nwmo
NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

August 09, 2012

Municipality of South Bruce
P.O. Box 540
21 Gordon St. E.
Teeswater, ON N0G 2S0

Attn: Ms. Sharon Chambers, CAO

Re: **Adaptive Phased Management Initial Screening – The Municipality of South Bruce**

Dear Ms. Chambers,

Further to the Municipality of South Bruce'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 South Bruce 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 South Bruce 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 South Bruce 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, South Bruce 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

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

c. Mayor Bill Goetz

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

# The Corporation of the Municipality of South Bruce

Report

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

# The Corporation of the Municipality of South Bruce


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**Project Number:**

60247068-2

**Date:**

August, 2012

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# Executive Summary

On, March 27, 2012, the Corporation of the Municipality of South Bruce 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 South Bruce 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 South Bruce from further consideration in the site selection process. The initial screening focused on the areas within the boundaries of the Municipality of South Bruce. 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 South Bruce from being further considered in the NWMO site selection process. The initial screening indicates that there are geological formations within the boundaries of the Municipality that are potentially suitable for safely hosting a deep geological repository. Potentially suitable host formations include the Upper Ordovician shale and limestone units that comprise the geology of the Municipality at typical repository depths.

It is important to note that the intent of this initial screening is not to confirm the suitability of the Municipality of South Bruce 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 South Bruce remain interested in continuing with the site selection process, more detailed studies would be required to confirm and demonstrate whether the Municipality of South Bruce 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 South Bruce contains limited constraints that would prevent the development of the repository's surface facilities. The Municipality contains sufficient land to accommodate the surface and underground facilities associated with the repository.

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

The Municipality of South Bruce 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 of South Bruce. One conservation area, the Saugeen Conservation reserve, is present within the Municipality, approximately 15 km southeast of the village of Teeswater. There are four provincially designated

protected areas within the Municipality of South Bruce comprising the Greenock Swamp, and the Teeswater, Otter Creek, and Kinloss Creek wetlands. These areas cover approximately 6 % of the Municipality and are classified as Provincially Significant Wetlands and/or Life Science Areas of Natural Scientific Interest (ANSI). Limited heritage constraints were identified in the Municipality. There is only one documented archaeological site within the boundaries of the Municipality. There are no National Historic Sites listed within the Municipality of South Bruce.

The absence of other 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 (approximately 500 m) for the Municipality of South Bruce. The Ontario Ministry of Environment Water Well Records indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Municipality of South Bruce. Water wells in the Municipality obtain water from overburden or shallow bedrock aquifers at depths ranging from 3 to 128 m. Experience in similar geological settings across southern Ontario suggests that the potential for deep groundwater resources at repository depths is low throughout the Municipality of South Bruce. 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

Based on the review of readily available information, the Municipality of South Bruce contains sufficient land, free of known economically exploitable natural resources, to accommodate the required repository facilities. The Municipality of South Bruce has no documented oil and gas resources or economic minerals. Four historic exploration wells drilled within the Municipality of South Bruce for hydrocarbon exploration resulted in dry holes with no production potential. There is no record of metallic mineral production in the past, and no exploration potential for metallic minerals has been identified within the Municipality of South Bruce. Known non-metallic mineral resources in the region include bedrock-derived crushed stone, natural surficial sand and gravel resources, salt and building stone. Current licensed non-metallic mineral extraction in the Municipality of South Bruce is limited to sand and gravel resources. However, the risk that these shallow resources pose for future human intrusion is considered low, as quarrying operations would be limited to very shallow depths.

## 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 South Bruce comprises large areas of land that do not contain obvious known geological and hydrogeological conditions that would make the area unsuitable for hosting a deep geological repository. The initial screening indicates that the sedimentary rock sequence beneath the Municipality of South Bruce is potentially suitable for hosting a deep geological repository. Potentially suitable host formations include the Upper Ordovician shale and limestone units that are laterally extensive, and thick enough beneath the entire Municipality.

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# 1. Introduction

On March 27, 2012, the Corporation of the Municipality of South Bruce 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 South Bruce against five screening criteria using readily available information. The initial screening focused on the areas within the boundaries of the Municipality of South Bruce. 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 South Bruce is situated within Bruce County in southern Ontario along Highway 9, approximately 30 km northeast of Goderich, Ontario (Figure 2.1). The Municipality is approximately 488 $km^2$ in size and is made up of the former townships of Carrick and Culcross. The villages of Mildmay and Teeswater are the two largest communities in the Municipality of South Bruce, and the municipal offices are located in Teeswater (Figure 2.1). Satellite imagery for the Municipality of South Bruce (Spot 5, taken in 2006) is presented on Figure 2.2.

## 2.2 Topography

The Municipality of South Bruce 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 South Bruce and surrounding areas.

The western part of the Municipality of South Bruce lies in the Horseshoe Moraines physiographic region, while the eastern part of the Municipality lies in the Teeswater Drumlin Field physiographic region. The Municipality is covered with Quaternary glacial deposits, and numerous small lakes, streams, and swampy areas are found throughout.

The Digital Elevation Model (DEM) for the Municipality of South Bruce is presented on Figure 2.4. The terrain in the Municipality is dominated by a low relief, gently undulating land surface with an elevation of approximately 250 to 395 metres above sea level (mASL). The highest elevations (approximately 395 mASL) are found in the drumlinized plain that stretches from north to south through the centre of the Municipality. The lowest elevations are associated with the flat, low-lying topography in the swamp and wetland areas located in the northwestern corner of the Municipality. A deep valley has been cut through the overlying till and into the limestone bedrock by Formosa Creek, which flows east to west in the north-central portion of the Municipality (Figure 2.5).

## 2.3 Drainage

Surface water drainage for the Municipality of South Bruce is shown in Figure 2.5. Drainage is generally northwest to westerly into Lake Huron. The Municipality of South Bruce is located within the Saugeen sub-watershed of the Western Georgian Bay and Eastern Lake Huron sub-basins.

The most prominent drainage feature in the Municipality of South Bruce is the Teeswater River, which flows from east to west through the southern portion of the Municipality before bending to flow northwards along the western boundary, through the northern limit of the Teeswater Wetland Complex, and into the Greenock Swamp located in the northwestern corner of the Municipality (Figure 2.5). The Teeswater River ultimately discharges into the Saugeen River at Paisley, Ontario. Formosa Creek, a main tributary of the Teeswater River, flows east to west and drains the northwestern portion of the Municipality, also discharging into the Greenock Swamp. Drainage in the eastern half of the municipality is directed northwards, and flow is conveyed through Otter Creek and other smaller tributaries of the Saugeen River. Wetland areas lie along the western boundary of the Municipality of South Bruce (Figure 2.5). The Teeswater Wetland Complex occupies the southwestern portion of the Municipality, while the Greenock Swamp occupies the northwestern corner. A small wetland area is also present along Otter Creek, near Mildmay. Numerous other low-lying, poorly drained swampy areas exist within the Municipality and the region (Figure 2.5).

## 2.4 Protected Areas

### 2.4.1 Parks and Reserves

There is one conservation reserve within the Municipality of South Bruce, the Saugeen Conservation Reserve, which occupies approximately 1.5 km$^2$ in the south east portion of the Municipality (Figure 2.1). There are no provincial or national parks within the Municipality of South Bruce. The nearest parks are Point Farms Provincial Park and Inverhuron Provincial Park, located along the shore of Lake Huron approximately 30 km southwest and 30 km northwest of the Municipality respectively.

There are four provincially designated protected areas within the Municipality of South Bruce comprising the Greenock Swamp, and the Teeswater Wetland Complex, Otter Creek Wetland , and Kinloss Creek Wetland (Figure 2.1). These areas cover approximately 6% of the area of the Municipality (approximately 29 km$^2$) and are classified as Provincially Significant Wetlands and/or Life Science Areas of Natural Scientific Interest (ANSI), as indicated on Figure 2.1 (Provincial Policy Statement, 2005). The Greenock Swamp is one of the largest wetland areas in southern Ontario with an area of about 90 km$^2$. This feature extends beyond the northern boundary of the Municipality of South Bruce. There are several locally significant wetlands also located within the Municipality as shown on Figure 2.5.

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) will 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 South Bruce 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). There are 126 registered archaeological sites in the area examined (approximately 40 km radius around the municipality) with an overwhelming majority near the shores of Lake Huron. There are no National Historic Sites listed in the municipality or surrounding area. Locations of known archaeological sites are not shown in maps within this report to comply with Ministry of Tourism and Culture publication guidelines.

The only known archaeological site in the Municipality of South Bruce is located in the western portion of the Municipality. This site is of Aboriginal cultural affiliation and characterized by a scatter of chipping detritus, retouched flakes and projectile points. Of the other 125 archaeological sites in the areas outside of the Municipality of South Bruce, seventy six (76) are Aboriginal cultural affiliation while the remaining forty nine (49) are of Euro-Canadian affiliation.

The potential for archaeological sites within the Municipality of South Bruce is high. 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 (Government of Ontario, 1997).

The absence of other 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.

# 3. Geology and Seismicity

This section provides a general overview of the geology and seismicity of southern Ontario, including the Municipality of South Bruce 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 South Bruce 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 South Bruce (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 (Figure 3.1; 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 east to Lake Huron in the west, passing north of the Municipality of South Bruce (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 rock units within the Precambrian crystalline basement, rather than features of the overlying Paleozoic sedimentary rock succession.

The Municipality of South Bruce is underlain by a moderate gravity signal. The lowest intensities occur in the northwestern corner, and the highest occur along the eastern boundary of the Municipality (Figure 3.4). The

Municipality of South Bruce is located over a moderate aeromagnetic anomaly that is ringed by lower magnetic field values (Figure 3.5). 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 South Bruce and surrounding area are within the region described by the centre column of Table 3.1. The Paleozoic sedimentary stratigraphy includes shale, carbonate and evaporite units formed predominantly from marine sediments that were deposited when this portion of eastern North America was located at tropical latitudes and intermittently covered by shallow seas (Johnson et al., 1992; Armstrong and Carter, 2010).

The sedimentary bedrock stratigraphy shown in Table 3.1 and in Figure 3.3 adopts a subsurface nomenclature while geological mapping as shown in Figure 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.

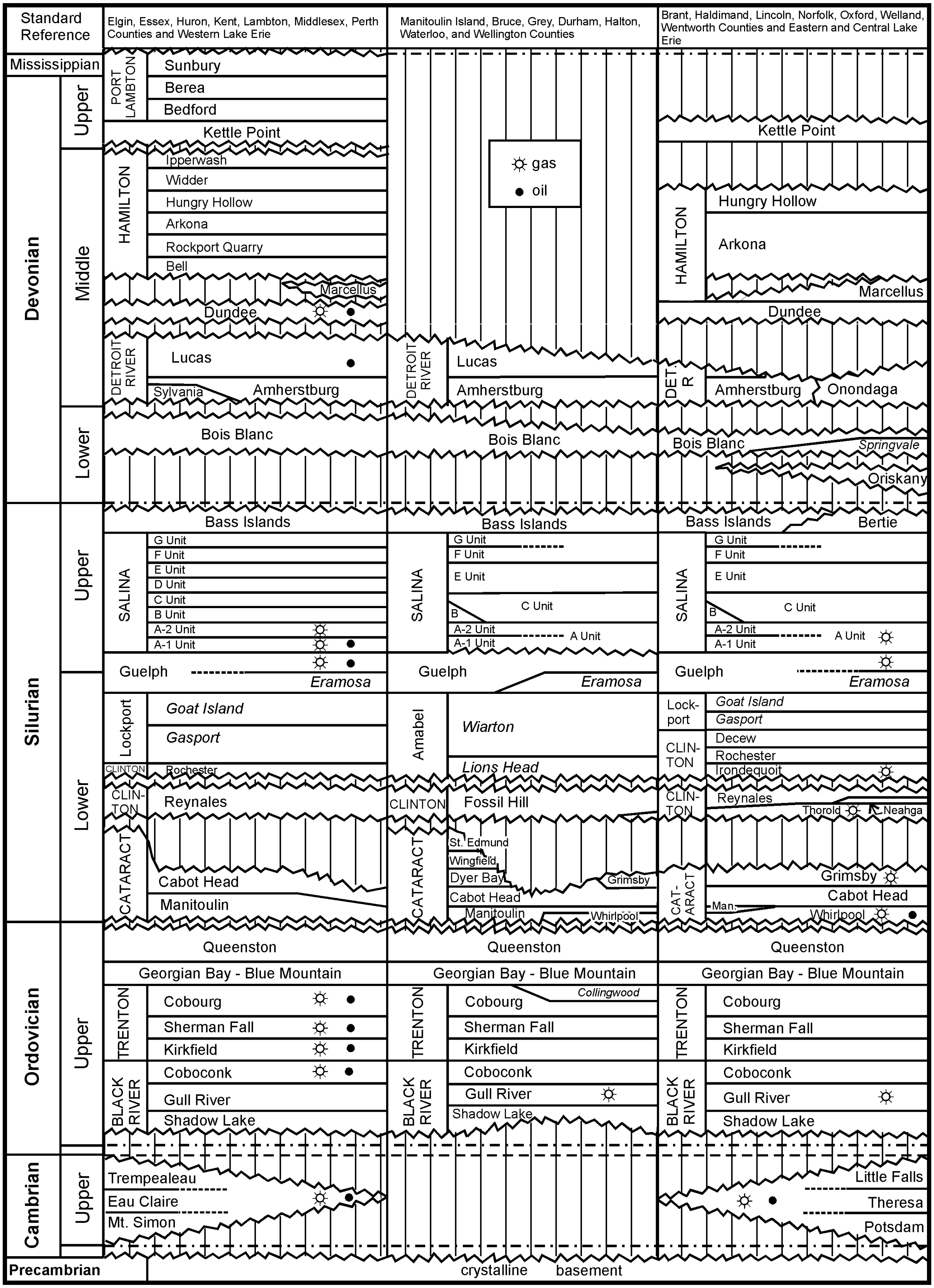
The cross-section shown in Figure 3.3, located approximately 20 km north of South Bruce (see Figure 3.2), illustrates the high degree of lateral continuity of individual units within the Paleozoic sedimentary bedrock succession of southern Ontario. This cross-section also shows the uniformity of thicknesses and bedding dip magnitudes for the deep Upper Ordovician shale and limestone sedimentary rocks across the area. 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 South Bruce.

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 sequences presented in the central column of Table 3.1.

*Cambrian*

The Cambrian bedrock geology in southern Ontario is dominated by white to grey quartzose sandstone with regional lithological variations that include fine to medium crystalline dolostone, sandy dolostone, and argillaceous dolostone to fine to coarse quartzose sandstone (Hamblin, 1999). Cambrian 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). 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 unit is expected to be absent beneath the Municipality of South Bruce because it is interpreted to pinch out west of the Municipality (Itasca Canada and AECOM, 2011). This relationship is confirmed by deep drilling within the Municipality, as discussed later in Section 3.2.1. There are no surface exposures of the Cambrian unit in southwestern Ontario.

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



*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.

