevation calculated within a 2 km radius. This figure highlights in shades of red the many local features of positive relief present within the Central Huron area, such as kames, till ridges, drumlins, and eskers. As the detailed topography in this landscape is almost entirely controlled by surficial deposits, the relief in Figure 9 can be interpreted as local departures in drift thickness. Thus, for example, the map suggests that overburden thickness within some of the kames and till ridges is from about 5 to 35 m greater than that beneath the adjacent terrain. The slope profile shown in Figure 9 (inset B) illustrates how local topographic highs result in relatively thick drift, as shown by the till ridges on the Wyoming Moraine and the kames on the Wawanosh Moraine. The lower reaches of the Maitland and Bayfield rivers are the features that are most heavily inset into the landscape, with as much as about 20 to 45 m of incision illustrated in Figure 9. These inset features are local areas of thin drift, as is shown where the Maitland River crosses the slope profile in Figure 9 (inset B).

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 Central Huron area. The inset map in Figure 10 shows the areas with at least 8 and 24 m of relief calculated at this scale. The greatest relief is associated with the lower reaches of the Maitland and Bayfield rivers. For example, at a few bends on the Maitland River, one side of the valley extends between about 55 and 60 m above the river channel. The high relief along these valleys appears to have been one of the main local impediments to road development in the area. Areas of low relief are ideal for certain types of development. The most extensive area of relatively flat terrain is located in the southeast quadrant of the Central Huron area (Figure 10, inset) and is associated with the Stratford till plain (Figure 6, inset A). For illustrative purposes, the largest areas of low relief within the Municipality have been delineated and numbered in Figure 10 and are summarized in terms of area, elevation, landform, and surficial deposit permeability in Table 6. The largest low relief area (no. 11) is also the area of highest elevation in the Municipality. In contrast, three narrow, north-trending low relief areas (nos. 1-3) have been delineated within about 3 km of the

Lake Huron shoreline within the zone that was once submerged beneath glacial Lake Warren (Figure 6, inset B). Except for the area around the Hullett Marsh, the other low relief areas (nos. 4-9) are located within the Horseshoe moraines physiographic region, either on the floors of spillways or in locally flat parts of the moraines.

3.2.3 Slope

Steep slopes in the Central Huron area are associated with drumlins, river valleys, spillway margins, kames and till ridges, and raised shore bluffs (Figure 11). Areas with slopes of at least 6° are rare in this landscape, with only 2.5 % of the Central Huron area covered by slopes of such magnitude. Many of the flattest areas are associated with poor drainage and the presence of wetlands and small waterbodies.

Table 6 Characteristics of low relief areas within the Municipality.

				Elevation (m)			
ID[1]	**Area (km²)**	**Landform**	**Permeability[2]**	**Min**	**Max**	**Range**	**Mean**
1	6.3	Sand/till plain	Low	200	221	21	211
2	6.4	Sand/till plain	Low	194	220	26	207
3	5.2	Sand/till plain	Low	219	238	19	229
4	7.0	Spillway	High	240	269	29	254
5	12.7	Spillway	High	247	276	29	260
6	12.2	Kame moraine	High	263	287	24	276
7	3.6	Kame moraine	High	281	300	19	293
8	3.8	Kame moraine	High	287	303	16	295
9	8.8	Kame moraine	High	279	305	26	295
10	22.9	Organic terrain	Low	294	320	26	301
11	51.0	Till plain	Low	300	341	41	324

[1]ID numbers are shown on Figure 10

[2]Permeability of dominant surficial deposits

4 DRAINAGE

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 and distribution of lakes and wetlands in the Central Huron area. Section 4.2 describes the watersheds and surface flow directions in the map area.

4.1 WATERBODIES AND WETLANDS

Apart from Lake Huron, the map area is devoid of large or even medium sized lakes. Waterbodies cover 11.0 km^2 or 0.8 % of the Central Huron area. Seven of the ten largest lakes in the Central Huron area are associated with the Hullett Marsh and are located within the Hullett Wildlife Management Area (Figure 12 and Table 7). The largest lake is 1.3 km^2 in extent. None of the lakes in Table 7 have been assigned official names.

Table 7 Size of ten largest lakes in the Central Huron area.

Lake[1]	Perimeter (km)	Area (km^2)
	0.8	0.04
Hullett Marsh	1.5	0.05
	2.5	0.05
Hullett Marsh	2.3	0.09
	4.0	0.17
Hullett Marsh	3.1	0.17
Hullett Marsh	3.9	0.24
Hullett Marsh	9.9	0.43
Hullett Marsh	6.8	0.52
Hullett Marsh	8.9	1.32

[1]Metrics obtained from LIO OHN Waterbody file

Lake Huron, the second largest of the Great Lakes, has a surface area of approximately 63,500 km^2 and a maximum depth of 229 m. Within the map area (Figure 12), the floor of Lake Huron reaches a minimum elevation of 162 m, equivalent to a maximum depth of 14 m. Apart from Lake Huron, there is no information on the depths of other lakes within the map area.

Wetlands are lands that are covered seasonally or permanently by shallow water, including lands where the water table is at or close to the surface. Wetlands depicted on Figure 12 are from the

Wetland Unit map file produced by the MNR and from a wetlands file supplied by the Ausable Bayfield Conservation Authority. Provincially significant wetlands are those 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). The provincially significant wetland complexes in the Central Huron area consist of the Saratoga Complex, Westfield Complex, Morris Creek Complex, Sunshine Tract, Blyth Brook Headwater Complex, Hullett Marsh Complex, Holmesville Creek Complex, and Tricks Creek Complex (Figure 12). The later three fall within the Municipality. Many of the provincially significant wetlands are situated within spillways, such as the Tricks Creek Complex, Holmesville Creek Complex and Saratoga Complex, which are located within north-south trending spillways that extend along the axis of the Wyoming Moraine. It is likely that these spillway wetlands receive some of their source water from shallow surficial aquifers within the surrounding till and kame moraine ridges.

In total, wetlands cover 78.4 km^2 (5.6 %) of the Central Huron area, while wooded areas cover 218.1 km^2 (15.6 %), and wetlands cover 8.8% of the Municipality. 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. Many of the wetlands and wooded areas are distributed along property boundaries, illustrating how their distribution is largely controlled artificially through various land uses. The absence of wetlands southeast of the Municipality appears distinctly artificial and, although it is possible that unmapped wetlands exist in that area, it is also possible that this relates to drainage or filling of wetlands for agricultural or other land uses.

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 Central Huron area 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.

The Central Huron area is contained entirely within the Great Lakes - St. Lawrence primary watershed, which drains towards the Atlantic Ocean through the St. Lawrence River. This 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.

Surface flow over the Central Huron area is directed to the west towards Lake Huron, and is associated with three tertiary watersheds: the Maitland and Ausable watersheds, and to a lesser extent the Penetangore watershed (Figure 13, inset A). In the descriptions below, the ID numbers of the nine quaternary watersheds shown on Figure 13 are referenced in brackets.

4.2.1 MAITLAND WATERSHED

The Maitland watershed covers 69.4 % of the Central Huron area (Figure 13, inset). Within this area, the watershed has been divided into five quaternary watersheds. The Maitland River is the primary drainage feature in the watershed.

The Lower Maitland watershed (2FE-02) contains the lower reach of the Maitland River, which meanders through a deep, forested valley locally incised through bedrock. Tributaries at least partly contained within the Central Huron area include Sharpes, Bridgewater, Hopkins, and Belgrave creeks, Blyth Brook and the South Maitland and Middle Maitland rivers (Figure 13). The area near Clinton is drained by Hopkins Creek, which feeds into Bridgewater Creek before emptying into the Maitland River north of Holmesville. Sharpes Creek and Blyth Brook are the two longer of the small streams that feed directly into the Maitland River in this area. The Maitland River makes a sharp bend where it extends through the Wyoming Moraine (Figure 6), which, along with the Wawanosh Moraine, represents an important groundwater recharge area within the watershed.

The South Maitland watershed (2FE-03) drains much of the east-central part of the Central Huron area. The watershed drains the Hullett Marsh, a significant water storage area that likely contributes to reduced flooding, higher base flows and reduced occurrence of high flows on the South Maitland River and to a lesser extent on the Maitland River. The southeast part of the watershed drains the Stratford till plain, where agriculture is common, while the northwest part drains the Wawanosh Moraine.

A small portion of the Middle Maitland watershed (2FE-04) extends north south along the eastern edge of the map area (Figure 13). Draining part of the Dundalk till plain, an area with abundant agriculture, Beauchamp Creek is the main tributary to the Middle Maitland River in this area. A minor part of the Little Maitland watershed (2FE-05), which contains the Little Maitland River, a tributary of the Middle Maitland River, is contained in the northeast corner of the map area. These rivers drain part of the Teeswater drumlin field in the northeast corner of the map area, an area with extensive forest cover.

The South Shore watershed (2FE-01) is a small watershed extending between Lake Huron and the Wyoming Moraine (Figure 13). Naftel’s Creek is the largest stream in this highly dissected till and sand plain. The reason for the high density of streams is the low permeability of the St. Joseph Till and underlying glaciolacustrine silts and clays found along this slope. Within these small watersheds draining the level slope west of the Wyoming Moraine (e.g., 2FD-07, 2FE-01, 2FF-06), seepage from the higher rolling terrain above the glacial Lake Warren beach or bluff has a tendency to collect and create swampy conditions (Chapman and Putnam, 2007).

4.2.2 AUSABLE WATERSHED

The Ausable watershed covers 26.1 % of the Central Huron area (Figure 13). Within this area, the watershed has been divided into three quaternary watersheds. The Bayfield River is the primary drainage feature in this part of the watershed.

The Main Bayfield watershed (2FF-07) extends east west along the southern part of the map area, draining land west of the Seaforth Moraine (Figure 6). Tributaries to the Bayfield River in this area include Tricks and Silver creeks, Liffy Ditch and the Bannockburn River. The Bayfield River cuts through the Wyoming Moraine before emptying into Lake Huron. Recharge areas within this watershed include the Dublin, Seaforth, Wawanosh and Wyoming moraines.

The Bannockburn watershed (2FF-08) is the main tributary of the Bayfield River in this area, draining a small area along the southern edge of the map area. In addition, a small, highly dissected basin (2FF-06) extending between Lake Huron and the Wyoming Moraine is located in the southwest corner of the map area.

4.2.3 PENETANGORE WATERSHED

The Penetangore watershed covers 4.5% of the Central Huron area (Figure 13, inset A). With this area, the watershed is represented by one quaternary watershed (2FD-07), where Allans Creek forms the main drainage feature. A very dense network of west trending creeks testifies to the poor drainage of the sand and till plain. Gully erosion is common where the creeks intersect the Lake Huron bluff. Seepage from granular layers within the bluffs along the Lake Huron shoreline also contributes to gully erosion in this area.

4.3 DRAINAGE WITHIN THE MUNICIPALITY

To provide more detail on drainage within the Municipality, stream densities and the percentages of wetlands and lakes have been compiled for the portions of the four quaternary watersheds that extend into the Municipality (Figure 13, inset B, Table 8). The short descriptions below pertain to the portions of the watersheds that extend into the Municipality.

Table 8 Characteristics of quaternary watersheds extending into the Municipality.

Watershed ID	Watershed area (km^2)	Stream density[1]	Lake extent	Wetland extent
2FE-01	65.6	0.0016	0.1%	5.2%
2FE-02	110.1	0.0011	0.4%	8.0%
2FE-03	171.7	0.0012	1.7%	11.0%
2FF-07	109.4	0.0011	0.6%	8.1%

[1]Total length of streams divided by watershed area

The South Maitland watershed (2FE-03) covers the largest portion of the Municipality and contains the largest percentages of lakes and wetlands, mainly due to the presence of the Hullett Marsh Complex, although wetlands are present elsewhere in the watershed (Figure 12). The Hullett Marsh is situated within an oval depression bounded dominantly by morainal ridges (Figure 8), which the South Maitland River passes through several kilometres before its mouth.

The Lower Maitland watershed (2FE-02) covers the second largest portion of the Municipality and contains the third largest percentage of wetlands. The Holmesville Creek Complex, located in the headwaters of Bridgewater Creek and along the lower portion of Hopkins Creek (Figure 12),, is the largest of the wetlands in this part of the watershed. Blyth Brook cuts through the Wawanosh Moraine in the northern tip of the Municipality.

The Main Bayfield watershed (2FF-07) covers a slightly smaller portion of the Municipality compared to the Lower Maitland watershed (2FE-02). The largest wetland complex in this part of the watershed is the Tricks Creek Swamp (Figure 12), which is located within a major spillway within the Wyoming Moraine.

The South Shore watershed (2FE-01) is a small watershed situated in the northwest corner of the Municipality. This basin contains the highest stream density and the lowest percentages of lakes and wetlands of the four watersheds extending into the Municipality. The evenness of the plain west of the Wyoming Moraine results in very few topographic depressions where lakes or wetlands could be established. The high stream density is related to the low permeability of the underlying till and glaciolacustrine sediments.

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 Central Huron area have been mapped at the scale of 1:50,000 by Cooper and Fitzgerald (1977), Cooper et al. (1977) and Cowan et al. (1986). 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 in Figure 6 based on the work of Chapman and Putnam (2007). Section 2.2 introduced the surficial deposits and landforms in the Central Huron area 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 Central Huron area, including a brief description of buried valley complexes, and it provides more detail on the distribution of surficial deposits.

