NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel

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

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Municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores

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EXECUTIVE SUMMARY

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of each of the Communities for safely hosting a deep geological repository (Step 3). This request followed successful completion of initial screenings conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessments of the Communities are reported in integrated preliminary assessment reports (NWMO, 2014a: 2014b: 2014c: 2014d: 2014e).

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The identification of potentially suitable areas focused on the areas within the boundaries of the Communities. Areas beyond the municipal boundaries of the five communities were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Communities and surrounding areas, referred to in this report as the "Area of the Five Communities".

The geoscientific preliminary assessment was conducted using available geoscientific information and geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. These include: geology; structural geology; surface conditions; protected areas; and the potential for economically exploitable natural resources. The geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Assembly and detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology and overburden deposits (surficial deposits);
- Interpretation of available geophysical surveys;
- Interpretation of available borehole geophysical data and selected 2-D seismic reflection surveys to provide information on the geometry and potential structural features of the subsurface bedrock geology;
- Terrain analysis studies to help assess overburden (surficial deposits) type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones;
- Assessment of land use and protected areas including parks, conservation reserves, heritage sites and source water protection areas; and
- The identification and evaluation of general potentially suitable areas based on systematic assessment of key geoscientific characteristics and constraints that can be realistically assessed at this stage of the assessment.

The geoscientific desktop preliminary assessment showed that the geological setting in the Area of the Five Communities has a number of favourable characteristics for hosting a deep geological

repository for used nuclear fuel. However, the assessment revealed that there are areas that have more potential than others to satisfy NWMO's geoscientific site evaluation factors. The assessment identified the Ordovician Cobourg Formation (limestone) as the preferred host rock formation for a used nuclear fuel deep geological repository. It was determined that a minimum depth of 500 metres below ground surface (mBGS) would be preferred in order to maintain the integrity of a repository within the Cobourg Formation. Based on the key geoscientific characteristics and constraints considered in the assessment, it was concluded that:

- The Municipality of Brockton, the Municipality of South Bruce and the Township of Huron-Kinloss appear to contain large areas that have the potential to meet the geoscientific site evaluation factors outlined in the site selection process document.

- The Municipality of Arran-Elderslie does not contain sufficient land areas that have the potential to meet the geoscientific site evaluation factors outlined in the site selection process document.

- The Town of Saugeen Shores has very limited potential to contain areas that would meet the geoscientific site evaluation factors outlined in the site selection process document.

While the the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss appear to contain large areas with favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The assumption of transferability of geoscientific characteristics and understanding based on regional data and data from the Bruce nuclear site to the communities of Brockton, South Bruce and Huron-Kinloss would need to be confirmed. The potential for hydrocarbon resources and faults within the sedimentary sequence beneath the three communities would also need to be further assessed.

Should the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss be selected by the NWMO to advance to Phase 2 study, and remain interested in continuing with the site selection process, several years of progressively more detailed studies would be required to confirm and demonstrate whether they contain sites that can safely contain and isolate used nuclear fuel. This may include the acquisition and interpretation of higher resolution geophysical surveys, detailed geological mapping, and the drilling of deep boreholes.

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Processing and Interpretation of Geophysical Data, Municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores (PGW, 2014)

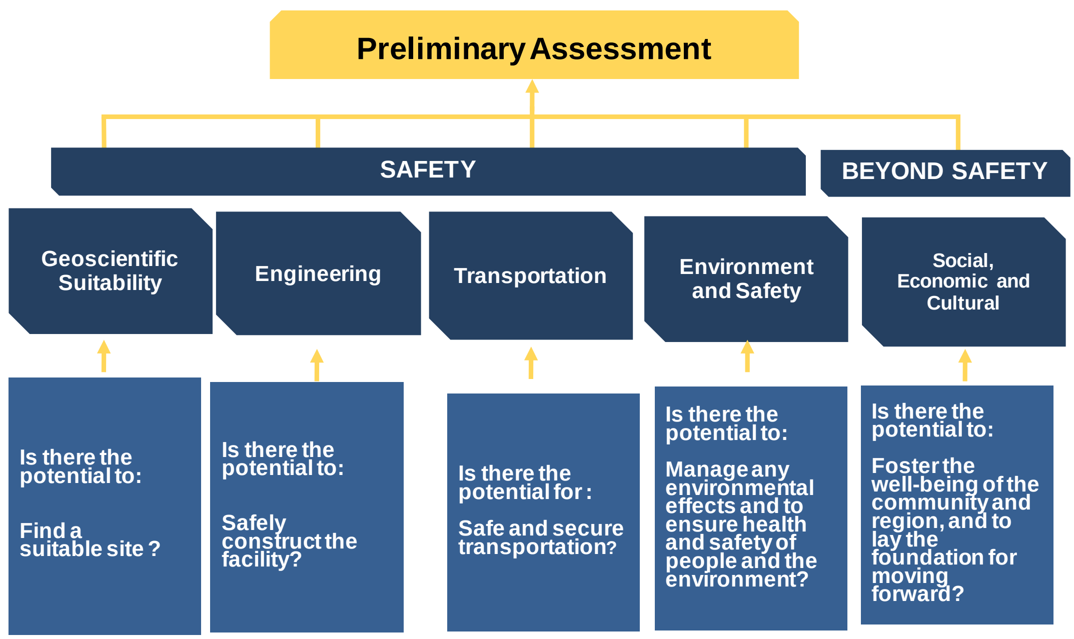
Processing and Interpretation of Borehole Geophysical Log and 2D Seismic Data, Municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores (Geofirma Engineering Ltd., 2014)

1 INTRODUCTION

1.1 Background

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of each of the Communities for safely hosting a deep geological repository (Step 3). This request followed the successful completion of initial screenings conducted during Step 2 of the site selection process (AECOM, 2012a; 2012b; 2012c; 2012d; 2012e).

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments as illustrated in the diagram below. The five components of the preliminary assessment address geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. A brief description of the project, the assessment approach and the findings of the preliminary assessments are documented in integrated preliminary assessment reports (NWMO, 2014a: 2014b; 2014c; 2014d; 2014e).



The objective of the geoscientific preliminary assessment is to assess whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

The preliminary assessment is conducted in two phases:

- ***Phase 1 - Desktop Study.*** For all communities electing to be the focus of a preliminary assessment. This phase involves desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment.

- ***Phase 2 - Preliminary Field Investigations.*** For a subset of communities selected by the NWMO, to further assess potential suitability. This phase involves preliminary field investigations that include high resolution geophysical surveys, geological mapping and the drilling of deep boreholes.

The subset of communities considered for Phase 2 of the preliminary assessment will be selected based on the findings of the overall desktop preliminary assessment considering both technical and community well-being factors presented in the above diagram.

This report presents the results of a geoscientific desktop preliminary assessment of potential suitability (Phase 1), conducted by Geofirma Engineering Ltd.

1.2 Geoscientific Desktop Preliminary Assessment Approach

The objective of the Phase 1 geoscientific desktop preliminary assessment is to assess whether the Communities contain general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in the site selection process document (NWMO, 2010). The location and extent of identified potentially suitable areas would be confirmed during subsequent site evaluation stages.

The geoscientific desktop preliminary assessment built on the work previously conducted for the initial screenings (AECOM Canada Ltd., 2012a; 2012b; 2012c; 2012d; 2012e). The identification of potentially suitable areas focused on the area within the boundaries of the Communities (Municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores). Areas beyond the municipal boundaries of the five communities were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Five Communities and surrounding areas, referred to in this report as the Area of the Five Communities (Figure 1.1). The Phase 1 Geoscientific Desktop Preliminary Assessment included the following review and interpretation activities:

- Assembly and detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology and overburden deposits (surficial deposits);
- Interpretation of available geophysical surveys;
- Interpretation of available borehole geophysical data and selected 2-D seismic reflection surveys to provide information on the geometry and potential structural features of the subsurface bedrock geology;
- Terrain analysis studies to help assess overburden (surficial deposits) type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones;
- Assessment of land use and protected areas including parks, conservation reserves, heritage sites and source water protection areas; and
- The identification and evaluation of general potentially suitable areas based on systematic assessment of key geoscientific characteristics and constraints that can be realistically assessed at this stage of the assessment.

The details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2014); geophysical interpretation (PGW, 2014); and borehole geophysical log and 2D seismic data interpretation (Geofirma Engineering Ltd., 2014). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

As discussed in the NWMO site selection process, the suitability of potential sites will be evaluated in a staged manner through a series of progressively more detailed scientific and technical assessments using a number of geoscientific site evaluation factors, organized under five safety functions that a site would need to ultimately satisfy in order to be considered suitable (NWMO, 2010):

- ***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 caused by human activities and natural events?

- ***Long-term resilience to future geological processes and climate change:*** Is the rock formation at the siting area 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 geological and climate change process such as earthquakes and glacial cycles?

- ***Safe construction, operation and closure of the repository:*** Are conditions at the site suitable for the safe construction, operation and closure of the repository?

- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance through future exploration or mining?

- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

The list of site evaluation factors under each safety function is provided in Appendix A.

The assessment was conducted in two steps. The first step assessed the potential to find general potentially suitable areas within the Communities using key geoscientific characteristics that can realistically be assessed at this stage of the assessment based on available information (Section 7.2). The second step assessed whether identified potentially suitable areas have the potential to ultimately meet all of the safety functions outlined above (Section 7.3).

1.4 Available Geoscientific Information

Geoscientific information for the Area of the Five Communities was obtained from many data sources, including maps, reports, databases and technical papers, as well as data assembly and interpretative assessment reports of the these basic data. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B. Figure 1.2 shows the available geological map coverage and geophysical data surveys for the Area of the Five Communities.

Key databases/datasets of geoscientific information used in this report include the Petroleum Wells Subsurface Database from the Oil, Gas, and Salt Resources Library (OGSRL) (2013), Ontario

Geological Survey (OGS) digital bedrock geology of Ontario seamless coverage (Armstrong and Dodge, 2007), digital surficial geology of Ontario seamless coverage (OGS, 2010), OGS Paleozoic unit fault compilation from Armstrong and Carter (2010), and OGS bedrock topography and overburden thickness mapping of southern Ontario (Gao et al., 2006).

Key and noteworthy data assembly and interpretative reports reviewed include: the geotechnical feasibility assessment of the Bruce nuclear site for construction of a deep geological repository (DGR) for low and intermediate level waste (Golder Associates Ltd., 2003a); the geoscientific review of the suitability of the sedimentary sequence in southern Ontario to host a DGR for used nuclear fuel (Mazurek, 2004); and the geoscientific assessment of the Bruce nuclear site for hosting a DGR for low and intermediate level waste at a regional scale as part of a Geosynthesis (NWMO, 2011) including several supporting technical reports, and at the Bruce nuclear site scale as part of the development of a Descriptive Geosphere Site Model (DGSM, Intera Engineering Ltd., 2011).

The geoscientific data from characterization of the Bruce nuclear site (Intera Engineering Ltd., 2011; NWMO, 2011) provide detailed information on the geological, hydrogeological and geomechanical properties of the sedimentary strata found within the Area of the Five Communities. Based on the available information regarding the geoscientific characteristics of the sedimentary sequence beneath the Area of the Five Communities, the Ordovician Cobourg Formation (argillaceous limestone) would be the preferred host rock for a used nuclear fuel deep geological repository. The DGR for low and intermediate level waste at the Bruce nuclear site is also proposed for the Cobourg Formation argillaceous limestone. Geoscientific data released subsequent to the assessment reports for the proposed DGR at the Bruce nuclear site are also reviewed and assembled in this report.

The review of existing information identified that there is sufficient geoscientific information available to conduct the Phase 1 preliminary geoscientific assessment to identify potentially suitable general areas within the Communities.

1.4.1 Geology

Subcropping bedrock mapping for the Area of the Five Communities was compiled by Armstrong and Dodge (2007) and available digitally from the OGS. Surficial overburden (Quaternary) mapping of the same areas has been completed at a scale of 1:50,000 and is available in a seamless digital format (OGS, 1997; 2010). Information on Quaternary geology and glacial history for the Area of the Five Communities is available from Barnett (1992), Karrow (1993, 1989, 1974), Peltier (2011) and JDMA (2014). Eyles (2012) and Hallet (2011) provide information on glacial erosion processes and rates in the Area of the Five Communities.

Armstrong and Carter (2006, 2010) and Johnson et al., (1992) summarize the subsurface Paleozoic stratigraphy of southern Ontario. The Paleozoic stratigraphic nomenclature for subsurface and surface bedrock formations is not identical in Ontario and needs to be considered when comparing these data sets (e.g., the Lindsay Formation in surface outcrop mapping is the Cobourg Formation in subsurface mapping). In addition, several stratigraphic designations (e.g., Upper vs. Middle Ordovician) in Armstrong and Carter (2006) were updated for their 2010 report. These minor nomenclature inconsistencies and stratigraphic updates are discussed in further detail in Section 3.1. All stratigraphic designations used in this report follow that of Armstrong and Carter (2010), except where information is referenced directly from the site characterization activities at the Bruce nuclear site which followed that of Armstrong and Carter (2006).

Information on subsurface Paleozoic bedrock geology in the Area of the Five Communities is available from the Petroleum Wells Subsurface Database from the OGSRL (2013) and from three-dimensional interpretations of these data completed as part of geosynthesis activities undertaken at and regionally proximal to the Bruce nuclear site (Itasca Consulting Canada Inc. and AECOM Canada Ltd., 2011) and other studies (Sanford, 1976). Bedrock geology mapping at a 1:50,000 scale is available for the Area of the Five Communities from the OGS (2007).

Detailed lithological and mineralogical information on the Paleozoic bedrock formations in the Area of the Five Communities is available from Armstrong and Carter (2010), and from studies completed as part of geosynthesis activities undertaken at and regionally proximal to the Bruce nuclear site (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011) and at the Bruce nuclear site (Intera Engineering Ltd., 2011). The Bruce nuclear site DGSM data set (Intera Engineering Ltd., 2011) contains information on rock mass and fracture infilling mineralogy from laboratory petrographic, X-ray diffraction and lithogeochemical analyses of rock cores.

Information on structural (fault) subsurface mapping of the Paleozoic bedrock in the Area of the Five Communities is available from Armstrong and Carter (2010), who provide a compilation of earlier interpretations of structural contour maps completed by Brigham (1971) and Bailey Geological Services Ltd. and Cochrane (1984a, 1984b). OGS (2011) provides a digital release of the earlier isopach mapping by Bailey Geological Services Ltd. and Cochrane. Information on fracture and joint mapping of the Paleozoic bedrock outcrops in southern Ontario including the Area of the Five Communities is summarized by AECOM Canada Ltd. and Itasca Consulting Canada Inc. (2011), NWMO and AECOM Canada Ltd. (2011) and Cruden (2011). An assessment of karst occurrences in the Paleozoic bedrock of southern Ontario, including the Area of the Five Communities, is available from Brunton and Dodge (2008) and Worthington (2011).

Interpretation of the Precambrian basement underlying the Paleozoic bedrock within southern Ontario and the Area of the Five Communities is reported by Carter and Easton (1990), Easton (1992), Easton and Carter (1995), Carter et al., (1996), and Boyce and Morris (2002) from the study of drill core and cuttings that penetrate the basement rocks and the interpretation of aeromagnetic and gravity maps.

1.4.2 DEM, Satellite Imagery and Geophysics

The digital elevation model (DEM) data for the Area of the Five Communities is the Canadian Digital Elevation Data (CDED), a 1:50,000 scale, 20 m resolution, elevation model constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (Table 1.1; GeoBase, 2011). The DEM provided a good quality data set for quantifying ground slopes and relief, and for assessing regional surface water drainage and likely groundwater flow directions.

SPOT-5 satellite imagery for the Area of the Five Communities (GeoBase, 2010) has good resolution (20 m grid size for spectral data, and 10 m grid size for panchromatic data). Satellite imagery was a high-quality data set for illustrating land use and land cover throughout the Area of the Five Communities. Figure 2.1 shows the SPOT-5 panchromatic satellite imagery for the Communities.

Table 1.1 Summary of DEM, Satellite and Geophysical Source Data Information for the Area of the Five Communities

Dataset	*Product*	*Source*	*Resolution*	*Coverage*	*Acquired*	*Additional Comments*
DEM	Canadian Digital Elevation Data (CDED);1:50,000 scale	Geobase, 2011	20 m	Entire Area of the Five Communities	1978-1995	Hill-shaded used for mapping
Satellite Imagery	Spot4/5; Orthoimage, multispectral/ panchromatic	Geobase, 2010	10 m (panchromatic) 20 m (multispectral)	Entire Area of the Five Communities	2006-2007	Good Coverage
Geophysics	Waterloo fixed wing magnetic survey	Geological Survey of Canada	926m line spacing 305m sensor height	Central	1986	Large overlap with newer survey to the south
	Lake Huron fixed wing magnetic survey	Geological Survey of Canada	1900m line spacing 305m sensor height	West	1986	
	Georgian Bay fixed wing magnetic survey	Geological Survey of Canada	1200m line spacing 298m sensor height	Northeast	1985	
	Ontario #28 fixed wing magnetic survey	Geological Survey of Canada	805m line spacing 305m sensor height	East central	1950	Southwest superseded by newer survey
	Strathroy magnetic survey	Randsburg International Gold Corp	700 x 700m m grid 305mASL sensor height	Coast along west shore	1999	Higher resolution than GSC surveys. Terrain clearance varies from 130m to 275m
	South Ontario Radon Survey – Block 2	Geological Survey of Canada	1000m line spacing 150m sensor height	Southern part of Area of Five Communities	2008	Survey includes unlevelled magnetic data
	South Central Ontario – Collingwood-Hamilton	Geological Survey of Canada	1000m line spacing 150m sensor height	Northern part of Area of Five Communities	2009	
	Ground gravity measurements	Geological Survey of Canada	6 km (onshore), 1.6 km x 18 km (offshore)/surface	Entire Area of Five Communities	1945-2007	Variable station spacing
	Ground gravity measurements	PGW	0.4 km x 2 km/surface	Entire Area of Five Communities	1980s-90s	Higher resolution than GSC coverage, variable station spacing

Low-resolution airborne magnetic data collected by the Geological Survey of Canada (GSC, 2013) provide complete coverage of the Area of the Five Communities. These magnetic data were flown from 1950 to 1986 in four different surveys, at 805 to 1900 m flight line spacing and sensor heights of 298 to 305 m (Table 1.1). Medium-resolution magnetic data are also available covering a portion of the west side of the Area of the Five Communities (Figure 1.2; see PGW, 2014). This survey was flown on a 700 m x 700 m grid pattern at a survey height of 450 m above sea level, corresponding to a variable terrain clearance height of approximately 130 m to 275 m. Radiometric data from the GSC was acquired during two separate surveys provide low-resolution (1 km flight line spacing) data coverage over the Area of the Five Communities (GSC, 2013). These data were flown in 2008 and 2009 as part of the South Ontario Radon Survey (Table 1.1).

Gravity data from the GSC provide relatively sparse coverage for the Area of the Five Communities (GSC, 2013). The data was acquired for the Area of the Five Communities and the surrounding region and consists of an irregular distribution of 237 station measurements (Table 1.1). On land, the data consists of 149 station measurements comprising roughly a station every 3 to 6 km. Offshore, the data consists of 88 station measurements comprising roughly a station every 1.6 to 18 km along marine track lines. Additional, higher-resolution gravity data are available for a big portion of the Area of the Five Communities (Figure 1.2; PGW, 2014). This proprietary gravity dataset is derived from numerous ground surveys conducted in southwestern Ontario for oil and gas exploration purposes and is based on a dense network of stations with average station separation of 400 m (roughly 45 times the GSC coverage) collected mainly along the local roads.

1.4.3 2D Seismic Data

Four historical 2D seismic reflection data lines acquired for oil and gas exploration purposes in the 1970's within the Communities were purchased for reprocessing and reinterpretation. Figure 1.2 shows the location of the four 2D seismic data lines and Table 1.2 summarizes their characteristics.

Table 1.2 Summary Characteristics of 2D Seismic Data Lines for the Communities

Data Characteristic	***Line 725937***	***Line 825938***	***Line A003900020***	***Line A002800018***
Community Location	South Bruce	Brockton	Huron-Kinloss	Huron-Kinloss
Source Spacing	30 m	30 m	20 m	20 m
Receiver Spacing	30 m	30 m	20 m	20 m
Line Length	7.35 km	4.47 km	17.82 km	23.52 km
Fold	12	12	24	24
Owner at Acquisition	Pacific Petroleum	Pacific Petroleum	Shell Canada	Shell Canada
Current Data Owner	Suncor Energy	Suncor Energy	Shell Canada	Shell Canada
Year Acquired	1977	1977	1976	1976
Recording Instrumentation	DFS III – 24 channel	DFS III – 24 channel	DFS IV – 48 channel	DFS IV – 48 channel

Two of the seismic lines acquired are located in the Township of Huron-Kinloss, and the other two are within the municipalities of South Bruce and Brockton, respectively (Figure 1.2). Although a number of seismic lines were available within the Township of Huron-Kinloss, this assessment incorporated the data from two longer lines that are oriented approximately east-west and north-south. These seismic lines were acquired with 48 channel seismographs and 20 m station spacing. The lines in the municipalities of Brockton and South Bruce represent the only seismic lines that were available for those communities. Both of these lines were acquired with 24 channel seismographs and sparse 30 m station spacing. There were no seismic lines available for the Municipality of Arran-Elderslie or the Town of Saugeen Shores. Based on the survey acquisition characteristics, these seismic lines are relatively low quality and low spatial resolution compared to more modern seismic acquisition systems.

1.4.4 Deep Borehole Data

Data from deep boreholes (typically >100 m) provides the majority of information on subsurface geoscientific conditions of the Paleozoic bedrock within the Area of the Five Communities. Deep borehole data are available from oil and gas exploration activities and OGS geological investigations (OGSRL, 2013), interpretations of those oil and gas borehole data (Bailey Geological Services Ltd. and Cochrane, 1990; OGS, 2011b), and site characterization work completed at the Bruce nuclear site (Intera Engineering Ltd., 2011; Geofirma Engineering Ltd., 2012). Information from shallow boreholes is available from the Ontario Ministry of the Environment (2013a) Water Well Information System.

Deep borehole data within OGSRL (2013) usually contain records of lithology from chip samples of bedrock formations encountered, frequently contain borehole geophysical logs (i.e., neutron and natural gamma) suitable for formation identification, and occasionally contain samples of recovered drill core. Approximately 2 % of the total borehole length within the OSGRL database for the Area of the Five Communities, excluding the Bruce DGR boreholes, contains information from cored sections of boreholes.

Deep borehole data are also available from site characterization work completed at the Bruce nuclear site. Geoscientific data on the entire Paleozoic bedrock sequence is available from six continuously-cored deep boreholes and summarized by Intera Engineering Ltd. (2011). Available borehole data from these wells include geological information on formation depth, orientation, and rock quality, natural fracture frequency from detailed core logging, core photography and borehole geophysical logging. Additional deep borehole data at the Bruce nuclear site are reported by Geofirma Engineering Ltd. (2012) as part of the geoscientific characterization of two shaft investigation boreholes.

1.4.5 Hydrogeology and Hydrogeochemistry

Basic hydrogeological and hydrogeochemical information (water levels, shallow stratigraphy, well yields/pumping tests, water quality, etc.) for the Area of the Five Communities are available principally from the Ontario Ministry of the Environment (MOE) Water Well Information System database (Ontario Ministry of the Environment, 2013a). This database contains simple hydrogeological and hydrogeochemical information on the overburden and shallow bedrock aquifers.

Interpretations of these shallow hydrogeological and hydrogeochemical data in conjunction with available overburden and bedrock geological mapping are provided in municipal, regional and watershed groundwater studies undertaken as part of the Ontario's Source Water Protection work under the Clean Water Act. Note major interpretative studies available include: Grey Bruce County

Groundwater Study (Waterloo Hydrogeologic Inc., 2003), Huron County Groundwater Study (Golder Associates Ltd., 2003b), and the Ausable Bayfield, Maitland Valley, Saugeen Valley and Grey Sauble Source Protection Areas Assessment Reports (Ausable Bayfield Maitland Valley Source Protection Committee 2011; and Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a, b). These studies interpret the available shallow groundwater information with respect to assessment of local and regional aquifers and aquitards, groundwater flow systems, aquifer vulnerability assessments, identification of significant groundwater recharge areas, and well head protection areas for municipal groundwater supplies.

Hydrogeological information on deeper Paleozoic bedrock units below the potable water horizon of about 100 m depth are available from the Bruce nuclear site (NWMO, 2011; Sykes et al., 2011) and in several earlier summary reports of regional hydrogeological and geotechnical conditions (Mazurek, 2004; Golder Associates Ltd., 2003a). These hydrogeological data are largely interpreted from information contained within the Petroleum Wells Subsurface Database (OGSRL, 2013) and the Bruce nuclear site DGSM site characterization study (Intera Engineering Ltd., 2011). The Ontario Petroleum Institute (Carter and Fortner, 2011) have provided a hydrogeological interpretation of Petroleum Wells Subsurface Database information to describe regional bedrock aquifers and a conceptual groundwater flow model for southern Ontario. The site-specific hydrogeological and related information available from Intera Engineering Ltd. (2011) and Geofirma Engineering Ltd. (2012) includes the following information for the Paleozoic bedrock:

- hydrogeological information on formation permeability, specific storage, formation pressure and porosity from field straddle-packer and laboratory testing of rock cores;
- petrophysical information on the fluid saturations, relative gas-brine permeability, gas entry pressures, pore-size distributions and diffusion properties of formations from laboratory testing; and
- hydrogeological information on the in-situ formation pressures from long-term monitoring of deep multi-level monitoring casings.

Hamilton (2011) provides a summary of groundwater hydrogeochemical data for shallow overburden and bedrock aquifers in southwestern Ontario based on 2007-2010 OGS sampling from water wells, including several located within the Area of the Five Communities. Ontario Ministry of the Environment (2013b) provides on-going water level and groundwater quality data for monitoring wells that are part of the Provincial Groundwater Monitoring Well Network, including several wells located within the Area of the Five Communities.

Hydrogeochemical data for deeper Paleozoic bedrock units below the potable water horizon of about 100 m depth are available from the Petroleum Wells Subsurface Database (OGSRL, 2013), the Bruce DGR Geosynthesis (NWMO, 2011) and related supporting technical reports including Hobbs et al. (2011) and references therein, and from Intera Engineering Ltd. (2011). These data sources provide hydrogeochemical information on general water quality types and the geochemical and isotopic characterization of Paleozoic formation porewater, groundwater and gas from field and laboratory testing.

1.4.6 Natural Resources – Economic Geology

Information regarding the petroleum, metallic mineral and non-metallic mineral resources potential for the Area of the Five Communities has been obtained from a variety of sources including provincial databases and assessment reports and papers.

Information on oil, gas and salt resources is available from the Petroleum Wells Subsurface Database (OGSRL, 2013), reports in the Oil Gas and Salt Resources Library in London, Ontario, the Bruce DGR Geosynthesis and DGSM studies, and OGS studies evaluating the hydrocarbon and shale gas potential of Paleozoic rocks in southern Ontario (OGS, 2011b; Béland Otis, 2012). Engelder (2011) provides an assessment of the potential for shale gas occurrence at the Bruce nuclear site and Béland-Otis (2012) provides a similar assessment for the Ordovician shale located 20 km east of the town of Mount Forest and 28 km east of the Area of the Five Communities.

Information on metallic mineral resources is available from the Abandoned Mines Information System (AMIS) database (MNDM, 2011), the Mineral Deposit Inventory (MDI) database (OGS, 2013b), the Assessment File Research Imaging (AFRI) database (MNDM, 2013a) and the CLAIMaps database (MNDM, 2013b). The Assessment File Research Imaging (AFRI) database contains information on mineral exploration and mining activity in the Province of Ontario. Information from the AFRI database has routinely been used in OGS reports and in journal publications. The Abandoned Mines Information System (AMIS) contains the location of abandoned and inactive mines sites. The database has records on mining related features including mining hazards and abandoned mines and is considered to be a good quality dataset but not to be complete. The CLAIMaps and MDI databases contain up-to-date information on mining claims, mineral occurrences, producing mines, and past producing mines with and without mineral reserves.

Information on non-metallic mineral resources including sand and gravel aggregates and crushed and building stone is available from the OGS's Aggregate Resources Inventory Papers (ARIP) which are prepared on a County and Township basis. Data for Bruce County and Huron County are summarized by Rowell (2012) and OGS (2004).

1.4.7 Geomechanical Properties

There was no available site-specific information on rock geomechanical properties of deep Paleozoic bedrock formations within the Area of the Five Communities. Information on rock geomechanical properties, including rock strengths, rock quality, thermal conductivity and in situ stresses for Paleozoic rocks in the Area of the Five Communities are inferred from data collected for similar geologic units at the Bruce nuclear site and elsewhere in southern Ontario.

Information on the regional geomechanical properties of the Paleozoic bedrock of southern Ontario is summarized by Golder Associates Ltd., (2003a), Mazurek (2004), Lam et al. (2007) and by NWMO and AECOM Canada Ltd. (2011) and NWMO (2011) as part of the geosynthesis study of the Bruce nuclear site. AECOM Canada Ltd. and Itasca Consulting Canada, Inc. (2011), NWMO and AECOM Canada Ltd., (2011) and NWMO (2011) summarize the current knowledge on bedrock jointing and structural discontinuities, geomechanical intact rock properties, geomechanical rock mass properties, including subsurface excavation experience, and regional in-situ stress, based on bedrock geotechnical studies and structural mapping studies, primarily on relatively shallow bedrock. Fracture patterns in shallow bedrock of southern Ontario and within the Area of the Five Communities are reported by Andjelkovic et al., (1996; 1997), Andjelkovic and Cruden (1998) and by Cruden (2011).

Information on the geomechanical properties of deeper Paleozoic bedrock can be inferred from Intera Engineering Ltd. (2011), as well as from more recent geotechnical testing and logging of shaft investigation boreholes (Geofirma Engineering Ltd., 2012; Golder Associates Ltd., 2013). These studies summarize the following:

- geomechanical information on the abrasivity, slake durability, swelling potential and compressive, tensile and shear strength of the intact rock from extensive laboratory and field testing;
- rock mass geomechanical characteristics including rock quality designation, natural fracture frequency and fracture sets; and
- interpretation of in-situ rock stresses from available borehole information.

1.4.8 Seismicity and Neotectonics

National seismicity data sources were reviewed to provide an indication of seismicity in the Area of the Five Communities and the surrounding region. Information on earthquake occurrence in these areas is available from the National Earthquake Database maintained by Natural Resources Canada (2013a).

The findings of earthquake monitoring and reporting using four monitoring stations located at Tiverton, Walkerton, Ashfield and Maryville Lake, is reported annually by the Canadian Hazards Information Service of the Geological Survey of Canada (Hayek et al., 2011) as part of an ongoing micro-seismic monitoring program around the Bruce nuclear site. The findings are also applicable to the Area of the Five Communities.

Information on neotectonics in the Area of the Five Communities is available from JDMA (2014) and Slattery (2011) as well as for the larger southern Ontario region based on earlier work by McFall (1993) and Karrow and White (2002).

2 PHYSICAL GEOGRAPHY

2.1 Location

The Area of the Five Communities includes the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores as shown on Figure 1.1 based on 2011 Ontario Ministry of Natural Resources basemapping. Figure 2.1 shows the location and extent of the Five Communities on black-and-white 2006 SPOT-5 satellite imagery. The Area of the Five Communities includes parts of Bruce County, Grey County and Huron County. All of the five Communities are located within Bruce County.

The Municipality of Arran-Elderslie is located approximately 15 km southwest of Owen Sound and is about 469 km^2 in size. The largest settlement areas in the Municipality are those of Paisley, located along the southwestern boundary; Chesley, in the southwest corner; and Tara, in the northeast corner of the Municipality.

The Municipality of Brockton is located between Owen Sound and Goderich. It is about 570 km^2 in size. The largest settlement area in the Municipality is Walkerton, located in the southeastern portion of the Municipality, along Highway 9.

The Municipality of South Bruce is situated along Highway 9, approximately 30 km northeast of Goderich and is about 489 km^2 in size. The villages of Mildmay, Formosa and Teeswater are the three largest settlement areas in the Municipality of South Bruce.

The Township of Huron-Kinloss borders Lake Huron and is located between Owen Sound and Goderich. The Township is approximately 443 km^2 in size and includes the settlement areas of Ripley and Lucknow. The largest settlement area in the Township of Huron-Kinloss is Ripley, which is located in the central part of the Township.

The Town of Saugeen Shores is situated approximately 40 km southwest of Owen Sound, along the shoreline of Lake Huron, and is about 170 km^2 in size. The largest settlement areas in the Town are Port Elgin and Southampton, located along Highway 21 near Lake Huron.

2.2 Physiography and Topography

A detailed terrain analysis was completed for the Area of the Five Communities as part of the preliminary assessment of potential suitability for the Communities (JDMA, 2014). This section presents a summary of that analysis. The landform and topography information for the Area of the Five Communities is illustrated on Figure 2.2 (physiographic regions and terrain features) and Figure 2.3 (ground surface elevation).

2.2.1 Physiographic Regions and Terrain Features

There are six physiographic regions within the Area of the Five Communities: Arran drumlin field, Horseshoe moraines, Huron fringe, Huron slope, Saugeen clay plain and Teeswater drumlin field (Figure 2.2). These physiographic regions are defined by Chapman and Putnam (2007) based on the presence of major topographic features such as valleys, drumlin fields, and till plains. The descriptions of the physiographic regions provided by these authors include information on the surficial deposits and topography. Table 2.1 shows the areal extent of these physiographic regions within the Communities (JDMA, 2014).

Table 2.1 Areal Extent of Physiographic Regions within the Communities (in %)

Physiographic Region	***Arran Drumlin Field***	***Horseshoe Moraines***	***Huron Fringe***	***Huron Slope***	***Saugeen Clay Plain***	***Teeswater Drumlin Field***
Municipality of Arran-Elderslie	55	0	3	1	41	0
Municipality of Brockton	0	62	0	2	33	3
Municipality of South Bruce	0	41	0	0	0	59
Township of Huron-Kinloss	0	36	2	59	0	3
Town of Saugeen Shores	3	0	54	38	5	0

The Arran drumlin field is located in the northern part of the Area of the Five Communities. It occupies more than half (55 %) of the Municipality of Arran-Elderslie and contains about 300 long narrow drumlins in an area between Southampton and Owen Sound (Figure 2.2). Lacustrine clay occurs between drumlins in some areas, particularly in the southern part of the field. The drumlins in this field are younger than those found in the Teeswater drumlin field located to the south. The drumlins are oriented southwest having been formed by the advance of an ice sheet located in the basin now occupied by Georgian Bay. The western margin of the field is very clearly defined by a very steep shore bluff associated with glacial Lake Algonquin (Figure 2.2).

The Horseshoe moraines are an elaborate array of moraines and spillways located in the southern region of the Area of the Five Communities. The moraines within this belt are known as the Port Huron Moraine system. The belt is about 20 km wide in the eastern part of the Township of Huron-Kinloss and the northwestern part of the Municipality of South Bruce. The Horseshoe moraines occupy 62 % of Municipality of Brockton, 41 % of the Municipality of South Bruce and 36 % of the wonship of Huron-Kinloss. The main landform components in the Horseshoe Moraines are the irregular, till or kame moraines and the generally pitted sand and gravel terraces and swampy valley floors.

The Huron fringe is a belt of wave-cut terraces of glacial Lake Algonquin and Lake Nipissing consisting of boulders, gravel bars and sand dunes located within a narrow fringe of land extending along the Lake Huron shoreline. The Huron fringe occupies more than half (54 %) of the Town of Saugeen Shores, creating a massive beach of sand and gravel which was built across the mouth of the Saugeen valley during Lake Algonquin times.

The Huron slope occupies the section of land along the east shore of Lake Huron located between the Algonquin bluff and the Horseshoe moraines. The land slopes gently from about 180 to 260 or 275 m elevation across this physiographic region. The area is characterized by a till plain containing a narrow strip of sand and the twin sand beaches of glacial Lake Warren (JDMA, 2014) that are oriented parallel to the existing shoreline and located about 5 to 15 km inland from Lake Huron (Figure 2.2).

The Huron slope occupies the southern 38 % of the Town of Saugeen Shores and western 59 % of the Township of Huron-Kinloss.

The Saugeen clay plain located in the watershed of the Saugeen River north of the Horseshoe moraine, occupies the southern 41 % of the Municipality of Arran-Elderslie and the northern third of the Municipality of the Brockton. The area contains a deep stratified lacustrine clay deposit that formed in a bay of Lake Warren. The largest area of thick lacustrine clay is located in the topographic low between the moraines at Walkerton and Chelsey (Figures 2.3 and 2.4). At the junction of the Saugeen and Teeswater rivers, a delta was formed in Lake Warren and resulted in a sand plain in that area. Kames can also be found locally in this area (Figure 2.3).

The Teeswater drumlin field is located in the south central part of the Area of the Five Communities and contains more than 380 drumlins concentrated in an area between Wingham, Mildmay and Harriston. The Teeswater drumlin field occupies the southeastern half of the Municipality of South Bruce and a small part of the southeast corner of the Municipality of Brockton. Towards the outer margin of the field, the drumlins become weaker and gradually fade into an undulating till plain. The drumlin field is interrupted in a few places by the presence of kames and associated outwash. One set of sand hills is found south of Mildmay, and another area of sand hills is located east of Clifford.

2.2.2 Topography and Ground Elevation

The large-scale topography in the Area of the Five Communities is controlled by bedrock topography, whereas the detailed topography is often controlled by surficial deposits and erosional landforms cut into the surficial sediments.

The pattern of elevation across the Area of the Five Communities based on CDED data (Figure 2.3) controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient in the Area of the Five Communities from southeast to northwest is from about 400 m to 176 m, with this elevation drop occurring over an approximate 70 km lateral distance. The highest point in the Area of the Five Communities is located in the southeastern corner of the area near Harriston.

The municipalities of Arran-Elderslie, Brockton and South Bruce are located inland of Lake Huron, with minimum elevations ranging from 180 to 249 m (Table 2.2). The Municipality of South Bruce has the highest elevation of the Five Communities. This high elevation is associated with the Horseshoe moraines and the Teeswater drumlin field. The Town of Saugeen Shores has the lowest elevation of the Five Communities and this is associated with the Huron Slope and Huron Fringe.

Figure 2.3 shows the occurrence of an abrupt elevation change near Lake Huron within the Town of Saugeen Shores and the Township of Huron-Kinloss and between the Bruce nuclear site and Tiverton. This elevation change is the Algonquin bluff associated with former glacial Lake Algonquin (JDMA, 2014). Figure 2.3 also illustrates the decreased elevation within the central part of the Municipality of Brockton and the Town of Saugeen Shores and within the southwestern part of the Municipality of Arran-Elderlsie associated with the Saugeen River system.

Table 2.2 Ground Surface Elevation Statistics for the Communities

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

2.3 Drainage

Section 2.3.1 provides information on the size, distribution and depth of lakes and wetlands in the Area of the Five Communities. Section 2.3.2 describes the existing watershed map file, and Section 2.3.3 describes surface flow and drainage within the Area of the Five Communities.

2.3.1 Waterbodies and Wetlands

Apart from Lake Huron, the largest lake within the Area of the Five Communities is Arran Lake, covering an area of 3.9 km^2 in the northern portion of the Municipality of Arran-Elderslie. Table 2.3 summarizes the size of the nine largest lakes within the Area of the Five Communities. Of these nine largest lakes, four (Arran, Silver, Rosalind and Clam lakes) are located within the Communities (Figure 2.4). Excluding Lake Huron, waterbodies cover 38.7 km^2 or 0.8% of the Area of the Five Communities. Lakes within the Area of the Five Communities are generally shallow with depths less than 15 m. The greatest known lake depth for an inland lake is 19.8 m, which was measured in Silver Lake in the Township of Huron-Kinloss. The average water level of Lake Huron is about 176 mASL (Figure 2.3). The floor of Lake Huron reaches and elevation of 13 m below sea level near the northwest corner of the Area of the Five Communities, resulting in a maximum depth of 189 m within the Area of the Five Communities.

Figure 2.4 also shows both provincially significant wetlands and other wetlands that are evaluated and not considered to be provincially significant, or are not evaluated. Some of the larger provincially significant wetland complexes in the Communities include: the Greenock Swamp Wetland Complex, which occupies approximately 12.8% of the Municipality of Brockton and a small portion of the Municipality of South Bruce; and the MacGregors Point Wetland Complex located in the Town of Saugeen Shores near Lake Huron. There is also a relatively large (8.0 km^2) provincially significant wetland complex surrounding Arran Lake in the northern portion of the Municipality of Arran-Elderslie. Many of the wetland complexes in the Area of the Five Communities are situated in topographic lows between drumlins or in spillways.

Table 2.3 Size of Nine Largest Lakes within the Area of the Five Communities

Lake	***Perimeter (km)***	***Area within the Area of the Five Communities (km^2)***	***Community***
Arran Lake	23.5	3.9	Municipality of Arran-Elderslie
Chesley Lake	9.7	2.1	Not in Communities
Silver Lake	4.7	0.59	Township of Huron-Kinloss
Williams Lake	6.1	0.58	Not in Communities
McCullough Lake	6.2	0.54	Not in Communities
Lakelet Lake	3.8	0.40	Not in Communities
Lake Rosalind	6.8	0.43	Municipality of Brockton
Town Line Lake	2.7	0.39	Not in Communities
Clam Lake	5.1	0.39	Township of Huron-Kinloss

Table 2.4 summarizes the extent of wetlands and forest cover within the Communities. The Municipality of Brockton contains the largest percentages of areas covered by wetland and forest, which is partly due to the presence of the Saugeen clay plain and the Greenock Swamp Wetland Complex.

Table 2.4 Extent of Wetlands and Forest Cover in the Communities

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

2.3.2 Watersheds

A watershed, also known as a catchment, basin or drainage area, includes all of the land that is drained by a watercourse and its tributaries. The most detailed available watershed delineation for the Area of the Five Communities is the quaternary watershed file produced by the MNR (LIO, 2013).

Figure 2.5 shows the divides that delineate the five tertiary-scale watersheds (Penetangore, Saugeen, Maitland, Bruce Peninsula and Southwest Georgian Bay) associated with the main river systems in the Area of the Five Communities, as well as several quaternary-scale watersheds that further compartmentalize surface drainage.

The Municipality of Arran-Elderslie lies within both the Bruce Peninsula and the Saugeen watersheds. The municipalities of Brockton and South Bruce are almost entirely within the Saugeen Watershed. The Township of Huron-Kinloss is predominately within the Penetangore Watershed, with portions of the eastern limits of the township within the Saugeen Watershed. The Town of Saugeen Shores is mostly in the Saugeen Watershed, with a small area in the southwest corner adjacent to Lake Huron within the Penetangore Watershed (Figure 2.5).

2.3.3 Surface Flow

The Area of the Five Communities is contained entirely within the St. Lawrence Drainage Area, which drains towards the Atlantic Ocean through the St. Lawrence River. The St. Lawrence Drainage Area covers parts of the provinces of Ontario and Quebec, and the states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Vermont and Wisconsin. The main rivers draining the Area of the Five Communities flow towards Georgian Bay and Lake Huron.

Surface flow over the vast majority of the Area of the Five Communities is directed to the west into Lake Huron (Figure 2.5). Much of this flow into Lake Huron is accomplished by the Saugeen and Maitland rivers, and to a lesser extent by smaller rivers such as the Sauble, Little Sauble, Penetangore, Pine, Eighteen Mile and Nine Mile rivers or creeks.

The Sauble River, and its northern tributary the Rankin River, drain an area of about 915 km^2 (JDMA, 2014), the northern limits of which extend north of the Area of the Five Communities. The actual drainage area is difficult to estimate due to the presence of disappearing streams on the Bruce Peninsula. The Sauble River follows a circuitous course through two contrasting landscape types (Figure 2.5), the upper part being among the hills of the Arran drumlin field whereas the lower portion extends through the Algonquin sand plain.

The Saugeen River, which flows through the middle of the Municipality of Brockton and the Town of Saugeen Shores, drains an area of 4,025 km^2 (JDMA, 2014, Figure 2.5) some of which represents the highest land in southern Ontario. The main tributaries are the Teeswater, South Saugeen, Beatty Saugeen, Rocky Saugeen and North Saugeen rivers. The Teeswater drains the Greenock Swamp Wetland Complex, which results in a uniform summer flow. Upstream of Walkerton, the branches of the Saugeen flow in old spillways associated with the Horseshoe moraine system. These valleys contain broad gravel terraces (Figure 2.2) and generally trend west to northwest (Figure 2.5).

The Nine Mile River drains an area of 246 km^2 underlain by moraine and spillway with considerable swamp and woodlot, which supports a steady flow. Other streams draining the east shore of Lake Huron within the Penetangore tertiary watershed include the Penetangore, North Penetangore, Pine and South Pine rivers.

The Maitland River, which drains the southern part of the Area of the Five Communities, empties into Lake Huron at Goderich and drains an area of 2,646 km^2 (JDMA, 2014). The main tributaries are the South Maitland, Middle Maitland and Little Maitland rivers. The Middle Maitland and Little Maitland rivers join the main branch near Wingham.

2.4 Land Use and Protected Areas

Figure 2.6 shows land disposition and ownership within the Area of the Five Communities. Most of the land in the Area of the Five Communities consists of private agricultural land, with only several very small parcels of Crown leased, unpatented and disposition lands; and federal lands. The Chippewas of Saugeen First Nation Reserve is located immediately north of the Municipality of Arran-Elderlsie and the Town of Saugeen Shores.

2.4.1 Land Use

Land use within the Area of the Five Communities consists mostly of wetlands, forested areas, agricultural lands and developed/built-up areas with residential, commercial and industrial land uses. Figure 2.4 shows the distribution of all mapped wetlands within the Area of the Five Communities. Wetlands and forested areas represent 14.3 % and 25.2 % respectively of the land area shown on Figure 2.5. The Bruce nuclear site is located within the Area of the Five Communities in the Municipality of Kincardine on the shore of Lake Huron (Figure 2.6).

2.4.2 Parks, Reserves, Provincially Significant Wetlands and Earth Science ANSIs

Figure 2.6 shows the distribution of Provincial Parks, Conservation areas and reserves, Provincially Significant Wetlands and earth science Areas of Natural Scientific Interest (ANSI) within the Area of the Five Communities. With the exception of earth science ANSIs, these land uses are considered within this report as protected areas. Table 2.5 lists the percentage of each of the Communities covered by these different types of areas, and the following sub-sections summarize the available information on them on a community basis. Because of overlapping protected areas (e.g., Provincially Significant Wetlands, Provincial Parks and Conservation areas/reserves) the total combined protected areas and earth science ANSIs in Table 2.5 may be less than the sum of the individual areas listed in the Table.

