



NUCLEAR WASTE MANAGEMENT ORGANIZATION  
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

February 15, 2013

Municipality of Central Huron  
P.O. Box 400, 23 Albert Street  
Clinton, ON N0M 1L0

Attn: Mayor Jim Ginn

**Re: Adaptive Phased Management Initial Screening – Municipality of Central Huron**

Dear Mayor Ginn,

Further to the Municipality of Central Huron's request to Learn More about the Adaptive Phased Management program and request for an initial screening, I am pleased to attach a report outlining the findings from the initial screening, as described in the Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel (May, 2010). As you know, the purpose of the initial screening in Step 2 of the process is to determine whether, based on readily-available information and five screening criteria, there are any obvious conditions that would exclude the Municipality of Central Huron from further consideration in the site selection process.

As the report indicates, the review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Municipality of Central Huron from further consideration in the NWMO site selection process. The initial screening suggests that the Municipality comprises geological formations that are potentially suitable for hosting a deep geological repository for Canada's used nuclear fuel. It is important to note that this initial screening has not confirmed the suitability of your community. Should your community choose to continue to explore its potential interest in the project, your area would be the subject of progressively more detailed assessments against both technical and social factors. Several years of studies would be required to confirm whether a site within your area could be demonstrated to safely contain and isolate used nuclear fuel.

The process for identifying an informed and willing host community for a deep geological repository for the long-term management of Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future. The NWMO expects that the selection of a preferred site would take between seven to ten years. It is important that any community which decides to host this project base its decisions on an understanding of the best scientific and social research available and its own aspirations. Should the Municipality of Central Huron continue to be interested in exploring the project, over this period there would be ongoing engagement of your community, surrounding communities and others who may be affected. By the end of this process, Central Huron as a whole community would need to clearly demonstrate that it is willing to host the repository in order for this project to proceed.

The next evaluation step would be to conduct a feasibility study as described in Step 3 of the site selection process. This feasibility study would focus on areas selected in collaboration with the community. As your community considers whether it is interested in advancing to the feasibility study phase, the NWMO encourages you to continue community discussion and further learning about the project. Support programs are available to assist your community to reflect on its long-term vision and whether this project is consistent with achieving that vision. Programs and resources are also available to engage your community residents in learning more about this project and becoming involved. We would be very pleased to provide further information about these programs.

Once again, I thank you for taking the time to learn about Canada's plan for the safe, secure management of Canada's used nuclear fuel.

Sincerely,



Kathryn Shaver,  
Vice President, APM Public Engagement and Site Selection

Cc: Peggy Van Mierlo-West, CAO



**INITIAL SCREENING FOR SITING A DEEP GEOLOGICAL  
REPOSITORY FOR CANADA'S USED NUCLEAR FUEL**

**The Corporation of the Municipality of  
Central Huron**

Report



## **INITIAL SCREENING FOR SITING A DEEP GEOLOGICAL REPOSITORY FOR CANADA'S USED NUCLEAR FUEL**

# **The Corporation of the Municipality of Central Huron**

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February, 2013

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## Executive Summary

On September 10, 2012 the Corporation of the Municipality of Central Huron expressed interest in learning more about the Nuclear Waste Management Organization (NWMO) site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report summarizes the findings of an initial screening, conducted by AECOM, to evaluate the potential suitability of the Municipality of Central Huron against five screening criteria using readily available information. The purpose of the initial screening is to identify whether there are any obvious conditions that would exclude the Municipality of Central Huron from further consideration in the site selection process. The initial screening focused on the areas within the boundaries of the Municipality of Central Huron. Areas within neighbouring municipalities were not included in the initial screening.

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Municipality of Central Huron from being further considered in the NWMO site selection process. The initial screening indicates that the Municipality comprises geological formations that are potentially suitable for safely hosting a deep geological repository. These include the Upper Ordovician shale and limestone units that comprise the geology of the Municipality at typical repository depths. The review also identified the presence of salt formations beneath the Municipality. The extent to which potential salt mining activities within the Municipality could affect the integrity of a repository located within the underlying Ordovician shale and limestone units would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

It is important to note that the intent of this initial screening is not to confirm the suitability of the Municipality of Central Huron to host a deep geological repository, but rather to provide early feedback on whether there are known reasons to exclude it from further consideration. Should the community of Central Huron remain interested in continuing with the site selection process, more detailed studies would be required to confirm and demonstrate whether the Municipality of Central Huron contains sites that can safely contain and isolate used nuclear fuel. The process for identifying an informed and willing host community for a deep geological repository for Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future.

The five initial screening criteria are defined in the site selection process document (NWMO, 2010) and relate to: having sufficient space to accommodate surface and underground facilities, being outside protected areas and heritage features, absence of known groundwater resources at repository depth, absence of known economically exploitable natural resources and avoiding known hydrogeologic and geologic conditions that would make an area or site unsuitable for hosting a deep geological repository.

A brief summary of the assessment against each of the initial screening criterion is provided below.

### Availability of Land

Review of available mapping and satellite imagery indicates that the Municipality of Central Huron contains sufficient land to accommodate the surface and underground facilities associated with the repository. This land could be accessible for construction and field investigation activities. The Municipality contains limited constraints that would prevent the development of the repository's surface facilities. The main land constraints include the wetland complexes, which account for 2% of the Municipality, and the residential and commercial infrastructure associated with the settlement areas of Clinton, Holmesville, Kinburn and Londesborough.

## **Protected Areas, Heritage Sites, Provincial Parks and National Parks**

The Municipality of Central Huron contains sufficient land outside of protected areas, heritage sites, provincial parks and national parks to accommodate the repository's facilities. There are no provincial or national parks within the Municipality. Protected areas account for about 10% of the area within the Municipality. These include: two conservation areas; three designated Provincially Significant Wetlands; two Earth Science Areas of Natural and Scientific interest (ANSI); two Life Science ANSIs; and a NGO Nature Reserve. Limited heritage constraints were identified in the Municipality. There are 16 localized, small known archaeological sites within the Municipality. No National Historic Sites were identified.

The absence of locally protected areas and heritage sites would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

## **Absence of Known Groundwater Resources at the Repository Depth**

The review of available information did not identify any known groundwater resources at repository depth for the Municipality of Central Huron. The Ontario Ministry of Environment Water Well Records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Municipality of Central Huron. Water wells in the Municipality obtain water from overburden or shallow bedrock aquifers to a maximum depth of 134 m. Experience in similar geological settings across southern Ontario suggests that the potential for deep groundwater resources is low throughout the Municipality of Central Huron. The absence of groundwater resources at repository depth would need to be confirmed during subsequent site evaluation stages if the community remains interested in continuing with the site selection process.

## **Absence of Economically Exploitable Natural Resources as Known Today**

The review of readily available information indicates that the sedimentary rock sequence beneath the Municipality of Central Huron contains deep rock formations that are free of known economically exploitable natural resources.

There is no record of past metallic mineral production, and no exploration potential for metallic minerals has been identified within the Municipality. Current licensed non-metallic mineral extraction in the Municipality of Central Huron is limited to sand and gravel resources. However, the risk that these resources pose for future human intrusion is negligible, as quarrying operations would be limited to very shallow depths.

Oil and gas resources within the Municipality were actively exploited in the past at two hydrocarbon pools. These two pools are currently depleted and used for natural gas storage. The review did not identify known currently economically exploitable hydrocarbon pools within the Municipality. However, given that there has been previous exploitation of oil and gas resources within the Municipality, the potential for these resources would need to be further assessed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

While the review identified the presence of salt beds beneath the Municipality, these thin out quickly towards the east and extend significantly outside the western and southern boundaries of the Municipality. If salt were to be mined in the future within the Municipality, the distance between the salt beds and the underlying potentially suitable Ordovician shale and limestone units is likely to provide a sufficient buffer to isolate and maintain the integrity of a repository in the long-term. However, this would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

## **No Known Geological and Hydrogeological Characteristics That Would Prevent the Site from Being Safe**

Based on the review of available geological and hydrogeological information, the Municipality of Central Huron comprises deep geological formations with no obvious known geological and hydrogeological conditions that would make the Municipality unsuitable for hosting a deep geological repository. Potentially suitable host formations include the Upper Ordovician shale and limestone units.



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# 1. Introduction

On September 10, 2012, the Corporation of the Municipality of Central Huron expressed interest in learning more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report presents the results of an initial screening, conducted by AECOM, as part of Step 2 in the site selection process to evaluate the potential suitability of the Municipality of Central Huron against five screening criteria using readily available information. The initial screening focused on the areas within the boundaries of the Municipality of Central Huron. Areas within neighbouring municipalities were not included in the initial screening.

## 1.1 Background

The ultimate objective of Adaptive Phased Management (APM) is long-term containment and isolation of used nuclear fuel in a deep geological repository in a suitable rock formation. The NWMO is committed to implementing the project in a manner that protects human health, safety, security and the environment, while fostering the long-term well-being of the community and region in which it is implemented (NWMO, 2005).

In May 2010, the NWMO published and initiated a nine-step site selection process to find an informed and willing community to host the repository (NWMO, 2010). The site selection process is designed to address a broad range of technical, social, economic and cultural factors as identified through dialogue with Canadians including Aboriginal peoples, and draws from experiences and lessons learned from past work and processes developed in Canada to site facilities for the management of other hazardous material. It also draws from similar projects in other countries pursuing the development of deep geological repositories for used nuclear fuel. The suitability of potential candidate sites will ultimately be assessed against a number of site evaluation factors, both technical and social in nature.

The geoscientific suitability of candidate sites will be assessed in three main phases over a period of several years, with each step designed to evaluate the site in progressively greater detail upon request of the community. The three site evaluation phases include: Initial Screenings to evaluate the potential suitability of the community against a list of initial screening criteria, using readily available information (Step 2); Feasibility Studies to determine if candidate sites within the proposed areas are potentially suitable for developing a safe deep geological repository for used nuclear fuel (Step 3); and Detailed Site Evaluations, at one or more selected sites, to confirm suitability based on detailed site evaluation criteria (Step 4). It is up to the communities to decide whether they wish to continue to participate in each step of the process.

## 1.2 Objectives and Approach for Conducting Initial Screenings

The overall objective of the initial screening is to evaluate proposed geographic areas against a list of screening criteria using readily available information. Initial screening criteria (NWMO, 2010) require that:

1. The site must have enough available land of sufficient size to accommodate the surface and underground facilities.
2. This available land must be outside of protected areas, heritage sites, provincial parks and national parks.
3. This available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.
4. This available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.

5. This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the safety factors outlined in Section 6 of the Site Selection Document (NWMO, 2010).

The initial screening step involves the systematic consideration of each of the five initial screening criteria on a qualitative basis using readily available information from provincial, federal, municipal and other sources of information. It is not the intent of the initial screening study to conduct a detailed analysis of all available information, but rather to identify any obvious conditions that would exclude a community from further consideration in the site selection process. For example, a site with known economically exploitable natural resources or geological or hydrogeological characteristics that are clearly unfavourable would be excluded from further consideration.

For cases where readily available information is limited and where assessment of some of the criteria is not possible at the screening stage, the area would be advanced to the feasibility study stage for more detailed evaluation, provided the community remains interested in continuing to participate in the siting process.

The initial screening commences with an analysis of readily available information in order to develop an overall understanding of the geoscientific and other relevant characteristics of the site. The initial screening criteria are then applied in a systematic manner based on the understanding of the proposed area or site. The tasks involved include the following:

- Reviewing the regional and local physical geography, geology, seismicity, structural geology and Quaternary geology (surface geology);
- Reviewing the hydrogeology, including, regional groundwater flow, deep and shallow aquifers and hydrogeochemistry;
- Reviewing the economic geology, including hydrocarbon resources, and metallic and non-metallic mineral resources;
- Applying the screening criteria; and
- Summarizing the findings with regard to potential suitability.

## **2. Physical Geography**

### **2.1 Location**

The Municipality of Central Huron is situated within Huron County in southern Ontario, along the shore of Lake Huron, between Goderich and Bayfield (Figure 2.1). The Municipality is approximately 456 km<sup>2</sup> in size. The largest settlement area in the Municipality of Central Huron is Clinton, where the municipal offices are located (Figure 2.1). Other settlement areas in the Municipality include Holmesville, Kinburn and Londesborough. Satellite imagery for the Municipality of Central Huron (Spot 5, taken in 2006) is presented on Figure 2.2, which illustrates that the majority of the Municipality is comprised of agricultural lands.

### **2.2 Topography**

The Municipality of Central Huron is located in the Western St. Lawrence Lowlands physiographic region, a low-relief, gently undulating land surface (see index map of Figure 2.3). Figure 2.3 shows the detailed physiographic regions of the Municipality of Central Huron and surrounding areas.

The Municipality of Central Huron lies within four physiographic regions, the boundaries of which are oriented in a general north-south direction, parallel to the Lake Huron shoreline. The Huron Fringe physiographic region makes up the narrow westernmost strip of the Municipality of Central Huron, along the shoreline of Lake Huron. East of the Huron Fringe, a slightly wider belt is occupied by the Huron Slope physiographic region. The central portion of the Municipality lies within the Horseshoe Moraines physiographic region, which makes up the majority of the Municipality, and the eastern quarter is characterized by the Stratford Till Plain. The Municipality is covered with Quaternary aged glacial sediments, as described in section 3.5.

The Digital Elevation Model (DEM) for the Municipality of Central Huron is presented on Figure 2.4. The land surface in the Municipality ranges from a maximum of 347 metres above sea level (mASL) to a minimum of 176 mASL along the shores of Lake Huron. The land surface shows a general slope down towards Lake Huron from east to west. Relief within the Municipality is undulating to hummocky in areas characterized by deposits of the Wyoming and Wawanosh moraines (Figure 2.4), while low relief areas are present along the Lake Huron shoreline. A narrow band of locally higher elevation runs parallel to the shoreline and represents the north-south trending crest of the Wyoming moraine and shoreline scarps to the west (Figure 2.4). Narrow gullies up to 20 m deep are encountered along the small streams flowing from the west side of the Wyoming Moraine, through the Huron Slope physiographic region, and into Lake Huron on the western edge of the Municipality (Ausable Bayfield & Maitland Valley Source Protection Region, 2011a). The Maitland River has also cut a well-defined valley along the northern boundary of the Municipality (Figure 2.4).

### **2.3 Drainage**

Surface water drainage for the Municipality of Central Huron is shown in Figure 2.5. The Municipality of Central Huron occupies two sub-watersheds within the Western Georgian Bay/Eastern Lake Huron sub-basin. The northern two-thirds of the Municipality are located within the Maitland sub-watershed and the southern third is located within the Ausable sub-watershed.

The most prominent drainage features in the Municipality of Central Huron and surrounding area are the Maitland and the Bayfield Rivers, which coincide with parts of the northern and southern municipal boundaries, respectively (Figure 2.5). The Maitland River discharges to Lake Huron at the Town of Goderich, and the Bayfield River discharges to Lake Huron at the Village of Bayfield, just north and south of the Municipality, respectively. The

dominant drainage direction within the Municipality of Central Huron is east-west towards Lake Huron. Several tributaries within the Maitland sub-watershed flow in a northwesterly direction as they approach the Maitland River (Figure 2.5). Likewise, certain tributaries within the Ausable sub-watershed flow southward towards the Bayfield River. Numerous other smaller rivers and streams, many of which are agricultural drains, flow east to west through the Huron Slope physiographic region and into the lake along the western boundary of the Municipality within both watersheds. Extensive channel modification has occurred in the southern portion of the Maitland sub-watershed and this area is characterized by flash flows following storm events (Ausable Bayfield & Maitland Valley Source Protection Region, 2011a).

A large wetland complex, the Hullet Marsh Complex, is located in the southeastern portion of the Municipality within the Maitland subwatershed and has an area of approximately 8 km<sup>2</sup>. The Holmesville Creek Complex and the Tricks Creek Swamp are located along rivers draining into the Maitland and Bayfield Rivers, respectively, and form a nearly continuous band that extends north-south down the centre of the Municipality (Figure 2.5).

## 2.4 Protected Areas

### 2.4.1 Parks and Reserves

There are no provincial or national parks within the Municipality of Central Huron. The nearest parks are the Morris Tract Provincial Nature Reserve immediately north of the Municipality and the Point Farms Provincial Park approximately 6 km north of the Municipality along the shoreline of Lake Huron (Figure 2.1).

There are two conservation areas within the Municipality of Central Huron: the Naftels Creek and Black's Point conservation areas. Both of these are located in the northwestern portion of the Municipality (Figure 2.1). They have a combined area of approximately 0.5 km<sup>2</sup> (about 0.1% of the Municipality). Several conservation areas are also found along the northern banks of the Maitland River, immediately north of the Municipality, and include the Sager Subdivision, Fall's Reserve, and Kilgour Tract conservation areas (Figure 2.1).

There are eight designated protected areas within the Municipality of Central Huron (Figure 2.1). Three Provincially Significant Wetlands, the Hullet Marsh Complex, Holmesville Creek Complex, and Tricks Creek Swamp, cover a combined area of 11 km<sup>2</sup> and comprise 2% of the Municipality. Two Earth Science Areas of Natural Scientific Interest (ANSIs) are present within the Municipality: the Seaforth-West Wawanosh Moraines Area is located in the southeastern portion of the Municipality, immediately south of the Hullet Marsh Complex, and the Holmesville Area is located in the north-central portion of the Municipality, immediately north of the Holmesville Creek Complex (Figure 2.1). Two Life Science ANSIs are present in the southwestern corner of the Municipality: the Bayfield River and Bayfield North Areas (Figure 2.1). The ANSIs represent prominent glacial geological features and/or representative segments of Ontario's biodiversity and natural landscapes that support unique habitats and protect groundwater infiltration and recharge function. In addition, the G.G. Newton Nature Reserve is a 40 hectare former farm property owned by the Federation of Ontario Naturalists located in the northwestern portion of the Municipality, west of the Holmesville ANSI. The combined extent of all protected areas within the Municipality of Central Huron is approximately 45 km<sup>2</sup> and accounts for approximately 10% of the total area of the Municipality.

The presence and function of other natural features and areas, such as significant woodlands, significant valleylands or significant wildlife habitats (Provincial Policy Statement, 2005; Bruce County Official Plan, 2011) would be addressed during subsequent site evaluation stages, if the community remains interested in continuing to participate in the site selection process.

## 2.4.2 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Municipality of Central Huron and surrounding areas, using the Ontario Archaeological Sites Database maintained by the Ontario Ministry of Tourism, Culture and Sport (Ontario Ministry of Tourism and Culture, undated).

The majority of archeological sites in and around the Municipality are of Aboriginal cultural affiliation and include lithic scatter, chipping station, findspots, and camp sites. Several are of Euro-Canadian affiliation, which include domestic, residential, and homestead sites dated between mid-19<sup>th</sup> to early 20<sup>th</sup> century.

There are 16 known archaeological sites documented within the boundaries of the Municipality of Central Huron. Fifteen are of Aboriginal cultural affiliation. Of these 15, six are of undetermined cultural affiliation but are distinguished as campsites, one is an Early Archaic campsite, one is a Middle Woodland campsite, one is a Late Woodland campsite, four are findspots, including one distinguished as a prehistoric findspot, and two are Middle/Late Woodland (Iroquois/Petun and Saugeen) campsite/villages. The sixteenth site is a multi-component site containing an Aboriginal component consisting of a campsite of unknown cultural affiliation and a Euro-Canadian house dating to the mid-19<sup>th</sup> century located near Sharpes Creek Line. There are no National Historic Sites in the area. Locations of known archaeological sites are not shown on maps within this report to comply with Ministry of Tourism and Culture publication guidelines.

Consultation of the Ontario Heritage Properties Database (Ontario Ministry of Tourism and Culture, 2005), which records heritage resources that have been designated for their Provincial cultural value or interest under the *Ontario Heritage Act*, confirmed the presence of 15 Provincially designated heritage properties within the Municipality; these are located within the settlement area of Clinton and along County Road 8.

The potential for archaeological sites within the Municipality of Central-Huron is high for both Aboriginal and Euro-Canadian finds. Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modelling, a distance to water criterion of 300 m is generally employed for primary water courses, including lakeshores, rivers and large creeks, while a criterion of 200 m is applied to secondary water sources, including swamps and small creeks (Ontario Ministry of Culture, 1997).

The absence of other protected areas and heritage sites would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.



### 3. Geology and Seismicity

This section provides a general overview of the geology and seismicity of southern Ontario, including the Municipality of Central Huron and surrounding areas, focusing on information that is most relevant to this initial screening.

#### 3.1 Regional Geology

##### 3.1.1 Regional Geological Setting

The bedrock geology of southern Ontario consists of a thick Paleozoic sedimentary sequence from Cambrian to Mississippian in age, deposited approximately 542 million to 318 million years ago (Johnson et al., 1992; Walker and Geissman, 2009). This sedimentary sequence unconformably overlies the Precambrian crystalline basement of the Grenville Province, the south-easternmost subdivision of the Canadian Shield (Figure 3.1; Figure 3.2). The Grenville Province comprises 2,690 million to 990 million year old rocks deformed during orogenic events 1,100 to 970 million years ago (Percival and Easton, 2007; Carr et al., 2000; White et al., 2000). The Precambrian Grenville Province, which extends from Labrador to Mexico, is generally considered to have been relatively tectonically stable since approximately 970 million years ago (Percival and Easton, 2007, see Section 3.3).

Southern Ontario is underlain by two main paleo-depositional centres, the Appalachian and Michigan Basins, which are separated by a Precambrian crystalline basement high referred to as the Algonquin Arch (Figure 3.1). The Paleozoic succession underlying the Municipality of Central Huron and surrounding area was deposited in the Michigan Basin, a broadly circular intracratonic basin centred in Michigan. The Paleozoic succession thins from a maximum of approximately 4,800 m at the centre of the Michigan Basin to approximately 850 m on the flank of the Algonquin Arch east of the Municipality of Central Huron (Figure 3.1). 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 3.2 presents the bedrock geology of southern Ontario. Figure 3.3 shows a geological cross-section (location shown on Figure 3.2), which highlights the west-southwesterly dip of the Paleozoic succession from the Niagara Escarpment in the northeast, to Lake Huron in the southwest, passing southwest of the Municipality of Central Huron (note approximately 45x vertical exaggeration). Also note that on Figure 3.3, due to differences in outcrop versus subsurface stratigraphic nomenclature, the colour-shaded bedrock units in the cross-section do not correspond directly to the colour shades shown in the bedrock map and accompanying legend on Figure 3.2.