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 throughout southern Ontario. Drift thickness in the Central Huron area ranges from zero up to about 91 m (Figure 14), with an average thickness of 28 m. The pattern of thicker drift shown in Figure 14 is largely consistent with that of high relief shown in Figure 8. That is, much of the thickest overburden in the area is associated with till moraines and kame moraines, particularly the Wyoming Moraine (Figure 14, inset) and the northeast extension of the Wawanosh Moraine. The largest zone of thick (>40 m) drift is located within the Wyoming Moraine. The slope profile drawn through the Municipality in Figure 14 (inset B) illustrates the general increase in overburden thickness observed from east to west passing from the Stratford till plain through the Wawanosh Moraine and into the Wyoming Moraine.

The only buried valley mapped by Gao (2011) within the Central Huron area is a north-south trending feature located in the northeast corner of the area (Figure 14). Gao (2011) referred to this valley as the Hutton Heights valley, which extends north to Wingham (approximately 7 km north of the Central Huron area). Based on an interpretation of the bedrock topography map of Karrow et al. (1965), Cooper and Fitzgerald (1977) and Cooper et al. (1977) suggested several bedrock valleys in the Central Huron area. They reported one in the general location of each of the Maitland and Bayfield rivers, one trending east-west passing beneath the town of Clinton, and others near the towns of Brussels, Londesborough and Seaforth. As none of the bedrock valleys mentioned above stand out in the drift thickness map shown on Figure 14, and none were mapped by Gao (2011), it is suspected that these valleys represent relatively small features compared with the valleys described by Gao (2011). In addition, as there is a north-trending linear zone of thicker overburden in the southeast corner of the Central Huron area (Figure 14) that does not correspond with a positive surficial landform (Figure 9), this feature could be a buried valley not identified by Gao (2011).

5.2 SURFICIAL DEPOSITS WITHIN THE CENTRAL HURON AREA

Table 9 provides a summary in percentages of the areal extent of the different surficial deposits mapped within the Central Huron area and within the Municipality (Figure 5). The percentages presented in Table 9 were queried from the digital surficial geology map (OGS, 2010; Figure 5).

Morainal deposits (Table 9, ‘M’) occur extensively throughout the Central Huron area (Figure 5), covering about 53 % of the area. Morainal deposits exposed at the surface in the Central Huron area have been classified into three main till formations, as shown on Figure 5 (inset A) and summarized in Table 4. The Rannoch Till is the most abundant till, mapped over 29 % of the area. The St. Joseph Till is the next most common till formation, covering 17 % of the area. The Elma Till covers about 7 % 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 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 Central Huron area is 20 m, whereas it is 45 m in areas where St. Joseph Till is mapped, and 24 m for Rannoch Till. The 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.

Table 9 Extent of surficial deposits based on primary genesis of deposit

	Primary genesis[1] (expressed as % area)						
	F	**M**	**GF**	**GL**	**L**	**O**	**R**
Municipality of Central Huron	2.0	45.8	34.2	17.8	0.0	0.1	0.1
Central Huron area	2.4	53.4	26.3	17.0	0.1	0.7	0.1

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

Glaciofluvial deposits (Table 9, 'GF') consisting primarily of sand or sand and gravel are exposed over 26.3 % of the Central Huron area (Figure 5). Glaciofluvial deposits associated with kames 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. The north-south trending eskers located in the northeast corner of the Central Huron area were deposited during the retreat of the Georgian Bay ice lobe, while the rest of the eskers in the area trend generally east-west and were associated with the Huron ice lobe.

Glaciolacustrine deposits are exposed over 17.0 % of the Central Huron area, with about 79 % of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 21 % as coarse-grained deposits of sand or sand and gravel. The largest coarse-grained glaciolacustrine deposit in the area is represented by a shallow north-south trending gravelly sand deposit associated with glacial Lake Warren (Cooper and Fitzgerald, 1977) extending between the Maitland and Bayfield rivers near Lake Huron. Fine-grained glaciolacustrine deposits are found throughout the Stratford till plain, where these deposits exhibit low permeability similar to that of the adjacent Rannoch Till. These fine-grained glaciolacustrine deposits represent local pondings of meltwater during deglaciation (Cooper and Clue, 1974).

Other surficial deposits in the Central Huron area include fluvial, lacustrine and organic deposits (Figure 5). Fluvial deposits, covering 2.4 % of the area, represent 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 shore of Lake Huron, covering only 0.1 % of the area. Organic deposits of peat and muck have been mapped over 0.7 % of the area, with many of the deposits located within either spillways or topographic lows within till plains.

Areas of exposed bedrock or thin drift with sporadic bedrock exposures make up only 0.1 % of the Central Huron area (Table 9). Exposed bedrock is found within the channel of the Maitland River downstream of the Wyoming Moraine and on the floor of the Middle Maitland River near the east edge of the area (Figure 5).

Table 10 presents a summary of the permeability of the various surficial deposits mapped within the Central Huron area and within the Municipality. 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 10 Texture-derived permeability of surficial deposits.

	Texture-derived permeability[1] (expressed as % of area)				
	Low	Low-medium	Medium-high	High	Variable
Municipality of Central Huron	55.3	0.3	0.0	42.4	2.0
Central Huron area	59.2	7.3	0.0	31.0	2.5

[1]Permeability based on OGS (2010)

5.3 Surficial deposits within the Municipality

Drift thickness in the Municipality ranges from zero to 80 m, with an average of 31 m. The thickest drift (40-80 m) occurs in the western part of the community in association with the Wyoming Moraine (Figure 14). The thinnest drift occurs along the Maitland and South Maitland rivers, where bedrock is exposed locally in the channels. Relatively thin drift is also found within a broad area extending along the southeast boundary of the Municipality, within the Stratford till plain.

The Stratford till plain extends into the eastern corner of the Municipality (Figure 6, Inset A), where Rannoch Till is the dominant surface material (Figure 5). In addition to being one of the areas of thinnest (0-20 m) drift in the Municipality, this area was also shown to be the largest of the low relief areas delineated on Figure 10. Both the Rannoch Till and the adjacent fine-grained glaciolacustrine deposits common in this area are of low permeability. Thus, this part of the Municipality is characterized by thin drift, low relief, high elevation and low permeability within surficial deposits.

The central part of the Municipality is dominated by a very hummocky and irregular topography underlain largely by glaciofluvial deposits associated with the Wawanosh Moraine (Figure 5).

Ice-contact deposits of sand and gravel are abundant in this area. The Wawanosh Moraine formed in an interlobate deltaic environment during the interaction of the advancing Huron and retreating Georgian Bay ice lobes when the Rannoch and Elma tills were being deposited (Cooper and Fitzgerald, 1977; Cowan et al., 1986). The ice-contact deposits in the Wawanosh Moraine overlie Elma Till and locally underlie Rannoch Till (Cooper et al., 1977). Thus, the aquifers in the ice-contact deposits are in some locations confined by Rannoch Till, while in others they are unconfined. Chapman and Putnam (2007) describe the Wawanosh Moraine as a complex of low glacial till ridges and hills of sand and gravel in which the gravelly knobs invariably stand up as the highest peaks, while the less rugged parts of the moraine are generally of silt to silty clay till. Gravel trains and sandy outwash are also common in depressions on the moraine.

The Wyoming Moraine represents a north-south trending band of hummocky topography about 5 to 6 km wide located in the western part of the Municipality (Figure 6). A network of meltwater channels extends between the Wawanosh and Wyoming moraines and in the valleys of the Maitland and Bayfield rivers (Figure 5). One of the largest areas of outwash is a broad flat meltwater channel extending north and south of Holmesville (Figure 5). The outwash deposits near Holmesville and along the Maitland River and, to a lesser extent, the Bayfield River were reported to contain large quantities of good quality aggregate (Cooper and Fitzgerald, 1977). Most of the Wyoming Moraine is underlain by St. Joseph Till, which is a silt to silty clay till that has incorporated underlying fine-grained sediments (Cooper and Fitzgerald, 1977). Several facies are present within the St. Joseph Till, including stiff basal till, sheared and deformed clay and silt, and till with interbeds of sand and silt (Cowan et al., 1986; Broster, 1982). Therefore, between the sand and gravel in the spillways and other topographic lows and the silts and clays in the till ridges and other topographic highs, the Wyoming Moraine is characterized by strong topographically controlled contrasts in permeability.

The westernmost part of the Municipality, west of the glacial Lake Warren beaches (Figure 6), is characterized by a bevelled till plain with shallow deposits of sand, silt and clay (Cooper and Fitzgerald, 1977). The shallow sand deposits below the glacial Lake Warren beaches typically consist of stratified sand 0.6 to 1.2 m in thickness (Chapman and Putnam, 2007), with silty clay till (St. Joseph Till) of low permeability underlying this sandy veneer. The St. Joseph Till is reported to be 2 to 3 m thick and resting on stratified clay (Chapman and Putnam, 2007). Therefore, the westernmost part of the Municipality is dominated by a highly permeable veneer of sand resting over several metres of silts and clays of low permeability.

Exposed bedrock is mapped in 0.1 % of the Municipality, all of which is found within the channel of the Maitland River (Figure 5).

6 GROUNDWATER

A detailed discussion of the hydrogeology of the Central Huron area is provided by Geofirma Engineering Ltd. (2015). 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 that provide drinking water supplies to residences and shallow confined bedrock aquifers that provide water supplies to both municipalities and residences (Waterloo Hydrogeologic Inc., 2007). The shallow groundwater regime typically extends to depths of less than 60 m. 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 Central Huron area is provided in the Provincial Source Water Protection Assessment Reports (Ausable Bayfield Maitland 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 Central Huron area. 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., 2007). 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 (Ausable Bayfield Maitland Source Protection Region, 2011a; 2011b). Within the Central Huron area, all groundwater-based municipal drinking water supplies are sourced from shallow bedrock aquifers.

Figure 5 shows that glacial overburden deposits in the Central Huron area 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., 2007). The more permeable glaciofluvial deposits, which are exposed at surface in the central part of the Municipality and along Lake Huron, 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. Unconfined shallow overburden aquifers within the Municipality occur within spillway and outwash deposits near Holmesville and within the Wawanosh Moraine, and in sand and gravel deposits of the glacial Lake Warren and Lake Huron shorelines.

Throughout the Municipality and the Central Huron area the shallow bedrock aquifer, consisting of the Dundee Formation limestone and to a lesser extent the Lucas Formation limestone, is confined by overlying layers of clay and silt till. Near the contact of the Lucas Formation with the overlying Dundee Formation in the eastern part of the Central Huron area near Brussels (Figure 4), the Lucas limestone has been associated with localized karst (i.e., sinkhole) development (Ausable Bayfield Maitland Source Protection Region, 2011b). Such areas of karst and sinkhole development in the Lucas Formation provide high quality, high yielding aquifers extensively used as sources of drinking water. Areas that drain into sinkholes are Significant Groundwater Recharge Areas under Ontario’s Clean Water Act.

Contour maps of the groundwater table surface within the overburden deposits and shallow bedrock aquifers of the Central Huron area have been prepared in the Provincial Source Water Protection Assessment Reports and in the hydrogeologic modelling report based on the large number of water wells that access the overburden and shallow bedrock for water supply (Waterloo Hydrogeologic Inc., 2007). These potentiometric surface maps show that both overburden and shallow bedrock groundwater within the Municipality flows broadly to the west from the highland areas along the eastern edge of the area (Figure 7) towards Lake Huron, similar to surface water flow within the Ausable and Maitland Valley watersheds (Figure 13). The potentiometric surface for the shallow bedrock is within the overlying tills confirming the hydrogeological confinement of the shallow bedrock aquifer.

7 NEOTECTONIC FEATURES

The Central Huron area 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), north of the Central Huron area, represents the best available neotectonic investigation completed in this region. The study used desktop and field-based methods to search for evidence of paleoseismicity in Quaternary deposits within 50 km of the Bruce nuclear site, which is located about 50 km north of the Central Huron area. 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. All of the features initially identified using air photos and LiDAR data as potential neotectonic features, such as offset landforms (e.g., ancient beaches and shore bluffs), were later explained by causes other than paleoseismicity. Some of these features were related to anthropogenic causes, such as road building and residential development, while others were related to natural causes such as differential erosion. Liquefaction features related to seismic events as recent as 500 to 1,000 years ago were stated to be impossible to identify in map view despite the use of air photographs and satellite imagery. All of the observations made in sediment exposures were explained by causes other than paleoseismicity. As a result, 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 Central Huron area contains a dense network of highways and local 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 Central Huron area is high and is generally uniform except for some local areas of lower density.

The main accessibility constraints in the Central Huron area are associated with areas of wet and swampy ground (Figure 12), and areas of relatively high relief associated with river valleys, drumlins, kames and till ridges (Figures 9 and 10). The largest flat areas within the Municipality were delineated on Figure 10. These eleven areas range in extent from 3.6 to 51.0 km^2 (Table 6).

The distance to the nearest road was computed for all points within the Central Huron area . The distances range from zero to 1,682 m, with an average of 320 m. Over 75 % of the area is within 500 m of a road. The two largest areas devoid of existing roads are located along the lower reaches of the Maitland and Bayfield rivers on the north and south boundaries of the Municipality, respectively.

9 SUMMARY

This report presents an assessment of the terrain in the onshore portion of a 44 km by 35 km region around the Municipality of Central Huron (the Central Huron area) using available remote sensing and geoscientific information sources. The main information sources relied on in this study are the 1:50,000 scale surficial mapping by the Ontario Geological Survey (Cooper and Fitzgerald, 1977; Cooper et al., 1977; Cowan et al., 1986; 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 and roads obtained from Land Information Ontario (LIO).