Table 2.5 Summary of Protected Areas and Earth Science ANSIs in the Communities

Community	***Area as % of Total Community Area***				
	Provincial Parks	***Provincially Significant Wetlands***	***Conservation Areas/ Reserves***	***Earth Science ANSI***	***Total Combined Protected Areas and Earth Science ANSIs***
Municipality of Arran-Elderslie	0	3.9	0.6	4.8	9.1
Municipality of Brockton	0	12.7	6.4	0.01	13.4
Municipality of South Bruce	0	5.5	0.5	0	5.9
Township of Huron-Kinloss	0	4.9	<0.01	0.47	5.4
Town of Saugeen Shores	5.7	1.2	1.3	0	7.1

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

2.4.2.1 Municipality of Arran-Elderlsie

There are no national or provincial parks within the Municipality of Arran-Elderslie. There are six conservation areas within the Municipality of Arran-Elderslie; the McBeath and Lockerby conservation areas located in the southwestern corner of the Municipality; the Tara Conservation Area on the eastern boundary of the settlement area of Tara; the Arran Lake Conservation Area within the northeastern portion of the Arran Lake Wetland Complex; the Denny's Dam Conservation Area located in the extreme northwest corner of the Municipality adjacent to the Saugeen River; and the Saugeen Conservation Area present within the Elderslie Swamp Wetland Complex (Figures 2.4 and 2.6). These conservation areas cover a combined area of about 2.6 km^2 or about 0.5 % of the Municipality.

There are four designated Provincially Significant Wetlands within the Municipality of Arran-Elderslie comprising the Sangs Creek Wetland Complex, the Allenford Station Wetland Complex, the Tara Floodplain Wetland Complex and the Arran Lake Wetland Complex (Figure 2.4). These wetlands have a combined area of approximately 19 km^2, comprising 3.9 % of the Municipality. Several earth science Areas of Natural Scientific Interest (ANSI) are present within the Municipality and include the Tara Moraine and Arkwright Drumlins, located just outside of Tara; the Tara Moraine and Esker and Dobbinton Eskers, located in the east-central portion of the Municipality; and the Williscroft Moraine in the south-central portion of the Municipality (Figure 2.6). These features cover approximately another 4.8 % of the Municipality with a combined area of approximately 23 km^2. The ANSI's represent prominent glacial geological features that support unique habitats and protect groundwater infiltration and recharge functions.

These protected areas and earth science ANSIs occupy approximately 9.1 % of the Municipality of Arran-Elderslie.

2.4.2.2 Municipality of Brockton

There are no national or provincial parks within the Municipality of Brockton. There are six conservation areas/reserves with the Municipality of Brockton. Three of these conservation lands are associated with or proximate to Provincially Significant Wetlands; the Greenock Swamp Wetland Complex, the Chepstow Swamp and the Edengrove Wetland Complex. A small rectangular area east of the Glammis Bog and north of the Greenock Swamp Wetland Complex and two small rectangular areas west and south of Walkerton (Figure 2.6) are unnamed conservation lands.

There are three designated Provincially Significant Wetlands within the Municipality of Brockton comprising: the Greenock Swamp Wetland Complex, the Edengrove Wetland Complex and the Chepstow Swamp (Figure 2.4). These Provincially Significant Wetlands cover 12.7 % of the area of the Municipality (Provincial Policy Statement, 2005), and some of the lands within them have been designated as Conservation Areas (Figure 2.6). The Greenock Swamp Wetland Complex is one of the largest wetland areas in southern Ontario, with an area of about 90 km^2. This feature extends beyond the southern boundary of the Municipality of Brockton. There are two small earth science ANSIs (Saugeen River Section and Formosa North Road Cut) covering a combined area of 0.07 km^2 within the Municipality.

These protected areas occupy approximately 13.4 % of the Municipality of Brockton.

2.4.2.3 Municipality of South Bruce

There are no national or provincial parks, and no earth science ANSIs within the Municipality of South Bruce. There are four conservation areas/reserves within the Municipality of South Bruce. The largest of these is the Saugeen Conservation Reserve, which occupies approximately 1.5 km^2 in the southeast portion of the Municipality, followed by the Greenock Swamp Wetland Complex located in the northwest corner of the Municipality (Figure 2.6). Two smaller unnamed conservation lands are located west of Teeswater and southeast of the Saugeen Conservation Reserve.

There are three provincially designated Provincially Significant Wetlands within the Municipality of South Bruce comprising the Greenock Swamp Wetland Complex, the Teeswater Wetland Complex and the Otter Creek Wetland (Figure 2.5). These areas cover approximately 6% of the area of the Municipality (approximately 29 km^2) and some of their lands are designated as conservation areas (Figure 2.5). The Greenock Swamp Wetland Complex 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. The Teeswater Wetland Complex extends westward into the Township of Huron-Kinloss (Figure 2.5).

These protected areas occupy approximately 5.9 % of the Municipality of South Bruce.

2.4.2.4 Township of Huron-Kinloss

There are no national or provincial parks within the Township of Huron-Kinloss. One conservation area, the Lucknow Waterworks Conservation Area (0.6 ha), exists within the Township of Huron-Kinloss and is located in the settlement area of Lucknow, along the southern boundary of the Township (Figure 2.6).

There are seven designated Provincially Significant Wetlands within the Township of Huron-Kinloss comprising: the Greenock Swamp Wetland Complex, the Kinloss Creek Wetland, the Dickies Creek Wetland, the Dickies Creek Wetland Complex, the Anderson Creek Wetland, and parts of the Teeswater and Wingham wetland complexes (Figure 2.4). The Teeswater Wetland Complex and the Wingham Wetland Complex encroach into the east and southeast portions of the Township. Collectively these Provincially Significant Wetlands cover approximately 4.9 % of the area of the Township. The Lothian-Lake Warren Shorelines earth science ANSI is a glacial lake feature located along the southern boundary or the Township and is approximately 2 km^2 in size (Figure 2.6).

These protected areas and earth science ANSIs occupy approximately 5.4 % of the Township of Huron-Kinloss

2.4.2.5 Town of Saugeen Shores

There is one provincial park, the MacGregor Point Provincial Park, and one conservation area within the Town of Saugeen Shores. There are no national parks, or earth science ANSIs within the Town of Saugeen Shores.

The Saugeen Bluffs Conservation Area is located in the southeastern portion of the Town of Saugeen Shores and has an approximate size of 2 km^2 (Figure 2.6).

The MacGregor Point Provincial Park is situated west of Highway 21 in the southwestern corner of the Town of Saugeen Shores, along the shoreline of Lake Huron. The park is approximately 9.7 km^2 in size and occupies approximately 5.7 % of the area of the Town (Figure 2.6). The MacGregor Point Wetland Complex is the only Provincially Significant Wetland within the Town and is located primarily within MacGregor Point Provincial Park.

These protected areas occupy approximately 7.1 % of the Town of Saugeen Shores.

2.4.3 Heritage Sites

The assessment of cultural heritage examined known archaeological and historic sites in the Area of the Five Communities. Information on archaeological sites in Ontario is provided by the Ontario Ministry of Tourism and Culture, through their Archaeological Sites Database (Ontario Ministry of Tourism, Culture and Sport, 2013).

There are 44 registered archaeological sites in the Communities (von Bitter, 2013) with 15 in the Municipality of Arran-Elderslie, nine in the Municipality of Brockton, two in the Municipality of South Bruce, six in the Township of Huron-Kinloss, and 12 in the Town of Saugeen Shores. Of the 44 archaeological sites, 13 are recorded as being early Pre-Contact Aboriginal campsites or findspots. One Pre-Contact burial site has also been recorded, as well as two separate campsites with burials. All of the aforementioned sites have no established cultural affiliation or time period. Six archaeological sites have been identified as Middle or Late Woodland Aboriginal sites; four being campsites, one village, and one being an undetermined site type. In addition, one Archaic campsite and one undetermined Late Archaic site have been recorded. In total, 24 Pre-Contact registered archaeological sites are found within the Communities. Of the remaining 20 archaeological sites, nine are historic Euro-Canadian. One is identified as a Euro Canadian findspot, four are undetermined site types and four are recognized as being a homestead or having a cabin or building. No information was given for the 11 remaining archaeological sites.

The potential for archaeological sites within the Communities 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, as well as secondary water sources, including swamps and small creeks (Government of Ontario, 1997).

There are two National Historic Sites in the Communities (Parks Canada, 2013): the Chippewa Hill Donaldson Site located within the Denny's Dam Conservation Area in the Municipality of Arran-Elderlsie; and the Point Clark Lighthouse Site situated along the shore of Lake Huron in the Township of Huron-Kinloss. There are 56 properties designated as municipal or provincial heritage sites within the Area of the Five Communities (Ontario Minisitry of Tourism, Culture and Sport, 2013). Of these 56 designated heritage properties, two are located within the Municipality of South Bruce, 14 are located within the Municipality of Saugeen Shores, two are within the Township of Huron-Kinloss, 15 are within the Municipality of Brockton and 23 are within the Municipality of Arran-Elderslie. Additionally, there are no conservation easements or heritage districts currently administered by the Ontario

Heritage Trust in the Area of the Five Communities (Ontario Heritage Trust, 2013). The Lucknow Townhall Heritage Site is located within the built-up area of Lucknow in the Township of Huron Kinloss (Ontario Heritage Trust, 2013).

The presence of locally protected areas and heritage sites would need to be further confirmed in discussion with the Communities and First Nation and Métis communities in the vicinity during subsequent evaluation stages, if the community is selected by the NWMO and remains interested in continuing with the site selection process.

2.4.4 Source Water Protection Areas

Under Ontario's Clean Water Act, source water protection areas are defined for all public drinking water supplies, both groundwater and surface water. Source water protection areas are defined for each municipal water supply and identify areas where land use constraints may apply in order to ensure the safety and protection of Ontario's drinking water.

For surface water supplies, the source water protection areas are defined as Intake Protection Zones (IPZ) based on simple geometrical factors and hydrological modeling considering surface water flow and overland flow to surface water. Two IPZs are potentially defined for each surface water source. IPZ-1 is a simple circular area surrounding a surface water intake. IPZ-2 is a more complex area defined based on hydrological modeling of the 2-hour time-of-travel of surface water to the point of intake. The 2 hour time is an estimate of time required to shut down a water treatment plant.

For groundwater supplies the source water protection areas are defined as Well Head Protection Areas (WHPAs) based on simple geometrical factors and hydrogeological modeling considering the time of travel of groundwater to a drinking water supply well. Up to Five WHPAs (A to E) are defined for each well. WHPA-A is a simple 100 m radius around the well and WHPA-B, -C and -D are equal to 2, 5 and 25 year time-of-travel for groundwater to the well. Increasing WHPA by letter provides decreasing levels of protection of source water (i.e., WHPA-A has greater restrictions on land use than WHPA-B, which in turn has greater restrictions on land use than WHPA-C, etc.). WHPA-E is the 2-hour time of travel for any surface water that is connected to a well.

Table 2.6 lists the public surface water and groundwater drinking water supplies that create source water protection areas in the Communities, and Figure 2.7 summarizes the extents of the IPZs and WHPAs for these drinking water supplies, based on Assessment Reports completed by Ausable Bayfield Maitland Valley Source Protection Committee (2011) and Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region (2011a, 2011b). Figure 2.7 shows grouping of WHPAs into three categories: A, B and C; D; and E. Table 2.6 and Figure 2.7 also include the IPZs for the Kincardine Drinking Water System in the Municipality of Kincardine that has a land-based IPZ that extends into the Township of Huron-Kinloss, and the IPZs for the Ruhl Lake Water Supply that provides drinking water to Hanover in the Town of Hanover that is within the Municipality of Brockton. The Hanover Water Treatment Plant Well Supply located in the Municipality of Brockton proximate to the Lake Rosalind Well Supply also provides drinking water to Hanover. Table 2.6 and Figure 2.7 show that there are 18 source water protection areas in the Communities, consisting of 15 WHPAs to protect groundwater (GW) supplies and three IPZs to protect surface water (SW) supplies. Table 2.6 also identifies whether the municipal groundwater supplies are sourced from overburden (GW-O) or bedrock (GW-B).

Figure 2.7 also shows the extents of source water protection areas for the Area of the Five Communities. Other than the Kincardine and Hanover surface water supplies there are no other source water protection areas that extend into the Communities from adjacent municipalities.

Table 2.6 Summary of Source Water Protection Areas in the Communities

Municipality	***Drinking Water System***	***Supply Type (GW-O, GW-B or SW)***
Municipality of Arran-Elderslie	Chesley Well Supply	GW-O, GW-B
	Tara Well Supply	GW-B
Municipality of Brockton	Walkerton Well Supply	GW-O, GW-B
	Chepstow Powers Subdivision Well Supply	GW-B
	Lake Rosalind Well Supply	GW-O
	Hanover Water Treatment Plant Well Supply	GW-O
	Ruhl Lake Water Supply (Hanover)	SW
Municipality of South Bruce	Mildmay Well Supply	GW-B
	Teeswater Well Supply	GW-B
Township of Huron-Kinloss	Lucknow Well Supply	GW-B
	Whitechurch Well Supply	GW-B
	Point Clark Well Supply	GW-B
	Blair’s Grove Well Supply	GW-B
	Murdock Glen Well Supply	GW-B
	Huronville Well Supply	GW-B
	Village of Ripley Well Supply	GW-B
	Kincardine Drinking Water System	SW
Town of Saugeen Shores	Saugeen Shores Water System (Southampton)	SW

3 GEOLOGY

3.1 Regional Bedrock Geology

The following sections provide an overview of the bedrock geology of southern Ontario, including its geological and tectonic history and a brief description of the Precambrian basement. This overview includes detailed descriptions of the Paleozoic stratigraphy of the Area of the Five Communities, also shown in Table 3.1. It should be noted that the Paleozoic stratigraphic nomenclature has evolved over time and a recent compilation by Armstrong and Carter (2010) provides the current standard for usage. Two key stratigraphic designations have recently been revised. Firstly, strata traditionally referred to as Middle Ordovician, i.e., Black River and Trenton groups (from Armstrong and Carter, 2006), are now considered part of the Upper Ordovician. Secondly, the formal term Middle Silurian (from Armstrong and Carter, 2006) has been abandoned so all strata have been re-assigned to either the Lower or Upper Silurian.

In addition, the stratigraphic nomenclature in Table 3.1 adopts the subsurface nomenclature of Armstrong and Carter (2010), while geological mapping as shown in Figure 3.2 uses an outcrop nomenclature. This distinction primarily applies to the Trenton and Black River groups, where the Bobcaygeon Formation (outcrop) is equivalent to the Coboconk and Kirkfield formations (subsurface), and the Verulam and Lindsay formations (outcrop) are approximately equivalent to the Sherman Fall and Cobourg formations (subsurface), respectively.

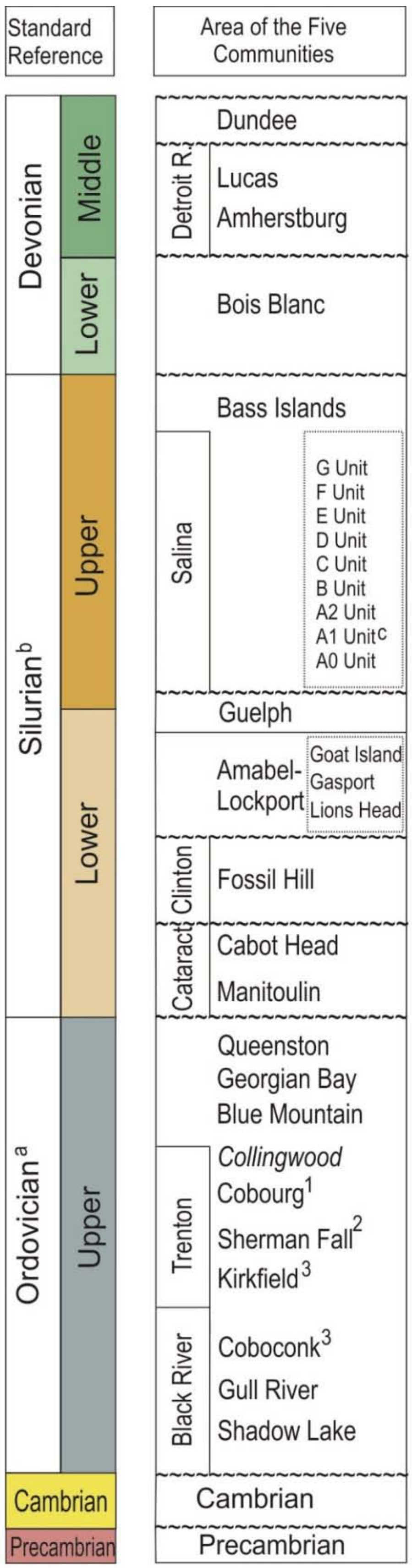
This section also provides overview descriptions of the current understanding regarding Paleozoic faults and fractures, diagenesis, karst and paleokarst distribution, glacial history and associated erosion for southern Ontario, as well as a discussion of the subsidence history of the Michigan Basin.

3.1.1 Geological Setting

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

The main geological features of southern Ontario are illustrated in Figure 3.1, after Armstrong and Carter (2010) and Johnston et al. (1992). Southern Ontario is underlain by two paleo-depositional centres referred to as the Michigan Basin and the Appalachian Basin. The Appalachian Basin is an elongate foreland basin that parallels the Appalachian orogen and comprises primarily siliciclastic sediments. The Michigan Basin is a broadly circular carbonate-dominated, evaporite-bearing intracratonic basin. These basins are separated by the northeast-trending Algonquin and Findlay arches which, along with the intervening east-southeast-trending Chatham Sag (CS) structural depression, define a regional basement high beneath southern Ontario and extending further southwestward into the northeastern United States. The Michigan Basin is also bounded, along its northwestern and northeastern flanks respectively, by the Fraserdale and Frontenac arches. These

Table 3.1 Stratigraphy of the Area of the Five Communities (after Armstrong and Carter, 2010)



Notes:
a - Strata traditionally referred to as Middle Ordovician (i.e,, Black River and Trenton groups; Armstrong and Carter, 2006) are now considered part of the Upper Ordovician.
b - The formal term Middle Silurian (e.g., Armstrong and Carter, 2006) has been abandoned so all strata have been re-assigned to either the Lower or Upper Silurian.
c - A-0 Unit (Salina Formation) is recognized based on site characterization activities at the Bruce nuclear site (Intera, 2011)

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

~~~~~ Unconformity
~~~~~

basement arches acted as structural and topographic controls on the depositional patterns within the basins during the Paleozoic Era (Johnson et al., 1992).

The Paleozoic sedimentary succession underlying the Area of the Five Communities was deposited within the Michigan Basin. Within the Michigan Basin the thickness of Paleozoic rocks range from a maximum of about 4,800 m at the centre of the basin (Johnson et al., 1992) to approximately 450 m at the northeast corner of the Area of the Five Communities (OGSRL, 2013). The Paleozoic strata dip gently (3.5 to 12 m/km) to the west or southwest throughout the southern Ontario portion of the Michigan Basin (Armstrong and Carter, 2010).

Figure 3.2 shows the bedrock geological map for southern Ontario and Figure 3.3 shows a vertically exaggerated cross-section through the Area of the Five Communities. The location of the cross-section is shown on Figure 3.2. The geological cross-section (Figure 3.3) shows the west-southwesterly dip of the Paleozoic sedimentary formations from the Niagara Escarpment in the east to below Lake Huron in the west. The large vertical exaggeration of 50 times used in Figure 3.3 results in apparent moderate formation dips when, in reality, the sedimentary formations within the Area of the Five Communities are almost flat lying with dips of 1º or less. These slight west-southwesterly dips result in outcrop or subcrop exposure of increasingly older sedimentary formations from west to east across southern Ontario, as shown on Figure 3.2.

3.1.2 Geological and Tectonic History

The structural and tectonic history of southern Ontario includes both Precambrian and Phanerozoic events. These events are described below, summarized in Table 3.2 and illustrated in Figures 3.4a and 3.4b.

Southern Ontario is located in the northeast part of North America and is part of the North American plate that extends from the mid-Atlantic Ridge in the east to the Juan de Fuca/Pacific plate margin in the west. The Precambrian Shield of North America and its cover of platform and intraplate basin sediments are considered to have been relatively tectonically stable since the early Paleozoic (Park and Jarozewski, 1994; Van der Pluijm and Marshak, 2004).

As mentioned in Section 3.1.1, the Paleozoic sedimentary sequence of southern Ontario lies unconformably on the Precambrian crystalline basement of the Grenville Province of the Canadian Shield. The Grenville Province is a complex orogenic belt that truncates several older geologic provinces. Basement rocks in southwestern Ontario have been affected by an approximately 1,210 to 970 million-year-old orogenic event, the Grenville Orogeny. The Grenville Orogeny is generally interpreted to have involved northwest-directed thrusting and imbrication of the entire crust, presumably as a result of a continent to continent collision with a continental landmass to the southeast. Older tectonic events, including the approximately 2,700 million year old Kenoran Orogeny and the approximately 2,000-1,700 million year old Trans-Hudson/Penokean Orogeny, built the proto-North American craton upon which Grenville deformation was imprinted (Easton, 1992). Post-Grenville extension associated with the initial opening of the Iapetus Ocean began about 750 million years ago (Thomas, 2006).

Table 3.2 Timetable of Major Tectonic Events in Southern Ontario

Million Years Before Present	*Tectonic Activity*	*Reference*
1,210 – 1,180	Regional metamorphism in Central Metasedimentary Belt Boundary Zone (see Figure 3.4b) (proto-Grenville)	Easton (1992), Lumbers et al. (1990), Hanmer and McEachern (1992)
1,109 – 1,087	Magmatism and formation of Midcontinent Rift	Van Schmus (1992)
1,030 – 970	Main phase of Grenville Orogeny	Carr et al. (2000), White et al. (2000)
970 – 530	Rifting and opening of the Iapetus Ocean	Thomas (2006)
530 – 320	Subsidence of Michigan Basin and Uplift of Frontenac and Algonquin Arches (episodic)	Howell and van der Pluijm (1999), Sanford et al. (1985), Kesler and Carrigan(2002)
470 – 440	Taconic Orogeny • E-W to NW-SE compression, uplift in foreland (Frontenac and Algonquin Arches)	Quinlan and Beaumont (1984), Sloss (1982), McWilliams et al. (2007)
410 – 320	Caledonian/Acadian Orogeny • E-W to NW-SE compression, uplift (Frontenac and Algonquin Arches)	Gross et al. (1992), Marshak and Tabor (1989), Sutter et al. (1985), Kesler and Carrigan (2002)
300 – 250	Alleghenian Orogeny • E-W to NW-SE compression	Gross et al. (1992), Engelder and Geiser (1980)
200 – 50	• Opening of the Atlantic Ocean • St. Lawrence rift system created • Reactivation of Ottawa-Bonnechère Graben • NE-SW extension • Uplift	Kumarapeli (1976, 1985)
Pre-50 - Present	• NE-SW compression (from ridge push) • Post-glacial uplift	Barnett (1992)

The erosional surface of the Precambrian basement rocks was produced by uplift and erosion of the Grenville orogen up until Cambrian times (about 540 to 490 million years ago), when the region experienced a marine transgression and the oldest Paleozoic sediments were deposited. Sediment accumulation was greatest in the Michigan and Appalachian basins and least above the intervening Algonquin Arch. Sedimentation in the Michigan Basin continued until the Mississippian, but was punctuated by periods of uplift and erosion marked by regional unconformities (Johnson et al., 1992).

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

Coincident with sediment deposition, the bedrock of southern Ontario was subjected to a complex history of Paleozoic tectonism,that included the Taconic (Ordovician), Caledonian/Acadian (Devonian) and Alleghenian (Carboniferous) orogenies (Howell and van der Pluijm, 1999). Subsequent events include the Mesozoic initiation of far field stresses associated with the opening of the Atlantic Ocean (Jurassic), compression from global-scale plate reorganization and ridge push (late Cretaceous-Eocene), and finally post-glacial uplift (Quaternary). Figure 3.4a, from Sanford et al. (1985), illustrates the major tectonic influences on southern Ontario and eastern North America since the late Proterozoic.

The most prominent tectonic zone boundaries in southern Ontario are defined based on aeromagnetic data and are: the southwestward continuation of the Grenville Front Tectonic Zone (GFTZ), which defines the westernmost boundary of the Grenville Province; and the Central Metasedimentary Belt Boundary Zone (CMBBZ, Figure 3.4b). The CMBBZ is an internal boundary within the Grenville Province that separates the rocks of the Central Gneiss Belt to the northwest from rocks of the Central Metasedimentary Belt to the southeast (Carter and Easton, 1990). Seismic reflection profiles image these structures dipping gently to moderately to the southeast (White et al., 1994; 2000). Although there is evidence of faulting coincident with the surface trace of the GFTZ in the area south of the Findlay Arch that was active during the Paleozoic (Ramsey and Onasch, 1999), in southern Ontario these basement structures appear to have been stable and inactive since the earliest Paleozoic (Milkereit et al., 1992). The southwestward extension of the CMBBZ coincides with several interpreted aeromagnetic linear features of the Precambrian basement identified by Boyce and Morris (2002) and Wallach et al. (1998). However, there is some uncertainty over the actual existence of some of these interpreted aeromagnetic linear features and whether they have expression in the overlying Paleozoic strata (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011).

3.1.3 Precambrian Geology

The geology of the Precambrian crystalline basement of the Grenville Province in southern Ontario has been well characterized by surface mapping north of the Paleozoic/Precambrian basement boundary (Figure 3.2), regional geophysical data (aeromagnetic and gravity), regional seismic reflection surveys and geochemical, geochronological and petrographic analyses of rock samples recovered from boreholes (O'Hara and Hinze, 1980; Green et al., 1988; Carr et al., 2000; Carter and Easton, 1990; Easton and Carter, 1995; Carter et al., 1996).

The Precambrian basement in southern Ontario has been grouped into two lithologic belts – the Central Gneiss Belt, located between the Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone, and the Central Metasedimentary Belt located southeast of the Central Metasedimentary Belt Boundary Zone (Figure 3.4b). The Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone are major subparallel shear zones several kilometres or more in width, characterized by strongly deformed rocks with northeast-trending, moderately to shallowly southeast-dipping tectonic layering and southeast plunging mineral lineations (Easton and Carter, 1995). Similar subparallel zones of intense deformation form boundaries between lithotectonic terranes within both the Central Gneiss Belt and Central Metasedimentary Belt (Easton and Carter, 1995).

Major tectonic zones in southern Ontario are defined by extrapolation of exposed basement structural boundaries beneath the Paleozoic cover. This process is aided by field mapping, borehole stratigraphic correlation, interpretation of seismic, aeromagnetic and gravity surveys (e.g., Boyce and Morris, 2002; Wallach et al., 1998), and by geochemical, geochronological and petrographic analyses of samples recovered from drill cuttings and core (Carter and Easton, 1990; Carter et al., 1996). Figure 3.4b illustrates the current understanding of tectonic zone boundaries and fault contacts for southern Ontario.

Based on aeromagnetic data and borehole samples, the Precambrian basement of the Central Gneiss Belt below the sedimentary rock cover has been subdivided into several lithotectonic domains and boundary zones similar in scale and form to those found where the Precambrian bedrock of the Grenville Province is exposed (Carter and Easton, 1990). Much of southern Ontario, including the Area of the Five Communities, is underlain by Precambrian crystalline basement of the Central Gneiss Belt and consists mainly of quartzofeldspathic gneissic rocks that have generally been metamorphosed to upper amphibolite facies, and locally to granulite facies. Most of these gneisses are believed to be plutonic in origin, with subordinate amounts of metasedimentary gneiss (Easton and Carter, 1995).

The Huron Domain, shown on Figure 3.4b, is a lithotectonic domain within the Central Gneiss Belt defined by Carter and Easton (1990), Easton and Carter (1995) and Carter et al. (1996) that acted as single crustal block during the Paleozoic (Easton and Carter, 1995). The Huron Domain underlies all of the Area of the Five Communities. It is defined based on lithologic data from boreholes and published aeromagnetic maps, and is described further in Section 3.2.1.1 based on published information and reinterpretation of geophysical data undertaken by PGW (2014) for the Area of the Five Communities.

3.1.4 Paleozoic Stratigraphy

Table 3.1 illustrates the Paleozoic bedrock stratigraphy for Area of the Five Communities (after Armstrong and Carter, 2010). The Paleozoic stratigraphy includes shale, carbonate and evaporite units formed predominantly from marine sediments that were deposited when this portion of eastern North America was located at tropical latitudes and intermittently covered by shallow seas (Johnson et al., 1992; Armstrong and Carter, 2010).

3.1.4.1 Cambrian

The Cambrian bedrock geology in southern Ontario is dominated by white to grey quartzose sandstone, with regional lithological variations that include fine to medium crystalline dolostone, sandy dolostone, and argillaceous dolostone to fine to coarse quartzose sandstone (Hamblin, 1999). Cambrian sedimentary rocks unconformably overlie the Precambrian basement. These sedimentary rocks are generally characterized as a succession of clastic and carbonate rocks resulting from transgressive Cambrian seas that flooded across the broad platform of the Algonquin Arch and into the subsiding Michigan and Appalachian basins (Hamblin, 1999). The Cambrian units are largely absent over the Algonquin Arch as the result of a pre-Ordovician regional-scale unconformity (Bailey Geological Services Ltd. and Cochrane, 1984a). The Cambrian unit is interpreted to pinch out eastwards, near the western boundaries of the Municipalities of Arran-Elderslie, Brockton and South Bruce (Bailey Geological Services Ltd. and Cochrane, 1984a), and thus is expected to be absent beneath the eastern and central parts of the Area of the Five Communities. There are no surface exposures of the Cambrian unit in southwestern Ontario.

3.1.4.2 Upper Ordovician

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

The lower carbonate unit of the Upper Ordovician succession is a thick sequence of predominantly limestone formations (carbonate and argillaceous carbonate sedimentary rocks), which include, from bottom to top: the Shadow Lake, Gull River and Coboconk formations of the Black River Group; and the Kirkfield, Sherman Fall, and Cobourg (including the Collingwood Member) formations of the Trenton Group (Table 3.1). These rocks range in character from coarse-grained bioclastic carbonates to carbonate mudstone with interbedded calcareous and non-calcareous shales. The Shadow Lake Formation, at the base of the Black River Group, is characterized by poorly sorted, red and green sandy shales, argillaceous and arkosic sandstones, minor sandy argillaceous dolostones and rare basal arkosic conglomerate. The lower part of the overlying Gull River Formation consists mainly of light grey to dark brown limestones and the upper part of the formation is very fine grained with thin shale beds and partings. The Coboconk Formation, at the top of the Black River Group, is composed of light grey-tan to brown-grey, medium to very thick bedded, fine to medium grained bioclastic limestones (Armstrong and Carter, 2010).

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

The upper unit of the Upper Ordovician succession is characterized by a thick sequence of predominantly shale sedimentary rocks, which comprise from base to top: the Blue Mountain, Georgian Bay and Queenston formations. The Blue Mountain Formation is characterized by uniform soft and laminated grey non-calcareous shale with minor siltstone and minor impure carbonate (Johnson et al., 1992; Hamblin, 1999). In the lower part of the Blue Mountain Formation there is downward gradation from grey to greenish-grey shales to a very dark grey to black shale (Armstrong and Carter, 2010). This lower part of the Blue Mountain Formation was historically named the Rouge River Member (Russell and Telford, 1983). The overlying Georgian Bay Formation is composed of blue-grey shale with intermittent centimetre-scale siltstone and limestone interbeds. The Queenston Formation is characterized by maroon, with lesser green, shale and siltstone with varying amounts of carbonate. The top of the Queenston Formation is marked by a regional erosional unconformity (Table 3.1; Armstrong and Carter, 2010).

3.1.4.3 Lower Silurian

The Lower Silurian units, including the Cataract and Clinton groups and the Amabel-Lockport and Guelph formations, unconformably overlie the Upper Ordovician shale units (Table 3.1). The Guelph Formation is the subcropping bedrock unit in the northeast part of the Municipality of Arran-Elderslie (Figures 3.2 and 3.6). A major marine transgression at the top of the Clinton Group marks the transition to deposition of the extensive carbonate-dominated Amabel and Guelph formations. These Lower Silurian units form the cap-rock of the Niagara Escarpment in outcrop. The Lower to Upper Silurian boundary occurs within the Guelph Formation (Table 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. Within the Area of the Five Communities the Cataract Group includes the Manitoulin Formation and the Cabot Head Formation. The Clinton Group is composed of thin- to medium-bedded, very fine- to coarse-grained fossiliferous dolostone. Within the Area of the Five Communities the Clinton Group includes the Fossil Hill Formation.

The Amabel-Lockport Formation includes a lower unit of light grey to grey-brown, finely crystalline, thin- to medium-bedded, sparingly fossiliferous dolostone with minor chert nodules. It also includes an upper unit of blue-grey, fine- to coarse-grained, thick bedded to massive dolostone, which locally contains minor dolomitic limestone. The 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. Within the Area of the Five Communities, the Amabel-Lockport Formation includes the Lions Head, Gasport and Goat Island units. The nomenclature of the Amabel-Lockport Formation is in transition with evolving stratigraphic naming provided by Johnson et al. (1992), Armstrong and Carter (2010) and Brunton et al. (2012).

The Guelph Formation varies from reefal to inter-reefal dolostones and dolo-mudstones (Armstrong and Goodman, 1990). Reefal facies represent pinnacle, patch and barrier reefs and their distribution defines the key aspects of the paleogeography during deposition. The widespread inter-reefal dolostones are typically sucrosic, dark brown to black dolo-mudstones with pebble-size fragments lithologically similar to the underlying Goat Island unit (Armstrong and Carter, 2006). Within the Area of the Five Communities, the Guelph Formation is characterized by facies deposited between the basinward pinnacle reef belt found along the eastern shore of Lake Huron, the patch reefs found in the central parts of the Area of the Five Communities, and the basin margin reef complex typically located in the eastern part of the Area of Five Communities (Johnson et al., 1992). Brintnell (2012) and Brunton et al. (2012) have proposed alternate depositional history and facies delineation for the Guelph Formation and its relationship to the underlying Lockport formations in Ontario and Michigan.

3.1.4.4 Upper Silurian

The Upper Silurian units include the evaporite and evaporite-related sedimentary rocks of the Salina Group, and the overlying dolostones and minor evaporites of the Bass Islands Formation (Table 3.1).

These rocks represent the subcropping bedrock within most of the Town of Saugeen Shores and the Municipality of Arran-Elderslie, and eastern parts of the municipalities of Brockton and South Bruce. 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, comprising Units A through G. The Salina Group salt beds (i.e., B, D, E and F Unit salts) have been dissolved in parts of southern Ontario, resulting in collapse structures within the overlying Silurian and Devonian strata (Sanford, 1993; 1976).

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

3.1.4.5 Lower and Middle Devonian

The Lower and Middle Devonian units unconformably overlie the Upper Silurian Bass Islands Formation and are dominated by carbonate sedimentary rocks of the Bois Blanc Formation, the Detroit River Group consisting of the Amherstburg and Lucas formations. The Bois Blanc Formation consists of cherty, fossiliferous limestones and argillaceous dolostones that unconformably overlie Silurian strata. The Lucas Formation is fine-crystalline, fossiliferous dolostone and limestone. The Amherstburg Formation is a bituminous bioclastic fossiliferous limestone and dolostone (Table 3.1). The Dundee Formation, which does not subcrop within the Communities, comprises sparsely fossiliferous limestones and minor dolostones that unconformably overly the Detroit River Group.

The Detroit River Group rocks represent the subcropping bedrock within western and central parts of the municipalities of Brockton and South Bruce and all of the Township of Huron-Kinloss (Figures 3.2 and 3.6). Devonian rocks are not present beneath the Municipality of Arran-Elderslie (Figures 3.2 and 3.6). The Devonian carbonates are found southwest of the Municipality and crop out along the shoreline of Lake Huron and north shoreline of Lake Erie (Figure 3.2).

3.1.5 Faulting and Fracturing of the Paleozoic Strata

Figure 3.2 shows basement-seated faults that displace the Paleozoic strata in southern Ontario. Faulting of the Paleozoic strata in southern Ontario is generally assumed to be sourced from faulting of the underlying Precambrian basement (Carter et al, 1996). Faults shown on Figure 3.2 were compiled from several sources by the Ontario Geological Survey (Armstrong and Carter, 2010) and given relative ages based on the youngest geological unit that is offset: i) Shadow Lake/Precambrian, ii) Trenton Group (Ordovician-aged) and iii) Rochester Formation (Silurian-aged). These faults are interpreted from vertical displacements of key unit-top surfaces in the Paleozoic strata of southern Ontario, based on earlier compilation and assessment work completed by Brigham (1971) and Bailey Geological Services Ltd. and Cochrane (1984a; 1984b). Vertical displacement of unit-top surfaces was identified primarily on hand contouring and interpretation of formation top data in the Petroleum Wells Subsurface Database from the Ontario OGSRL. Where these data are numerous, such as in the southwestern corner of southern Ontario, the faults are identified with a high degree of confidence, and are often named (e.g., Dawn Fault and Electric Fault, see Figure 3.4b). In areas where oil and gas exploration wells are widely spaced, such as in the Area of the Five Communities, faults are identified with a lower degree of confidence.

The borehole geophysical log and 2D seismic assessment (Geofirma Engineering Ltd., 2014) included an assessment of historic 2D seismic data, including seismic line 725937 in the Municipality of South Bruce. This seismic line also crosses a mapped subsurface fault previously identified as being of Trenton Group age (Figure 3.6). The reinterpretation of this seismic line identified a potential fault that extends upwards from the Precambrian basement into the base of the Silurian Cabot Head Formation. The coincidence between this interpreted seismic anomaly and the mapped subsurface fault provides a certain amount of confidence in the existence of a fault in the area crossed by the seismic line. However, given the poor quality and limited lateral resolution of the seismic data at this location, the confidence in the exact location and nature of this fault, including its upward continuation into the Silurian succession, is very low (Geofirma Engineering Ltd., 2014).

Sanford et al. (1985) proposed a conceptual fracture model for the Paleozoic bedrock of southern Ontario based on: surface lineament patterns derived from low resolution Landsat imagery; and information on subsurface faulting from formation top offsets based on hand contouring of borehole data. The Sanford et al. (1985) conceptualization of faulting of the Paleozoic bedrock identified two separate megablocks as distinct tectonic units with systematic fracturing: the Bruce Megablock and the Niagara Megablock. Figure 3.4b shows the conceptual megablock boundary. Within the Bruce Megablock, which includes the Area of the Five Communities, the conceptual fracture framework is characterized by east-southeast to east-west trending faults regularly spaced at distances of 10-15 km. There are questions concerning the validity of the fracture framework proposed for the Bruce Megablock as defined by Sanford et al. (1985) based on the reliability of the data used to define the fault occurrence, and the consistency of the faulting with other geological fault mapping information (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011). The Sanford et al. (1985) fracture and fault framework, at least for the Bruce Megablock, is not consistent with: other OGS fault mapping (Johnson et al., 1992; Armstrong and Carter, 2010), the lack of systematic offsets of structural contours of the Precambrian basement surface (Itasca Consulting Canada Inc. and AECOM Canada Ltd, 2011), known joint distributions for Paleozoic rocks in southern Ontario (NWMO and AECOM Canada Ltd, 2011), the lack of Paleozoic faulting in the area of the Bruce nuclear site that was subject to detailed site characterization (Intera Engineering Ltd., 2011), and the known absence of seismicity in the area (Hayek et al., 2011).

NWMO and AECOM Canada Ltd. (2011) and AECOM Canada Ltd. and Itasca Consulting Canada, Inc. (2011) summarize the available information on the genesis and orientation of fractures in southern Ontario from the geological literature. Cruden (2011) provides a similar summary for the Area of the Five Communities including the shoreline of Lake Huron near the Bruce nuclear site. As the majority of fractures observed in southern Ontario exhibit no measurable slip or dilation, they are considered to be joints (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011). The majority of joint planes measured in southern Ontario are in outcrops or shallow excavations such as quarries. Joint planes develop normal to minimum principal stress either due to pure tension, or extension due to compression. Joints in southern Ontario may form through three mechanisms: vertical compaction under conditions of high pore fluid pressure, tectonic loading events, and unloading and isostatic rebound (NWMO and AECOM Canada Ltd., 2011).

Although joint orientations have been observed to vary spatially across southern Ontario and to a lesser degree between major groups of Paleozoic formations (e.g., Cambrian, Ordovician, Silurian and

Devonian) some general observations are possible. It can be expected that most joints in Paleozoic rocks across southern Ontario will be vertical to sub-vertical. The regionally most persistent joint sets are oriented southeast, northeast and east-northeast, followed by joint sets oriented north-northeast and south-southeast (NWMO and AECOM Canada Ltd., 2011). In many locations joints are present as at least two major sets and two minor sets. The spacing and length of vertical joints observed at surface are typically on the order of metres (Andjelkovic et al., 1996; 1997; Andjelkovic and Cruden, 1998).

3.1.6 Michigan Basin Subsidence and Thermal History

The following is a summary of the Michigan Basin subsidence and thermal history, based on the current literature.

Based on studies of Ordovician diagenesis and stratigraphic relationships (Coniglio and William-Jones, 1992) and apatite fission track dating (Wang et al., 1994), burial-erosion curves for Ordovician carbonate rocks in the Michigan Basin of southern Ontario estimated maximum burial depths to range from 1,500 to 3,500 m, occurring during the Permian and Triassic about 200 to 300 million years ago. Based on these data, approximately 1,000 m of sediment was estimated to have been eroded from the Paleozoic succession during and after the late Paleozoic and early Mesozoic periods at the Bruce nuclear site (NWMO, 2011).

Thermal history of the Paleozoic rocks in southern Ontario was also estimated based on the above burial histories, geothermal gradients and conodont thermal alteration index studies. Legall et al., (1981) characterized two thermal alteration facies in the Paleozoic strata of southern Ontario. The first, from the top of the Paleozoic succession to the Upper Ordovician Trenton Group limestones, represents an organically immature to marginally mature facies that attained a maximum temperature of about 60º C. The second facies extends downward from the Trenton Group limestones and includes the Black River Group and the Cambrian. These rocks attained maximum burial temperatures of 60º to 90º C, suggesting organically marginally mature to mature facies. This interpretation is consistent with the observation that these same rocks beneath the Bruce nuclear site only barely reached the oil window in terms of hydrocarbon maturation (Intera Engineering Ltd., 2011).

3.1.7 Diagenesis

Several diagenetic processes have influenced or altered the Paleozoic rocks of southern Ontario since Cambrian times (Coniglio and Williams-Jones, 1992). The most significant of these is dolomitization, whereby calcite or aragonite is converted to dolomite by the replacement of calcium ions by magnesium ions. The primary dolomitization mechanisms recognized in southern Ontario (Morrow, 1990) are: sabhka type; mixed-water type; seepage reflux; burial compaction; and hydrothermal. The timing of dolomitization events in southern Ontario ranged from during or shortly after marine carbonate deposition during the Ordovician to Late Paleozoic/Early Mesozoic (ca. 450 to 250 million years ago), and or corresponding to maximum burial compaction (see Section 3.1.6 above). Hydrothermal dolomitization selectively altered the Paleozoic rocks along and adjacent to discrete fracture systems in response to tectonic events during the Paleozoic and early Mesozoic. Such dolomitization has been documented as occurring within the Trenton-Black River Group limestones of southwestern Ontario and Michigan (Davies and Smith, 2006). However, the conditions that led to dolomitization of southern Ontario carbonate rocks have not existed for last 200 to 250 million years

(Coniglio and Williams-Jones, 1992).

Other important post-dolomitization diagenetic phases include late stage calcite cements, Mississippi Valley Type mineralization, and late stage anhydrite and gypsum (Budai and Wilson, 1991; Coniglio et al., 1994). All of these diagenetic phases are volumetrically minor. Other diagenetic events, potentially locally important within the Paleozoic rocks of southern Ontario include salt dissolution and subsequent collapse features in overlying Upper Silurian and Devonian strata, clay alteration at the Precambrian-Paleozoic boundary, and hydrocarbon migration and emplacement (NWMO, 2011).

Salt dissolution in the Salina Group is identified at the margin of the Michigan Basin in a zone extending from the Bruce Peninsula south along Lake Huron and into southwestern Ontario. This process occurred during the late Silurian to Devonian (Caledonian Orogeny) and Late Devonian-Mississippian (Acadian Orogeny) (Sanford et al., 1985).

3.1.8 Karst and Paleokarst

Worthington (2011) and Brunton and Dodge (2008) provide a summary of the formation processes and occurrences of karst and paleokarst in southern Ontario carbonate rocks. The following is a summary of the information in these reports.

Rocks such as carbonates and evaporites are eroded principally by dissolution, part of the process of karstification. This process, to a great extent, is a function of the flux of water through an aquifer and the chemical undersaturation of that water with respect to minerals that comprise the aquifer solids. Consequently, karstification tends to be most pronounced at shallow depths below the surface, where most of the permeability of carbonates and evaporites is created by dissolution.

In southern Ontario karstification is most active in the shallow subsurface, usually down to approximately 200 m depth. Dissolution of Devonian carbonates can potentially reach down to about 300 m depth in southern Huron County and western Perth County, south of the Area of the Five Communities. Deep Upper Silurian carbonates are unlikely to be affected by karstification due to increased groundwater salinities caused by anhydrite and salt dissolution, and the deeper Ordovician limestones in southern Ontario are unaffected by modern karstification processes (Worthington, 2011).

The OGS map of karst distribution in Paleozoic strata throughout southern Ontario (Brunton and Dodge, 2008; Figure 3.5) identifies the following areas of known karst in the shallow subsurface of:

- Ordovician, Silurian and Devonian age rocks in the Bruce Peninsula region, and near Owen Sound (see Figure 3.5);
- Ordovician carbonates cropping out to the south of the Canadian Shield that extend into eastern Ontario;
- Silurian carbonates exposed along the Niagara Escarpment;
- The aquifer formed by the Amable-Lockport and Guelph formations in some locations such as Guelph;
- Evaporite units of the Salina Group; and

- Devonian carbonates in southwestern Ontario, particularly in areas where there is a deep unsaturated zone (>100 m).

Brunton and Dodge (2008) define inferred karst as regions of carbonate rocks most vulnerable or susceptible to karstification where direct field observations have not been made by OGS staff or other sources. Potential karst is defined as areas of carbonate rocks most susceptible to karst processes. Based on Figure 3.5, there are very minor known occurrences of near-surface karst within the Municipality of Arran-Elderslie and the Township of Huron-Kinloss, and no known occurrences within the Town of Saugeen Shores, and the municipalities of Brockton and South Bruce. Brunton and Dodge (2008) document the occurrence of a significant near-surface karst feature near the shoreline at Douglas Point in the vicinity of the Bruce nuclear site. Identification of this significant karst occurrence is likely due to the limited drift cover near the shoreline. Figure 3.5 also shows that all of the Communities include areas of inferred and/or potential near-surface karst.