##### 3.1.2 Precambrian Crystalline Basement Geology

The Precambrian crystalline basement beneath much of southern Ontario is characterized by gneisses and metamorphic rocks of the Grenville Province of the Canadian Shield (Figure 3.1; Carter and Easton, 1990). Geophysical investigations provide useful information regarding the character of these basement rocks. Seismic profiles of the crystalline basement have been interpreted as representing the penetrative ductile Grenville-aged deformation fabric beneath the undeformed Paleozoic sedimentary rocks (e.g., Milkereit et al., 1992). Similarly, the gravity and residual total magnetic field maps of Southern Ontario, shown in Figures 3.4 and 3.5, reflect the distribution of the rock units of the Precambrian crystalline basement, rather than features of the overlying Paleozoic sedimentary rock succession.

The Municipality of Central Huron is underlain by a moderate to high gravity signal. The lowest intensities occur in the eastern third of the Municipality and increase towards the west, reaching a maximum along the Lake Huron

shoreline (Figure 3.4). Low to moderate aeromagnetic field values are generally present throughout the Municipality of Central Huron. The lowest magnetic field values are present in both the northwest corner and in the eastern portion of the Municipality, and are part of an irregularly shaped series of lows that extend in a northeasterly direction from Goderich to Owen Sound (Figure 3.5). Slightly higher magnetic field values form a narrow band through the centre of the Municipality, separating the two distinct areas of low field values, with the highest values recorded in the southwestern corner of the Municipality. The observed variations of both gravity and magnetic intensity in southern Ontario may be in part the result of mineralogical and structural variation within and between recognized lithotectonic terranes of the Precambrian crystalline basement (Easton, 1992; Boyce and Morris, 2002).

### 3.1.3 Regional Sedimentary Bedrock Stratigraphy

Table 3.1 illustrates the Paleozoic bedrock stratigraphy for three different geographic regions in southern Ontario (Armstrong and Carter, 2010). The Municipality of Central Huron and surrounding areas are within the region described by the left column of Table 3.1. The Paleozoic sedimentary stratigraphy includes shale, carbonate and evaporate 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).

The sedimentary bedrock stratigraphy shown in Table 3.1 and in Figure 3.3 adopts a subsurface nomenclature, while geological mapping as shown in Figures 3.2 and 3.6 uses an outcrop nomenclature (e.g., Armstrong and Carter, 2010). 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 cross-section shown on Figure 3.3 (adapted from Armstrong and Carter, 2010) illustrates the high degree of lateral continuity of individual units within the Paleozoic sedimentary bedrock succession of southern Ontario. The geological units within southern Ontario display a high level of lateral consistency, and the geological cross-section is considered representative of the stratigraphy within the Municipality of Central Huron.

The following descriptions of the Paleozoic bedrock stratigraphy in southern Ontario utilize the subsurface nomenclature as defined in Table 3.1. The descriptions are primarily adapted from Johnson et al. (1992) and Armstrong and Carter (2010), the latter of which is an update of the stratigraphy presented by Armstrong and Carter (2006). The Paleozoic bedrock stratigraphy is described according to the main sedimentary sequence presented in the left column of Table 3.1. The Middle Devonian Hamilton Group and the Upper Devonian Port Lambton Group are absent beneath the Municipality of Central Huron (Figures 3.2 and 3.6) and thus their descriptions are not included in this report.

#### 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 deposits are generally characterized as a succession of clastic and carbonate rocks resulting from transgressive Cambrian seas that flooded across the broad platform of the Algonquin Arch and into the subsiding Michigan and Appalachian basins (Hamblin, 1999).

**Table 3.1 Stratigraphy of Southern Ontario (Armstrong and Carter, 2010)**

Standard Reference	Elgin, Essex, Huron, Kent, Lambton, Middlesex, Perth Counties and Western Lake Erie	Manitoulin Island, Bruce, Grey, Durham, Halton, Waterloo, and Wellington Counties	Brant, Haldimand, Lincoln, Norfolk, Oxford, Welland, Wentworth Counties and Eastern and Central Lake Erie
Mississippian	Upper		
	Middle		
	Lower		
Devonian	Upper		
	Middle		
	Lower		
Silurian	Upper		
	Lower		
Ordovician	Upper		
Cambrian	Upper		
Precambrian		crystalline basement	

The Cambrian deposits west of the Municipality of Central Huron are divided into three distinct units: the Mount Simon, Eau Claire and Trempealeau formations. The Mount Simon Formation consists of white to light grey quartzose sandstone and is overlain by fine to medium-grained sandstone of the Eau Claire Formation. The sandstones of the Eau Claire Formation are interbedded with grey, fine-crystalline dolostone, grey, shaly dolostone, and minor amounts of glauconite. The Trempealeau Formation overlies the Eau Claire Formation and is comprised mainly of buff to grey-buff, fine- to medium-crystalline dolostones (Armstrong and Carter, 2006).

The Cambrian units are largely absent over the Algonquin Arch as the result of a pre-Ordovician regional-scale unconformity (Bailey Geological Services and Cochrane, 1984). Based on the regional stratigraphic framework, the Cambrian is interpreted to pinch out from west to east (Itasca Canada and AECOM, 2011) and it is expected to be thin to absent beneath most of the Municipality. This relationship is confirmed by deep drilling within the Municipality which shows absent or thin Cambrian deposits (Section 3.2.1). There are no surface exposures of the Cambrian unit in southwestern Ontario.

### Upper Ordovician

Unconformably overlying the Cambrian unit is a thick sequence of Ordovician sedimentary units with a distinctly bimodal composition; 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 unit shale-dominated sediments (Hamblin, 1999). The Upper Ordovician carbonates subcrop in the northeastern part of southern Ontario around the Lake Ontario and Lake Simcoe regions and the Upper Ordovician shales subcrop east of the Niagara Escarpment between Owen Sound and Niagara Falls (Figure 3.2).

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 3.1). 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 lowest interval of the Trenton Group is the Kirkfield Formation which 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 unit. 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. The Collingwood Member is discontinuously present in the area where the Municipality of Central Huron is located (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 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). 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 3.1; Armstrong and Carter, 2010).

#### Lower Silurian

The Lower Silurian units, including the Cataract and Clinton groups and the Lockport and Guelph formations, unconformably overlie the Upper Ordovician shales (Table 3.1). A major marine transgression at the boundary of the Clinton and Cataract groups, and isolation of the Michigan Basin from the Appalachian Basin as a result of tectonic activity, was responsible for deposition of the extensive carbonate-dominated Lockport 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 3.1; 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 Lockport Formation comprises the lower Gasport Member which consists of blue-grey, fine to coarse grained, thick bedded to massive dolostone and the upper Goat Island Member which consists of light grey to brown, very fine- to fine-crystalline, locally cherty, thin- to medium-bedded, variably argillaceous dolostones.

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. The Guelph Formation in the Municipality of Central Huron is characterized by facies deposited in the pinnacle reef belt. Large quantities of hydrocarbons have been produced from pinnacle and patch reefs in southern Ontario (see Section 5.1).

#### Upper Silurian

The Upper Silurian units include the evaporite and evaporite-related Salina Group and overlying dolostones and minor evaporites of the Bass Islands Formation (Table 3.1). The Upper Silurian units subcrop in a northwest trending belt that extends from south of Niagara Falls to west of Owen Sound (Figure 3.2). The Salina Group is characterized by repeated, cyclical deposition of carbonate, evaporite and argillaceous sedimentary rocks. Thick salt deposits of the Salina Group are mined in Goderich just north of the Municipality of Central Huron, as well as in other locations of southern Ontario (see section 5.3.3). A change to normal marine carbonate conditions away from the cyclic carbonate and evaporate setting 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).

#### 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 and the Detroit River Group (Table 3.1). The Dundee Formation consists of carbonates that unconformably overlie the Detroit River Group. Outcrops of these carbonates are found along the shoreline of Lake Huron and north shoreline of Lake Erie (Figure 3.2).



## 3.2 Local Sedimentary Bedrock Geology of the Municipality of Central Huron

### 3.2.1 Stratigraphy

The bedrock geology of the Municipality of Central Huron and surrounding area is shown in Figure 3.6. The figure also shows the location of oil and gas boreholes and pools from the Oil, Gas and Salt Resources Library Petroleum Wells Subsurface Database (Ontario Oil, Gas and Salt Resources Library (OGSRL), 2006) in the Municipality of Central Huron and the surrounding area.

Review of readily available information indicates that the subsurface Paleozoic bedrock geology of the Municipality of Central Huron is consistent with the regional geological framework described in Section 3.1.3. The Municipality is underlain by a Cambrian to Devonian Paleozoic sedimentary sequence that was deposited approximately 501 to 380 million years ago (Walker and Geissman, 2009; Armstrong and Carter, 2010). Additional information on the sedimentary bedrock geology is available from the recently completed site characterization program at the Bruce nuclear site for OPG's proposed DGR for low and intermediate level radioactive waste (OPG-DGR) described in detail by NWMO (2011) and Intera (2011). Key available borehole data include:

- Forty-six oil and gas wells within the Municipality (Table 3.2), including three deep boreholes (Wells #F011970, #F011974, and #T006364; Table 3.3), drilled in 1939, 1955, and 1985, respectively, that extend through the entire Paleozoic sedimentary sequence to the top of the Precambrian crystalline basement at depths ranging from approximately 1,060 metres below ground surface (mBGS) to 1,125 mBGS (Figure 3.6).
- Oil and gas boreholes surrounding the Municipality as shown in Figure 3.6 (Ontario Oil, Gas and Salt Resources Library (OGSRL), 2006; Itasca and AECOM, 2011).
- Boreholes (DGR-1 to DGR-6) at the Bruce nuclear site, approximately 70 km north of the Municipality, with depths ranging from 463 to 869 mBGS, including one borehole (DGR-2), which intersects the top of the Precambrian crystalline basement at a depth of 861 mBGS (Intera, 2011).

The stratigraphy beneath the Municipality of Central Huron, as interpreted from Ontario Oil, Gas and Salt Resources Library Wells #F011970, #F011974, #T006364, and #F011982 (Figure 3.6), is shown in Table 3.3. The type and number of individual stratigraphic units identified and described in Table 3.3 are consistent with the regional stratigraphic framework summarized in Section 3.1.3. All wells drilled within the Municipality are located within the Dundee Formation Subcrop area (Figure 3.6, Table 3.2).

The differences in the number of individual logged units between the wells in Table 3.3 is likely the result of stratigraphic nomenclature changes over the years and differences in geological interpretation between individual well loggers. Also, thin Salina Formation evaporite units can be preferentially dissolved resulting in minor vertical variations of the Silurian stratigraphy, and Guelph Formation thicknesses are known to vary based on the presence or absence of reefal facies. The variation in stratigraphy within the Upper Ordovician units (Georgian Bay / Blue Mountain, Collingwood and Cobourg formations) is also likely related to differences in geological interpretation. The Collingwood Member, for example, may be grouped with the Cobourg Formation or overlying shales. It is suspected that the Trenton Group and Black River Group units for Wells #F011970 and #F011974 were grouped entirely within the Cobourg Formation.

The Paleozoic sequence interpreted to exist below the Municipality of Central Huron was also encountered in the deep boreholes beneath the Bruce nuclear site (Intera, 2011). Based on the information from Wells #F011970, #F011974, and #T006364, the average thickness of the Paleozoic strata within the Municipality of Central Huron is approximately 1,055 m (Table 3.3).

**Table 3.2 Subcrop Geological Unit and Final Well Completion Unit for Oil and Gas Wells within the Municipality of Central Huron**

Well License #	Total Depth (mBGS)	Top Geological Unit (Subcrop)	Bottom Geological Unit
F011928	639.2	Dundee Formation	Cabot Head Formation
F011941	627.9	Dundee Formation	Cabot Head Formation
F011953	544.1	Dundee Formation	Cabot Head Formation
F011965	611.7	Dundee Formation	Cabot Head Formation
F011970	1062.8	Dundee Formation	Precambrian
F011973	561.7	Dundee Formation	Cabot Head Formation
F011974	1124.4	Dundee Formation	Precambrian
F011975	565.4	Dundee Formation	Cabot Head Formation
F011976	563.6	Dundee Formation	Cabot Head Formation
F011977	561.4	Dundee Formation	Cabot Head Formation
F011978	506.3	Dundee Formation	Cabot Head Formation
F011981	495.3	Dundee Formation	Cabot Head Formation
F011982	516.6	Dundee Formation	Manitoulin Formation
F011986	548.9	Dundee Formation	Cabot Head Formation
F011987	605.0	Dundee Formation	Cabot Head Formation
F011989	566.9	Dundee Formation	Cabot Head Formation
T000085	584.6	Dundee Formation	Cabot Head Formation
T001092	524.0	Dundee Formation	Rochester Formation
T002731	64.9	Dundee Formation	Dundee Formation
T002731A	620.3	Dundee Formation	Rochester Formation
T002842	619.9	Dundee Formation	Rochester Formation
T003607	532.5	Dundee Formation	Goat Island Formation
T003632	41.5	Dundee Formation	Lucas Formation
T003632A	526.4	Dundee Formation	Eramosa Formation
T003785	617.5	Dundee Formation	Gasport Formation
T005166	640.5	Dundee Formation	Cabot Head Formation
T005326	589.0	Dundee Formation	Cabot Head Formation
T006251	622.0	Dundee Formation	Cabot Head Formation
T006341	619.4	Dundee Formation	Queenston Formation
T006346	635.6	Dundee Formation	Cabot Head Formation
T006364	1123.8	Dundee Formation	Precambrian
T007179	594.0	Dundee Formation	Rochester Formation
T008843	621.0	Dundee Formation	Cabot Head Formation
T010054	665.0	Dundee Formation	Reynales/Fossil Hill Formation
T010686	640.0	Dundee Formation	Goat Island Formation
T011649	564.0	Dundee Formation	Guelph Formation
T011650	1086.0	Dundee Formation	Guelph Formation
T011651	564.0	Dundee Formation	Guelph Formation
T011714	581.0	Dundee Formation	Guelph Formation
T011715	579.0	Dundee Formation	Guelph Formation
T011716	578.0	Dundee Formation	Guelph Formation
T011956	604.0	Dundee Formation	Guelph Formation
T011957	589.0	Dundee Formation	Guelph Formation
T011959	598.0	Dundee Formation	Guelph Formation
T011960	567.0	Dundee Formation	Guelph Formation

Note:\* Well #F011968 did not extend past overburden and is not included in Table 3.2.



**Table 3.3 Stratigraphy Derived from Oil and Gas Exploration Wells #F011970 (1939), #F011974 (1955), #T006364 (1985) and #F011982 (1941) in the Municipality of Central Huron (Ontario Oil, Gas and Salt Resources Library (2012), and Itasca and AECOM (2011) after Ontario Oil, Gas and Salt Resources Library (2006))**

Standard Reference		Geological Unit*	#F011970	#F011974	#T006364	#F011982
			Top (mBGS)	Top (mBGS)	Top (mBGS)	Top (mBGS)
Quaternary		Drift	0.6	0.6	2.0	0.6
Devonian	Middle	Dundee	36.6	51.8	59.8	15.2
		Lucas	65.5	68.6	85.5	16.8
		Amherstburg	-	-	164.0	-
	Lower	Bois Blanc	-	175.3	209.0	120.4
Silurian	Upper	Bass Islands / Bertie Formation	239.3	262.1	255.5	176.8
		Salina G Unit	269.7	297.2	350.5	224.0
		Salina F Unit	-	304.8	357.0	-
		Salina E Unit	-	357.5	411.7	262.1
		Salina D Unit	-	386.8	-	-
		Salina C Unit	-	394.1	448.8	295.7
		Salina B Unit	371.9	420.6	455.0	327.7
		Salina A-2 Unit	446.5	493.8	479.0	379.5
		Salina A-1 Unit	495.3	556.3	516.1	417.0
	Lower	Guelph Formation	536.4	598.9	526.4	459.0
		Goat Island Formation	-	-	591.3	-
		Gasport Formation	-	-	600.7	-
		Rochester Formation	-	624.5	-	486.2
		Reynales / Fossil Hill Formation	-	627.9	631.3	488.9
		Cabot Head Formation	566.9	630.9	638.2	496.8
Ordovician	Upper	Manitoulin Formation	-	660.2	659.7	516.6
		Queenston Formation	603.5	670.0	668.6	527.0
		Georgian Bay / Blue Mountain Formation	682.8	748.0	761.0	
		Collingwood Formation	815.3	825.1	-	
		Cobourg Formation	829.1	886.4	885.5	
		Sherman Fall Formation	-	-	914.7	
		Kirkfield Formation	-	-	985.5	
		Coboconk Formation	-	-	1029.3	
		Gull River Formation	-	-	1053.6	
Cambrian	Precambrian	Shadow Lake Formation	-	-	1119.4	
		Mt. Simon Formation	1060.7	1115.6	-	
Precambrian		Precambrian	1062.8	1124.4	1123.8	

Note: \* Nomenclature at the Formation level in this table is slightly different than the recently updated nomenclature used in Table 3.1 (Armstrong and Carter, 2010).

- Unit not logged

Table 3.3 shows that at depths that are typically considered as generally suitable for hosting a deep geological repository (about 500 m or more), the geology of the Municipality of Central Huron is interpreted to comprise the following units:

- Upper Silurian carbonates, evaporites, and shales and Lower Silurian carbonate and shale units. These units are not described in detail in this report as they were found to be unlikely suitable for hosting a deep geological repository in southern Ontario due to high hydraulic conductivities, insufficient thickness and/or vertical and lateral heterogeneity (Mazurek, 2004).

- Underlying the Silurian rocks are Upper Ordovician shale units, which include the Collingwood, Georgian Bay/Blue Mountain, and Queenston formations. These shale units are interpreted to be approximately 220 m thick, and found at depths of about 670 mBGS in the western part of the Municipality, shallowing up to approximately 530 mBGS towards the eastern end of the Municipality (Table 3.3, Figure 3.6).
- Underlying the Upper Ordovician shales are Upper Ordovician limestone units which comprise the Gull River, Coboconk, Kirkfield, Sherman Fall, and Cobourg formations. They are interpreted to be approximately 230 m thick and expected to be found at depths of about 900 mBGS in the western end of the Municipality and shallow to approximately 750 mBGS towards the eastern portion (Table 3.3; Figure 3.6).

There is limited readily available information on the geoscientific characteristics of the Upper Ordovician shale and limestone units beneath the Municipality of Central Huron. However, based on the regional geological understanding it is expected that they are similar to the characteristics of the Upper Ordovician units beneath the Bruce nuclear site, which are described as comprising relatively undeformed, near horizontally layered, low porosity and low hydraulic conductivity sequences. These sequences are correlative over large lateral extents as a result of their simple geometry and uniform thicknesses (NWMO, 2011). The consistency of the thickness of the Upper Ordovician sequence (approximately 450 m) between Wells #F011970, #F011974, and #T006364 (Table 3.3), and the deep boreholes at the Bruce nuclear site (NWMO, 2011) suggests lateral continuity and predictability of the Ordovician stratigraphic units across this part of southern Ontario. This interpretation would have to be confirmed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

### 3.3 Deformation and Metamorphism

#### 3.3.1 Tectonic History

The geologic evolution of southern Ontario is characterized by a series of tectonic events, structural uplift, erosion, burial and faulting, which have occurred over the past 1,210 million years. Readily available information indicates that the Paleozoic sedimentary sequence in southern Ontario has not undergone regional-scale metamorphism (Armstrong and Carter, 2010). Table 3.4 summarizes the timing of major tectonic events that have influenced the Precambrian and Paleozoic rocks beneath southern Ontario.

**Table 3.4 Timetable of Major Tectonic Events in Southern Ontario**

Time Interval Before Present (millions of years)	Tectonic Activity	Reference
1,210 – 1,180	Regional metamorphism (proto-Grenville)	Lumbers et al., 1990; Easton, 1992; 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	Extensional rifting and opening of the Iapetus Ocean	Thomas, 2006
530 – 320	Subsidence of Michigan Basin and Uplift of southern Ontario basement arches (episodic)	Sanford et al., 1985; Howell and van der Pluijm, 1999; Kesler and Carrigan, 2002
470 – 440	Taconic Orogeny • E-W to NW-SE compression, uplift (southern Ontario arches)	Sloss, 1982; Quinlan and Beaumont, 1984; McWilliams et al., 2007
410 – 320	Caledonian/Acadian Orogeny • E-W to NW-SE compression, uplift (southern Ontario arches)	Sutter et al., 1985; Marshak and Tabor, 1989; Gross et al., 1992; Kesler and Carrigan, 2002
300 – 250	Alleghenian Orogeny • E-W to NW-SE compression	Engelder and Geiser, 1980; Gross et al., 1992
200 – 50	• Opening of the Atlantic Ocean • St. Lawrence rift system created • reactivated Ottawa-Bonnechere Graben • NE-SW extension • uplift	Kumarapeli, 1976; Kumarapeli, 1985
50 – Present	• NE-SW compression (from ridge push) • post-glacial uplift	Barnett, 1992

### Precambrian Tectonic History

After a phase of regional metamorphism of the Precambrian crystalline basement rocks during the Grenville Orogeny, a continent-scale rifting event occurred, which generated magmatism in the form of intrusive mafic dykes and sills and extrusive basaltic flows (Easton, 1992; Van Schmus, 1992). This phase was followed by crustal shortening and the main phase of the Grenville Orogeny (Carr et al., 2000; White et al., 2000).

The end of the Grenville Orogeny is marked by the transition to a passive tectonic phase of extension and rifting during the opening of the Iapetus Ocean (Table 3.4; Thomas, 2006).

### Paleozoic Tectonic History

Deposition of the Paleozoic rocks in southern Ontario began with a large rifting event and subsequent subsidence and deposition within the Michigan Basin (Sanford et al., 1985). The Middle Ordovician to Devonian-Mississippian sedimentary rocks reflect the complex interaction between regional-scale tectonic forces, sedimentation, and eustatic sea level fluctuations associated with the Taconic, Caledonian/Acadian, and Alleghenian orogenic events (Table 3.4). Uplift of the Precambrian crystalline basement arches in southern Ontario, and episodic subsidence within the Michigan Basin during these three main tectonic events are largely responsible for the regional variations in depositional setting and rock types.

### Mesozoic-Cenozoic Tectonic History

The Atlantic Ocean began to open approximately 200 million years ago during the Triassic Period and associated tectonic activity was focused at the margin of the continent. A transition from northwesterly to west-southwesterly North American plate motion and initiation of spreading in the North Atlantic approximately 50 million years ago controls the current east-northeast-oriented compressional stress field of eastern North America that characterizes the most recent tectonic phase (Barnett, 1992).