Quaternary glaciations have played a major role in shaping the landscape of the Central Huron area. 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 between 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 westernmost low-lying portion of the Central Huron area was submerged beneath glacial Lake Warren approximately 12,500 years ago (Figure 6, inset B).

The thickness and distribution of the various surficial deposits and associated physiographic units were reviewed. The overburden is generally thick in the Central Huron area, with values as high as 91 m and an average value of about 28 m. The largest area of thick (>40 m) drift is associated with the Wyoming Moraine, while the thinnest overburden is found within river channels, where bedrock is exposed locally, and along the eastern margin of the Municipality beneath the Stratford till plain (Figure 14). Major bedrock valleys have not been mapped in this area, although minor bedrock valleys have been described. Several moraines are present within the Central Huron area, including the Mitchell, Dublin, Seaforth, Wawanosh and Wyoming moraines (Figure 6).

Surficial deposits within the Municipality can be divided into four zones extending across the area from west to east (Figure 6). The westernmost zone is characterized by a discontinuous high permeability sand veneer draped over low permeability deposits of St. Joseph Till overlying glaciolacustrine silts and clays. The next zone eastward consists of the Wyoming Moraine and adjacent spillways. This zone of very thick drift (40 to 91 m) consists of low permeability St.

Joseph Till forming till ridges and other topographic highs, while high permeability sand and gravel outwash deposits exist in spillways and other topographic lows. The third zone consists of the Wawanosh Moraine and adjacent spillways. In this zone, highly permeable and locally very thick ice-contact sand and gravel forms kames and other topographic highs, while outwash sand and gravel is exposed in spillways and other topographic lows. Low permeability Rannoch Till has been deposited over some of the ice-contact and outwash deposits, rendering some of the sand and gravel deposits as confined aquifers. The easternmost zone, which exhibits the highest elevations of the four zones, is represented by the Stratford till plain. This is the largest area of low relief and the largest area of thin drift within the Municipality, an area underlain largely by Rannoch Till and sporadic deposits of glaciolacustrine silts and clays.

The large-scale pattern of elevation across the Central Huron area (Figure 7) controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from west (Lake Huron) to east is from 176 to 366 m, with the highest elevations located along the Mitchell Moraine.

Relief within a given radius was calculated as the range in elevation and as the departure from the average elevation. As the detailed topography in the Central Huron area is predominantly controlled by surficial deposits, the elevation departures within 2 km and 20 km radii were useful for highlighting the areas of relatively thin or thick drift (Figures 8 & 9). For example, kames and till ridges were shown to stand from 5 to 35 m above the adjacent terrain. A map showing the range in elevation within a 250 m radius enabled the delineation of a set of large areas of low relief, areas that were characterized in terms of their elevation, landforms, surficial deposit permeability, and areal extent.

Apart from Lake Huron, the map area contains no large lakes, with waterbodies covering 11.0 km^2 or 0.8 % of the onshore portion of the map area (Figure 12). Several provincially significant wetland complexes are present within the Central Huron area, including the Saratoga Complex, Westfield Complex, Morris Creek Complex, Sunshine Tract, Blyth Brook Headwater Complex, Hullett Marsh Complex, Holmesville Creek Complex, and Tricks Creek Complex. In total, wetlands cover 78.4 km^2 or 5.6 % of the Central Huron area. The Hullett Marsh Complex, located in the southeast corner of the Municipality, is one of the largest wetland complexes in the area and is one of the more significant wildlife habitat developments in Eastern Canada.

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 Central Huron area 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 west toward Lake Huron. Surface flow over the vast majority of the Central Huron area is directed through the Maitland and Bayfield rivers and their tributaries (Figure 13).

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 confined 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 Central Huron area 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 Central Huron area, often forming unconfined shallow overburden aquifers that are locally important sources of drinking water.

Although the Central Huron area 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 to the north of this 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 Central Huron area contains a dense network of highways and local roads that could be used to gain access for site characterization (Figure 15). The main accessibility constraints in the area represent areas of wet and swampy ground, and areas of high relief associated with river valleys, drumlins, till ridges and kames. The distance to the nearest road was computed, revealing that over 75 % of the area is within 500 m of a road. Two of the larger areas devoid of existing roads are located along the lower reaches of the Maitland and Bayfield rivers.

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REPORT SIGNATURE PAGE

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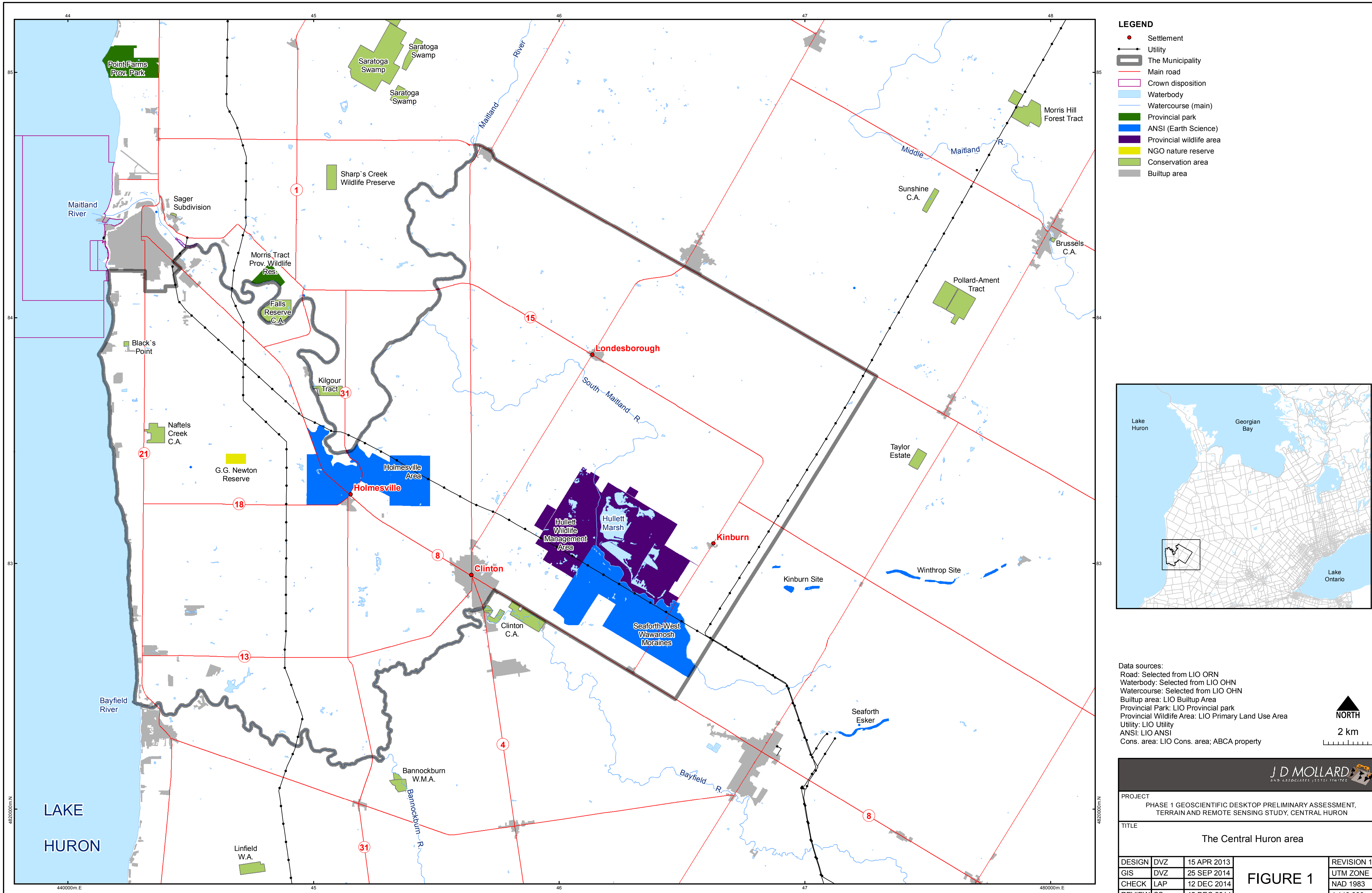
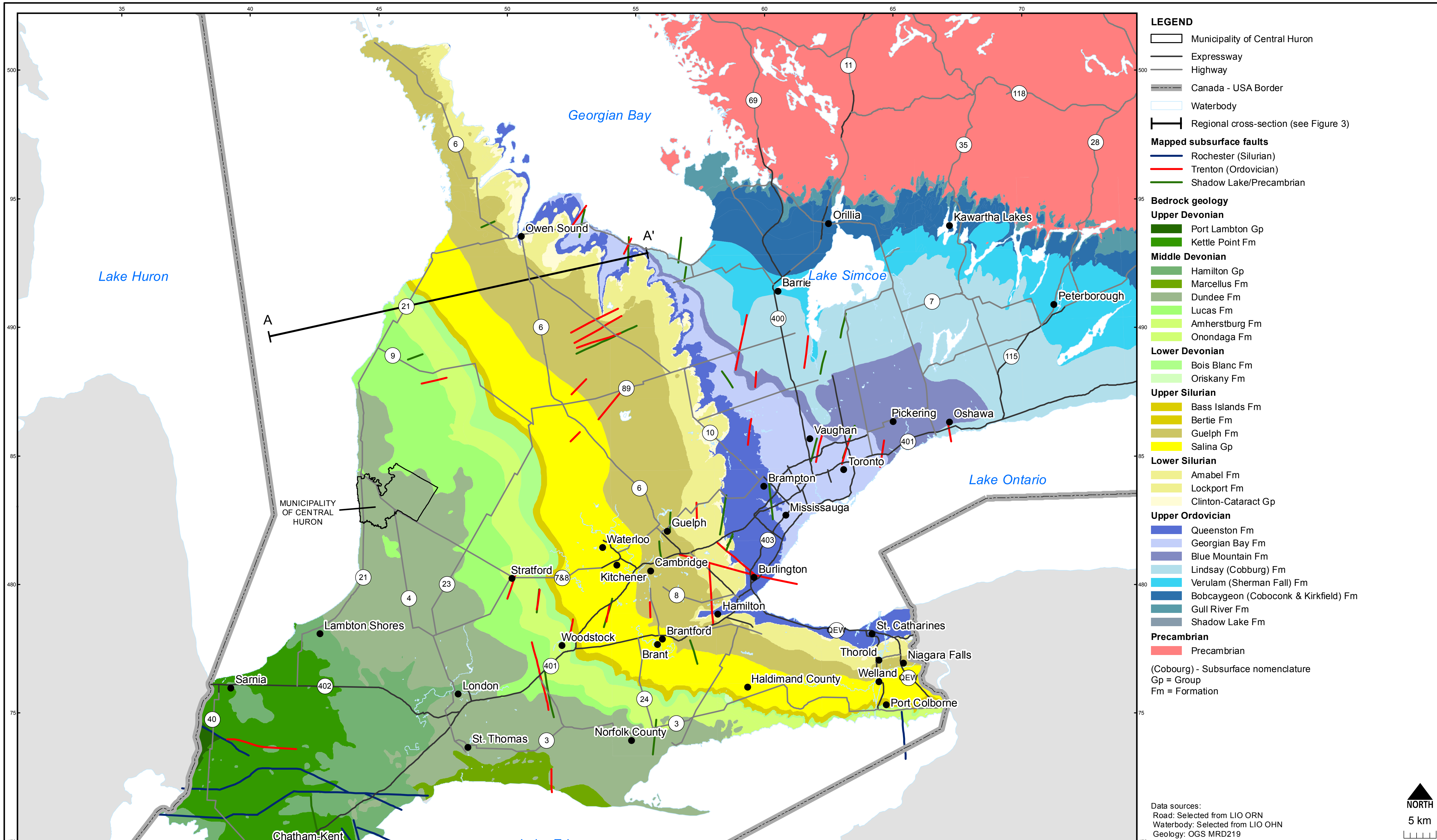
FIGURES


LEGEND
Settlement
Utility
The Municipality
Main road
Crown disposition
Waterbody
Watercourse (main)
Provincial park
ANSI (Earth Science)
Provincial wildlife area
NGO nature reserve
Conservation area
Builtup area
Point Farms Prov. Park
Saratoga Swamp
Saratoga Swamp
Saratoga Swamp
Maitland River
Sharp`s Creek Wildlife Preserve
Maitland River
Sager Subdivision
Morris Tract Prov. Wildlife Res.
Falls Reserve C.A.
Black`s Point
Kilgour Tract
Naftels Creek C.A.
G.G. Newton Reserve
Holmesville Area
Holmesville
Londesborough
South Maitland R.
Hullett Wildlife Management Area
Hullett Marsh
Kinburn
Clinton
Clinton C.A.
Seaforth-West Wawanosh Moraines
Kinburn Site
Winthrop Site
Seaforth Esker
Bayfield R.
Bayfield River
Bannockburn W.M.A.
Bannockburn R.
Linfield W.A.
LAKE HURON
Morris Hill Forest Tract
Middle Maitland R.
Sunshine C.A.
Brussels C.A.
Pollard-Ament Tract
Taylor Estate
1
15
31
21
18
8
13
4
31
8
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
Provincial Wildlife Area: LIO Primary Land Use Area
Utility: LIO Utility
ANSI: LIO ANSI
Cons. area: LIO Cons. area; ABCA property
NORTH
2 km
J D MOLLARD
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON
TITLE
The Central Huron area
DESIGN DVZ 15 APR 2013
GIS DVZ 25 SEP 2014
CHECK LAP 12 DEC 2014
REVIEW SS 12 DEC 2014
FIGURE 1
REVISION 1
UTM ZONE 17
NAD 1983
1:140,000
440000m.E
480000m.E
4820000m.N