Paleokarst is a rock that has been karstified and subsequently buried by later deposition. In most instances, paleokarst porosity has been infilled with younger sediments and secondary minerals, such as evaporites (salt, gypsum and anhydrite). In southwestern Ontario, some interpreted paleokarst zones that have not been occluded by cements or evaporites form hydrocarbon reservoirs. The potential for paleokarst zones is greatest at large breaks in the sedimentary record that defines regional erosional unconformities (e.g., Silurian - Devonian boundary).

Worthington (2011) summarizes the potential for karst and paleokarst within the Area of the Five Communities based on assessment of the Bruce nuclear site. He concludes that multiple lines of evidence support the assertion that the upper approximately 180 m of bedrock beneath the Bruce nuclear site are karstic. Higher-permeability confined intervals at depths of about 326 to 329 mBGS (Salina A1 dolostone) and 375 to 379 mBGS (Guelph Formation) also show evidence of potential karstification. No evidence for karstification in deeper strata at the site was found in the documents reviewed. The deeply buried Ordovician carbonates are unlikely to be affected by modern karstification processes and have extremely low hydraulic conductivities. Furthermore, the presence of significant underpressures or overpressures in the strata between the elevation of the Ordovician carbonates and the surface suggest that there is an absence of high-permeability karstic pathways between the Ordovician carbonates and the surface.

3.1.9 Glaciations and Glacial Erosion

The North American continent has been subject to nine glacial events in the last million years (Peltier, 2011). These past glacial events markedly altered the landscape and physiography of southern Ontario, and created significant perturbations on the sedimentary sequence and regional groundwater flow systems (NWMO, 2011).

The Late Pleistocene Laurentide Ice Sheet that developed in the Arctic and advanced over most of Canada into the United States was the most recent of the major glacial events to affect southern Ontario. It began about 120,000 years ago. At last glacial maximum, approximately 25,000 years ago, the Laurentide Ice Sheet exceeded 2,800 m in thickness over most of the glaciated regions of the continent including southern Ontario. Within the Great Lakes region, as the ice sheet retreated 14,000 years ago, glacial meltwaters from the retreating ice filled erosional depressions that evolved into the modern day Great Lakes Basin. The weight of the ice sheet depressed the ground surface in southern

Ontario by approximately 500 m (Peltier, 2011). After the ice retreated, the ground surface rebounded in a process known as glacio-isostatic rebound, a process that is still occurring today. In the Bruce region this adjustment increases northward with uplift rates of 1.5 mm/year. Conversely, this adjustment induces subsidence to the south of the Great Lakes Basin at about the same rate, resulting in the slight upward tilting of the continent in the north.

Deglaciation of the Great Lakes Basin occurred as the margin of the Laurentide Ice Sheet retreated generally in a northeasterly direction in series of pulses, first exposing the Lake Erie basin approximately 15,500 years ago and finally the Lake Superior basing about 9,500 years ago (Dyke et al., 2003). During this retreat, a series of ice-marginal and proglacial lakes formed shorelines of different ages that are upwarped today toward the north-northeast in the direction of thicker and longer lasting ice. JDMA (2014) provides a description of these ice-marginal and proglacial lakes that are responsible for much of the mapped Quaternary geology in southern Ontario (see also Section 3.2.3).

Hallet (2011) provides an assessment of glacial erosion rates for southern Ontario, including the Area of the Five Communities. The study by Hallet (2011) concluded that although uncertainties remain in ice sheet reconstructions and estimates of erosion by ice and melt water, all lines of study indicate that, in southern Ontario, glacial erosion would not exceed a few tens of metres in 100,000 years with a conservative estimate of 100 m per 1 million years for the Bruce nuclear site.

Eyles (2012) discusses glacial erosion processes for the Ordovician and Silurian dolostones of the Bruce Peninsula and Manitoulin Island north of the Area of the Five Communities. He observed the occurrence of a distinct hard bed landform assemblage of rock drumlins, megagrooves and megaflutes within the north-facing escarpments that were cut into the dolostones by fast flowing ice of the late Wisconsinan (about 18,000 years ago) advance of the Laurentide Ice Sheet. Eyles (2012) concludes that the geomorhoplogy of the Niagara Escarpment does not primarily reflect a lengthy history of preglacial Cenozoic (2 – 63 million years ago) fluvial erosion, but instead shows geologically-brief episodes of accelerated abrasion and quarrying below ice streams within successive Pleistocene ice sheets.

Gao (2011a; 2011b) based on compilation, review and analysis of borehole, petroleum well and water well information, mapped regional buried bedrock valleys in southern Ontario. One of the regional buried bedrock valleys extends from Wellesley, through Milverton to Wingham (the Wingham – Milverton Valley). Another extends from Drayton to Mount Forest (the Mount Forest Valley). These buried bedrock valleys are located south and east of the Area of the Five Communities, with the exception that the northern limit of the Wingham-Milverton Valley extends slightly into the southcentral part of the Area of the Five Communities at Wingham. Gao (2011a, 2011b) identifies a complex of bedrock valleys including the Walkerton trough within the Area of the Five Communities, located east and west of Walkerton that extend northwest to Lake Huron (Figure 3.23). He also maps the buried Onondaga Escarpment that coincides with the western extent of the Walkerton trough within the Area of the Five Communities. JDMA (2014) present drift thickness mapping and identification of buried bedrock valleys within the Area of the Five Communities. Gao (2011b) concluded that large linear bedrock depressions in southern Ontario likely resulted from glacial and/or subglacial meltwater erosion, and that faults were not the controlling factor in the development of these morphometric features.

3.2 Local Bedrock and Quaternary Geology

Bedrock and Quaternary geology of the Area of the Five Communities is described in this section based on studies completed as part of detailed site characterization work at and near the Bruce nuclear site (Intera Engineering Ltd., 2011; NWMO, 2011). Information is also drawn from supporting technical studies completed as part of this preliminary assessment (PGW, 2014; Geofirma Engineering Ltd., 2014; JDMA, 2014) to provide insight on the characteristics of the Paleozoic Upper Ordovician shale and limestone units identified as potentially suitable in the initial screenings (AECOM, 2012a; 2012b; 2012c; 2012d; 2012e).

The presentation of the local bedrock and Quaternary geology in this section is focused on the Area of the Five Communities. Figure 3.6 shows the bedrock geology, oil and gas wells, and acquired 2D seismic data in the Area of the Five Communities. Figure 3.7 shows the bedrock geology, oil and gas wells, and the acquired 2D seismic data, as well as the location of geological cross-sections constructed through the Communities as part of this assessment. Figure 3.7 is presented at a slightly larger scale to accommodate wells used in the construction of the geological cross-sections that are located outside of the Area of the Five Communities.

3.2.1 Precambrian Geology

3.2.1.1 Lithotectonic Domains

As described in Section 3.1.4, the Huron Domain of the Precambrian Central Gneiss Belt in the Grenville orogen underlies the entire Area of the Five Communities (Figure 3.4b). In southern Ontario, this crystalline basement domain is lithologically dominated by quartzofeldspathic rocks varying in composition from granitic to monzonitic to tonalitic in composition (Easton and Carter, 1995). Based on available core these rocks are strongly gneissic with some isolated high quartz contents suggestive of metaclastic rocks and some isolated occurrences of dioritic and gabbroic rocks (Carter and Easton, 1990). Drilling at the Bruce nuclear site identified the Precambrian basement as pink to grey, fine- to medium-crystalline felsic granitic gneiss with major minerals of quartz, K-feldspar and biotite (Intera Engineering Ltd., 2011), confirming the general lithological conclusion by Carter and Easton (1990). Uranium-lead dating of zircons in the Precambrian basement core recovered from the Bruce nuclear site yielded ages of 1,526 to 1,371 million years (NWMO, 2011), which are in the range expected for the Huron Domain (Easton, 2008).

As part of the geophysical interpretation study (PGW, 2014), the available magnetic and gravity data were interpreted in the Area of the Five Communities. Figures 3.8 to 3.10 show the distributions of magnetic and gravity features located within the Area of the Five Communities. Both the magnetic data (Figures 3.8 and 3.9), and gravity data (Figure 3.10) for the Area of the Five Communities are based on merging of high-resolution and low-resolution data sets. This merging of data sets creates linear or irregularly-shaped features along the data set boundaries that are entirely due to the stitching of data sets. For example, the north-trending line that extends through the Township of Huron-Kinloss was created entirely due to data set stitching.

In the Area of the Five Communities, it is assumed that the majority of the observable magnetic response is generated from the Precambrian basement rocks, and the overlying sedimentary units are considered magnetically transparent. This is consistent with the interpretation of magnetic data over

Lake Huron by O'Hara and Hinze (1980), as discussed below.

Magnetic data covering Lake Huron show a distinct magnetic high that is parallel to the trend of the Grenville Front Tectonic Zone (e.g. O'Hara and Hinze, 1980; Boyce and Morris, 2002; PGW 2014). In the central portion of the Area of the Five Communities, the enhanced magnetic data display curvilinear to elliptical magnetic anomalies that are interpreted as areas of ductile deformation that is preserved in the Precambrian basement (PGW, 2014). These ductile features are interpreted as being associated with the internal fabric of the crystalline basement and likely include tectonic foliation or gneissosity. Interpretations derived from the magnetic data were compared to results from available literature on basement lithology of the Grenville Province in southern Ontario (e.g. O'Hara and Hinze, 1980; Turek and Robinson, 1982; Carter and Easton, 1990; Easton and Carter, 1995; Carr et al, 2000; Boyce and Morris, 2002), as well as on the Precambrian basement rocks exposed further to the northeast of the Area of the Five Communities (Easton, 1992). Based on subtle variability of character and pattern of the magnetic data observed in the Area of the Five Communities, the Precambrian basement has been subdivided into domains which may reflect changes in basement lithology or lithotectonic domains (Figure 3.8; PGW, 2014).

The observed Bouguer gravity data over the Area of the Five Communities exhibit mainly broad responses that are attributed to spatial variability in lithology of the Precambrian basement (PGW, 2014). Similar assumptions have been made elsewhere in southern Ontario where the gravity responses are attributed to the Precambrian basement (O'Hara and Hinze, 1980). The resulting responses display a significant gravity high on the western portion of the Area of Five Communities, which broadly trends in the northeastern direction and corresponds fairly well to the magnetic data. This gravity high has been suggested to indicate a significant thickening of the Precambrian basement rocks associated with the Grenville Front Tectonic Zone (Easton, 1992). The gravity data in the central portion of the Area of the Five Communities show a significant lower gravity response, which may reflect a thinning of the Precambrian basement in this portion of the area. The first vertical derivative of the Bouguer gravity shows clear wavy to curvilinear features that display similar trends and texture as the magnetic data. These features may correspond to ductile patterns of the Precambrian basement rocks (PGW, 2014).

3.2.1.2 Faults

The presence and nature of faults within Precambrian basement in the Area of the Five Communities are poorly defined. Boyce and Morris (2002) mapped aeromagnetic and gravity lineaments in southern Ontario, including the Area of the Five Communities. These authors interpreted the identified lineaments as zones of shearing and faulting in the Precambrian basement underlying the Paleozoic sedimentary sequence in southern Ontario. The data and lineament interpretation of Boyce and Morris (2002) have been reviewed as part of this assessment based on the newly purchased higher resolution aeromagnetic and gravimetric data (see Section 1.4.2, and PGW, 2014). Figure 3.8 shows the pole-reduced, first vertical derivative of total magnetic intensity for the Area of the Five Communities. Figure 3.9 shows the aeromagnetic data together with the Boyce and Morris aeromagnetic lineaments and OGS-mapped subsurface faults within the Paleozoic sediments. Figure 3.10 shows the first vertical derivative of Bouguer gravity data within the Area of the Five Communities (PGW, 2014).

Data processing used in this preliminary assessment is similar to that used by Boyce and Morris (2002) in the identification of aeromagnetic and gravity lineaments. However, interpretation of magnetic lineaments by Boyce and Morris (2002) was based on regional, 805 m flight line spacing aeromagnetic data, while interpretation of lineaments from gravity data used a much lower resolution regional gravity data set compared to the one used in this assessment.

The Boyce and Morris (2002) lineament interpretation, in general, does not agree well with the aeromagnetic data at the scale of the Area of the Five Communities. This lack of coincidence is largely due to the differences in interpretation scale between the Boyce and Morris (2002) study versus this assessment, as well as the overall low-resolution of the magnetic data used for interpretation. Where the Boyce and Morris (2002) lineaments were identified in the Area of the Five Communities, they predominantly comprise curved to circular lineaments that appear to align with the aeromagnetic data used for this assessment (Figure 3.9), and are interpreted as most likely lithologically-related magnetic anomalies, and or reflective of the ductile fabric of the Precambrian basement (PGW, 2014), as opposed to cross-cutting brittle fault structures (e.g., within the southwestern part the Township of Huron-Kinloss). The most significant aeromagnetic lineament interpretated by Boyce and Morris (2002) within the Area of the Five Communities is associated with the Grenville Front Tectonic Zone (GFTZ) within Lake Huron.

As described in Section 3.1.5, basement-seated faults that displace the Paleozoic strata in southern Ontario have been compiled by Armstrong and Carter (2010). These faults are interpreted to originate in the Precambrian basement and propagate upwards through the Paleozoic sequence (Carter et al, 1996), and are classified based on the youngest geological unit that is offset. Figures 3.6 and 3.9 show the two subsurface faults mapped in the Area of the Five Communities. Review of Figure 3.9 shows that the mapped subsurface faults are not observed in the regional aeromagnetic data and are not comparable to the Boyce and Morris aeromagnetic lineaments. Section 3.2.2.4 describes in detail the Paleozoic basement-seated faults present within the Communities.

3.2.2 Paleozoic Geology

3.2.2.1 Formation Descriptions

Detailed lithological descriptions of the Paleozoic formations within the Area of the Five Communities are not available from the OGSRL Petroleum Wells Database (OGSRL, 2013), as such wells are usually not continuously cored. However, in southern Ontario the lithology of the Paleozoic formations is generally similar over large distances, and therefore descriptions provided in Section 3.1.4 (based mainly on Armstrong and Carter, 2010) are indicative of what can be expected for the Area of the Five Communities. Detailed descriptions of the Paleozoic stratigraphy are available from logging of continuously cored boreholes drilled at the Bruce nuclear site (Intera Engineering Ltd., 2011). These are generally consistent with those of Armstrong and Carter (2010).

3.2.2.2 Formation Depth and Thickness

The assessment of the depth and thickness of Paleozoic formations within the Area of the Five Communities is mostly based on interpretation of available borehole geophysical and 2D seismic data interpretation work (Geofirma Engineering Ltd., 2014) carried out as part of this assessment. One of the main objectives of Geofirma Engineering Ltd. (2014) was to reinterpret the depth of key formation tops using borehole geophysical data available from the OGSRL Database. Eight key formations tops were defined (Geofirma Engineering Ltd., 2014) based on:

- Ability to interpret them using borehole geophysical data and to consistently trace them throughout the Area of the Five Communities and surrounding region;
- Geological significance of the Paleozoic formation packages defined by these key formation tops for the overall objective of the geoscientific desktop preliminary assessment; and,
- Grouping of Paleozoic formations to provide a reasonable dataset for use in gravity stripping (PGW, 2014).

The set of eight key formation tops was reinterpreted in 111 wells in the Area of the Five Communities and surrounding region for which useful gamma ray and/or neutron logs were available, 37 of which are located within the Area of the Five Communities. An updated database was then compiled for the key formation tops, including: key formation tops reinterpreted using borehole geophysics; and historical key formation tops picks from the OGSRL database for those wells where no geophysical data is available. Geofirma Engineering Ltd. (2014) describes the methodology for selecting the key formation tops, and the rationale for their reinterpretation from geophysical data.

The updated database of key formation tops was used to construct six geological cross-sections through the Communities (Figures 3.11 to 3.13) to better illustrate the depths and thicknesses of the key Paleozoic stratigraphic packages (Geofirma Engineering Ltd., 2014). The Cambrian sandstone is not a key formation identified with confidence in the OGSRL database, however the interpreted subsurface distribution is shown in Figures 3.11 to 3.13. Figure 3.20 also shows the interpreted subsurface distribution of the Cambrian sandstone across the Area of the Five Communities.

Figure 3.7 shows the location of each of these cross-sections. The orientation and position of each cross-section was defined to maximize subsurface coverage both approximately parallel and perpendicular to the regional northwesterly strike of formations across the Area of the Five Communities. In creating the cross-sections, an effort was taken to utilize primarily those boreholes with available geophysical data as control points. However, due to the limited availability of borehole geophysical data, additional boreholes without accompanying geophysical data were also used in constructing the cross-sections. In these latter cases, historical interpretations of the key formation tops from the OGSRL database were used. Solid and dashed lines are utilized to indicate where confidence was higher versus lower in extending key formation top surfaces across the cross-sections. The geological cross-sections in Figures 3.11 to 3.13 also show the bedrock surface from Gao (2006), the ground surface from a smoothed DEM (Geofirma Engineering Ltd., 2014), gamma ray logs when available, and the extent of the Communities.

Figures 3.11 to 3.13 show that the Upper Ordovician shale and limestone packages exhibit relatively uniform thicknesses (i.e., about 200 m each) regardless of the orientation of the cross-sections, thus highlighting the lateral uniformity of both key formation packages beneath the Area of the Five Communities. The Silurian formation package shows some variability in total thickness, most likely due to:

- The understanding that the top of the Bass Islands Formation is a regional unconformity (e.g., Armstrong and Carter, 2010);

- Salt dissolution throughout the Salina Group, which would have induced substantial, and likely heterogeneous thinning of the Silurian formation package; and
- The existence of several types of reef facies (e.g., pinnacle, patch, barrier) in the Guelph Formation across the Area of the Five Communities.

Paleozoic formations in the Area of the Five Communities are known to dip uniformly to the southwest at between 0.23° and 1° (e.g., Watt et al., 2009; Intera Engineering Ltd., 2011). The inflections in the dips of key formation tops observed in the cross-sections are an artefact rather than actual variability in the dip of the layering. This is because none of the cross-section lines is uniformly parallel or perpendicular to the strike of the layering. Note also that the dips are also magnified by the 25X vertical exaggeration employed in the construction of the cross-sections. Based on the cross-sections it is not possible to interpret any basement-seated fault structures in the Paleozoic sequence. This is mainly due to the sparse distribution of available boreholes.

The cross-sections presented in Figures 3.11 to 3.13 provide the best possible representation of the subsurface geometry based on the limitations of the available data. It is important to note that all of the cross-sections constructed during this assessment are comparable in terms of geometry and formation package thickness to information from the work done as part of the detailed site characterization of the Bruce nuclear site (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011; NWMO, 2011).

Table 3.3 shows the depth of the different Paleozoic formation tops in the wells within the Communities and highlights the key formation tops that were reinterpreted in wells where geophysical data were available. The data summarized in this table are based on the updated database of key formation tops (Geofirma Engineering Ltd., 2014), which used data from boreholes in the Area of the Five Communities and surrounding area to generate contour maps for the top of the Coboconk, Cobourg and Queenston formations.

All contoured formation tops were created using the iterative minimum curvature gridding method with a grid cell size of 500 meters (Geosoft, 2012), with the exception of the Cobourg Formation and Precambrian surfaces. The Cobourg Formation and Precambrian surfaces were computed with a grid cell size of 1,000 m. This larger cell size for these surfaces is based on a fewer number of boreholes which intersects these two surfaces. Surfaces were generated using a minimum curvature gridding tolerance of 0.001 and percent-pass tolerance of 99.99% with a blanking distance between 20 and 40 km. Figures 3.17, 3.18 and 3.19 show isopach maps for the Black River Group, Trenton Group and the Upper Ordovician shales. These contoured thicknesses were determined as the difference between the formation top depth surfaces.

The depth contour and isopach maps shown on Figures 3.14 to 3.19 illustrate depth and thickness variations of the Paleozoic units in the Area of the Five Communities. Figure 3.14 shows that the depth to the top of the Coboconk Formation ranges from approximately 450 mBGS to 900 mBGS in the Communities. The thickness of the Black River Group within the Communities is relatively uniform and on the order of 70 to 100 m (Figure 3.17). Depth to the top of the Cobourg Formation ranges from about 350 mBGS in the northern corner of the Municipality of Arran Elderslie to approximately 800 mBGS in the Township of Huron-Kinloss (Figure 3.15). Thickness of the Trenton Group within the

Table 3.3 Summary of Bedrock Formation Top Depths within the Communities (in mBGS)

Standard Reference		Geological Unit	Municipality of Brockton						Municipality of South Bruce			
		OGSRL Well ID	***F012088***	***F012089***	***F012090***	***F012093***	***T002730***	***T004854***	***F012062***	***F012068***	***F012077***	***T004881***
		Date Drilled	*1948*	*1948*	*1948*	*1948*	*1969*	*1979*	*1942*	*1941*	*1941*	*1978*
		Total Depth (mBGS)	*75.29*	*26.52*	*64.01*	*35.05*	*428.56*	*892.8*	*869.6*	*322.79*	*276*	*881.5*
Devonian	Middle	Lucas / Amherstburg Formation					36.6	76.5	9.5	24.1	29.0	19.8
	Lower	Bois Blanc Formation					134.4	117.7	82.0	45.4	59.1	100.9
Silurian	Upper	Bass Islands*	5.2	1.5		3.7	160.3	150.6	136.6	92.7	117.7	130.8
		Salina G Unit*	21.6	9.1		20.4	189.1	189.6	177.1	133.2	156.7	172.5
		Salina F Unit*					197.1	196.9				181.4
		Salina E Unit	50.6				231.7	240.2	217.3	171.0	192.0	225.6
		Salina C Unit	78.9				263.4	270.1	248.4	207.9	225.3	254.8
		Salina B Unit					282.6	285.9				268.2
		Salina A-2 Unit					306.3	312.1	282.9	242.9	253.6	295.4
		Salina A-1 Unit					334.1	340.8	316.7	274.9	284.1	320.4
	Upper / Lower	Guelph Formation					379.5	391.4	359.7	317.0	329.8	365.5
	Lower	Reynales / Fossil Hill Formation					424.9	427.0	393.2			
		Cabot Head Formation*					427.1	435.3	402.7			406.7
		Manitoulin Formation						453.3	419.4			425.5
Ordovician	Upper	Queenston Formation*						462.1	428.9		428.9	434.1
		Georgian Bay / Blue Mtn Formation						542.0	504.8		525.2	515.7
		Collingwood Member*						678.8	625.8		609.6	658.1
		Cobourg Formation						692.8	657.5		659.9	673.4
		Sherman Fall Formation						721.2	700.4			705.9
		Kirkfield Formation						773.6	748.6			760.5
		Coboconk Formation*						807.1	789.7			795.9
		Gull River Formation						830.9	802.5			816.3
		Shadow Lake Formation						882.7	861.1			870.8
Precambrian		Precambrian*						888.5	867.8			874.5

*Note: * and shading indicate Key Formations*

Table 3.3 Summary of Bedrock Formation Top Depths within the Communities (in mBGS) (Continued)

Standard Reference		Geological Unit	Township of Huron-Kinloss							Town of Saugeen Shores		
		OGSRL Well ID	**F012061**	**F012063**	**F012066**	**F012078**	**T002663**	**T003535**	**T003553**	**T001720**	**T001720A**	**T001892**
		Date Drilled	*1956*	*1959*	*1956*	*1955*	*1969*	*1973*	*1978*	*1964*	*1964*	*1965*
		Total Depth (mBGS)	*1020.6*	*568.1*	*566.3*	*506.9*	*607.8*	*582.5*	*509.6*	*315.1*	*718.8*	*769.6*
Devonian	Middle	Lucas / Amherstburg Formation	47.2	26.8	26.2	39.0	49.4	64.3	65.5			
	Lower	Bois Blanc Formation	139.6	138.4		106.4	153.0	164.3	175.9			
Silurian	Upper	Bass Islands*	199.9	198.4	182.3	162.2	214.3	183.2	208.5			44.5
		Salina G Unit*	250.8	241.9	222.4	201.4	267.6	232.3	247.5			71.1
		Salina F Unit*		250.4	230.4	208.2	277.1	241.0	255.1			81.1
		Salina E Unit	305.7	285.9	258.5	254.5	311.2	276.8	291.1	60.7	68.0	119.5
		Salina C Unit	319.4	314.6	296.6	276.5	352.7	307.5	326.1	84.7	83.3	151.5
		Salina B Unit	369.7	342.0	316.4		368.5	314.9	344.4			
		Salina A-2 Unit	421.5	414.2	353.9	299.9	450.2	370.0	388.0	114.3	113.4	177.4
		Salina A-1 Unit	477.9	506.6	380.4	317.3	518.8	400.8	424.6	136.6	137.8	204.6
		Guelph Formation	516.0	522.4	426.1	331.6	566.6	418.8	471.5	140.2	140.9	210.0
	Lower	Reynales / Fossil Hill Formation	540.7	548.6	557.2			565.1		264.0	269.5	314.3
		Cabot Head Formation*	550.4	560.8	561.8		600.1	576.8		281.0	283.4	330.1
		Manitoulin Formation	570.9							290.8	290.2	337.4
Ordovician	Upper	Queenston Formation*	580.0								310.4	359.1
		Georgian Bay / Blue Mtn Formation	657.7								361.5	416.7
		Collingwood Member*	773.6								521.4	570.1
		Cobourg Formation	804.1								534.9	582.6
		Sherman Fall Formation	840.6								565.8	612.4
		Kirkfield Formation	890.9									
		Coboconk Formation*									640.1	688.6
		Gull River Formation	932.1									697.1
		Shadow Lake Formation	1009.8								709.9	756.8
Precambrian		Precambrian*	1016.5								713.4	768.1

*Note: * and shading indicate Key Formations*

Communities is also relatively uniform and on the order of 100 to 130 m (Figure 3.18). Within the Communities depth to the top of the Upper Ordovician shales (i.e. top of the Queenston Formation) ranges from approximately 150 mBGS to almost 600 mBGS (Figure 3.16), with a relatively uniform total thickness of the Upper Ordovician shale units ranging from approximately 200 m to 250 m based on borehole logs from within the Area of the Five Communities (Figure 3.19).

Erosion, pinnacle reef formation and salt bed dissolution introduce a certain degree of non-uniformity into the Paleozoic sequence in the Area of the Five Communities, mostly in relation to the thickness and presence/absence of certain formations. For example, due to the regional dip of the Paleozoic units and erosion there are no Devonian formations present within the Municipality of Arran-Elderslie, most of the Town of Saugeen Shores and part of the Municipality of Brockton (Figures 3.6 and 3.20). For the same reasons, the thicknesses of subcropping bedrock units will locally vary, as shown in the cross-sections on Figures 3.11 to 3.13. The Cambrian unit in the Area of the Five Communities is interpreted to pinch out eastwards from the shores of Lake Huron and is expected to be absent beneath most of the Municipalities of Arran-Elderslie, Brockton and South Bruce (Figure 3.20; Section 3.1.4.1).

As described in Section 3.1.4.3, the lithology of the Guelph Formation varies from reefal to inter-reefal dolostones, with reefal facies including pinnacle, patch and barrier reefs of variable dimensions. The presence of different types of reefal facies introduces variations in the thickness of the Guelph formation locally (Figure 3.20). Figure 3.20 also shows the extent of the Salina B Unit salt beds and areas of salt bed dissolution. In the Area of the Five Communities, the Salina B salt unit is only present in the Township of Huron-Kinloss and the southwest corner of the Municipality of Brockton. The Salina B salt unit is part of the Salina B Unit that also includes other carbonate and anhydrite strata. Minor thicknesses of other Salina salt beds may be present in the other Communities. Where salt dissolution occurred, there is the potential to have collapse structures in the overlying formations.

3.2.2.3 Pinnacle Reefs

Section 3.1.4.3 describes the variable lithology (i.e. reefal to inter-reefal) of the Guelph Formation and the distribution of the reefal facies in southern Ontario. The majority of southern Ontario's pinnacle reefs occur within the Silurian-aged "pinnacle reef belt" located primarily in Lambton County and Huron County (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011). Pinnacle reefs have heights up to 128 m above the regional inter-pinnacle surface (McMurray, 1985) and they originate within the Guelph Formation. In map view, pinnacle reefs can range from 10's of hectares up to 120 hectares or approximately 1000 m in maximum diameter (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011).

The Area of the Five Communities lies in portions of the pinnacle to patch to barrier reef zones of the Guelph Formation. Known locations of pinnacle reefs (OGS, 2011b) in the Area of the Five Communities are shown on Figure 3.20. The locations of such known reefs are defined based on thickening of the Guelph Formation from borehole observations. As described in Section 5.1.2, pinnacle reefs in the Guelph Formation often host hydrocarbon pools in southern Ontario. There are 12 known pinnacle reefs identified in the Area of the Five Communities (OGS, 2011a), three and two of which lie within the Township of Huron-Kinloss and the Town of Saugeen Shores, respectively (Figure 3.20). The pinnacle reefs in these two communities do not have proven hydrocarbon resources.

It was not possible to identify any additional pinnacle reefs, that were not already identified in the OGSRL database, within the Area of the Five Communities using the constructed cross-sections (Section 3.2.2.2; Geofirma Engineering Ltd., 2014), given the sparse borehole distribution and the limited number of key formation tops reinterpreted. The top of the Guelph Formation was deemed not to be a clear, high confidence pick in borehole geophysical data and so no detail for this formation was provided from the reinterpretation of borehole geophysics. Also, the interpretation of four 2D seismic lines in the Township of Huron-Kinloss and the municipalities of Brockton and South Bruce did not identify any pinnacle reef structures.

As part of the interpretation of geophysical data, PGW (2014) completed an evaluation of the gravity data within the Area of the Five Communities in an attempt to identify the locations of known pinnacle reefs, and to also identify the potential presence of unknown pinnacle reefs. In particular, to assess coincidence, the locations of the known pinnacle reefs in the Area of the Five Communities were compared to the responses from the observed Bouguer gravity and its first vertical derivative data. In an effort to emphasize lithological changes within the Paleozoic sequence (i.e. pinnacle reefs compared to the surrounding bedrock), the influence of the overburden and Paleozoic sequence were modeled and subsequently stripped from the Bouguer gravity data (PGW, 2014). The resulting stripped Bouguer gravity data do not appear to be advantageous in highlighting the locations of the known pinnacle reef structures within the Area of the Five Communities. The majority of the gravity responses in both the observed and stripped Bouguer gravity data sets are assumed to result from the lithological variability within the Precambrian basement rocks.

Although gravity data has been used throughout southern Ontario to locate pinnacle reefs for exploration programs (Pohly, 1966), the gravity data within the Area of the Five Communities do not provide any evidence of pinnacle reef type anomalies within the Paleozoic sedimentary sequence. In this area, the lack of anomaly may result from a negligible density contrast between the reef and the surrounding rock, or an insufficient amount of gravity measurements collected (PGW, 2014).

3.2.2.4 Faults and Fractures

Information on the location and relative age of potential faults within the Paleozoic bedrock sequence in the Area of the Five Communities is available from Armstrong and Carter (2010), as discussed in Sections 3.1.5 and 3.2.1.2, as well as from the interpretation of four 2D seismic lines completed as part of this assessment (Geofirma Engineering Ltd., 2014).

The fracture framework of Sanford et al. (1985), as discussed in Section 3.1.5, is not considered suitable for the identification of potential faults within the Area of the Five Communities given the conceptual nature of the interpretation, the reliability of the data on which faulting is identified, and consistency issues between the conceptualization and other geological mapping information for the area (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011).

As described in Section 3.1.5, basement-seated faults that displace the Paleozoic strata in southern Ontario have been compiled by Armstrong and Carter (2010). These faults are interpreted to originate in the Precambrian basement and propagate upwards through the Paleozoic sequence, and are classified based on the youngest geological unit that is offset. Figure 3.6 shows the mapped subsurface faults in the Area of the Five Communities.

There are two basement-seated faults mapped within the Communities, one in the Municipality of Brockton and the other in the Municipality of South Bruce extending into the Township of Huron-Kinloss (Figure 3.9). Both are about 5 to 10 km in length and bothare interpreted to strike east-northeast. The fault in the Municipality of Brockton is located at the west end of the Municipality extending to the west beyond the municipal boundaries, and it is interpreted to offset up to the Shadow Lake Formation/Precambrian units. The other mapped subsurface fault in the area is identified within the Trenton Group limestones, and located in the northwest corner of the Municipality of South Bruce, extending west into the Township of Huron-Kinloss. These two faults were identified by vertical offsets in structural tops from hand contouring of manually-picked formation top information in the OGSRL database by Bailey Geological Services Ltd. and Cochrane (1984a; 1984b). The Shadow Lake fault in the Municipality of Brockton is defined based on about a 10 m interpreted offset in two geophysically-logged wells located 3.5 km apart. The Trenton Group (Cobourg Formation) fault in the Municipality of South Bruce and the Township of Huron-Kinloss is defined based on about a 35 m interpreted offset in one well without geophysical logs, with the closest well (with geophysics) being 13 km away. Given the approach taken to identify these faults, the locations of the interpreted faults are only accurate to the well spacing used in the interpretation. Thus the Trenton Group fault, assuming it is real, could be located anywhere between the 13 km that separates the two wells, and the Shadow Lake fault anywhere within the 3.5 km that separates the wells. Given the sparse borehole data used to identify these two faults there is some uncertainty associated to their location, orientation and existence.

Reprocessing and interpretation of the four acquired 2D seismic data sets provides information on the potential occurrence of faults within the Paleozoic bedrock of the Communities. Figure 3.21 shows the results of the reprocessing and interpretation of seismic line 725937 within the Municipality of South Bruce oriented east-northeast to west-southwest. The figure shows the processed seismic data in a time vs line length plot, with interpreted major reflectors and locations of potential faults based on vertical offsets in the major reflectors. Major reflectors which include: the tops of Bass Islands/Salina G-Unit (difficult to distinguish the two), Salina B-Unit, Salina A2-Unit Carbonate, Salina A1-Unit Carbonate, Fossil Hill, Cabot Head/Queenston (difficult to distinguish and likely actual reflecting the hard carbonate Manitoulin Formation sandwiched between these units), Cobourg and the Shadow Lake/Precambrian are noted on the data plot. Figure 3.22 shows the same information for the seismic line A002800018 within the Township of Huron-Kinloss oriented northwest to southeast.

Two sub-vertical faults based on vertical offsets in major reflectors were interpreted as part of the 2D seismic interpretation study (Geofirma Engineering Ltd., 2014). One of these interpreted faults, located approximately 1.5 km from the west end of seismic line 725937, is interpreted as a near vertical reverse fault extending from the Precambrian basement up to the base of Silurian formations. Given the poor quality and limited lateral resolution of the seismic data at this location the confidence in this fault, in terms of its nature and actual location, is very low. However a mapped subsurface fault crosses the same seismic line, which may provide some indication that the interpreted fault is real (Figure 3.20). The second of the interpreted faults, located approximately 4.25 km from the northwest end of seismic line A002800018, is thought to be a near vertical reverse fault that extends upwards from the Precambrian basement and into the Silurian Cabot Head Formation. The confidence in the general location (though not strike) of this fault location is slightly higher than the other interpreted fault due to the reasonable quality of the data and the distinct offset in seismic signal at this location.

Information on the occurrence of fractures, including joints, in exposed bedrock is available from outcrop mapping by Cruden (2011) for the Bruce nuclear site and nearby Inverhuron Park, and for other areas of exposed Devonian and Silurian bedrock including the southern part of Bruce peninsula (NWMO and AECOM Canada Ltd., 2011). This outcrop mapping within and proximal to the Area of the Five Communities defines the occurrence of dominant east-northeast and north-northwest striking joints and subordinate northeast, northwest and north striking joint sets primarily within the surficial Devonian dolostones. Cruden (2011) interpreted fractures mapped along the Lake Huron shoreline as being Middle Devonian in age and, as part of a wider basin concentric fracture set, related to basin-centered subsidence (Howell and van der Pluijm, 1999). Information on subsurface fracture occurrences from borehole data is provided in Section 6.2 of this report.

3.2.3 Quaternary Geology

Information on Quaternary geology in the Area of the Five Communities is described in detail in the Terrain and Remote Sensing Study Report (JDMA, 2014) and a summary of that information is provided here.

Quaternary glaciations have played a major role in shaping and creating the landscape of southern Ontario (Barnett, 1992). Glacial landforms and associated sediments within the Area of the Five Communities were deposited by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet during the Late Wisconsinan 23,000 to 10,000 years ago (Karrow, 1993). Exposures of older deposits are rare as they are mostly buried beneath the Late Wisconsinan sediments and can only be seen in such places as riverbank exposures, lake bluffs or man-made exposures in quarries and pits (Barnett, 1992). Glacial deposits remaining after the last glaciation determine the current physiography of the Area of the Five Communities, the nature and distribution of surficial aquifers, groundwater discharge and recharge areas and sand and gravel deposits. Seamless mapping of surficial geology in the Area of the Five Communities is provided in Figure 3.24 (OGS, 2010).

A summary of glacial periods and Quaternary deposits in the Area of the Five Communities is presented in Table 3.4 after JDMA (2014) and Barnett (1992). The surficial deposits of the Area of the Five Communities have been mapped at the scale of 1:50,000 by Cowan (1977), Cowan et al. (1986), Cowan and Pinch (1986), Feenstra (1994), Karrow (1993), Sharpe and Broster (1977), Sharpe and Edwards (1979) and Sharpe and Jamieson (1982). The overburden can exceed 100 m in this area with values in the range of 30 to 60 m (Karrow, 1989).

Overburden thickness in the Area of the Five Communities is shown on Figure 3.25. Overburden thickness in the area shown on Figure 3.25 ranges from zero up to about 104 m, with the thickest overburden in the area associated with buried bedrock valleys (Figures 3.23 and 3.25; Gao, 2011a; 2011b) previously discussed in Section 3.1.9. Table 3.5 lists the overburden thickness within each of the Communities based on the data release of Gao et al. (2006) that involved quality assurance checking to remove erroneous water well information from the MOE Water Well Information System (MOE, 2013a) upon which Figure 3.25 is based.

Table 3.6 provides a summary in percentages of the areal extent of the different surficial deposits mapped within the Area of the Five Communities and the individual Communities, as shown in Figures 2.2 (physiography) and Figure 3.24 (surficial geology). For the purposes of Table 3.6, percentages for the Area of the Five Communities are calculated based on land area, excluding Lake Huron. The table indicates that morainal deposits are exposed at the surface over 45.6 % of the Area of the Five Communities. Morainal deposits are composed of till and are found within the areas mapped in Figure 2.2 as drumlinized and undrumlinized till plains, bevelled till plains and till moraines. The Elma Till is the most abundant till mapped over 23 % of the Area of the Five Communities. The St. Joseph Till is the next most common till formation, covering 20 % of the Area of the Five Communities. The Dunkeld and Rannoch tills each cover about 1 % of the Area of the Five Communities.

Table 3.4 Summary of Quaternary Deposits and Events in the Area of the Five Communities

Age (yrs)	*Glacial Period*	*Deposit or Event*	*Landform*
10,000 - present	Holocene	Organic deposits	Wetlands
		Fluvial deposits	River and floodplain landforms
		Glacial Lake Nipissing deposits	Raised beaches and bluffs
12,000 – 11,800	Two Creeks Interstade	Glacial Lake Algonquin deposits	Raised shore bluffs, sand sheets deposited within Huron Fringe
		Glaciofluvial deposits	Outwash and ice-contact landforms
13,100 – 12,300	Port Huron Stade	Glacial Lake Warren deposits	Saugeen clay plain, Warren beaches
		St. Joseph Till	Wyoming, Banks and Williscroft moraines
14,000 – 13,000	Mackinaw Interstade	Glaciolacustrine deposits	Clay plains
15,200 – 13,800	Port Bruce Stade	Glaciofluvial deposits	Outwash and ice-contact landforms
		Dunkeld Till	Walkerton Moraine
		Rannoch Till	Wawanosh Moraine
		Elma Till	Teeswater and Arran drumlin fields, Singhampton Moraine
16,500 – 15,500	Erie Interstade	Glaciolacustrine deposits	Buried
23,000 – 18,000	Nissouri Stade	Catfish Creek Till	Buried

Table 3.5 Summary of Overburden Thickness within the Communities

Community	*Overburden Thickness (m)*		
	Min	*Max*	*Mean*
Municipality of Arran-Elderslie	0	89	37
Municipality of Brockton	0	104	33
Municipality of South Bruce	0	73	20
Township of Huron-Kinloss	9	91	39
Town of Saugeen Shores	2	86	50

Table 3.6 Extent of Surficial Deposits within the Communities

Community	Primary Genesis[1]								
	C	AE	F	M	GF	GL	L	O	R
Municipality of Arran-Elderslie	0.0	0.0	3.2	45.6	8.2	39.3	0.0	3.4	0.1
Municipality of Brockton	0.0	0.0	6.3	20.3	14.1	54.5	0.0	4.7	0.2
Municipality of South Bruce	0.0	0.0	4.9	35.8	44.6	9.7	0.0	4.6	0.3
Township of Huron-Kinloss	0.0	0.0	5.0	63.5	18.0	9.9	1.3	2.3	0.0
Town of Saugeen Shores	1.4	0.6	8.2	26.7	0.7	61.9	0.5	0.0	0.0
Area of the Five Communities	0.1	0.0	3.8	45.6	21.2	23.7	0.2	4.4	1.0

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

Glaciofluvial deposits consisting primarily of sand or sand and gravel are exposed over 21.2 % of the Area of the Five Communities. These deposits are associated with the kame moraines, spillways and eskers shown in Figure 2.2. Glaciolacustrine deposits of primarily clay, silt and sand are exposed over 23.7 % of the Area of the Five Communities with about 58 % of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 42 % as coarse-grained deposits of sand or sand and gravel. The largest glaciolacustrine deposit mapped in the Area of the Five Communities is represented by the Saugeen clay plain (Figure 2.2). Fluvial deposits are represented by the modern and abandoned floodplains of the major rivers and creeks. These deposits are primarily composed of silt, sand and gravel and cover about 3.8 % of the Area. Lacustrine deposits of sand and gravel consisting of beaches, bars and spits have been mapped along the shores of Lake Huron and Georgian Bay, covering only 0.2 % of the Area of the Five Communities. Organic deposits of peat and muck have been mapped over 4.4 % of the Area of the Five Communities, with many of the deposits located within spillways, topographic lows, till plains or on rocky plains of the Bruce Peninsula.

The Municipality of Arran-Elderslie contains an abundance of morainal and glaciolacustrine deposits with one of the smallest percentages of glaciofluvial deposits of the Communities. The glaciolacustrine deposits are partly associated with the Saugeen clay plain, and the morainal deposits are largely associated with the Arran drumlin field. A total of 149 drumlins have been mapped within the Municipality in Figure 2.2. The Williscroft, Banks and Tara moraines are end moraines in this area formed by the Georgian Bay lobe of the Laurentide Ice Sheet.

The Municipality of Brockton contains the smallest percentage of morainal deposits of the Communities. The morainal deposits are largely associated with the Walkerton Moraine and the drumlinized till plain to the south. The till deposited as the Walkerton Moraine and as ground moraine in parts of the Saugeen valley is Dunkeld Till, which was deposited during a minor re-advance of the Georgian Bay lobe over glaciolacustrine silts of glacial Lake Saugeen. The till forming the Teeswater drumlin field is Elma Till. Glaciolacustrine deposits largely associated with glacial Lake Saugeen have been mapped over 55 % of the Municipality. Glaciofluvial deposits in the Municipality are generally associated with the Walkerton Moraine or are located south of the moraine between Walkerton and Hanover. Fluvial deposits are associated with the floodplains of the Saugeen and Teeswater rivers and their tributaries. This Municipality has the largest percentage of area covered by organic deposits of the Communities, with 4.7 % of the surface delineated as organic deposits.

The Municipality of South Bruce contains the largest percentage of glaciofluvial deposits and the smallest percentage of glaciolacustrine deposits of the Communities. The glaciolacustrine deposits are isolated deposits filling local topographic lows. The glaciofluvial deposits are associated with the Wawanosh Moraine, Saugeen Kames and a network of spillways. Most of the morainal deposits in the Municipality are formed of Elma Till, with much smaller amounts of Dunkeld and Rannoch tills exposed. Organic deposits are about as abundant as they are immediately to the north in the Municipality of Brockton. Bedrock is exposed locally within river and creek beds, such as along the Teeswater River.

The Township of Huron-Kinloss contains the greatest proportion of morainal deposits and one of the smallest proportions of glaciolacustrine deposits of the Communities. The morainal sediments are represented by an extensive plain of St. Joseph Till interrupted by a narrow strip of sand and the twin beaches of glacial Lake Warren. The till sheet is formed of brown calcareous clay and is generally only 2 to 3 m thick and rests on stratified clay of the same colour (Chapman and Putnam, 2007). The strip of sand extending parallel with and about 1.5 km west of the Warren beach consists of a shallow deposit of sand spread over the clay and in certain conditions results in a perched groundwater table above the clay. The sand strip is generally unevenly ribbed with swampy streaks occupying the lows. The Wawanosh Moraine represents the main area mapped as glaciofluvial sediment in this area.

The Town of Saugeen Shores contains the largest percentages of glaciolacustrine and fluvial deposits and the smallest percentages of glaciofluvial and organic deposits of the Communities. A massive beach of sand and gravel was built parallel to the Lake Huron shoreline a short distance inland of Port Elgin during Lake Algonquin times. Glaciolacustrine sediments behind the beach are composed of fine sand and silt deposited to a considerable depth. Delta sands extend from the beach up to a distinct bluff about 800 m from the present shore. Gravel bars built by Lake Nipissing rib the terrace surface below the bluff. Most of the till exposed in the area is St. Joseph Till, with smaller amounts of Elma Till exposed locally. Despite the lack of glaciofluvial deposits in the area, there are several active aggregate pits located along the ancient beach on the east edge of Port Elgin.

3.3 Seismicity and Neotectonics

3.3.1 <u>Seismicity</u>

The Area of the Five Communities overlies the Grenville Province of the Canadian Shield and the interior of the North American continent, where large parts have remained tectonically stable for the last 970 million years (Percival and Easton, 2007). Figure 3.26 presents the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada from 1627 until 2012 (Natural Resources Canada, 2013b). Figure 3.26 shows that no seismic events exceeding a magnitude of 6 have been recorded within 300km of the Area of the Five Communities.