## **3.3.2 Fault History**

Documented basement-seated faults that displace the Paleozoic strata in southern Ontario are shown on Figure 3.2 (compiled by Armstrong and Carter, 2010). The faults are organized into three categories based on the youngest geological unit that is offset: i) Shadow Lake/Precambrian, ii) the Trenton Group (Ordovician-aged) and iii) the Rochester Formation (Silurian-aged). These faults have been interpreted using borehole data obtained from oil and gas wells (structural contour maps) and geophysical analysis (e.g., Brigham, 1971). The faulting is interpreted to be caused by re-activation of pre-existing faults in the Precambrian crystalline basement during the evolution of the Paleozoic Michigan and Appalachian Basins (Sanford et al., 1985; Marshak and Paulsen, 1996).

Mapped faults within southern Ontario are shown as segments measuring from a few metres to about 40 km in length, with one exception that is almost 100 km in length (Figure 3.2). The faults are generally interpreted to be nearly vertical in dip, exhibit normal and/or strike-slip motion, and cluster into two main orientations; east-northeast to southeast and north to north-northeast (Figure 3.2). Displacements on all faults range from a few metres up to a maximum of 100 m (Brigham, 1971; Carter et al., 1996). Where faults strike easterly, the predominant offset is south-side-down. This fault orientation is most common near the Chatham Sag in southwestern Ontario where a marked concentration of faults occur along, and southeast of, the trace of the Algonquin Arch (Figures 3.1 and 3.2).

Sanford et al. (1985) introduced a conceptual fracture framework for southern Ontario, based on hand contouring of isopachs of selected Silurian units and structure contours on the top of the Silurian Rochester Formation (outcrop nomenclature, equivalent to the Fossil Hill Formation). Some similarity exists between this conceptual fault model

and the distribution of known faults located southeast of the Algonquin Arch and in particular proximal to the Chatham Sag. However, such a systematic fault pattern is not observed in structural contours on the top of the Precambrian basement surface to the northwest of the Algonquin Arch in the southern Ontario portion of the Michigan Basin, nor is it consistent with known or interpreted mapped faults in this area (Bailey Geological Services and Cochrane, 1984; Carter et al., 1996; Armstrong and Carter, 2010). Johnson et al. (1992) also noted that although fractures may exist, the extensive fracture framework conceptualized by Sanford et al. (1985), which includes an ordered and approximately 10 km-spaced set of faults offsetting Silurian strata, is not recognized.

No Paleozoic faults are mapped within the Municipality of Central Huron (Figure 3.6). The nearest fault, reported approximately 36 km north of the Municipality (Figure 3.6), exhibits an east-northeast strike orientation and is interpreted to postdate the deposition of the Ordovician Trenton Group carbonates that occurred approximately 450 million years ago (e.g., Sutter et al., 1985), but predate the deposition of the overlying Upper Ordovician shales.

In summary, no basement-seated faults are recognized within approximately 30 km of the Municipality of Central Huron (Figure 3.6). The nearest faults outside of this area have an ancient history, which predates deposition of the Upper Ordovician shale formations. There is no evidence from the regional stratigraphic framework that anomalous structural complexity due to tectonic faulting occurs within the Paleozoic sedimentary succession beneath the Municipality of Central Huron. This would have to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

### 3.3.3 Diagenesis

Diagenesis includes changes (chemical, physical, biological) undergone by sediments after their initial deposition, not including metamorphism or surface weathering. The Paleozoic rocks of southern Ontario have been altered through their depositional and post-depositional lifecycle by diagenetic processes. The primary diagenetic process in the Michigan Basin is dolomitization of limestone, which is interpreted to have occurred in response to tectonically driven fluid migration associated with Paleozoic orogenic events (e.g., Coniglio and Williams-Jones, 1992). Other diagenetic processes that have occurred in the Paleozoic sedimentary sequence in southern Ontario include clay alteration (Ziegler and Longstaffe, 2000), and hydrocarbon formation, migration and emplacement (e.g., Armstrong and Carter, 2010).

Diagenesis through salt dissolution in the Salina Formation and creation of subsequent collapse features (Upper Silurian and Devonian stratigraphy) has also altered the Paleozoic rocks in southern Ontario. The process of salt dissolution and the creation of collapse features occurred in response to tectonic events that pushed large volumes of fluid through the stratigraphy dissolving the salt. This process occurred more than 300 million years ago during the Silurian to Devonian Caledonian Orogeny and the Devonian to Mississippian Acadian Orogeny (Sanford et al., 1985).

In summary, significant diagenetic events affecting the Paleozoic rocks of southern Ontario correspond to major tectonic events, which have not been active since approximately 200 million years ago (Table 3.4). There is limited readily available information regarding the diagenetic character of the Paleozoic sedimentary rocks beneath the Municipality of Central Huron. This information would need to be assessed further during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

### 3.3.4 Karst

Karst is created by the dissolution of carbonate and evaporite rocks as groundwater migrates through the sedimentary strata. Karst processes are most active in the shallow subsurface, typically less than 200 mBGS, and potentially down to 300 m BGS in Devonian carbonates in southern Huron County (Worthington, 2011). Deeply

buried rocks beneath southern Ontario are unlikely or not affected by modern karst processes (Worthington, 2011). These deeper formations could have been affected by karst processes during or after their deposition, referred to as paleokarst. In southern Ontario, these paleokarst zones are most likely to be observed at large breaks in the sedimentary record marked by regional unconformities (Table 3.1). In most cases, including at the Bruce nuclear site, the paleokarst porosity has been infilled with younger sediments, such as evaporites, that destroy the porosity and permeability of the original karst (NWMO, 2011).

The distribution of near-surface known, inferred and potential karst in southern Ontario is presented in Figure 3.7 (Brunton and Dodge, 2008). The Municipality of Central Huron lies within an area of inferred karst identified as part of the Detroit River Group and Dundee Formations (Figure 3.7; Brunton and Dodge, 2008). Areas of known karst have been mapped immediately south of the Municipality, as well as near Goderich, immediately northwest of the Municipality (Figure 3.7). Also, Hurley et al. (2008) identified more than 50 sinkholes in the Devonian carbonates in the area to the east of the Municipality of Central Huron and indicated that the karst features in bedrock extended over a much larger area than that represented by the sinkholes at surface. It was noted that although areas of groundwater depression up to 100 m were frequently correlated with the mapped upper contact of the Devonian Lucas Formation, karstification in the area was determined to have a high spatial variability and no definitive correlation with water table elevations or stratigraphic relationships could be found (Hurley et al., 2008).

Figure 3.7 shows that in southern Ontario, mapped karst is found in the Ordovician carbonates that outcrop along the boundary with the Canadian Shield between Georgian Bay and eastern Ontario, Silurian carbonates exposed along the Niagara escarpment (Lockport, Amabel, and Guelph formations, and the Bass Islands and Bertie formations) and Devonian carbonates in southern Ontario (Dundee Formation and Detroit River Group). Inferred and potential karst incorporates the outcrop and subcrop areas of the known karst geological units as outlined above. Brunton and Dodge (2008) noted that large-scale karstification is found both proximal to significant escarpments or cuesta margins and/or laterally within a few hundred metres of incised river systems. Modern karstification of carbonates is likely to occur almost exclusively in shallow freshwater zones.

In summary, modern karst processes in southern Ontario are generally considered active down to about 200 mBGS, potentially reaching approximately 300 mBGS locally. These processes are unlikely to affect the deep subsurface geological or hydrogeological conditions at typical repository depth (approximately 500 m or more). The depth of modern karstification and the influence that paleokarst may have on the deep carbonate rock formations beneath the Municipality of Central Huron would need to be assessed further during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

### 3.4 Geomechanical Properties

No readily available information on rock geomechanical properties was found for the Municipality of Central Huron. However, a detailed assessment of the geomechanical properties of the Paleozoic sequence underlying the Bruce nuclear site was conducted as part of detailed site characterization for the OPG-DGR project (Golder, 2003; NWMO, 2011; NWMO and AECOM, 2011). The assessment was based on the understanding of the regional geomechanics of southern Ontario, as well as on a suite of field and laboratory observations and measurements conducted at the Bruce nuclear site. A wide range of geomechanical properties of the sedimentary sequence was assessed, including short- and long-term behaviour of underground openings at typical repository depths. A brief summary of the relevant properties is given below, focusing on the Upper Ordovician shale and limestone units, which are interpreted to exist at typical repository depths beneath the Municipality of Central Huron. The information below relates mostly to Upper Ordovician units at depths shallower (of about 450 to 650 mBGS) than those at which they are found in the Municipality of Central Huron (see Section 3.2.1).



Previous construction experience with the excavation of underground openings in southern Ontario indicates that excavated openings in either the Upper Ordovician shale or limestone units are likely to be dry and stable (Golder, 2003). These include the 925 m long Darlington cooling water intake tunnel and the 470 m long storage cavern access tunnel at the Wesleyville Generating Station. The Darlington tunnel was completed within the Cobourg Formation beneath Lake Ontario. The Wesleyville tunnel intersects both the Cobourg Formation and the underlying Sherman Fall Formation.

Available information from the Bruce nuclear site on strength and in situ stresses suggest that the Upper Ordovician shale and limestone units have a high strength and favourable geomechanical characteristics, which makes them amenable to the excavation of stable underground openings. For example, estimated mean uniaxial compressive strengths for Upper Ordovician limestone (Cobourg Formation) and shale (Georgian Bay Formation) units were 113 MPa and 32 MPa, respectively at the Bruce nuclear site (Intera, 2011). These values compare favourably with other sedimentary formations considered internationally for the long-term management of radioactive waste (NWMO, 2011). Compressive strengths for these formations at greater depths would need to be assessed during subsequent site evaluation stages, if the community remains interested in the site selection process.

Numerical simulations of the behaviour of underground openings in the limestone of the Cobourg Formation for the OPG-DGR project suggest that the openings will remain stable during construction and operation, requiring only standard support. The simulations also suggest that, in the long-term, the barrier integrity of the enclosing Ordovician bedrock formations will not be affected under various loading scenarios associated with glacial ice sheet, seismic ground motions and repository gas pressure (NWMO, 2011). While the data discussed above provides a general understanding of the geomechanical characteristics of the Upper Ordovician units, their long-term geomechanical behavior may be different beneath the Municipality of Central Huron (see Section 3.2.1), where they are found at greater depths and in-situ stresses will be higher.

In summary, available information on geomechanical properties of the Upper Ordovician shale and limestone units in southern Ontario suggests these units have a high strength, and favourable geomechanical characteristics, which makes them amenable to the excavation of stable underground openings. This interpretation would have to be confirmed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

### 3.5 Quaternary Geology

The extent and type of Quaternary deposits in the Municipality of Central Huron and surrounding areas are illustrated in Figure 3.8, which shows that the Municipality is entirely covered by overburden. The Quaternary cover in the area mostly comprises glacial deposits including tills, glaciofluvial, and glaciolacustrine sediments deposited during the late Pleistocene Wisconsinan glaciations. The Quaternary sediments were deposited during fluctuations of the Huron and Georgian Bay Lobes of the Laurentide Ice Sheet that occurred between approximately 23,000 and 10,000 years ago during the Wisconsinan glaciation, prior to final retreat of glacial ice (Karrow, 1974). Overlying the mapped Quaternary deposits in several river valleys, including the Maitland and South Maitland River valleys, are recent alluvial sediments (not mapped in Figure 3.8).

Mapping of the Quaternary deposits in the Municipality of Central Huron shows that glacial till and glaciofluvial outwash and ice-contact deposits are prevalent throughout the Municipality, forming hummocky topography (Figure 3.8). The eastern half of the Municipality is dominated by the Wawanosh Moraine, which is characterized by an area of interbedded till and glaciofluvial ice-contact deposits. Two east-west trending eskers are present in this area. Localized deposits of glaciolacustrine sands, silts, and clays are present on the eastern side of the feature. In the western half of the Municipality, the Wyoming Moraine forms well-defined north-south ridge crests parallel to the Lake Huron shoreline. A broad, low area of glaciofluvial outwash sediments borders its eastern flank, separating it

from the Wawanosh Moraine to the east. Outwash is also found locally within the Bayfield River valley, and more extensively within the Maitland River valley. On the west flank of the Wyoming Moraine, gravelly-sandy glaciolacustrine beach deposits and poorly developed shorelines scarps associated with proglacial Lake Warren are present in the area that slopes down towards the lake. The narrow strip of land running along the Lake Huron shoreline is characterized by a bevelled till plain and localized glaciolacustrine deposits present in the southern corner of the Municipality, which represents the former Warren Lake bottom (Cooper and Fitzgerald, 1977) (Figure 3.8).

### 3.5.1 Quaternary Overburden Thickness

The thickness of the Quaternary deposits in the Municipality of Central Huron and surrounding areas is shown in Figure 3.9 (Gao et al., 2006). The Municipality of Central Huron is covered by Quaternary deposits with overburden thicknesses ranging from approximately less than 1 m to 134 m (Derived from MOE Water Well Records; Section 4.1), with the majority of the Municipality covered by greater than 10 m. The thickest overburden deposits are found in the western half of the Municipality and are associated with the Wyoming Moraine, the crest of which runs north-south through the Municipality, parallel to the Lake Huron shoreline. Overburden thickness in the eastern half of the Municipality is variable, with localized highs and lows representative of the hummocky till and kame deposits of the Wawanosh Moraine. Along with the localized lows present in the eastern half of the Municipality, areas of thinner overburden are present in the Maitland River valley, and in the short, narrow, gullied streams that flow down the western flank of the Wyoming Moraine to Lake Huron (Figure 3.9).

### 3.5.2 Glacial Erosion

Southern Ontario is expected to be affected by major glaciations recurring approximately every 100,000 years (Peltier, 2011). Hallet (2011) studied glacial erosion in the area around the Bruce site caused by the Laurentide Ice Sheet, and concluded that significant glacial erosion likely did not occur, based on observations of striated surfaces with multiple episodes preserved, the relative absence of friction cracks, and the pervasive low relief of striated surfaces. Hallet (2011) also concluded that although uncertainties remain in ice sheet reconstructions and estimates of erosion by ice and melt water, all lines of study indicate that, at the Bruce nuclear site, glacial erosion would conservatively be 100 m per 1 million years. The study undertaken by Hallet (2011) was specific to the topographic and geological conditions surrounding the Bruce site about 70 km north of the Municipality, and while it may be generally applicable, this interpretation would have to be confirmed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

## 3.6 Neotectonic Activity

Neotectonics refers to deformations, stresses and displacements in the earth's crust of recent age or which are still occurring. The Late Pleistocene Laurentide Ice Sheet that advanced over most of Canada into the United States began approximately 120,000 years ago (Peltier, 2011). At last glacial maximum 25,000 years ago the Laurentide Ice Sheet surpassed 2,800 m in thickness over the most glaciated regions of the continent (Peltier, 2002). The weight of the ice sheet depressed the surface of the earth by approximately 600 m (Peltier, 2011). After the ice retreated some 14,000 years ago, the earth's surface has rebounded through a process known as glacio-isostatic adjustment which continues today. In southern Ontario and the Great Lakes region, the magnitude of glacio-isostatic adjustment is about 1.5 mm/year (Peltier, 2011). This glacial unloading results in a stress regime in shallow bedrock areas that can lead to the development of stress release features such as elongated compressional ridges or pop-ups that are documented in southern Ontario (McFall, 1993).



A neotectonic study was conducted as part of detailed site characterization for OPG's proposed DGR at the Bruce nuclear site to analyse Quaternary landforms for the presence of seismically-induced soft-sediment deformation (Slattery, 2011). The study found no evidence for neotectonic activity associated with the most recent glacial cycle approximately 25,000 years ago (Slattery, 2011). The study by Slattery (2011) was undertaken within a radius of up to 50 km surrounding the Bruce site and while generally applicable to the area of the Municipality of Central Huron, this interpretation would have to be confirmed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process

### 3.7 Seismicity

The Municipality of Central Huron is located in the Grenville Province of the Canadian Shield, where much of southern Ontario has remained tectonically stable since approximately 970 million years ago (Percival and Easton, 2007; Table 3.4). Figure 3.10 shows the location of all earthquakes with a magnitude greater than 3 that are known to have occurred in Canada from 1627 until 2010 (Natural Resources Canada, 2012) and Figure 3.11 (Earthquakes Canada, 2012) shows the locations and magnitudes of all earthquakes recorded in southern Ontario between 1985 and 2012 (Natural Resources Canada, 2012). All recorded earthquakes in southern Ontario have a magnitude of less than 5 (Figures 3.10 and 3.11; Natural Resources Canada, 2012, Earthquakes Canada, 2012). Most of the earthquakes in the region around the Municipality of Central Huron are concentrated in the area located southeast of the Algonquin Arch and, to a lesser extent, offshore in Lake Huron and Georgian Bay (Figure 3.11). The nearest recorded earthquakes to the Municipality are interpreted to have occurred 25 km to the south, and have a magnitude of less than 3 (Figure 3.11).

In summary, available literature and recorded seismic events indicate that the Municipality of Central Huron is located within a region of low seismic hazard.

## 4. Hydrogeology

### 4.1 Groundwater Wells

Information on groundwater in the Municipality of Central Huron was obtained from the Ontario Ministry of the Environment (MOE) Water Well Record Database (Ontario Ministry of the Environment, 2012). The location of known water wells is shown on Figure 4.1.

The Municipality of Central Huron relies on overburden and shallow bedrock aquifers for its domestic, industrial and municipal water supply. In addition to being used for potable supply, shallow groundwater also supports baseflow to numerous streams and wetlands within the area. There are seven active municipal water supply well fields serving the Municipality of Central Huron. Those within the Maitland Valley Source Protection Area (SPA) include the Kelly Well Supply, McClinchey Well Supply, and Auburn Well Supply, and those within the Ausable Bayfield Source Protection Area (SPA) include the S.A.M. Well Supply, Vandewetering Well Supply, and Dundass Well Supply (Ausable-Bayfield & Maitland Valley Source Protection Region, 2011a,b). The Clinton Well Supply lies within both source protection areas. Well head protection areas in the Municipality would need to be examined further during subsequent site evaluation stages, if the community decides to continue in the site selection process.

The MOE Water Well Record Database contains a total of 1,049 water well records for the Municipality of Central Huron (Figure 4.1; Table 4.1). Of these 1,049 well records, 19 records contained information only on location and provided no data on well type, depth, or hydrogeological conditions. A summary of the 1,030 well records with hydrogeological data is provided in Table 4.1.

**Table 4.1 MOE Water Well Record Details**

Well Type	Number of Well Records	Depth Range (m)		Static Level Range (mBGS)		Well Yield (L/min)		
		Min	Max	Min	Max	Min	Max	Mean
Overburden	64	1.2	134.1	0.3	27.4	0.2	18.1	3.3
Bedrock	966	7.0	129.5	0.0	96.0	0.2	213.4	4.3

The MOE Water Well Records indicate that no potable water supply wells are known to exploit aquifers at depths greater than 134 m within the Municipality of Central Huron (Table 4.1). Of the 1,030 well records that contained stratigraphic completion records, 64 well records show completion in overburden aquifers, and 966 well records indicate completion in bedrock aquifers (Table 4.1). Wells completed within overburden range in depths from approximately 1 to 134 m. Overburden well yields range from 0.2 to 18.1 L/min, with mean values of 3.3 L/min. Wells completed in the bedrock range in depth from approximately 7 to 130 m. Bedrock well yields range from 0.2 to 213.4 L/min, with mean values of 4.3 L/min. These yields reflect the purpose of the wells, and do not necessarily reflect the maximum sustained yield that might be available from the aquifer.

### 4.2 Deep Groundwater System

There is no direct hydrogeological information available on the deep groundwater system beneath the Municipality of Central Huron. However, as described in Section 3.2.1, there is a high degree of lateral continuity and predictability of the Paleozoic sequence across this part of southern Ontario. This suggests that the hydrogeological setting beneath the Municipality of Central Huron is likely to be similar to that interpreted from regional hydrogeological information and the detailed site characterization work completed at the Bruce nuclear site for OPG's proposed DGR project (Hobbs et al., 2011; Intera, 2011; NWMO, 2011).

These studies indicate that the active groundwater system at the Bruce nuclear site is shallow, and is limited to the upper approximately 200 mBGS (NWMO, 2011), which coincides with the lower contact of the Bass Islands Formation. The shallow groundwater system may extend to greater depth beneath the Municipality of Central Huron where the lower contact of the Bass Islands Formation is found at depths ranging from 225 m to 350 mBGS.

Below the shallow system, an intermediate and a deep groundwater system have been recognized both regionally and at the Bruce nuclear site (Intera, 2011; NWMO, 2011). Field data from the Bruce nuclear site indicates that the deep groundwater system has low groundwater yields due to the very low hydraulic conductivities (approximately  $10^{-15}$  to  $10^{-11}$  m/s) of the Upper Ordovician formations encountered at a depth of about 450 m. The deep groundwater system beneath the Bruce nuclear site is interpreted as diffusion-dominated and isolated from the shallow groundwater system by multiple near horizontally layered, laterally extensive, low permeability formations (NWMO, 2011).

As mentioned in section 3.3.4, karst development down to 300 mBGS has been described in some parts of southern Huron County (Worthington, 2011). The effect that karst would have on the depth of the shallow active groundwater system would have to be assessed during subsequent stages of the site evaluation, if the community remains interested in continuing with the site selection process.

In summary, there are no known exploitable groundwater resources at depths greater than 134 m in the Municipality of Central Huron based on a review of water well records. In addition, Upper Ordovician shale and limestone units which are found at typical repository depth beneath the Municipality are expected to exhibit very low hydraulic conductivities making them unsuitable for groundwater resources. Also, as discussed in Section 4.3, available regional information indicates a transition from fresh to non-potable, saline groundwater below approximately 200 mBGS (Hobbs et al., 2011; NWMO, 2011).

## 4.3 Hydrogeochemistry

There is no direct readily available information on groundwater hydrogeochemistry at depth for the Municipality of Central Huron. However, the regional hydrogeochemistry for southern Ontario has been described as part of site characterization activities for OPG's proposed DGR at the Bruce nuclear site (Hobbs et al., 2011; NWMO, 2011).

Two geochemical systems are interpreted at the regional scale in southern Ontario by Hobbs et al. (2011). These include a shallow system (generally less than 200 mBGS) containing fresh through brackish waters. Waters in this system have stable isotopic compositions ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) consistent with mixing of dilute meteoric or cold-climate (glacial) waters with more saline waters. The second geochemical system is an intermediate to deep system (generally more than 200 mBGS) containing brines which have elevated total dissolved solids (TDS) values (200,000 to 400,000 mg/L) and distinct stable oxygen and hydrogen isotopic signatures (Hobbs et al., 2011; NWMO, 2011).