J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Bedrock geology of southern Ontario

DESIGN	DVZ	15 APR 2013	FIGURE 2	REVISION 2
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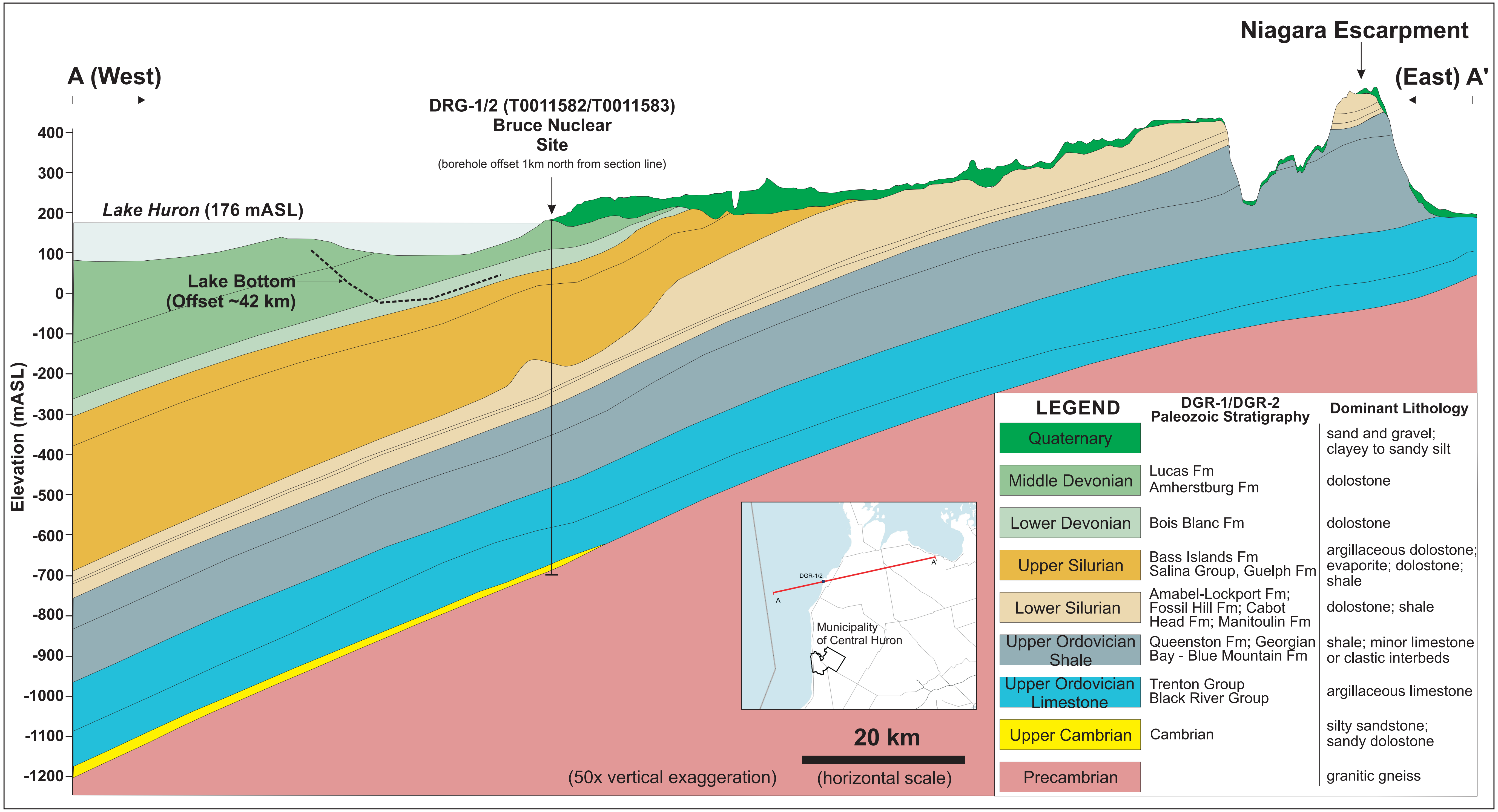
CHECK	LAP	08 SEP 2015		NAD 1983
REVIEW	SS	08 SEP 2015		1:1,500,000



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PROJECT

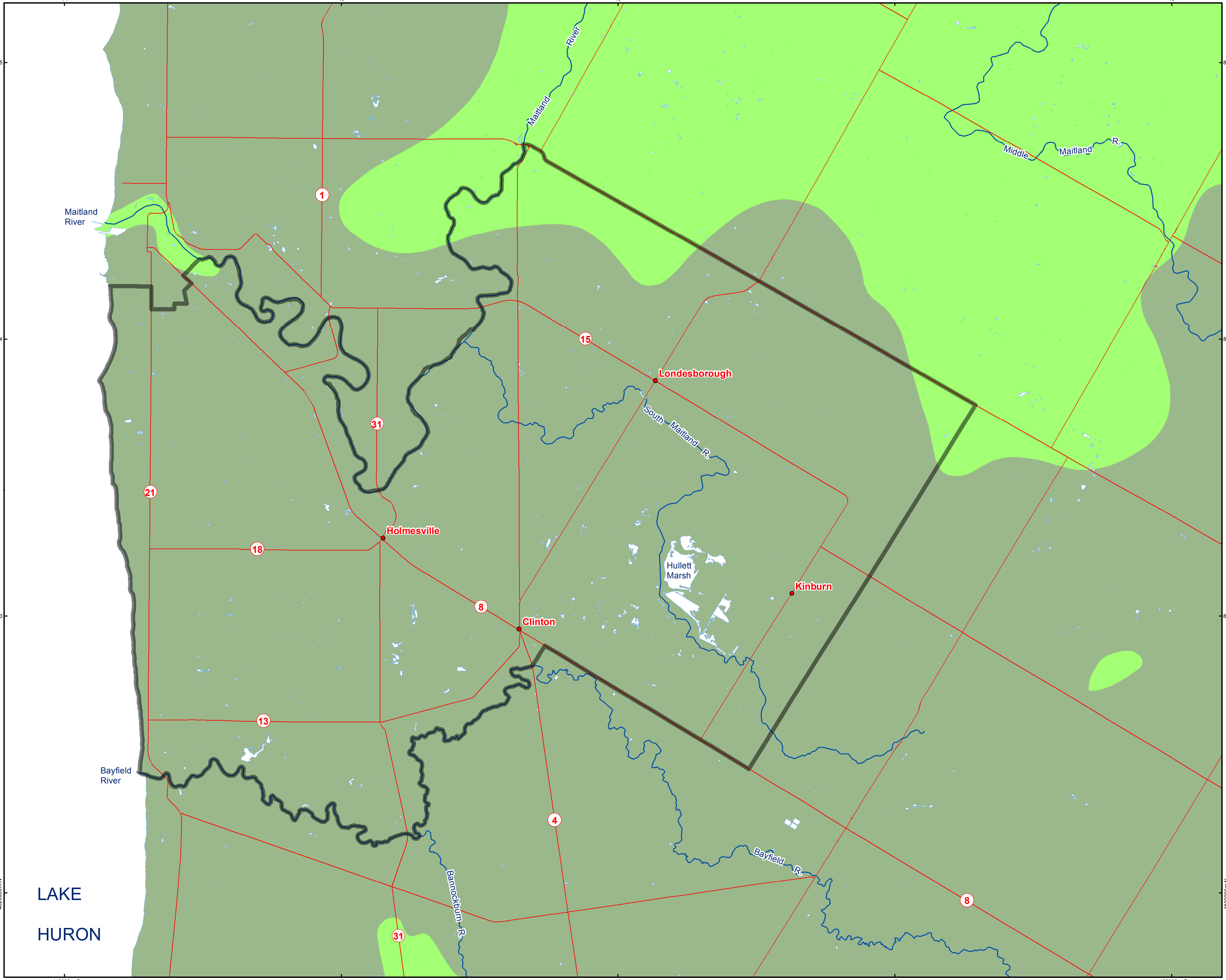
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE

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

DESIGN	NMP	15 APR 2013	FIGURE 3	REVISION 1
GIS	DVZ	12 DEC 2014		
REVIEW	LAP	12 DEC 2014		

Data source: NWMO, 2011



LEGEND

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

Bedrock geology

Middle Devonian

- Dundee
- Lucas

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

NORTH

2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Bedrock geology of the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 4	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
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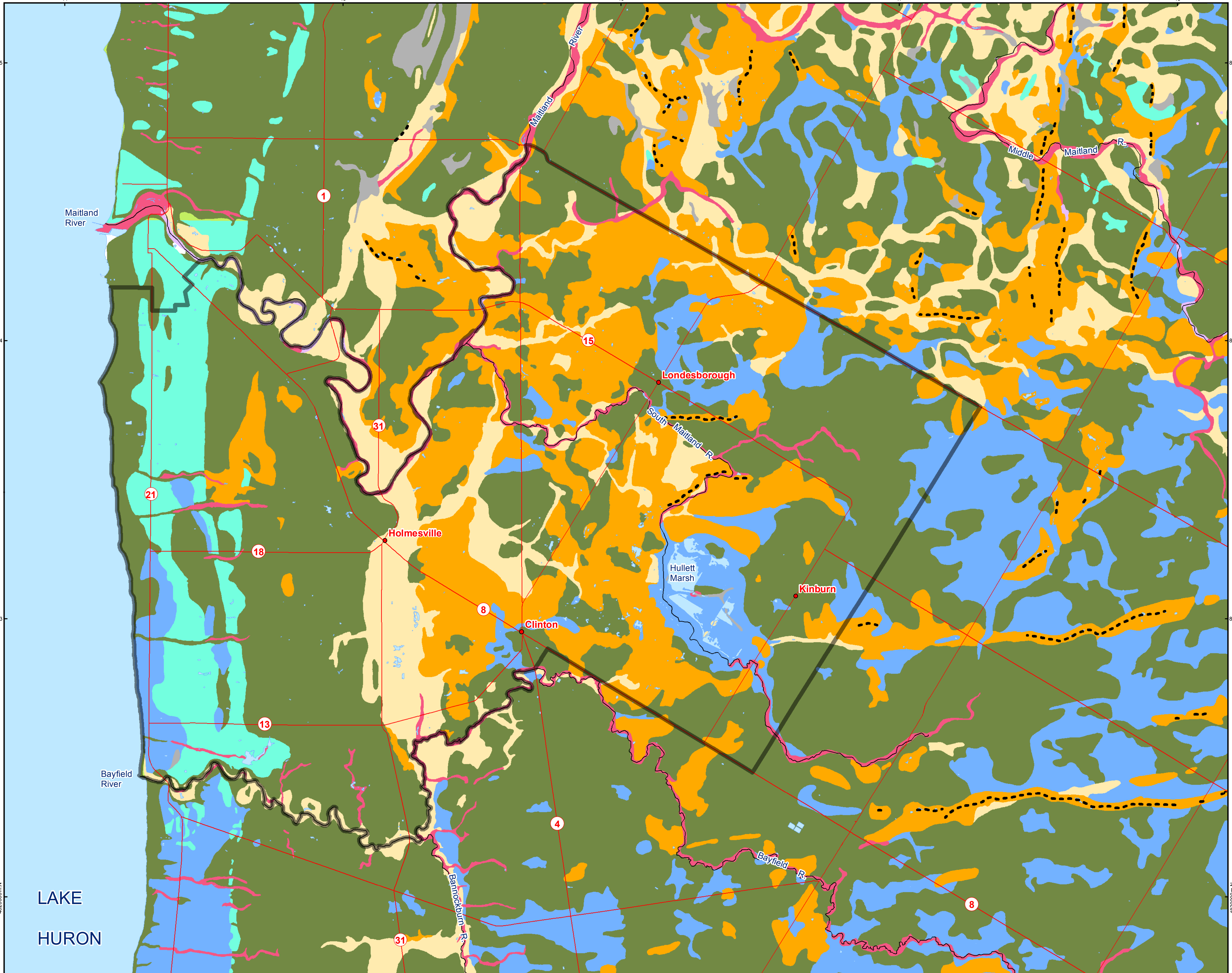
REVIEW	SS	16 OCT 2014		1:140,000



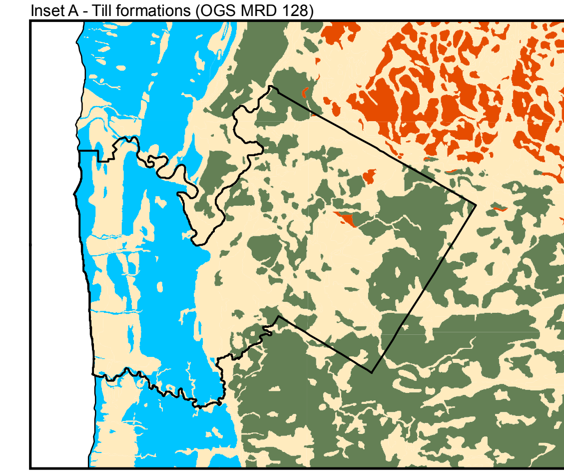
LEGEND

- Settlement
- The Municipality
- Esker
- Main road
- Waterbody
- Watercourse (main)