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 (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 Amabel and Guelph formations, unconformably overlie the Upper Ordovician shale (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 Amabel and Guelph formations. These Lower Silurian units form the cap-rock of the Niagara Escarpment in outcrop. The Lower to Upper Silurian boundary occurs within the Guelph Formation (Table 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 Amabel Formation includes a lower unit of light grey to grey-brown, finely crystalline, thin- to medium-bedded, sparingly fossiliferous dolostone with minor chert nodules. It also includes an upper unit of blue-grey, fine- to coarse-grained, thick bedded to massive dolostone, which locally contains minor dolomitic limestone. The upper unit is lithologically very similar to the lower unit but is more argillaceous and locally contains vugs filled with gypsum, calcite, halite, or fluorite. The Guelph Formation lithology varies from reefal to inter-reefal dolostones and dolo-mudstones (Armstrong and Goodman, 1990).

*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. A change to normal marine carbonate conditions away from the cyclic carbonate and evaporite 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 Bois Blanc Formation is primarily a cherty dolostone unit overlain by mixed limestones and dolostones of the Detroit River Group (Amherstburg and Lucas formations). The Amherstburg Formation is a grey-brown to dark brown, fine- to coarse-grained, bituminous, bioclastic, fossiliferous, commonly cherty limestone and dolostone. Local reef development within the Amherstburg Formation is commonly also known as the Formosa Limestone. The Lucas Formation consists of brownish-grey, brown and cream, thin- to thick-bedded, fine crystalline dolostone. The Devonian carbonates crop out 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 South Bruce

### 3.2.1 Stratigraphy

The bedrock geology of the Municipality of South Bruce and surrounding area is shown in Figure 3.6. The figure also shows the location of deep oil and gas boreholes within the Municipality of South Bruce and surrounding areas from the Oil, Gas and Salt Resources Library Petroleum Wells Subsurface Database (OGSRL, 2006). A review of readily available information indicates that the subsurface Paleozoic bedrock geology of the Municipality of South Bruce is consistent with the regional geological framework described in Section 3.1.3. The Municipality is underlain by an Ordovician to Devonian Paleozoic sedimentary sequence that was deposited approximately 488 to 359 million years ago (Walker and Geissman, 2009; Armstrong and Carter, 2010). Additional information on the local sedimentary bedrock geology is available from the recently completed site characterization program at the nearby 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 includes:

- Four oil and gas wells within the Municipality (Table 3.2), including two deep boreholes (Wells #F012062 and #T004881) drilled in 1942 and 1979, that extend through the entire Paleozoic sedimentary sequence to the top of the Precambrian crystalline basement at a depth of approximately 870 metres below ground surface (mBGS) (Figure 3.6)

- Oil and gas boreholes surrounding the Municipality as shown in Figure 3.6 (OGSRL, 2006).
- Six boreholes (DGR-1 to DGR-6) at the Bruce nuclear site with depths ranging from 463 to 869 mBGS (Figure 3.6), including one borehole (DGR-2), which intersects the top of the Precambrian crystalline basement at a depth of 861 mBGS (Intera, 2011).

The wells in the OGSRL database, including DGR-1 and DGR-2 at the Bruce nuclear site, were used to develop a geological framework model for the OPG-DGR project (Itasca Canada and AECOM, 2011). The model allows for interpretation and simple 2-D and 3-D visualization of the stratigraphy over a portion of southern Ontario such as the geological cross-section shown in Figure 3.3.

The stratigraphy beneath the western area of the Municipality of South Bruce, as interpreted from OGSRL Well #F012062 and Well #T004881, is shown in Table 3.3. These wells are located in close proximity, approximately 3 km apart, in the southwestern quadrant of the Municipality. The stratigraphic units identified in Table 3.3 are consistent with the regional stratigraphic framework summarized in Section 3.1.3 and Table 3.1 (Armstrong and Carter, 2010). The differences in the number of individual logged units between Well #F012062 and Well #T004881 is likely the result of stratigraphic nomenclature changes over the years between 1942 and 1979 and differences in geological interpretation between individual well loggers. Thin Salina Formation evaporite units can also be preferentially dissolved (Sanford et al., 1985) resulting in minor differences in the Silurian stratigraphy. The major stratigraphic sequences are represented in both deep wells and are consistent in depth and thickness (Table 3.3).

The same Paleozoic succession encountered in South Bruce was also encountered in the deep boreholes beneath the Bruce nuclear site (Intera, 2011), with the exception of the Cambrian unit, which is interpreted to pinch out west of the Municipality of South Bruce (Bailey Geological Services and Cochrane, 1984). Based on the information from OGSRL Well #F012062 and #T004881 (Table 3.3), the total thickness of the Paleozoic strata is approximately 865 m. At typical repository depths (approximately 500 m), the geology of the Municipality of South Bruce comprises Upper Ordovician shale and limestone units. The Upper Ordovician limestone units beneath the western area of the Municipality are cumulatively more than 200 m thick, extending from 658 mBGS to 862 mBGS in Well #F012062, and from 659 mBGS to 872 mBGS in Well #T004881. The limestone units include the Gull River, Coboconk, Kirkfield, Sherman Fall, and Cobourg formations (Table 3.3). The shale units are also cumulatively more than 200 m thick, extending from 430 mBGS to 658 mBGS in Well #F012062, and from 435 mBGS to 659 mBGS in Well #T004881 and include the Collingwood, Georgian Bay/Blue Mountain, and Queenston formations. Given the regional shallowly southwest-dipping geometry of the Paleozoic sedimentary rocks (3.5 to 12 m/km to the west or southwest throughout the Ontario portion of the Michigan Basin (Armstrong and Carter, 2010)), the depth of the Upper Ordovician shale and limestone units is expected to decrease in elevation by about 200 m from the western side to the northeast corner of the Municipality. The individual formation thicknesses are expected to remain uniform (Section 3.1.3).

There is limited readily available information on the geoscientific characteristics of the Upper Ordovician shale and limestone units beneath the Municipality of South Bruce. However, it is expected that they are very similar to the characteristics of the Upper Ordovician units beneath the nearby Bruce nuclear site which are described as comprising relatively undeformed, near horizontally layered low porosity and low hydraulic conductivity sequences that are correlative over large lateral extents as a result of their simple geometry and uniform thicknesses (NWMO, 2011). The consistency of the major stratigraphic successions between Well #T004881 located within Municipality of South Bruce and the deep boreholes at the Bruce nuclear site suggests a high degree of 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.

**Table 3.2 Subcrop Geological Unit and Final Well Completion Unit for Oil and Gas Wells Within the Municipality of South Bruce**

| Well License # | Total Depth (mBGS) | Top Geological Unit (Subcrop) | Bottom Geological Unit |
|---|---|---|---|
| **T004881** | 876.6 | Lucas Formation | Precambrian |
| **F012062** | 868.4 | Lucas Formation | Precambrian |
| **F012068** | 317.3 | Lucas Formation | Guelph Formation |
| **F012077** | 660.5 | Lucas Formation | Cobourg Formation |

**Table 3.3 Stratigraphy Derived from Oil and Gas Exploration Wells OGSRL #F012062 (1942) and #T004881 (1979) in the Municipality of South Bruce (Itasca Canada and AECOM, 2011, after OGSRL, 2006)**

| Standard Reference | | Geological Unit* | #F012062 | | #T004881 | |
|---|---|---|---|---|---|---|
| | | | *Unit Top (mBGS)* | *Unit Thickness (m)* | *Unit Top (mBGS)* | *Unit Thickness (m)* |
| **Quaternary** | | Drift | 0.6 | 9.5 | 1.2 | 19.8 |
| **Devonian** | **Middle** | Lucas Formation | 10.1 | 72.5 | 21.0 | 32.3 |
| | | Amherstburg Formation | - | - | 53.3 | 48.8 |
| | **Lower** | Bois Blanc Formation | 82.6 | 54.6 | 102.1 | 35.1 |
| **Silurian** | **Upper** | Bass Islands | 137.2 | 40.5 | 137.2 | 36.5 |
| | | Salina G Unit | 177.7 | 40.2 | 173.7 | 8.9 |
| | | Salina F Unit | - | - | 182.6 | 44.2 |
| | | Salina E Unit | 217.9 | 31.1 | 226.8 | 26.5 |
| | | Salina D Unit | - | - | 253.3 | 2.7 |
| | | Salina C Unit | 249.0 | 34.5 | 256.0 | 13.4 |
| | | Salina B Unit | - | - | 269.4 | 27.2 |
| | | Salina A-2 Unit | 283.5 | 33.8 | 296.6 | 25.0 |
| | | Salina A-1 Unit | 317.3 | 43.0 | 321.6 | 45.1 |
| | | Guelph Formation | 360.3 | 33.5 | 366.7 | 10.0 |
| | **Lower** | Goat Island Formation | - | - | 376.7 | 18.0 |
| | | Gasport Formation | - | - | 394.7 | 7.8 |
| | | Reynales / Fossil Hill Formation | 393.8 | 9.5 | 402.5 | 4.4 |
| | | Cabot Head Formation | 403.3 | 16.7 | 406.9 | 19.8 |
| | | Manitoulin Formation | 420.0 | 9.5 | 426.7 | 8.6 |
| **Ordovician** | **Upper** | Queenston Formation | 429.5 | 75.9 | 435.3 | 74.3 |
| | | Georgian Bay / Blue Mountain Formation | 505.4 | 121.0 | 509.6 | 122.6 |
| | | Collingwood Formation | 626.4 | 31.7 | 632.2 | 27.1 |
| | | Cobourg Formation | 658.1 | 42.9 | 659.3 | 47.8 |
| | | Sherman Fall Formation | 701.0 | 48.2 | 707.1 | 54.6 |
| | | Kirkfield Formation | 749.2 | 41.1 | 761.7 | 35.4 |
| | | Coboconk Formation | 790.3 | 12.8 | 797.1 | 20.7 |
| | | Gull River Formation | 803.1 | 58.6 | 817.8 | 54.2 |
| | | Shadow Lake Formation | 861.7 | 6.7 | 872.0 | 3.7 |
| **Precambrian** | | Precambrian | 868.4 | | 875.7 | |

*Note: * Nomenclature at the Formation level in this table varies from the recently updated nomenclature used in Table 3.1 (Armstrong and Carter, 2010).*

## 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.

*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, Table 3.4). 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).

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

| Time Interval Before Present (millions of years) | Tectonic Activity | Reference |
|---|---|---|
| **1210 – 1180** | Regional metamorphism (proto-Grenville) | Lumbers et al., 1990; Easton, 1992; Hanmer and McEachern, 1992 |
| **1109 – 1087** | Magmatism and formation of Midcontinent Rift | Van Schmus, 1992 |
| **1030 – 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<br>• 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<br>• 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<br>• E-W to NW-SE compression | Engelder and Geiser, 1980; Gross et al., 1992 |
| **200 – 50** | • Opening of the Atlantic Ocean<br>• St. Lawrence rift system created<br>• reactivated Ottawa-Bonnechere Graben<br>• NE-SW extension<br>• uplift | Kumarapeli, 1976; Kumarapeli, 1985 |
| **50 – Present** | • NE-SW compression (from ridge push)<br>• post-glacial uplift | 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.

Only one Paleozoic fault is mapped within the Municipality of South Bruce (Figure 3.6). It strikes east-northeast and has a documented length of approximately 10 km. The fault was likely interpreted based on the intersection of the structure by borehole #F012077. This fault 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. Four other faults, all exhibiting the same east-northeast strike orientation, have been reported within an area of approximately 30 km surrounding the Municipality (Figure 3.2). Two of these, located approximately 30 km east of the Municipality, are interpreted to postdate the deposition of the Ordovician Trenton Group carbonates, but pre-date the deposition of the overlying Upper Ordovician shales, as is the case for the fault situated within the Municipality of South Bruce. The other two faults are interpreted to predate the deposition of the Ordovician Trenton Group carbonates. One of these lies approximately 10 km northwest of the Municipality boundary, and the other is found 30 km east of the Municipality.

In summary, five basement-seated faults are recognized within approximately 30 km of the Municipality of South Bruce (Figure 3.2). These faults 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 South Bruce. 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. The process of salt dissolution and the creation of collapse features in the rock 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 South Bruce. 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 infiltrates the sedimentary strata. Karst processes are most active in the shallow subsurface (less than 200 mBGS) while 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).

A map showing the distribution of areas with known, inferred or potential karst in southern Ontario is presented in Figure 3.7 (Brunton and Dodge, 2008). There is no known karst mapped within the Municipality of South Bruce. Within the Municipality, areas of inferred karst are identified in the Bass Islands and Bertie Formations and the Lucas Formation of the Detroit River Group, and areas of potential karst are identified in the Amherstburg Formation of the Detroit River Group (Figure 3.7; Brunton and Dodge, 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 Formation carbonates exposed along the 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, karst features in southern Ontario are unlikely to affect the deep subsurface geological or hydrogeological conditions at typical repository depth (approximately 500 m). The influence that paleokarst may have on the deeper carbonate rock formations beneath the Municipality of South Bruce 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 at typical repository depth was found for the Municipality of South Bruce. However, a detailed assessment of the geomechanical properties of the Paleozoic sequence underlying the nearby 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 found at typical repository depths beneath the Municipality of South Bruce.

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 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).

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).

In summary, available information on geomechanical properties of the Upper Ordovician shale and limestone units in southern Ontario suggests the units have a high strength, and favourable geomechanical characteristics, which makes them amenable to the excavation of stable underground openings.

## 3.5 Quaternary Geology

The extent and type of Quaternary deposits in the Municipality of South Bruce and surrounding area is illustrated in Figure 3.8. Most of the Municipality of South Bruce is covered by Quaternary deposits, with the exception of exposed limestone bedrock within the incised creek valleys. The Quaternary cover in the area mostly comprises glacial deposits including tills, glaciofluvial and glaciolacustrine sediments deposited during the late Pleistocene

Wisconsinan glaciations, as well as more recent fluvial, lacustrine and organic deposits. 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).

Mapping of the Quaternary deposits in the Municipality of South Bruce shows that glacial till, forming moraines and drumlins, is found throughout the Municipality, along with glaciofluvial outwash sediments associated with the retreat of glacial ice (Figure 3.8). Glaciofluvial ice-contact deposits mapped in the west and southwest portions of the Municipality are likely associated with the Wyoming Moraine. Drumlins are most pronounced in the central portion of the municipality with axes trending north-south to northeast-southwest. Broad terraces of outwash sands and gravels and kame deposits fill the valleys between the drumlins. A shallow deposit of silty material that blankets the area is interpreted as loess (Chapman and Putnam, 1984). Organic deposits, as well as a small area of glaciolacustrine material, are found in the northwestern corner of the Municipality and are associated with the wetlands that exist at that location (Figure 3.8).

### 3.5.1 Quaternary Overburden Thickness

The thickness of the Quaternary deposits in the Municipality of South Bruce and surrounding area is shown in Figure 3.9 (Gao et al., 2006). The Municipality of South Bruce is covered by Quaternary deposits with overburden thicknesses ranging from less than 1 m (exposed in the Formosa Creek Valley) to 92 m, with the majority of the Municipality covered by greater than 8 m. The thickest areas of overburden are found along the western boundary of the municipality, and locally within the northeastern corner, and are associated with glaciofluvial deposits and esker ridges. The till plains and drumlin fields show greater overburden thicknesses when compared with the interspersed glaciofluvial outwash deposits. The thinnest overburden deposits in the Municipality of South Bruce are found in the valleys of the Teeswater River and Formosa Creek – the latter cuts down into limestone bedrock (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 of the Bruce Peninsula 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 nearby Bruce nuclear site, glacial erosion would conservatively be 100 m per one million years.