Figure 3.27 shows the recent (1985 to 2013) record of seismic events recorded in southern Ontario as contained within the National Earthquake Database (Natural Resources Canada, 2013a). Earthquake magnitude resolution in Figure 3.27 was improved to <1 for the Area of the Five Communities and environs based on the 2007 installation of the microseismic monitoring network for the assessment of the Bruce nuclear site for construction of a proposed deep geological repository (DGR) for low and intermediate level waste project (University of Western Ontario, 2008), and to magnitude 2 for the remainder of southern Ontario based on an expanded POLARIS (Portable Observatories for

Lithospheric Analysis and Research Investigation Seismicity) network established in 2002. Figure 3.27 shows that since 1985 there have been no recorded earthquakes located within any of the Communities, with the closest recorded earthquakes located offshore in Lake Huron about 25-30 km northwest of the Town of Saugeen Shores, and north of Owen Sound. The maximum magnitude of these events was of 2.5 Nuttli Magnitude. A 4.3 Nuttli Magnitude earthquake was recorded in 2005 northeast of Owen Sound within Georgian Bay at distances of 80 to 110 km of the centres of the Communities (Hayek et al., 2011).

Hayek et al. (2011) note that there is limited accurate information on the depth of earthquakes in the vicinity of the Bruce nuclear site, and throughout the Area of the Five Communities, due to the lack of large enough earthquakes to reliably calculate depths. The reported depths of earthquakes by Hayek et al. (2011) range from 5 km to 18 km, with the 18 km value being the Geological Survey of Canada's default depth for all mid crust events.

A Probabilistic Seismic Hazard Assessment (PSHA) was conducted for the Bruce nuclear site as part of the regional Geosynthesis (AMEC Geomatrix, 2011). The PSHA conducted for the proposed Bruce DGR followed a Senior Seismic Hazard Advisory Committee (SSHAC) Level 2 process and explicitly incorporated uncertainties in the probabilistic models and model parameters that affect seismic hazard at the site. The results of the PSHA show that far field/regional seismic sources are the dominant contributors to the hazard for the site at ground level, with estimated surface bedrock peak ground motions of 18.7 and 60.1 % g for events of annual probabilities of 10^{-5} and 10^{-6}, respectively. Seismic analyses of an underground Bruce DGR emplacement room using ground motions of 10^{-5} and 10^{-6} annual probability events show that seismic shaking would not induce damage to the host rock other than potentially dislodging any already fractured rock mass around the openings.

In summary, available literature and recorded seismic events indicate that the Communities are located within a region of very low seismicity: the tectonically stable central craton portion of the Grenville Province of the Canadian Shield.

3.3.2 Neotectonic Activity

Neotectonics refers to deformation, stress and displacement in the Earth's crust of recent age or which are still occurring. These processes are related to tectonic forces acting in the North American plate as well as those associated with the numerous glacial cycles that have affected the northern portion of the plate during the last million years, including all of the Canadian Shield (Shackleton et al., 1990; Peltier, 2002).

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major horizontal principal stress orientation in central North America based on the World Stress Map (Zoback, 1992) is NE (63° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Zoback, 1992; Baird and McKinnon, 2007), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973) which has likely persisted since the most recent Cretaceous-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

The geology of the Area of the Five Communities is typical of many areas of southern Ontario, which have been subjected to nine glacial cycles during the last million years (Peltier, 2002). Continental-scale tectonic movements are therefore overprinted by post-glacial isostatic rebound in the northern portion of the North America plate. During the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the Earth's crust was depressed by more than 340 m in the Minnesota/North Dakota area (Brevic and Reid, 1999), due to the weight of glacial ice. The amount of crustal depression in the Area of the Five Communities would be of a somewhat greater magnitude (approximately 500 m as per Section 3.1.9), due to its closer proximity to the main centre of glaciation located over Hudson's Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. The ''hinge line'' separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2006). The vertical velocity contours developed from the lake water level data sets compared well with the postglacial rebound models, which in turn indicated estimated present day rebound rates in the Area of the Five Communities of about 1.5 mm/yr (Peltier, 2011). As a result of the glacial unloading, principal stress magnitudes and orientations are changed. Seismic events can then be associated with such post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall (1993) and Karrow and White (2002) from some areas of southern Ontario. There is no documentation of similar pop-up or unloading type neotectonic features within the Area of the Five Communities.

Slattery (2011) completed a remote-sensing and field-based study that analysed Quaternary landforms for the presence of seismically-induced soft-sediment deformation within 5 to 50 km of the Bruce nuclear site. The investigation involved reviewing existing information sources (e.g., papers, reports, maps, etc.), interpreting air photos and a LiDAR digital elevation model, and searching for liquefaction structures displayed in sediment exposures in the field. The review of existing information and interpretation of air photos was done for the entire area within 50 kilometres of the Bruce nuclear site, providing coverage of the entire Area of the Five Communities. No conclusive geomorphological or sedimentological evidence of post-glacial neotectonic activity was identified within the study area (Slattery, 2011)

The Terrain and Remote Sensing Study (JDMA, 2014) also did not identify any neotectonic features and concluded it would be very difficult to impossible to identify such features using only the currently available remote sensing data.

4 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

The terms aquifer, aquitard and aquiclude are used in this section to assist in describing the hydrogeology and hydrogeochemistry of both overburden and bedrock systems likely to exist within the Area of the Five Communities.

Aquifers are defined as layers, formations or units that are sufficiently porous and permeable to store, transmit and yield significant quantities of groundwater. For overburden and shallow bedrock, aquifers are usually understood to be layers, formations or units that yield sufficient quantities of groundwater for water supply needs. For deeper bedrock, aquifers are practically defined as formations or units that yield sufficient water for groundwater sampling.

Information on physiographic and terrain features (Figure 2.2), surficial and Quaternary geology (Figure 3.24), and subsurface overburden occurrence from MOE water well records have been compiled and interpreted to broadly map the spatial distribution of overburden aquifers and aquitards within the Communities. This work has been completed principally in support of Provincial Source Water Protection initiatives (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011).

Information on bedrock aquifers, aquitards and aquicludes in the Communities is divided and interpreted into shallow bedrock and deep bedrock systems. Shallow bedrock hydrogeological information is available primarily to depths of 100 to 150 m from the MOE well records based on regional use of this shallow bedrock aquifer as a source of drinking water. There is no direct available information on hydrogeological conditions at typical repository depths in the Communities. Deep bedrock hydrogeological information is available from detailed drilling and testing investigations at the Bruce nuclear site, from regional compilations completed as part of the Geosynthesis Report (NWMO, 2011), and from interpretations of deep oil and gas drilling records maintained by the OGSR Library. Extrapolation of these deep bedrock data to the Communities is based on the known lateral traceability and predictability of these deep bedrock conditions within the Area of the Five Communities, but would need to be confirmed during subsequent site evaluation stages.

4.1 Groundwater Use

Information concerning groundwater use in the Communities was obtained principally from the Ontario Ministry of the Environment (MOE) Water Well Information System (WWIS) database (Ontario Ministry of the Environment, 2013a), as well as from regional groundwater studies and source water protection studies based on interpretation of these data. The locations of known water wells in the Area of the Five Communities are shown on Figure 4.1, which shows all known MOE water wells plotted by type – overburden or bedrock - on a background of surficial geology. Of the wells shown in Figure 4.1, 87 % obtain groundwater from bedrock aquifers. Table 4.1 summarizes the number and type of water well records within the Communities. There are an additional 6,409 water wells in the Area of the Five Communities, but outside of the municipal boundaries of the five Communities.

There may be other water wells in the Area of the Five Communities that are not included in the MOE water well record database. For example, a flowing commercial water supply well in Formosa, South Bruce (PTTW3714-66KK3R, MOE, 2004) is not in the MOE database and appears to predate establishment of MOE water well record filing. The existence of additional wells not in the MOE database will be investigated in later stages of the site evaluation process.

Table 4.1 Water Well Record Summary for the Communities

Well Type	*No. of Well Records*	*Well Depth Range (mBGS)*		*Static Water Level Range (mBGS)*		*Well Yield (L/min)*		
		Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Mean*
Municipality of Arran-Elderslie (Total 723 Well Records)								
Overburden	98	4.6	101.8	-0.3	36.3	4.5	450	47
Bedrock	625	6.1	218	-1.2	36.3	9.0	495	42
Municipality of Brockton (Total 1154 Well Records)								
Overburden	244	2.7	114.6	-1.8	50	4.5	360	52
Bedrock	910	5.0	134.1	-2.1	54.3	9.0	1,230	57
Municipality of South Bruce (Total 845 Well Records)								
Overburden	53	2.7	96.9	0.6	20.7	13.5	1,350	95
Bedrock	792	3.7	163.1	-12.2	48.8	9.0	1,125	60
Township of Huron-Kinloss (Total 861 Well Records)								
Overburden	78	2.5	93.3	1.5	27.4	9.0	1,125	88
Bedrock	603	15.2	111.3	-6.1	45.1	18.0	1,125	81
Town of Saugeen Shores (Total 382 Well Records)								
Overburden	156	2.6	157	-0.6	49.1	4.5	200	42
Bedrock	226	6.7	182.9	-9.1	48.8	9.0	1,350	29

Figure 4.1 also shows the locations of the 17 monitoring wells (nine bedrock, eight overburden) within the Area of the Five Communities that are part of the Provincial Groundwater Monitoring Network (PGMN) (Ontario Ministry of the Environment, 2013b). These wells are regularly monitored for water level and groundwater quality by the Province. Seven of these wells are located within the Communities, with at least one well in each community (see Figure 4.1).

All of the Communities rely heavily on groundwater as the source of water for drinking, irrigation and other uses. Municipal water supplies located away from the shore of Lake Huron rely heavily on groundwater from bedrock aquifers for their drinking water supplies. Specifically, as summarized in Section 2.4.4, the municipalities of Arran-Elderslie, Brockton and South Bruce and the Township of Huron-Kinloss have public and municipal water supplies from wells sourcing shallow bedrock aquifers and occasionally overlying overburden aquifers. Municipal water supplies in the Town of Saugeen Shores are sourced from surface water of Lake Huron. There are a total of 15 public and municipal groundwater supply wells in the Communities.

The WWIS database contains a total of 12,442 water well records for the Area of the Five Communities shown on Figure 4.1. Not all of these water well records are complete and not all of these records provide useful hydrogeological information. For example, there are a total of 10,374 water wells plotted on Figure 4.1 for the Area of the Five Communities that have been reliably identified as overburden wells (1,337) and bedrock wells (9,037). The well type was uncertain for the remaining 2,068 wells. Most of the water well records provide useful information on well depth, lithology, well yield, and static water level, as indicated in Table 4.1.

Table 4.1 lists the hydrogeological information obtained from useful well records grouped by overburden and bedrock wells, as well as the total number of well records for each community. Negative static water levels in Table 4.1 indicate flowing or artesian well conditions. The reported well yields given in Table 4.1 reflect the recommended rates determined for the wells based on pumping tests and their intended use as provided by the well driller (i.e., primarily residential use).

Table 4.1 shows that the percentage of overburden wells is greatest in the Town of Saugeen Shores (40.8 %), followed by the Municipality of Brockton (21.1 %), the Municipality of Arran-Elderslie (13.6 %), the Township of Huron-Kinloss (9.1 %) and the Municipality of South Bruce (6.3 %).

4.1.1 Overburden Aquifers

There are 1,337 water well records in the Area of the Five Communities that can be confidently assigned to overburden aquifers. These wells are generally 10 to 100 m deep and have mean well yields of 40 to 90 L/min. These well yields reflect the purpose of the wells (i.e. primarily residential use) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers intersected by the wells.

Soil texture and results of well pumping tests are used to broadly distinguish overburden aquifers from aquitards. Sand and gravel of sand plains, kame moraines, eskers, glaciofluvial and fluvial deposits are commonly associated with overburden aquifers. In contrast, silt and clay of clay plains, till plains, till moraines, lacustrine and glaciolacustrine deposits are commonly associated with overburden aquitards.

Figure 3.24 and the Terrain and Remote Sensing Study (JDMA, 2014) show that the major glacial overburden deposits in the Area of the Five Communities include a widespread low permeability morainal till overlying bedrock which is overlain by more permeable glaciofluvial deposits and less permeable glaciolacustrine deposits. The more permeable glaciofluvial deposits which are apparent at surface in the southeastern part of the Township of Huron-Kinloss, throughout large parts of the Municipality of South Bruce and sporadically within the municipalities of Brockton and Arran-Elderslie, often form unconfined shallow overburden aquifers. These shallow aquifers are locally important sources of drinking water and are essential for their contribution to surface waters and ultimately recharge to the shallow bedrock aquifers.

Noteworthy overburden aquifers within the Communities include (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011):

- the confined sand and gravel Chesley Aquifer found in proximity to and north of Chesley, Municipality of Arran-Elderlsie;
- the partially confined sand and gravel Port Elgin-Southampton Aquifer found near and within the

lower part of the Saugeen River, Town of Saugeen Shores;

- the confined sand and gravel Hanover Aquifer in the Municipality of Brockton which provides municipal water supply for Hanover;
- the partially confined sand and gravel Walkerton Aquifer situated in the vicinity of Walkerton, Municipality of Brockton;
- the unconfined sand Lake Warren Shoreline Aquifer located as a narrow north-south band of glaciolacustrine deposits within the Township of Huron-Kinloss;
- the unconfined sandy beach deposits of the Lake Huron Beach Aquifer found along the present day shoreline of Lake Huron in the Township of Huron-Kinloss and the Town of Saugeen Shores; and
- the unconfined sand and gravel Wawanosh Kame Moraine Aquifer located in the southeast part of the Township of Huron Kinloss and the southwest part of the Municipality of South Bruce.

Source water protection assessment reports (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011) provide the location of significant groundwater recharge areas within the Area of the Five Communities. Significant groundwater recharge areas are areas where greater than average groundwater recharge likely occurs. These areas were mapped based on consideration of surficial geology, soils, land cover and topography. Figure 4.2 shows the interpreted mapping of significant groundwater recharge areas within the Area of the Five Communities. Significant groundwater recharge occurs in flat-lying/hummocky areas with sands and gravels at surface and limited land cover.

4.1.2 Bedrock Aquifers

No water wells were drilled to typical repository depths of approximately 500 mBGS. There are 9,037 water well records in the Area of the Five Communities that can be confidently assigned to shallow bedrock aquifers. Shallow bedrock hydrogeological information is available primarily to depths of 100 - 150 m from the MOE well records (MOE, 2013a) based on regional use of this shallow bedrock aquifer as a source of drinking water. Shallow bedrock is the most important source of drinking water in the Communities, and is the primary source of most of the municipal water supplies located inland from Lake Huron. Shallow bedrock aquifers within the Communities are composed of an aggregate of the upper few metres to over 100 m of the different shallow bedrock formations present, which range from Middle Devonian Lucas Formation dolostone in the southwest (Township of Huron-Kinloss) to Upper Silurian Guelph Formation dolostone in the northeast (Municipality of Arran-Elderslie) (Figure 3.6). The municipalities of Brockton and South Bruce are underlain at shallow depths by Lucas Formation dolostones through to Salina Group dolostones, shales and evaporites. The Town of Saugeen Shores is underlain by the Salina Group and a thin band of Upper Silurian Bass Islands Formation dolostone along its southern boundary. Water quantity and quality within the shallow bedrock aquifer can vary dramatically across the Communities as a consequence of the different chemical and physical characteristics of the individual bedrock formations.

In many parts of the Area of the Five Communities, an overlying layer of clay and silt till confines the shallow bedrock aquifer. In these areas the low permeability silt and clay till is considered to represent an aquitard that protects the shallow bedrock aquifer. The source water protection assessment reports (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011) map the areas of shallow bedrock aquifer vulnerability to surface sources of contamination within the Area of the Five Communities. Aquifer vulnerability is defined as low, medium and high based on calculation of intrinsic susceptibility index that considers the permeability (texture) and thickness of overburden deposits that overlie the shallow bedrock aquifer. Figure 4.2 shows the interpretative mapping of relative aquifer vulnerability within the Area of the Five Communities. Areas of high aquifer vulnerability generally correspond to areas of reduced overburden thickness and presence of sands and gravels in the overburden overlying the shallow bedrock.

4.1.3 Shallow Groundwater Regime

The shallow groundwater regime includes the overburden aquifers and aquitards, and shallow bedrock aquifers that provide drinking water supplies to both municipalities and residences. Within eastern parts of the municipalities of Brockton and South Bruce and within most of the Municipality of Arran-Elderslie and the Town of Saugeen Shores, the shallow groundwater regime will likely extend to depths of 150 m or more within the Guelph Formation. Within the Township of Huron-Kinloss the shallow groundwater regime likely extends to somewhat shallower depths of about 100 m.

Groundwater flow directions within shallow systems often mimic surface water flow directions with the groundwater table generally present as a subdued reflection of topography. Shallow groundwater flow will be directed from areas of higher hydraulic head, such as highlands and drainage divides to areas of lower hydraulic head such low-lying areas of valleys, depressions, and surface waters. The extent of such shallow flow systems will be defined by local, topography-controlled, drainage divides across which groundwater flow will not readily occur. Generally, for such shallow systems, groundwater divides will coincide with surface water drainage divides.

Contour maps of the groundwater table surface within the shallow bedrock aquifer within the Area of the Five Communities have been prepared in the source water protection assessment reports (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011) and used by Source Water Protection Regions to calibrate 3D groundwater flow models. These potentiometric surface maps show that shallow groundwater within the municipalities of Brockton and South Bruce, the Town of Saugeen Shores and the southwest half of the Municipality of Arran-Elderslie flows from the highland areas along the eastern edge of the Area of the Five Communities to the northwest towards Lake Huron, similar to surface water flow within the tertiary Saugeen Watershed (Figure 2.5). Within the Township of Huron-Kinloss shallow groundwater flows northwest and southwest toward Lake Huron similar to surface water flow within the tertiary Penetangore Watershed. The northeast half of the Municipality of Arran-Elderslie has shallow groundwater flow north and northeast paralleling surface water flow in the tertiary Bruce Peninsula Watershed to Lake Huron.

Local and regional distortions of these general shallow groundwater flow patterns, that are developed assuming relatively homogeneous hydraulic properties, will occur where there are major changes in the spatial distribution of permeable overburden and shallow bedrock units. An important regional shallow groundwater flow distortion noted within the Saugeen Valley source water protection area assessment report (Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a; 2011b; Ausable Bayfield Maitland Valley Source Protection Region, 2011), is the reversal of regional groundwater flow trends within the shallow bedrock where the Salina Group subcrops in bedrock valleys below the Saugeen River within the municipalities of Brockton and Arran-Elderslie and the Town of Saugeen Shores between Walkerton to Southampton (Figures 2.3 and 3.24). In these areas the easily erodible Salina Group has led to the development of large bedrock valleys that are infilled with permeable coarse sands and gravels that preferentially concentrate groundwater flow from the surrounding shallow bedrock into the bedrock valleys and eventually upward into the Saugeen River and Lake Huron (Waterloo Hydrogeologic Inc., 2003; Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Region, 2011a).

4.2 Hydrostratigraphy

Hydrostratigraphic units are geological formations, parts of formations, or groups of formations that have similar hydrogeologic characteristics that allow for grouping into aquifers, aquitards and aquicludes. Hydrostratigraphic units are operational definitions that facilitate hydrogeologic understanding and assessment. As part of the site characterization work carried out at the Bruce nuclear site, nine hydrostratigraphic (HS) units were defined, as shown in Figure 4.3a, based on hydrogeological data and reference stratigraphy depths described in Intera Engineering Ltd. (2011). These nine hydrostratigraphic units, adjusted for minor variations in bedrock formation depth, thickness and occurrence in each of the Communities, are broadly anticipated to be present with similar properties to those determined at the Bruce nuclear site based on the previously described lateral traceability and predictability of bedrock formations within the Area of the Five Communities, with the exception that a Cambrian aquifer is not likely present where the Cambrian unit is absent. This would need to be confirmed at later stages of the site evaluation process, through the collection of site-specific information.

Figure 4.3b shows the summary of the results of the comprehensive borehole hydraulic testing completed at the Bruce nuclear site that were used to develop the hydrogeological conceptualization (Intera Engineering Ltd., 2011). The lowest, average, horizontal hydraulic conductivities (K_h) are associated with the Upper Ordovician limestones of the Cobourg, Sherman Falls and Kirkfield formations (HS 6), ranging from $4x10^{-15}$ to $1x10^{-14}$ m/s.

The Upper Ordovician shale and limestone units correspond to hydrostratigraphic units 5 and 6, as shown in Figures 4.3a and 4.3b. The occurrence of these specific units within the Communities is reviewed below, although the presence of the associated geological formations has already been discussed in sub-section 3.2.2.2.

Based on Figure 3.16, the top of HS Unit 5 (Ordovician shale aquiclude) will be found at depths of about 475 to 600 mBGS in the Township of Huron-Kinloss, 200 to 475 mBGS in the municipalities of Brockton and South Bruce, 200 to 350 mBGS in the Town of Saugeen Shores and 150 to 300 mBGS in the Municipality of Arran-Elderslie. The estimated thickness of HS Unit 5 within the Communities (Figure 3.19) is 210 to 230 m in the Township of Huron-Kinloss, 220 to 250 m in the municipalities of Brockton and South Bruce, 200 to 220 m in the Town of Saugeen Shores and the Municipality of Arran-Elderslie.

Based on Figure 3.15, the top of very low hydraulic conductivity HS Unit 6 (Ordovician limestone aquiclude) will be found at depths of about 700 to 800 mBGS in the Township of Huron-Kinloss, 450 to 700 mBGS in the municipalities of Brockton and South Bruce, 400 to 575 mBGS in the Town of Saugeen Shores and 350 to 525 mBGS in the Municipality of Arran-Elderslie.

4.3 Hydrogeochemistry

Information on shallow overburden and bedrock groundwater geochemistry in southwestern Ontario, including the Area of the Five Communities is presented by the Ontario Geological Survey (Hamilton, 2011) and by the Ontario Ministry of the Environment (2013b). Within the Area of the Five Communities, Hamilton (2011) summarizes the groundwater geochemistry of 101 wells (43 overburden, 58 bedrock) to a maximum depth of 148 m recently sampled in 2007-2010; and Ontario Ministry of the Environment (2013b) present water quality information for the 17 wells that are part of the Provincial Groundwater Monitoring Network.

There is no direct readily available information on hydrogeochemistry at typical repository depths in the Communities. Figures 4.4 and 4.5 summarize the expected hydrogeochemistry of the shallow to deep Paleozoic and underlying Precambrian bedrock within the Area of the Five Communities based on detailed porewater and groundwater testing completed at the Bruce nuclear site (Intera Engineering Ltd., 2011) and on regional compilations of oil, gas and salt well data completed as part the Bruce nuclear site DGR Geosynthesis (NWMO, 2011; Hobbs et al., 2011), and by the Ontario Petroleum Institute (Carter and Fortner, 2011). Because the extremely low permeability of most of the Silurian and Ordovician formations precludes conventional groundwater sampling, significant reliance was placed on extraction and testing of porewater for determination of bedrock hydrogeochemical parameters.

Figure 4.4a shows the profile of TDS (in g/L) and water activity (a_w) of porewater and groundwater. Water activity is an easy to measure supporting indicator of TDS that decreases with increasing TDS and supplements the TDS data. Figure 4.4b shows the profiles of the concentrations of major ions of chloride and sodium expressed in mmol/kg of water. Figure 4.5 shows the profiles of the stable environmental isotopes of water, ^{18}O and Deuterium (^{2}H or D) expressed in delta (δ) notation as the per mil (‰) deviation relative to the Vienna Standard Mean Ocean Water (VSMOW). The environmental isotope data δ^{18}O and δD are natural tracers that provide information on the age and origin of porewaters and groundwaters.

The TDS and major ion data of sodium and chloride show that groundwater chemistry in the overburden HS Unit 1 is typically fresh Ca:Na-HCO_3 type with TDS less than 500 mg/L and oxidizing redox conditions. These overburden hydrogeochemical conditions are confirmed by recent sampling in the Area of the Five Communities by Hamilton (2011).

Groundwater and porewater chemistries in the shallow Devonian to deeper Upper Silurian dolostone bedrock of HS Unit 2 are transitional from fresh Ca:Mg-HCO_3 water (TDS ~500 mg/L) near the top of the bedrock to brackish Ca-SO_4 water (TDS ~5,000 mg/L) at the bottom of the unit at depths greater than about 100 m. These shallow bedrock hydrogeochemical conditions are also confirmed by recent sampling in the Area of the Five Communities by Hamilton (2011), with fresh to slightly brackish groundwater reported. The deeper parts of HS Unit 2 including the Bass Islands Formation show a depleted δ^{18}O and δD signature, and ^{14}C ages indicative of a glacial meltwater component. Mixing and exchange of higher TDS Ca-SO_4 water from underlying HS Unit 3 is also evident in HS Unit 2.

Groundwater and porewater chemistries in the Silurian carbonates, shales and evaporites of HS Unit 3 are transitional from brackish Ca-SO_4 water (TDS ~10,000 mg/L) near the top of the Unit (169.3 mBGS) to Na-Cl brine (TDS ~325,000 mg/L) at the bottom of the Unit (447.7 mBGS). The dramatic increase in TDS with depth in this unit (Figure 4.4a) is reflected in the major ion profiles (Figure 4.4b). Superimposed on this major ion chemistry profile in HS Unit 3 are significant decreases and increases in the salinity and chemistry of groundwater measured in the Upper A1 Unit aquifer and the Guelph aquifer, respectively. The moderate salinity profile in the upper aquitard suggests that exchange or mixing of porewater from this part of the aquitard has occurred and that the upper aquitard is likely more permeable than the middle and lower aquitards. The salinity contrast in the middle aquitard from TDS of about 30,000 mg/L at 328.5 mBGS to 370,000 mg/L at 374.5 mBGS is remarkable and suggests that the middle aquitard comprising the Salina A1 and A0 Units is of very low permeability. Based on the changes in concentrations of major ions and TDS across the lower aquitard, it is also likely of very low permeability.

Groundwater and porewater chemistries in the two thin Silurian dolostone aquifers of HS Unit 4 are remarkably different in each aquifer based on results of targeted groundwater sampling. The aquifer of the Salina Upper A1 Unit contains saline Na-Cl water with TDS of 30,000 mg/L. The lower aquifer of the Guelph Formation contains Na-Cl brine with TDS of 370,000 mg/L. The depleted $\delta^{18}O$ and δD signatures of groundwater within the Salina Upper A1 Unit aquifer indicates mixing of formation water with intruded glacial meltwater.

Porewater chemistries in the Ordovician shales of HS Unit 5 are relatively uniform consisting of Na-Cl brine (average TDS ~300,000 mg/L, Figure 4.4a) reflecting halite saturation and showing minor (up to 10%) decreases in TDS with depth through the Unit. This uniform chemistry profile is also evident in the major ion profiles (Figure 4.4b), and the $\delta^{18}O$ and δD profiles (Figure 4.5). The uniformity of major ion and environmental isotope data across HS Unit 5 indicates a tight aquiclude where solute transport is limited to slow diffusional processes.

Porewater chemistries in Ordovician Trenton Group limestones of HS Unit 6 show minor decreases in concentration from the top to the bottom of HS Unit 6. Porewater in HS Unit 6 consists of Na-Cl brine decreasing in TDS from about 285,000 mg/L at the top of unit to about 230,000 mg/L at the bottom of the unit (Figure 4.4a). This chemistry profile is evident in the major ion profiles (Figure 4.4b) and the $\delta^{18}O$ and δD profiles (Figure 4.5). Similar to HS Unit 5, the uniformity of major ion and environmental isotope data across HS Unit 6 indicates a tight aquiclude where solute transport is limited to slow diffusional processes.

Porewater chemistries in the Ordovician Black River Group limestones of HS Unit 7 are Na-Cl brine but are transitional with depth from the chemistry of the overlying Kirkfield Formation to that of the underlying Cambrian sandstone. TDS decreases from ~230,000 mg/L at the top of Coboconk Formation to ~200,000 mg/L in the top to middle of the Gull River Formation and then increases to ~230,000 mg/L at the bottom of the Gull River Formation (Figure 4.4a). There are numerous excursions in porewater chemistry from this general trend, with both higher and lower concentrations evident in HS Unit 7. The changes in porewater TDS chemistry with depth are evident in the major ion profiles (Figures 4.4b) and the $\delta^{18}O$ and δD profiles (Figure 4.5).

Groundwater and porewater chemistries in the Shadow Lake siltstone and Cambrian sandstone of HS Unit 8 are Na:Ca-Cl brine (TDS ~205,000 to 235,000 mg/L) but of lower salinity than the porewater of the upper parts of HS Unit 7 and of HS Units 6 and 5.

Groundwater and porewater chemistries in Precambrian basement rocks of HS Unit 9 are not known at the Bruce nuclear site or within the Area of the Five Communities, but have been extensively characterized elsewhere in Ontario (Frape and Fritz, 1987; Gascoyne et al., 1987), including the nearby Sudbury mining region. Canadian Shield groundwater from comparable depths (>860 mBGS) are typically Ca:Na-Cl brines with TDS greater than 50,000 mg/L towards an estimated Precambrian Shield source brine of more than 350,000 mg/L (Gascoyne et al., 1987; Pearson, 1987).

The current understanding of the origin of brines within the Michigan Basin indicates that they were formed by evaporation of sea water that was subsequently modified by: dilution of brines by lower salinity water; dissolution of halite by lower salinity water; and diagenetic water-rock interactions, particularly dolomitization. The data from the Bruce nuclear site is consistent with the regional scale understanding, and suggests a similar origin for brines in the Silurian and Ordovician rocks of the Communities. This would need to be confirmed during subsequent site evaluation stages, if the community is selected by the NWMO, and remains interested in continuing with the site selection process.

4.4 Formation Hydraulic Pressures

Formation hydraulic pressures in bedrock to depths of about 850 mBGS have been measured in-situ and reported for the entire Paleozoic bedrock sequence at the Bruce nuclear site using special multiple-port pressure monitoring instrumentation consisting of numerous packer-isolated test intervals installed in several deep boreholes (Intera Engineering Ltd., 2011). These ongoing hydraulic pressure measurements allow for determination of the presence of normally-pressured, overpressured or underpressured conditions within individual deep formations and an estimation of groundwater flow directions within shallow and permeable deep bedrock aquifers.

Figure 4.6 shows examples of deep formation hydraulic pressure profiles measured up to 10 months after instrumentation installation in two deep boreholes at the Bruce nuclear site (Intera Engineering Ltd., 2011). Figure 4.6 shows the measured pressure port data expressed as environmental head relative to ground surface and as pressure interval data relative to fresh water hydrostatic and density-compensated hydrostatic pressure lines. Figure 4.6 also shows the interpreted stable formation pressures determined from analysis of the borehole hydraulic testing.

Figure 4.6 shows there is significant underpressuring of the deep aquiclude of the Ordovician shales and Trenton Group limestones (HS Units 5 and 6) of up to 250 to 300 mBGS expressed as environmental water head. Figure 4.6 shows the temporal evolution of these underpressures and that the formation pressures are not currently at equilibrium values and continue to decrease over time. Such significant underpressures are an important hydrogeological characteristic of the Ordovician shales and Trenton Group limestones, indicating these formations would act as a barrier to groundwater migration. Possible explanations for the observed underpressures include: poroelastic response to glacial unloading and flexure; poroelastic response to Cenozoic erosional unburdening; capillary pressure effects due to the presence of a separate gas phase; and/or chemical osmosis (Intera Engineering Ltd., 2011). Although the genesis of these underpressures is ambiguous, their occurrence and persistence are clearly indicative of very low formation permeability and provide confidence in the very low permeabilities reported from hydraulic testing (K_h = 8x10^{-15} to 5x10^{-14} m/s) at the Bruce nuclear site (NWMO, 2011). These hydrogeological properties indicate an aquiclude with no advection of brine, and a system in which gas flow would also be diffusion controlled.

Figure 4.6 also shows the presence of significant overpressures of up to 165 metres above ground surface expressed as environmental water head within the permeable Cambrian sandstone (HS Unit 8) that propagates into some of the overlying Black River Group limestones and siltstones (HS Unit 7). Figure 4.6 also shows some moderate overpressures occur within the Salina A1 and A0 Units, Goat Island, Gasport, Lions Head and Fossil Hill formations and within the middle of the Blue Mountain Formation. Possible explanations for the cause of these overpressures include: hydraulic connection to a remote elevated regional recharge area (e.g., Niagara Escarpment, Canadian Shield); remnant overpressure from deep basin glacial meltwater recharge and post-glacial basin isostatic rebound; and/or up-basin regional fluid (brine or gas) migration and pressurization (Intera Engineering Ltd., 2011).

Current pressure measurements within the Salina Upper A1 Unit aquifer at the Bruce nuclear site indicate groundwater flow directions to the northwest toward Lake Huron (Intera Engineering Ltd., 2011) consistent with groundwater flow directions in the overlying shallow groundwater regime at the Bruce nuclear site and in the Area of the Five Communities. Similar current pressure measurements for the slightly deeper Guelph Formation aquifer indicate that groundwater flows in an up-dip direction to the east-northeast towards the Guelph Formation subcrop (Figure 3.6). At the Bruce nuclear site the calculated hydraulic gradients range from 0.0077 to 0.0086 m/m in the Salina Upper A1 Unit aquifer, and 0.0026 to 0.0039 m/m in the Guelph Formation aquifer.

Site-specific conditions would be confirmed during subsequent site evaluation stages, if the community is selected by the NWMO, and remains interested in continuing with the site selection process.

5 NATURAL RESOURCES - ECONOMIC GEOLOGY

Information regarding the natural resource potential for the Area of the Five Communities has been obtained from a variety of sources including provincial databases and assessment reports and papers listed in Section 1.4.6 and described below. Natural resources assessed for the Area of the Five Communities in this report broadly include: petroleum resources (conventional and unconventional oil and gas), metallic mineral resources, non-metallic mineral resources (sand and gravel, bedrock resources and salt) and deep potable groundwater resources associated with the Guelph Formation.

5.1 Petroleum Resources

Commercial accumulations of hydrocarbons have been discovered in more than a dozen stratigraphic units throughout the Paleozoic sedimentary sequence of southern Ontario. Figure 5.1 shows the distribution of active and former producing petroleum pools in southern Ontario based on the OGSRL (2012, 2006).

The main hydrocarbon play types in southern Ontario are listed in Table 5.1 after Sanford (1993) and NWMO (2011). Play ages described in this section have been updated to the stratigraphic nomenclature of Armstrong and Carter (2010) from the earlier version of Armstrong and Carter (2006). This includes assignment of Middle Ordovician units to Upper Ordovician age and combining Lower and Middle Silurian units to Lower Silurian age (i.e., changing of age range for Middle Ordovician and abandonment of Middle Silurian ages in the Paleozoic stratigraphic column).

5.1.1 Regional Oil and Gas Plays

Hydrocarbon production in southern Ontario was initially derived from shallow (120 m) Devonian carbonate reservoirs. Following additional discoveries of shallow Devonian reservoirs, commercial quantities of liquid hydrocarbons were discovered in deeper Silurian rocks. Exploration interest most recently has focussed on targets in the southwestern tip of Ontario in Upper Ordovician limestones of the Trenton and Black River groups, and in Upper Cambrian sandstones at depths of 800 to 1,000 m (Golder Associates Ltd., 2005). Most of the current exploration for oil and gas is concentrated within the geographic triangle between London, Sarnia and Chatham-Kent in the counties of Essex, Kent, Lambton, Norfolk and Elgin (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011) (Figure 5.1). Figure 5.1 shows a dot where the outline of a pool was too small to be seen on the map.

Cambrian oil and gas plays in southern Ontario are hosted in sandstone and dolostone reservoirs, with porosities (primary and secondary) of 8 to 20 % and permeabilities of 1 to 300 mD (Hamblin, 2008), corresponding to freshwater hydraulic conductivities of $1x10^{-8}$ to $3x10^{-6}$ m/s. Hydrocarbons in these plays are trapped by juxtaposition of the Cambrian reservoirs against low-permeability limestones of the Black River Group due to faulting and tilting (Sanford, 1993). Stratigraphic traps are also found where porous Cambrian units pinch out updip against the Precambrian basement and are sealed by the overlying Shadow Lake Formation shales, mostly around the edges of the Algonquin Arch (Hamblin, 2008; Carter, 2010). Cambrian pools are mainly located in the Appalachian Basin, along a geographic band between Windsor and Kitchener (Figure 5.1). No commercially producing Cambrian pools have been reported within the Michigan Basin in Ontario. As of 2010, cumulative oil and gas production from Cambrian plays in southern Ontario was of 5.2 million barrels (mmbl) of oil and 30.5 billion cubic feet (bcf) of gas, respectively (Carter, 2010).

Table 5.1 Hydrocarbon Exploration Plays in Southern Ontario

Play	***Reservoir Rocks***	***Trapping Mechanism***	***Geographic Distribution***
Cambrian (CAM)	• Upper Cambrian-Ordovician shallow marine sandstones and dolostones	• Pools controlled by faulting and tilting (juxtaposition against low-permeability limestones of the Black River Group) or as permeability pinch outs around the edges of the Algonquin Arch	• Mainly along the erosional boundary of the Cambrian along a line connecting Windsor and Hamilton. • No active economic reservoirs known on the Michigan Basin side.
Upper Ordovician Hydrothermal Dolomite (ORD)	• Hydrothermal dolostones within shallow marine carbonates of the Black River and Trenton groups	• Occur as narrow, linear, vertically oriented, fault-related hydrothermal dolomitization zones in the vicinity of rejuvenated faults along which spatially limited dolomitization took place (permeability pinch-out). Upper Ordovician shales act as cap rocks	• Southwest end of southern Ontario (London - Windsor area). Limited potential (not exploited) in the whole Niagara Megablock, low potential in the Bruce Megablock (3 small gas pools; low density of reservoirs expected because of less dense faulting and/or limited dolomitization).
Lower Silurian Sandstones (CLI)	• Sandstones (Whirlpool, Grimsby/Thorold (Medina) formations) and dolostones (Irondequoit Formation) of the Appalachian Basin	• Permeability pinch-out due to internal heterogeneity of the host formations (spatially variable cementation)	• Occurrence of the sandstones and pools mainly along the north shore of Lake Erie (Appalachian Basin, Niagara Megablock)
Upper Silurian Reefs (SAL)	• Reef limestones of the Guelph Formation, carbonates of the Salina Group (A1, A2)	• Related to patch and pinnacle reefs in Guelph Formation • All reservoirs are sealed by surrounding thick evaporite deposits of the Salina Group	• Along the edge of the Michigan Basin (from Lake St. Clair north along the shore of Lake Huron)
Middle Devonian (DEV)	• Shallow marine platform carbonates of Dundee Formation and Detroit River Group	• Structural traps generated by dissolution of underlying salt	• Southwestern Ontario (Chatham Sag)

Notes: Modified from Mazurek (2004), Sanford (1993), Carter (Ed.) (1990), Lazorek and Carter (2008), Hamblin (2008).

Upper Ordovician reservoirs of the Black River and Trenton groups occur as narrow, linear zones of porous and permeable dolomite associated with rejuvenated fault and fracture systems. Fluid migration through these faults and fractures produced solution enhancement and diagenetic high-temperature hydrothermal dolomitization of the limestones, providing suitable porosity and permeability. The Upper Ordovician shale units provide the vertical seal for these reservoirs; lateral seals are provided by the transition from the porous hydrothermal dolomites into the non-porous original limestones of the Trenton and Black River groups. Upper Ordovician reservoirs in southern

Ontario are usually about up to 1,200 m in width and 14 km in length, with average porosities ranging from 6 % to 8 %, and permeabilities ranging from less than 1 mD to up to 10,000 mD (Carter et al., 2008) corresponding to freshwater hydraulic conductivities of $1x10^{-8}$ to $1x10^{-4}$ m/s). Hydrothermal dolomite reservoirs are primarily found in the London to Windsor area of southern Ontario (Figure 5.1). As of 2010, cumulative production from this type of play in southern Ontario was 23.1 mmbl of oil and 41.2 bcf of gas (Carter, 2010).

Lower Silurian gas reservoirs in southern Ontario include sandstones of the Whirlpool, Grimsby and Thorold formations of the Clinton and Cataract groups, as well as dolostones of the Irondequoit Formation (see Table 3.1). These sandstones and dolostones are found in the Appalachian Basin and are extensive in the Niagara Peninsula and beneath central and eastern Lake Erie. Traps in this type of play are likely mostly stratigraphic, and defined by permeability pinch-outs due to textural and compositional variations in the sandstones, and to diagenetic changes. Porosity in the Lower Silurian reservoirs ranges from approximately 6 % to 18 % (mostly 10 % to 15 %), and permeability from typically 5 mD to 10 mD (Hamblin, 2008). These mD permeability values are equal to fresh water hydraulic conductivities of $5x10^{-8}$ to $1x10^{-7}$ m/s. Oil and gas Lower Silurian plays are mostly concentrated in Haldimand, Norfolk and Welland counties north of the eastern part of Lake Erie, as well as the eastern portion of the Canadian part of Lake Erie (Figure 5.1).

Upper Silurian hydrocarbon reservoirs occur in reef dolostones of the Guelph Formation and carbonates of the Salina Group (A1 and A2 Units). In the Guelph Formation, hydrocarbons are hosted in three types of reefs: pinnacle, incipient and patch reefs. Pinnacle and incipient reefs are found in the pinnacle reef belt running through Lambton, Huron and Bruce counties (see Sections 3.1.4.3 and 3.2.2.3), while patch reefs underlie very large geographic areas. Porosity and permeability in these reefs of the Guelph Formation are developed by dolomitization, and hydrocarbons are sealed by impermeable anhydrites and argillaceous carbonates and shales of the overlying Salina Group. The Salina A-1 and A-2 carbonates also host hydrocarbons where porosity is developed by dolomitization. In these cases, traps usually occur as structural drapes over reefs of the Guelph Formation or on the upthrown side of regional faults (Lazorek and Carter, 2008). Reefal reservoirs of the Guelph Formation in southern Ontario are typically found along the eastern edge of the Michigan Basin from Lake St. Clair north along the shore of Lake Huron. As of 2010, oil and gas cumulative production from Lower Silurian carbonates was 14.6 mmbl and 728 bcf, respectively.

It is noteworthy that potential exists to convert pinnacle reefs of the Guelph formation for use as natural gas storage reservoirs in depleted oil and gas fields. Twenty-nine gas storage reservoirs have been developed in pinnacle reefs in southern Ontario, with a cumulative storage capacity of 236 bcf (Hamblin, 2008).

Devonian carbonates of the Dundee Formation and Detroit River Group host hydrocarbons in structural domes formed by collapse over differential dissolution zones of the underlying Salina Group salt beds. Reservoir facies mostly include fractured limestones, dolomitized limestones, and sand-rich limestones. Porosity and permeability values are variable depending on the reservoir facies (Hamblin, 2008). Devonian reservoirs in southern Ontario are typically restricted to an area between Sarnia and Chatham-Kent associated with the Chatham Sag (Figure 5.1). Cumulative oil production from Devonian reservoirs in southern Ontario, as of 2010, is approximately 44.5 mmbl.

In 2009 the Ontario Geological Survey started a program to evaluate the shale gas potential of the Paleozoic shale units in southern Ontario. The Upper Devonian Kettle Point and Marcellus formations, the Upper Ordovician Georgian Bay and Blue Mountain formations, and the Collingwood Member of the Cobourg Formation were selected for such assessment. These shale units have high organic content, act as source rocks for economic hydrocarbon pools and are equivalent to shale gas units identified in the United States (Béland-Otis, 2012). In 2011, drilling and testing of these formations was undertaken and an assessment of their unconventional gas potential is still ongoing. No economically exploitable shale gas accumulations have been discovered in southern Ontario to date (Engelder, 2011).

5.1.2 Local Hydrocarbon Potential

As shown on Figure 5.2, there are three oil and gas pools in the Area of the Five Communities, all of them located immediately south of the Township of Huron-Kinloss. They include the Ashfield 5-IX WD Pool, the West Wawanosh 1-25-XII Pool and the Dungannon Pool. No hydrocarbon pools have been discovered within the Area of the Five Communities.

Table 5.2 lists the available information on the three petroleum pools located within the Area of the Five Communities, as well as other known pools within a 35 km radius of the Communities. All three pools within the Area of the Five Communities (i.e. Ashfield 5-IX WD, West Wawanosh 1-25-XII and Dungannon) are currently active and produce gas from pinnacle reefs of the Upper Silurian Guelph Formation (see Section 5.1.1) at a depth of approximately 500 m. These gas pools range in size from 32 to 62 ha. As of 2010, cumulative gas production from these pools was 242 million m^3. The most recent gas pool developed in the vicinity of the Area of the Five Communities is the West Wawanosh 1-25-XII Pool discovered by Northern Cross Energy Limited in 2007. Immediately south of the Area of the Five Communities there are two additional pools that also produce gas from pinnacle reefs of the Guelph Formation, the Ashfield 7-1-III ED Pool and the West Wawanosh 26-X Pool (Figure 5.2).

In addition to the pinnacle reefs associated with the Ashfield 5-IX WD, West Wawanosh 1-25-XII and Dungannon pools, there are nine additional known pinnacle reefs in the Area of the Five Communities. Two of these reefs are in the Town of Saugeen Shores, and three in the Township of Huron-Kinloss (Figure 5.2). Drilling through these additional pinnacle reefs did not encounter economical accumulations of hydrocarbons. As described in Section 3.2.2.3, interpretation of geophysical data, and borehole geophysical and 2D seismic data interpretation conducted as part of this assessment (PGW, 2014; Geofirma Engineering Ltd., 2014) did not identify any new potential pinnacle reefs in the Guelph Formation, or any other potential oil and gas plays in the Area of the Five Communities.