Surficial deposit

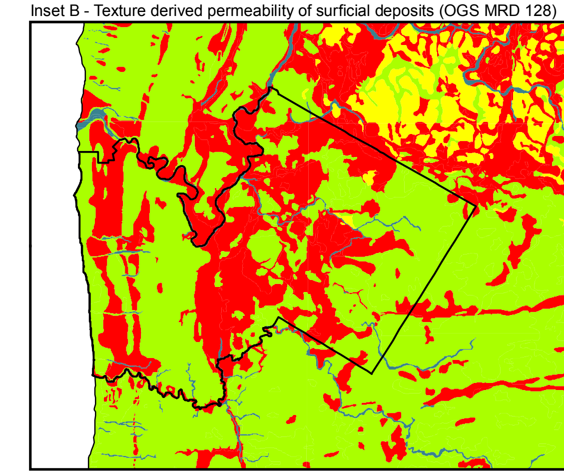
- Wetland
- Colluvial
- Lacustrine
- Fluvial
- Aeolian
- Glaciolacustrine (coarse)
- Glaciolacustrine (fine)
- Glaciofluvial (ice-contact)
- Glaciofluvial (outwash)
- Glacial (morainal)
- Bedrock-drift complex

Inset A - Till formations (OGS MRD 128)



Nonglacial   Elma Till   Rannoch Till   St Joseph Till

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



High   Low-Medium   Low   Variable

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

NORTH

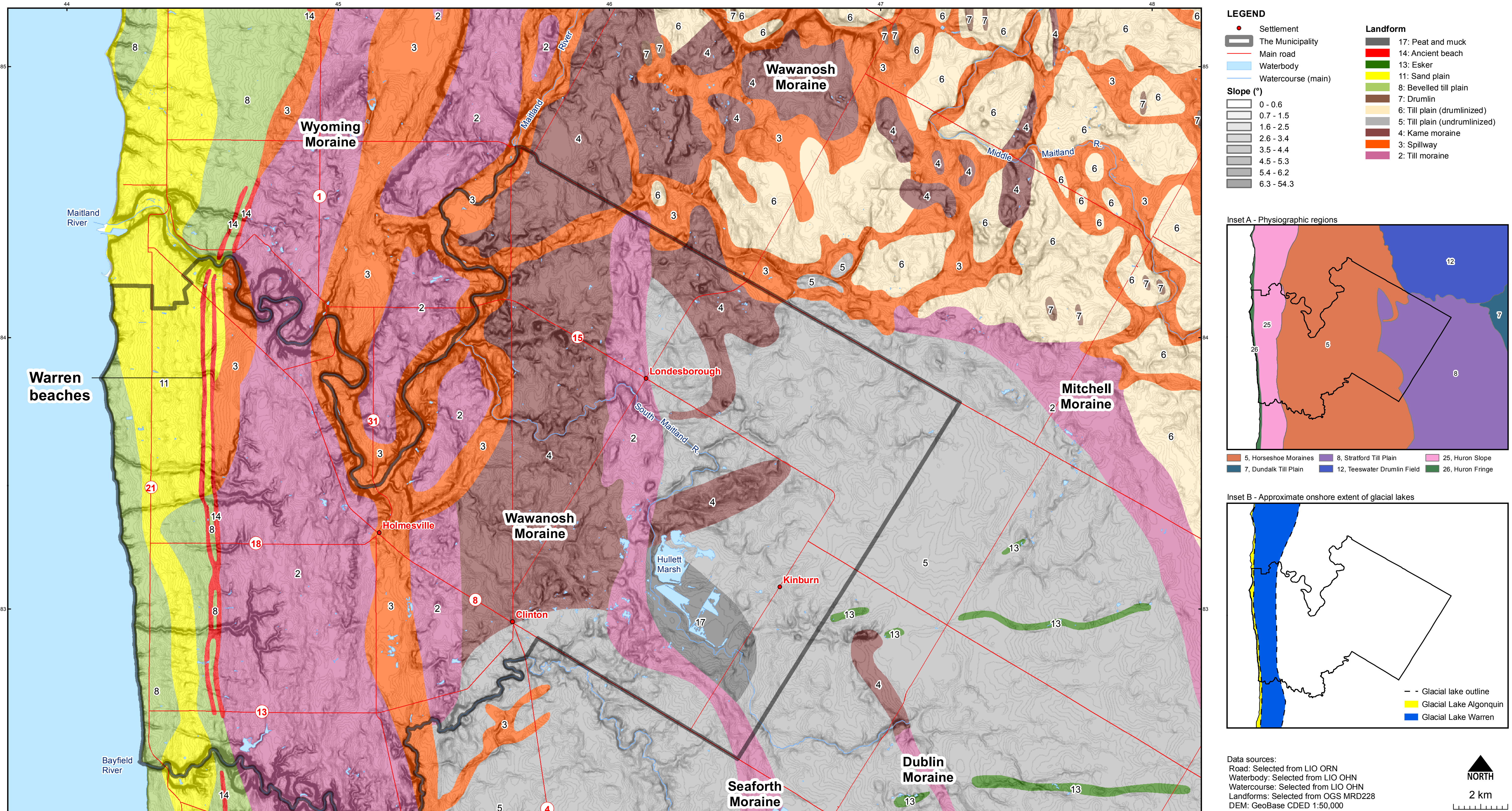
2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Surficial geology of the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 5	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



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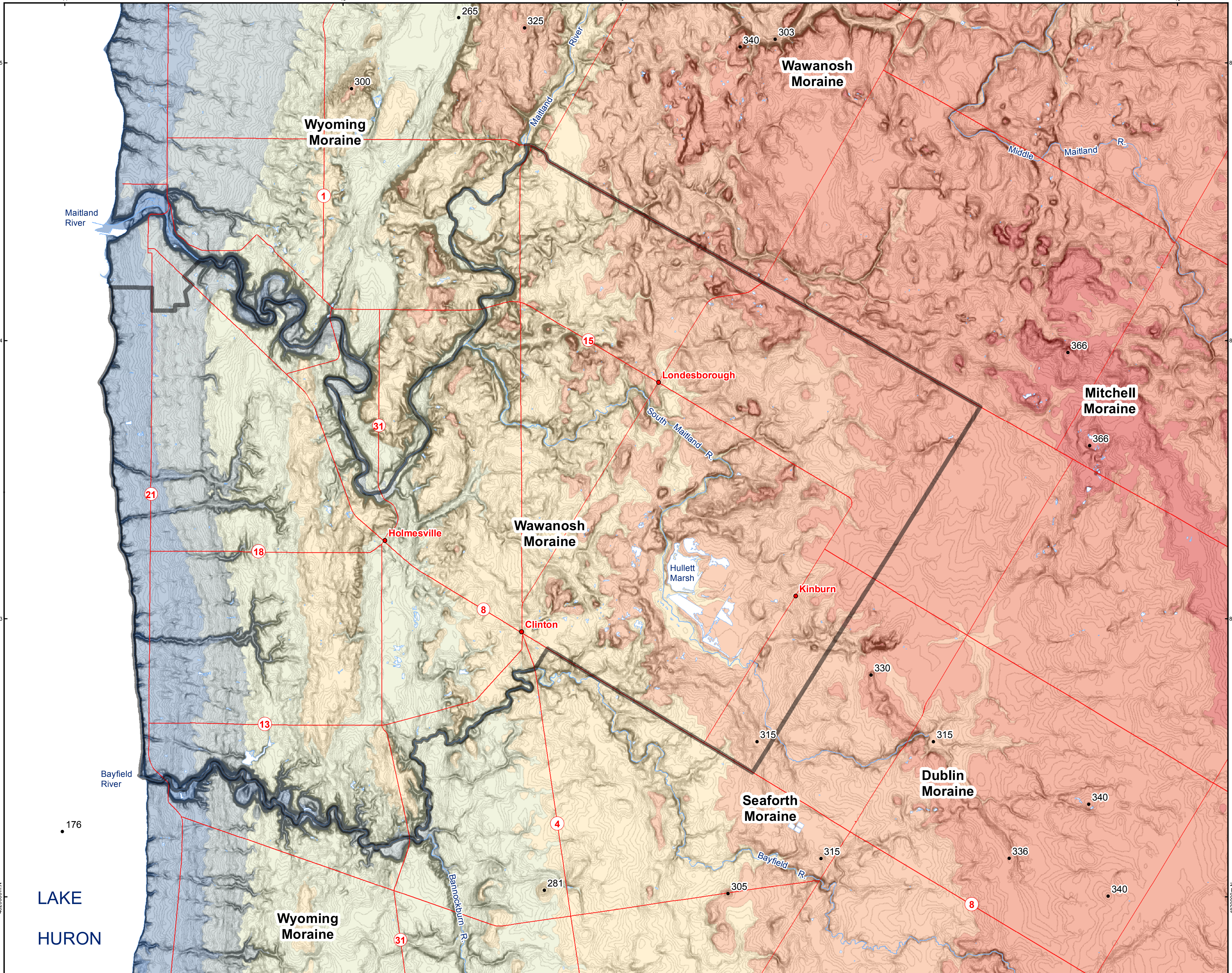
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Surficial landforms of the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 6	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



LEGEND

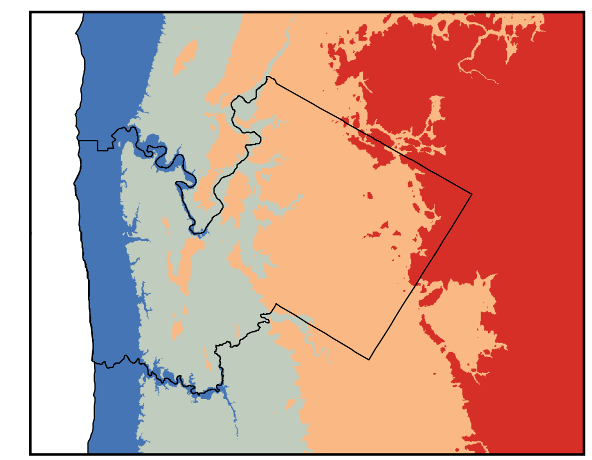
- Settlement
- Spot height (m)
- The Municipality
- Main road
- Waterbody
- Watercourse (main)

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 - 192
- 193 - 218
- 219 - 245
- 246 - 271
- 272 - 297
- 298 - 324
- 325 - 350
- 351 - 366



Elevation (m)

- 176 - 245
- 246 - 280
- 281 - 325
- 326 - 366

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

NORTH

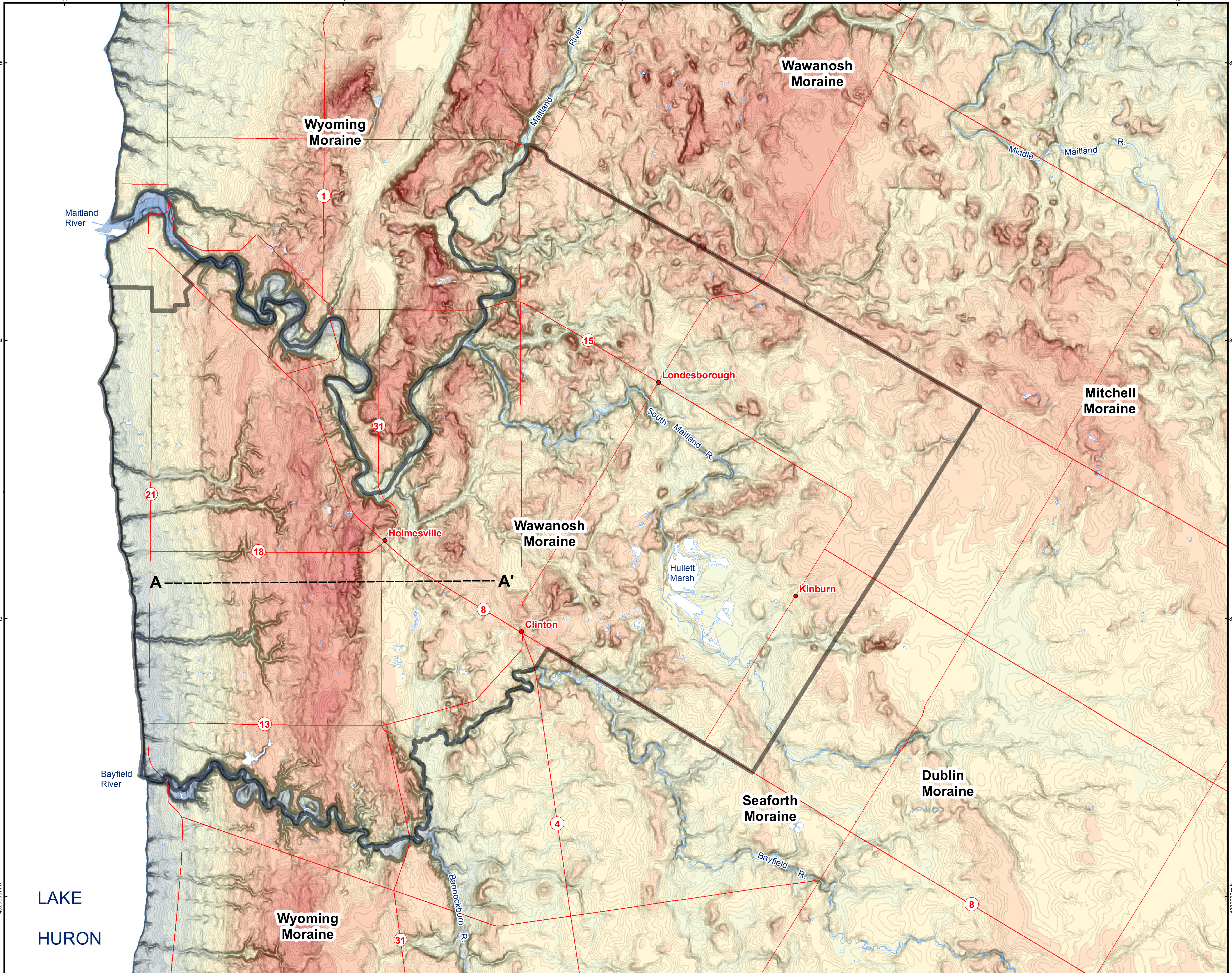
2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Elevation within the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 7	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