## 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 creates horizontal stresses in shallow bedrock areas. These natural stress release features include 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 was conducted within a radius of up to 50 km from the Bruce nuclear site, which includes parts of the Municipality of South Bruce. The study found no evidence for neotectonic activity associated with the most recent glacial cycle approximately 25,000 years ago (Slattery, 2011).

## 3.7 Seismicity

The Municipality of South Bruce 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). All recorded earthquakes in southern Ontario have a magnitude of less than 5 (Figure 3.10; Natural Resources Canada, 2012). 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 shows the locations and magnitudes of all earthquakes recorded in southern Ontario between 1985 and 2012 (Natural Resources Canada, 2012). Most of the earthquakes in the region around the Municipality of South Bruce 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).

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

# 4. Hydrogeology

## 4.1 Groundwater Wells

Information on groundwater in the Municipality of South Bruce was obtained from the Ontario Ministry of the Environment (MOE) Water Well Record Database. The location of known water wells are shown on Figure 4.1. The Municipality of South Bruce relies on shallow overburden and 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 study area. There are two active municipal water supply well fields in the Municipality of South Bruce; these include the Mildmay Well Supply and the Teeswater Well Supply with wellhead protection areas of 6.04 $km^2$ and 8.90 $km^2$, respectively (Saugeen, Grey Sauble, Northern Bruce Peninsula, 2011). The well head protection areas would need to be considered 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 815 water well records for the Municipality of South Bruce (Figure 4.1). Of these 815 well records, 7 records contained information only on location and provided no data on well type, depth, or hydrogeological conditions while 26 wells had duplicate well records for the same well number. A summary of the 808 wells 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** | 44 | 2.7 | 96.9 | 0.6 | 20.7 | 0.9 | 75.9 | 9.1 |
| **Bedrock** | 764 | 3.7 | 128.3 | -4.9 | 48.8 | 0.2 | 76.2 | 4.2 |

The MOE Water Well Records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths (approximately 500 m) within the Municipality of South Bruce. Of the 815 well records found for the Municipality of South Bruce, 44 wells were completed in overburden aquifers, 764 wells were completed in bedrock aquifers and 7 contained no stratigraphic completion records (Table 4.1). Wells completed within overburden range in depths from approximately 3 to 97 m. Overburden well yields range from 0.9 to 75.9 L/min, with mean values of 9.1 L/min. Wells completed in the bedrock range in depth from approximately 4 to 128 m. Bedrock wells yield range from 0.2 to 76.2 L/min, with mean values of 4.2 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. Note that a negative value in Table 4.1 for Static Level Range indicates an artesian well with the estimated head above the ground surface.

## 4.2 Deep Groundwater System

There is no direct hydrogeological information available on the deep groundwater system beneath the Municipality of South Bruce. However, as described in Section 3.2.1., there is a high degree of lateral continuity and predictability of the Upper Ordovician shale and limestone units across this part of southern Ontario. This suggests that the hydrogeological setting at depth beneath the Municipality of South Bruce is likely to be similar to that interpreted from regional hydrogeological information and the detailed site characterization work completed at the nearby 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 is shallow, and limited to the upper approximately 200 mBGS. Below this depth, an intermediate to deep groundwater system has 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 of the Upper Ordovician shale and limestone units (approximately $10^{-15}$ to $10^{-10}$ m/s). The deep groundwater system within the Upper Ordovician units at typical repository depth 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 shale, dolostone and anhydrite formations (NWMO, 2011).

In summary, there are no known exploitable groundwater resources at typical repository depths in the Municipality of South Bruce, due to the very low hydraulic conductivities of the Upper Ordovician shale and limestone units. 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 typical repository depth for the Municipality of South Bruce. 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 recognized at the regional scale in southern Ontario: 1) a shallow system (less than 200 mBGS) containing fresh through brackish waters. Waters in this system have stable isotopic compositions ($\delta^{18}O$ and $\delta^{2}H$) consistent with mixing of dilute meteoric or cold-climate (glacial) waters with more saline waters; and 2) an intermediate to deep system (more than 200 mBGS) containing predominately brines associated with hydrocarbons in reservoirs, 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 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 chemistries of the deep brines indicate that they were formed by evaporation of seawater, which was subsequently modified by fluid-rock interaction processes. The nature of the brines, in particular the high salinities and enriched $\delta^{18}O$ 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 (Hobbs et al., 2011; NWMO, 2011).

# 5. Economic Geology

## 5.1 Hydrocarbon Resources

The Paleozoic rocks of southern Ontario are known to include regions of commercial hydrocarbon accumulation; however there are no known oil and gas pools within the Municipality of South Bruce. Oil and gas exploration wells, known pools and mapped oil and gas pipelines are shown in Figure 3.6. There are nine known oil and gas pools in the 40 km area outside of the Municipality, hosted within Ordovician and Silurian aged formations. Two of these pools, the Dungannon Pool and the West Wawanosh 26-X Pool are located approximately 12 km southwest of the Municipality and are hosted within Silurian age formations. The Ashfield Silurian pool, to the west, and the Ordovician Egremont and Arthur pools, to the east and southeast, respectively, are located greater than 20 km outside the Municipality of South Bruce (Figure 3.6).

Historic exploration in the Municipality of South Bruce and surrounding area focused on Upper Ordovician (hydrothermal dolomite) and Upper Silurian (reef-type) units as potential hydrocarbon plays (e.g., Sanford, 1993; Hamblin, 2008; Lazorek and Carter, 2008). Four exploration wells have been documented in the Municipality of South Bruce in the Oil, Gas and Salt Resources Library (OGSRL) Petroleum Wells Subsurface Database (OGSRL, 2006). These wells are dry holes with no production and have been abandoned. The presence or absence of oil and gas plays including hydrothermal dolomite in the Municipality of South Bruce will need to be confirmed during subsequent site evaluation stages, if the community 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 plays where it overlies the Cambrian, and Upper Ordovician shale gas. With respect to potential Cambrian and Shadow Lake gas plays, the OGSRL database Well #T004481 and Well #012062 within the Municipality of South Bruce did not contain Cambrian deposits (Table 3.3). An analysis of the Upper Ordovician shale gas potential for the Bruce nuclear site, located 32 km to the northwest of the Municipality of South Bruce, found that insufficient total organic content of the Ordovician shales, as well as insufficient thermal maturity, would preclude any likelihood of commercial gas accumulations (Engelder, 2011).

In summary, no hydrocarbon pools have been identified within the Municipality of South Bruce. New types of conceptual hydrocarbon plays appear to have a relatively low probability of exploitation within the Municipality of South Bruce due to the unfavourable geological setting and history. The potential for existing and new conceptual hydrocarbon plays 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 South Bruce. 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 around Municipality of South Bruce include bedrock-derived crushed stone, natural surficial sand and gravel resources, salt and building stone. Current licensed non-metallic mineral extraction in the Municipality of South Bruce is limited to sand and gravel resources (Figure 5.1).

### 5.3.1 Sand and Gravel

Sand and gravel pits in the Municipality of South Bruce generally correspond to glaciofluvial outwash or ice-contact deposits found at surface (Figures 3.8 and 5.1). The Ontario Geological Survey Aggregate Resources Inventory for Bruce County (Rowell, 2012) indicates that 2010 aggregate production from the Municipality of South Bruce was 384,517 tonnes or approximately 17% of Bruce County's total sand and gravel resource extraction. Rowell (2012) designated primary, secondary and tertiary significance for sand and gravel resources based on quality and potential volume. Two areas within the Municipality of South Bruce were assigned a primary significance; these comprise the currently operating pits that are located west of Teeswater and in the northeast corner of the Municipality (Figure 5.1). Areas of secondary significance correspond to a large area of glaciofluvial ice-contact deposits in the north-central portion of the Municipality, two glaciofluvial outwash and ice-contact deposits located in the eastern portion of the Municipality, and glaciofluvial outwash deposits along the southern and northwestern boundaries of the Municipality (Figure 3.8). A number of pits operate within these areas of secondary significance.

### 5.3.2 Bedrock Resources

There are no known licensed bedrock quarries or commercial mining operations within the Municipality of South Bruce (Figure 5.1). Two small, unlicensed (typically abandoned or wayside) quarries have been identified within the Municipality (Rowell, 2012). There are no licensed quarries in the area immediately surrounding the Municipality.

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 South Bruce is covered by greater than 8 m of Quaternary sediments (Figure 3.9). Those areas with thin overburden or outcrop contain no unique bedrock resources with respect to aggregate, cement or building stone.

There are no known commercial salt resources located in the Municipality. Economic deposits of salt are mined approximately 30 km south of the Municipality in Goderich Ontario. The presence or absence of salt resources would have to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

# 6. Initial Screening Evaluation

This section provides an evaluation of each of the five initial screening criteria (NWMO, 2010) for the Municipality of South Bruce 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 South Bruce from further consideration in the site evaluation process.

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 (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 (375 ha) at a typical depth of about 500 m.

This criterion was evaluated by assessing whether the Municipality of South Bruce 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 South Bruce contains sufficient area for the repository's surface facilities (Figures 2.1, 2.2 and 2.5). Constraints would mainly include Provincially Significant Wetlands such as the Greenock Swamp, and the Teeswater, Kinloss Creek, and Otter Creek wetlands, which account for only 6 % of the area of the Municipality of South Bruce. Also, a small portion of the Municipality is covered by localized residential and industrial/commercial infrastructure, associated with the villages of Teeswater and Mildmay in the west and east-central areas of the Municipality, respectively, and the former hamlet of Formosa in the north-central area of the municipality. The remainder of the Municipality of South Bruce is largely agricultural land with development limited primarily to roadways and settlement areas.

As discussed in Section 2, topography is variable across the Municipality. However, no obvious topographic features have been identified that would prevent construction and characterization activities over most of the Township area. Most of the Municipality of South Bruce could be accessed from Highway 9 and the numerous subsidiary county and rural roads which cross the area (Figure 2.1).

As discussed in Section 6.5, readily available information suggests that the Municipality of South Bruce 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 South Bruce 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 South Bruce 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 (Land Information Ontario) and the Ontario Ministry of Tourism and Culture.

The Saugeen Conservation Reserve is present in the southeast portion of the Municipality with an approximate area of 1.5 $km^2$. There are no provincial or national parks within the Municipality of South Bruce (Figure 2.1). The nearest provincial parks are Point Farms Provincial Park and Inverhuron Provincial Park, located along the shores of Lake Huron approximately 30 km southwest and 30 km northwest of the Municipality. Provincially Significant Wetlands have been identified within the Municipality of South Bruce, such as the Greenock Swamp, and the Teeswater, Kinloss Creek, and Otter Creek wetland complexes, which account for approximately 6 % (25 $km^2$) of the area of the Municipality of South Bruce.

As discussed in Section 2.4, most of the land in the Municipality of South Bruce is free of known heritage constraints. There is only one localized known archeological site within the Municipality. There are no listed National Historic Sites in the Municipality of South Bruce.

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 South Bruce 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) 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 South Bruce. The Ministry of the Environment Water Well Records indicates that no potable water supply wells are known to exploit aquifers at typical repository depths (approximately 500 m) within the Municipality of South Bruce or the surrounding areas (Section 4.1). All water wells known in the Municipality of South Bruce obtain water from overburden or shallow bedrock sources at depths ranging from 3 to 128 m.

As discussed in Section 4.2, the potential for groundwater resources at the typical repository depth beneath the Municipality of South Bruce is extremely low. Experience from other areas in southern Ontario and the detailed site characterization work recently completed at the nearby Bruce nuclear site for OPG's proposed DGR for low and intermediate level radioactive waste has shown that there is no active deep groundwater system at typical repository depths due to the very low hydraulic conductivities of the Upper Ordovician shale and limestone units (approximately $10^{-15}$ to $10^{-10}$ m/s). The active groundwater system is shallow and limited to the upper approximately 200 m. Available hydrogeological data from OPG's proposed DGR project indicates that the deep groundwater regime within the Upper Ordovician units at typical repository depth is diffusion-dominated and isolated from the shallow groundwater system. In addition, as discussed in Section 4.3, a 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 South Bruce. Experience in similar geological settings in the region suggests that the potential for deep groundwater resources at repository depths is extremely low beneath the Municipality of South Bruce. 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.

The review of available information indicates that there are no known oil and gas pools within the Municipality of South Bruce. Four historic exploration wells drilled within the Municipality of South Bruce for hydrocarbon exploration resulted in dry holes with no production. An assessment of the shale gas potential at the Bruce nuclear site (located 32 km to the northwest of the Municipality of South Bruce) found that the likelihood of commercial gas accumulation in the Ordovician shale is low because of their low organic content and insufficient thermal maturity. This finding suggests that commercial gas accumulation in the Ordovician shales beneath the Municipality of South Bruce is also unlikely due to the proximity to the Bruce nuclear site and the consistency of the regional geological setting.

There are currently no operating mines within the Municipality of South Bruce. There is no record of metallic mineral production in the past. No exploration potential for metallic minerals has been identified within the Municipality.

Known non-metallic mineral resources in the region include bedrock-derived crushed stone, natural surficial sand and gravel resources, salt and building stone. Current licensed non-metallic mineral extraction in the Municipality of South Bruce 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.

> *Based on the review of readily available information, the Municipality of South Bruce contains sufficient land, free of known economically exploitable natural resources, to accommodate the required repository facilities. The absence of natural resources would need to be confirmed 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. <u>Long-term resilience to future geological processes and climate change</u>. 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. <u>Safe construction, operation and closure of the repository</u>. Are conditions at the site suitable for the safe construction, operation and closure of the repository?

4. <u>Isolation of used fuel from future human activities</u>. Is human intrusion at the site unlikely, for instance, through future exploration or mining?

5. <u>Amenable to site characterization and data interpretation activities</u>. 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 South Bruce, 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 South Bruce from further consideration in the site selection process at this stage.

<u>*Safe Containment and Isolation*</u>

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, 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 South Bruce is consistent with the regional geological framework. The Municipality is entirely underlain by a predictable and laterally extensive Ordovician to Devonian Paleozoic sedimentary sequence that was deposited approximately 488 to 359 million years ago.

Based on information from historic oil and gas deep exploration wells (Well #F012062 and #T004881, Table 3.3), the total thickness of the Paleozoic strata in the Municipality of South Bruce is approximately 855 m. The well data in the western sector of the Municipality show that at depths that are typically considered for deep geological repositories (approximately 500 m), the geology comprises Upper Ordovician shale and limestone units. The shale units are cumulatively more than 200 m thick (from approximately 430 mBGS to 659 mBGS) and overlay more than 200 m of limestone units (from approximately 659 mBGS to 872 mBGS). Given the regional shallowly southwest-dipping geometry of the Paleozoic sedimentary rocks, the elevation of the Upper Ordovician shale and limestone units is expected to decrease towards the northeast corner of the Municipality. The individual formation thicknesses are expected to remain relatively uniform.