Within the regional geochemical database, the maximum depth at which glacial waters are observed is 130 mBGS (Hobbs et al., 2011). The major ion composition of waters from the intermediate to deep system, in particular Cl and Br concentrations, support the interpretation that these waters evolved from ancient seawater by evaporation past halite saturation, with limited evidence for recent dilution by meteoric or glacial waters. The redox conditions are believed to be reducing, due to the presence of methane gas in hydrocarbon reservoirs (Hobbs et al., 2011). The nature of the brines, in particular the high salinities and enriched  $\delta^{18}\text{O}$  values of the porewaters, indicate that the deep system is isolated from the shallow groundwater system and that the porewaters have resided in the system for a very long time (NWMO, 2011).

## 5. Economic Geology

### 5.1 Hydrocarbon Resources

The Paleozoic rocks of southern Ontario are known to include regions of commercial hydrocarbon accumulation. In the Municipality of Central Huron there are two known hydrocarbon pools, the Tipperary and Tipperary South Pools, both located in the southwestern portion of the Municipality (Figure 3.6). These two pools were discovered in 1969 and 1979, respectively and produced gas from a pinnacle reef in the Silurian Guelph Formation. They are currently depleted and the reservoirs are being used for gas storage. Other Silurian pinnacle reefs hydrocarbon pools in the area surrounding the Municipality of Central Huron include the Ashfield 5-IX WD, Ashfield 7-1-III ED, Dungannon, and West Wawanosh 26-X pools located within 20 km north of the Municipality, and the Bayfield and Tuckersmith 30-III SHR pools within 3 km south of the Municipality (Figure 3.6). In addition to the Tipperary and Tipperary South wells, a number of wells were drilled within the Municipality of Central Huron through the Guelph Formation, resulting in either dry holes or uneconomical gas/oil shows.

Historic exploration in the region around the Municipality of Central Huron also focused on Upper Ordovician units (hydrothermal dolomites) as potential hydrocarbon plays (e.g., Sanford, 1993; Hamblin, 2008; Lazorek and Carter, 2008). No economical oil or gas volumes were reported for the Upper Ordovician in the three wells within the Municipality that were drilled through these units. The absence of Upper Ordovician hydrothermal dolomite plays would need to be confirmed during subsequent site evaluation stages, if the Municipality remains interested in continuing with the site selection process.

New conceptual hydrocarbon plays are identified for southern Ontario by Hamblin (2008). Potential plays include Cambrian gas deposits at the eastern edge of the Michigan Basin, Upper Ordovician Shadow Lake Formation where it overlies the Cambrian, and Upper Ordovician shale gas. With respect to potential Cambrian plays, Wells #F011970 and #F011974 within the Municipality of Central Huron did intersect Cambrian deposits 2.1 m and 8.8 m thick, respectively. Well #F011974 was found to be dry and was subsequently abandoned; gas shows were recorded in Well #F011970, however, the activity status of the well is not documented. Shadow Lake deposits 4.4 m thick were logged in Well #T006364, which was found to be dry and was abandoned. The absence of Cambrian and Shadow Lake gas plays in the Municipality of Central Huron would need to be confirmed during subsequent site evaluation stages, if the community remains interested in the site selection process.

Shale gas potential has been identified in southern Ontario in the Blue Mountain Formation and in the Collingwood member of the underlying Trenton Group (Hamblin, 2006). These units are considered equivalent to the Utica Group shales, which are found further east along the St. Lawrence River in Canada and extend southward into the United States. The Utica shales have been proved to have potential as shale gas plays (Lavoie et al., 2008). Recent investigations by the Ontario Geological Survey in Arthur Township (approximately 75 km northeast of the Municipality of Central Huron) by Béland Otis (2012a and 2012b) also suggest that the Rouge River Member of the Blue Mountain Formation and the Collingwood Member of the Cobourg Formation have shale gas potential. However, the presence and economical viability of gas resources in these shale units in southern Ontario is yet to be proven.

An analysis of the shale gas potential for the Bruce nuclear site, located 70 km north of the Municipality of Central Huron, found that insufficient total organic content of the Ordovician shales, as well as insufficient thermal maturity, would preclude any likelihood of commercial shale gas accumulations (Engelder, 2011). The organic content and thermal maturity of the Ordovician shales in the Municipality of Central Huron is unknown and the shale gas potential of these units would have to be further assessed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

In summary, two known hydrocarbon pools exist within the Municipality of Central Huron. These currently depleted pools exploited gas from pinnacle reefs in the Upper Silurian Guelph Formation and are now being used as natural gas storage reservoirs. There are six additional pinnacle reef hydrocarbon pools identified in the area surrounding the Municipality (Figure 3.6). The potential for Upper Silurian plays, as well as Upper Ordovician and new conceptual hydrocarbon plays within the Municipality would have to be examined during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

## 5.2 Metallic Mineral Resources

There is no record of current or past metallic mineral production, and no exploration potential for metallic minerals has been identified within the Municipality of Central Huron. The sole documented metallic mineral occurrence in southern Ontario is sphalerite associated with Mississippi Valley Type (MVT) lead/zinc deposits within Silurian dolomite on the Bruce Peninsula (e.g., Sangster and Liberty, 1971). No commercial MVT deposits or other metallic resources have been found within southern Ontario.

## 5.3 Non-Metallic Mineral Resources

Known non-metallic mineral resources in the region include bedrock-derived crushed stone, natural surficial sand and gravel resources, salt and building stone. Currently licensed non-metallic mineral extraction in the Municipality of Central Huron is limited to sand and gravel resources (Figure 5.1).

### 5.3.1 Sand and Gravel

Sand and gravel pits in the Municipality of Central Huron generally correspond to glaciofluvial outwash deposits found at surface (Figures 3.8 and 5.1). The Ontario Geological Survey Aggregate Resources Inventory for Huron County (Ontario Geological Survey, 2004) designated primary, secondary and tertiary significance for sand and gravel resources based on quality and potential volume.

Five areas within the Municipality of Central Huron were assigned a primary significance. The first of these areas comprises the currently operating pits that are located in a north-south oriented band through the centre of the Municipality and corresponds to the glaciofluvial outwash channel deposits between the Wyoming and Wawanosh Moraines (Figure 3.8 and 5.1). Pits are also present in the area associated with ice-contact sediments, identified near the southeastern boundary of the Municipality, in the area characterized by esker deposits in the eastern portion of the Municipality, and along the northeastern boundary of the Municipality where kame deposits comprise the aggregate resource. An additional resource of primary significance was identified along the northern boundary of the Municipality, on the eastern bank of the Maitland River, and corresponds to glaciofluvial outwash deposits, and a single pit is present on the Municipality border at this location.

Areas of secondary significance correspond to localized areas of outwash deposits in the eastern portion of the Municipality, as well as along the Maitland River at the northwestern boundary of the Municipality. However these are described as being limited in extent (Ontario Geological Survey, 2004). The glaciolacustrine beach deposits along the western side of the Municipality are also identified as areas of secondary significance, however these areas are described as being mostly depleted (Ontario Geological Survey, 2004).

### 5.3.2 Bedrock Resources

There are no known licensed bedrock quarries or commercial mining operations within the Municipality of Central Huron or within 20 km of the Municipality (Figure 5.1).

Economic bedrock resources are typically close to the surface, covered by less than 8 m of overburden, and must be of mineable thickness. Most bedrock extraction operations are located in areas where the overburden thickness is 3 m or less. The majority of the Municipality of Central Huron is covered by greater than 8 m of Quaternary deposits (Section 3.5.1 and Figure 3.9). Those areas with thin overburden or outcrop contain no unique bedrock resources with respect to aggregate, cement or building stone.

### 5.3.3 Salt Formations

Salt beds are present beneath the Municipality of Central Huron and surrounding area. Salt is currently being recovered in the Goderich Mine (Figure 5.1), north of the Municipality, through underground mining and brine-well methods. The Goderich mine is the largest salt mine in the world with an annual production capacity of 9,000,000 tonnes. It is situated approximately 550 m below ground surface, and extends approximately 5 km from the shore beneath Lake Huron (Sifto Canada Corp., 2012; Compass Minerals, 2012).

Figure 5.2 shows a geological cross-section prepared by Sanford (1975) that illustrates the Silurian to Devonian stratigraphy extending eastward from Goderich. The predicted areal distribution of Salina Formation salt is shown in Figure 5.3 (after Sanford et al., 1985). In this area, salt beds occur on the Salina A-2, B, D, and F units (Hewitt, 1962, Sanford, 1975). As shown on Figure 5.2, the salt beds quickly thin out east of the Municipality. However, they extend significantly to the west offshore under Lake Huron and to the south down to Sarnia along the eastern shore of Lake Huron (Figure 5.3). The estimated amount of salt present within the Sarnia-Goderich region is  $2.0 \times 10^{12}$  tonnes (Hewitt, 1962).

The cumulative thickness of these salt beds in the Goderich area is approximately 150 m (Figure 5.2, Sanford, 1975), with the Salina B being the thickest salt unit (approximately 80 m). Salt beds of the Salina Formation beneath the Municipality of Central Huron have cumulative thicknesses ranging between 12 m and 104 m (Salina A2 and B salt units), and an average cumulative thickness of 76 m (Ontario Oil, Gas and Salt Resources Library, 2006). These salt bearing units within the Municipality occur at depths ranging between 458 and 541 m BGS for the Salina A-2 salt bed, and between 323 and 486 m BGS for the Salina B salt. Depths to both the A2 and B salt beds are greatest on the western side of the Municipality and generally decrease to the northeast (Figure 5.2).



## 6. Initial Screening Evaluation

This section provides an evaluation of each of the five initial screening criteria (NWMO, 2010) for the Municipality of Central Huron based on the readily available information presented in Sections 2 to 5. The intent of this evaluation is not to conduct a detailed analysis of all available information or identify specific potentially suitable sites, but rather to identify any obvious conditions that would exclude the Municipality of Central Huron from further consideration in the site evaluation process. The initial screening focused on the areas within the boundaries of the Municipality of Central Huron. Areas within neighbouring municipalities were not included in the initial screening.

Initial screening criteria (NWMO, 2010) require that:

1. The site must have enough available land of sufficient size to accommodate the surface and underground facilities.
2. This available land must be outside of protected areas, heritage sites, provincial parks and national parks.
3. This available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.
4. This available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.
5. This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the outlined safety factors in Section 6 of the site selection document (NWMO, 2010).

For cases where readily available information is limited and where the assessment of some of the criteria is not possible at the initial screening stage, the area would be advanced to the feasibility study stage for more detailed evaluation, provided the community remains interested in continuing to participate in the siting process.

### 6.1 Screening Criterion 1: Land Availability

***The site must have enough available land of sufficient size to accommodate the surface and underground facilities.***

Surface facilities associated with the deep geological repository will require a surface land parcel of about 1 km by 1 km (1 km<sup>2</sup>; 100 ha) in size, although some additional space may be required to satisfy regulatory requirements. The underground footprint of the repository is about 1.5 km by 2.5 km (3.75 km<sup>2</sup>; 375 ha) at a typical depth of about 500 m or more.

This criterion was evaluated by assessing whether the Municipality of Central Huron contains parcels of land that are large enough to accommodate the surface facilities and whether there is a sufficient volume of rock at depth to accommodate the underground facilities. The available land areas should be accessible for the construction of surface facilities, and for the various field investigations that are necessary to characterize the rock volume required to accommodate the footprint of the repository (e.g., drilling of boreholes).

Availability of land was assessed by identifying areas where surface facilities are unlikely to be built due to constraints, such as the presence of natural features (e.g., large water bodies, topographic constraints), land use (developed areas, infrastructure), accessibility and construction challenges, based on the information presented in Section 2.

Review of available mapping and satellite imagery shows that the Municipality of Central Huron contains sufficient area to accommodate the repository's surface facilities (Figures 2.1 and 2.2). Wetland complexes, which account for approximately 2% of the land area, constitute the main land constraint within the Municipality of Central Huron. In addition, a small portion of the Municipality is covered by localized residential and commercial infrastructure, primarily located within the settlement area of Clinton in the south-central area of the Municipality (Figure 2.1). The remainder of the Municipality of Central Huron is largely agricultural land with development limited primarily to roadways and the settlement areas of Holmesville, Kinburn and Londesborough.

As discussed in Section 2, topography is variable across the Municipality of Central Huron (Figure 2.4). However, no obvious topographic features that would prevent construction and characterization activities have been identified. Most of the Municipality of Central Huron could be accessed from Highway 21 and the numerous subsidiary county and rural roads that cross the area (Figure 2.1).

As discussed in Section 6.5, readily available information suggests that the Municipality of Central Huron has the potential of containing sufficient volumes of host rock at depth to accommodate underground facilities associated with a deep geological repository. This would have to be confirmed in subsequent site evaluation stages, if the community remains interested in continuing to participate in the site selection process.

*Based on the review of readily available information, the Municipality of Central Huron contains sufficient land to accommodate the repository's surface and underground facilities.*

## 6.2 Screening Criterion 2: Protected Areas

***Available land must be outside of protected areas, heritage sites, provincial parks and national parks.***

The assessment of this criterion is needed to assure that the remaining available land, after excluding protected areas, is large enough to allow for the construction of the repository's facilities. For the purpose of this initial assessment protected areas are considered to be ecologically sensitive or significant areas, as defined by provincial or federal authorities.

The Municipality of Central Huron was screened for federal, provincial and municipal parks, conservation areas, nature reserves, national wildlife areas and archaeological and historic sites using available data from the Ontario Ministry of Natural Resources (2009) and the Ontario Ministry of Tourism and Culture (undated).

There are no provincial or national parks within the Municipality of Central Huron (Figure 2.1). The nearest parks are the Morris Tract Provincial Nature Reserve, immediately north of the Municipality, and the Point Farms Provincial Park approximately 6 km north of the Municipality. There are two conservation areas within the Municipality: the Naftels Creek and Black's Point Conservation Areas. There are also three Provincially Significant Wetlands, two Earth Science Areas of Natural and Scientific Interest (ANSI), two Life Science ANSIs, and the G.G. Newton NGO Nature Reserve (Figure 2.1). Known protected areas represent about only 10% of the Municipality of Central Huron.

As discussed in Section 2.4.2, most of the land in the Municipality of Central Huron is free of known heritage constraints. There are 16 known archeological sites within the Municipality. These sites are localized and small in size. There are also 15 provincially designated heritage properties within the Municipality, all located with the settlement area of Clinton and along County Road 8. There are no National Historic Sites in the Municipality of Central Huron.



The absence of locally protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

*Based on the review of readily available information, the Municipality of Central Huron contains sufficient land outside protected areas, heritage sites, provincial parks and national parks to accommodate the repository's facilities.*

### 6.3 Screening Criterion 3: Known Groundwater Resources at Repository Depth

***Available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.***

In order to minimize the future risk of human intrusion during the long post-closure period, the repository should be sited in a host rock formation that does not contain significant groundwater resources at repository depth (typically 500 m or more) that may encourage future generations to access those resources and potentially compromise the long-term performance of the repository.

The review of available hydrogeological information did not identify any known groundwater resources at repository depth beneath the Municipality of Central Huron. The Ontario Ministry of the Environment Water Well Records indicate that all water wells known in the Municipality of Central Huron obtain water from overburden or shallow bedrock sources at depths below 134 m (Section 4.1).

As discussed in Section 4.2, the potential for deep groundwater resources in the region and beneath the Municipality of Central Huron is expected to be low. The Upper Ordovician shale and limestone formations which are found below 530 mBGS and 700 mBGS beneath the eastern and western portions of the Municipality respectively are expected to have low groundwater yields due to very low hydraulic conductivities (approximately  $10^{-15}$  to  $10^{-11}$  m/s), based on recently completed field work at the Bruce nuclear site (NWMO, 2011). In addition, as discussed in Section 4.3, a regional-scale transition from fresh to non-potable and highly saline groundwater has been recognized below approximately 200 mBGS.

*The review of available information did not identify any known groundwater resources at repository depth beneath the Municipality of Central Huron. Experience in similar geological settings in the region suggests that the potential for deep groundwater resources at repository depths is very low beneath the Municipality of Central Huron. This would, however, need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.*

## 6.4 Screening Criterion 4: Known Natural Resources

***Available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.***

As with the assessment of groundwater resources, the need to minimize the risk of future human intrusion requires that the repository be sited in a host rock formation having a low potential for economically exploitable natural resources. Readily available information on past and potential future occurrences for natural resources such as oil and gas, metallic and non-metallic mineral resources was reviewed in Section 5.

There is no record of current or past metallic mineral production in the Municipality of Central Huron, and no exploration potential for metallic minerals has been identified within the Municipality. Current licensed non-metallic mineral extraction in the Municipality of Central Huron is limited to sand and gravel resources (Section 5.3). The risk that these resources pose for future human intrusion is negligible, as quarrying operations would be limited to very shallow depths.

The review of available information identified 46 documented hydrocarbon exploration wells and two known hydrocarbon pools, the Tipperary and Tipperary South pools, within the Municipality of Central Huron. Both of these pools exploited hydrocarbons from pinnacle reefs in the Silurian Guelph Formation at a depth of about 500 m. The two pools are now depleted and being used for natural gas storage. There are six additional known pinnacle reef hydrocarbon pools in the area surrounding the Municipality (Figure 3.6).

New conceptual hydrocarbon plays are identified for southern Ontario by Hamblin (2008), including Upper Ordovician shale gas, Cambrian gas and Upper Ordovician Shadow Lake Formation where it overlies the Cambrian. An assessment of the shale gas potential at the Bruce nuclear site 70 km north of the Municipality found that the likelihood of commercial gas accumulation in the Ordovician shale units is low because of their low organic content and insufficient thermal maturity. The organic content and thermal maturity of the Ordovician shales in the Municipality of Central Huron is unknown at this stage and the gas potential of these units would have to be further assessed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process. With respect to Cambrian and Shadow Lake plays, both formations were intersected in 3 wells within the Municipality of Central Huron, but none encountered economic hydrocarbon accumulations in these formations.

In summary, the review of readily available information did not reveal the existence of known current economically exploitable oil and gas resources beneath the Municipality of Central Huron. However, given that there has been historic exploitation of hydrocarbons within the Municipality, the potential for these resources would need to be further assessed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

As discussed in Section 5.3.3, salt beds are present beneath the Municipality of Central Huron and surrounding area. Beneath the Municipality, the salt beds have an average cumulative thickness of about 76 m. However, they thin out quickly towards the east and extend significantly outside the western and southern boundaries of the Municipality, including beneath Lake Huron (Figures 5.2 and 5.3).

The salt beds occur approximately at 100 m above the top of the thick Ordovician shale units and 300 m above the top of the limestone units, which are both considered as potentially suitable for hosting a deep geological repository from a geological and hydrogeological perspective (Section 6.5). The Upper Ordovician shale and limestone units are mechanically competent with very low hydraulic conductivities (Section 6.5). If salt were to be mined in the future

within the Municipality, the distance between the salt beds and the underlying Ordovician shale and limestone units is likely to provide a sufficient buffer to isolate and maintain the integrity of a repository in the long-term. This interpretation would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

*The review of readily available information indicates that the sedimentary rock sequence beneath the Municipality of Central Huron contains rock formations that are free of known economically exploitable natural resources, which include deep potentially suitable Ordovician shale and limestone units. The review also identified the presence of salt formations beneath the Municipality of Central Huron. The extent to which potential salt mining activities within the Municipality could affect the integrity of a repository located within the potentially suitable underlying Ordovician shale and limestone units would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.*

## 6.5 Screening Criterion 5: Unsafe Geological or Hydrogeological Features

***Available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the outlined safety factors in Section 6 of the site selection document (NWMO, 2010).***

The site should not be located in an area of known geological or hydrogeological features that would make the site unsafe, as per the following five geoscientific safety-related factors identified in the site selection process (NWMO, 2010):

1. Safe containment and isolation of used nuclear fuel. Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances?
2. Long-term resilience to future geological processes and climate change. Is the rock formation at the site geologically stable and likely to remain stable over the very long-term in a manner that will ensure the repository will not be substantially affected by natural disturbances and events such as earthquakes and climate change?
3. Safe construction, operation and closure of the repository. Are conditions at the site suitable for the safe construction, operation and closure of the repository?
4. Isolation of used fuel from future human activities. Is human intrusion at the site unlikely, for instance, through future exploration or mining?
5. Amenable to site characterization and data interpretation activities. Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

At this early stage of the site evaluation process, where limited geoscientific data at repository depth exist for the Municipality of Central Huron, the five safety-related geoscientific factors are assessed using readily available information, with the objective of identifying any obvious unfavourable hydrogeological and geological conditions that would exclude the Municipality from further consideration. These factors would be gradually assessed in more detail as the site evaluation process progresses and more site specific data is collected during subsequent site evaluation phases, provided the community remains interested in continuing with the site selection process.

As discussed below, the review of readily available geoscientific information did not identify any obvious geological or hydrogeological conditions that would exclude the Municipality of Central Huron from further consideration in the site selection process at this stage.

### Safe Containment and Isolation

The geological and hydrogeological conditions of a suitable site should promote long-term containment and isolation of used nuclear fuel and retard the movement of any potentially released radioactive material. This requires that the repository be located at a sufficient depth, typically around 500 m or deeper, in a sufficient rock volume with characteristics that limit groundwater movement. Readily available information on the local and regional geology and hydrogeology was reviewed in Sections 3 and 4.

As discussed in section 3.2.1, the geology of the Municipality of Central Huron is consistent with the regional geological framework. The Municipality is entirely underlain by a predictable and laterally extensive Paleozoic sedimentary sequence. Based on information from oil and gas exploration wells within the Municipality (Well #F011970, #F011974, and #T006364, Table 3.3), the average total thickness of the Paleozoic strata in the Municipality of Central Huron is interpreted to be approximately 1,055 m.

At depths that are typically considered as suitable for hosting a deep geological repository the geology beneath the Municipality of Central Huron is interpreted to comprise Upper and Lower Silurian units (carbonates, evaporates and shales) and Upper Ordovician shale and limestone units. Mazurek (2004) concluded that the Silurian formations in southern Ontario are not likely suitable for hosting a deep geological repository due to higher hydraulic conductivities, insufficient thickness and/or vertical and lateral heterogeneity.