LEGEND

- Settlement
- The Municipality
- Main road
- Slope profile
- Waterbody
- Watercourse (main)

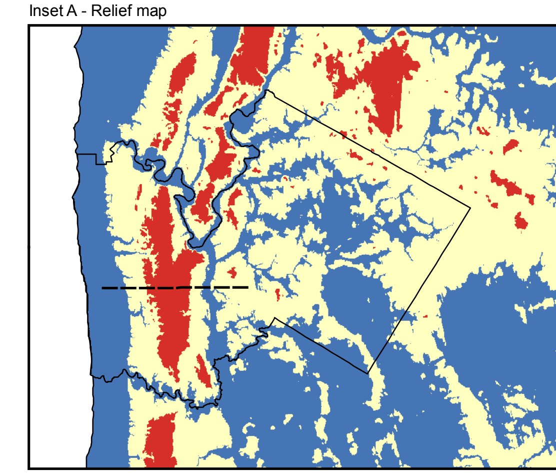
Slope (°)

- 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)

- -44 - -42
- -41 - -33
- -32 - -25
- -24 - -17
- -16 - -9
- -8 - -1
- 0 - 7
- 8 - 15
- 16 - 23
- 24 - 31
- 32 - 39
- 40 - 52

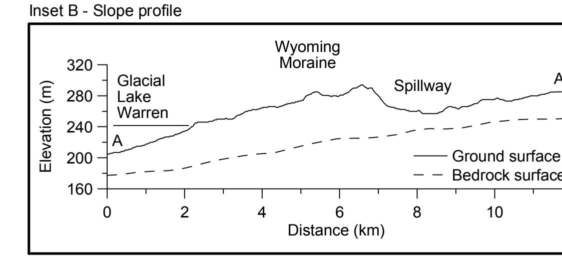
Inset A - Relief map



Relief (m)

- -44 - 5
- 6 - 25
- 26 - 52

Inset B - Slope profile



Vertical exageration = 20

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

NORTH

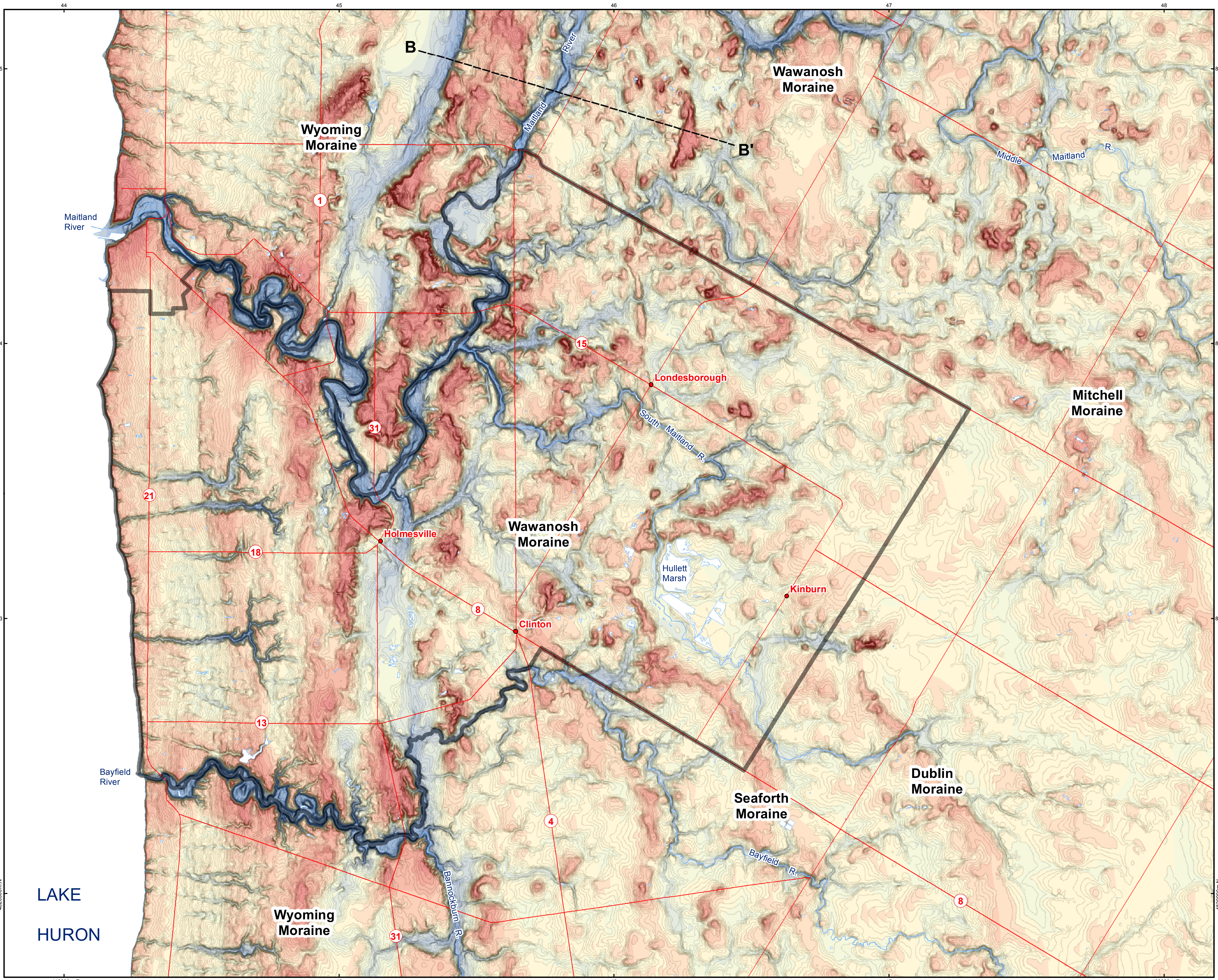
2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Elevation departure within 20 km radius

DESIGN	DVZ	15 APR 2013	FIGURE 8	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



LEGEND

- Settlement
- The Municipality
- Main road
- Slope profile
- Waterbody
- Watercourse (main)

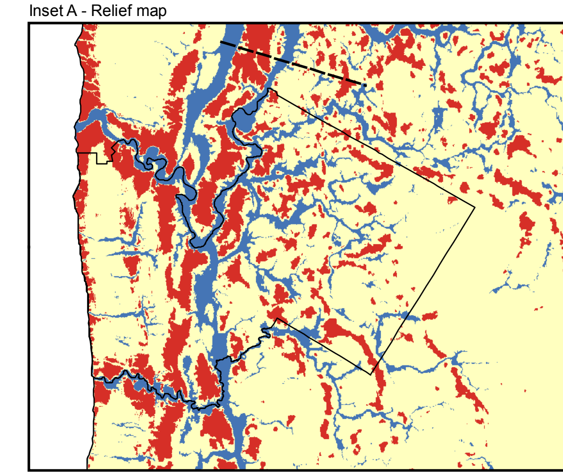
Slope (°)

- 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)

- -44 - -17
- -16 - -14
- -13 - -11
- -10 - -8
- -7 - -5
- -4 - -2
- -1 - 1
- 2 - 4
- 5 - 8
- 9 - 11
- 12 - 14
- 15 - 37

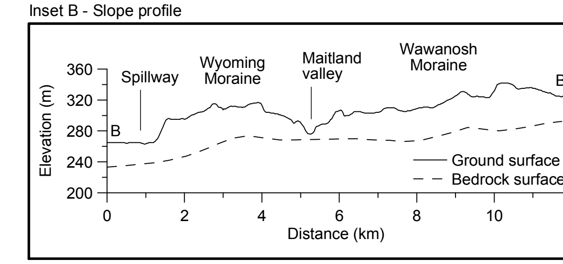
Inset A - Relief map



Relief (m)

- -44 - -5
- -4 - 5
- 6 - 37

Inset B - Slope profile



Vertical exageration = 20

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

NORTH

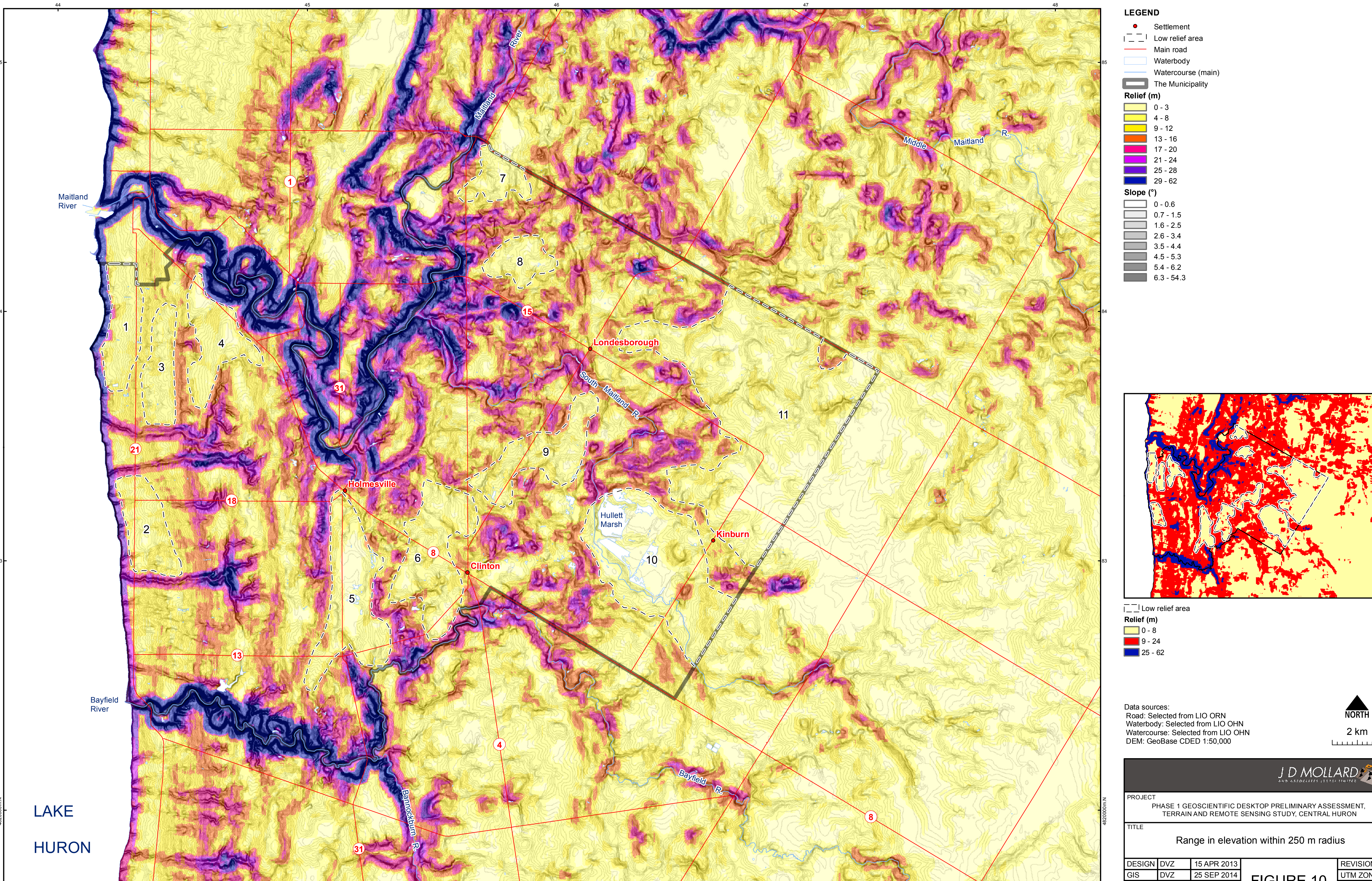
2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Elevation departure within 2 km radius

DESIGN	DVZ	15 APR 2013	FIGURE 9	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