While there is limited information on the geoscientific characteristics of the Upper Ordovician shale and limestone units beneath the Municipality of South Bruce, it is expected that they are similar to the Upper Ordovician units beneath the nearby 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. Given their depth, thickness and lateral extent, the Upper Ordovician shale and limestone units would potentially provide a sufficient volume of rock to physically contain and isolate a deep geological repository for used nuclear fuel.

Given the regional predictability of the geological setting, the hydrogeological and hydrogeochemical conditions at typical repository depth beneath the Municipality of South Bruce are expected to be similar to those beneath the Bruce nuclear site (Section 4.2). The deep groundwater regime within the Upper Ordovician shale and limestone units beneath the Bruce nuclear site is described as diffusion dominated and isolated from the shallow groundwater system which is limited to the upper 200 mBGS (Sections 4.2 and 4.3). Only one mapped fault is recognized in the Ordovician Trenton Group Carbonates beneath the Municipality of South Bruce (Figure 3.2). It is interpreted to predate the deposition of the overlying Upper Ordovician shales and therefore likely does not represent a potential pathway to the surface.

The isolated nature of the deep groundwater system is further supported by the regional hydrogeochemical setting (Section 4.3). Regional chemistries of the deep brines indicate 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.

In summary, the review of available information did not identify any obvious geological or hydrogeological conditions that would fail the containment and isolation requirements. The Upper Ordovician shale and limestone units that are found at typical repository depth beneath the Municipality of South Bruce 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 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 environments 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 beneath the Municipality of South Bruce, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the potential for paleokarst, 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 South Bruce. As discussed below, the review of readily available information did not reveal any obvious characteristics that would raise such concerns.

The Municipality of South Bruce 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). Only one mapped fault within the Ordovician Trenton Group Carbonates has been identified in the Municipality of South Bruce. There is no evidence suggesting that these types of faults have been tectonically active within the past approximately 450 million years.

The geology of the Municipality of South Bruce is typical of many areas of southern Ontario, which has 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 to analyse Quaternary landforms for the presence of seismically-induced soft-sediment deformation (Section 3.6). The study was conducted within a radius of up to 50 km from the Bruce nuclear site, which includes most of the Municipality of South Bruce. The study concluded that the area has not likely experienced any post-glacial neotectonic activity. 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, based on observations of striated surfaces with multiple episodes preserved, the relative absence of friction cracks, and the pervasive low relief of striated surfaces (Section 3.6). The study also concluded that potential future glacial erosion in the area would be limited with a conservative site-specific estimate of erosion of 100 m per 1 million years, which is much less than the typical depth of a used nuclear fuel repository (approximately 500 m).

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 South Bruce. 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 there are no known groundwater resources at repository depths or known economically exploitable natural resources in the Municipality of South Bruce.

*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.

From a constructability perspective, although no readily available site specific information on rock strength characteristics and in-situ stresses was found for the Municipality of South Bruce, there is abundant information at other locations of southern Ontario that could provide insight into what would be expected for the Municipality of South Bruce. Available information on strength and in-situ stresses suggests that the Upper Ordovician shale and limestone units have favorable geomechanical characteristics and are 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. These values compare favourably with other sedimentary formations considered internationally for the long-term management of radioactive waste (Section 3.4). 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, requiring only standard support. The simulations also show 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 3.5).

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 South Bruce 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 South Bruce 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 South Bruce is covered by Quaternary overburden deposits. As described in Section 3, overburden thickness in the Municipality range from less than 1 m to 92 m. The regional geological framework, the simple geometry and the predictability of the subsurface stratigraphic formations indicates that the thickness of the overburden cover is not likely to affect the ability to characterize the subsurface bedrock formations beneath the Municipality of South Bruce.

In summary, the review of readily available geological and geomechanical information for the Municipality of South Bruce (Section 3) did not indicate any obvious conditions which would make the rock mass unusually difficult to characterize or construct upon.

*Based on the review of available geological and hydrogeological information, the Municipality of South Bruce comprises land that does 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 South Bruce against five initial screening criteria using readily available information. The initial screening focused on the areas within the boundaries of the Municipality of South Bruce. 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 South Bruce from being further considered in the NWMO site selection process. The initial screening indicates that there are geological formations within the boundaries of the Municipality that are potentially suitable for safely hosting a deep geological repository. Potentially suitable host formations include the Upper Ordovician shale and limestone units that comprise the geology of the Municipality at typical repository depths.

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 South Bruce, but rather to identify whether there are any obvious conditions that would exclude it from the site selection process. Should the community of South Bruce 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 South Bruce 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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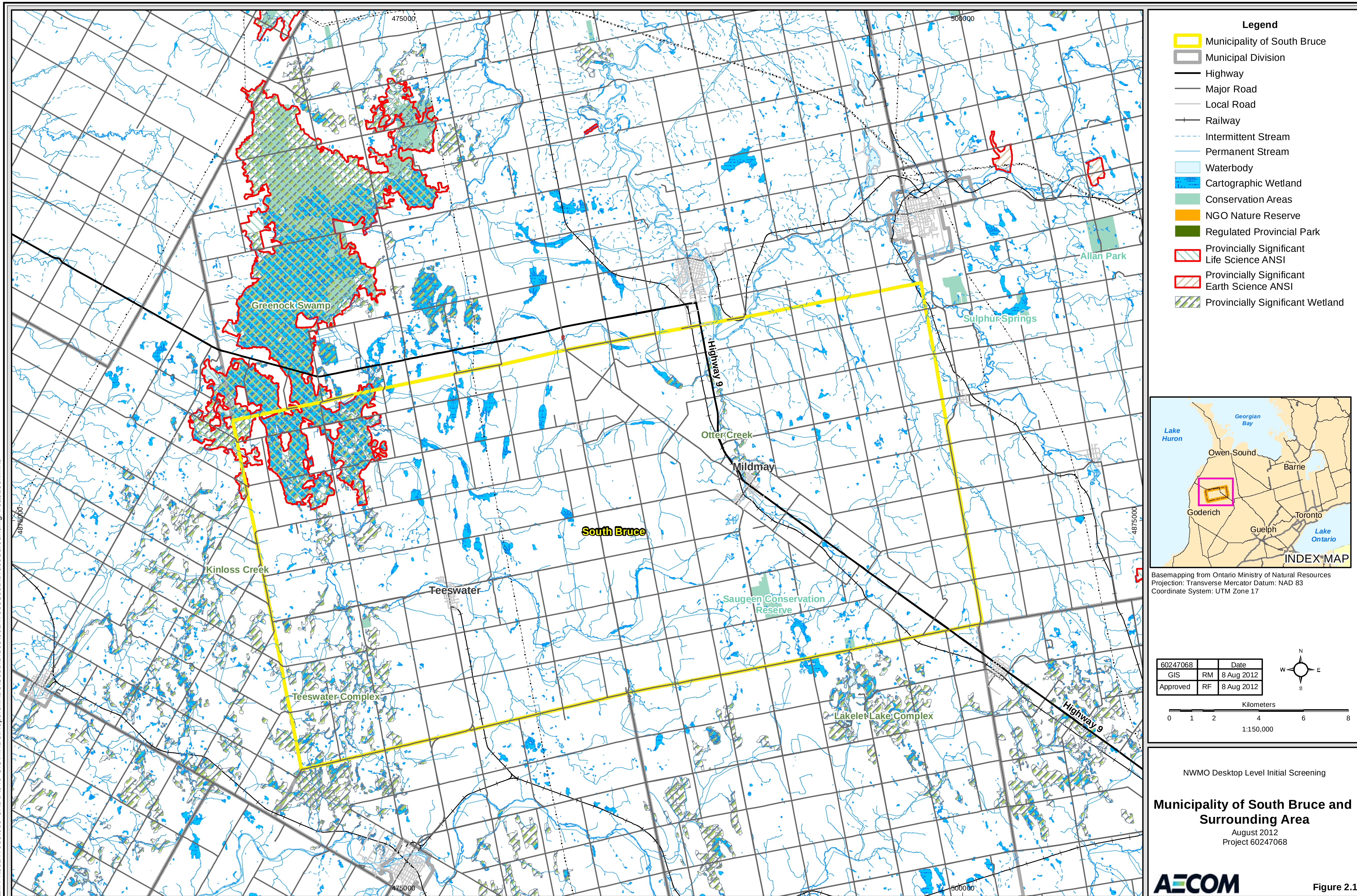


NWMO Desktop Level Initial Screening

**Municipality of South Bruce and Surrounding Area**

August 2012

Project 60247068

Figure 2.1


## Legend

- Municipality of South Bruce
- Highway
- Major Road


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

| 60247068 | | Date |
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| GIS | RM | 8 Aug 2012 |
| Approved | RF | 8 Aug 2012 |

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W E
S

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

NWMO Desktop Level Initial Screening

# Satellite Imagery of the Municipality of South Bruce

August 2012
Project 60247068

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Figure 2.2

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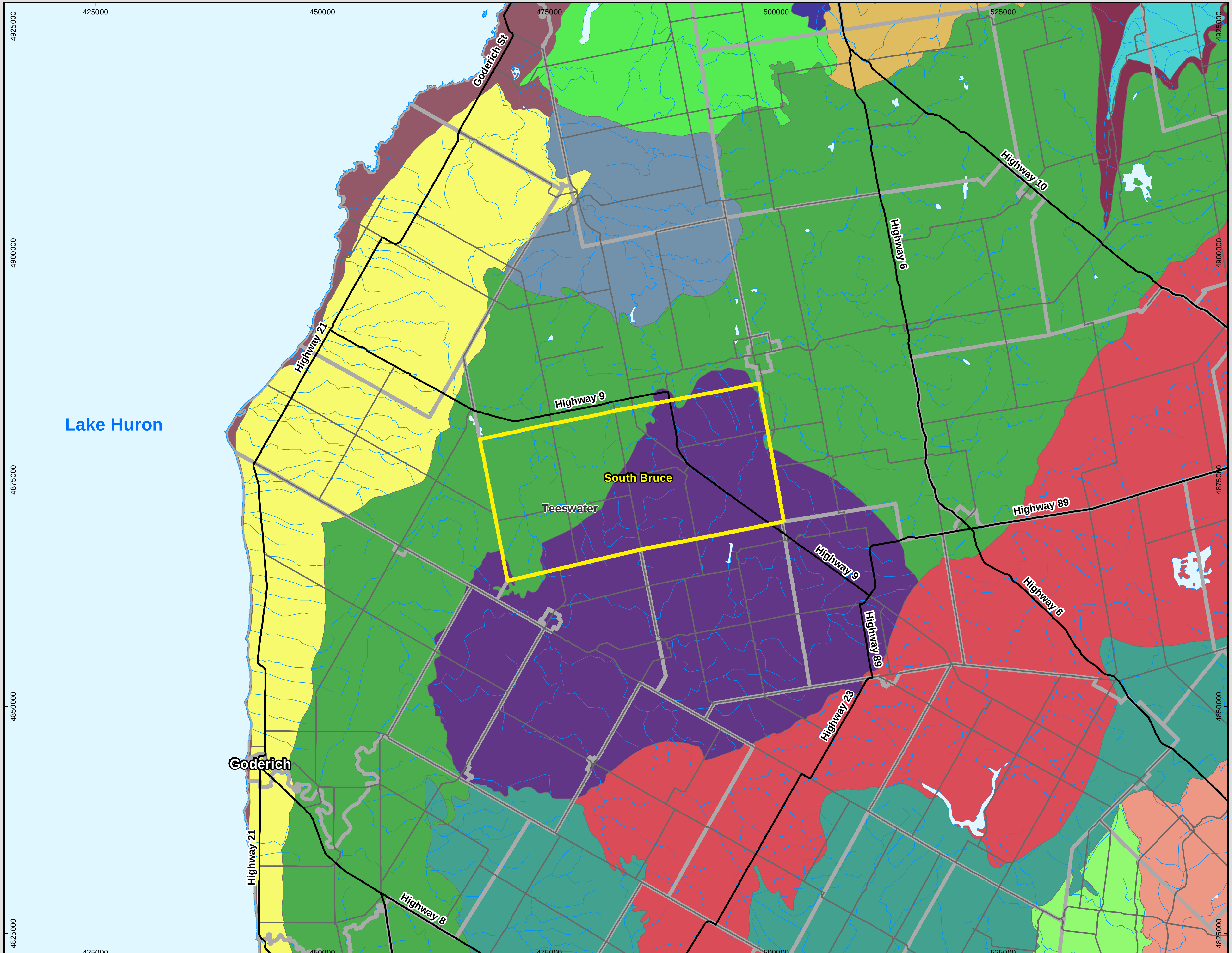


**Legend**

- Municipality of South Bruce
- Highway
- Secondary Highway
- Municipal Division
- Waterbody

**Physiographic Regions**

- Niagara Escarpment
- Beaver Valley
- Bighead Valley
- Horseshoe Moraines
- Dundalk Till Plain
- Stratford Till Plain
- Guelph Drumlin Field
- Teeswater Drumlin Field
- Arran Drumlin Field
- Oxford Till Plain
- Saugeen Clay Plain
- Huron Slope
- Huron Fringe
- Bruce Peninsula


Physiography: Chapman, L.J. and Putnam, D.F. 2007. Physiography of Southern Ontario; Ontario Geological Survey
Basemapping from Ontario Ministry of Natural Resources
Projection: Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 17

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| Approved | RF | 15 Jun 2012 |

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Kilometers
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NWMO Desktop Level Initial Screening