Underlying the Silurian formations in the Municipality of Central Huron are Upper Ordovician shale and limestone units. The Upper Ordovician shales are about 220 m thick and are found at depths of about 670 m in the western part of the Municipality to approximately 530 m towards the eastern end. The Upper Ordovician limestone units are interpreted to be about 230 m thick and found at depths of about 900 m and 750 m in the western and eastern parts of the Municipality, respectively. While there is limited information on the geoscientific characteristics of the Upper Ordovician shale and limestone units beneath the Municipality of Central Huron, it is expected that they are similar to the Upper Ordovician units beneath the Bruce nuclear site (Section 3.2.1). The latter are described as comprising relatively undeformed, low porosity and low hydraulic conductivity sequences that are correlative over large lateral extents as a result of their simple near horizontal geometry and uniform thicknesses. Both the Upper Ordovician shale and limestone units beneath the Municipality of Central Huron appear to have favourable geological characteristics, sufficient depth and rock volume to potentially host a deep geological repository.

As discussed in Section 4.2, it is likely that the hydrogeological and hydrogeochemical conditions at depth beneath the Municipality of Central Huron are similar to those beneath the Bruce nuclear site. The deep groundwater regime within the Upper Ordovician limestone and overlying shale units beneath the Bruce nuclear site is described as diffusion dominated and isolated from the shallow groundwater system which is generally limited to the upper 200 mBGS. No mapped faults are documented in the Municipality of Central Huron (Figures 3.2 and 3.6).

The interpreted isolated nature of the deep groundwater system is further supported by the regional hydrogeochemical setting (Section 4.3). Chemistry of the deep brines beneath the Bruce nuclear site suggests that they were formed by evaporation of seawater, which was subsequently modified by fluid-rock interaction processes. Limited evidence for recent dilution by meteoric or glacial waters was found within the regional geochemical database. The nature of the deep brines, in particular their high salinities and distinct isotopic signatures, suggests long residence times and indicates that the deep system has remained isolated from the shallow groundwater system (NWMO, 2011).

In summary, the review of available information indicates that the Municipality of Central Huron contains geological formations with no known obvious geological or hydrogeological conditions that would fail the containment and isolation requirements. The Upper Ordovician shale and limestone units beneath the Municipality of Central Huron are potentially suitable for hosting a deep geological repository for used nuclear fuel. These formations exist at a sufficient depth and in sufficient volumes to potentially host a deep geological repository. They are also expected to have hydrogeological characteristics that would limit groundwater movement. Similar conclusions were previously reached by Mazurek (2004) in a regional analysis of the sedimentary formations within southern Ontario, which identified the Upper Ordovician shale and limestone units as potentially suitable to host a deep geological repository for used nuclear fuel.

Additional geoscientific characteristics that may have an impact on the containment and isolation functions of a deep geological repository for used nuclear fuel such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, and the thermal and geomechanical properties of the rock would need to be further assessed during subsequent site evaluation stages, provided the community remains interested in continuing with the site selection process.

### Long-Term Stability

A suitable site for hosting a repository is a site that would remain stable over the very long-term in a manner that will ensure that the performance of the repository will not be substantially altered by future geological and climate change processes, such as earthquakes or glaciation. A full assessment of this geoscientific factor requires site specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the site has responded to past glaciations and geological processes and would entail a wide range of studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change.

At this early stage of the site evaluation process, the long-term stability factor is evaluated by assessing whether there is any evidence that would raise concerns about the long-term hydrogeological and geological stability of the Municipality of Central Huron. As discussed below, the review of readily available information did not reveal any obvious characteristics that would raise such concerns.

The Municipality of Central Huron is underlain by Precambrian crystalline basement of the Grenville Province, the south-easternmost subdivision of the Canadian Shield. The Precambrian Grenville Province, which extends from Labrador to Mexico, is generally considered to have been relatively tectonically stable since approximately 970 million years ago (Section 3). No faults have been reported within an area of approximately 30 km surrounding the Municipality. The nearest fault is within Trenton Group units and is mapped approximately 36 km north of the Municipality. There is no evidence from regional studies suggesting that these types of faults have been tectonically active within the past approximately 450 million years.

The geology of the Municipality of Central Huron is typical of many areas of southern Ontario, which have been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that

could occur in the future. However, findings from studies conducted in other areas of southern Ontario suggest that the deep subsurface Paleozoic sedimentary formations have remained largely unaffected by past perturbations such as glaciations (Sections 3 and 4).

A neotectonic study was conducted as part of detailed site characterization for OPG's proposed DGR at the Bruce nuclear site 70 km north of the Municipality to analyse Quaternary landforms for the presence of seismically-induced soft-sediment deformation (Section 3.3.3). The study was conducted within a radius of up to 50 km away from the Bruce nuclear site and concluded that the area has not likely experienced any post-glacial neotectonic activity. While generally applicable to the area of the Municipality of Central Huron, this interpretation would have to be confirmed during subsequent stages of site evaluation, if the community remains interested in continuing with the site selection process.

A study of the glacial erosion of the Bruce Peninsula caused by the Laurentide Ice Sheet concluded that significant glacial erosion likely did not occur (Section 3.5.2). The study also concluded that potential future glacial erosion in the area would be limited with a conservative site-specific estimate of 100 m per 1 million years, which is much less than the typical depths that are generally considered for used nuclear fuel repository (approximately 500 m or deeper).

In summary, the review did not identify any obvious geological or hydrogeological conditions that would fail to meet the long-term stability requirement for a potential repository within the Municipality of Central Huron. The long-term stability factor would need to be further assessed through detailed multi-disciplinary geoscientific and climate change site investigations, if the community remains interested in continuing with the site selection process.

#### Potential for Human Intrusion

The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities such as exploration or mining. Therefore, the repository should not be located within rock formations containing exploitable groundwater resources (aquifers) at repository depth and economically exploitable natural resources and other valuable commodities as known today.

This factor has already been addressed in Sections 6.3 and 6.4, which concluded that the potential for deep groundwater resources in the Upper Ordovician units is low and that there are no known metallic or currently economically exploitable oil and gas resources within the Municipality of Central Huron.

While the review identified the presence of salt beds beneath the Municipality, these thin out quickly towards the east and extend significantly outside the western and southern boundaries of the Municipality, including beneath Lake Huron. If salt were to be mined in the future within the Municipality, the distance between the salt beds and the underlying potentially suitable Ordovician shale and limestone units is likely to provide a sufficient buffer to isolate and maintain the integrity of a repository in the long-term. However, this would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

#### Amenability to Construction and Site Characterization

The characteristics of a suitable site should be favourable for the safe construction, operation, closure and long-term performance of the repository. Besides the requirement for space discussed in Section 6.1, this requires that the strength of the host rock and in-situ stress at repository depth are such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities; and that the soil cover depth over the host rock should not adversely impact repository construction and site investigation activities. Similarly, the host rock geometry and structure should be predictable and amenable to site characterization and interpretation activities.



As discussed in Section 3.4, there is no readily available information on the geomechanical properties of the rock formations beneath the Municipality of Central Huron. However, there is abundant information at other locations in southern Ontario that could provide insight into what would be expected for the Municipality of Central Huron. For example, available information from the Bruce nuclear site on strength and in situ stresses suggests that the Upper Ordovician shale and limestone units have a high strength and favourable geomechanical characteristics, which makes them amenable to construction and excavation of stable underground openings. Also, numerical simulation of the behaviour of underground openings in the limestone Cobourg Formation for the OPG-DGR project indicated that the openings will remain stable during construction and operation and that, in the long-term, the barrier integrity of the enclosing Ordovician bedrock formations will not be affected under various loading scenarios associated with glacial ice sheet, seismic ground motions and repository gas pressure (Section 3.4). The Upper Ordovician shale and limestone units beneath the Municipality of Central Huron are found at greater depths than those previously studied in other areas in the region, resulting in higher in-situ stresses. While this should not present any geomechanical conditions that could not be mitigated by conventional construction techniques, the geomechanical properties of the deeper Upper Ordovician shale and limestone units would have to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

In terms of predictability of the geologic formations and amenability to site characterization activities, the review of available information on the bedrock geology for the Municipality of Central Huron did not reveal any conditions that would make the rock mass difficult to characterize. As discussed in Section 3, the sedimentary sequences beneath the Municipality of Central Huron are consistent with the regional geological framework for southern Ontario. The Paleozoic bedrock stratigraphy is characterized by minimal structural complexity and a simple geometry, providing a basis for the subsurface predictability of stratigraphic formations.

The Paleozoic sedimentary sequence beneath the Municipality of Central Huron is covered by Quaternary overburden deposits. As described in Section 3, overburden thickness in the Municipality range from less than 1 m to approximately 134 m. The regional geological framework, the geometry and the interpreted predictability of the subsurface stratigraphic formations suggests that the thickness of the overburden cover is not likely to affect the ability to characterize the subsurface bedrock formations beneath the Municipality of Central Huron.

In summary, the review of readily available information did not indicate any obvious conditions that would hinder site characterisation and construction activities within the Municipality of Central Huron.

*Based on the review of available geological and hydrogeological information, the Municipality of Central Huron comprises geological formations that do not contain obvious known geological and hydrogeological conditions that would make the area unsuitable for hosting a deep geological repository.*



## 7. Initial Screening Findings

This report presents the results of an initial screening to assess the potential suitability of the Municipality of Central Huron against five initial screening criteria using readily available information. The initial screening focused on the areas within the boundaries of the Municipality of Central Huron. Areas within neighbouring municipalities were not included in the initial screening.

As outlined in NWMO's site selection process (NWMO, 2010), the five initial screening criteria relate to: having sufficient space to accommodate surface facilities, being outside protected areas and heritage sites, absence of known groundwater resources at repository depth, absence of known economically exploitable natural resources and avoiding known hydrogeologic and geologic conditions that would make an area or site unsuitable for hosting a deep geological repository.

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Municipality of Central Huron from being further considered in the NWMO site selection process. The initial screening indicates that the Municipality comprises geological formations that are potentially suitable for safely hosting a deep geological repository. These include the Upper Ordovician shale and limestone units that comprise the geology of the Municipality at typical repository depths. The review also identified the presence of salt formations beneath the Municipality. The extent to which potential salt mining activities within the Municipality could affect the integrity of a repository located within the underlying Ordovician shale and limestone units would need to be assessed in detail during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

It is important to note that at this early stage of the site evaluation process, the intent of the initial screening was not to confirm the suitability of the Municipality of Central Huron, but rather to identify whether there are any obvious conditions that would exclude it from the site selection process. Should the community of Central Huron remain interested in continuing with the site selection process, several years of progressively more detailed studies would be required to confirm and demonstrate whether the Municipality of Central Huron contains sites that can safely contain and isolate used nuclear fuel.

The process for identifying an informed and willing host community for a deep geological repository for Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future.

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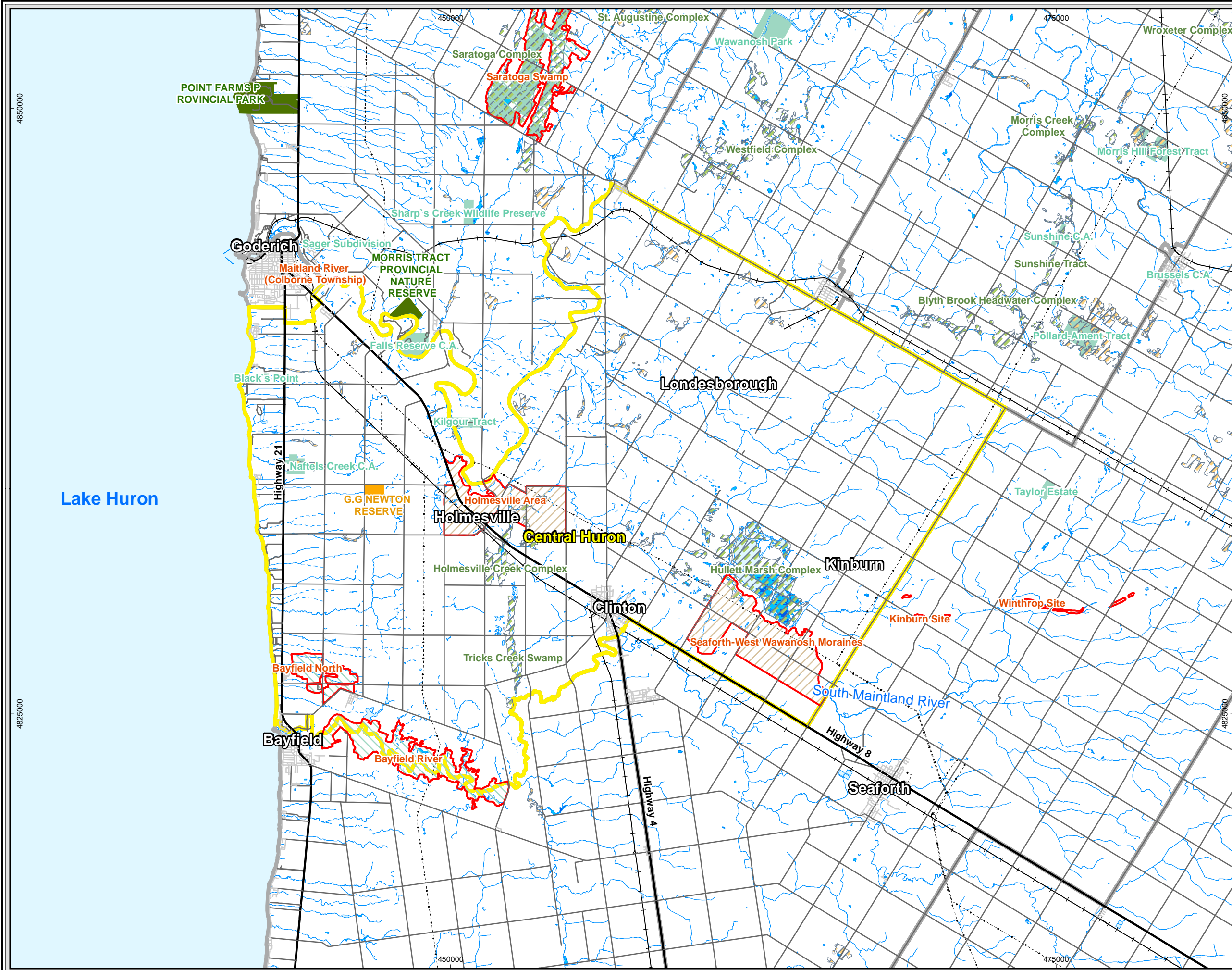
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# Figures



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**Legend**

- Municipality of Central Huron
- Municipal Division
- Highway
- Major Road
- Local Road
- Railway
- Transmission Line
- Intermittent Stream
- Permanent Stream
- Waterbody
- Cartographic Wetland
- Conservation Areas
- NGO Nature Reserve
- Regulated Provincial Park
- Provincially Significant Life Science ANSI
- Provincially Significant Earth Science ANSI
- Provincially Significant Wetland
- Locally Significant Wetland

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Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

60247068	Date
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Approved	RF 11 Feb 2013

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NWMO Desktop Level Initial Screening

**Municipality of Central Huron and Surrounding Area**

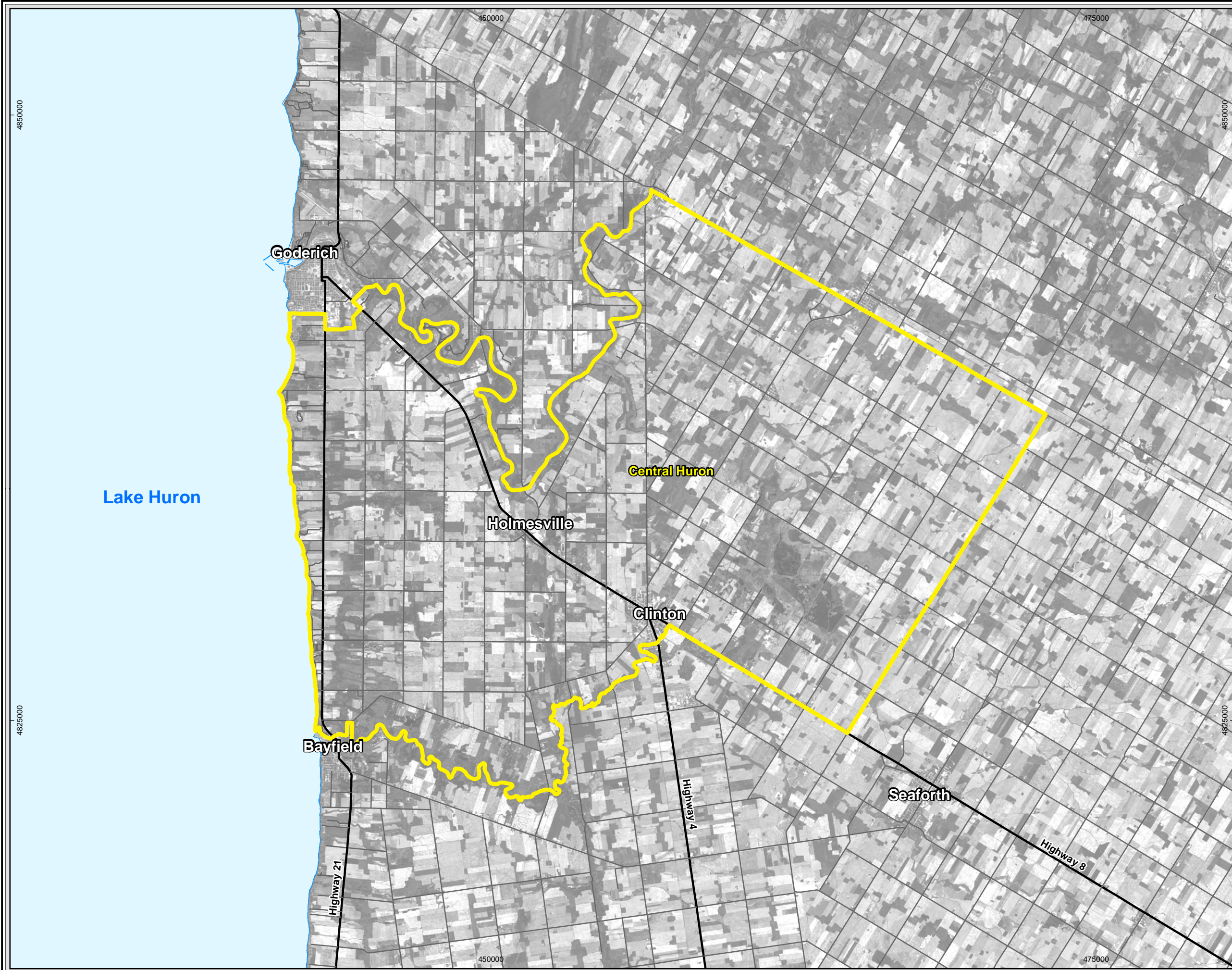
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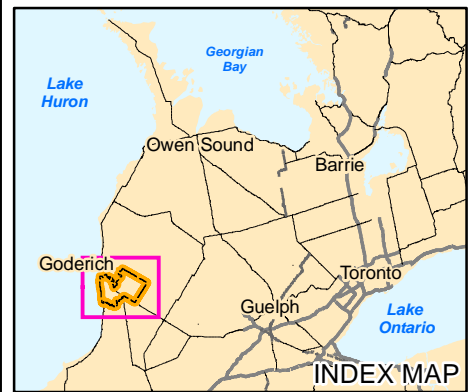
Figure 2.1



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- Legend**
- Municipality of Central Huron
  - Highway
  - Major Road
  - Waterbody



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Imagery: Spot 5, Obtained from Geobase (2006, 10 m resolution)  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

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NWMO Desktop Level Initial Screening

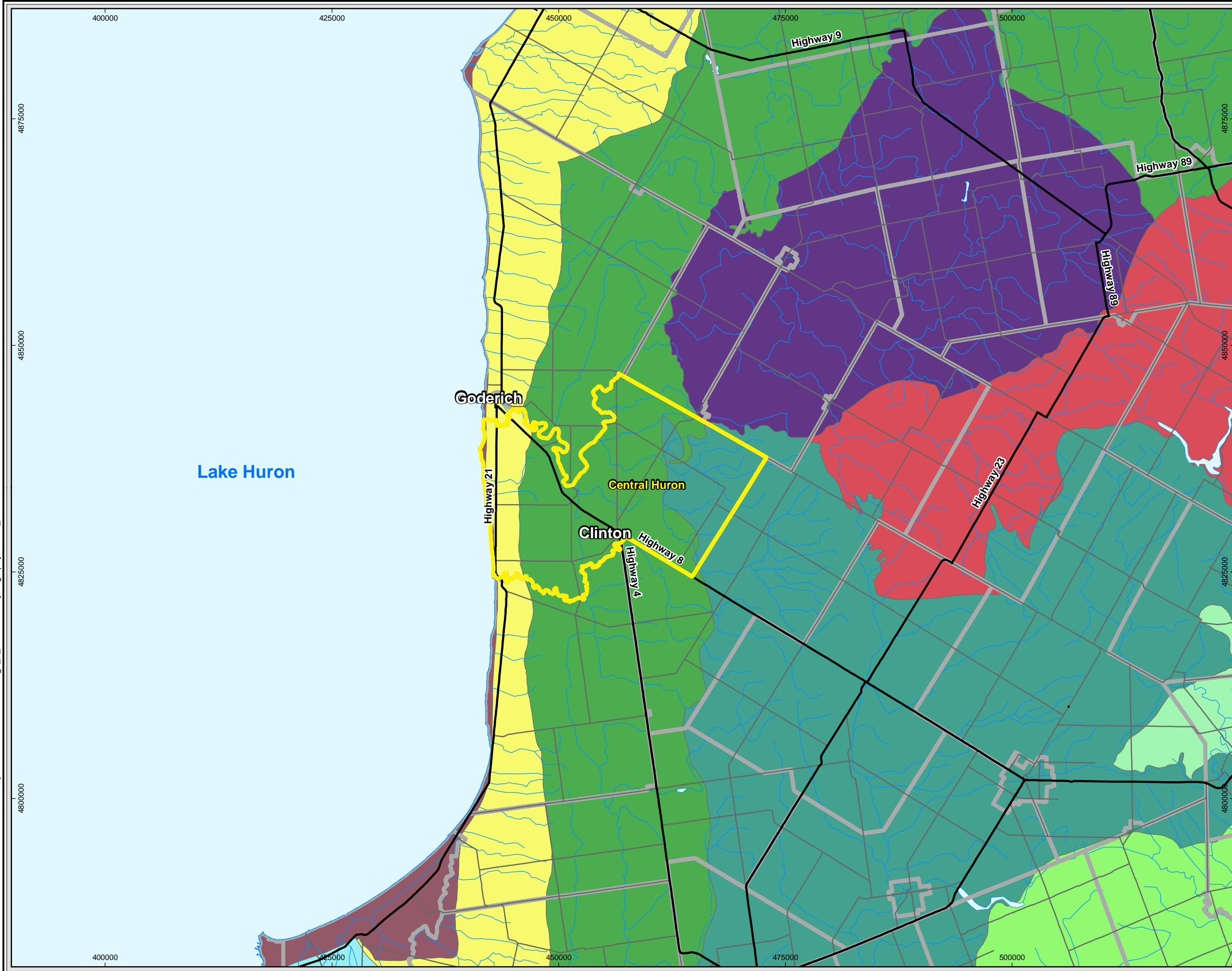
**Satellite Imagery of the Municipality of Central Huron**