As listed in Table 5.2 and shown on Figure 5.1, the Hepworth Pool, the two Egremont Pools and the Arthur Pool are located outside of the Area of the Five Communities. The Hepworth Pool is located 10 km north of the Municipality of Arran-Elderslie, the Egremont Pools are located 25 km east of the Municipality of South Bruce, and the Arthur Pool is located 32 km southeast of the Municipality of South Bruce. Gas in these pools is produced from Upper Ordovician hydrothermal dolomite plays in the Trenton and Black River groups (see Section 5.1.1). Only the Arthur Pool is active today. These three Upper Ordovician gas pools produce from reservoirs found at depths of 428 to 700 m, and range in size from 3.1 to 178 ha. As described in Section 3.2.2.4, there is one mapped subsurface fault in the Municipality of South Bruce that is interpreted to extend upward to the Trenton Group. No hydrothermal dolomitization of the Upper Ordovician limestones has been reported associated with

Table 5.2 Active and Abandoned Petroleum Pools Identified in the Area of the Five Communities and Immediate Periphery (modified after NWMO, 2011)

Name	Type	Mode	Geological Age	Area (m^2)	Township	Discovery Date	Depth (m)	Producing Formation	Cumulative Gas Production (1,000 m^3)	Cumulative Oil Production (m^3)
Ashfield 5-IX WD Pool	Gas Pool	Active	Silurian - Salina-Guelph	320,867.6	Ashfield	2/28/1979	556	Guelph	10564.37	0.0
West Wawanosh 1 25-XII Pool	Gas Pool	Active	Silurian - Salina-Guelph	--	West Wawanosh	11/09/2007	485	Guelph	409.29	0.0
Dungannon Pool	Gas Pool	Active	Silurian - Salina-Guelph	621,129.7	West Wawanosh	8/29/1958	510	Guelph	43481.77	0.0
Ashfield 7-1-III ED Pool	Gas Pool	Active	Silurian - Salina-Guelph	230,759.3	Ashfield	3/5/1979	582	Guelph	26501.4	0.0
West Wawanosh 26-X Pool	Gas Pool	Active	Silurian - Salina-Guelph	183,530.0	West Wawanosh	10/4/1968	509	Guelph	5124.04	0.0
Hepworth Pool	Gas Pool	Abandoned	Ordovician	1,788,257.5	Amabel	1900	428	Trenton, Black River	708.2	0.0
Egremont Pool	Gas Pool	Abandoned	Ordovician	31,370.6	--	--	--	--	--	--
Egremont Pool	Gas Pool	Active (no production)	Ordovician	212,710.9	Egremont	1966	666	Black River	0.0	0.0
Arthur Pool	Gas Pool	Active	Ordovician	729,558.5	Arthur	1968	700	Shadow Lake, Black River	34535.91	0.0
								2010 Cumulative Petroleum Production Totals:	**111,816.98**	**0.0**

Note: Compiled from OGSR Library (2012) subsurface dataset.
-- not available

this fault, and well F012077 drilled in the immediate vicinity of the fault was reported dry and abandoned.

Lower Silurian hydrocarbon plays are not expected to occur in the Area of the Five Communities, as the Paleozoic formations that form the reservoirs in this type of plays (i.e. Whirlpool, Grimsby and Thorold formations) are not present. Similarly, Devonian plays are not expected in the Area of the Five Communities due to a lack of the necessary geological conditions (presence of cap rocks and coincidence of Dundee and Detroit River Group with salt dissolution areas). Cambrian sandstones in the Area of the Five Communities are generally relatively thin and limited to the area along the shores of Lake Huron (Figure 3.19). All the exploration wells within the Communities were reported dry and abandoned.

As described in Section 5.1.1, the Ontario Geological Survey is currently assessing the potential for shale gas in southern Ontario, and in 2011 carried out a drilling program to evaluate shale gas potential of the Upper Ordovician Georgian Bay Formation, Blue Mountain Formation and Collingwood Member of the Cobourg Formation (Béland-Otis, 2012). Core samples of these shale units from depths of 304 to 488 mBGS were tested east of the Area of the Five Communities for total organic carbon (TOC), and gas content, composition and isotopes. The results from this work (Béland Otis, 2012) are not dissimilar to core gas testing completed at the Bruce nuclear site (Intera Engineering Ltd., 2011) on similar formations at deeper depths of 500 to 670 mBGS.

The results of the Bruce nuclear site core testing (Intera Engineering Ltd., 2011) show methane occurrences are highest in Blue Mountain Formation, and the Collingwood Member and Lower Member of the Cobourg Formation, with TOC concentrations of > 2.0 % (maximum 2.5 %) within a m-scale interval that extends from the upper part of the Collingwood Member into the base of the Blue Mountain Formation. These maximum TOC values are similar but less than those reported by Béland-Otis (2012) from a borehole drilled east of the Area of the Five Communities 20 km east of Mount Forest with a maximum TOC of 4.55 % measured in a discrete cm-scale zone at the top of the Collingwood Member. Methane isotopes measured on methane in porewater indicate the methane within the Blue Mountain Formation and Collingwood Member were derived from biogenic processes and not thermocatalytically (Intera Engineering Ltd., 2011).

Given the generally low TOC values measured, the biogenic origin of the methane in the Ordovician shales, and the recognized low thermal maturity of the Paleozoic formations that barely reached the oil window (Legall et al., 1981, Obermajer et al., 1996) in the Area of the Five Communities, the likelihood of commercial shale gas in the Communities is low (Engelder, 2011). The potential for petroleum resources, including hydrocarbon generation potential in low permeability formations, in the Area of the Five Communities will need to be further investigated in subsequent stages of the site evaluation process.

5.2 Metallic Mineral Resources

There are no known areas of active exploration interest for metallic mineral resources within the Communities, as evidenced by the lack of active mining claims (MNDM, 2013b) and the lack of metallic mineral occurrences (Figure 5.2; OGS, 2013). The Abandoned Mines Information System (MNDM, 2011) and Mineral Deposits Inventory (OGS, 2013) show that there are no currently or past producing metallic mineral mines within the Area of the Five Communities.

Sphalerite concretions within Silurian dolomites on the Bruce Peninsula have in the past attracted some base metal exploration interest for potential Mississippi Valley Type (MVT) deposits (Sangster and Liberty, 1971). However, no commercial MVT deposits have been discovered in southern Ontario.

HudBay Minerals Inc. conducted limited exploration drilling to assess possible zinc occurrences in the bedrock of Wellington County in the southwest corner of the Area of the Five Communities (The Wellington Advertiser, 2007), five to seven kilometres southeast of the Municipality of South Bruce. This exploration work was based on elevated zinc concentrations observed in shallow groundwater and geophysical anomalies reported in the 1970s. Information within the Petroleum Wells Database (OGSRL, 2013) indicates that three wells (T011771, T011772 and T011773, see Figure 3.6) were drilled in 2008 to depths of 260 to 280 mBGS into the Queenston Formation. However, no economically exploitable zinc deposits were reported as a result from this exploration program.

Although sediment-hosted metallic mineral deposits (e.g., MVT lead-zinc, strataform copper) are common in many parts of the world and often host some of world's largest ore deposits, the geological conditions of the sedimentary formations in southern Ontario are not favourable for their occurrence. Sediment-hosted metallic mineral deposits typically require long-term migration of low-temperature metal-containing fluids across redox boundaries or into traps resulting in metal precipitation often within porous and permeable carbonate strata. The low porosity and permeability of most of the Paleozoic carbonate sequence in southern Ontario do not support such fluid migration. Consequently, the potential for metallic mineral resources is in the Area of the Five Communities is considered low.

5.3 Non-Metallic Mineral Resources

5.3.1 Surficial Sand and Gravel

Sand and gravel pits are operating throughout the Area of the Five Communities. Most of these pits are shallow (<8 m depth) and located within esker, glaciofluvial outwash, ice contact and glaciolacustrine beach deposits. Because of their importance as aggregate sources, many of the large eskers have been mined extensively within the Area of the Five Communities and are nearing depletion. The Ontario Aggregate Resources Inventory for Bruce County (Rowell, 2012) provides additional information on aggregate production and significance of areas for sand and gravel resources. Table 5.3 summarizes the aggregate production in 2010 within the Communities.

Table 5.3 2010 Aggregate Production by Community, County of Bruce (after Rowell, 2012)

Community	***2010 Aggregate Production (tonnes)***	***Percentage of Bruce County Total***
Municipality of Arran-Elderslie	159,394	7.05
Municipality of Brockton	243,673	10.77
Municipality of South Bruce	384,517	17.00
Township of Huron-Kinloss	420,752	18.60
Town of Saugeen Shores	364,529	16.12

5.3.2 Bedrock Resources

Many of the Paleozoic rocks found at surface or under the overburden within the Area of the Five Communities have been extracted elsewhere across southern Ontario for their aggregate potential, for building stone, and for brick manufacture. For these bedrock resources to be economic, the rock must be close to surface (less than 8 m deep), and be of mineable thickness. Most bedrock extraction operations are developed in areas where the overburden thickness is 3 m or less. Table 5.4 summarizes information on economic bedrock resources in and near the Area of the Five Communities, including aggregate and other economic resources.

Current quarrying activities in the region surrounding the Area of the Five Communities are almost exclusively limited to Lower Silurian dolostones, which are extracted for building stone, landscaping stone and aggregate on or near the Niagara Escarpment and Bruce Peninsula where overburden thickness is reduced. The massive dolostone of the Wiarton-Colpoy Bay Member of the Amabel Formation and Eramosa Member of the Guelph Formation are currently actively quarried on or near the Niagara Escarpment and at other locations in Bruce and Grey Counties. Shales of the Georgian Bay and Queenston formations have historically been quarried for brick making near Collingwood, east of the Area of the Five Communities.

There are no known licensed bedrock quarries or commercial bedrock mining operations within the Communities, presumably due to the presence of thick overburden (e.g. 19.6 to 49.8 m overburden thickness; Table 3.3). There are a small number of small unlicensed (typically abandoned or wayside) quarries within the Communities, notably in the municipalities of Brockton and South Bruce.

As shown on Figure 5.2, discretionary mineral occurrences of salt, gypsum, limestone, dolostone and marl have been reported within the Area of the Five Communities. With the exception of salt, all of these discretionary mineral occurrences are related to shallow bedrock quarrying for aggregate and building stone use (OGS, 2004). Salt resources are discussed in more detail in Section 5.3.3.

5.3.3 Salt

As described in Section 3.1.4.4, the Upper Silurian Salina Group includes a number of salt beds that exist in variable thicknesses in southern Ontario. Salt is currently being mined at several locations in southern Ontario, including at the Goderich Mine approximately 30 km south of the Township of Huron-Kinloss. Salt in the Goderich Mine is produced through underground mining and brine-well methods, with an annual production capacity of 9,000,000 tonnes. It is situated approximately 550 m below ground surface, and extends approximately 5 km from the shore beneath Lake Huron (Sifto Canada Corp., 2013; Compass Minerals, 2013). Underground mining of salt at the Goderich Mine is from the Salina A2 Unit salt (Hewitt, 1962).

Figure 5.2 shows the lateral extent of the Salina B Unit salt bed, which is the most extensive of the Salina Group salt beds in the Area of the Five Communities. The Salina B salt is mainly found beneath the Township of Huron-Kinloss, where it is typically found at depths of about 350 to 400 mBGS (OGSRL, 2013). Based on Sanford (1976) and OGSRL (2013), the thickness of the Salina B Unit salt in the southwestern part of the Township of Huron Kinloss is approximately 75 m and decreases eastward until it pinches-out near the eastern limit of the Township (Figure 5.2).

Table 5.4 Summary of Economic Bedrock Units in and Near the Area of the Five Communities (after NWMO, 2011)

Age	*Group/Formation*	*Type*	*Potential Usage*	*Location*
Upper Ordovician	Lower Lindsay Formation (Cobourg Formation)	Limestone	Aggregate	Collingwood Area
Upper Ordovician	Lindsay Formation (Collingwood Member)	Calcareous shale	Oil Shale	Collingwood Area
Upper Ordovician	Blue Mountain Formation	Noncalcareous shale	Structural clay products, pottery	Collingwood- Georgian Bay
Upper Ordovician	Georgian Bay Formation	Limestone and shales	Manufacture of bricks	Collingwood area – Georgian Bay shore
Upper Ordovician	Queenston Formation	Shale	Brick Making	Bruce Peninsula/ Base of Niagara Escarpment
L. Silurian	Whirlpool Formation	Sandstone	Building stone	Niagara Escarpment
L. Silurian	Manitoulin Formation	Dolomitic limestone	Landscaping and building stone, aggregate	Niagara Escarpment, St. Vincent and Sarawak Counties
L. Silurian	Cabot Head Formation	Shales	Aggregate potential/brick, tile	Niagara Escarpment
L. Silurian	St. Edmund Formation	Dolostone	Fill, crushed stone, asphalt and concrete suitable	Manitoulin Island
L. Silurian	Wiarton/Colpoy Bay Member of the Amabel Formation	Massive dolostone	Industrial mineral use (glass manufacturing), dimension stone, dolomitic lime, crushed stone, concrete aggregate and building stone	On or near Niagara Escarpment to end of Bruce Peninsula (Grey County, Bruce County - Albemarle Twp., Sydenham Twp.)
U. Silurian	Guelph Formation	Thickly bedded dolostone	Dolomitic lime, crushed stone, concrete aggregate and building stone	Bruce County – Amabel Twp.
L. Silurian	Guelph Formation (Eramosa Member)	Thinly bedded bituminous dolostone	Building and landscaping stone (flag, paving, ashlar, and polished dimension stone)	Bruce County – Albemarle Twp., Amabel Twp. – Grey County – Keppel Twp.
U. Silurian	Salina Group	Evaporite	Salt, brine	Southwestern ON: Windsor, Goderich, Sarnia, North Wellington City. Only in subsurface.
M. Devonian	Detroit River Group (Amherstburg (Formosa Reef) and Lucas Formations)	Limestone	Cement manufacture, high purity and used by the steel, cement and chemical industries	Southern Grey and northern Wellington Counties
M. Devonian	Anderdon Member limestone of the Lucas Formation	Limestone	Aggregate, building stone, armour stone, lime and cement	Wellington County

Notes: Twp = township. Data are from recent aggregate resources inventory report (OGS, 2004)

The Salina Group salt beds in the Area of the Five Communities are identified as discretionary mineral occurrences (Figure 5.2), and their economic viability has not been proven to date.

5.4 Groundwater in the Guelph Formation

The Guelph Formation dolostone is a recognized regionally important water supply aquifer. It is present over most of the Area of the Five Communities and provides municipal water supply to the settlement areas of Tara and Chesley in the Municipality of Arran-Elderslie, and other larger settlement areas east and south of the Area of the Five Communities (e.g. Guelph and Cambridge). Within the Communities, the top of the Guelph Formation is found at depths ranging from about 5 m in the Municipality of Arran Elderslie to a maximum of over 500 m in the Township of Huron-Kinloss.

Given the recognized potential of the Guelph Formation as a water supply aquifer, there is potential for its development as a fresh water source below depths typically assumed for shallow bedrock water supplies in the Area of the Five Communities (see Section 4.3.1). In order for the Guelph Formation to be accessed as a water supply aquifer, the groundwater must be potable.

Carter and Fortner (2011), based on analysis of groundwater quality data within the OGSRL database mapped the occurrence of fresh water and salty/sulphurous water within the Guelph Formation. Figure 5.2 shows the inferred extent of the occurrence of fresh water within the Guelph Formation in the Area of the Five Communities based on the Carter and Fortner (2011) data. The northeastern extent of fresh water in the Guelph Formation shown in Figure 5.2 is the mapped outcrop limit of the Guelph Formation (Figure 3.6). The southwestern limit of fresh water occurrence within the Guelph Formation shown in Figure 5.2 is defined by formation depth contours between 200 to 250 mBGS. Potable water is likely to occur above this depth horizon.

Brunton et al. (2012) as part of a regional bedrock aquifer mapping program of the Early Silurian carbonates in southern Ontario has noted that deep potable groundwater resources may also be found in the strata of the Amabel-Lockport Formation underlying the Guelph Formation.

5.5 Exploration Borehole Seal Integrity

Poorly sealed old deep oil and gas exploration wells of known location and wells of unknown location are recognized as potential constraints in evaluation of potential siting areas within the Area of the Five Communities. For exploration wells of known location it is now recognized that some form of well barrier or integrity failure should be anticipated in a percentage of the wells (Davies et al., 2014). The role of potentially leaking old oil and gas exploration wells in site selection will need to be assessed in subsequent evaluation stages

6 GEOMECHANICAL AND THERMAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and in situ stresses are needed to design stable underground openings, and to predict the subsequent behaviour of the rock mass around these openings. Additionally, thermal properties including thermal conductivity, thermal diffusivity and specific heat provide information on how effectively the rock will transfer heat from the repository and dissipate it into the surrounding rock. As such, geomechanical and thermal property information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010).

There are no data on geomechanical properties of the Paleozoic bedrock formations at potential repository depths within the Communities. However, geomechanical property data are available from detailed drilling and testing investigations at the nearby Bruce nuclear site (Intera Engineering Ltd., 2011, Golder Associates Ltd., 2013), and from regional compilations of geomechanical data (NWMO and AECOM Canada Ltd., 2011; Golder Associates Ltd., 2003a).

Similar to geomechanical data, there are no data on thermal properties of Paleozoic bedrock formations at potential repository depths within the Communities. Thermal property data are available from detailed drilling and testing investigations at the nearby Bruce nuclear site (Atomic Energy of Canada Ltd., 2011), and from compilations of data available in the published literature (Clauser and Huenges, 1995; Sass et al., 1984; Cermak and Rybach, 1982).

Based on the lateral traceability and predictability of the Paleozoic sequence in southern Ontario, geomechanical and thermal properties of the Paleozoic sequence in the Communities can be expected to be similar to those measured at the Bruce nuclear site and elsewhere in southern Ontario. Site-specific geomechanical and thermal data would need to be obtained during later stages of the site evaluation process.

6.1 Intact Rock Properties

Intact rock strength properties for Paleozoic formations present in the Communities are inferred based on measured properties for the same formations at the Bruce nuclear site (Intera Engineering Ltd., 2011). Figure 6.1a shows a profile presentation of intact rock geomechanical properties (i.e. Uniaxial compressive strength [UCS], Elastic Modulus, and Poisson`s Ratio) for the Paleozoic formations at the Bruce nuclear site based on laboratory testing (Intera Engineering Ltd., 2011; NMWO, 2011).

Figure 6.1a shows that intact rock properties of the Trenton Group units (i.e. Cobourg and Sherman Fall formations) are variable. Limestones of the Cobourg Formation have high strength (i.e. average UCS value of 113 MPa), thus indicating a high degree of stability for deep underground excavations. Intact rock properties of the Cobourg Formation at the Bruce nuclear site agree with available regional data, with the exception of the UCS, which is significantly higher than the regional values (i.e. regional average UCS value of 72 MPa). This may be attributed to different sampling methods, mineralogical variations, improved sample preservation methods, and/or the quality of the laboratory testing. As shown on Figure 6.1a, the Sherman Fall Formation is considerably weaker than the Cobourg Formation, with a best estimate mean peak UCS of 49 MPa. Intact rock properties for the Black River Group formations from limited testing at the Bruce nuclear site are comparable to the values measured for the Cobourg Formation (Figure 6.1a).

The Upper Ordovician shales have a moderate strength, with lower UCS estimated mean values than the Cobourg Formation of 48 MPa and 32 MPa for the Queenston and Georgian Bay formations, respectively. Regional UCS data of both formations lie within the same range (NWMO and AECOM Canada Ltd., 2011).

Information on point load strengths, shear strength, triaxial compression strengths slake durability, free swell potential, abrasiveness and dynamic elastic constants of the Paleozoic bedrock based on testing at the Bruce nuclear site is provided in Intera Engineering Ltd., (2011). Site specific geotechnical assessments would need to be conducted during later stages of the site evaluation process.

6.2 Rock Mass Properties

Rock mass properties address the behaviour of a body of rock, including its fracture or joint network. The presence of fractures changes the strength of a rock mass compared to what would be measured on small intact samples of the rock. For example, the uniaxial compressive strength of a rock mass containing a network of joints will be lower than the uniaxial compressive strength of a core sample measured in a laboratory. Fracture spacing, orientation and condition (width or aperture, mineral fill, evidence of relative displacement, etc.) of the fractures tend to influence the overall mechanical response of the rock mass.

Data on rock mass properties of Paleozoic rocks are available from studies completed at the Bruce nuclear site as part of the Descriptive Geosphere Site Model (DGSM, Intera Engineering Ltd., 2011), and are summarized in the Geosynthesis Report (NWMO, 2011) and the Regional Geomechanics Geosynthesis Report (NWMO and AECOM Canada Ltd., 2011). Golder Associates Ltd. (2003a) estimated rock mass classification ratings in common usage for geomechanics purposes for selected Paleozoic formations based on shallow bedrock excavation experience in southern Ontario.

Figure 6.1b summarizes core recovery, rock quality designation (RQD), and fracture frequency results for Paleozoic formations from investigations at six boreholes at the Bruce nuclear site. The figure shows that the Upper Ordovician shale and limestone units at the Bruce nuclear site are very sparsely fractured and of excellent quality (Intera Engineering Ltd., 2011). The rock mass designation, based on RQD (Deere at al.1967), for all of the Upper Ordovician shale formations is generally excellent (RQD of 90 to 100%) with occasional local zones of lower quality. The measured fracture frequency is similar in all of the formations and ranges from 0 to 1.7 fractures per metre, with an average value of generally less than 0.3 fractures per metre. The fractures appear to be very tight and well sealed. Similarly, the Trenton Group limestone formations (i.e. Cobourg and Sherman Fall formations) have a rock mass designation of excellent with RQD generally ranging between 90 and 100%. The fracture frequency in all three Trenton Group formations is comparable. Similar rock mass geomechanical properties are observed for the Black River Group limestone formations (Figure 6.1b). Photographic examples of intact recovered core runs from these formations at the Bruce nuclear site are given in Figure 6.3.

Information on the orientation of fractures logged in deep boreholes drilled at the Bruce nuclear site and comparison of those orientations to available surface fracture orientation data are summarized by Intera Engineering Ltd. (2011). Fractures logged in deep boreholes intersecting Silurian and Ordovician formations at the Bruce nuclear site showed the presence of a dominant sub-horizontal fracture set. Subordinate steeply-dipping to moderately inclined fractures logged in deep boreholes intersecting Silurian and Ordovician formations, with prominent northeasterly and northwesterly strikes, were comparable in orientation to some of the surface fractures mapped in Devonian outcrop close to the Bruce nuclear site and in southern Bruce peninsula (Cruden, 2011; AECOM Canada Ltd. and Itasca Consulting Canada, Inc., 2011).

Information on rock mass geomechanical properties from investigations at the Bruce nuclear site provide a good preliminary indication of what can be expected beneath the Communities. However, the effect that the depth of the potentially suitable formations may have on fracture frequency and other geomechanical properties would need to be investigated at later stages of the assessment through collection of site-specific data.

6.3 In Situ Stresses

Knowledge of the in situ stresses at a site is required to model the stress concentrations around underground excavation designs. These stress concentrations are ultimately compared to the strength of a rock mass to determine if conditions are stable or if the excavation design needs to be modified. This is particularly important in a repository design scenario, where minimization of excavation-induced rock damage is required.

There are no direct measurements of in situ stresses from either traditional strain-relief or less reliable hydraulic fracturing methods for the Paleozoic rocks in the Area of the Five Communities (NWMO and AECOM Canada Ltd., 2011). However, information on the state of in-situ stress likely to exist in the Paleozoic rocks of the Communities is indirectly available from regional summaries of in situ measurements made in the surrounding Appalachian and Michigan Basins (NWMO and AECOM Canada Ltd., 2011), from behaviour of borehole core and walls during characterization of the Bruce nuclear site (Intera Engineering Ltd., 2011; NWMO, 2011), and from numerical modeling to develop a preliminary stress model for the Bruce nuclear site (NWMO, 2011).

Figure 6.3a summarizes the available regional information on the distribution of principal stresses with depth in the Appalachian and Michigan basins. These data indicate the presence of relatively high horizontal compressive stresses characteristic of a thrust fault regime, where both horizontal stresses are greater than vertical stresses. These regional data also indicate that the maximum horizontal in-situ stress is consistently oriented in a northeasterly to east-northeasterly direction (NWMO and AECOM Canada Ltd., 2011). Analysis of borehole ellipticity data from the Bruce nuclear site (NWMO, 2011) suggests a similar direction of maximum horizontal stress for Paleozoic rocks.

Figure 6.3b summarizes the results of the calculated vertical and maximum horizontal stress profiles for the stratigraphic column at the Bruce nuclear site. Figure 6.3b is based on analysis of the lack of borehole breakouts in deep exploratory boreholes, and in-situ stress modeling (using FLAC3D) of the Paleozoic rocks at the Bruce nuclear site to simulate tectonic strains observed at the Norton mine in Ohio, which has a similar depth horizon and stratigraphy (Itasca Consulting Canada, Inc., 2011). Comparison of Figures 6.1a and 6.3b shows that the calculated in-situ stresses are related to relative formation strengths and stiffnesses with the high strength/stiffness of the Cobourg Formation showing higher calculated in-situ stresses.

In-situ stresses for sedimentary rock formations will increase with increasing depth of the formations, consequently, site-specific measurements of in-situ stress in the Communities would need to be collected during later stages of the site evaluation process.

6.4 Thermal Properties

Thermal properties of potential host rocks provide information on how effectively the rock will transfer heat from the repository and dissipate it into the surrounding rock. The thermal properties of a rock are in part dependent on its mineral composition. The literature on thermal conductivities of sedimentary rocks similar to those present in the Communities suggest values of about 2.07 W/(m˚K) for shale, 2.29 W/(m˚K) for limestone, 2.47–4.5 W/(m˚K) for sandstone, 3.62-5.50 W/(m˚K) for dolostone, to 4.05-5.14 W/(m˚K) for anhydrite (Clauser and Huenges,1995; Sass et al., 1984). Thermal diffusivities of sedimentary rocks are reported to range from 0.85 mm^2/s for dolostone to 2.24 mm^2/s for anhydrite (Cermak and Rybach, 1982).

The mean measured thermal conductivity, thermal diffusivity and specific heat for Paleozoic formations measured on core samples collected at the Bruce nuclear site normal to bedding planes and immersed in deionized water for 24 hours are presented in Table 6.1 (after Atomic Energy of Canada Ltd.,2011). The data listed in Table 6.1 are generally consistent with thermal property data reported in the literature for sedimentary rocks. Table 6.1 shows the Cobourg Formation has slightly higher thermal conductivity that the overlying Ordovician shales, and underlying Sherman Fall Formation.

The values for thermal properties of Paleozoic rocks given in Table 6.1 are considered useful for comparison purposes as part of this preliminary assessment. However, site-specific thermal properties would need to be measured at later stages of the site evaluation process.

Table 6.1 Summary of Thermal Properties of Paleozoic Rocks at the Bruce Nuclear Site (after Atomic Energy of Canada Ltd., 2011)

Rock Formation/Unit	***Thermal Conductivity (W/(m°K))***	***Thermal Diffusivity (mm/s^2)***	***Specific Heat ($MJ/m^3/°K$)***
Lucas	3.638	1.860	1.967
Bois Blanc	3.867	1.740	2.226
Bass Islands	4.770	1.502	3.181
Salina F Unit	4.679	3.001	1.790
Salina B Unit	2.040	0.948	2.159
Salina A2 Carbonate Unit	3.072	1.231	2.506
Salina A2 Evaporite Unit	5.208	2.038	2.558
Goat Island	2.659	1.195	2.231
Queenston	2.102	0.929	2.263
Georgian Bay	2.176	1.223	1.864
Blue Mountain	2.234	1.323	1.748
Cobourg	2.619	1.209	2.180
Sherman Fall	2.311	1.064	2.227

7 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE COMMUNITIES

7.1 Approach

The objective of the Phase 1 geoscientific desktop preliminary assessment is to assess whether the Communities contain general areas that have the potential to satisfy the geoscientific evaluation factors and safety functions outlined in the site selection process document (NWMO, 2010). The location and extent of general potentially suitable areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field investigations.

The repository is expected to be constructed at a depth of about 500 mBGS or greater. The surface facilities will require a dedicated surface area of about 600 x 550 m for the main buildings and about 100 x 100 m for the ventilation exhaust shaft (NWMO, 2014). The actual depth and underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock, the final design of the repository and the inventory of used fuel to be managed. For the purpose of this preliminary assessment, it is assumed that the repository would require a footprint on the order of 2 x 3 km.

The geoscientific assessment of suitability was carried out in two steps. The first step (Section 7.2) was to identify general potentially suitable areas using the key geoscientific characteristics described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all NWMO's geoscientific site evaluation factors (NWMO, 2010). The potential for finding general areas was assessed using the following key geoscientific characteristics and constraints:

- ***Geological Setting:*** The initial screenings of the Five Communities (AECOM Canada Ltd., 2012a; 2012b; 2012c; 2012d; 2012e) identified the Upper Ordovician shale and limestone units as potentially suitable host rock formations. As described in Section 3.2.2, the 500 to 1000 m thick Paleozoic bedrock sequence within the Five Communities typically includes Devonian dolostones overlying Silurian dolostones, shales and evaporites, overlying Upper Ordovician shales and limestones, and occasionally Cambrian sandstone, overlying Precambrian basement. The Upper Ordovician Cobourg Formation argillaceous limestone is overlain by about 200 m of Upper Ordovician shales and underlain by about 150 m of deeper Upper Ordovician limestones.

  Based on available information on the geoscientific characteristics of the sedimentary sequence beneath the Five Communities, the Ordovician Cobourg Formation (argillaceous limestone) would be the preferred host rock for a used nuclear fuel deep geological repository. The natural geological setting in this formation would provide the most favourable geoscientific characteristics for ensuring safety. As described in Sections 4.2 and 6, the Cobourg Formation underlies Bruce County in sufficient thickness and volume, and has the favourable characteristics of very low hydraulic conductivity and high geomechanical strength (Figures 4.3b and 6.1a).

  While the other Trenton Group limestone formations (i.e. Sherman Fall and Kirkfield formations) and the Upper Ordovician shales (i.e. Queenston, Georgian Bay and Blue Mountain formations) also have very low hydraulic conductivities, they are less preferred than the Cobourg Formation from a geomechanical perspective (i.e. lower rock strength). The limestone formations of the Black River Group are also less preferred as they have uniformly higher hydraulic conductivity values than the Cobourg Formation (Figure 4.3b). The favourable characteristics of the Cobourg

Formation are complemented by the presence of approximately 200 m of overlying very low permeability Ordovician shale formations, which act as an additional hydraulic barrier.

There are only two mapped subsurface faults within the Communities, in the municipalities of Brockton and South Bruce and the Township of Huron-Kinloss. Two faults were also interpreted from the analysis of available 2D seismic data within the Communities (Section 3.2.2.4). The fault in the Municipality of Brockton is interpreted to extend downward from the top of the Shadow Lake Formation/Precambrian basement. The fault in the Municipality of South Bruce and the Township of Huron-Kinloss is interpreted to extend downward from the top of the Trenton Group. For the purpose of this preliminary assessment, these faults were not considered as key constraints in the identification of general potentially suitable areas as the possible faults are very localized and there is uncertainty at this stage regarding their location, orientation and existence. The potential for faults in the Paleozoic sequence within the Communities would need to be assessed during subsequent stages of the site selection process.

- ***Minimum Depth of Top of the Cobourg Formation:*** For the sedimentary sequence in the Area of the Five Communities, it was determined that a minimum depth of 500 metres below ground surface (mBGS) would be preferred in order to maintain the integrity of a repository within the Cobourg Formation. This preferred depth would also protect the 200 m thick Ordovician shale barrier under the most conservative assumptions of future bedrock removal rates due to glacial erosion (Section 3.1.9; Hallet, 2011).

- ***Protected Areas:*** All known protected areas with the Communities were excluded from further consideration. These include exclusion areas identified by the Communities for future development, Conservation Areas and Reserves, First Nation Reserves, Provincial Parks, Provincially Significant Wetlands, and built-up areas.

- ***Source Water Protection Areas:*** Land-based water protention zones (IPZs, Intake Protection Zones) 1 and 2, and groundwater protection areas (WHPAs, Well Head Protection Areas) A, B and C were excluded from further consideration, given that they provide the highest level of protection for municipal groundwater supplies through land use planning and controls. The consideration of WHPAs D and E would need to be further assessed in collaboration with the Communities in future studies.

- ***Natural Resources:*** The potential for natural resources in the Area of the Five Communities is shown on Figure 5.1. Discretionary mineral occurrences of limestone, dolostone, and marl present within the Communities are not considered as siting constraints due to the shallow depth associated with these occurrences (typically less than 20 m). While oil and gas pools exist immediately south of the Township of Huron-Kinloss, and potential for petroleum resources is recognized in southern Ontario, there are no known oil and gas pools within the Communities and all the exploration wells drilled within them resulted in dry holes. Salt beds of the Silurian Salina Group are known to be present beneath the Township of Huron-Kinloss; these are also not considered as a siting constraint at this stage given the relatively thin nature of the deposits and their relatively shallow occurrence underneath the Township of Huron-Kinloss (approximately 350 to 400 mBGS) compared to the depth of the Cobourg Formation (approximately 700 to 800 mBGS). The potential for hydrocarbon and salt resources within the Communities would need to be further assessed during subsequent stages of the site evaluation process.

- ***Surface Constraints:*** Surface features such as overburden, the limited extents of wetlands outside protected areas, the relatively flat topography and the ease of accessibility within the Communities were not found to be significant siting constraints. Overburden cover is extensive and locally thick within the Communities, and wetlands cover from 10 to 20 % of each of the Communities. However, these features were not considered to as significant constraints to siting at this stage. Water bodies cover a relatively small area.

7.2 Potential for Finding General Potentially Suitable Areas

Figure 7.1 shows the key geoscientific characteristics and constraints in the Area of the Five Communities used to identify general potentially suitable areas, including: depth to the top of the Cobourg Formation; protected areas, earth science ANSIs and areas reserved by the Communities; source water protection areas; built-up areas and potential for natural resources. The legend of the figure includes a 2 km by 3 km box to illustrate the approximate extent of suitable rock that would be needed to host a repository. The Area of the Five Communities has a number of favourable characteristics for hosting a DGR for used nuclear fuel. However, there are areas that have more potential than others.

The consideration of the above key geoscientific characteristics and constraints for the area covered by the Communities revealed that the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss contain large areas that have the potential to satisfy NWMO's geoscientific evaluation factors. The assessment also revealed that the Municipality of Arran-Elderslie and the Town of Saugeen Shores have limited potential to satisfy the geoscientific evaluation factors outlined in the site selection process (NWMO, 2010) when the above geoscientific characteristics and constraints are coupled with land use constraints.

The following sections provide a summary of how the key geoscientific characteristics and constraints discussed above were applied to the Communities to assess whether they contain general potentially suitable areas. At this early stage of the assessment, the boundaries of these general areas are not yet defined. The location and extent of general potentially suitable areas would be further refined during subsequent site evaluation stages.

7.2.1 <u>Town of Saugeen Shores</u>

The Town of Saugeen Shores contains several protected areas that occupy about 25 % of the Town. These include the Saugeen Bluffs Conservation Area, MacGregor Point Provincial Park, provincially significant wetlands, water intake protection zones at Southampton, and built-up areas at Port Elgin and Southampton. The land west of Highway 21 was excluded as it is preserved for future expansion.

There are no oil and gas pools or mineral occurrences recorded within the Town of Saugeen Shores. Two pinnacle reefs of the Guelph Formation are known to exist in the southern portion of the Town (Figure 5.2). While pinnacle reefs of the Guelph Formation are known to host economically exploitable petroleum resources elsewhere in southern Ontario (e.g. approximately 50 km south of the Town), exploration wells drilled through the pinnacle reefs in the Town of Saugeen Shores resulted in dry holes and did not encounter commercial hydrocarbon accumulations.

As described in Section 3, the bedrock geology in the Area of the Five Communities, including the Town of Saugeen Shores, is characterized by a laterally extensive and predictable sequence of Paleozoic formations. Based on borehole data, the cumulative thickness of the sedimentary sequence is estimated to be more than 700 m in the southern portion of the Town. Contour mapping shown on Figure 3.15 indicates that the depth to the top of the preferred Cobourg Formation decreases from approximately 584 mBGS near the southern boundary of the Town to about 400 mBGS in the northern part. The area where the depth to the top of the Cobourg Formation is greater than the preferred 500 mBGS represents roughly 40 % of the Town area, and is located in the southern portion of the Town (Figure 7.1). There are no faults mapped within the Paleozoic sequence beneath the Town of Saugeen Shores.

Although the Cobourg Formation is present at depths greater than the preferred 500 mBGS over roughly 40 % of the Town, the area contains a number of constraints that greatly reduce the prospect of finding areas that are large enough for hosting the repository's surface and underground facilities. These constraints include: the MacGregor Point Provincial Park along the shore of Lake Huron, the Saugeen Bluffs Conservation Area, a Surface Water Intake Protection Zone in Southampton, built-up areas at Port Elgin and Southampton, and the Saugeen River and its tributaries (Figure 7.1). In addition, the land west of Highway 21 was excluded from further consideration at the request of the Community, as it is preserved for future expansion. When all these constraints are considered, limited area remains available for potentially hosting a deep geological repository.

In summary, the Town of Saugeen Shores has very limited potential to contain areas that would meet the geoscientific siting factors discussed above.

7.2.2 Municipality of Arran-Elderslie

There are six conservation reserves, four provincially significant wetlands and several earth science Areas of Natural Scientific Interest (ANSIs) within the Municipality, which combined account for approximately 9 % of the area of the Municipality (Table 2.5, Figure 7.1). In addition there are also two wellhead protection areas: that associated with the Tara well supply, and part of the WHPA associated to the Chesley well supply (Section 2.4.4; Figure 2.7). Other surface constraints within the Municipality include the build-up areas of the settlement areas of Paisley, Chesley and Tara.

There are no oil and gas pools or mineral occurrences recorded within the Municipality of Arran-Elderslie, so there are no known natural resource constraints at this stage for identifying general potentially suitable areas within the Municipality. There are no faults mapped within the Municipality.

There are no boreholes drilled within the Municipality of Arran-Elderlsie to provide direct information on the subsurface bedrock geology. However, information on the bedrock geology beneath the Municipality can be obtained from wells surrounding the Municipality and from the regional understanding of the Paleozoic geology. The Municipality of Arran-Elderslie is underlain by a laterally extensive and uniform Paleozoic sequence, which is interpreted to have a cumulative thickness on the order of 700 m. Contour mapping (Figure 3.15) shows that the preferred Cobourg Formation is expected to be found at depths ranging from approximately 343 mBGS in the northeastern portion of the Municipality to approximately 545 mBGS towards its southwestern portion. The area within the Municipality where the top of the Cobourg Formation is at preferred depth of greater than 500 mBGS represents only about 5 % of the area of the Municipality, which is insufficient for hosting a deep geological repository. This area contains a number of surface constraints that further reduce land availability. These include: the McBeath Conservation Area, built-up areas associated with the settlement area of Paisley, railway infrastructure and the Teeswater River.

In summary, the Municipality of Arran-Elderslie does not contain sufficient land areas that have the potential to meet the geoscientific site evaluation factors discussed above.

7.2.3 Municipality of Brockton

The Municipality of Brockton is underlain by a predictable and laterally extensive Paleozoic sedimentary sequence. Based on information from well T004854 located near the western edge of the Municipality (Table 3.3; Figure 3.6), the thickness of the Paleozoic sequence in this area is approximately 890 m.

Depth contour mapping (Figure 3.15) shows that a large portion (about 70 %) of the Municipality has the preferred Cobourg Formation at depths greater than the preferred depth (500 mBGS). The top of the Cobourg Formation varies from about 404 mBGS in the northeastern portion of the Municipality to approximately 691 mBGS towards the western margin of the Municipality. The thickness of the overlying Upper Ordovician shale formations is estimated to be relatively uniform and more than 200 m thick within the Municipality (Figure 3.19). There is one mapped subsurface fault within the Paleozoic sedimentary sequence in the Municipality, located at the west end of the Municipality and extending to the west beyond the municipal boundaries (Figure 3.6). The mapped subsurface fault is interpreted to offset the Shadow Lake Formation/Precambrian units.

Known potential for economically exploitable natural resources in the Municipality of Brockton is limited to a few shallow discretionary limestone and marl occurrences located mostly in the vicinity of Walkerton (Figure 5.2). There are no known oil and gas pools identified within the Municipality, and all six exploration wells drilled within the Municipality resulted in dry holes with no petroleum potential.

The only significant built-up area in the Municipality is that associated with the settlement area of Walkerton (Figure 7.1). The western portion of the Municipality of Brockton is covered by the Greenock Swamp Wetland Complex (68 km^2), which is designated as a Provincially Significant wetland complex. Part of this wetland complex is also designated as a conservation area (Figure 2.6). The wellhead protection area, zones A to C, associated with the Walkerton well supply system cover approximately 6 km^2 on the southern portion of the Municipality, just west of the settlement area of Walkerton (Figure 7.1). A wellhead protection area and a surface water protection zone are also present on the eastern edge of the Municipality, associated with water supply to the settlement area of Hannover (Figure 2.7). There are two very small earth science ANSIs located in the central and south-central parts of the Municipality.

The consideration of the above geoscientific characteristics and constraints indicates that the central portion of the Municipality of Brockton appears to have favourable geoscientific characteristics for hosting a deep geological repository. This general potentially suitable area is located north of the settlement area of Walkerton and east and north of the Greenock Swamp Wetland Complex (Figure 7.1). The top of the preferred Cobourg Formation beneath this area occurs at depth ranging from about 500 to 650 mBGS, which is greater than the preferred minimum depth (Figure 3.15). This general potentially suitable area is mostly free of surface constraints and protected areas, with just a few localized provincially significant wetlands located along the banks of the Saugeen River, two small rectangular localized conservation areas/reserves (i.e., that are part of the Saugeen Conservation Area and Lands), a small earth science ANSI (Saugeen River Section), and a small well head protection area for the Chepstow Powers Subdivision well supply. The area is easily accessible via the existing road network (Figure 7.1).

Topography in the general potentially suitable area is relatively flat, although distinct topographic features are identified associated with the Saugeen and Teeswater rivers (Figure 2.3). The area also contains non-designated wetlands and extensive overburden deposits with thicknesses of up to approximately 100 m locally. As discussed in Section 7.1, at this early stage of the assessment, topographic features, wetlands and overburden thickness are not considered as key constraints for the identification of general potentially suitable areas.

7.2.4 Municipality of South Bruce

The bedrock geology of the Municipality of South Bruce comprises a thick Paleozoic sequence that is laterally extensive and predictable. Data from two boreholes (F012062 and T004881) drilled through the entire Paleozoic sequence within the Municipality indicate that the estimated total thickness of the Paleozoic package is approximately 870 m (Table 3.3). Available borehole data within the Municipality confirm the presence of the preferred Cobourg Formation at depths ranging from about 433 mBGS in the northeast corner of the Municipality to 717 mBGS towards its southwestern portion (Figure 3.15). The Cobourg Formation is overlain by a more than 200 m thick shale package (i.e. Upper Ordovician shale units; Figure 3.19). There is only one subsurface fault mapped within the Paleozoic sequence in the northwest corner of the Municipality of South Bruce (Figure 3.6). This fault is interpreted to displace the Trenton Group limestones and deeper formations only, including the Precambrian basement. The reinterpretation of seismic line 725937, which crosses the mapped subsurface fault in the Municipality of South Bruce, identified a potential fault that extends upwards from the Precambrian basement into the base of the Silurian Cabot Head Formation. The coincidence between this interpreted seismic anomaly and the mapped subsurface fault provides a certain amount of confidence in the existence of a fault in the area crossed by the seismic line.

There are no known oil and gas pools within the Municipality of South Bruce, and the three exploration boreholes drilled within the Municipality resulted in dry holes with no petroleum potential. There are a number of discretionary limestone occurrences in the central portion of the Municipality (Figure 5.2); the potential for limestone, however, is limited to very shallow depths and was not considered as a siting constraint.

Protected areas include the Provincially Significant Greenock Swamp and Teeswater wetland complexes in the western portion of the Municipality, and the Otter Creek Wetland Complex north of Mildmay. There is also the Saugeen Conservation Reserve south of Mildmay, and small parts of the wetland complexes are designated as conservation areas (Figure 7.1). Other siting constraints within the Municipality include built-up areas in Teeswater, Mildmay and Formosa and well head protection areas associated to the water supply systems in Teeswater and Mildmay, and the southern extension of the Walkerton well head protection area (Figure 7.1).

The consideration of the above geoscientific characteristics and constraints indicates that the Municipality of South Bruce contains large areas that have the potential to meet NWMO's geoscientific site evaluation factors. The potentially suitable area covers most of the Municipality with the exception of the westernmost portion and the northeast corner of the Municipality, as well as localized areas around Mildmay, Teeswater and Formosa (Figure 7.1). The top of the Cobourg Formation is interpreted to be at depths greater than the preferred 500 mBGS beneath the entire the Municipality, except in small area in the northeastern corner. Other local constraints within the Municipality are mostly limited to: Provincially Significant Wetlands in the western portion of the Municipality; two wellhead protection areas; built-up areas in Mildmay, Teeswater and Formosa; and the Saugeen Conservation Reserve (Figure 7.1). The potentially suitable area in the Municipality is easily accessible via the existing road and railway network (Figure 7.1).

Non-designated wetlands are uniformly mapped throughout the potentially suitable area (Figure 2.4) and overburden deposits are widespread, with mean thicknesses of about 20 m (Section 3.2.3; Figure 3.25). Topography in the identified general potentially suitable area is relatively flat (Figure 2.3). As discussed in Section 7.1, at this early stage of the assessment, topographic features, wetlands and overburden thickness are not considered as key constraints for the identification of potentially suitable areas.

7.2.5 Township of Huron-Kinloss

The bedrock geology beneath the Township of Huron-Kinloss consists of a laterally extensive and predictable Paleozoic sequence. Based on data from one well (F012061, Table 3.3, Figure 3.6) drilled through to the Precambrian basement in the southern portion of the Township, the total thickness of the Paleozoic sequence in that area is approximately 1,000 m. Based on contour mapping, the depth to the top of the preferred Cobourg Formation is interpreted to range from approximately 683 mBGS in the northeastern portion of the Township to about 809 mBGS towards its southern portion. Data from well F012061 confirms that the Cobourg Formation within the Township is overlain by about 200 m of Upper Ordovician shale formations. One mapped subsurface fault extends into the eastern part of the Township of Huron-Kinloss (Figure 3.6). In addition, a possible fault was interpreted in a seismic line in the Township of Huron-Kinloss (Section 3.2.2.4; Geofirma, 2014).

While there are a number of pools that produce gas from pinnacle reefs of the Guelph Formation immediately south of the Township of Huron-Kinloss (Figures 5.1 and 5.2), there are no known oil and gas pools within the Township. All seven wells drilled within the Township resulted in dry holes and did not encounter economical accumulations of hydrocarbons, including wells drilled through three known pinnacle reefs. As described in Section 5.3.3 salt beds of the Silurian Salina Group exist beneath the Township of Huron-Kinloss; the Salina B-Salt is interpreted to be approximately 75 m thick towards the southwestern portion of the Township, thinning out towards its eastern part. Salt beds of the Salina Group extend beyond the Township boundaries to the south and are currently being exploited approximately 30 km south of the Township, at Goderich. Given that the Salina salt beds are relatively thin within the Township and occur approximately 400 m above the Cobourg Formation, they are not considered a constraint from a siting perspective at this stage of the assessment. There are no other mineral occurrences within this community.

Protected areas within the Township of Huron-Kinloss include seven designated Provincially Significant Wetlands located in the eastern portion of the Township (Figure 7.1; Section 2.4.2.4). The area west of Highway 21 was excluded from consideration at the request of the community. There is also one earth science ANSI northwest of Lucknow, seven well head protection areas, and one surface water protection zone (Section 2.4.4; Figure 2.7). Built-up areas are associated with the settlement areas of Kincardine and Point Clark, in the area west of Highway 21, and with the settlement areas of Ripley and Lucknow (Figure 7.1).