**Physiographic Regions of the Municipality of South Bruce and the Surrounding Area**

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**Figure 2.3**

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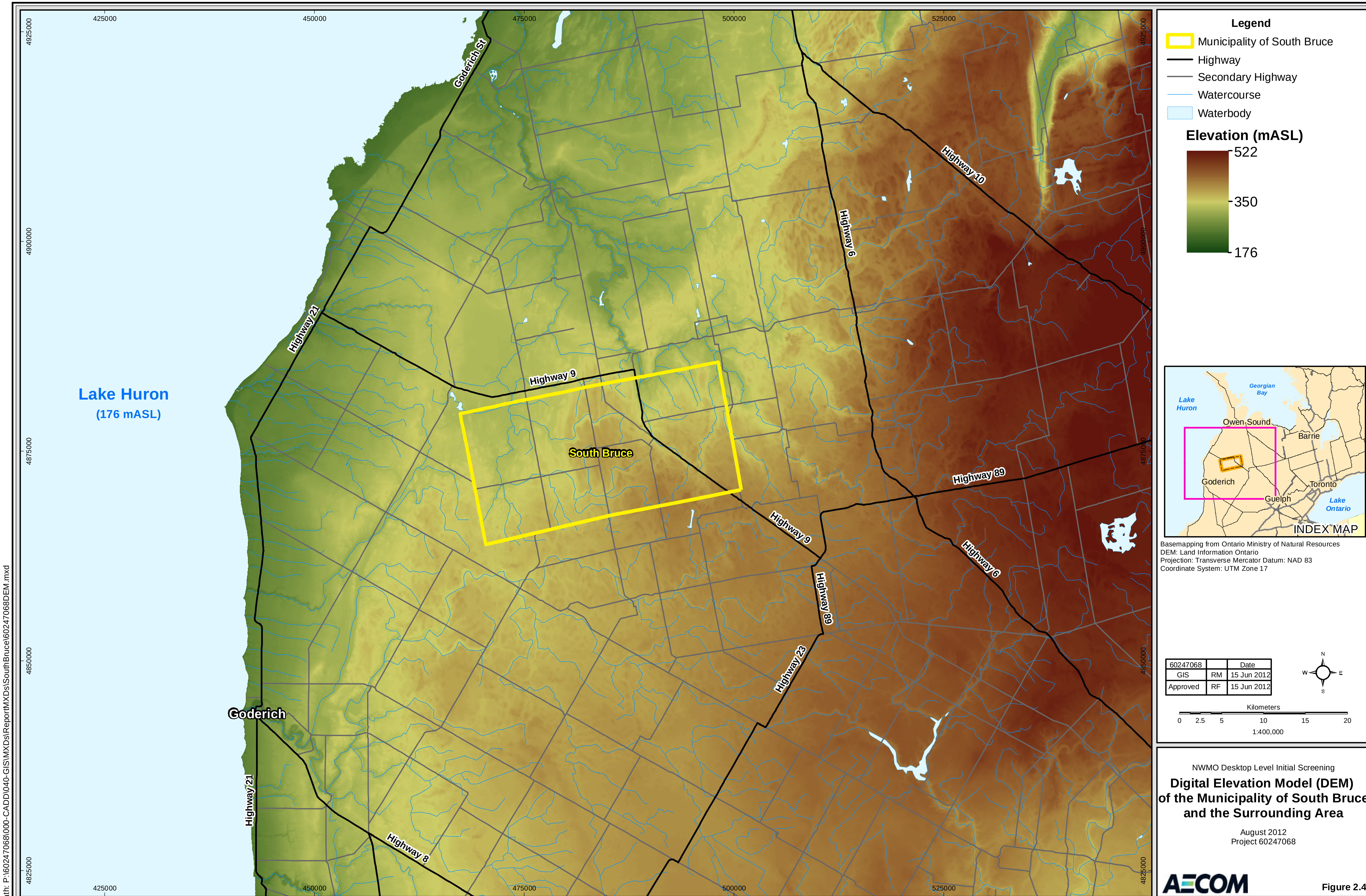


NWMO Desktop Level Initial Screening

**Digital Elevation Model (DEM) of the Municipality of South Bruce and the Surrounding Area**

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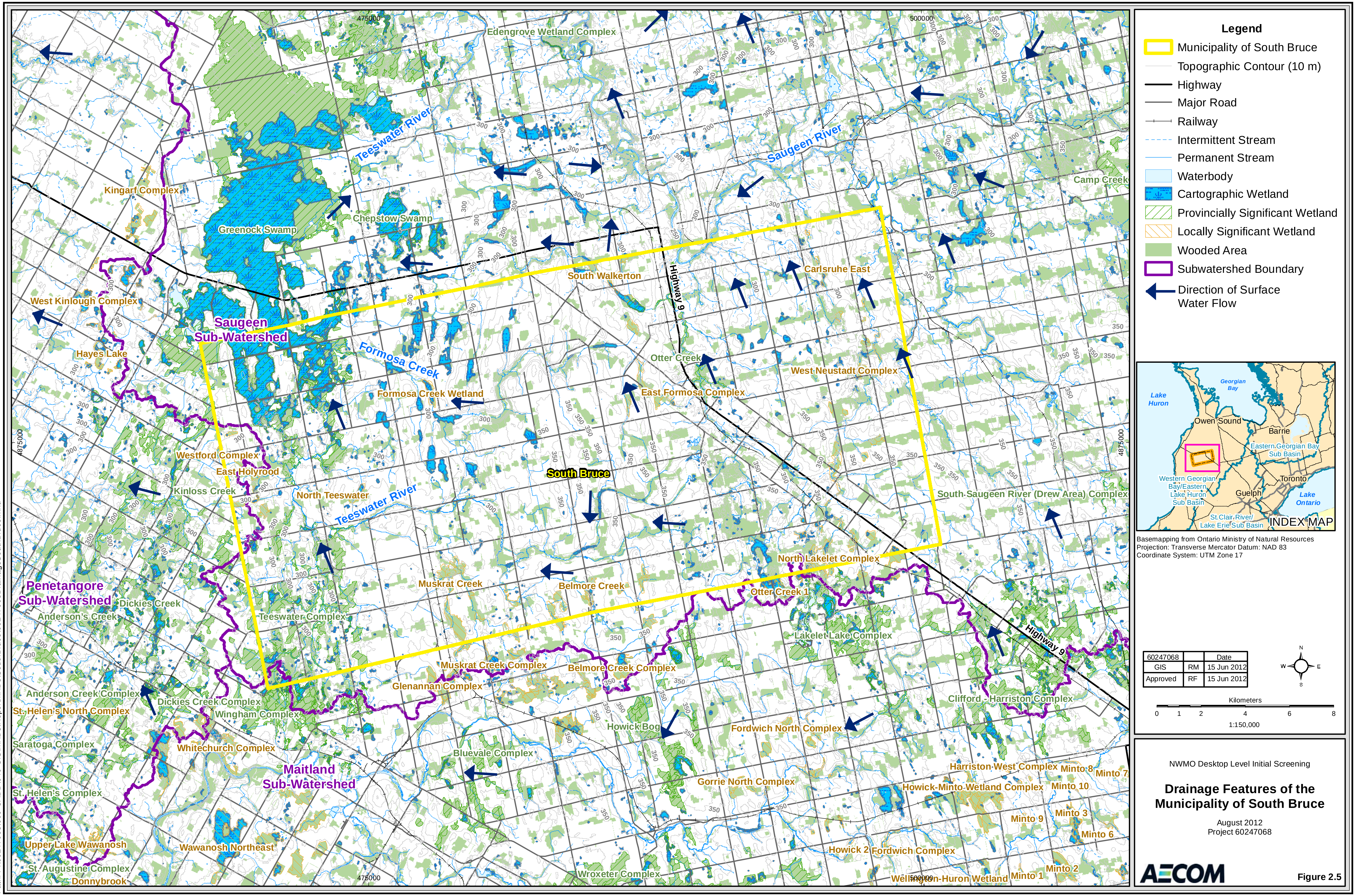
Project 60247068

AECOM

Figure 2.4




NWMO Desktop Level Initial Screening

**Drainage Features of the Municipality of South Bruce**

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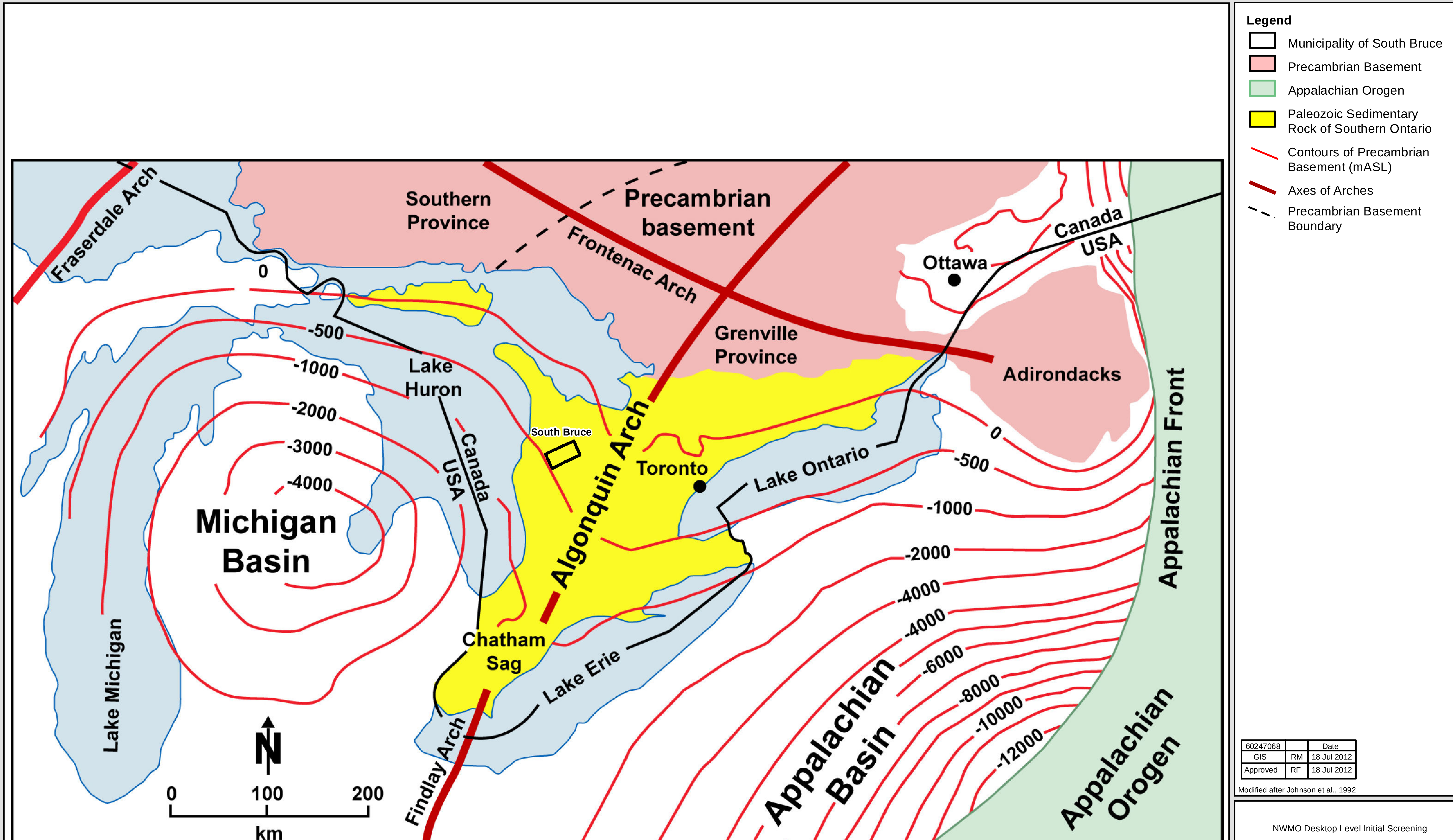
Figure 2.5

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Modified after Johnson et al., 1992

NWMO Desktop Level Initial Screening

**Geological Features of Southern Ontario**

August 2012
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Figure 3.1

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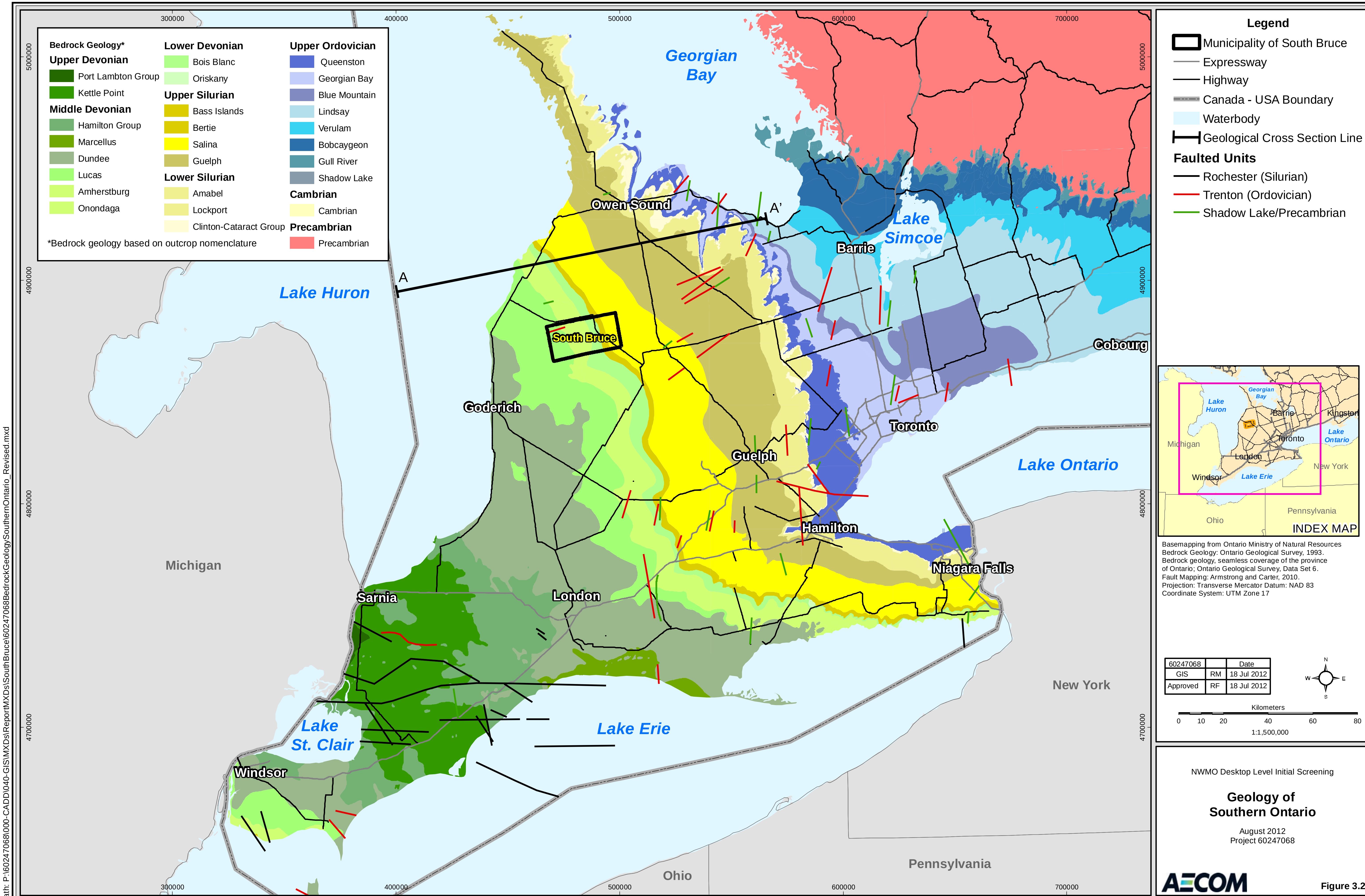
Bedrock Geology*
Upper Devonian
Port Lambton Group
Kettle Point
Middle Devonian
Hamilton Group
Marcellus
Dundee
Lucas
Amherstburg
Onondaga
Lower Devonian
Bois Blanc
Oriskany
Upper Silurian
Bass Islands
Bertie
Salina
Guelph
Lower Silurian
Amabel
Lockport
Clinton-Cataract Group
Upper Ordovician
Queenston
Georgian Bay
Blue Mountain
Lindsay
Verulam
Bobcaygeon
Gull River
Shadow Lake
Cambrian
Cambrian
Precambrian
Precambrian
*Bedrock geology based on outcrop nomenclature
Legend
Municipality of South Bruce
Expressway
Highway
Canada - USA Boundary
Waterbody
Geological Cross Section Line
Faulted Units
Rochester (Silurian)
Trenton (Ordovician)
Shadow Lake/Precambrian
Georgian Bay
Lake Huron
Lake Simcoe
Lake Ontario
Lake Erie
Lake St. Clair
Owen Sound
Barrie
South Bruce
Goderich
Guelph
Toronto
Hamilton
Niagara Falls
Cobourg
London
Sarnia
Windsor
Michigan
New York
Pennsylvania
Ohio
A
A'
300000
400000
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600000
700000
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4900000
4800000
4700000
INDEX MAP
Basemapping from Ontario Ministry of Natural Resources
Bedrock Geology: Ontario Geological Survey, 1993.
Bedrock geology, seamless coverage of the province of Ontario; Ontario Geological Survey, Data Set 6.
Fault Mapping: Armstrong and Carter, 2010.
Projection: Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 17
60247068 | Date
GIS | RM | 18 Jul 2012
Approved | RF | 18 Jul 2012
Kilometers
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NWMO Desktop Level Initial Screening
Geology of Southern Ontario
August 2012
Project 60247068
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Figure 3.2
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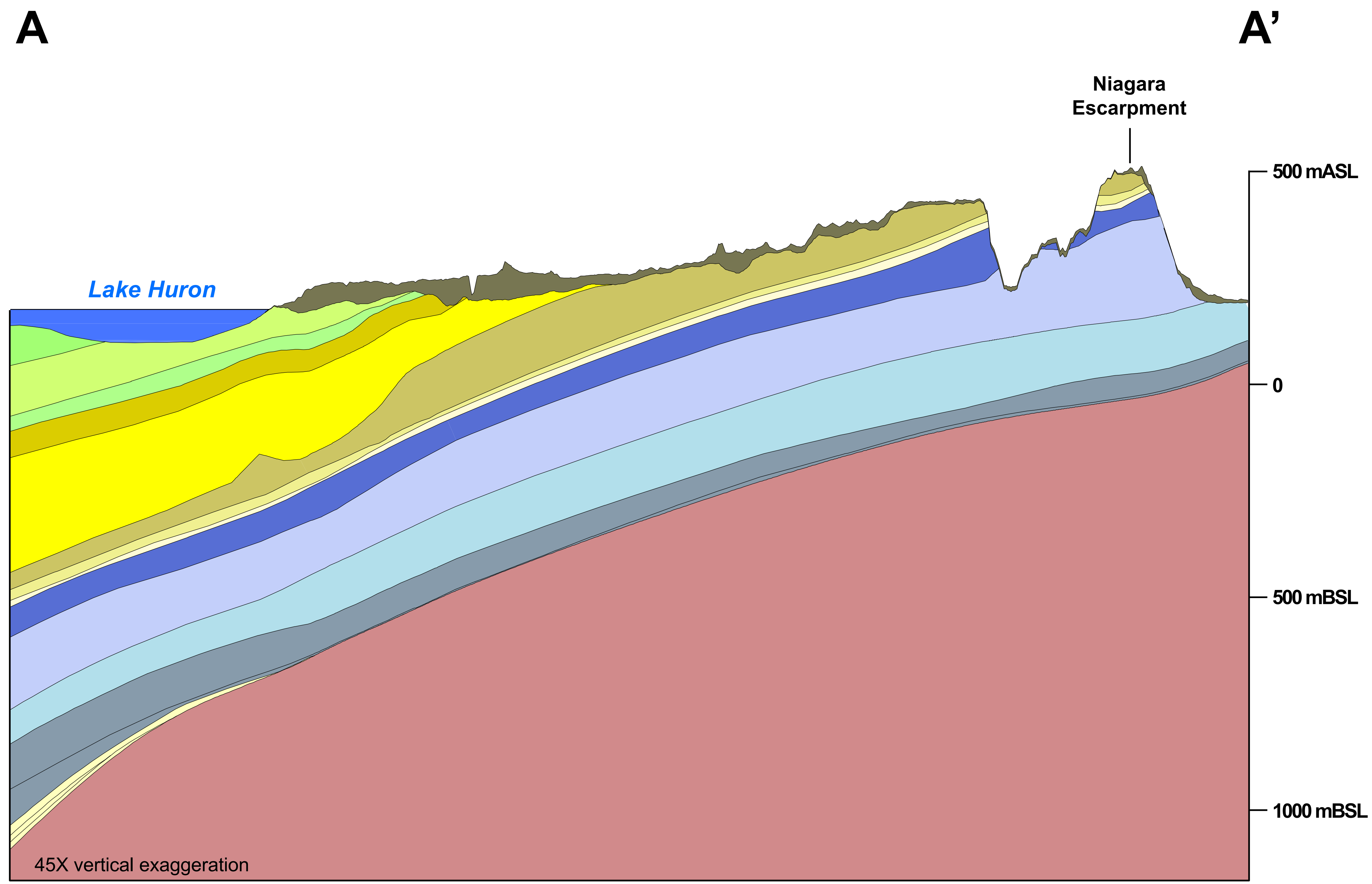