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Figure 2.2



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**Legend**

- Municipality of Central Huron
- Municipal Division
- Highway
- Secondary Highway
- Waterbody

**Physiographic Regions**

- Horseshoe Moraines
- Dundalk Till Plain
- Stratford Till Plain
- Waterloo Hills
- Teeswater Drumlin Field
- Oxford Till Plain
- St. Clair Clay Plains
- Huron Slope
- Huron Fringe

Physiography: Chapman, L.J. and Putnam, D.F. 2007. Physiography of Southern Ontario; Ontario Geological Survey Produced by AECOM under licence from Ontario Ministry of Natural Resources, Copyright © Queens Printer 2012 Basemapping from Ontario Ministry of Natural Resources Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17

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Kilometers  
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NWMO Desktop Level Initial Screening

**Physiographic Regions of the Municipality of Central Huron and the Surrounding Area**

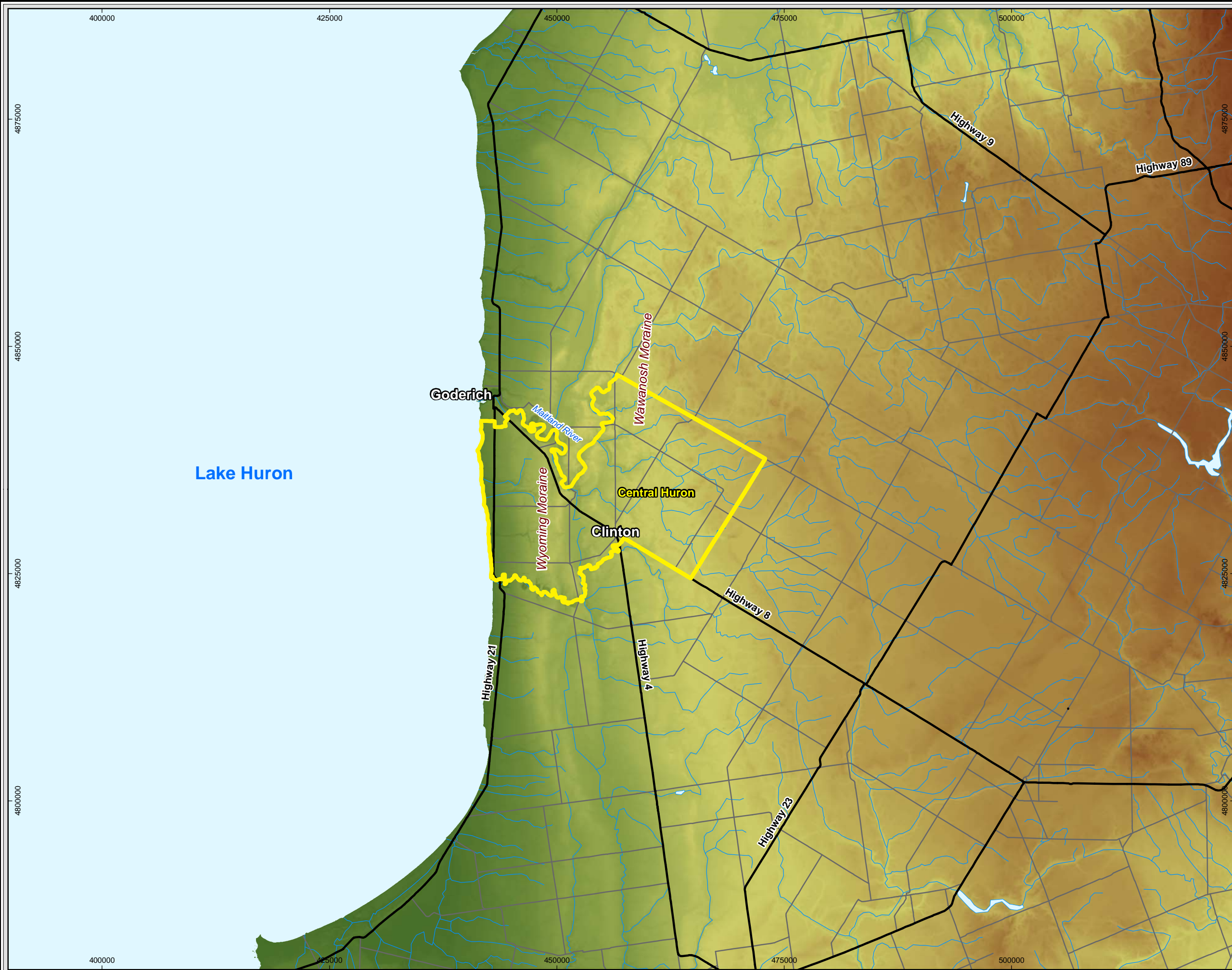
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**AECOM**

Figure 2.3



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**Legend**

- Municipality of Central Huron
- Highway
- Secondary Highway
- Watercourses
- Waterbodies

**Elevation (mASL)**

522  
350  
176

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Basemapping from Ontario Ministry of Natural Resources  
DEM: Land Information Ontario  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

60247068		Date
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Kilometers  
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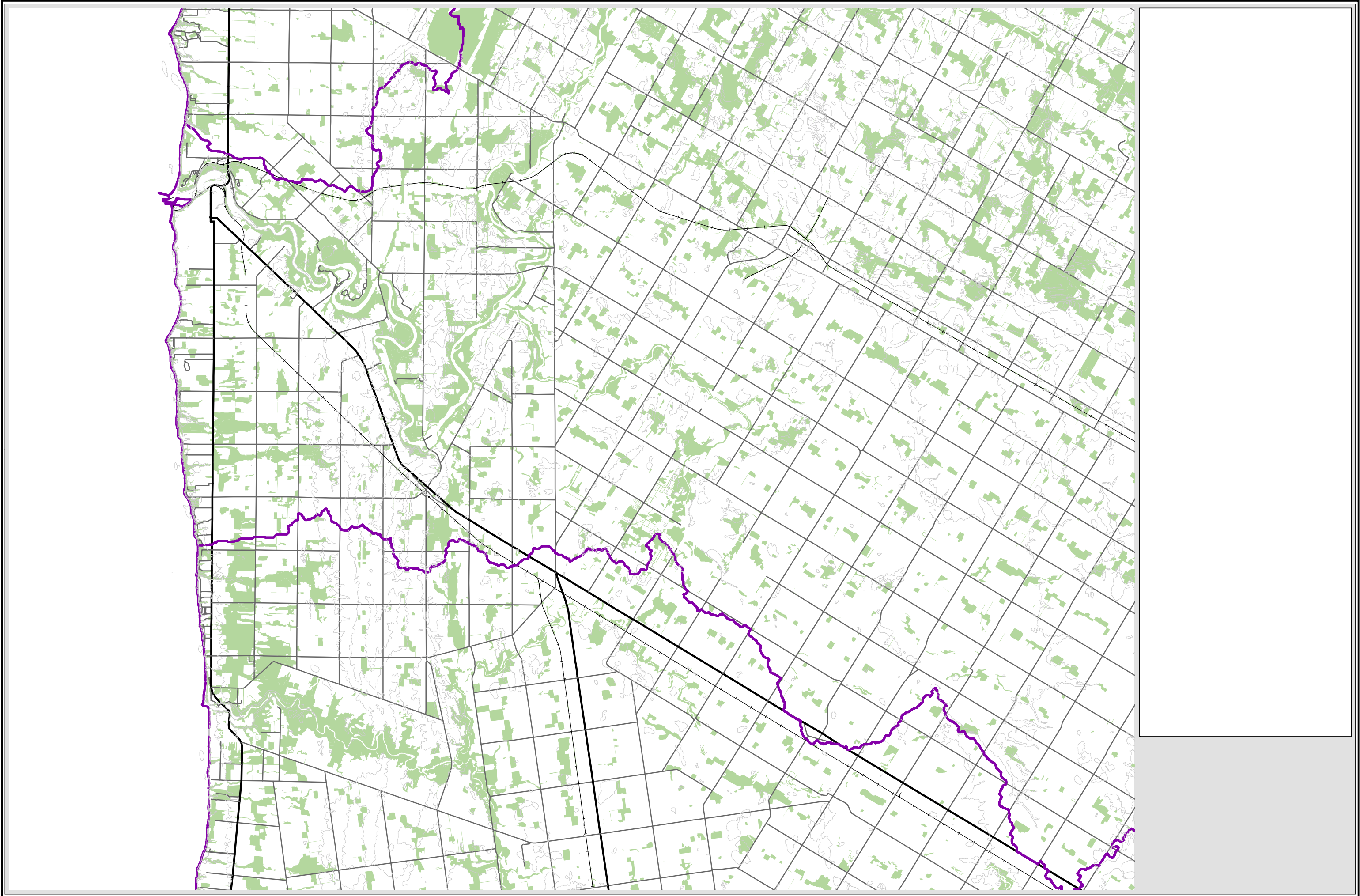
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NWMO Desktop Level Initial Screening  
**Digital Elevation Model (DEM) of  
the Municipality of Central Huron  
and the Surrounding Area**  
February 2013  
Project 60247068

**AECOM**

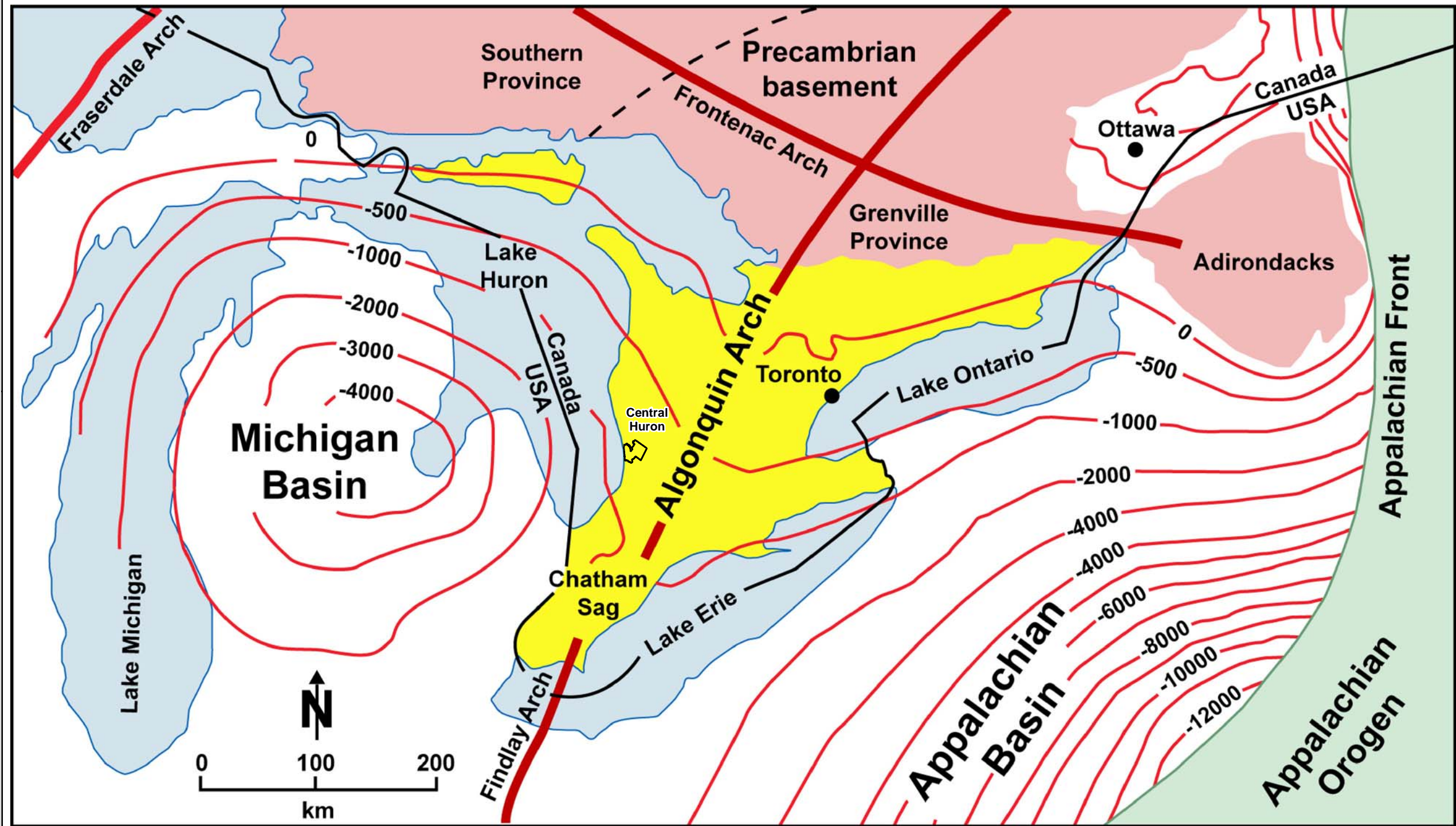
Figure 2.4







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- Legend**
- Municipality of Central Huron
  - Precambrian Basement
  - Appalachian Orogen
  - Paleozoic Sedimentary Rock of Southern Ontario
  - Contours of Precambrian Basement (mASL)
  - Axes of Arches
  - Precambrian Basement Boundary

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Modified after Johnson et al., 1992

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**Geological Features of Southern Ontario**

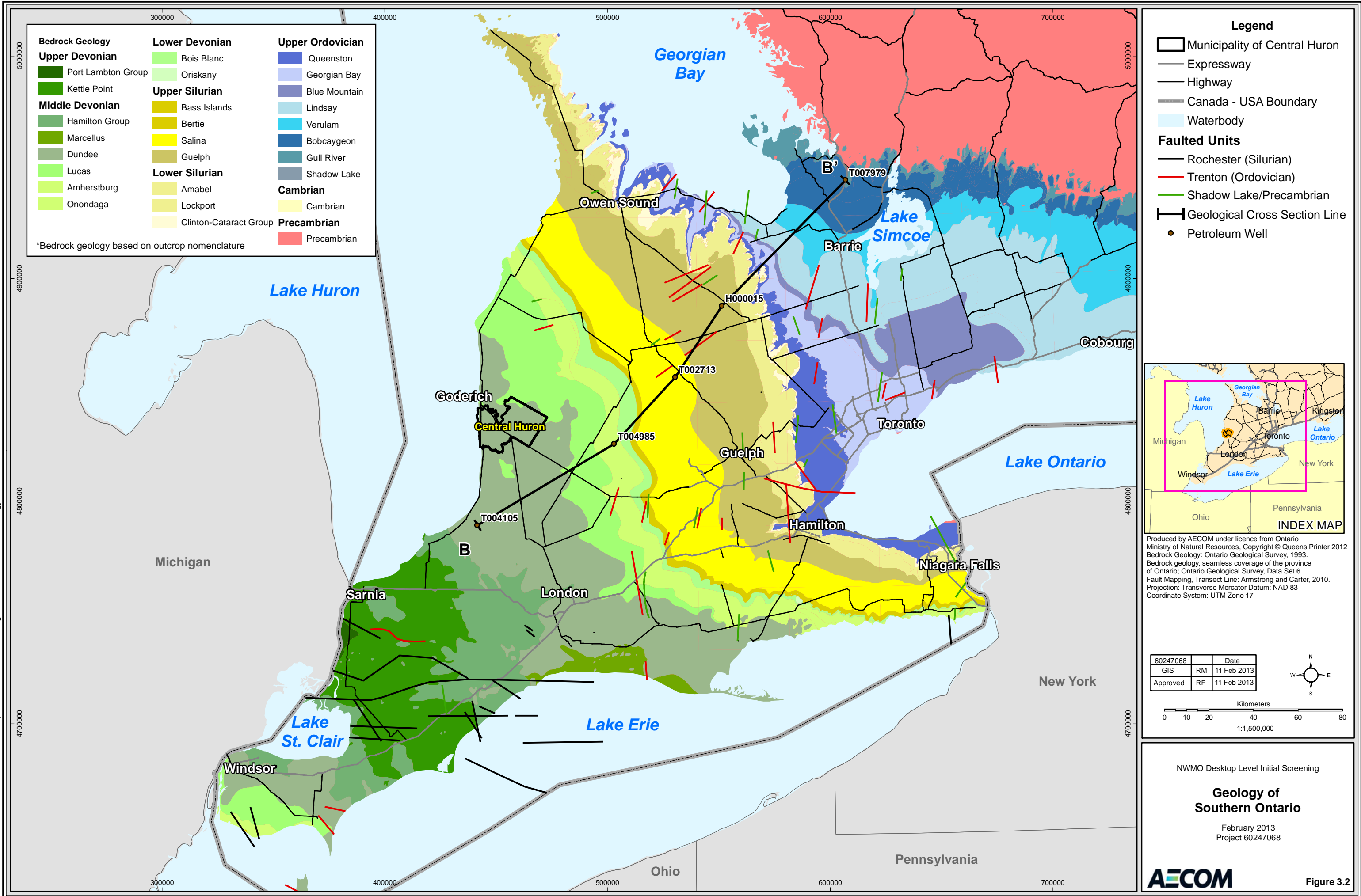
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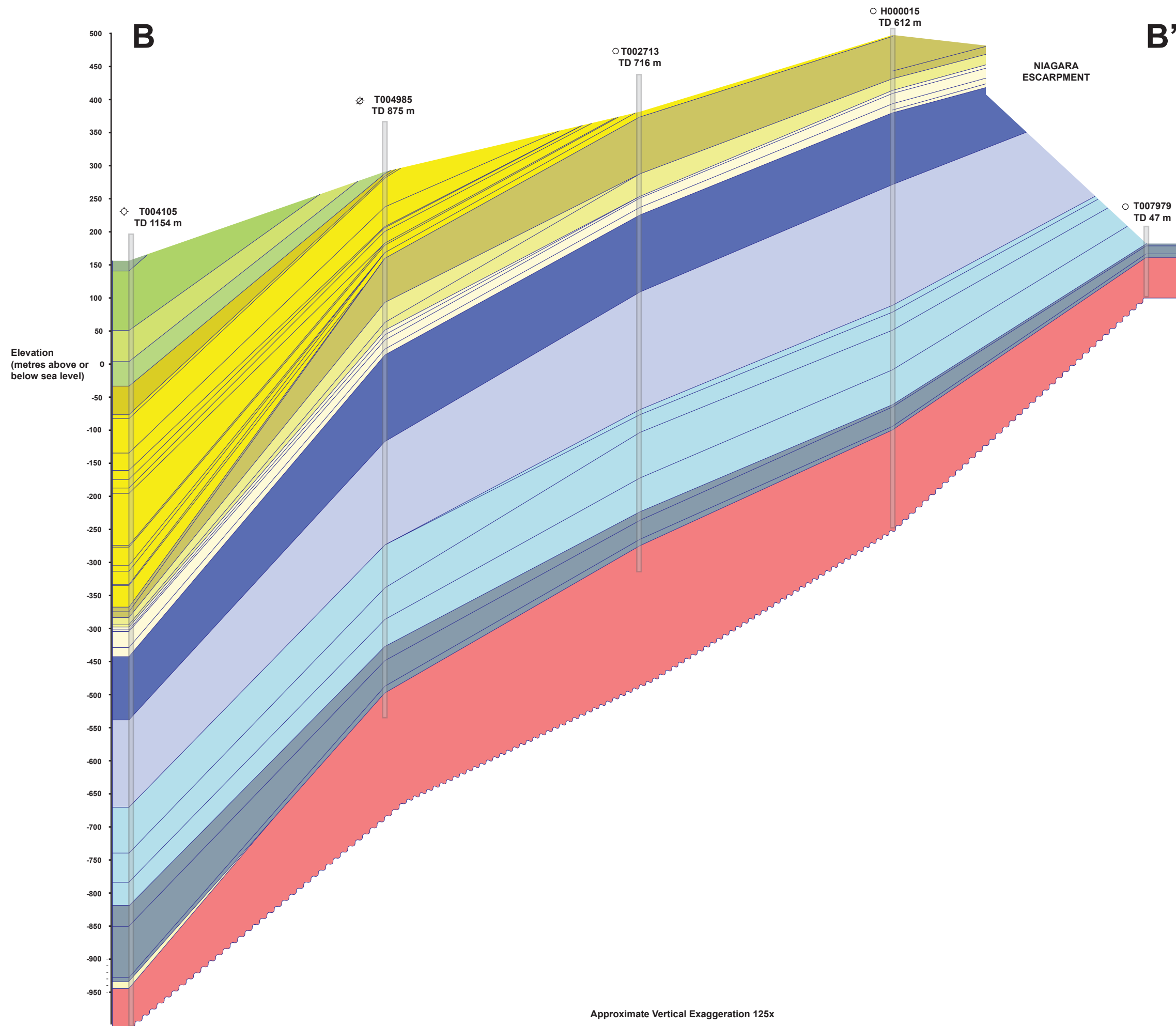
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Figure 3.1



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**Legend**

**Bedrock Geology**

**Middle Devonian**

- Dundee
- Lucas
- Amherstburg

**Lower Devonian**

- Bois Blanc

**Upper Silurian**

- Bass Islands
- Salina
- Guelph

**Lower Silurian**

- Lockport (Goat Island, Gasport)
- Clinton-Cataract Group (Fossil Hill, Reynales Rochester, Cabot Head, Manitoulin)

**Upper Ordovician**

- Queenston
- Georgian Bay/Blue Mountain
- Trenton (Cobourg, Sherman Fall, Kirkfield)
- Black River (Coboconk, Gull River, Shadow Lake)

**Cambrian**

- Cambrian

**Precambrian**

- Precambrian

**OGS Reference Wells**

- Dry Hole
- Abandoned Dry Hole
- Brine Disposal Location/Strat Test

Base reference: Armstong and Carter (2010)

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FINAL	RF	11 Feb 2013

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**Geological Cross-Section**  
(Location Shown in Figure 3.2)