The consideration of the above geoscientific characteristics and constraints indicates that the Township of Huron-Kinloss contains large areas that have the potential to meet NWMO's geoscientific site evaluation factors. These include most of the area between the wetland complexes in the eastern portion of the Township and Highway 21, outside of protected areas and surface constraints (i.e. Provincially Significant Wetland Complexes, area west of Highway 21 reserved by the Township for future development, ANSIs, water source protection zones and built-up areas). As discussed above, the top of the preferred Cobourg Formation is interpreted to be at depths greater than the preferred 500 mBGS beneath the identified general potentially suitable area.

Topography in the general potentially suitable area is relatively flat, gradually decreasing from east to west (Figure 2.3). There are no significant topographic constraints and only a few non-designated wetlands are mapped within the central portion of the Township. Access to the general potentially suitable area is easy with the existing road and railway network where it has been retained (Figure 7.1).

7.3 Evaluation of the General Potentially Suitable Areas in the Communities

As discussed above, the assessment of the key geoscientific characteristics and constraints indicates that the Municipality of Arran-Elderslie and the Town of Saugeen Shores have limited potential to satisfy the geoscientific evaluation factors outlined in the site selection process. This section focuses on the potentially suitable areas identified within the municipalities of Brockton and South Bruce and the Township of Huron-Kinloss. The section briefly describes how these areas were evaluated to verify if they have the potential to satisfy the geoscientific safety functions outlined in NWMO's site selection process (NWMO 2010). At this early stage of the site evaluation process, where limited geoscientific information is available, the intent is to assess whether there are any obvious conditions within the identified potentially suitable areas that would fail to satisfy the geoscientific safety functions. These include:

- ***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 caused by human activities and natural events?

- ***Long-term resilience to future geological processes and climate change:*** Is the rock formation at the siting area 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 geological and climate change process such as earthquakes and glacial cycles?

- ***Safe construction, operation and closure of the repository:*** Are conditions at the site suitable for the safe construction, operation and closure of the repository?

- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance through future exploration or mining?

- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

The evaluation factors under each safety function are listed in Appendix A. At this early stage of the site evaluation process, where limited data at repository depth exist, the intent is to assess whether there are any obvious conditions within the identified potentially suitable areas that would fail to satisfy the safety functions.

An evaluation of the three general potentially suitable areas in the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

The geological, hydrogeological, chemical and mechanical characteristics of a suitable site should promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; promote long-term containment of used nuclear fuel within the repository; and restrict groundwater movement and retard the movement of any released radioactive material.

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;
- The hydrogeological regime within the host rock should exhibit low groundwater velocities;
- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and
- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation function of the repository.

The above factors are interrelated as they contribute to more than one safety function. The remainder of this section provides an integrated assessment of the above factors based on information that is available at the desktop stage of the evaluation.

As discussed in Section 3.1, the geology of the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss is consistent with the regional geological framework. These three Communities are entirely underlain by a predictable and laterally extensive Paleozoic sedimentary sequence that was deposited approximately 460 to 385 million years ago.

Given the predictability of the Paleozoic bedrock in the region, the Cobourg Formation, which is considered as the preferred host rock in this assessment (Section 7.1), is interpreted to extend laterally beneath all three general potentially suitable areas identified. Based on information from historic oil and gas wells and depth contour mapping, the top of the Upper Ordovician Cobourg Formation within the three potentially suitable areas is interpreted to be at depths greater than the preferred 500 mBGS (see Section 7.1). The thickness of the Cobourg Formation at the Bruce nuclear site is approximately 30 m (Intera Engineering Ltd., 2011); data from wells where geophysical data were available for the reinterpretation of the top of the Cobourg Formation within these three communities (i.e. T004854, and T004881; Geofirma Engineering Ltd., 2014) indicate that the thickness of the preferred host formation in the potentially suitable areas identified is expected to be similar. Given its thickness and lateral extent, the Upper Ordovician Cobourg Formation would provide a sufficient volume of rock to physically contain and isolate a deep geological repository for used nuclear fuel.

While there is limited site-specific information on the geoscientific characteristics of the Cobourg Formation beneath the three general potentially suitable areas, it is expected that they will be similar to the characteristics of the Cobourg Formation beneath the nearby Bruce nuclear site. As described in Sections 4.2 and 6.2, the Cobourg Formation is characterized by very low hydraulic conductivities and a very low frequency of fractures. These are favourable characteristics for the containment and isolation of used fuel. In addition, the Cobourg Formation in the potentially suitable areas is overlain by approximately 200 m of very low permeability Upper Ordovician shale units, which would act as an additional barrier.

Given the regional predictability of the Paleozoic bedrock sequence, the hydrogeological and hydrogeochemical conditions beneath the potentially suitable areas in the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss are expected to be relatively similar to those beneath the Bruce nuclear site (Section 4). The deep groundwater regime within the Upper Ordovician shale and limestone units beneath the Bruce nuclear site, including the Cobourg Formation, is described as diffusion dominated and isolated from the shallow groundwater which is generally limited to the upper 200 mBGS. There are two mapped subsurface faults within the Area of the Five Communities, both of them outside of the identified potentially suitable areas (Figure 3.6). 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 geoscientific information did not reveal any obvious conditions that would fail the three identified potentially suitable areas to satisfy the containment and isolation function. Potential suitability of these areas would need to be further assessed during subsequent stages of the site evaluation process.

7.3.2 Long-term Resilience to Future Geological Processes and Climate Change

The containment and isolation function of the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.

The assessment of the long-term stability of a suitable site would require that:

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term;
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation function of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and
- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

A full assessment of these processes requires detailed 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 detailed studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change. At this desktop preliminary assessment 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 stability of the three general potentially suitable areas identified in the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss. The remainder of this section provides a summary of the factors listed above.

The Area of the Five Communities, including the three potentially suitable areas, is underlain by Precambrian crystalline basement of the Grenville Province, the southeastern-most subdivision of the Canadian Shield. The Precambrian Grenville Province is generally considered to have been relatively tectonically stable since approximately 970 million years ago (Section 3.1.1). There are two mapped subsurface faults within the Area of the Five Communities, both of them outside of the identified potentially suitable areas. The uppermost formations cut by these faults include the Shadow Lake Formation/Precambrian for one fault and the Cobourg Formation for the other fault. There is no evidence in the literature suggesting that these faults have been tectonically active within the past approximately 440 million years. Interpretation of an available 2D seismic line provides some indication that one of the subsurface mapped faults may have been active after the deposition of the lower Silurian-aged Cabot Head Formation (Geofirma, 2014).

The geology of the Area of the Five Communities is typical of many areas of southern Ontario, which has been subjected to nine glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur in the future. Findings from studies conducted in other areas of southern Ontario (NWMO, 2011) suggest that the deep subsurface Paleozoic sedimentary formations have remained largely unaffected by past perturbations such as glaciations (Sections 3 and 4).

Land in the Area of the Five Communities is still experiencing isostatic rebound following the end of the Wisconsinan glaciations (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. The ‘‘hinge line’’ separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2006). The estimated present day rebound rate in the Area of the Five Communities is of about 1.5 mm/yr (Peltier, 2011).

A neotectonic study conducted by Slattery (2011) as part of the detailed site characterization work at the Bruce nuclear site analyzed Quaternary landforms for the presence of seismically-induced soft-sediment deformation (Section 3.3.2). The study was conducted within a radius of up to 50 km from the Bruce nuclear site, which includes the three potentially suitable areas, and concluded that the area has not likely experienced any post-glacial neotectonic activity. Hallet (2011) conducted a study on glacial erosion caused by the Laurentide Ice Sheet in southern Ontario, including the three potentially suitable areas identified. The study concluded that potential future glacial erosion rates in the area would be limited with a conservative estimate of erosion of 100 m per 1 million years.

In summary, available information indicates that the identified general potentially suitable areas in the Area of the Five Communities have the potential to satisfy the long-term stability function. The review did not identify any obvious conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes. The long-term stability of the area would need to be further assessed through detailed multidisciplinary site-specific geoscientific and climate change site investigations.

7.3.3 Safe Construction, Operation and Closure of the Repository

The characteristics of a suitable site should be favourable for the safe construction, operation, closure and long term performance of the repository.

This requires that:

- The available surface area should be sufficient to accommodate surface facilities and associated infrastructure;
- The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities; and
- The soil cover depth over the host rock should not adversely impact repository construction activities.

There are few surface constraints that would limit the construction of surface facilities in the three general potentially suitable areas identified in the Area of the Five Communities. The potentially suitable areas are characterized by a relatively flat topography with limited obvious topographic features, and each contains enough surface land outside of protected areas and major water bodies to accommodate the required repository surface facilities.

From a constructability perspective, although no site-specific information on rock strength characteristics and in-situ stresses was found for the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss, there is abundant information from at other locations of southern Ontario that could provide insight into what would be expected for the area. Given the greater depth of the Cobourg Formation in the Township of Huron-Kinloss, there is potential for higher in-situ stresses for a proposed DGR in the Township of Huron-Kinloss. However, available information on strength and in-situ stresses suggests that the Upper Ordovician Cobourg Formation has favorable geomechanical characteristics and is amenable to the excavation of stable underground openings. Limestones of the Cobourg Formation at the Bruce nuclear site have high strength, with an average UCS value of 113 MPa, thus indicating a high degree of stability for deep underground excavations. Intact rock properties of the Cobourg Formation at the Bruce nuclear site agree with available regional data (Section 6.1). In addition, the Cobourg Formation is expected to have favourable rock mass properties which would not influence the measured rock strength. At the Bruce nuclear site, the Cobourg Formation is very sparsely fractured and of excellent quality, with a rock mass designation of excellent and RQD generally ranging between 90 and 100% (Section 6.2).

Information on geomechanical properties of the Cobourg Formation from investigations at the Bruce nuclear site provide a good preliminary overview of what can be expected beneath the general potentially suitable areas. However, the geomechanical properties of the sedimentary sequence at repository depths would need to be confirmed at later stages of the site evaluation process through collection of site-specific data.

Overburden cover in the three potentially suitable areas is extensive, with overburden thickness ranging from less than 10 m up to about 100 m locally. However, at this early stage of the evaluation, it is anticipated that overburden cover is not a limiting factor in any of the identified general areas. This is because the occurrence and characteristics of the important deep Ordovician limestone and shale formations are not affected by subcropping bedrock features, but are regionally predictable based on deep borehole data within the Area of the Five Communities.

In summary, the three identified general potentially suitable areas have good potential to satisfy the safe construction, operation and closure function.

7.3.4 Isolation of Used Fuel from Future Human Activities

A suitable site must not be located in areas where the containment and isolation function of the repository are likely to be disrupted by future human activities.

This requires that:

- The repository should not be located within rock units containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today; and

- The repository should not be located within geologic units containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

The mineral potential in the identified potentially suitable areas is limited to: discretionary occurrences of limestone and dolostone in the municipalities of Brockton and South Bruce; and salt occurrences in the Township of Huron-Kinloss (Figure 5.1). The potential for bedrock resources (i.e. limestone and dolostone) in the potentially suitable areas of the municipalities of Brockton and South Bruce is limited to very shallow depths and would not have an effect on a deep geological repository hosted in the Cobourg Formation at greater than 500 mBGS. Salt beds of the Salina Group are known to occur beneath the potentially suitable area identified in the Township of Huron-Kinloss (Section 5.3.3). However, their economic viability in this area is unknown at this stage, and given their relatively thin nature, and that they occur about 400 m above the top of the Cobourg Formation, the presence of these salt beds is not expected to compromise the containment and isolation functions of a potential repository hosted in this formation.

There are no known commercial oil and gas resources within the municipalities of Brockton and South Bruce or the Township of Huron-Kinloss. However, there are three oil and gas wells located south of the Township of Huron-Kinloss (Figure 5.2) that produce from pinnacle reefs of the Upper Silurian Guelph Formation (Section 5.1.2). As the bottom of these pinnacle reefs are about 280 m above the top of the Cobourg Formation, investigation of the reefs for possible oil and gas development is not expected to disrupt a potential repository hosted in the Cobourg Formation. The available information on shale gas occurrence in the Ordovician shales indicates potential for commercial development of shale gas resources in low.

The review of available hydrogeological information did not identify any known groundwater resources within the Cobourg Formation beneath the three identified general potentially suitable areas. The Ministry of the Environment Water Well Records indicate that no potable water supply wells are known to exploit aquifers in the Cobourg Formation within the Area of the Five Communities (Section 4.1). All known water wells in the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss obtain water from overburden or shallow bedrock sources at depths ranging from about 3 to 163 mBGS (Section 4.1).

As discussed in Section 4.2, the potential for groundwater resources within the Upper Ordovician limestone and shale units in the Area of the Five Communities is extremely low. Experience from other areas in southern Ontario, and from the detailed site characterization work completed at the Bruce nuclear site, has shown that there is no active deep groundwater system in the area due to the very low hydraulic conductivities of the Upper Ordovician units. Trenton Group limestones (i.e. Cobourg, Sherman Fall and Kirkfield formations) at the Bruce nuclear site have average horizontal hydraulic conductivity values ranging from $4x10^{-15}$ to $1x10^{-14}$ m/s. Available hydrogeological data from the Bruce nuclear site indicate that the deep groundwater system within the Upper Ordovician units 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 active groundwater system in the three identified general potentially suitable areas is shallow and limited to the upper approximately 200 m (Intera Engineering Ltd., 2011; Waterloo Hydrogeologic Inc., 2003).

In summary, the potential for the containment and isolation function of a repository in the three general potentially suitable areas to be disrupted by future human activities is low.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

In order to support the case for demonstrating long-term safety, the geoscientific conditions at a potential site must be predictable and amenable to site characterization and data interpretation.

Factors affecting the amenability to site characterization include: geological heterogeneity; structural and hydrogeological complexity; accessibility, and the presence of lakes or overburden with thickness or composition that could mask important geological or structural features.

As discussed in Section 3, the Paleozoic sedimentary sequence beneath the Area of the Five Communities, including the potentially suitable areas, is 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 review of available information on the bedrock geology for the Area of the Five Communities did not reveal any conditions that would make the rock mass difficult to characterize.

Quaternary overburden deposits cover all three general potentially suitable areas identified in the municipalities of Brockton and South Bruce and the Township of Huron-Kinloss (Figure 3.25), with thicknesses ranging from less than 10 m to up to about 100 m locally (Section 3.2.3). Given the regional geological framework, the simple geometry and the predictability of the subsurface Paleozoic sequence, the thickness of the overburden cover is not likely to affect the ability to characterize the subsurface bedrock formations beneath the identified potentially suitable areas.

The three general potentially suitable areas identified in the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss are all accessible using the existing road and rail network where it has been retained.

In summary, the review of available information did not indicate any obvious conditions which would make the subsurface Paleozoic bedrock geology beneath the three identified general areas unusually difficult to characterize.

8 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors. At this stage of the assessment, the intent is not to identify specific repository-scale sites, but rather to identify general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in the site selection process document (NWMO, 2010). The location and extent of potentially suitable areas would need to be refined during subsequent site evaluation stages through more detailed studies and field evaluations.

The preliminary geoscientific assessment built on the work previously conducted for the initial screenings (AECOM, 2012a; 2012b; 2012c; 2012d; 2012e) and focused on the the Area of the Five Communities (Figure 1.1). The geoscientific preliminary assessment was conducted using available geoscientific information and key geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. These include: geology; structural geology; surface conditions; protected areas; and the potential for economically exploitable natural resources. The geoscientific data from characterization of the Bruce nuclear site (Intera Engineering Ltd., 2011) was especially important in that it provided detailed information on the geological, hydrogeological and geomechanical properties of the sedimentary strata found within the Area of the Five Communities. Where information for the Area of the Five Communities was limited or not available, the assessment drew on information and experience from other areas with similar geological settings in southern Ontario. The geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Assembly and detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology and overburden deposits (surficial deposits);
- Interpretation of available geophysical surveys;
- Interpretation of available borehole geophysical data and selected 2-D seismic reflection surveys to provide information on the geometry and potential structural features of the subsurface bedrock geology;
- Terrain analysis studies to help assess overburden (surficial deposits) type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones;
- Assessment of land use and protected areas including parks, conservation reserves, heritage sites and source water protection areas; and
- The identification and evaluation of general potentially suitable areas based on systematic assessment of key geoscientific characteristics and constraints that can be realistically assessed at this stage of the assessment.

The geoscientific desktop preliminary assessment showed that the geological setting in the Area of the Five Communities has a number of favourable characteristics for hosting a deep geological repository for used nuclear fuel. However, the assessment revealed that there are areas that have more potential than others to satisfy NWMO's geoscientific site evaluation factors. The assessment identified the Ordovician Cobourg Formation (limestone) as the preferred host rock formation for a used nuclear fuel deep geological repository. It was determined that a minimum depth of 500 metres below ground surface (mBGS) would be preferred in order to maintain the integrity of a repository within the Cobourg Formation. Based on the key geoscientific characteristics and constraints considered in the assessment, it was concluded that:

- The Municipality of Brockton, the Municipality of South Bruce and the Township of Huron-Kinloss appear to contain large areas that have the potential to meet the geoscientific site evaluation factors outlined in the site selection process document.

- The Municipality of Arran-Elderslie does not contain sufficient land areas that have the potential to meet the geoscientific site evaluation factors outlined in the site selection process document.

- The Town of Saugeen Shores has very limited potential to contain areas that would meet the geoscientific site evaluation factors outlined in the site selection process document.

While the the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss appear to contain large areas with favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The assumption of transferability of geoscientific characteristics and understanding based on regional data and data from the Bruce nuclear site to the communities of Brockton, South Bruce and Huron-Kinloss would need to be confirmed. The potential for hydrocarbon resources and faults within the sedimentary sequence beneath the three communities would also need to be further assessed.

Should the municipalities of Brockton and South Bruce, and the Township of Huron-Kinloss be selected by the NWMO to advance to Phase 2 study, and remain interested in continuing with the site selection process, several years of progressively more detailed studies would be required to confirm and demonstrate whether they contain sites that can safely contain and isolate used nuclear fuel. This may include the acquisition and interpretation of higher resolution geophysical surveys, detailed geological mapping, and the drilling of deep boreholes.

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10 REPORT SIGNATURE PAGE

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APPENDIX A

Geoscientific Factors

Table A.1 Safety Factors, Performance Objectives and Geoscientific Factors

Safety Factors	***Performance Objectives***	***Evaluation Factors to be Considered***
Containment and isolation characteristics of the host rock	**1.** The geological, hydrogeological and chemical and mechanical characteristics of the site should: • Promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; • Promote long-term containment of used nuclear fuel within the repository; and • Restrict groundwater movement and retard the movement of any released radioactive material.	**1.1** The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events. **1.2** The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities. **1.3** The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multi-barrier system. **1.4** The hydrogeological regime within the host rock should exhibit low groundwater velocities. **1.5** The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement. **1.6** The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.
Long-term stability of the site	**2.** The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes.	**2.1** Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term. **2.2** The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository. **2.3** The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository. **2.4** The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

Safety Factors	***Performance Objectives***	***Evaluation Factors to be Considered***
Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	**3.1** The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. **3.2** The soil cover depth over the host rock should not adversely impact repository construction activities. **3.3** The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	**4.** 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.	**4.1** The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. **4.2** The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	**5.** The characteristics of the site should be amenable to site characterization and site data interpretation activities.	**5.1** The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.

APPENDIX B

Geoscientific Data Sources

Table B.1 Summary of Geoscientific Databases for the Area of the Five Communities.

Database	***Description***	***Scale (Regional / Local)***	***Used? (Yes/ No)***
AFRI	The AFRI database contains the technical results from all exploration work carried out in Ontario. Data includes location, property ownership, type of work done, commodities sought for each assessment file and a link to a pdf version of each file. Spatial data is collected for each file in the form of polygons indicating property outlines.	Regional	Yes
Ambient Groundwater Geochemistry Data (MRD-283)	This release contains the data for all of southwestern Ontario. The data include detailed inorganic chemistry for more than 900 water samples.	Regional	Yes
AMIS (Abandoned Mines Information System Database)	AMIS is a database containing information on all known abandoned and inactive mine sites within the province of Ontario. There are currently 5,700 known abandoned mine sites scattered throughout the Province, which contain more than 16,400 mine features.	Regional	Yes
Bedrock Geology (MRD-126-Revision 1)	Bedrock Geology contains information about the solid rock underlying the Province of Ontario at a compilation scale of 1:250,000. Data includes: bedrock units, major faults, dyke swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
Bedrock Topography and Overburden Thickness Mapping, Southern Ontario (MRD-207)	The bedrock topography map was created from point data from a variety of sources including water well records, geotechnical borehole records, oil and gas well records, existing geologic maps and field observations. The release also includes a report detailing the methodology used to generate the maps.	Regional	Yes
CLAIMaps	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
Earthquakes Canada (NEDB)	The National Earthquake DataBase (NEDB) comprises a number of separate databases that together act as the national repository for all raw seismograph data.	Regional	Yes
Geoscience Data Repository for Geophysical and Geochemical Data	A database with aeromagnetic, gravity and radioactivity data for all of Canada.	Regional	Yes
Karst of Southern Ontario and Manitoulin Island (GRS005)	This digital data release contains reconnaissance-level field data and polygons depicting the nature and regional distributions of karstification of Paleozoic bedrock unit s within thin drift and exposed bedrock regions of southern	Regional	Yes
Mineral Deposits Inventory (MDI)	The database contains an overview of mineral occurrences in the province of Ontario. The data includes the occurrence type (mineral or discretionary), primary and secondary commodity, deposit name and a link to the full record on Geology Ontario.	Regional	Yes

Database	***Description***	***Scale (Regional / Local)***	***Used? (Yes/ No)***
Paleozoic Geology of Southern Ontario (MRD-219)	The database contains mapping of the Paleozoic geology of southern Ontario based primarily on 1:50 000 scale maps. The data set consists of 5 categories of data including Paleozoic geological units; linear features, such as faults and contacts; point features, such as quarry, drill hole and outcrop locations; as well as an index containing references to all published OGS Paleozoic maps.	Regional	Yes
Physiography of Southern Ontario (MRD-228)	There are four categories of data on the physical structure of southern Ontario in this release. The categories include linear features, such as beaches and escarpments; point features, such as dunes and mud flow scars; as well as landforms (drumlins and moraines) and physiographic regions.	Regional	Yes
Provincial Groundwater Monitoring Network Program	The Provincial Groundwater Monitoring Information System (PGMIS) is a web-driven application that assists the Ministry of the Environment and stakeholders to monitor the state of the Province's groundwater resources.	Regional	Yes
Regional Structure and Isopach Maps of Potential Hydrocarbon-Bearing Strata For Southern Ontario (MRD-276)	The data release contains digital structure contour and isopach maps of selected Paleozoic units in southern Ontario. The data set consists of contour information on thickness or elevation of Paleozoic geological units; linear features, such as faults and depositional edges; point features, that include drill holes; as well as polygonal data capturing reefs and oil and gas pools.	Regional	Yes
Quaternary Geology (Data Set 14)	Ontario's Quaternary Geology at a compilation scale of 1:1000000. This layer includes Quaternary geology units, point features such as drumlins and glacial striae and line features such as eskers, shore bluffs and moraines.	Regional	Yes
Surficial Geology of Southern Ontario (MRD-128-Revised)	A seamless map of the surficial geology of southern Ontario. There are 7 primary datasets in this release including information on Quaternary geological units; sand and gravel pits; linear features, such as eskers and bluffs; point features, such as drumlins and striae; as well as other polygonal coverages, including hummocky topography and moraines. Also included is a shaded relief image created using the digital elevation model (DEM) produced by the Ontario Ministry of Natural Resources.	Regional	Yes
WWIS (Water Wells)	Database containing water well records throughout Ontario from 1949 to present.	Regional	Yes

Table B.2 Summary of Geophysical Mapping Sources for the Area of the Five Communities

Product	***Source***	***Type***	***Line Spacing/ Sensor Height***	***Coverage***	***Date***	***Additional Comments***
Waterloo	GSC	Fixed wing magnetic	926m/305m	Central	1986	Large overlap with newer survey to the south.
Lake Huron	GSC	Fixed wing magnetic	1,900 m/303 m	West	1986	Low resolution survey over Lake Huron
Georgian Bay	GSC	Fixed wing magnetic	1,200 m/298 m	Northeast	1985	Low resolution survey over Georgian Bay
Ontario #28	GSC	Fixed wing magnetic	805 m/305 m	East central	1950	Southwest superseded by newer survey.
Strathroy	Randsburg International Gold Corp.	Fixed wing magnetic	700 m x 700 m grid/450m above sea level	Coast along west shore	1999	Higher resolution than GSC surveys.
GSC Gravity Coverage	GSC	Ground gravity measurements	6 km (onshore), 1.6 km x 18 km (offshore)/surface	Entire Area of the Five Communities	1945-2007	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field were extracted from the GSC gravity compilation. Station locations were extracted from the point data.
PGW Gravity Coverage	PGW	Ground gravity measurements	0.4 km x 2 km/surface	Onshore west and south	1980s-90s	Much higher resolution than GSC coverage. Station spacing variable.
South Ontario Radon Survey – Block 2	GSC	Fixed wing radiometric and magnetic	1,000 m/150 m	Southern half of the Area	2008	Recent survey providing radiometric coverage of the southern half of the area. Survey includes unlevelled magnetic data.
South Central Ontario – Collingwood-Hamilton	GSC	Fixed wing radiometric	1,000 m/150 m	Northern half of the Area	2009	Recent survey providing radiometric coverage of the northern half of the area.
Douglas Point	GSC	Fixed wing magnetic, radiometric and VLF-EM	1,000 m/120 m	Local survey extending offshore	1982	Magnetic and radiometric data superseded by more recent survey.

Table B.3 Summary of Geological Mapping Sources for the Area of the Five Communities

Map Product	*Title*	*Author*	*Source*	*Scale*	*Date*	*Coverage*	*Additional Comments*
M2544	Bedrock Geology of Ontario, Southern Sheet	Ontario Geological Survey	OGS	1:1000000	1991	Full	Regional-scale bedrock mapping
OFM 0162	Extension of Grenville Basement Beneath Southwestern Ontario	R. M. Easton and T.R. Carter	OGS	1:1013760	1991	Full	Regional-scale basement mapping
Open File Report 401	Isopach of the Salina B Salt, Southwestern Ontario	B.V. Sanford	GSC	1:250000	1976	Partial	Geological mapping and cross sections
P2625	Petroleum Resources Map, Structure Top Trenton Group, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2628	Structure Top Trenton Group, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2631	Structure Top Black River Group, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2634	Structure Top Black River Group, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2637	Isopach Trenton Group, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2640	Isopach Trenton Group, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2643	Isopach Black River Group, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs

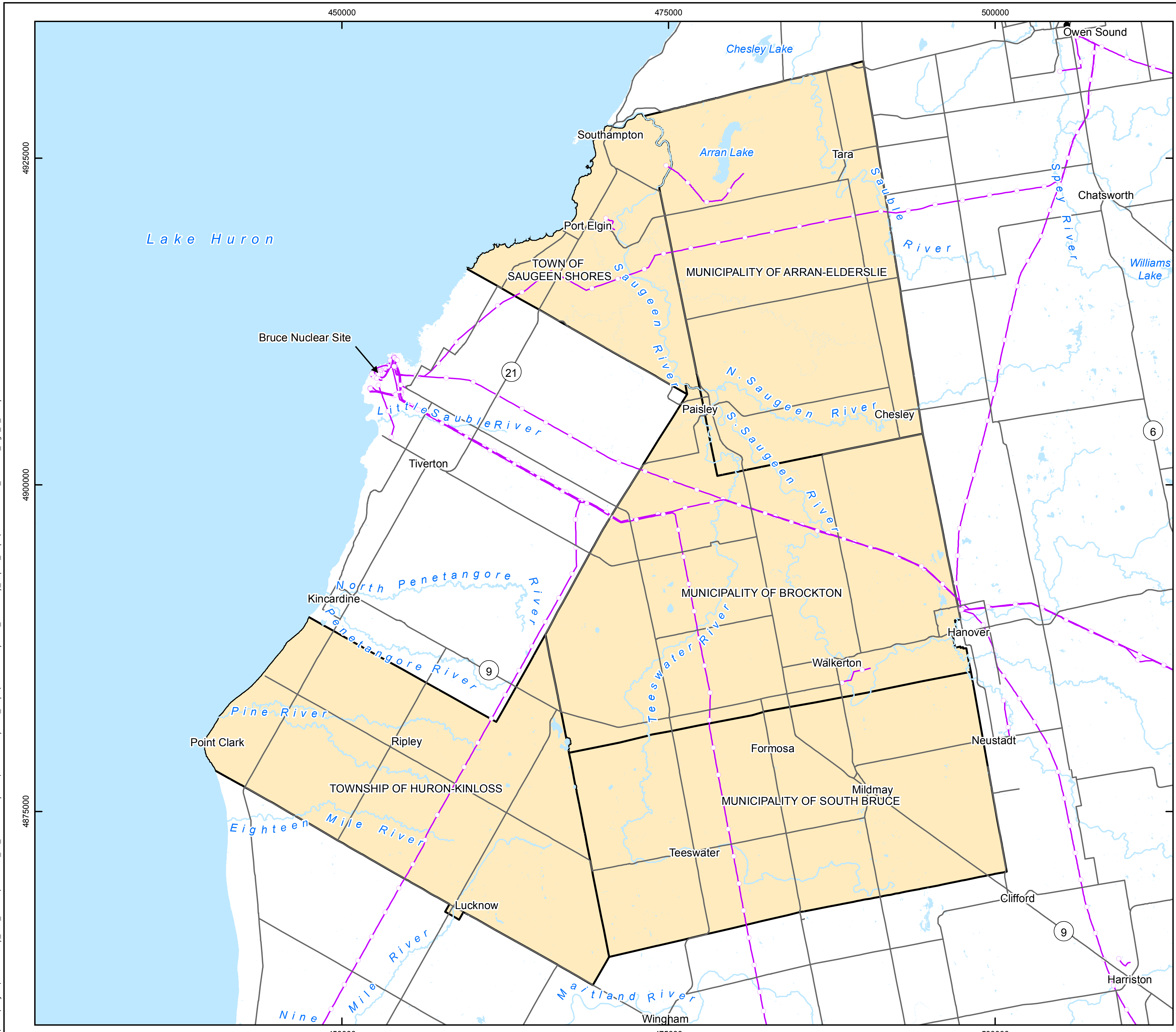
Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
P2646	Isopach Black River Group, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2649	Structure Top Shadow Lake Formation, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2652	Structure Top Shadow Lake Formation, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2655	Structure Top Precambrian, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2658	Structure Top Precambrian, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2661	Isopach Shadow Lake Formation to Precambrian, North West Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2664	Isopach Shadow Lake Formation to Precambrian, North Central Area, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:250000	1984	Partial	Structural mapping based on borehole logs
P2757	Structure, Top Pre-Hamilton, Devonian Carbonates, Huron County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs
P2759	Structure, Top Pre-Hamilton, Devonian Carbonates, Bruce County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs
P2812	Structure, Top Devonian Sulphur Water - Porosity, Huron County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P2814	Structure, Top Devonian Sulphur Water - Porosity, Bruce County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs
P2823	Isopach Top Devonian Carbonate to Top Sulphur Water - Porosity, Huron County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs
P2825	Isopach Top Devonian Carbonate to Top Sulphur Water - Porosity, Bruce County, Southern Ontario	Bailey Geological Services Ltd.	OGS	1:100000	1985	Partial	Structural mapping based on borehole logs
P2895	Structure Top Rochester Formation, Huron County, Southern Ontario	R.O. Cochrane and Bailey Geological Services Ltd.	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2898	Structure Top Rochester Formation, Dufferin County, Southern Ontario	R.O. Cochrane and Bailey Geological Services Ltd.	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2899	Structure Top Rochester Formation, Simcoe County, Southern Ontario	R.O. Cochrane and Bailey Geological Services Ltd.	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2900	Structure Top Rochester Formation, Bruce County, Southern Ontario	R.O. Cochrane and Bailey Geological Services Ltd.	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2901	Structure Top Rochester Formation, Gray County, Sothern Ontario	R.O. Cochrane and Bailey Geological Services Ltd.	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs

Map Product	*Title*	*Author*	*Source*	*Scale*	*Date*	*Coverage*	*Additional Comments*
P2946	Isopach Silurian Whirlpool Sandstone, Dufferin County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2947	Isopach Silurian Whirlpool Sandstone, Grey County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P2948	Isopach Silurian Whirlpool Sandstone, Simcoe County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1986	Partial	Structural mapping based on borehole logs
P3013	Isopach Top Guelph to Top Rochester, Huron County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3016	Isopach Top Guelph to Top Rochester, Dufferin County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3017	Isopach Top Guelph to Top Rochester, Simcoe County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3018	Isopach Top Guelph to Top Rochester, Bruce County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3019	Isopach Top Guelph to Top Rochester, Grey County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P3039	Structure Top Salina A-2 Carbonate, Huron County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3040	Structure Top Salina A-2 Carbonate, Bruce County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3054	Structure Top Salina A-2 Carbonate, Grey County, Southern Ontario	Bailey Geological Services Ltd. and R.O. Cochrane	OGS	1:100000	1988	Partial	Structural mapping based on borehole logs
P3201	Drift Thickness, Lucknow Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3202	Drift Thickness, Walkerton Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3203	Drift Thickness, Kincardine Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3204	Drift Thickness, Wingham Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3206	Bedrock Topography, Lucknow Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3207	Bedrock Topography, Walkerton Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3208	Bedrock Topography, Kincardine Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs
P3209	Bedrock Topography, Wingham Area, Southern Ontario	R.I. Kelly and T.R. Carter	OGS	1:50000	1993	Partial	Contour mapping based on borehole logs

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P3236	Paleozoic Geology of the Southern Bruce Peninsula. Southern Ontario	D.K. Armstrong	OGS	1:50000	1993	Partial	Mapping of northwestern part of study area
P3251	Quaternary Geology, Markdale Area, Markdale-Owen Sound, Ontario	B.H. Feenstra	OGS	1:50000	1994	Partial	Mapping of northern part of study area
SV 04	Geology of Ontario	M.D. Johnson D.K. Armstrong B.V. Sanford P.G. Telford M.A. Rutka	OGS	Numerous maps with a range of different scales	1992	Full	Chapter 20 details the Paleozoic and Mesozoic geology of Ontario
SV 07	The Subsurface Paleozoic Stratigraphy of Southern Ontario	D.K. Armstrong T.R. Carter	OGS	Numerous maps with a range of different scales	2010	Full	Reference document for describing Paleozoic rocks



LEGEND

- The Communities
- Highway/Major Road
- Utility Line
- Waterbody
- Watercourse

SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Produced by Geofirma Engineering Ltd under license from
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NORTH

PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE
The Area of the Five Communities

FIGURE 1.1

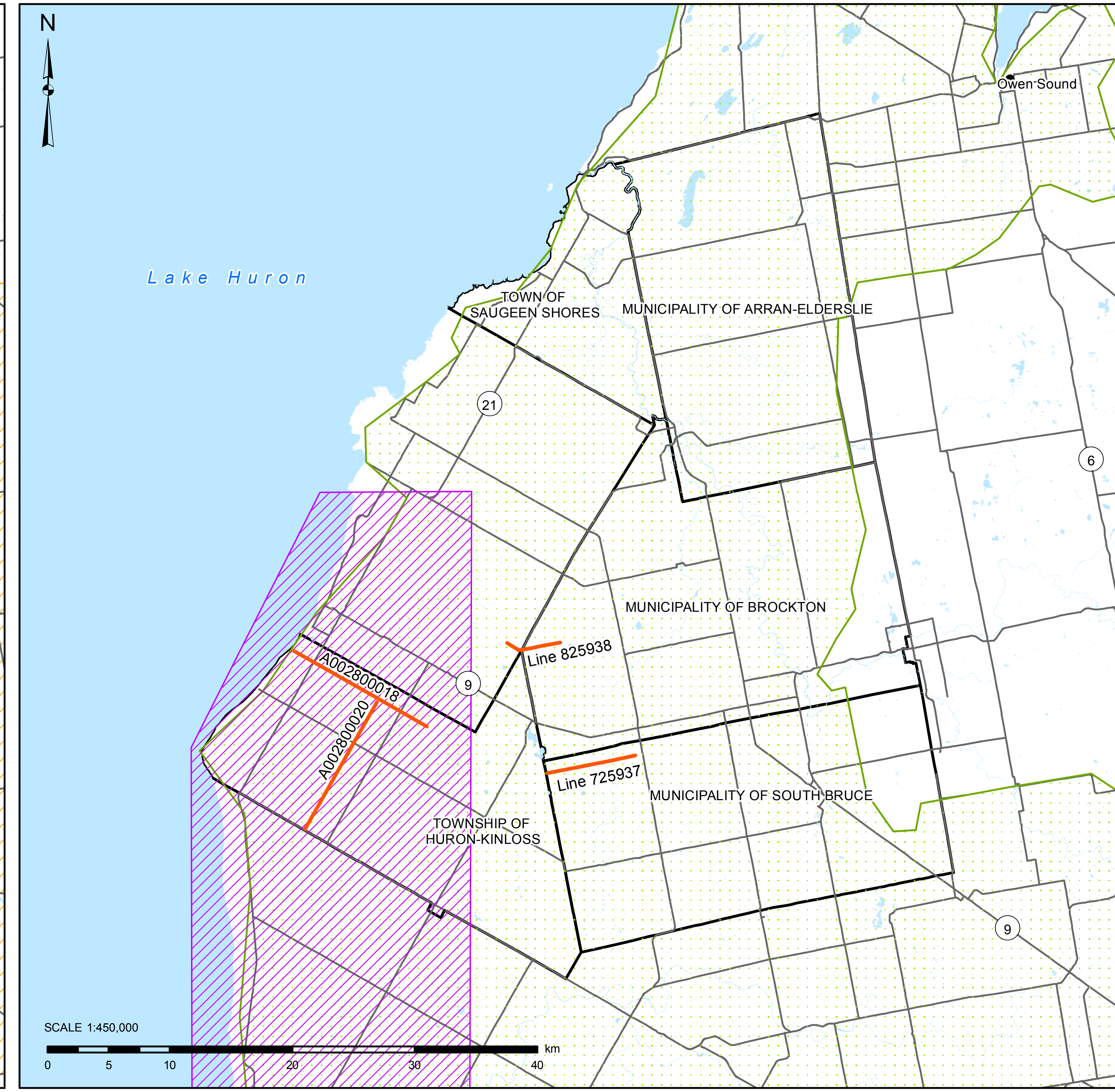
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 7/3/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig1_1_StudyAreas.mxd

Geology Mapping Coverage

Geophysics Mapping Coverage



LEGEND

The Communities
Highway
Water Area, Permanent

Detailed Geology Extent
Sanford, (1976)

Full Geology Coverage
Armstrong and Carter (2010)
Brunton and Dodge (2008)
Gao et al. (2006)
Johnson et al. (1992)
OGS (2007)
OGS (2011)
OGS (2010)
OGS (1997)

Full Geophysics Coverage
Boyce & Morris (2002)
GSC (2013)
GSC (2013)
GSC (2013)

Detailed Geophysical Extent
Acquired 2D Seismic Data
GSC (2013) and PGW (2014)
GSC (2013) and PGW (2014)

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE: Basemap Layers: LIO MNR, obtained 2010-2013
Ontario Geological Survey, MNDM, PGW, 2013
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PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

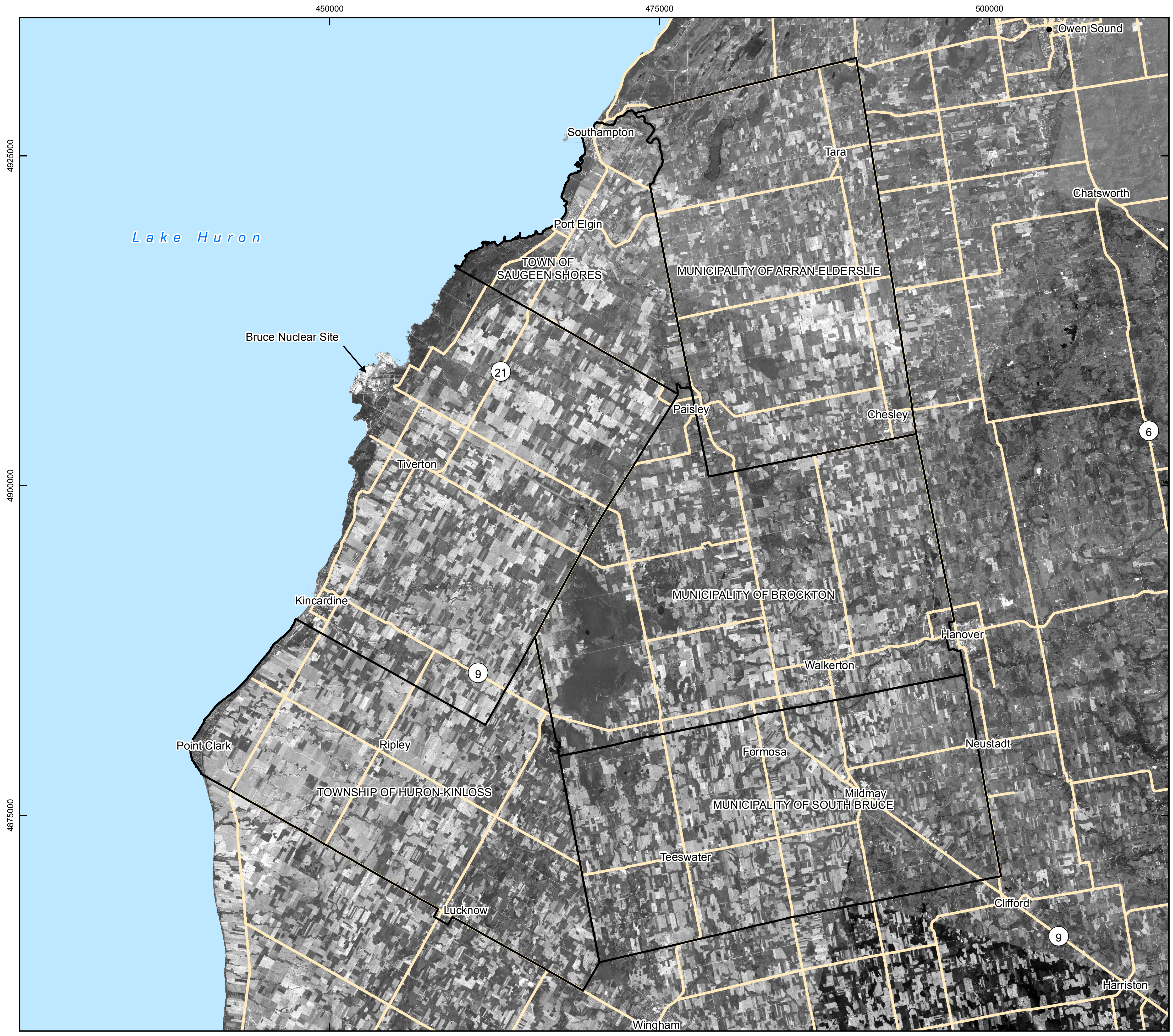
TITLE
Geoscience Mapping and Geophysical Coverage of the Area of the Five Communities

FIGURE 1.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/DJH
REV: 0
DATE: 6/26/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig1_2_Geoscience_Mapping_and_Geophysical_Coverage.mxd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody

SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Satellite Imagery: SPOT 4 and 5, Geobase, 2010
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PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE
Satellite Imagery of the Area of the Five Communities

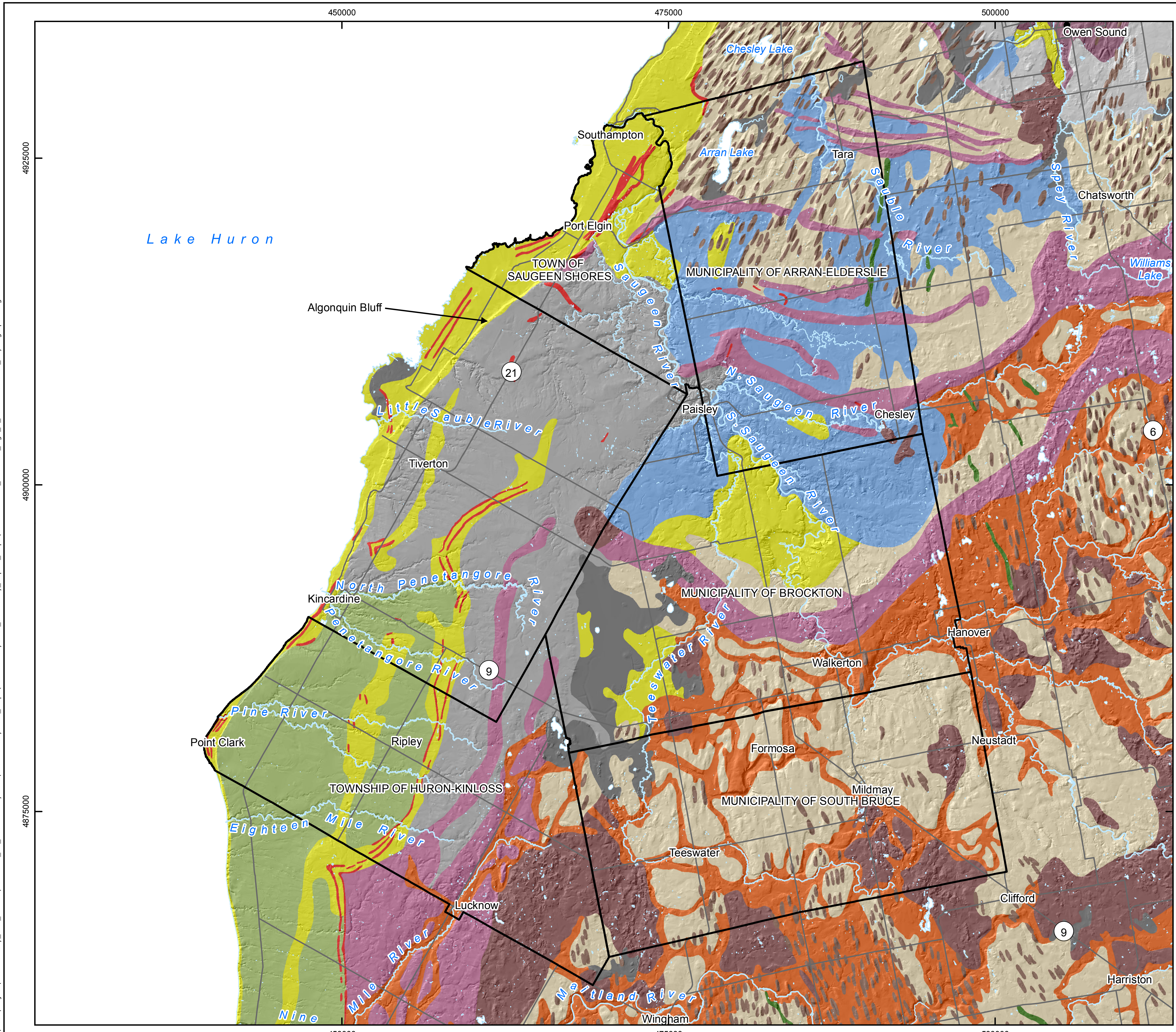
FIGURE 2.1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 7/4/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig2_1_SatelliteImagery.mxd