## Legend

- Overburden

**Bedrock Geology**

**Middle Devonian**
- Lucas
- Amherstburg

**Lower Devonian**
- Bois Blanc

**Upper Silurian**
- Bass Islands
- Salina
- Guelph

**Lower Silurian**
- Lockport (Goat Island, Gasport)
- Clinton-Cataract Group (Fossil Hill, Cabit 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

modified after NWMO (2011)

| 60247068 | | Date |
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| | SB | 08 Aug 2012 |
| Approved | RF | 08 Aug 2012 |



NWMO Desktop Level Initial Screening

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

August 2012
Project 60247068

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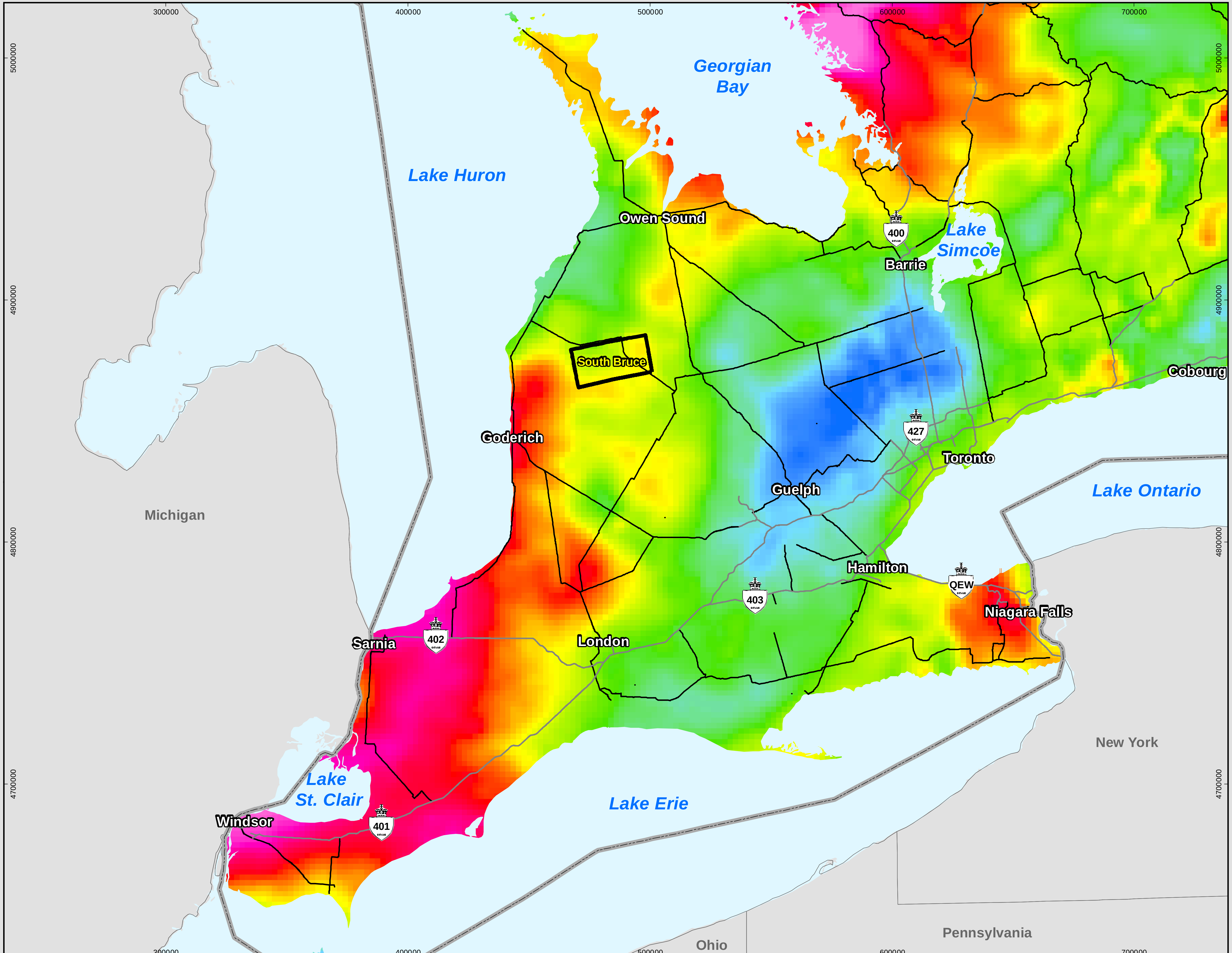
**Figure 3.3**




**Legend**

- Municipality of South Bruce
- Expressway
- Highway
- Canada - USA Boundary
- Waterbody

Gravity Anomaly (mGal)

-2.84

-71.46


Basemapping from Ontario Ministry of Natural Resources
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
Coordinate System: UTM Zone 17

| 60247068 | | Date |
|---|---|---|
| GIS | RM | 18 Jul 2012 |
| Approved | RF | 18 Jul 2012 |

N W E S

Kilometers
0 10 20 40 60 80
1:1,500,000

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**Gravity Map of Southern Ontario**

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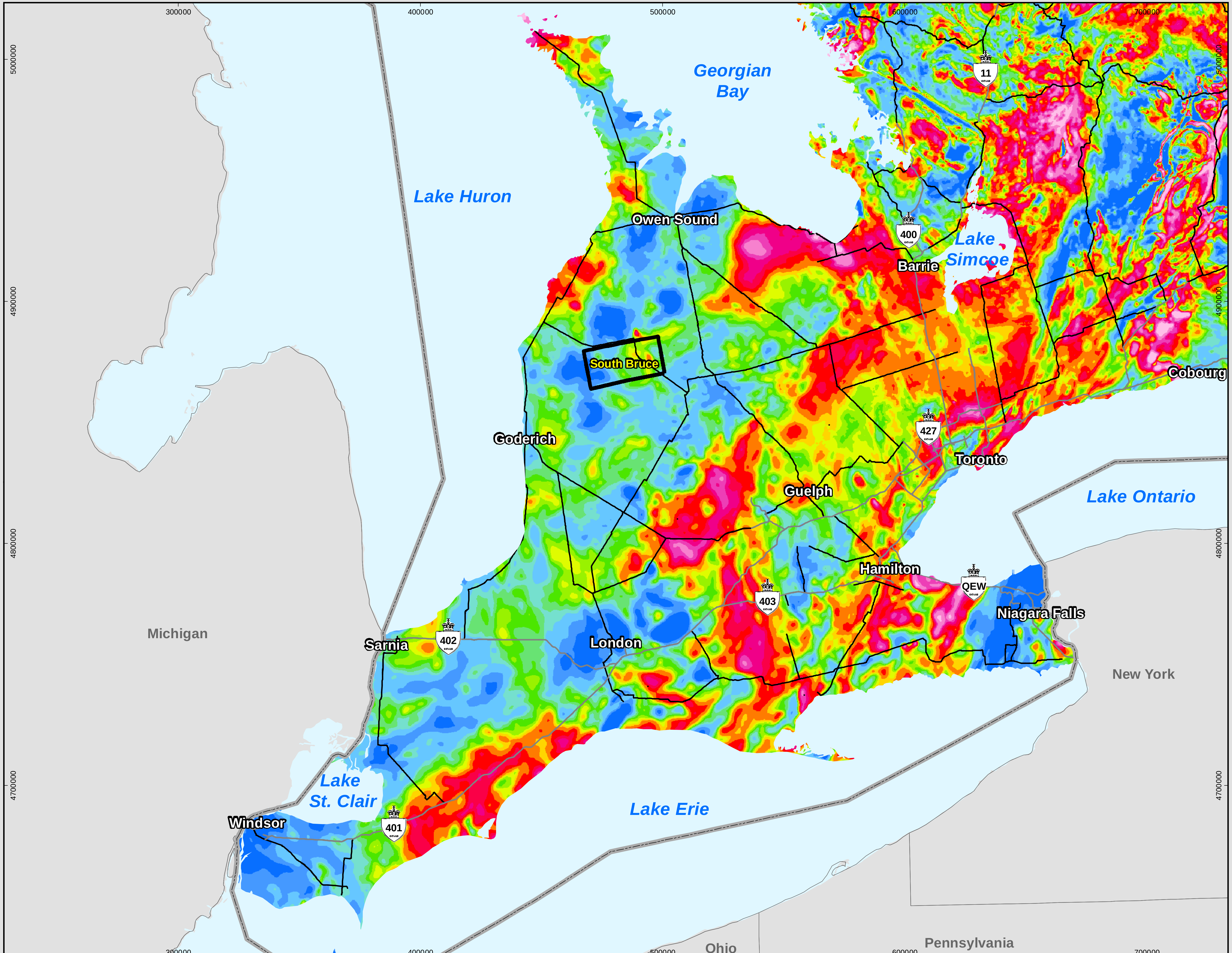
**Figure 3.4**

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068GravityAnomalies.mxd




**Legend**

- Municipality of South Bruce
- Expressway
- Highway
- Canada - USA Boundary
- Waterbody

Residual Total Magnetic Field (nT)

1235

250

-543


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

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N W E S

Kilometers

0 10 20 40 60 80

1:1,500,000

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**Residual Total Magnetic Field of Southern Ontario**