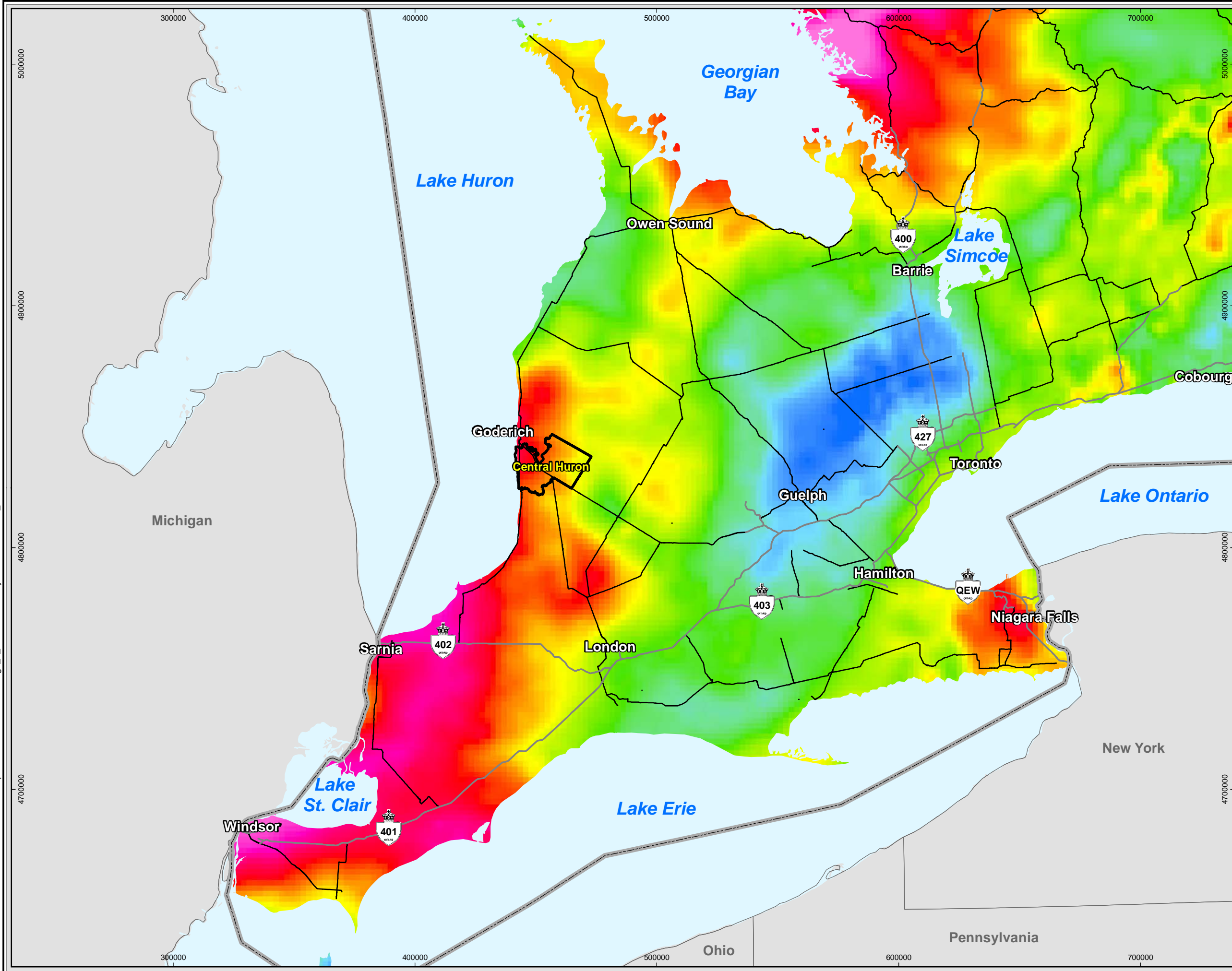
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Figure 3.3

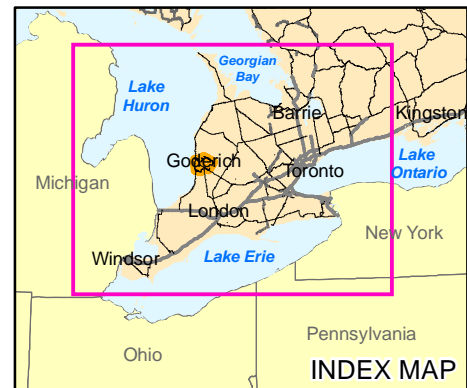
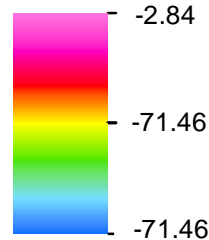


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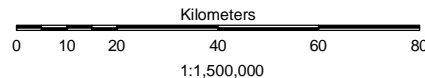
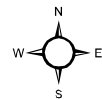
- Legend**
- Municipality of Central Huron
  - Expressway
  - Highway
  - Canada - USA Boundary
  - Waterbody

Gravity Anomaly (mGal)



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Gravity: Canadian Geodetic Information System, Gravity  
& Geodetic Networks Section, Geodetic Survey Division,  
Geomatics Canada, Earth Sciences Sector, Natural  
Resources Canada  
Projection: Transverse Mercator Datum: NAD 83  
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### Gravity Map of Southern Ontario

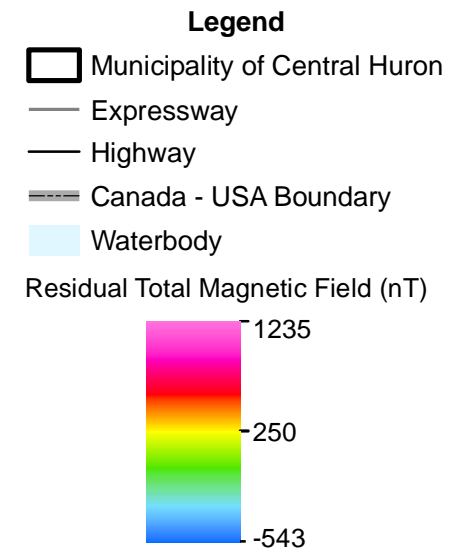
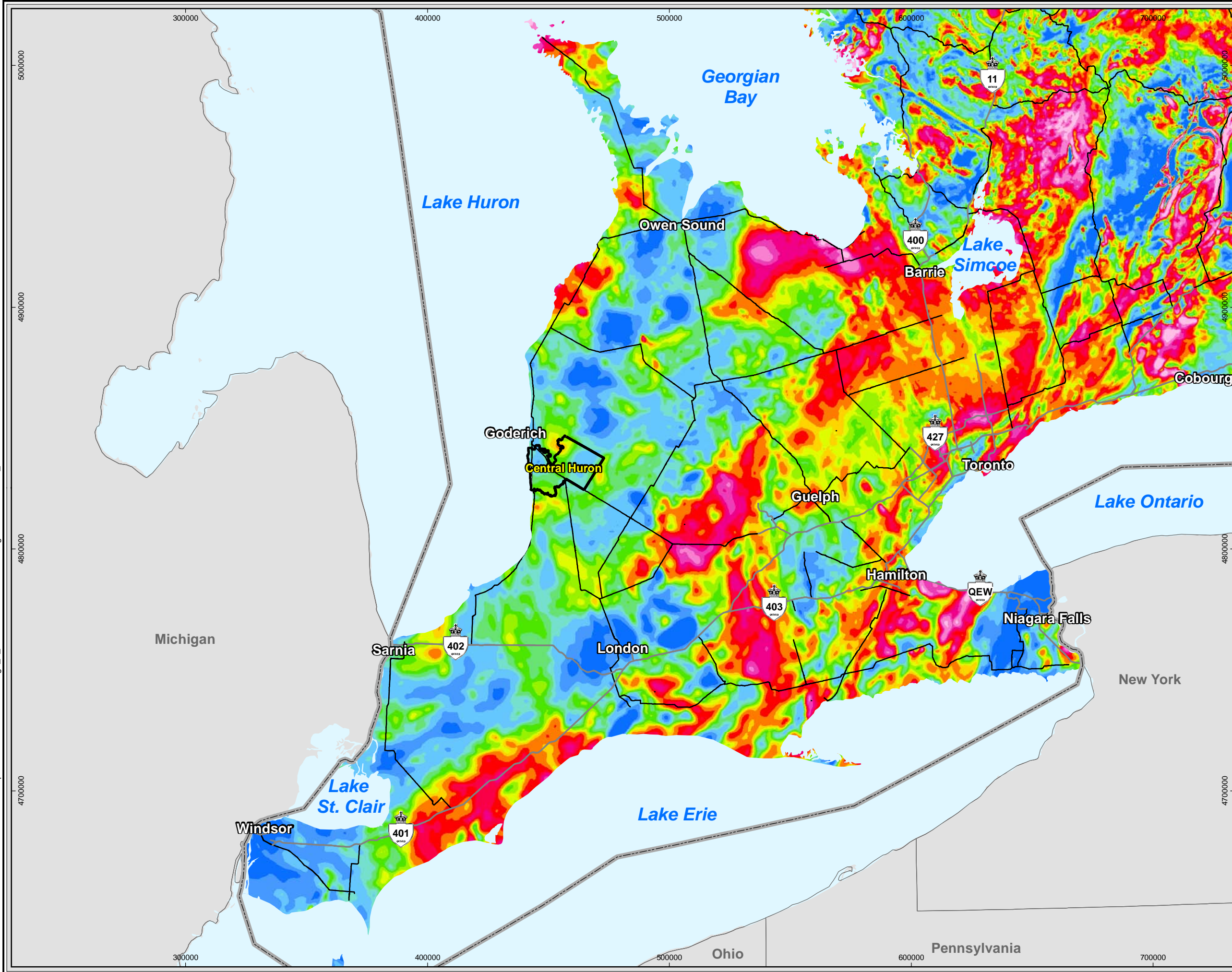
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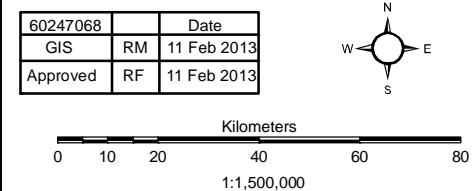
Figure 3.4



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Aeromagnetic Data: 2011 Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada, 2011  
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NWMO Desktop Level Initial Screening

**Residual Total Magnetic Field of Southern Ontario**

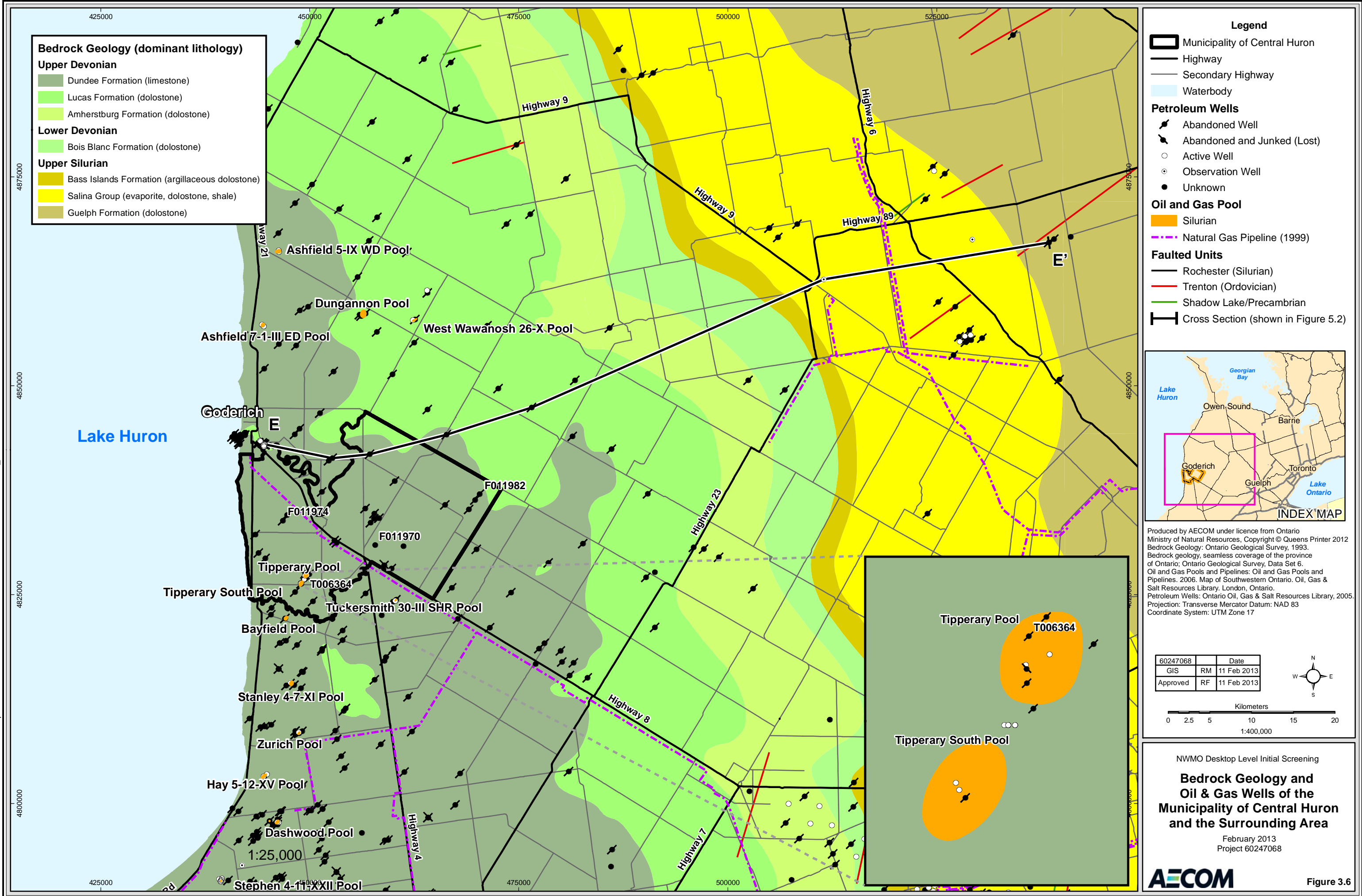
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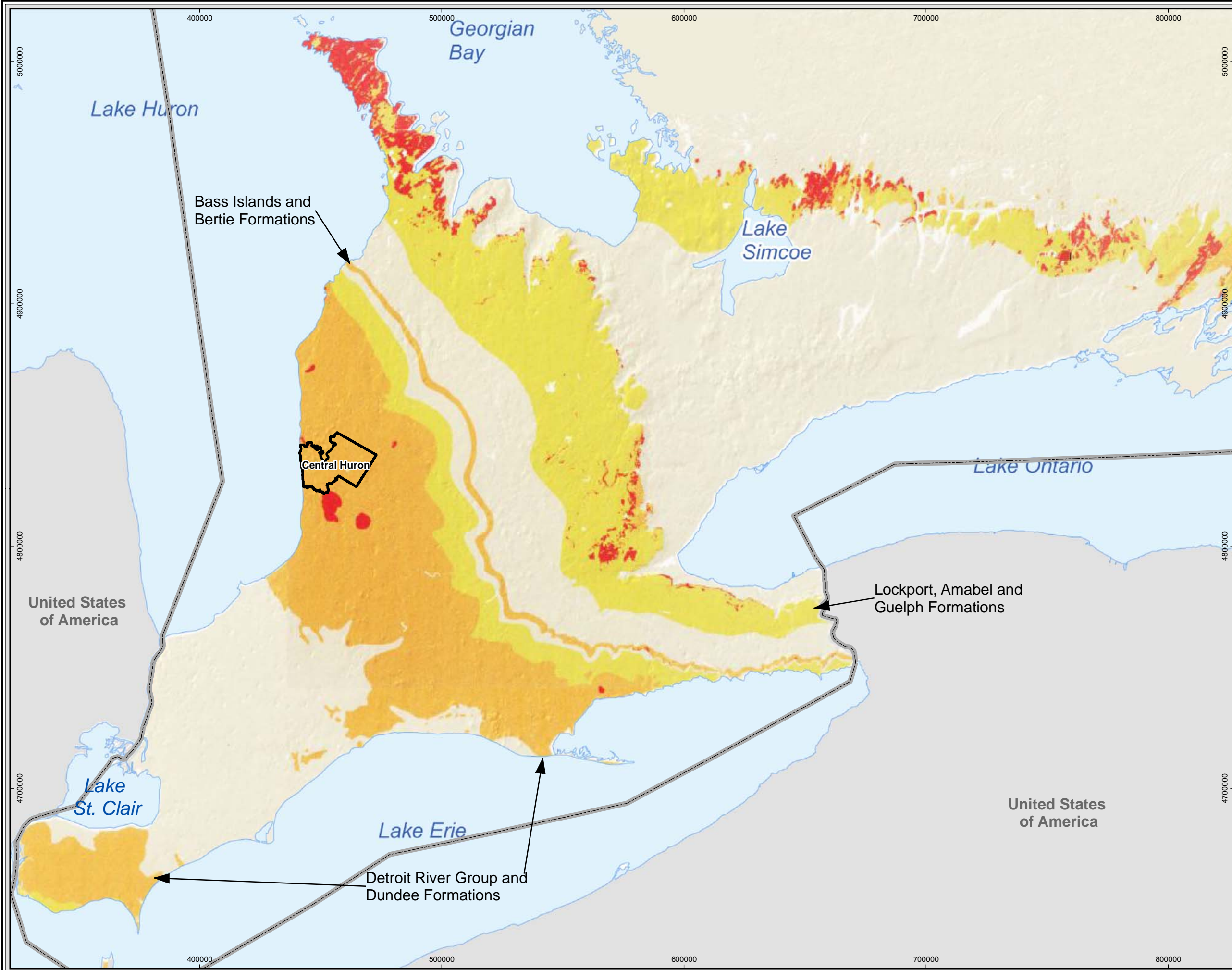
Figure 3.5



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\ArranElderslie\GasResourcesArran\_Elderslie.mxd



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig3\_7\_60247068KarstCentral\_Huron.mxd



**Legend**

- Municipality of Central Huron
- Canada - USA Boundary
- Major Waterbody
- Known Karst
- Inferred Karst
- Potential Karst

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Karst: Modified from Brunton and Dodge (2008)  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

60247068	Date
GIS	RM 11 Feb 2013
Approved	RF 11 Feb 2013

Kilometers

0 10 20 40 60 80

1:1,500,000

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**Karst Mapping of  
Southern Ontario**

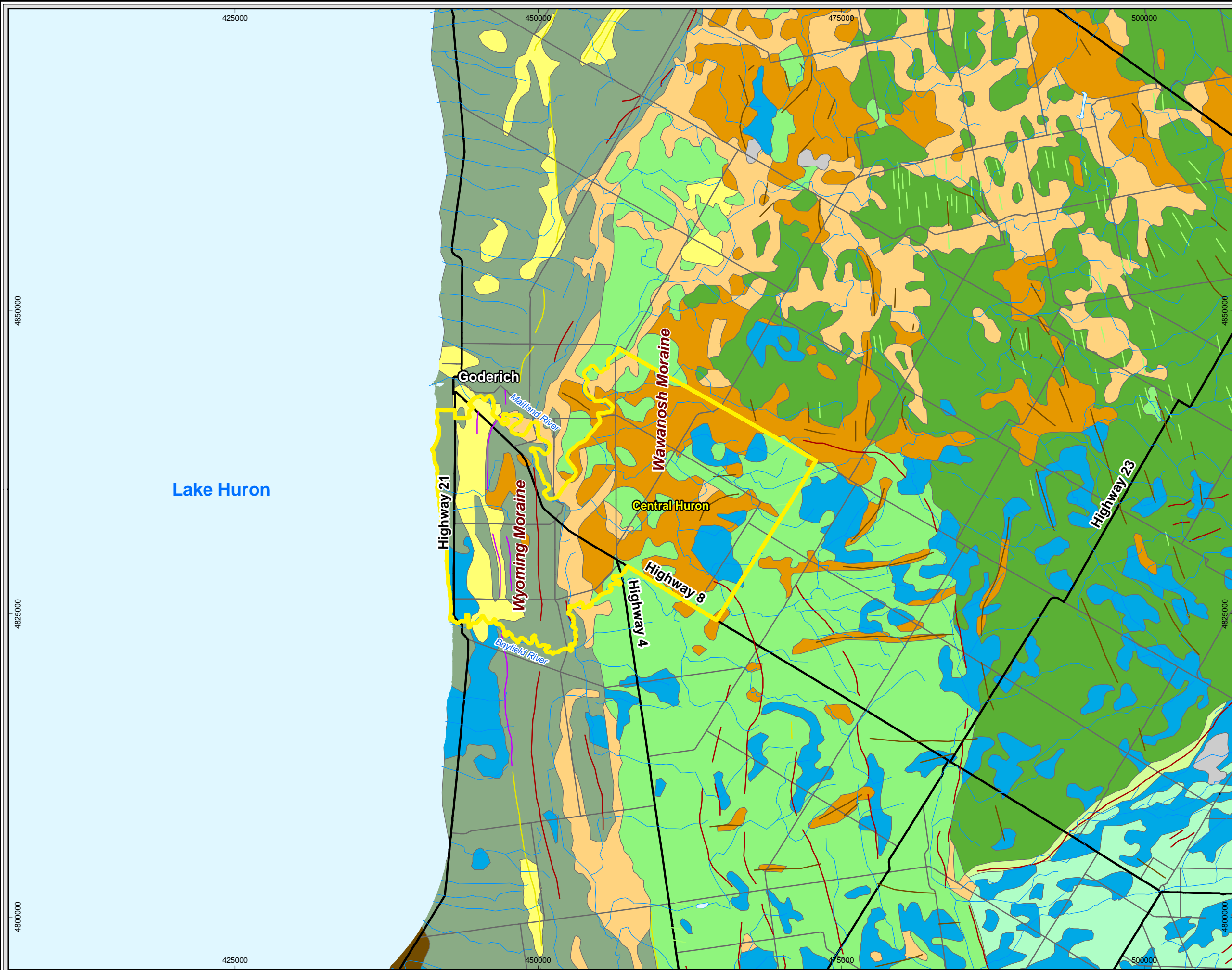
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Figure 3.7



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig3\_8\_60247068QuaternaryGeologyCentral\_Huron.mxd



**Legend**

- Municipality of Central Huron
- Highway
- Secondary Highway
- Waterbody
- Watercourse
- beach, bar or spit
- drumlin or area of drumlins
- esker or area of eskers
- terrace escarpment (abandoned shore bluff)
- trend of end moraine crest

**Quaternary Geology**

- Stratford Till
- Wartburg Till
- Elma Till
- Rannoch Till
- Dunkeld Till
- St. Joseph Till
- Glaciofluvial ice-contact deposits
- Glaciofluvial outwash deposits
- Glaciolacustrine deposits
- Glaciolacustrine beach deposits
- Lacustrine deposits
- Organic deposits

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Ministry of Natural Resources, Copyright © Queens Printer 2012  
Quaternary Geology: Quaternary Geology of Ontario Seamless  
Coverage-Data Set 14  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

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GIS	RM	11 Feb 2013
Approved	RF	11 Feb 2013