LEGEND

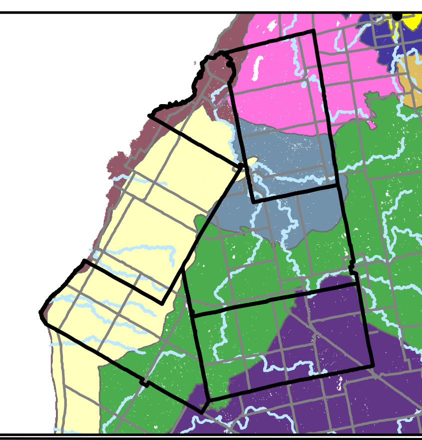
- The Communities
- Highway/Major Road
- Waterbody
- Watercourse

Physiography

- Peat And Muck
- Beaches
- Eskers
- Clay Plains
- Sand Plains
- Shale Plains
- Limestone Plains
- Bevelled Till Plains
- Drumlins
- Till Plains (Drumlinized)
- Till Plains (Undrumlinized)
- Kame Moraines
- Spillways
- Till Moraines

Physiographic Regions

- Bighead Valley
- Cape Rich Steps
- Horseshoe Moraines
- Dundalk Till Plain
- Teeswater Drumlin Field
- Arran Drumlin Field
- Saugeen Clay Plain
- Huron Slope
- Huron Fringe
- Bruce Peninsula



SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Physiography: OGS MRD228
Settlement: OGS MRD126-REV1 Physiography of Southern Ontario 1:50,000, 2007
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PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

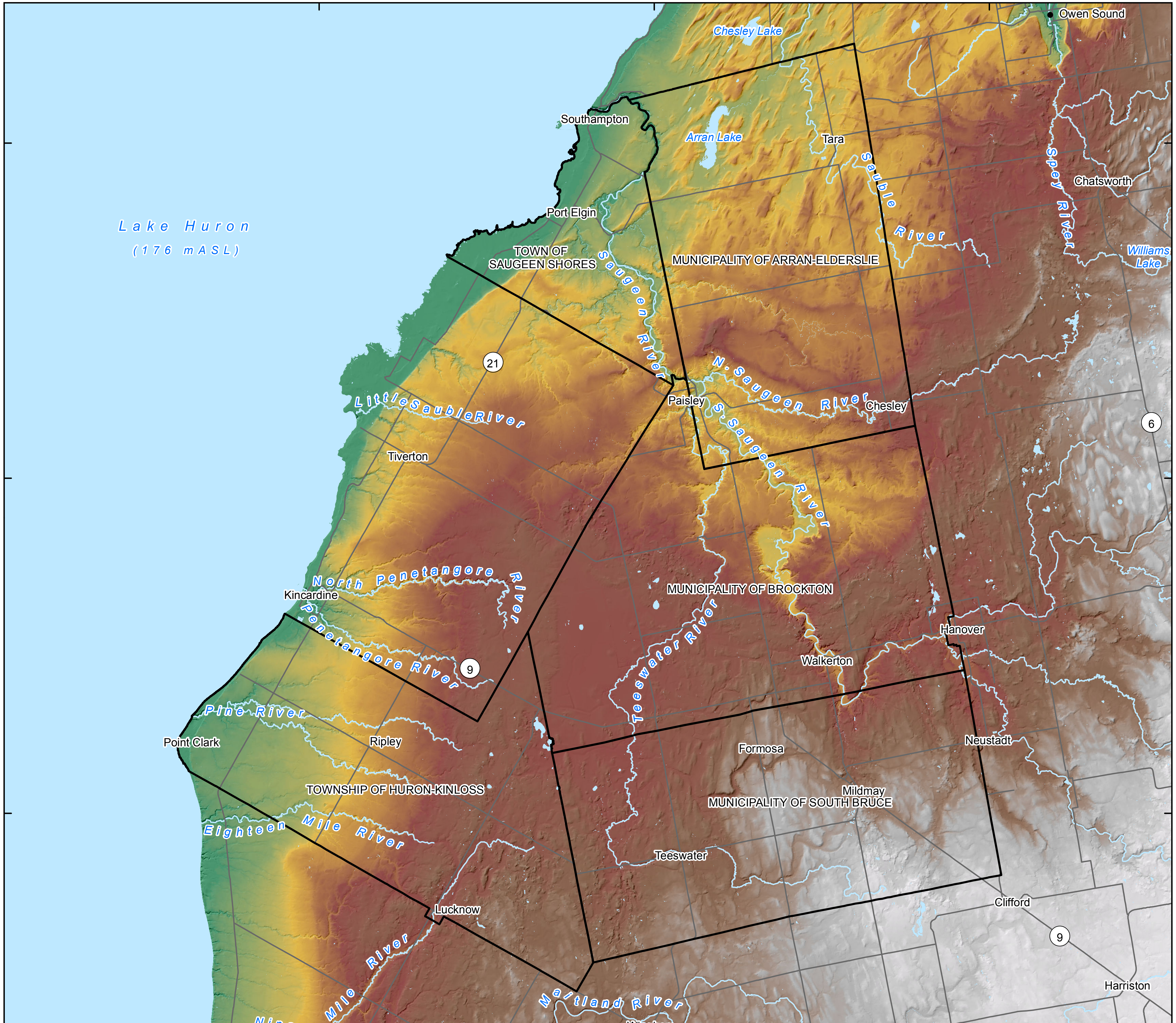
TITLE
Terrain (Physiographic) Features and Physiographic Regions of the Area of the Five Communities

FIGURE 2.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 04/06/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig2_2_TerrainFeatures_PhysiographicRegions.mxd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse

Digital Elevation Model (mASL)

High : 401

Low : 176

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Topography: DEM, LIO, MNR, 2012
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Ground Surface Elevation of the Area of the Five Communities

FIGURE 2.3

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig2_3_Elevation_MajorTopographic_Features.mxd

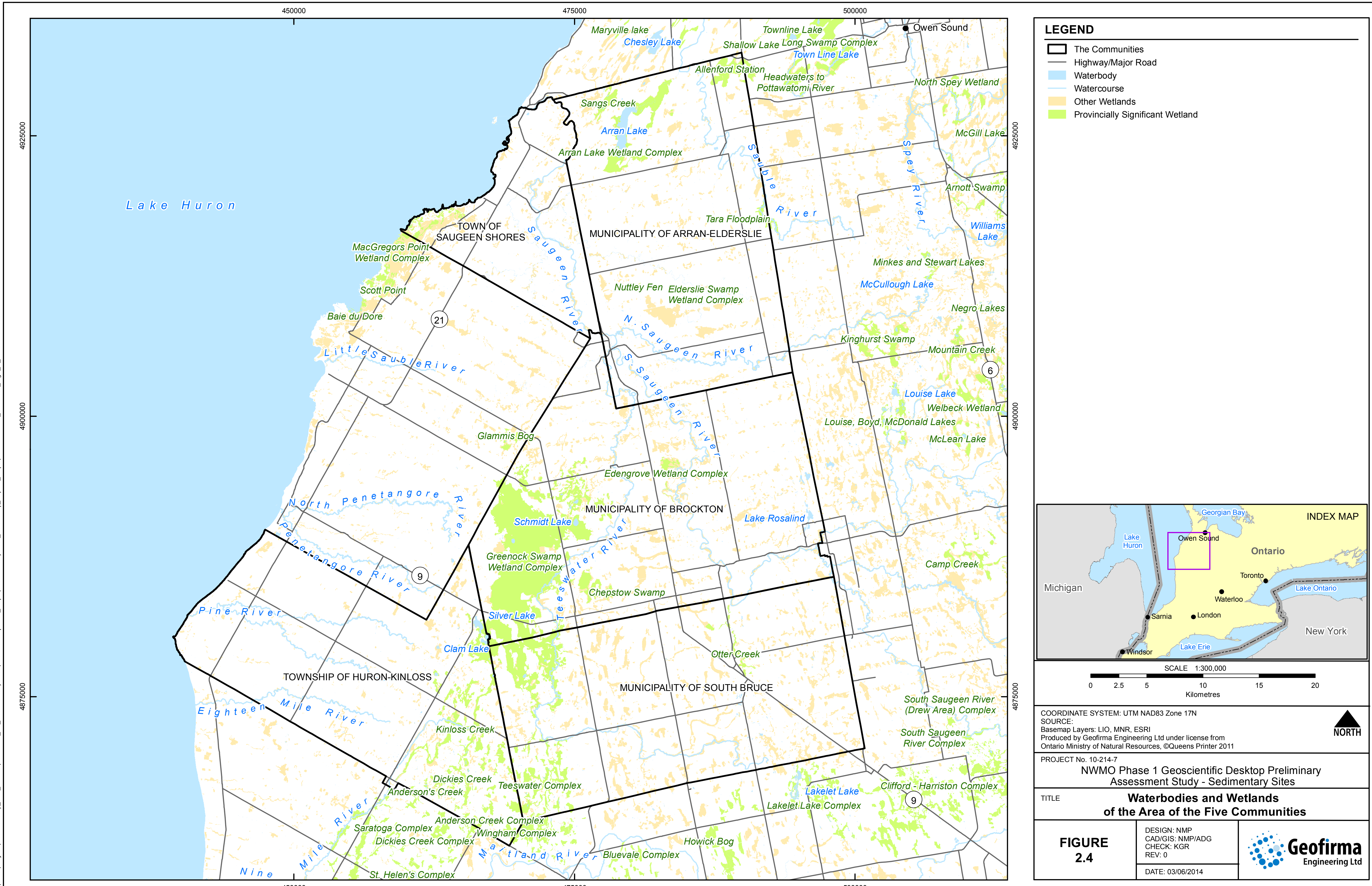
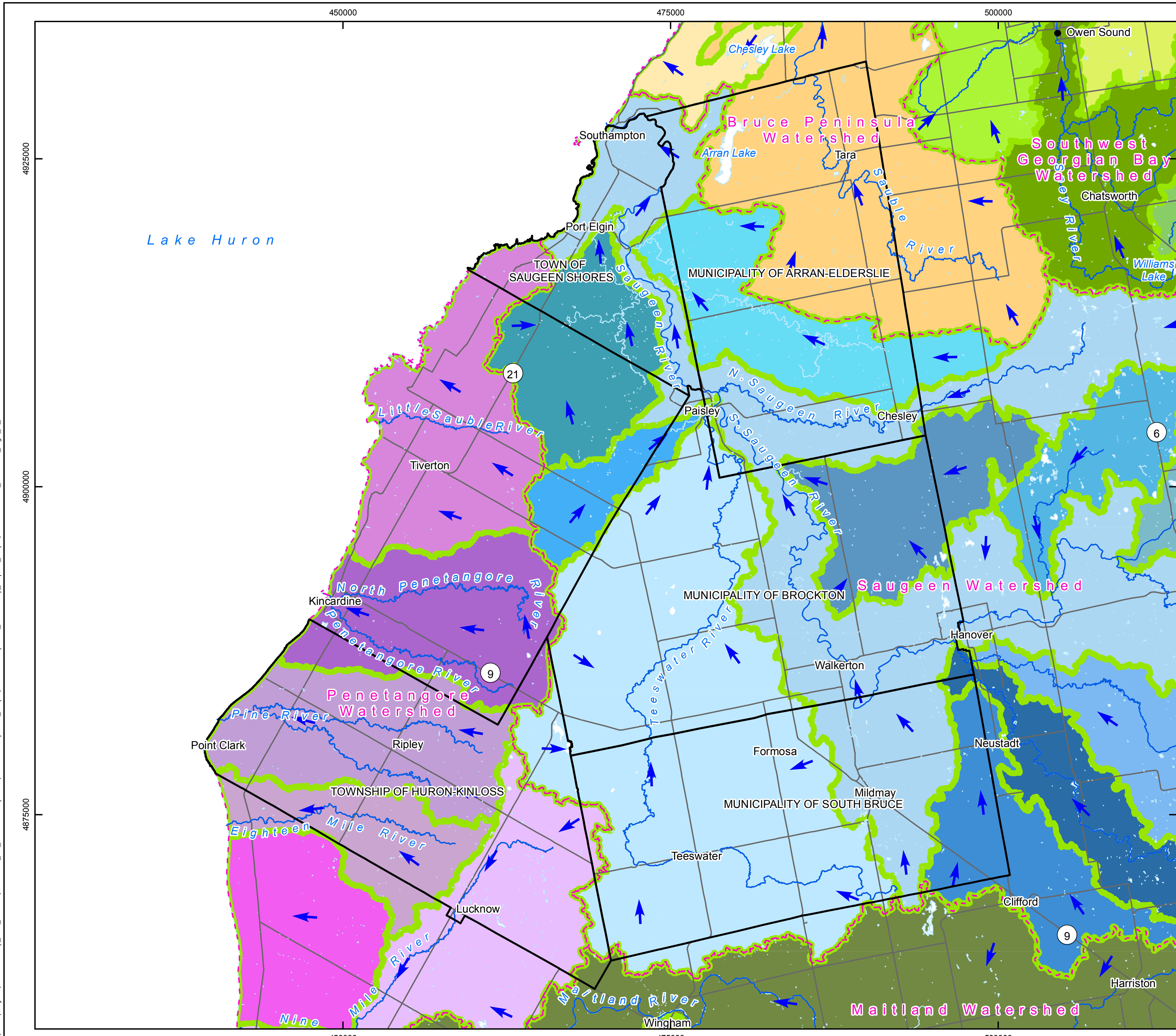


FIGURE 2.4 Waterbodies and Wetlands of the Area of the Five Communities



LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse
- Tertiary Watershed
- Quaternary Watershed
- Surface Water Flow Direction

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Watersheds: LIO MNR, 2013
Flow Directions : JDMA, 2014
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NORTH

PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE
Watersheds and Surface Water Flow in the Area of the Five Communities

FIGURE 2.5

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 04/06/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig2_5_WatershedsandSurfaceWaterFlow.mxd

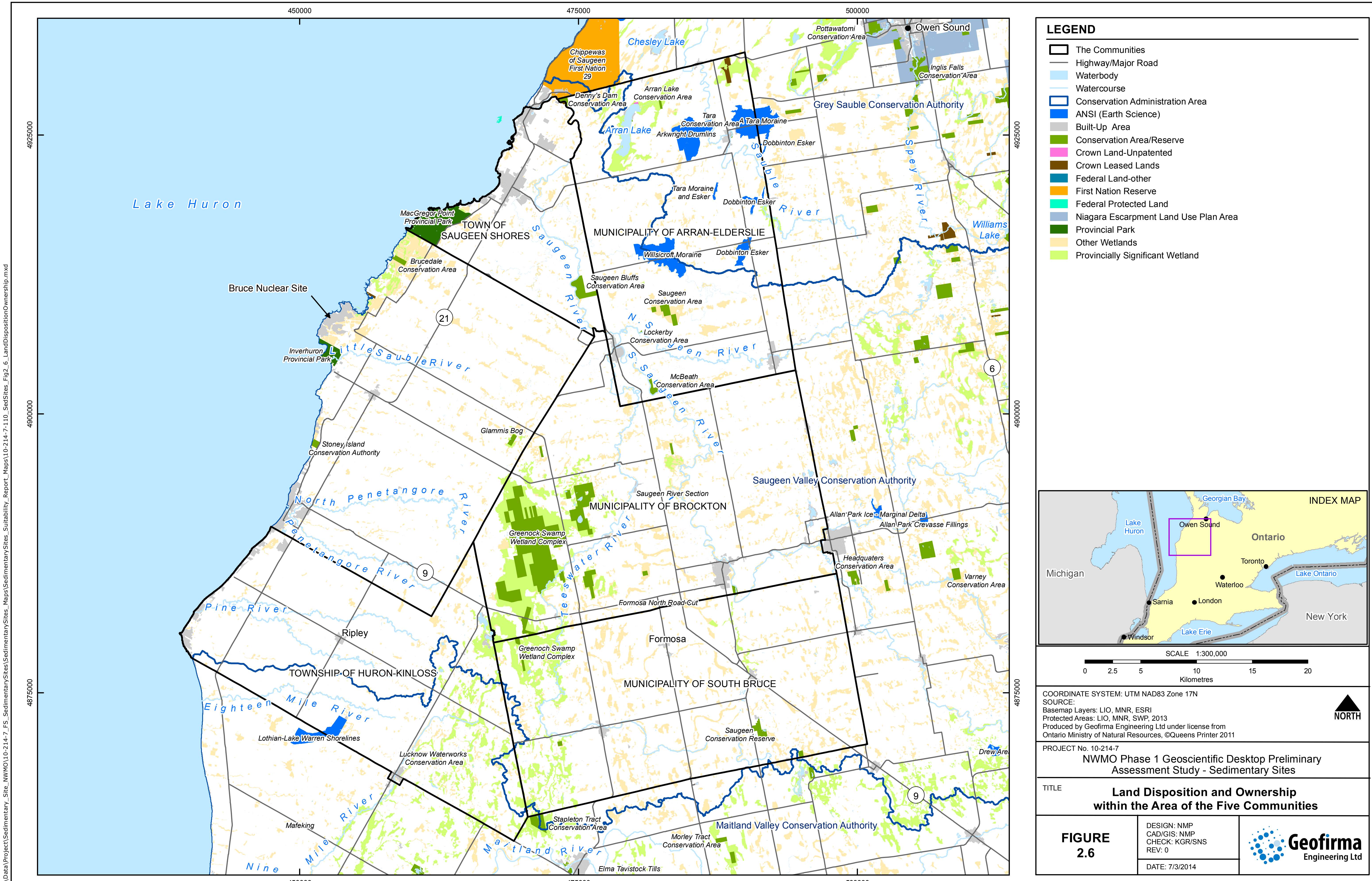
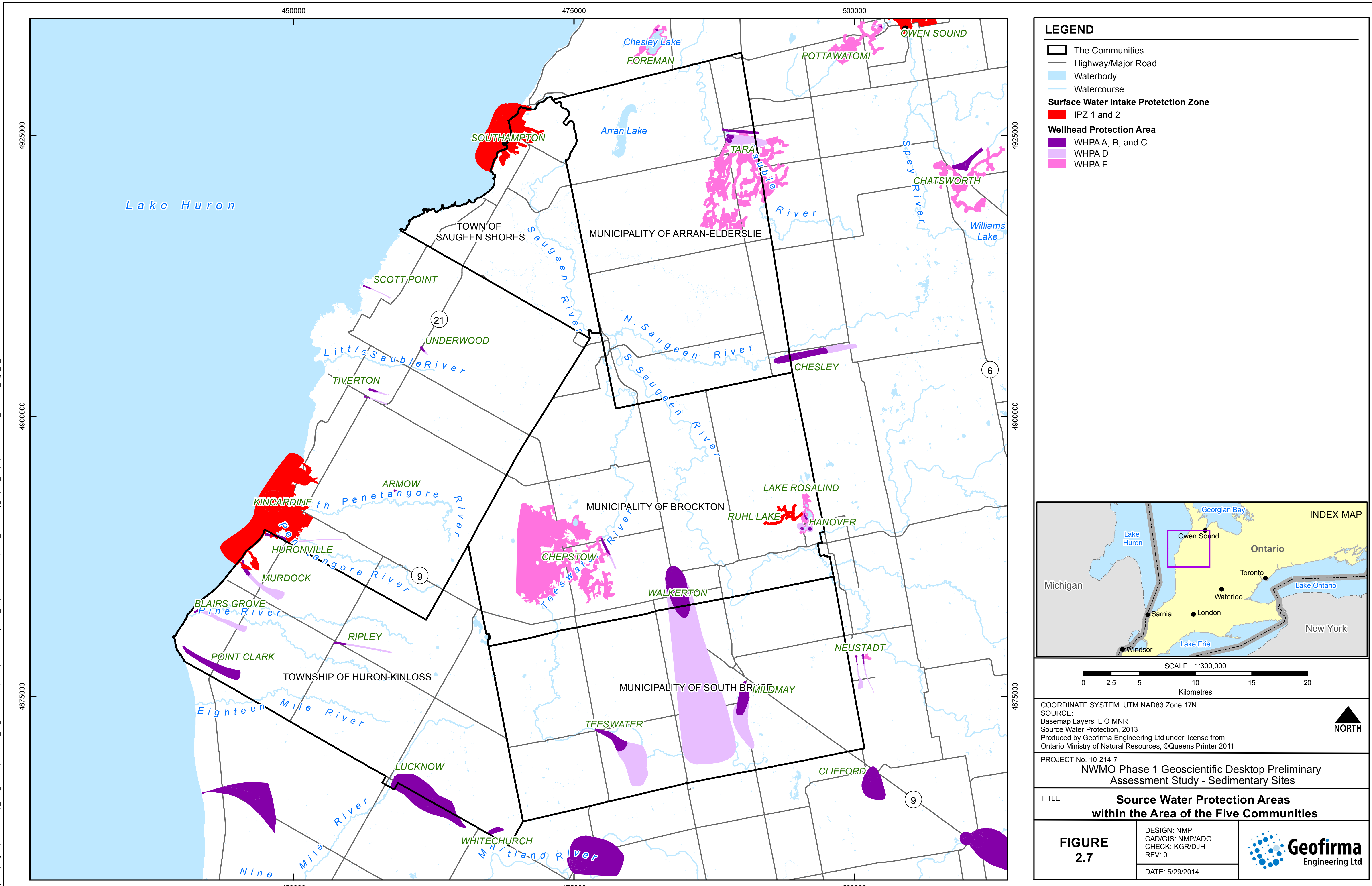
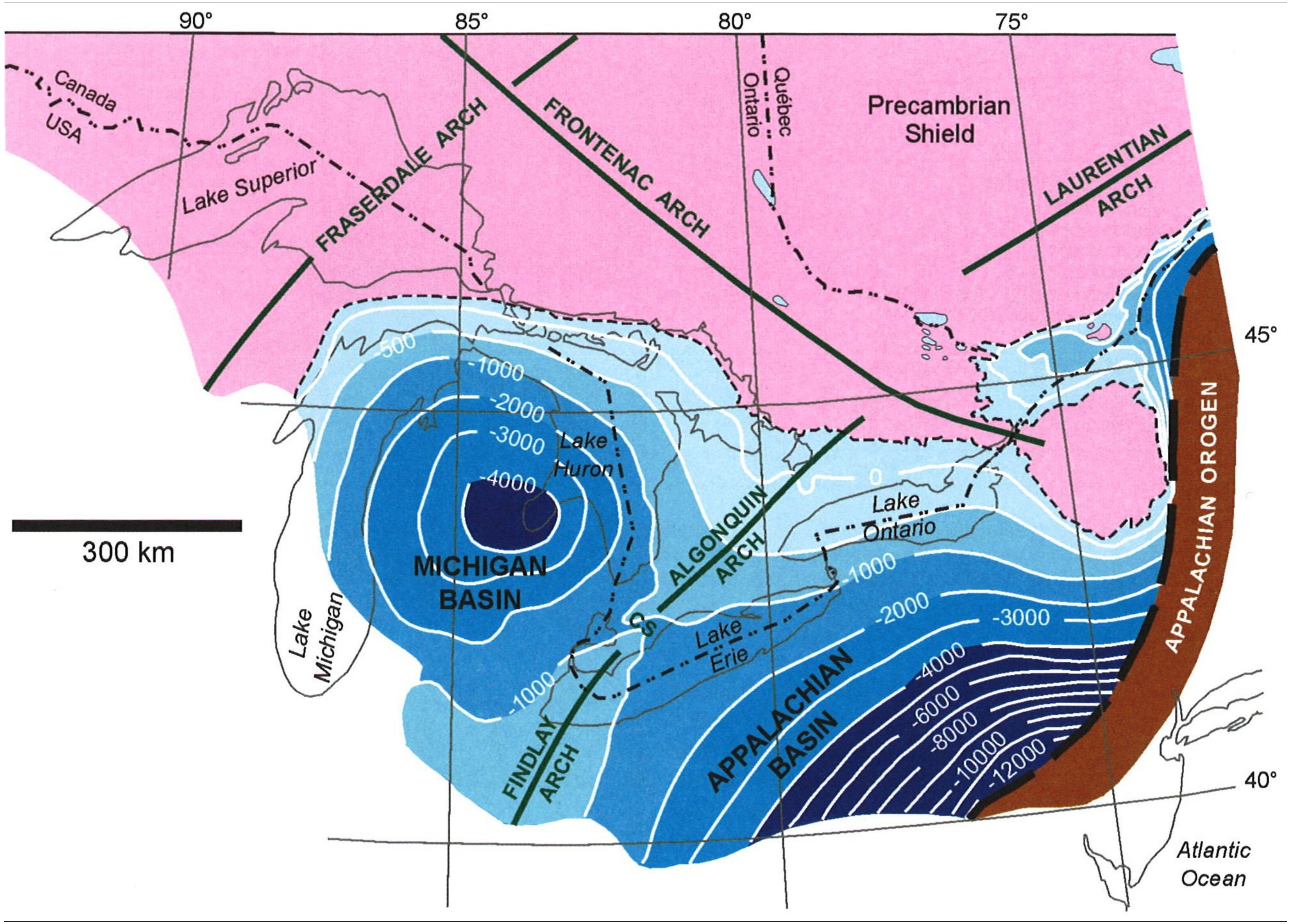


FIGURE 2.6 – Land Disposition and Ownership within the Area of the Five Communities



450000
475000
500000
4925000
4900000
4875000
Lake Huron
Chesley Lake
FOREMAN
POTTAWATOMI
OWEN SOUND
SOUTHAMPTON
Arran Lake
TARA
Sauble River
Spey River
CHATSWORTH
Williams Lake
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
Saugeen River
SCOTT POINT
21
UNDERWOOD
N. Saugeen River
CHESLEY
6
Little Sauble River
TIVERTON
S. Saugeen River
ARMOW
North Penetangore River
KINCARDINE
MUNICIPALITY OF BROCKTON
LAKE ROSALIND
RUHL LAKE
HANOVER
Penetangore River
HURONVILLE
CHEPSTOW
Teeswater River
9
MURDOCK
WALKERTON
BLAIRS GROVE
Pine River
RIPLEY
NEUSTADT
POINT CLARK
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF SOUTH BRUCE
MILDMAY
Eighteen Mile River
TEESWATER
LUCKNOW
CLIFFORD
River
WHITECHURCH
Maitland River
Nine Mile River
G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig2_7_SouceWaterProtectionAreas.mxd
LEGEND
The Communities
Highway/Major Road
Waterbody
Watercourse
Surface Water Intake Protetction Zone
IPZ 1 and 2
Wellhead Protection Area
WHPA A, B, and C
WHPA D
WHPA E
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Michigan
Toronto
Lake Ontario
Waterloo
Sarnia
London
New York
Lake Erie
Windsor
SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO MNR
Source Water Protection, 2013
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary
Assessment Study - Sedimentary Sites
TITLE
Source Water Protection Areas
within the Area of the Five Communities
FIGURE
2.7
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/DJH
REV: 0
DATE: 5/29/2014
Geofirma Engineering Ltd



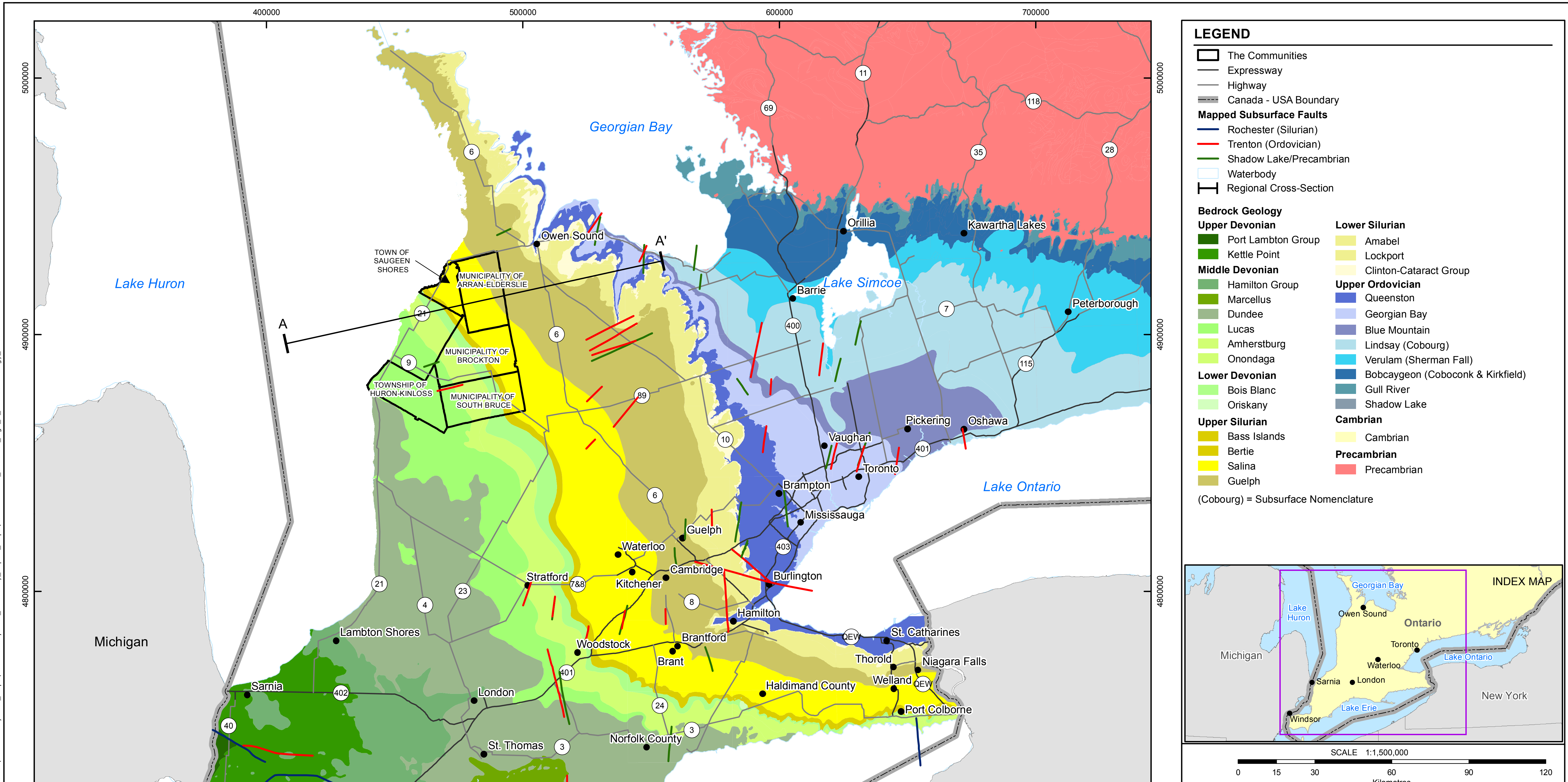
Data Source: Johnson et al. (1992); Armstrong and Carter (2010)

FIGURE 3.1 - Geological Features of Southern Ontario	Prepared by: ECK
	Reviewed by: KGR/SNS
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites	Date: 12/02/2014

Michigan and Appalachian sedimentary basins (blue), Algonquin and Findlay basement arches (green) and the Chatham Sag (CS). Contour lines (white) indicate elevation of the top of the Precambriam basement in meters below mean sea level. The Appalachian orogenic is indicated in brown, with the extent of the thrusting shown as a thick, black dashed line. Thinner dashed line represents the present-day erosional edge of Paleozoic rocks (After Johnson et al. 1992)

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig3_1_GeologicalFeaturesofSouthernOntario.cdr"



COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
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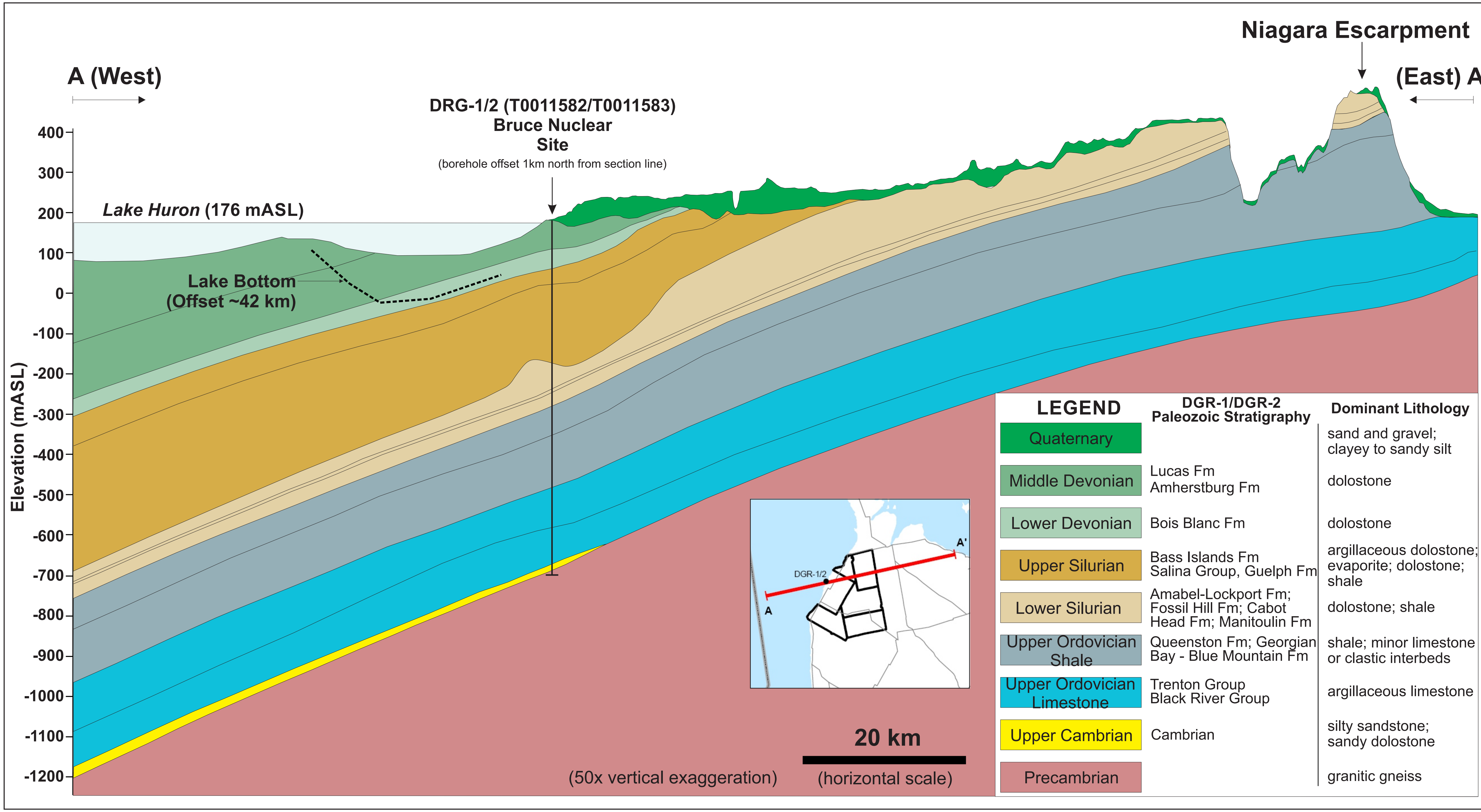
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE
Bedrock Geology of Southern Ontario

FIGURE 3.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 6/27/2014

Geofirma Engineering Ltd



Data Source: after NWMO, 2011

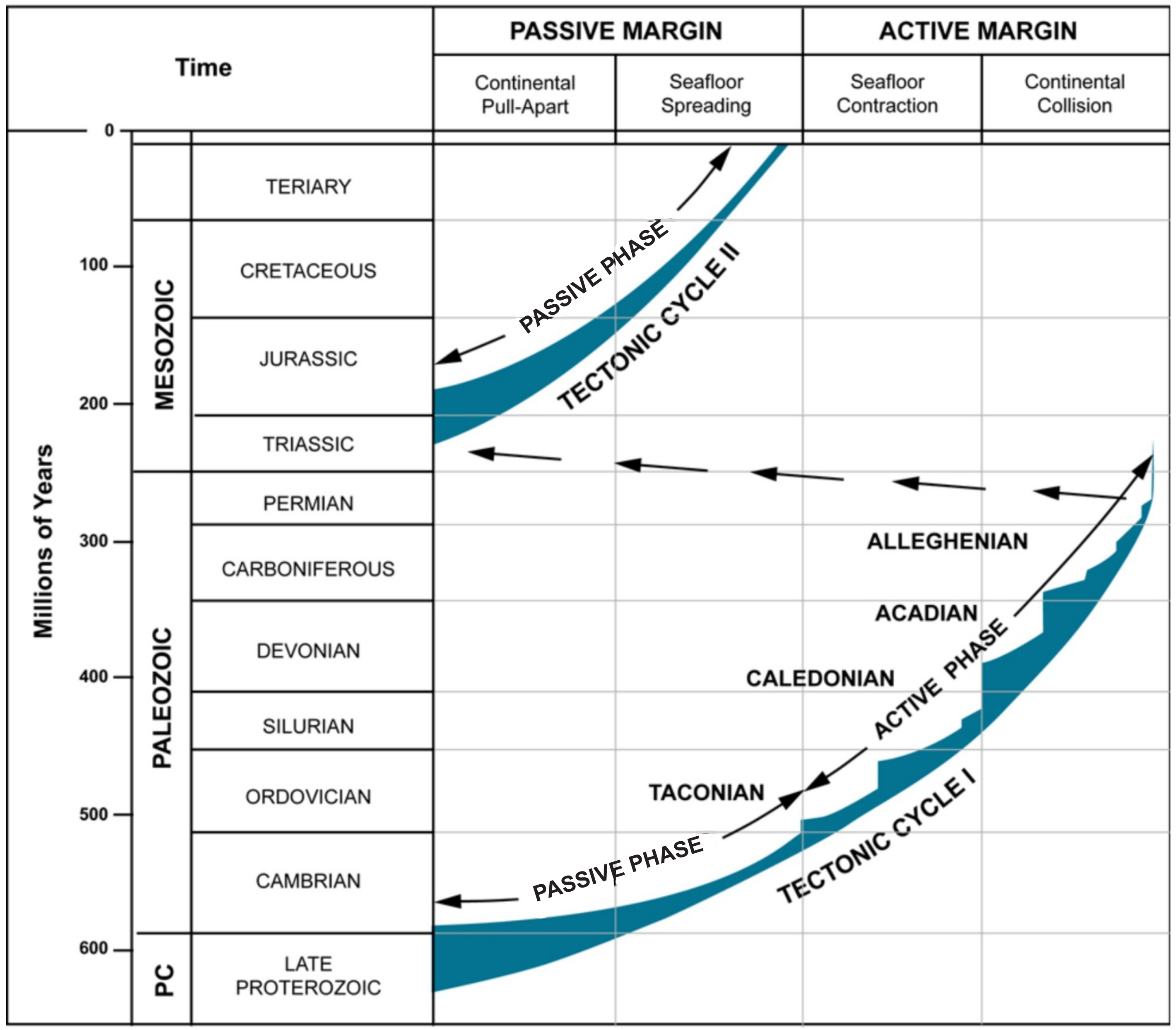
FIGURE 3.3 - Regional Geological Cross-Section of the Eastern Flank of the Michigan Basin

PROJECT No: 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: KGR/SNS
Date: 10/02/2014

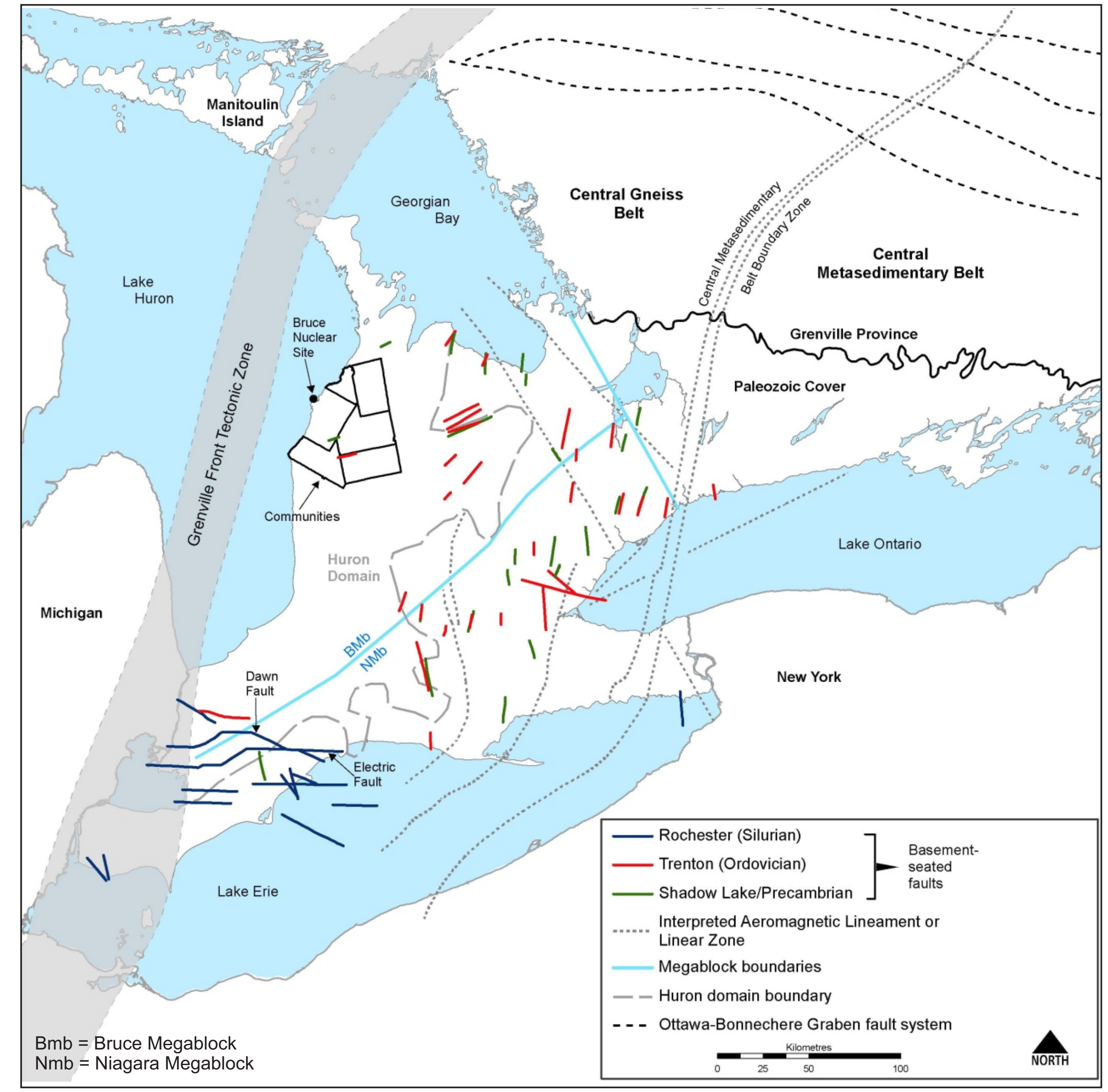
Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig3_3_Cross_Section_EasternFlankMichiganBasin_R0B.cdr"



Data Source: Sanford et al. (1985).

a. Phanerozoic Tectonic Cycles



Data Source: Contacts are based on field mapping and interpretations aided by subsurface drilling, borehole stratigraphic correlation, and aeromagnetic and gravity imaging (Liberty and Bolton (1971), and compiled from Brigham (1971), Bailey and Cochrane (1984a), Bailey and Cochrane (1984b), Sanford et al. (1985), Carter and Easton (1990), Sage (1991), Jacobi and Fountain (1993), Easton and Carter (1995), Carter et al. (1996), Wallach et al. (1998), Ketchum and Davidson (2000), Boyce and Morris (2002)

b. Tectonic Boundaries and Fault Contacts.

FIGURE 3.4 - Structural Geology of Southern Ontario: a – Phanerozoic Tectonic Cycles; b –Tectonic Boundaries and Fault Contacts.