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Project 60247068

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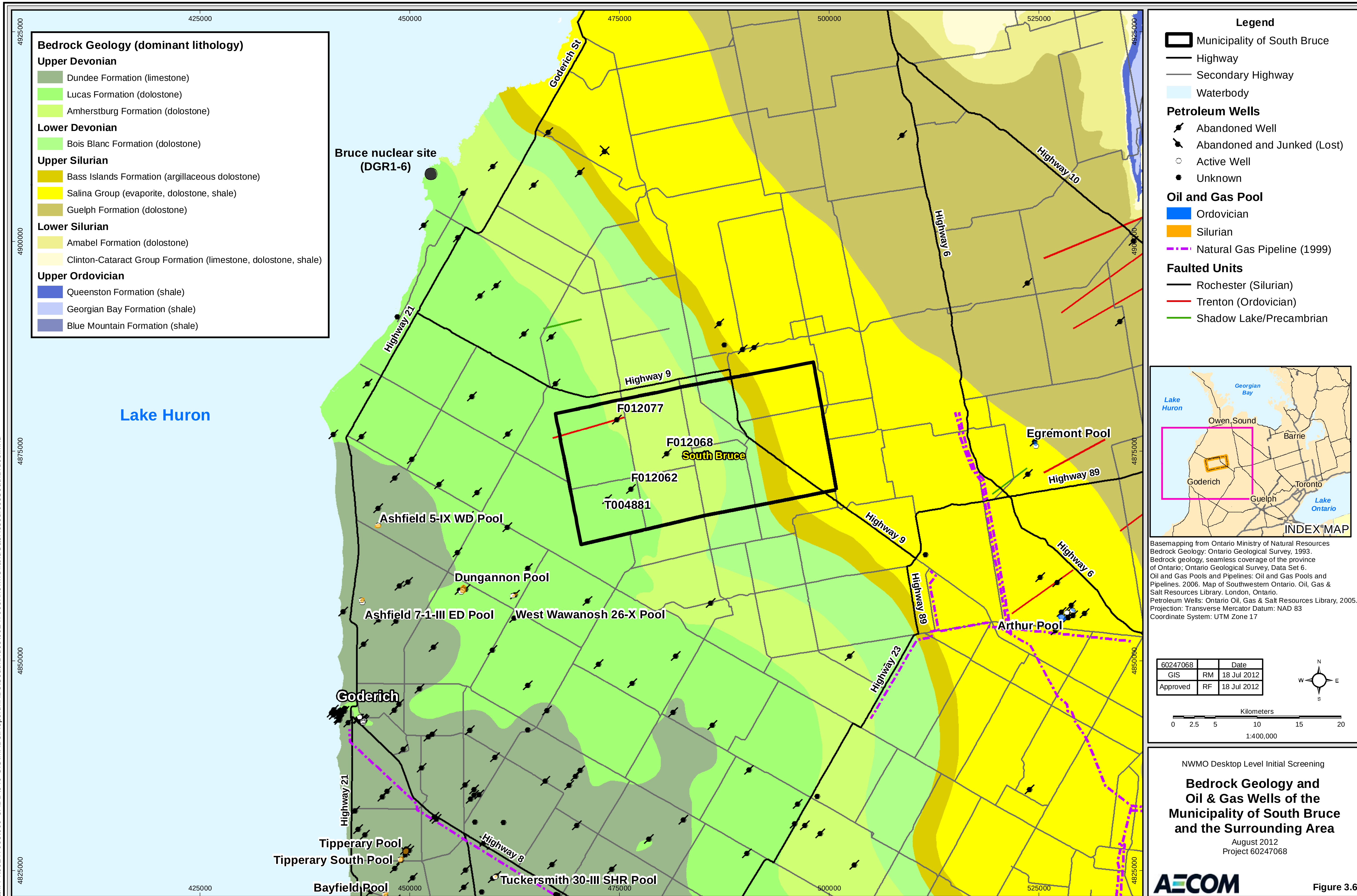
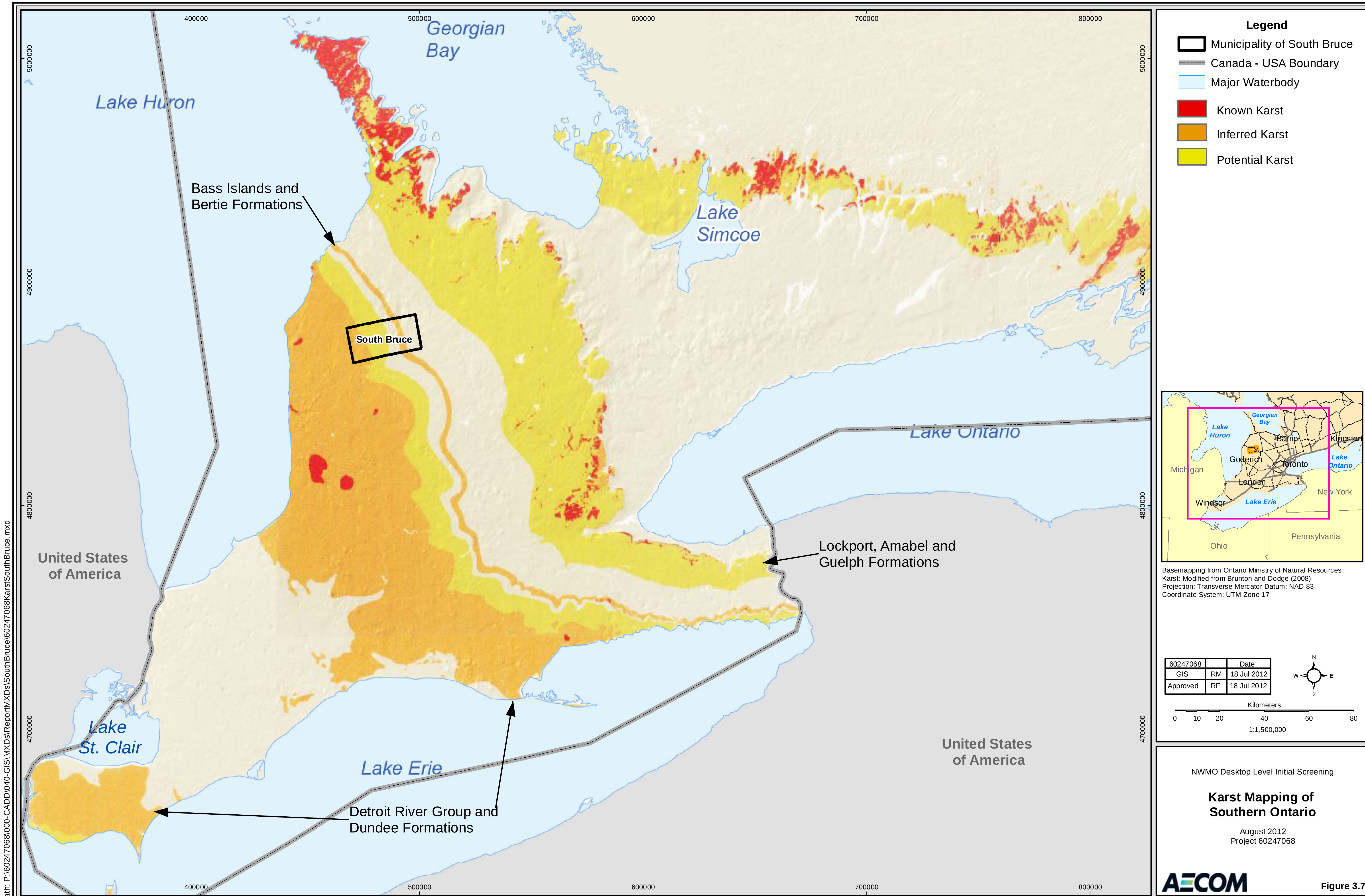
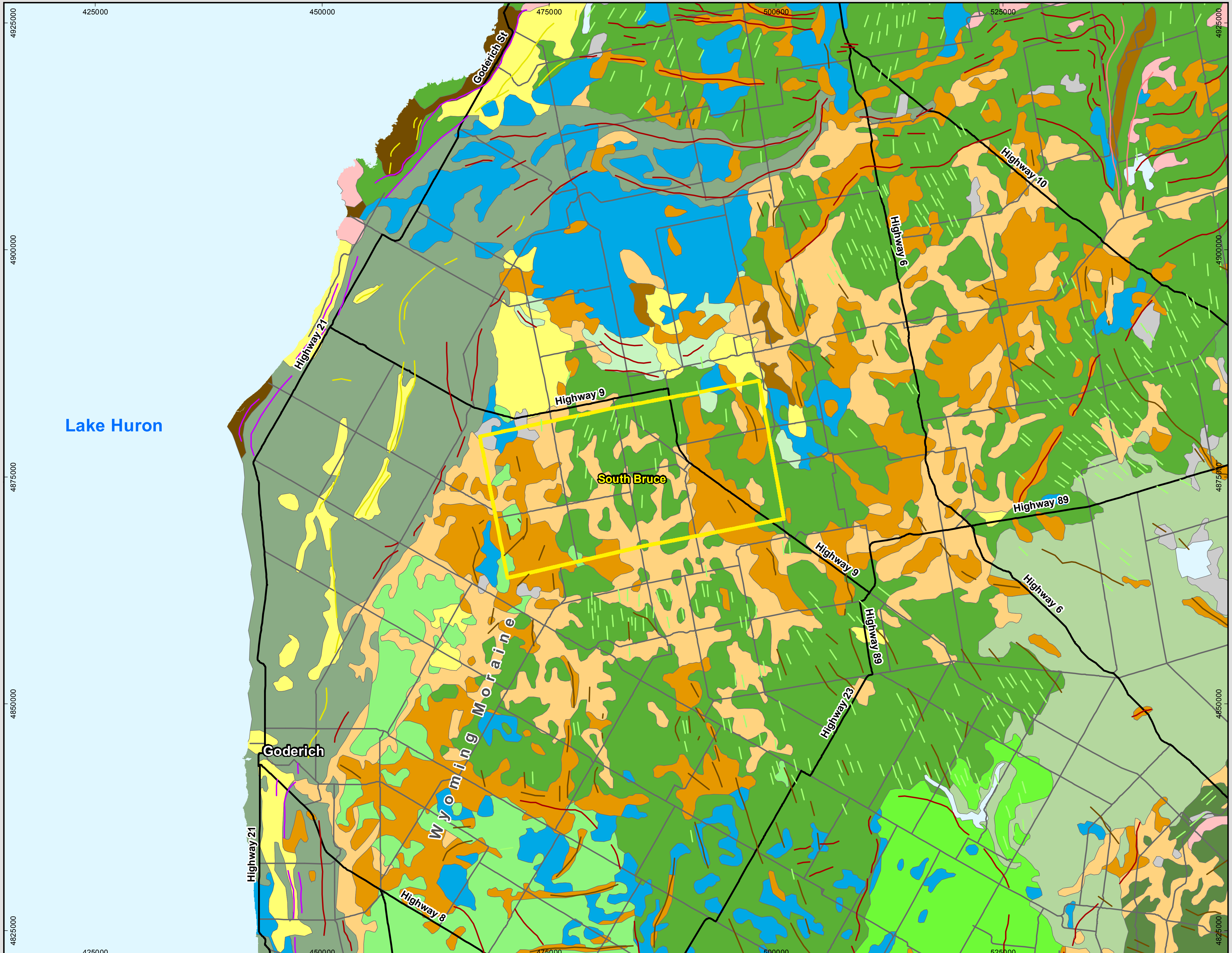
**Figure 3.5**

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068ResidualTotalMagneticField.mxd




Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068KnownOilandGasResourcesSouthBruce.mxd


Georgian Bay
Lake Huron
Lake Simcoe
Lake Ontario
Lake Erie
Lake St. Clair
United States of America
United States of America
South Bruce
Bass Islands and Bertie Formations
Lockport, Amabel and Guelph Formations
Detroit River Group and Dundee Formations
400000
500000
600000
700000
800000
5000000
4900000
4800000
4700000
Legend
Municipality of South Bruce
Canada - USA Boundary
Major Waterbody
Known Karst
Inferred Karst
Potential Karst
Georgian Bay
Lake Huron
Barrie
Kingston
Goderich
Toronto
Lake Ontario
Michigan
London
New York
Windsor
Lake Erie
Ohio
Pennsylvania
Basemapping from Ontario Ministry of Natural Resources
Karst: Modified from Brunton and Dodge (2008)
Projection: Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 17
60247068 | | Date
GIS | RM | 18 Jul 2012
Approved | RF | 18 Jul 2012
N
W
E
S
Kilometers
0 10 20 40 60 80
1:1,500,000
NWMO Desktop Level Initial Screening
Karst Mapping of Southern Ontario
August 2012
Project 60247068
AECOM
Figure 3.7
Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068KarstSouthBruce.mxd

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## Quaternary Geology of the Municipality of South Bruce and the Surrounding Area

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Figure 3.8

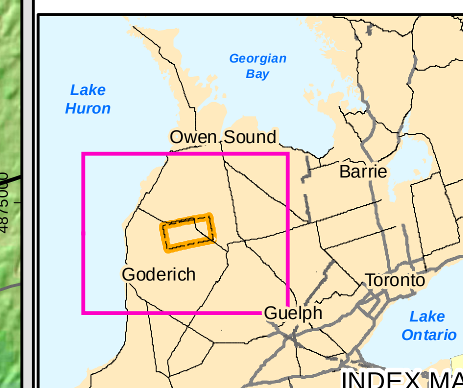
Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068QuaternaryGeologySouthBruce.mxd


**Legend**

- Municipality of South Bruce
- Highway
- Secondary Highway
- Waterbody

**Overburden Thickness (m)**

120
60
0




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

| 60247068 | | Date |
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| GIS | RM | 18 Jul 2012 |
| Approved | RF | 18 Jul 2012 |

N W E S

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

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## Overburden Thickness in the Municipality of South Bruce and the Surrounding Area

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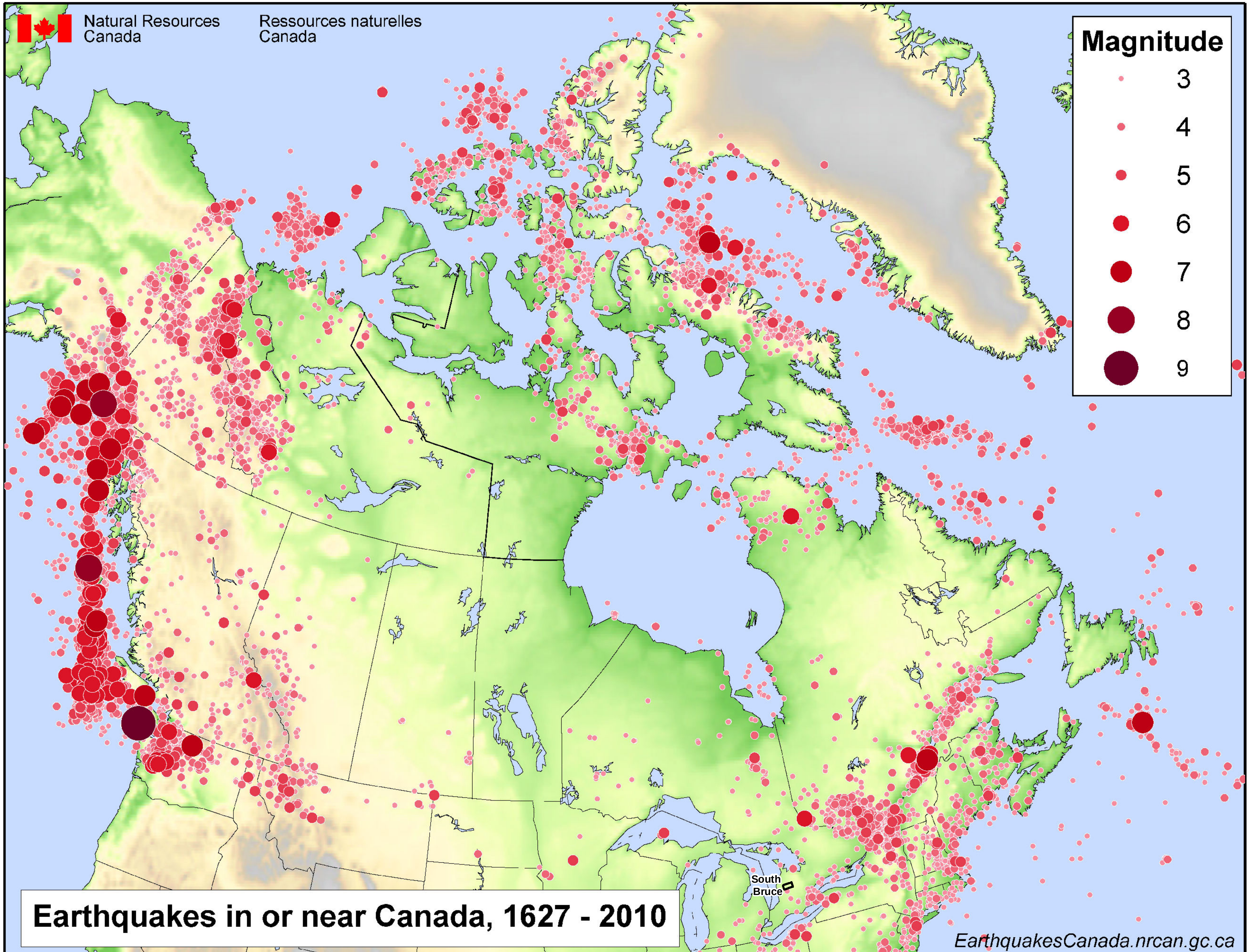
Figure 3.9