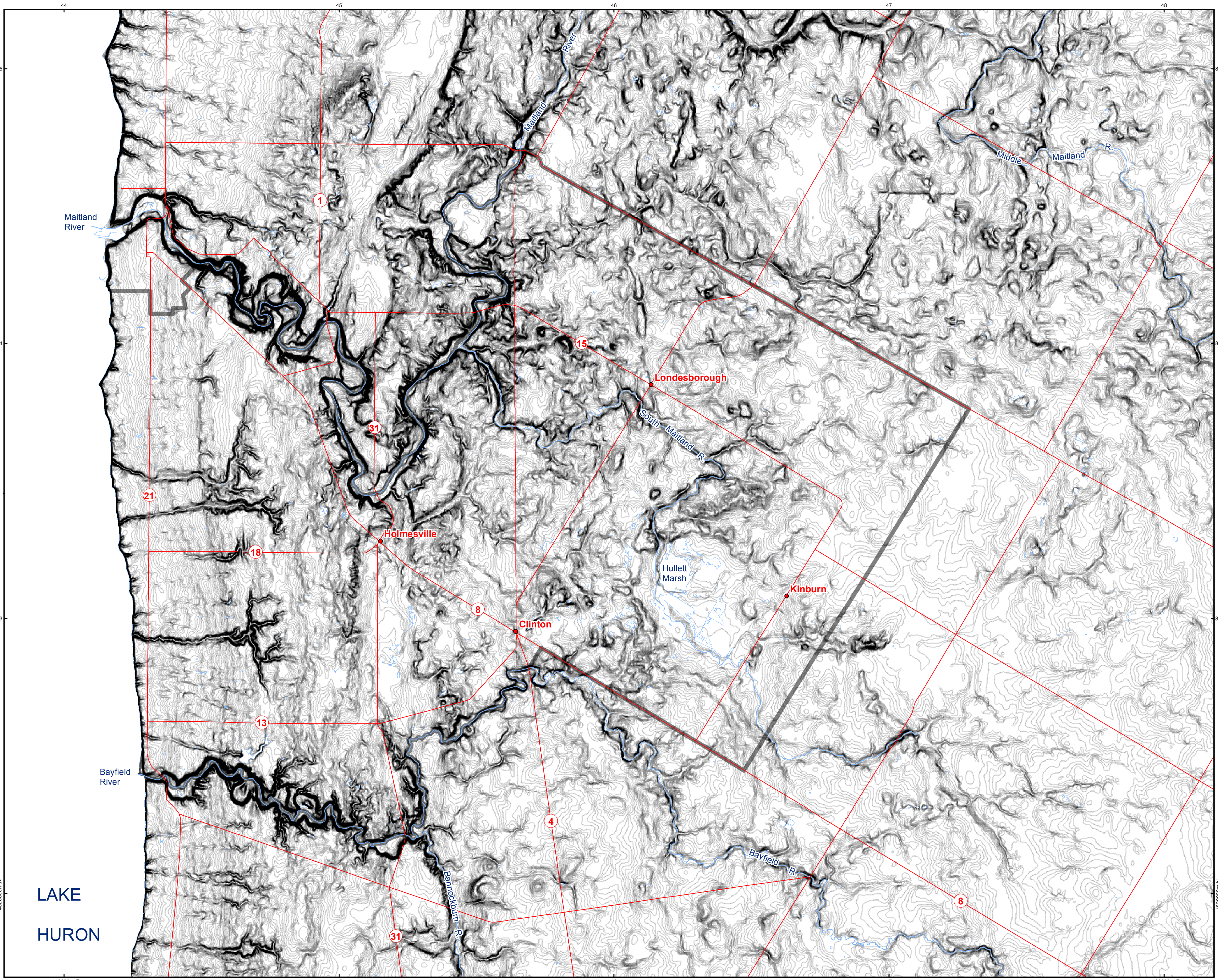
Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
DEM: GeoBase CDED 1:50,000

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Range in elevation within 250 m radius

DESIGN	DVZ	15 APR 2013	FIGURE 10	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000

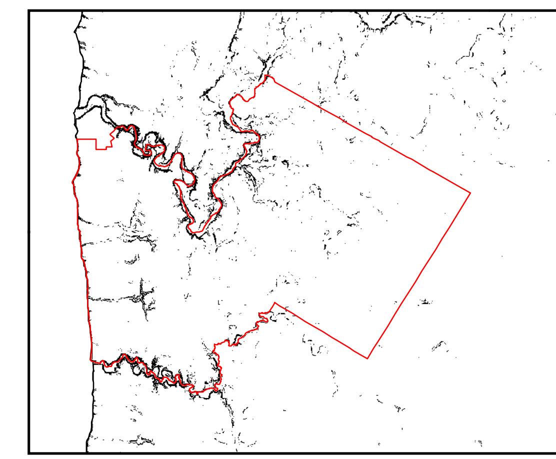


LEGEND

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

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



Slope (°)

- 0 - 6
- 7 - 54

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

NORTH

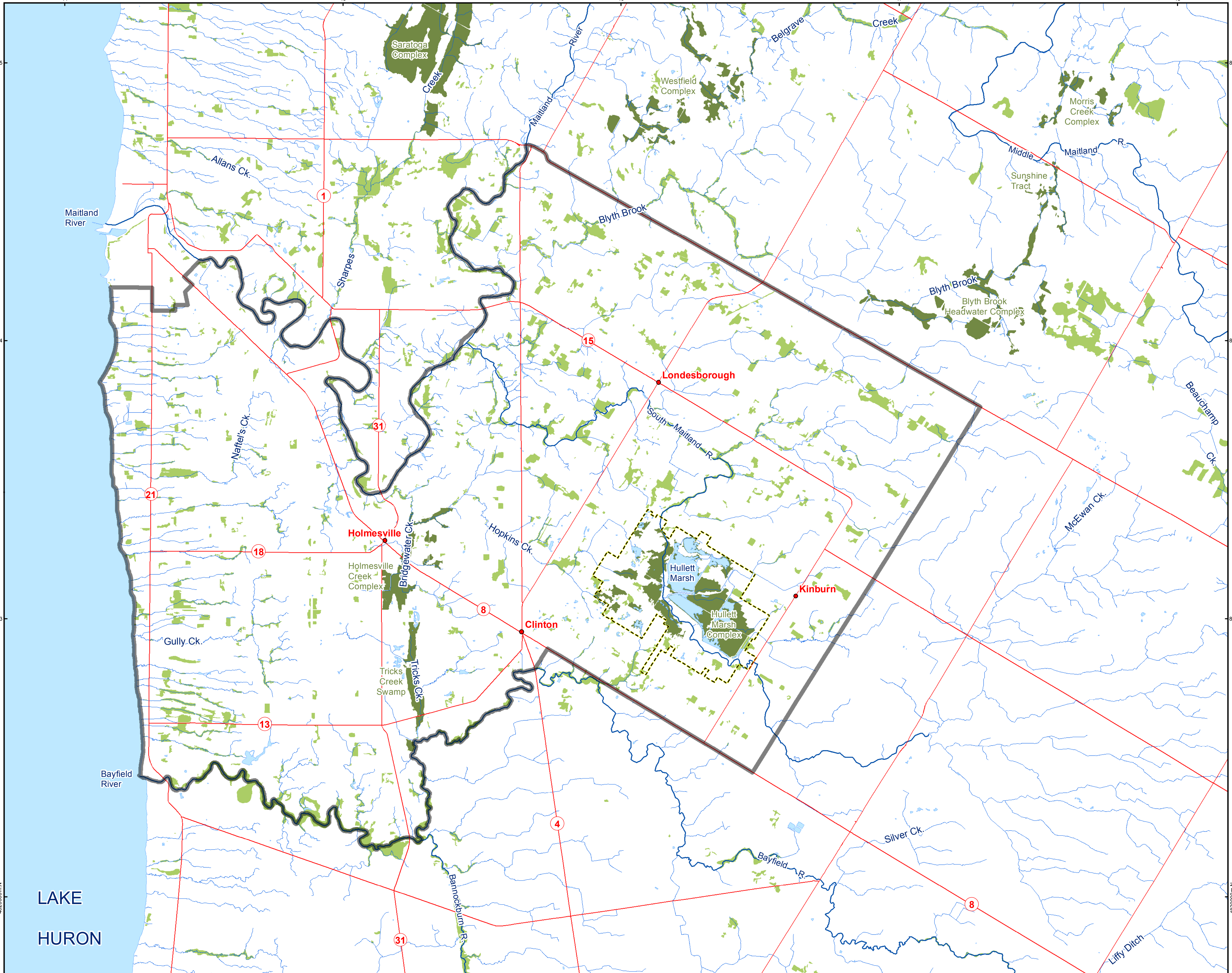
2 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Slope within the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 11	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



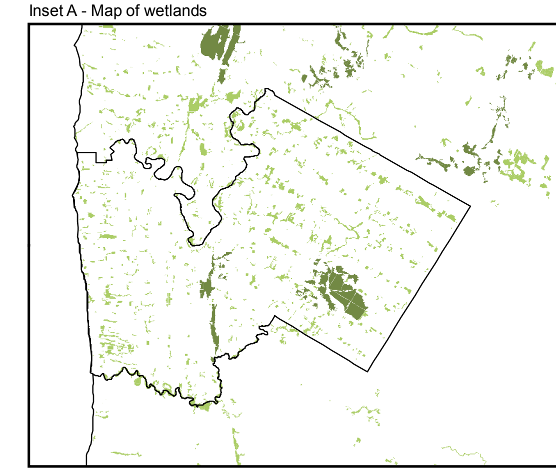
LEGEND

- Settlement
- The Municipality
- Main road
- Hullett Wildlife Management Area
- Waterbody
- Watercourse (main)
- Watercourse (other)

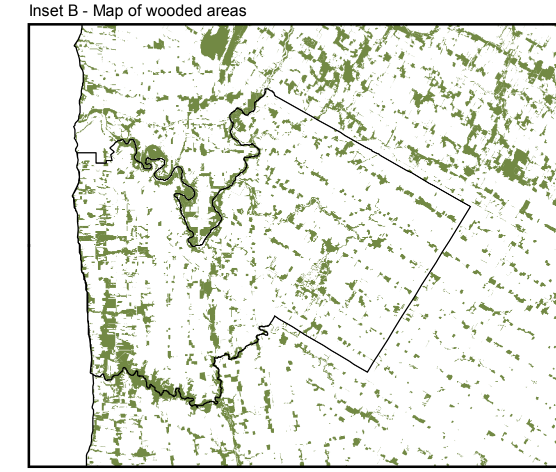
Wetland

- Other wetland
- Provincially significant

Inset A - Map of wetlands



Inset B - Map of wooded areas



Data sources:
Road: Selected from LIO ORN
Waterbody: LIO Waterbody OHN
Watercourse: LIO Watercourse OHN
Wetland: LIO Wetland; ABCA wetland
Wooded area: LIO Wooded Area

NORTH

2 km

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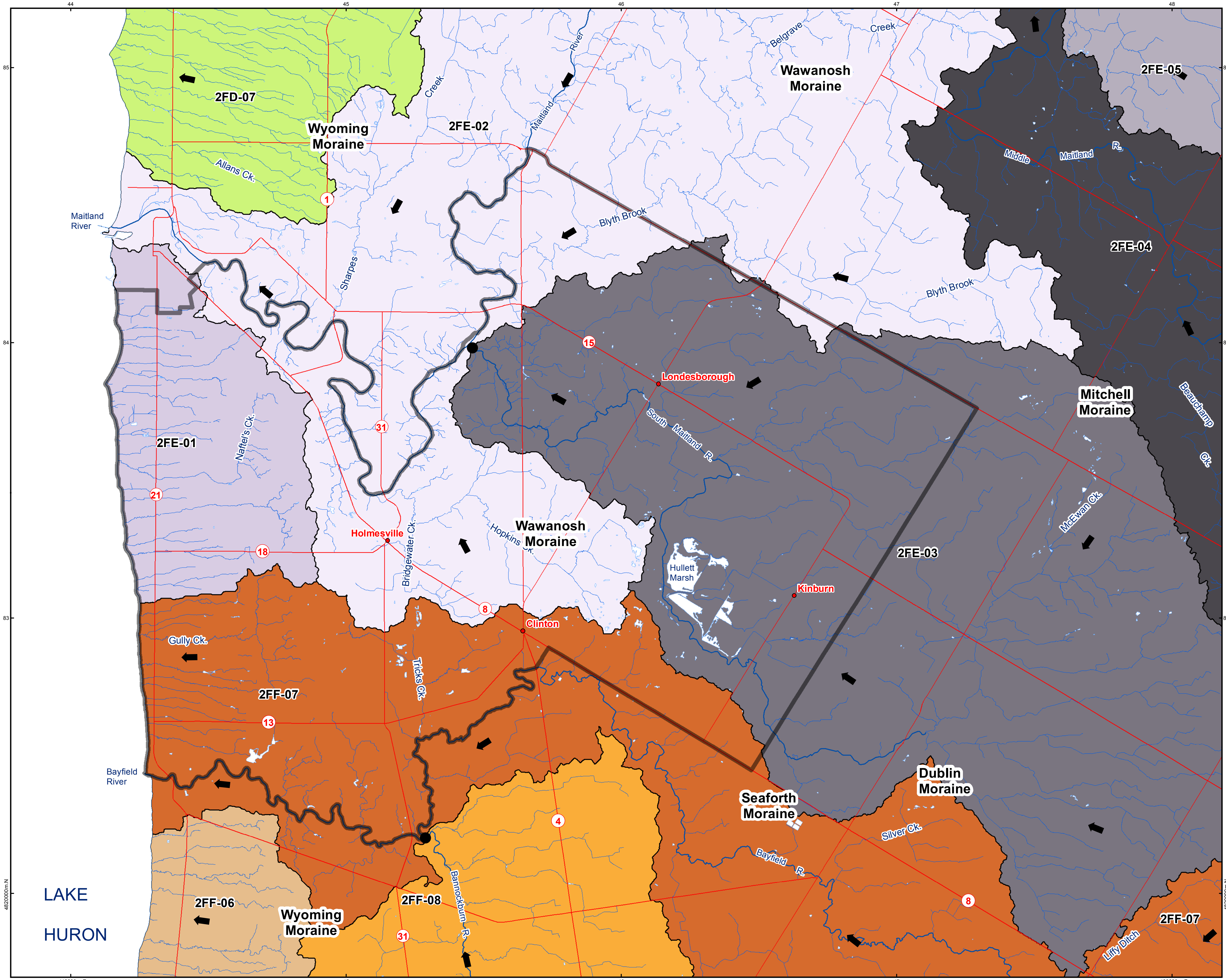
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Drainage features of the Central Huron area