Kilometers

0 2.5 5 10 15

1:300,000

N  
W E  
S

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**Quaternary Geology of  
the Municipality of Central Huron  
and the Surrounding Area**

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**AECOM**

Figure 3.8



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig3\_9\_60247068OverburdenThicknessCentral\_Huron.mxd



**Legend**

- Municipality of Central Huron
- Highway
- Secondary Highway
- Waterbody

**Overburden Thickness (m)**

120  
60  
0

INDEX MAP

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Overburden Thickness: Gao, C., Shirota, J., Kelly, R. I., Brunton, F.R., van Haften, S. 2006. Bedrock topography and overburden thickness mapping, southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 207. ISBN 1-4249-2550-9  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

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GIS	RM	11 Feb 2013
Approved	RF	11 Feb 2013

Kilometers  
0 2.5 5 10 15 20  
1:400,000

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**Overburden Thickness in  
the Municipality of Arran-Elderslie  
and the Surrounding Area**

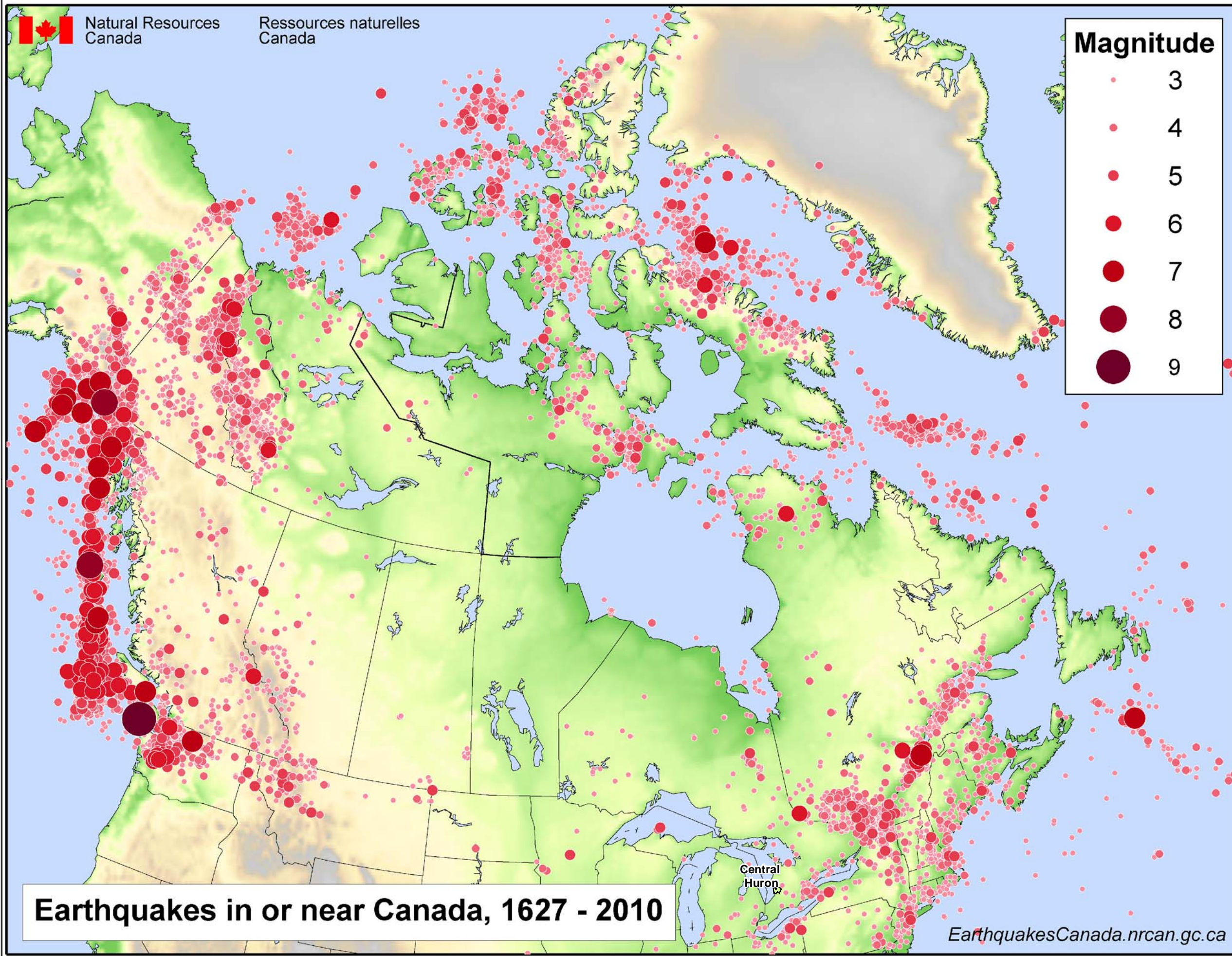
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Figure 3.9



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig3\_10\_60247068HistoricalEarthquakesCanadaCentral\_Huron.mxd



**Legend**

Municipality of Central Huron

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Seismic: NRCAN. Earthquake Map of Canada 1627 -2010  
Projection: NA

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**Earthquake Map of Canada  
1627 - 2010**

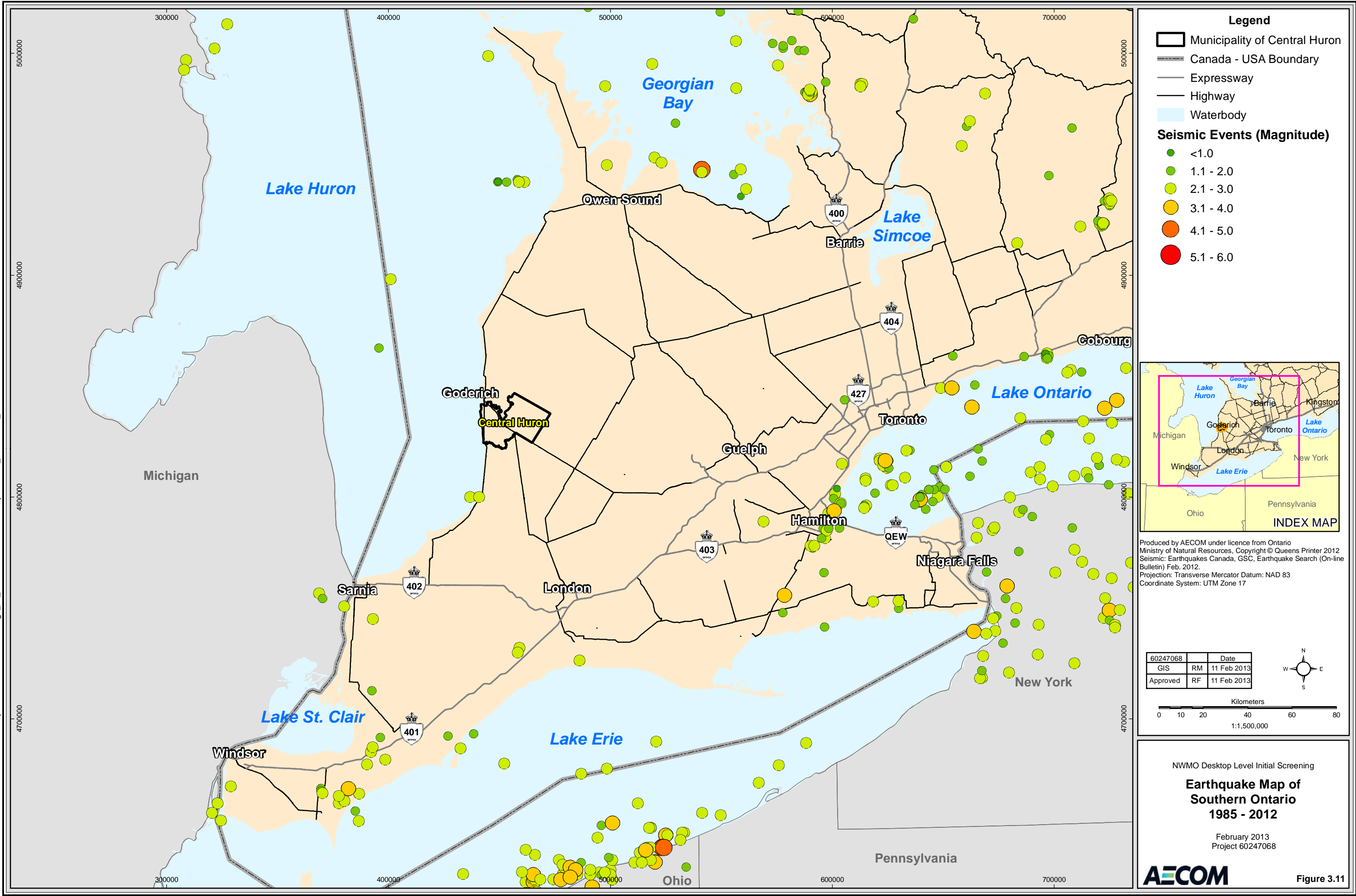
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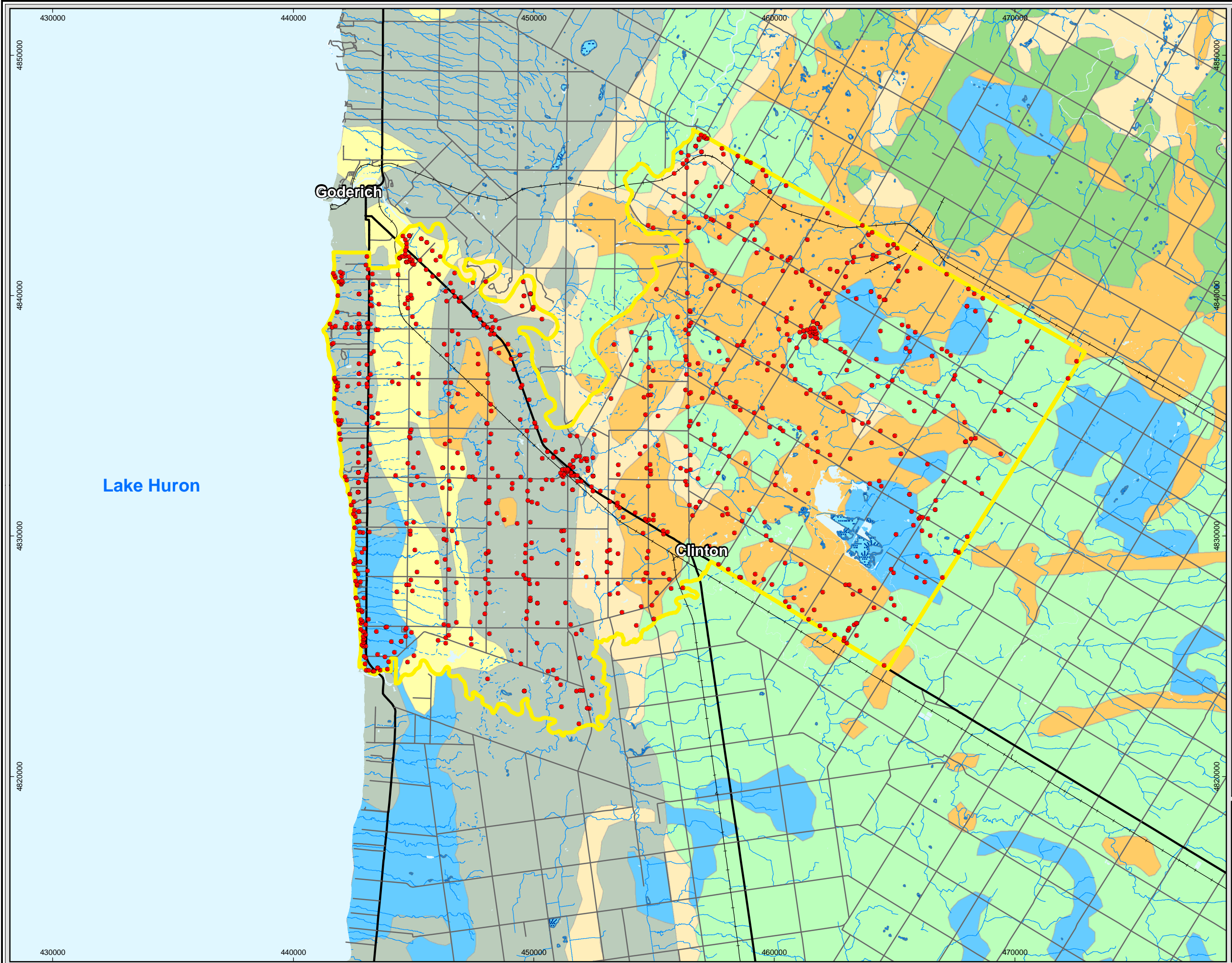
Figure 3.10



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig3\_11\_60247068HistoricalEarthquakesSW\_OntCentral\_Huron.mxd



Path: P:\60247068\000-CADD\040-GIS\MXDs\Report\MXDs\CentralHuron\Fig4\_1\_60247068WaterWellsCentral\_Huron.mxd



### Legend

- Municipality of Central Huron
- MOE Water Well Record
- Highway
- Major Road
- Railway
- Intermittent Stream
- Permanent Stream
- Waterbody
- Wetland

### Quaternary Overburden

- Bedrock
- Elma Till
- Rannoch Till
- Dunkeld Till
- St. Joseph Till
- Glaciofluvial ice-contact deposits
- Glaciofluvial outwash deposits
- Glaciolacustrine deposits
- Glaciolacustrine beach deposits
- Lacustrine deposits
- Organic deposits

INDEX MAP

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Quaternary Geology: Quaternary Geology of Ontario Seamless  
Coverage-Data Set 14  
Wells: Ministry of Environment, 2012  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

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Kilometers  
0 1 2 4 6 8  
1:150,000

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## Water Well Records of the Municipality of Central Huron

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Figure 4.1



Path: P:\60247068\000-CADD\040-GIS\MXD\s\Report\MXD\S\CentralHuron\Fig5\_1\_60247068EconomicBedrockResourcesCentral\_Huron.mxd



**Legend**

- Municipality of Central Huron
- Highway
- Secondary Highway
- Waterbody
- Bruce County
- Sand, Gravel, Limestone & Salt Extraction**
- Pit
- Quarry
- Salt Extraction

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Sand, Gravel & Limestone Extraction: Ontario Ministry of Natural Resources  
Projection: Transverse Mercator Datum: NAD 83  
Coordinate System: UTM Zone 17

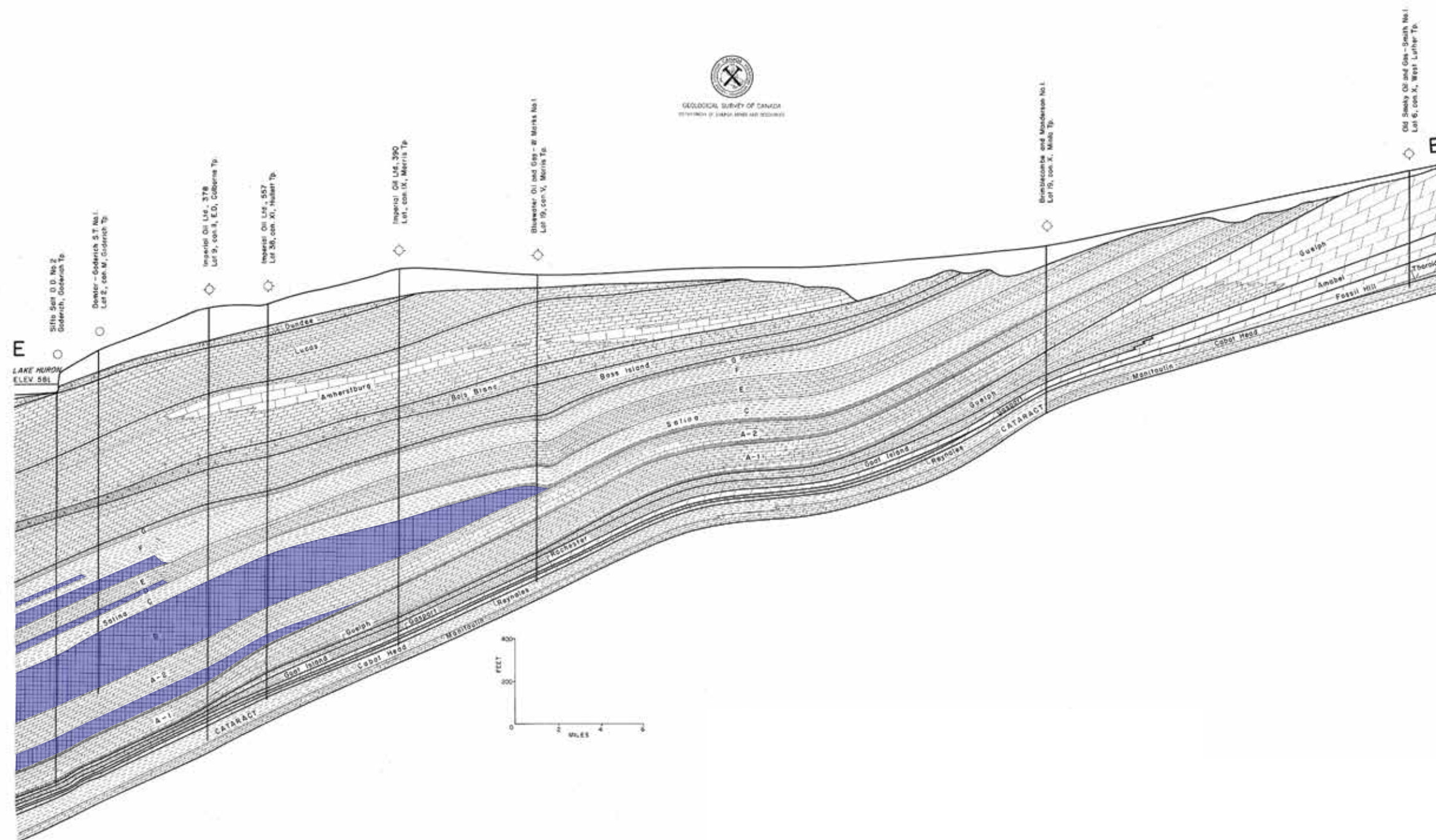
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Approved	RF	11 Feb 2013

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**Non-metallic Bedrock  
Resources of the  
Municipality of Central Huron  
and the Surrounding Area**

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Figure 5.1



- ### Legend
- Dominant Lithology**
- Salt
  - Shale
  - Limestone
  - Dolostone



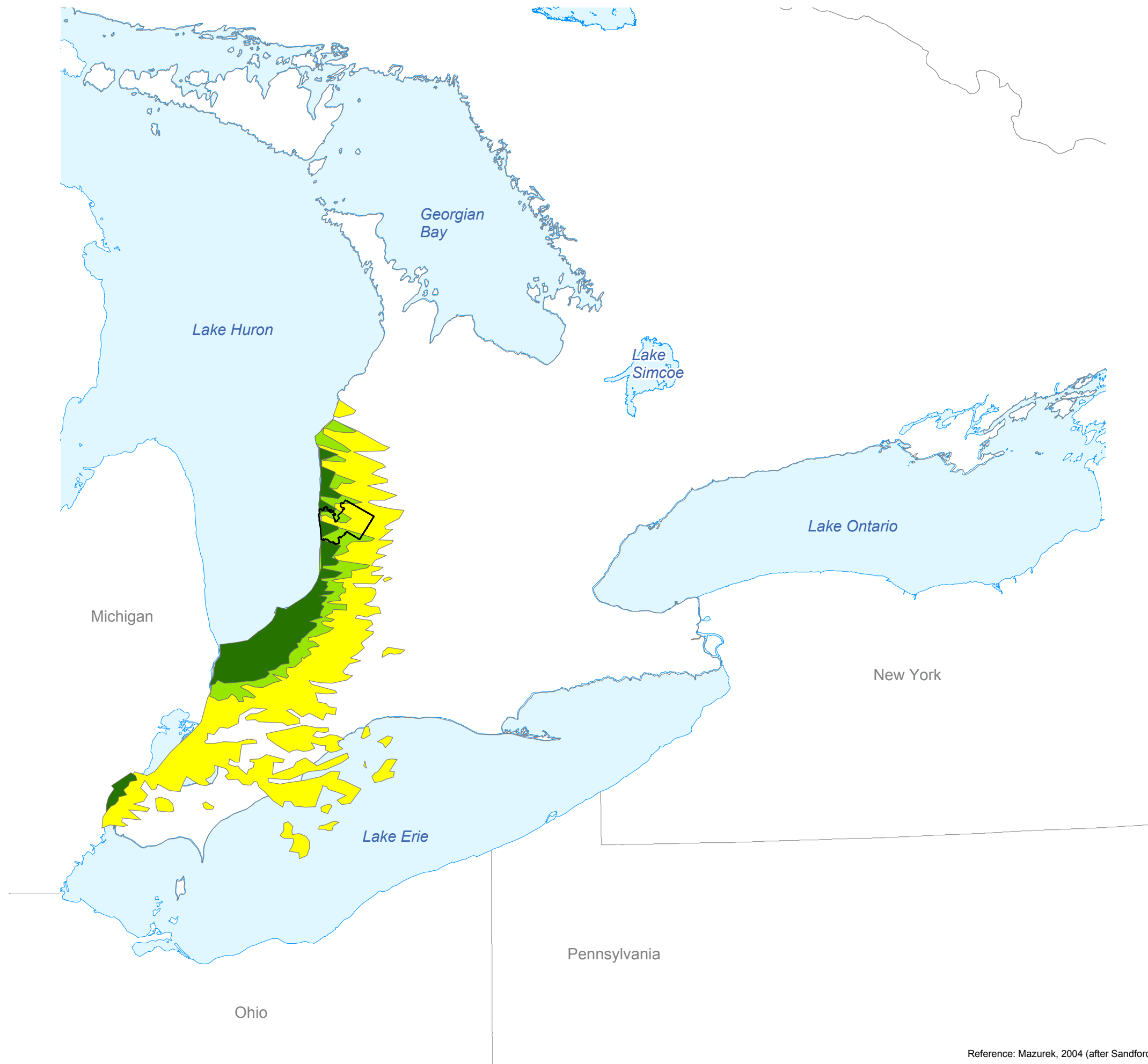
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Modified after Sanford, B.V., 1975

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**Silurian-Devonian Geological Cross Section of Southwestern Ontario**  
 February 2013  
 Project 60247068



Figure 5.2



Legend

- Occurrence of E + F salt
- Occurrence of D salt
- Occurrence of B salt
- Municipality of Central Huron



0 Kilometres 100

60247068		Date
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**Distribution of Salina  
Formation Salt**

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Figure 5.3

Reference: Mazurek, 2004 (after Sandford et al. 1985)