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068OverburdenThicknessSouthBruce.mxd




**Legend**

Municipality of South Bruce

| 60247068 | | Date |
|---|---|---|
| GIS | RM | 18 Jul 2012 |
| Approved | RF | 18 Jul 2012 |

Basemapping from Ontario Ministry of Natural Resources
Seismic: NRCAN. Earthquake Map of Canada 1627 -2010
Projection: NA

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**Earthquake Map of Canada**
**1627 - 2010**

August 2012
Project 60247068

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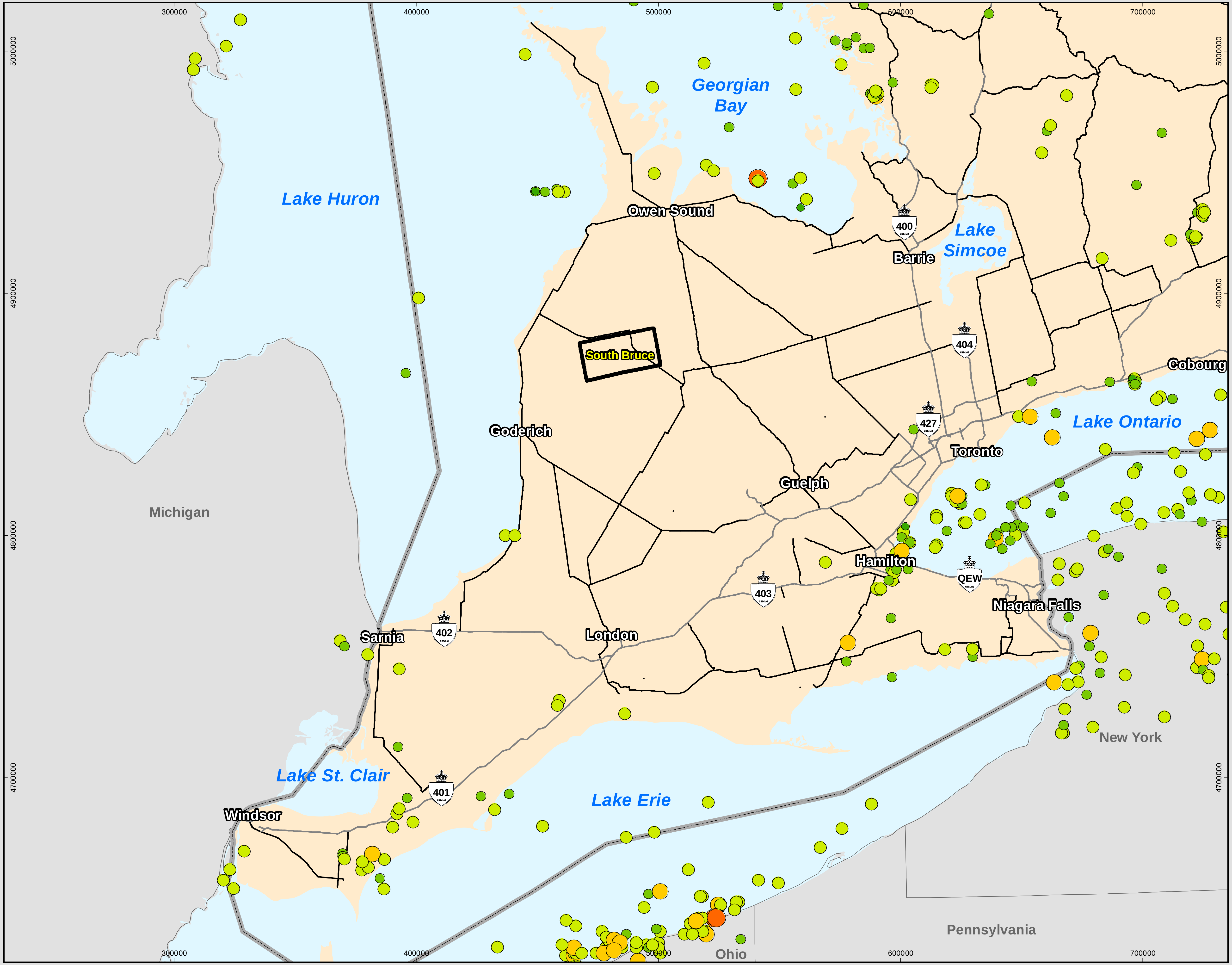
**Figure 3.10**

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068HistoricalEarthquakesCanada.mxd





Basemapping from Ontario Ministry of Natural Resources
Seismic: Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin) Feb. 2012.
Projection: Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 17

| 60247068 | | Date |
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| GIS | RM | 18 Jul 2012 |
| Approved | RF | 18 Jul 2012 |

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**Earthquake Map of Southern Ontario 1985 - 2012**

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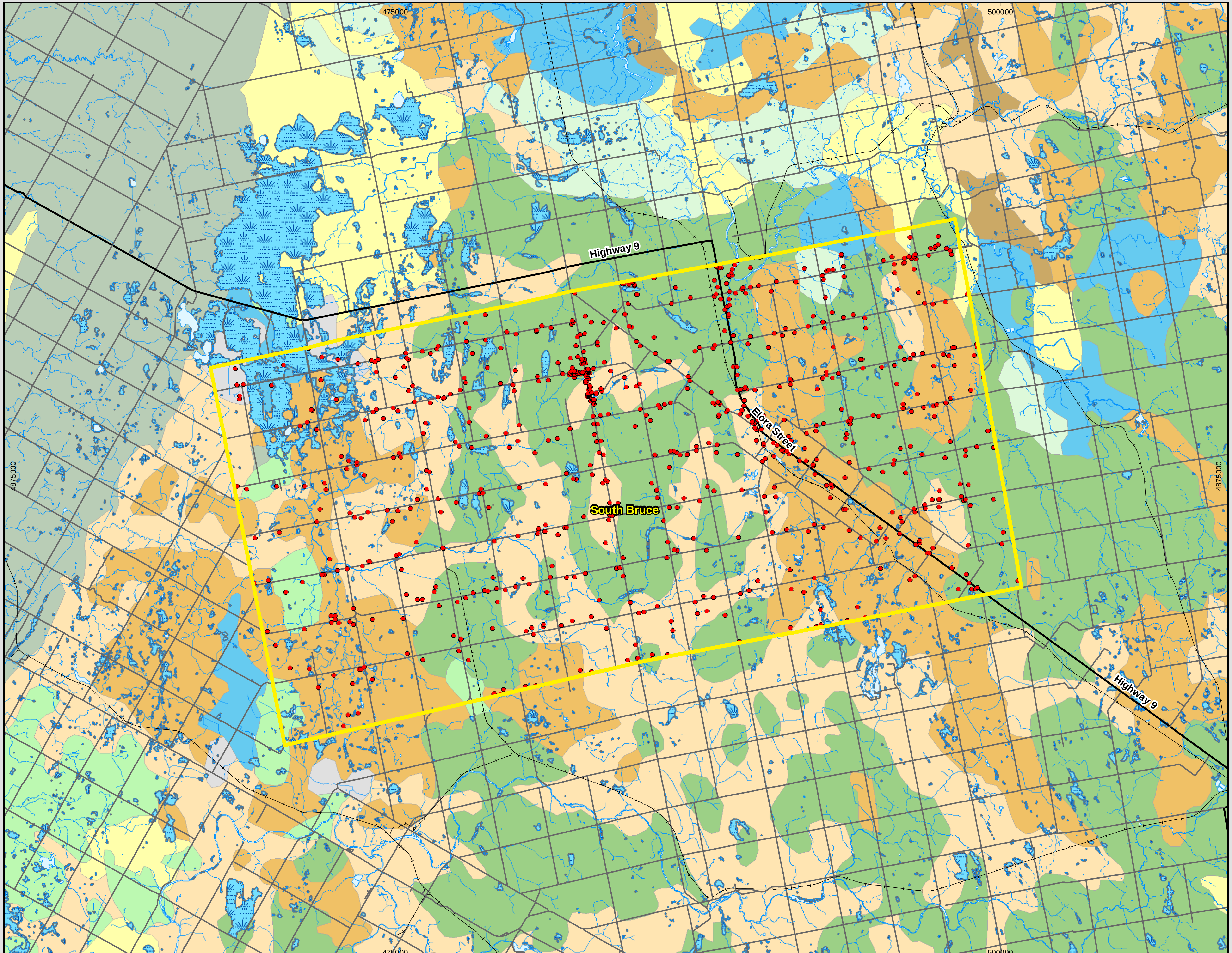
Figure 3.11

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068HistoricalEarthquakesSW_Ont.mxd




**Legend**

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

**Quaternary Overburden**

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


Basemapping from Ontario Ministry of Natural Resources
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

| 60247068 | | Date |
|---|---|---|
| GIS | RM | 15 Jun 2012 |
| Approved | RF | 15 Jun 2012 |

N / E / S / W

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

NWMO Desktop Level Initial Screening

## Water Well Records of the Municipality of South Bruce

August 2012
Project 60247068

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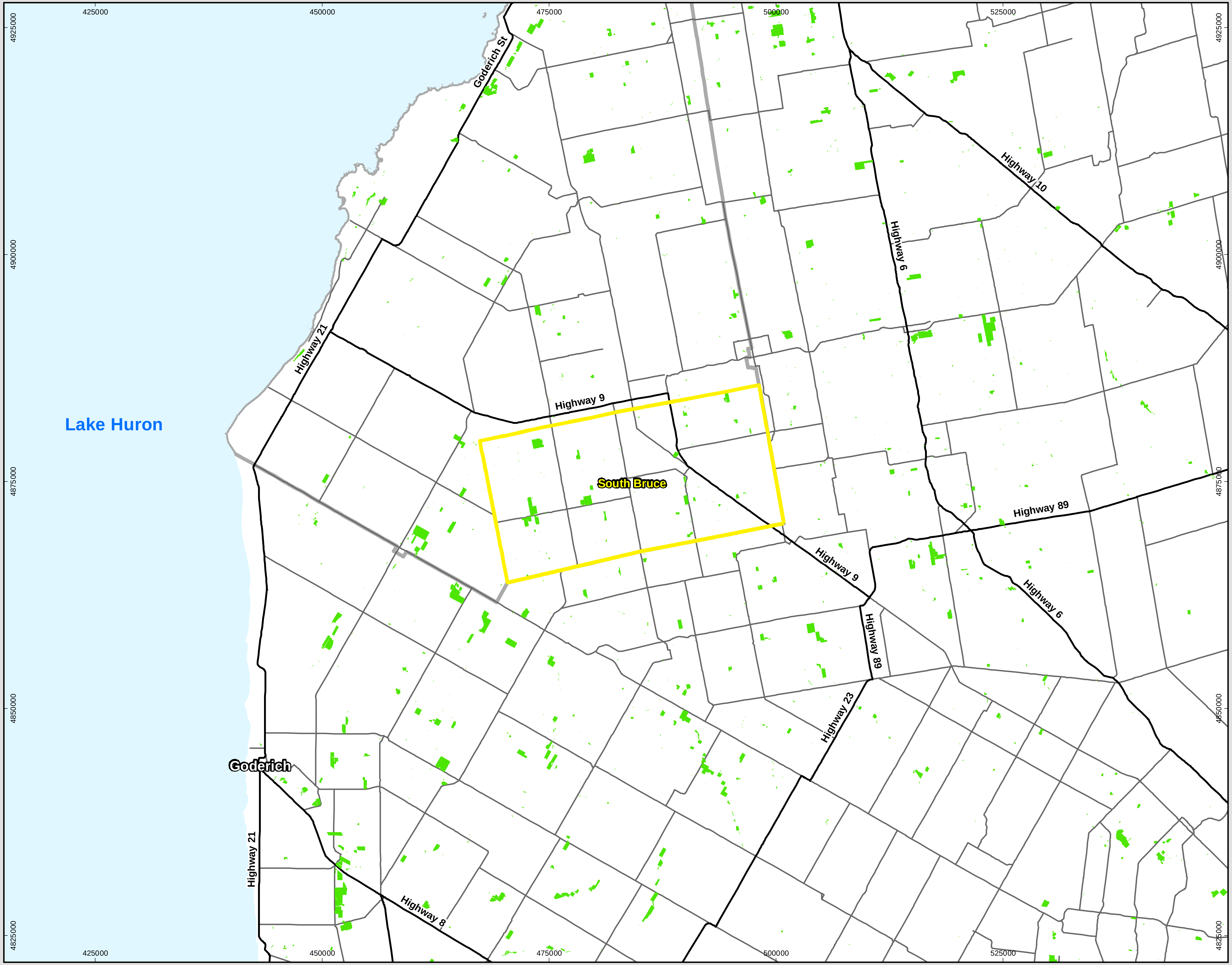
Figure 4.1

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068WaterWellsSouthBruce.mxd

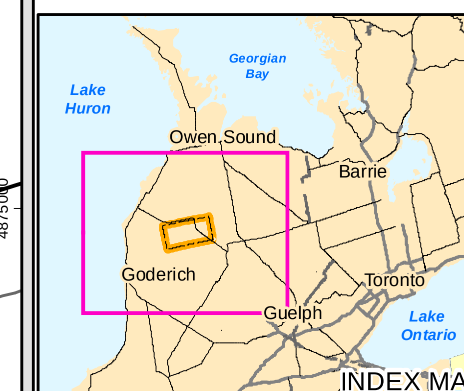



**Legend**

- Municipality of South Bruce
- Highway
- Secondary Highway
- Waterbody
- Bruce County

Sand, Gravel & Limestone Extraction

- Pit




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

| 60247068 | | Date |
|---|---|---|
| GIS | RM | 15 Jun 2012 |
| Approved | RF | 15 Jun 2012 |

N W E S

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

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**Non-metallic Bedrock Resources of the Municipality of South Bruce and the Surrounding Area**

August 2012
Project 60247068

AECOM

**Figure 5.1**

Path: P:\60247068\000-CADD\040-GIS\MXDs\ReportMXDs\SouthBruce\60247068EconomicBedrockResources.mxd