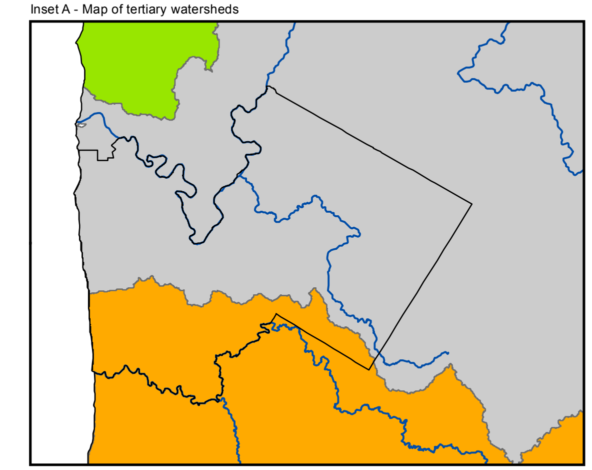
DESIGN	DVZ	15 APR 2013	FIGURE 12	REVISION 1
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	12 DEC 2014		NAD 1983
REVIEW	SS	12 DEC 2014		1:140,000



LEGEND

- Settlement
- Flow direction
- Watershed outflow
- The Municipality
- Main road
- Waterbody
- Watercourse (main)
- Watercourse (other)
- Quaternary watershed

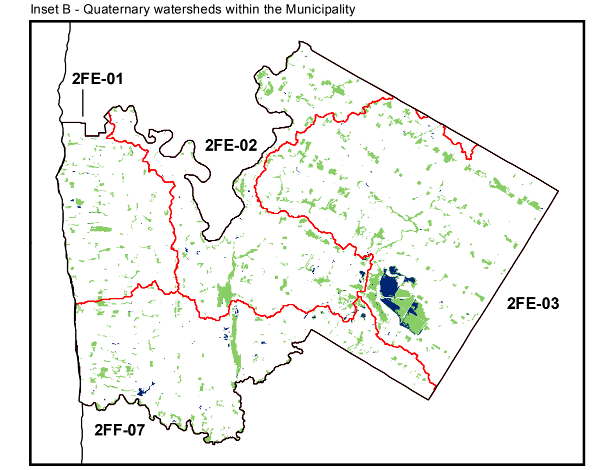
Inset A - Map of tertiary watersheds



Tertiary watershed

- Ausable watershed
- Maitland watershed
- Penetangore watershed

Inset B - Quaternary watersheds within the Municipality



- Watershed
- Waterbody
- Wetland

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

NORTH

2 km

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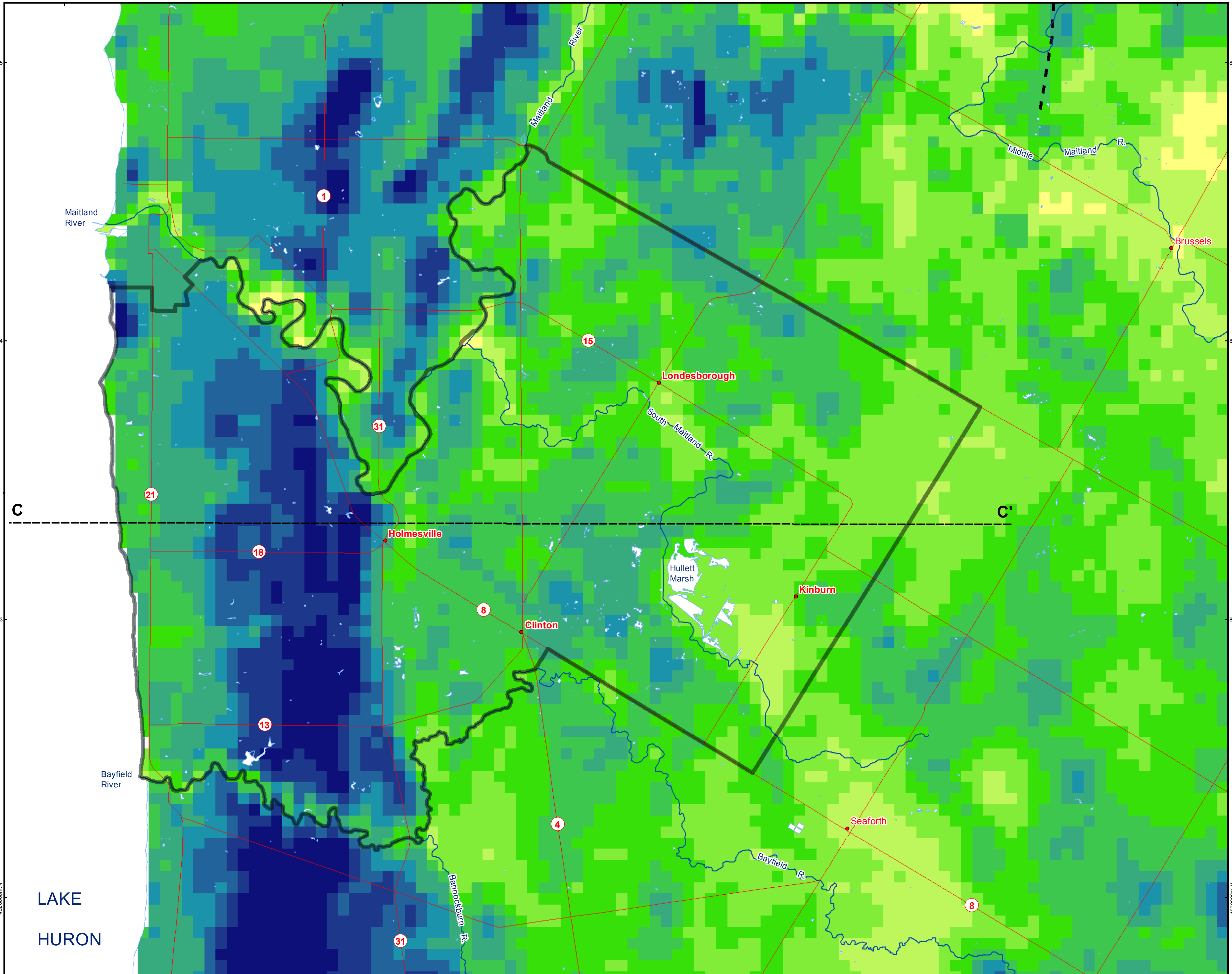
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Watersheds of the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 13	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



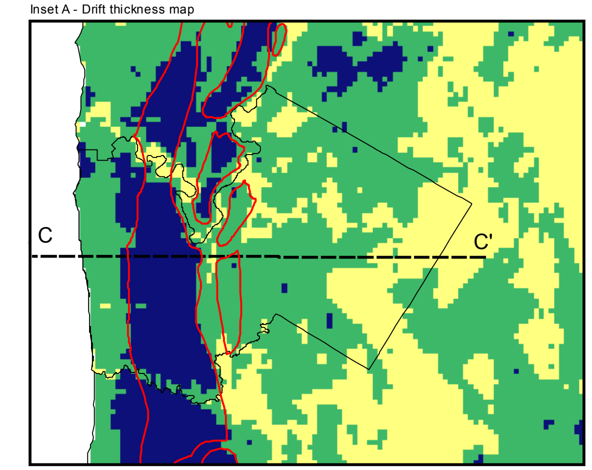
LEGEND

- Settlement
- The Municipality
- Main road
- Slope profile
- Waterbody
- Watercourse (main)
- Buried valley (Gao, 2011)

Drift thickness (m)

- 0 - 5
- 6 - 11
- 12 - 18
- 19 - 25
- 26 - 32
- 33 - 38
- 39 - 45
- 46 - 52
- 53 - 59
- 60 - 91

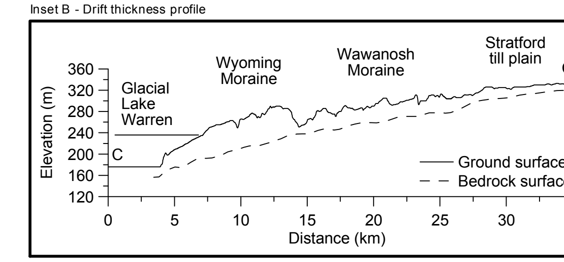
Inset A - Drift thickness map



Drift thickness (m)

- 0 - 20
- 21 - 40
- 41 - 91
- Wyoming Moraine
- Slope profile

Inset B - Drift thickness profile



Vertical exageration = 40

Data sources:
Road: Selected from LIO ORN
Waterbody: Selected from LIO OHN
Watercourse: Selected from LIO OHN
Drift thickness: OGS MRD207

NORTH

2 km

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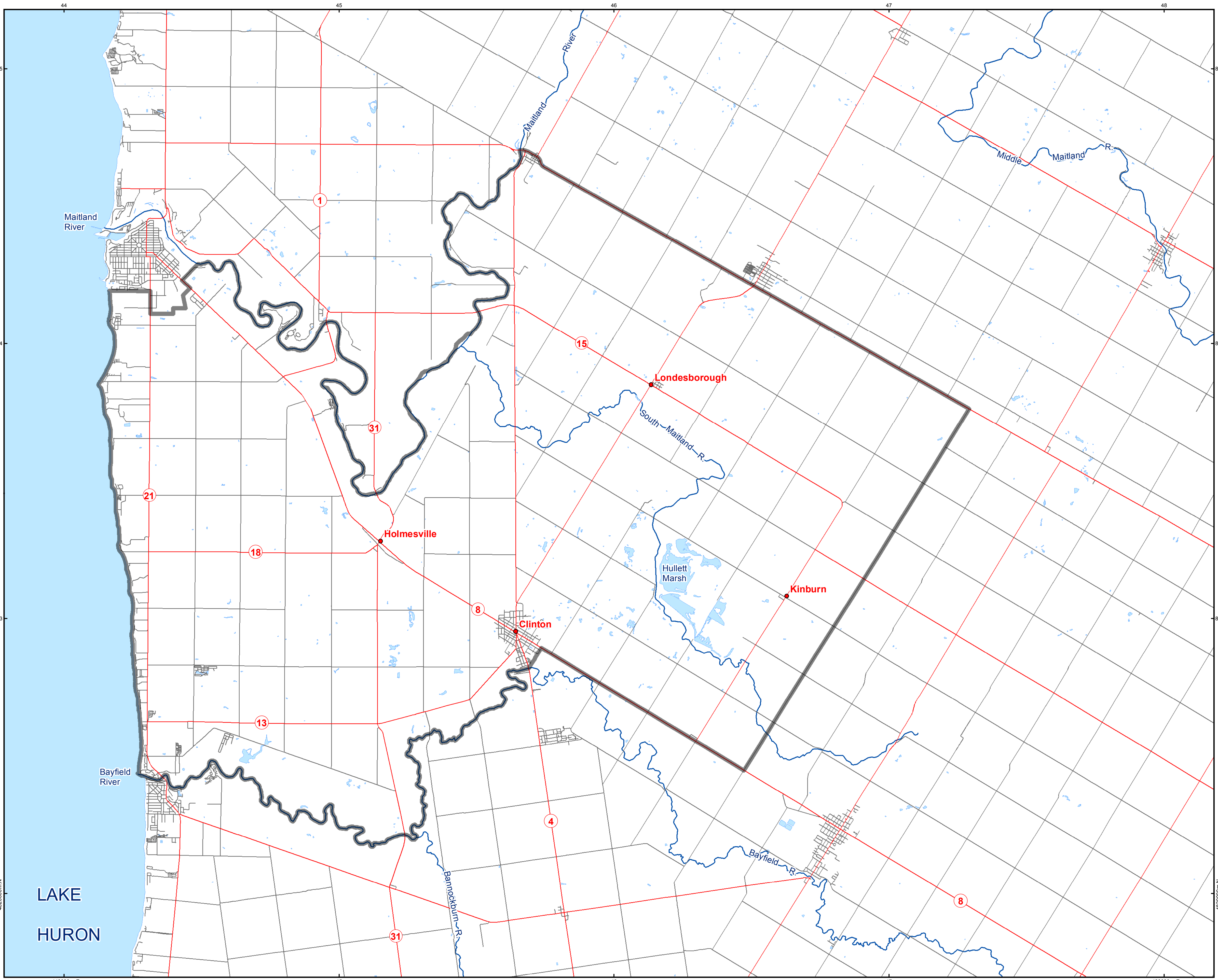
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE

Drift thickness of the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 14	REVISION 0
GIS	DVZ	25 SEP 2014		UTM ZONE 17
CHECK	LAP	08 OCT 2014		NAD 1983
REVIEW	SS	16 OCT 2014		1:140,000



LEGEND

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

NORTH

2 km

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

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PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, CENTRAL HURON

TITLE
Roads within the Central Huron area

DESIGN	DVZ	15 APR 2013	FIGURE 15	REVISION 1
GIS	DVZ	12 DEC 2014		UTM ZONE 17
CHECK	LAP	12 DEC 2014		NAD 1983
REVIEW	SS	12 DEC 2014		1:140,000