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites	Prepared by: ECK/ADG Reviewed by: KGR/SNS Date: 28/05/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig3_4_Tectonics_R1.cdr"

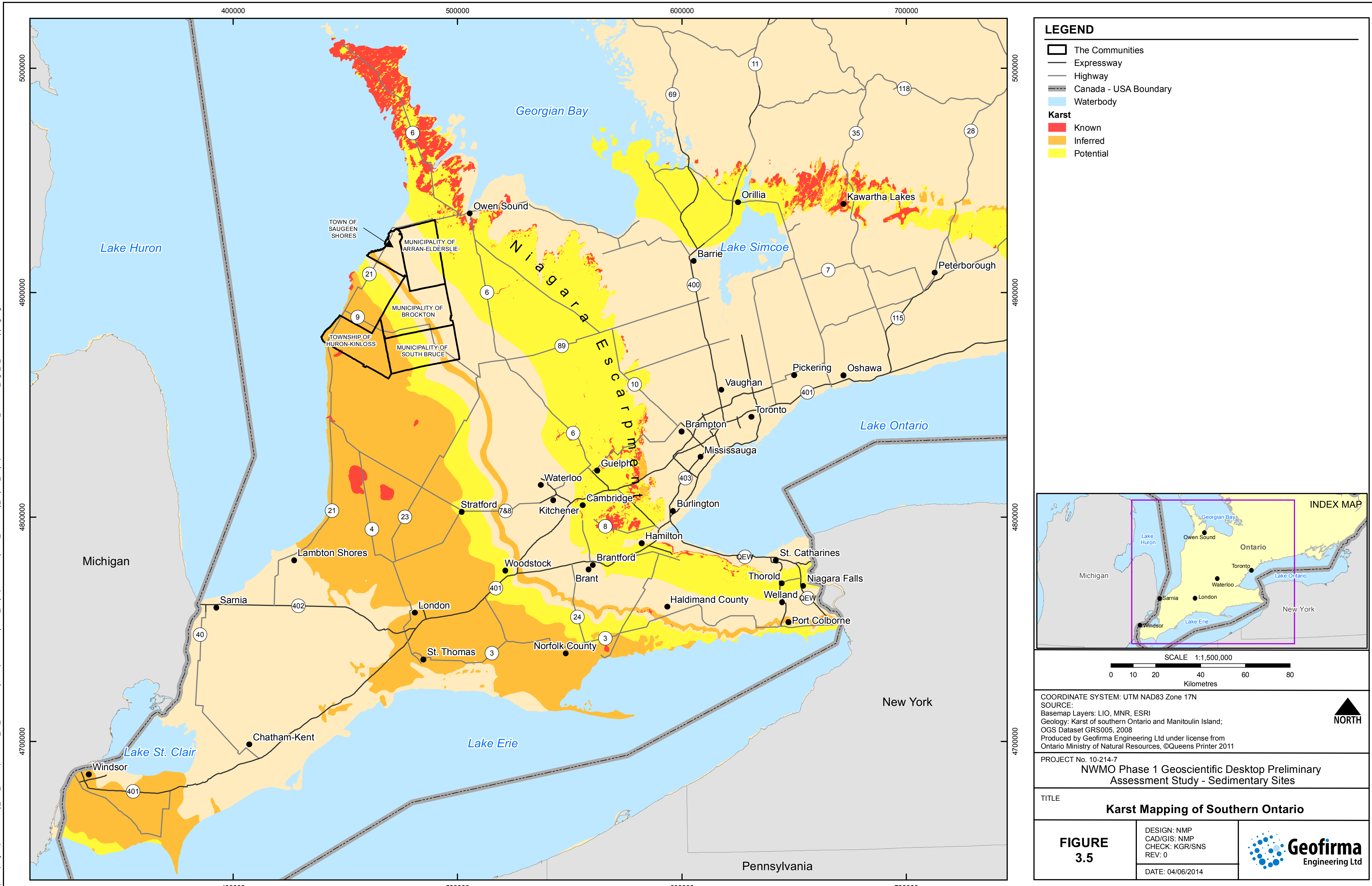


FIGURE 3.5

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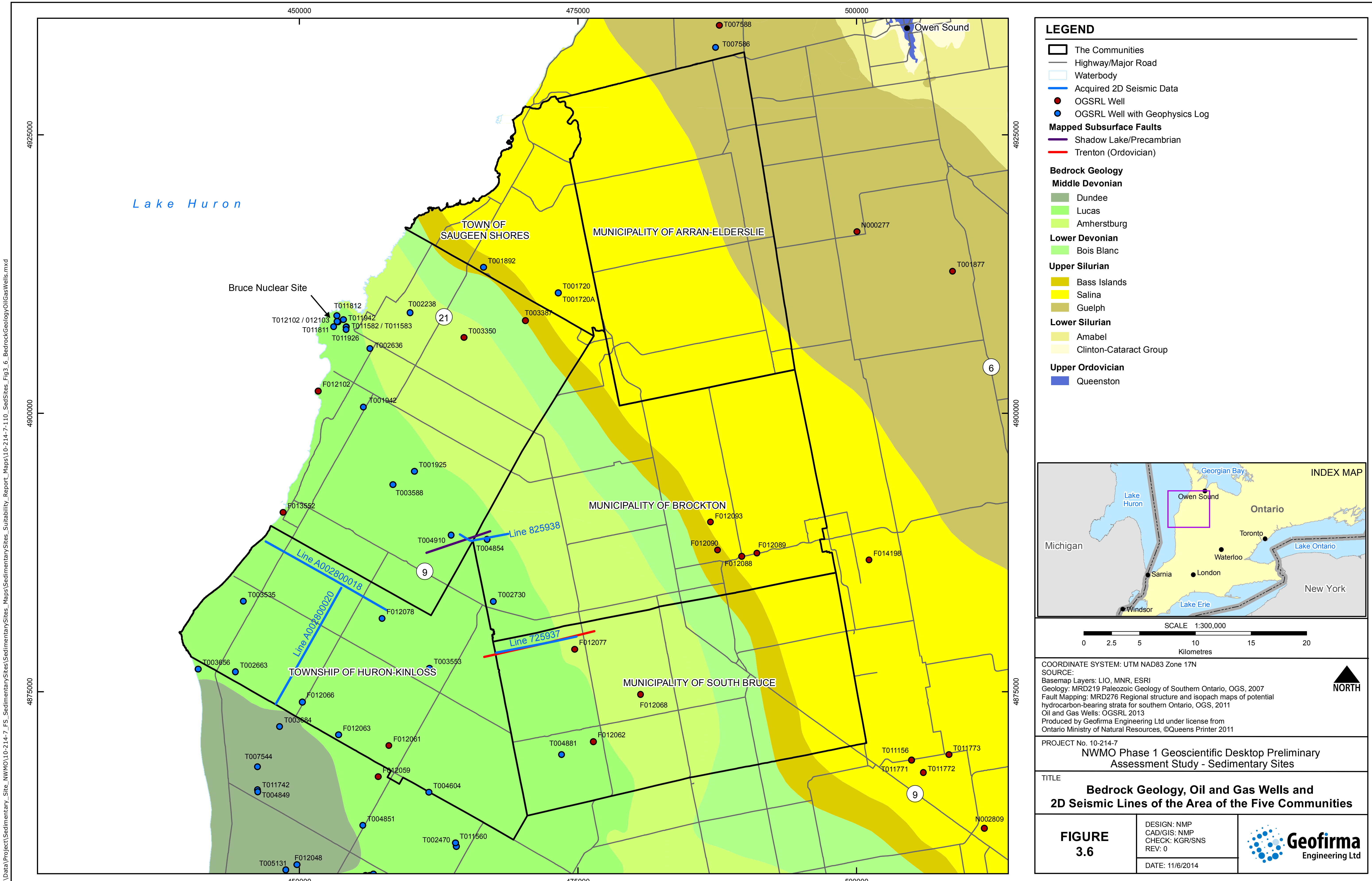

450000
475000
500000
4925000
4900000
4875000
Owen Sound
Lake Huron
Bruce Nuclear Site
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
MUNICIPALITY OF BROCKTON
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF SOUTH BRUCE
Line 825938
Line A002800018
Line A002800020
Line 725937
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T007586
N000277
T001877
T001892
T001720
T001720A
T003387
T003350
T002238
T011812
T012102 / 012103
T011942
T011811
T011582 / T011583
T011926
T002636
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T004854
T002730
T003535
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T002663
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F012068
T003684
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T004604
T004851
T002470
T011560
T005131
F012048
T011156
T011773
T011771
T011772
N002809
21
9
6
LEGEND
The Communities
Highway/Major Road
Waterbody
Acquired 2D Seismic Data
OGSRL Well
OGSRL Well with Geophysics Log
Mapped Subsurface Faults
Shadow Lake/Precambrian
Trenton (Ordovician)
Bedrock Geology
Middle Devonian
Dundee
Lucas
Amherstburg
Lower Devonian
Bois Blanc
Upper Silurian
Bass Islands
Salina
Guelph
Lower Silurian
Amabel
Clinton-Cataract Group
Upper Ordovician
Queenston
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Toronto
Michigan
Waterloo
Lake Ontario
Sarnia
London
New York
Lake Erie
Windsor
SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Fault Mapping: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites
TITLE
Bedrock Geology, Oil and Gas Wells and 2D Seismic Lines of the Area of the Five Communities
FIGURE 3.6
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 11/6/2014
Geofirma Engineering Ltd
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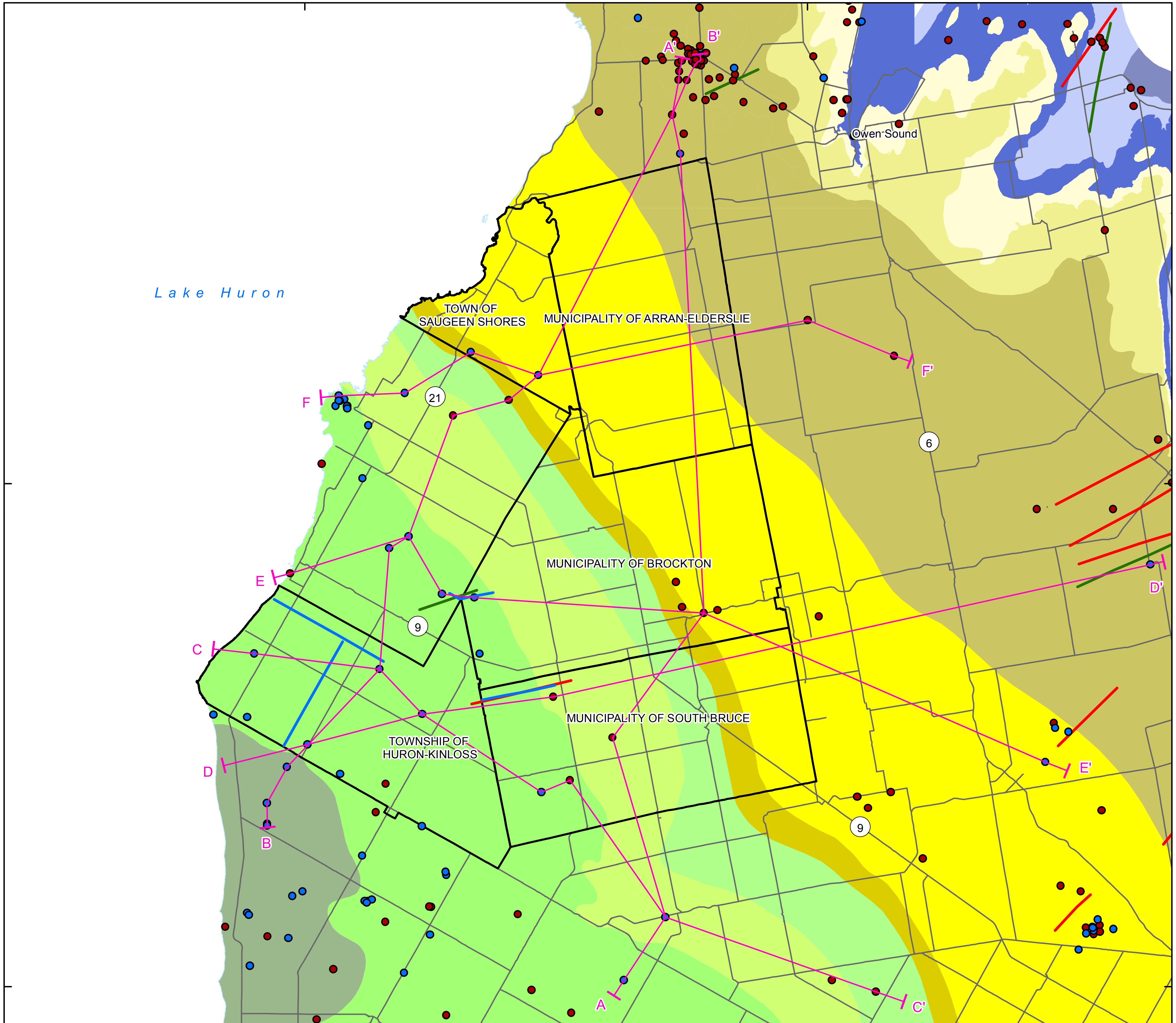

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)
- Acquired 2D Seismic Data
- OGSRL Well
- OGSRL Well with Geophysics Log
- Cross-Section

Bedrock Geology

Middle Devonian

- Dundee
- Lucas
- Amherstburg

Lower Devonian

- Bois Blanc

Upper Silurian

- Bass Islands
- Salina
- Guelph

Lower Silurian

- Amabel
- Clinton-Cataract Group

Upper Ordovician

- Queenston
- Georgian Bay
- Blue Mountain

INDEX MAP

SCALE 1:400,000

0 3.75 7.5 15 22.5 30

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N

SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Fault Mapping: Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Location of Cross-Sections and 2D Seismic Lines

FIGURE 3.7

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

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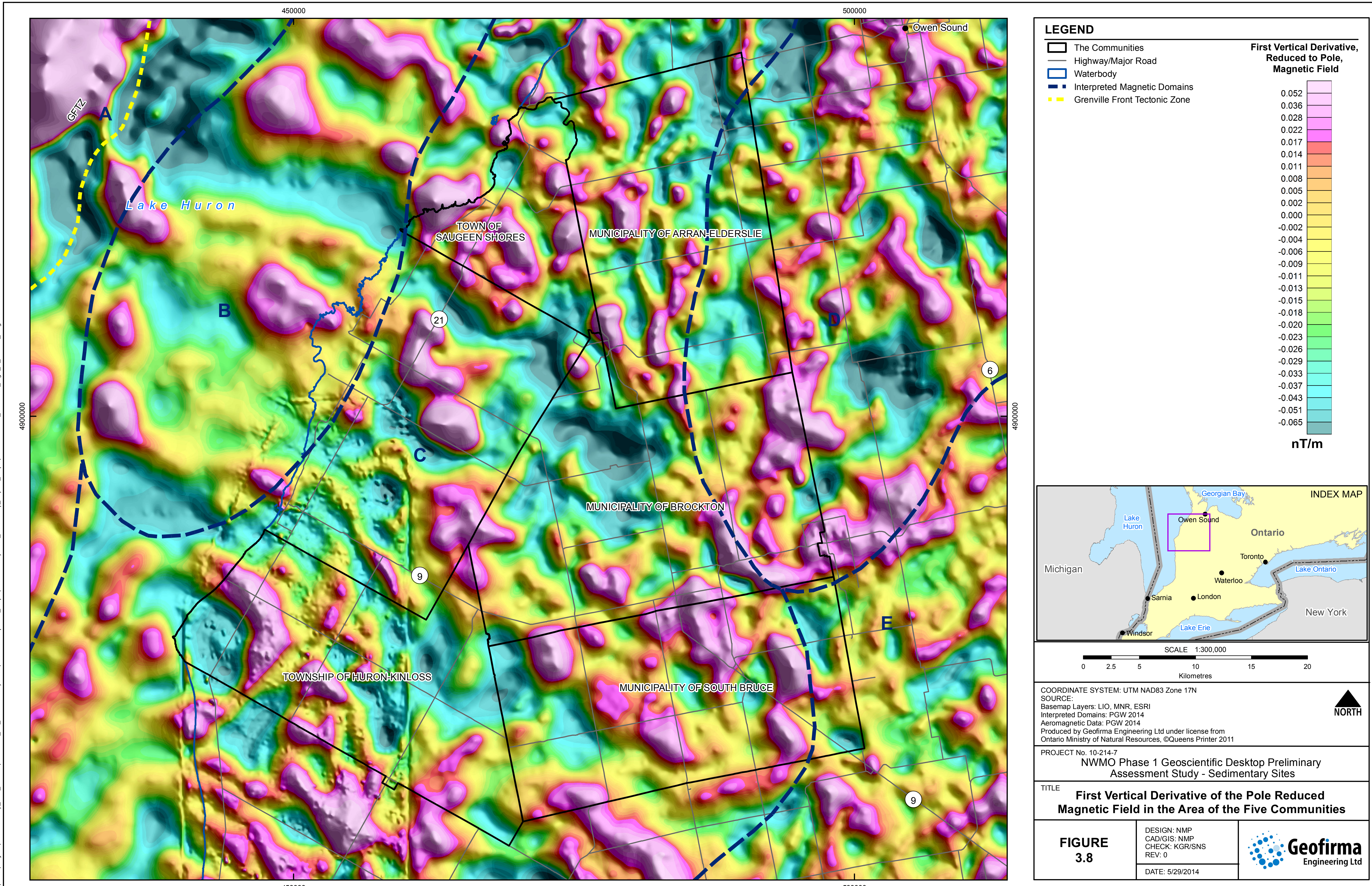
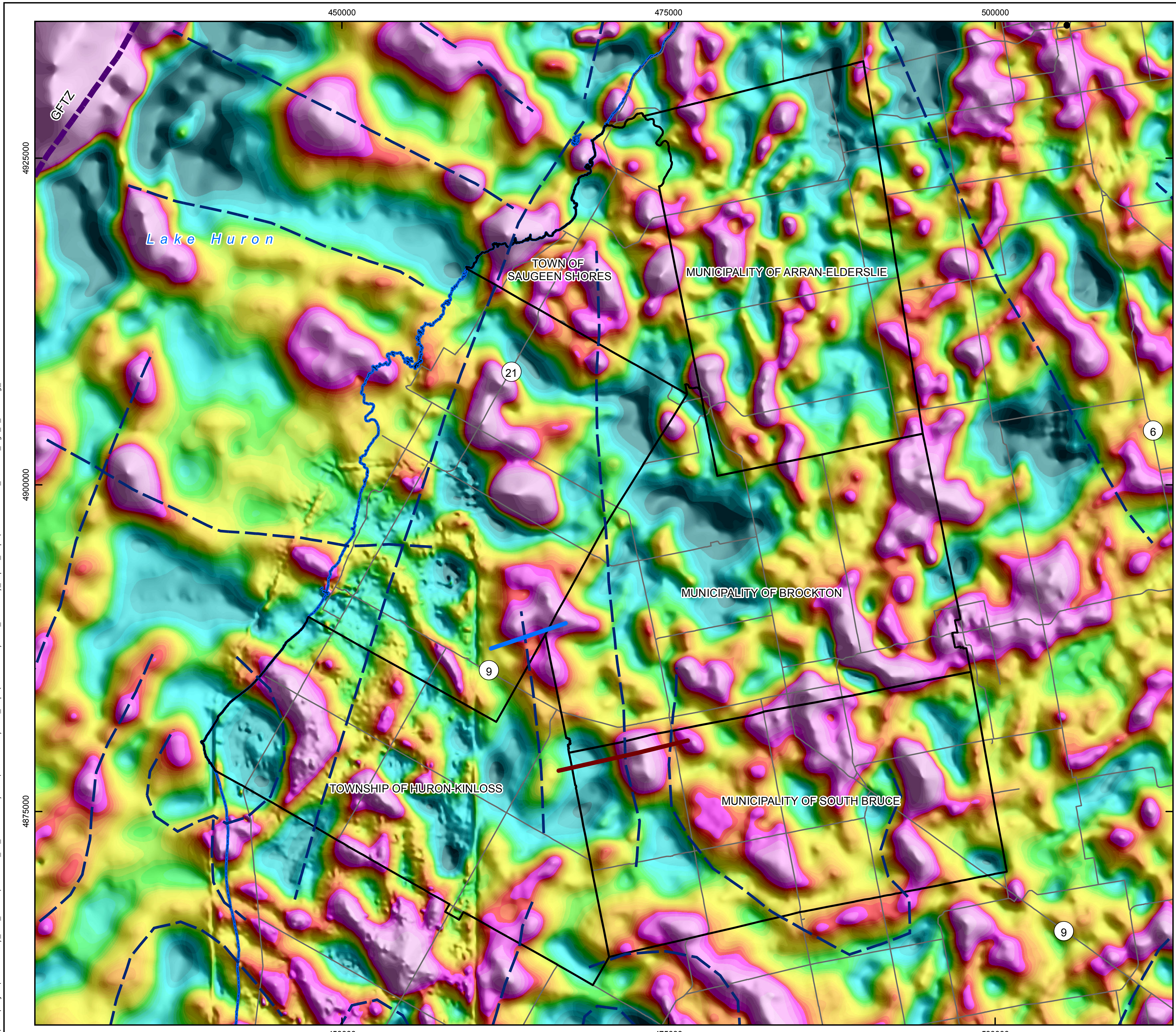


FIGURE 3.8

First Vertical Derivative of the Pole Reduced Magnetic Field in the Area of the Five Communities



LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

Boyce & Morris

- Minor Aeromagnetic Lineament
- Major Aeromagnetic Lineament

First Vertical Derivative, Reduced to Pole, Magnetic Field

0.052
0.036
0.028
0.022
0.017
0.014
0.011
0.008
0.005
0.002
0.000
-0.002
-0.004
-0.006
-0.009
-0.011
-0.013
-0.015
-0.018
-0.020
-0.023
-0.026
-0.029
-0.033
-0.037
-0.043
-0.051
-0.065

nT/m

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Aeromagnetic Data: PGW 2014
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
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NORTH

PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE
Boyce and Morris (2002) Aeromagnetic Lineaments, Mapped Subsurface Faults and Aeromagnetic Data in the Area of the Five Communities

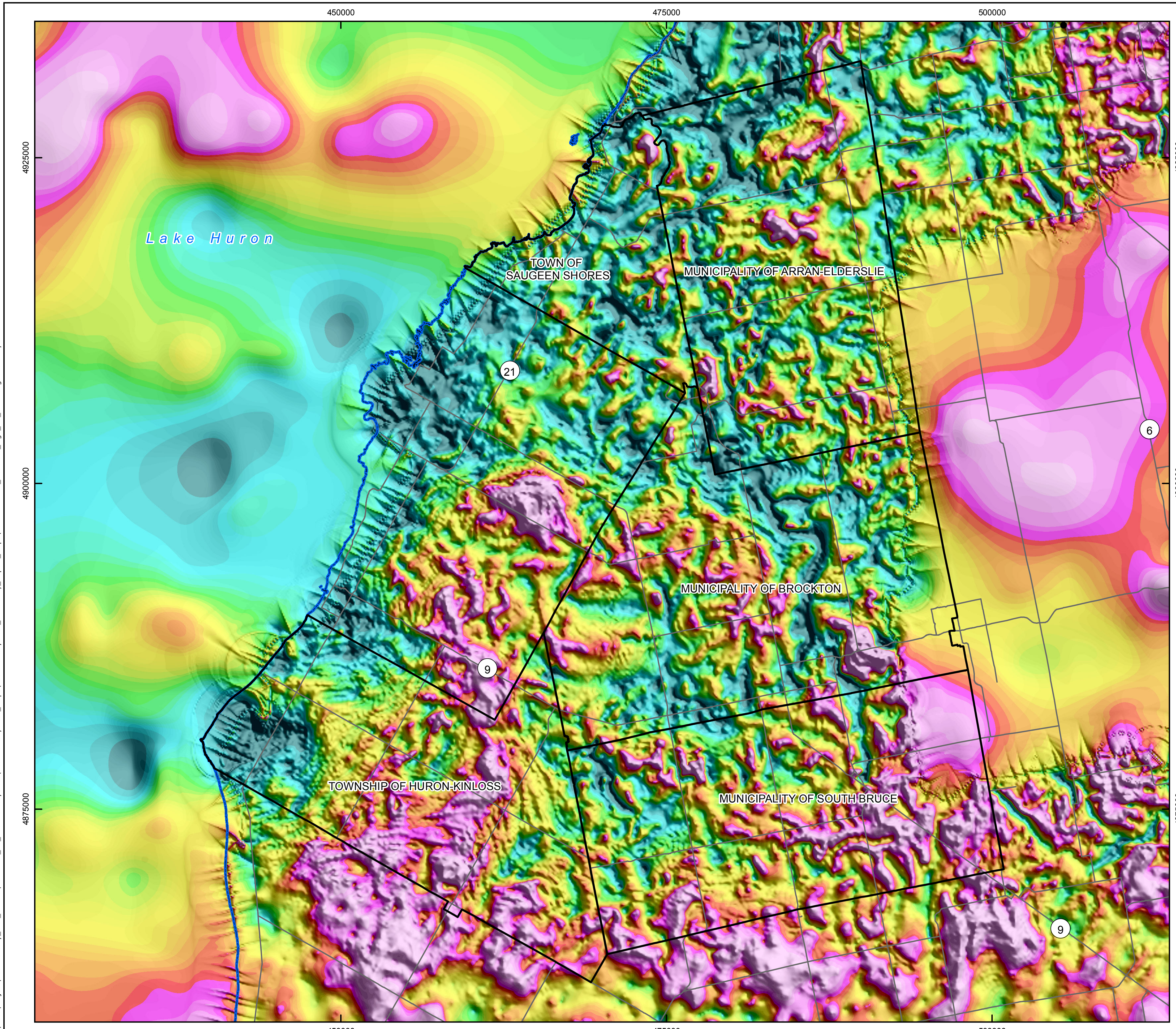
FIGURE 3.9

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig3_9_Aeromag_OGSFaults.mxd



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LEGEND

- The Communities
- Highway/Major Road
- Waterbody

First Vertical Derivative of Bouguer Gravity

0.00085
0.00070
0.00055
0.00050
0.00040
0.00035
0.00025
0.00020
0.00010
0.00005
0.00000
-0.00005
-0.00015
-0.00020
-0.00025
-0.00030
-0.00040
-0.00045
-0.00055
-0.00060
-0.00070
-0.00075
-0.00085
-0.00090
-0.00100
-0.00115
-0.00140

mGal/m

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

NORTH

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Gravity Data: PGW 2014
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

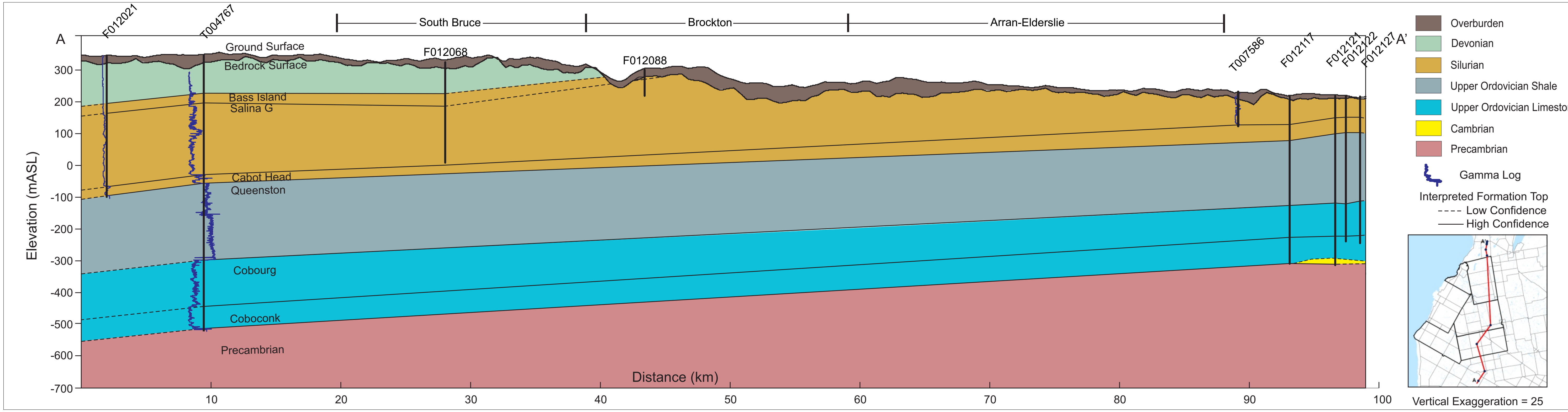
First Vertical Derivative of the Bouguer Gravity in the Area of the Five Communities

FIGURE 3.10

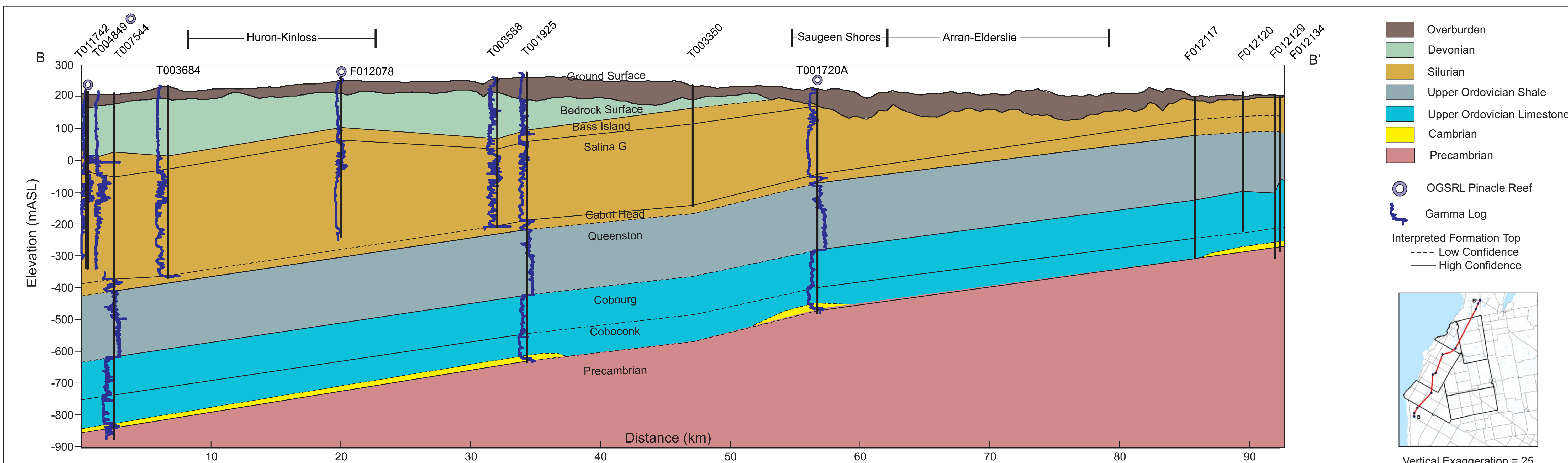
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 5/29/2014

Geofirma Engineering Ltd



(a) Cross-Section A-A'



Data Source: OGSRL, 2013

(b) Cross-Section B-B'

FIGURE 3.11 - Geological Cross-Sections (a) A-A' and (b) B-B'

PROJECT No: 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: KGR/SNS
Date: 23/06/2014

Geofirma Engineering Ltd

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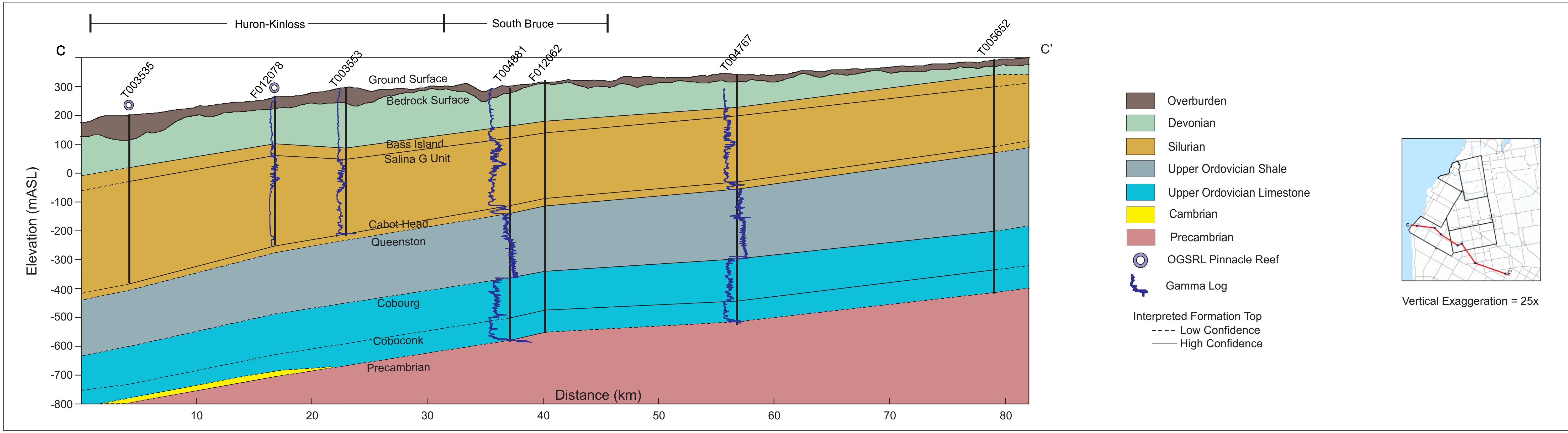
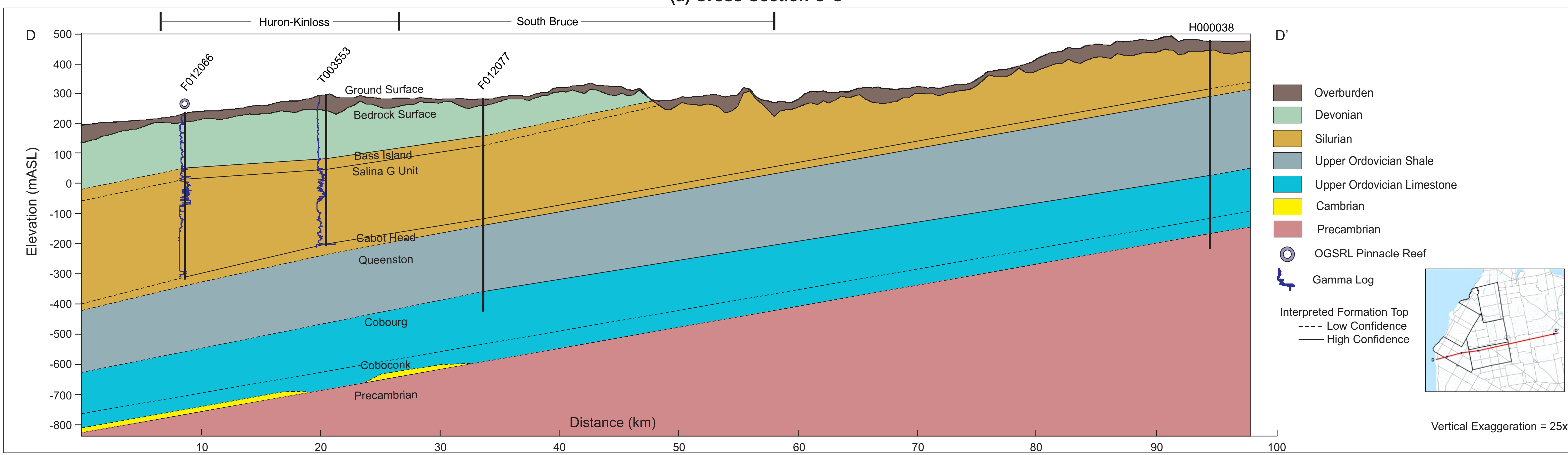


(a) Cross-Section C-C'



Data Source: OGSRL, 2013

(b) Cross-Section D-D'

FIGURE 3.12 - Geological Cross-Sections (a) C-C' and (b) D-D'

PROJECT No: 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: KGR/SNS
Date: 23/06/2014

Geofirma Engineering Ltd

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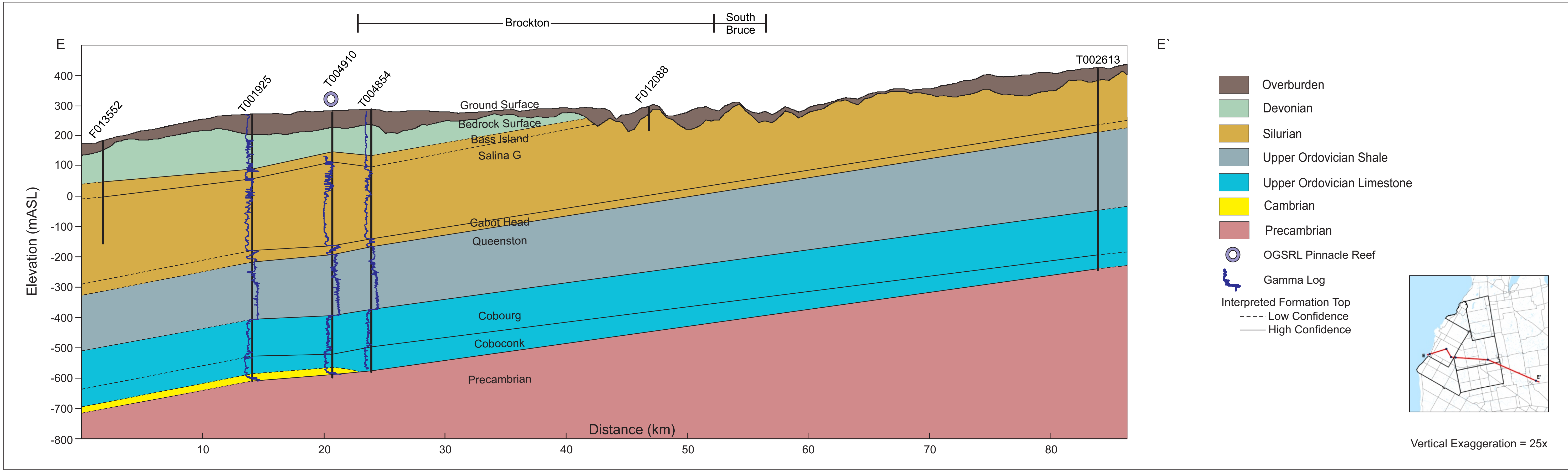
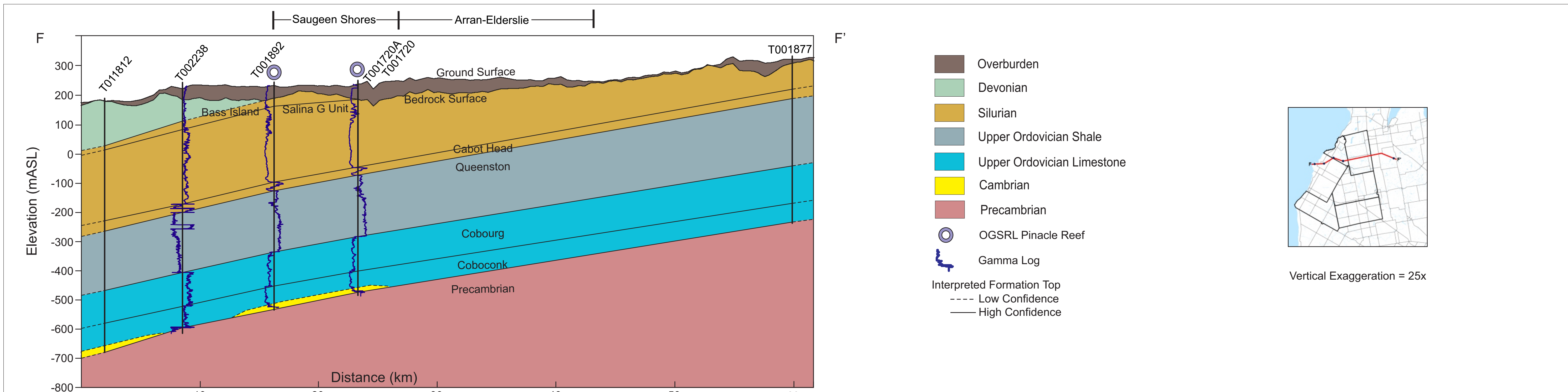


(a) Cross-Section E-E'



(b) Cross-Section F-F'

Data Source: OGSRL, 2013

FIGURE 3.13 - Geological Cross-Sections (a) E-E' and (b) F-F'

PROJECT No: 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: KGR/SNS
Date: 23/06/2014

Geofirma Engineering Ltd

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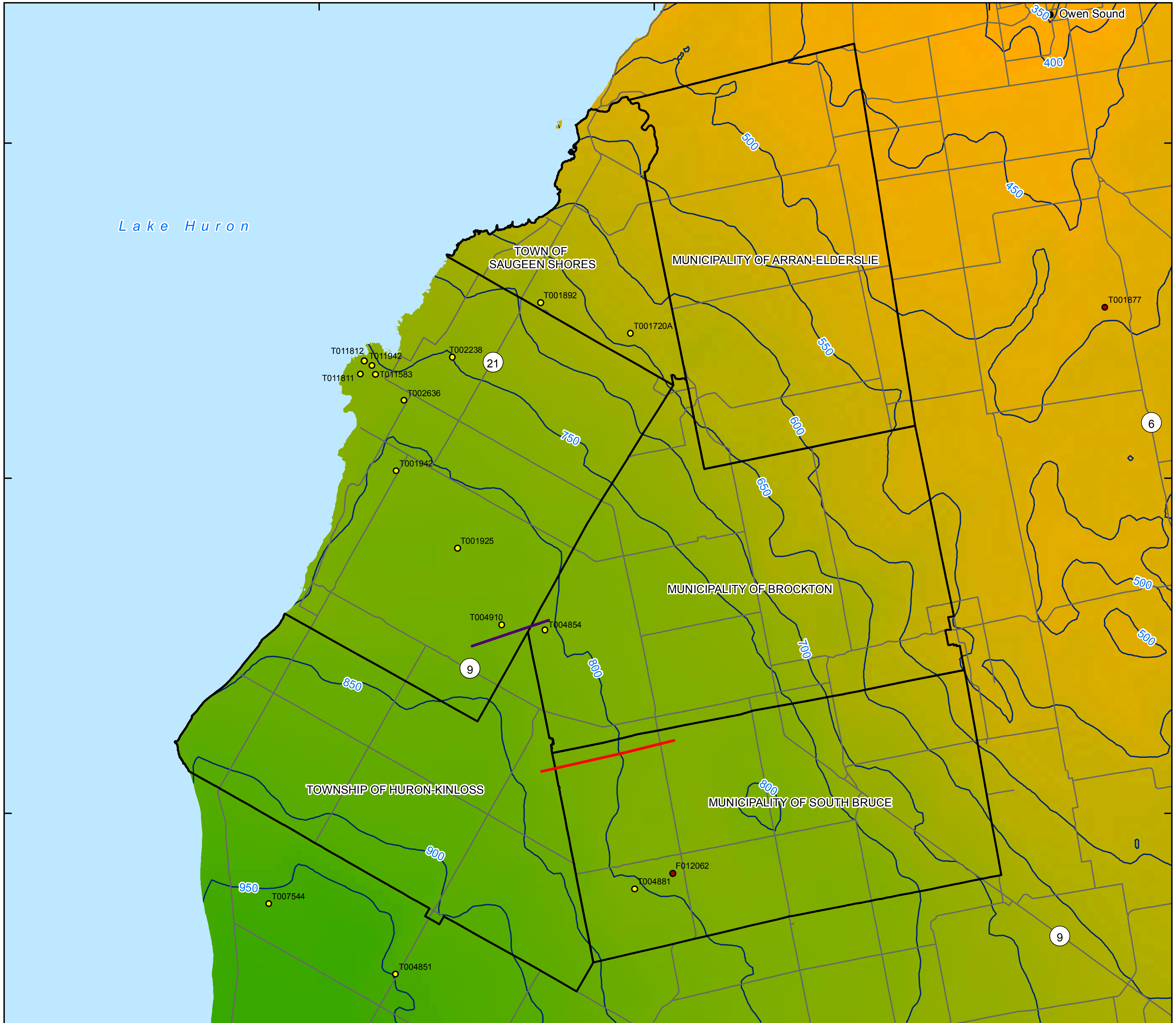

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

OGSRL Well with Data Used to Create Top of the Coboconk Formation

- OGSRL Well with Geophysics Log
- OGSRL Well

Depth to the Coboconk Formation (mBGS)

High : 996

Low : 331

- Contour of Depth to top Coboconk Formation (50m interval)

INDEX MAP

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N

SOURCE:

Basemap Layers: LIO, MNR, ESRI

Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011

Oil and Gas Wells: OGSRL 2013

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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Depth to Top of the Coboconk Formation in the Area of the Five Communities

FIGURE 3.14

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

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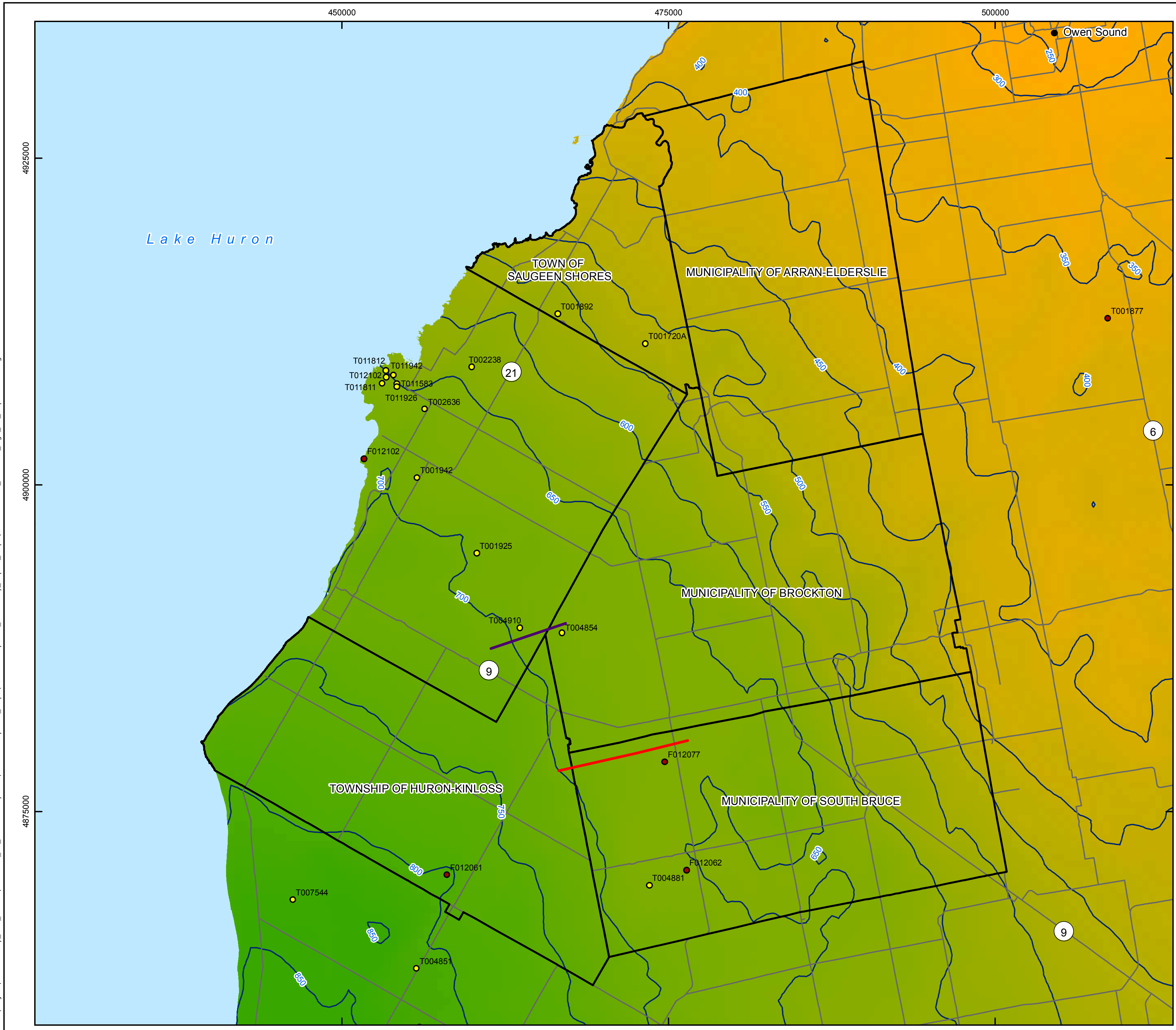

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

OGSRL Well with Data Used to Create Top of the Cobourg Formation

- OGSRL Well with Geophysics Log
- OGSRL Well

Depth to the Cobourg Formation (mBGS)

High : 864

Low : 200

- Contour of Depth to the Cobourg Formation (50m interval)

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Depth to Top of the Cobourg Formation in the Area of the Five Communiies

FIGURE 3.15

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

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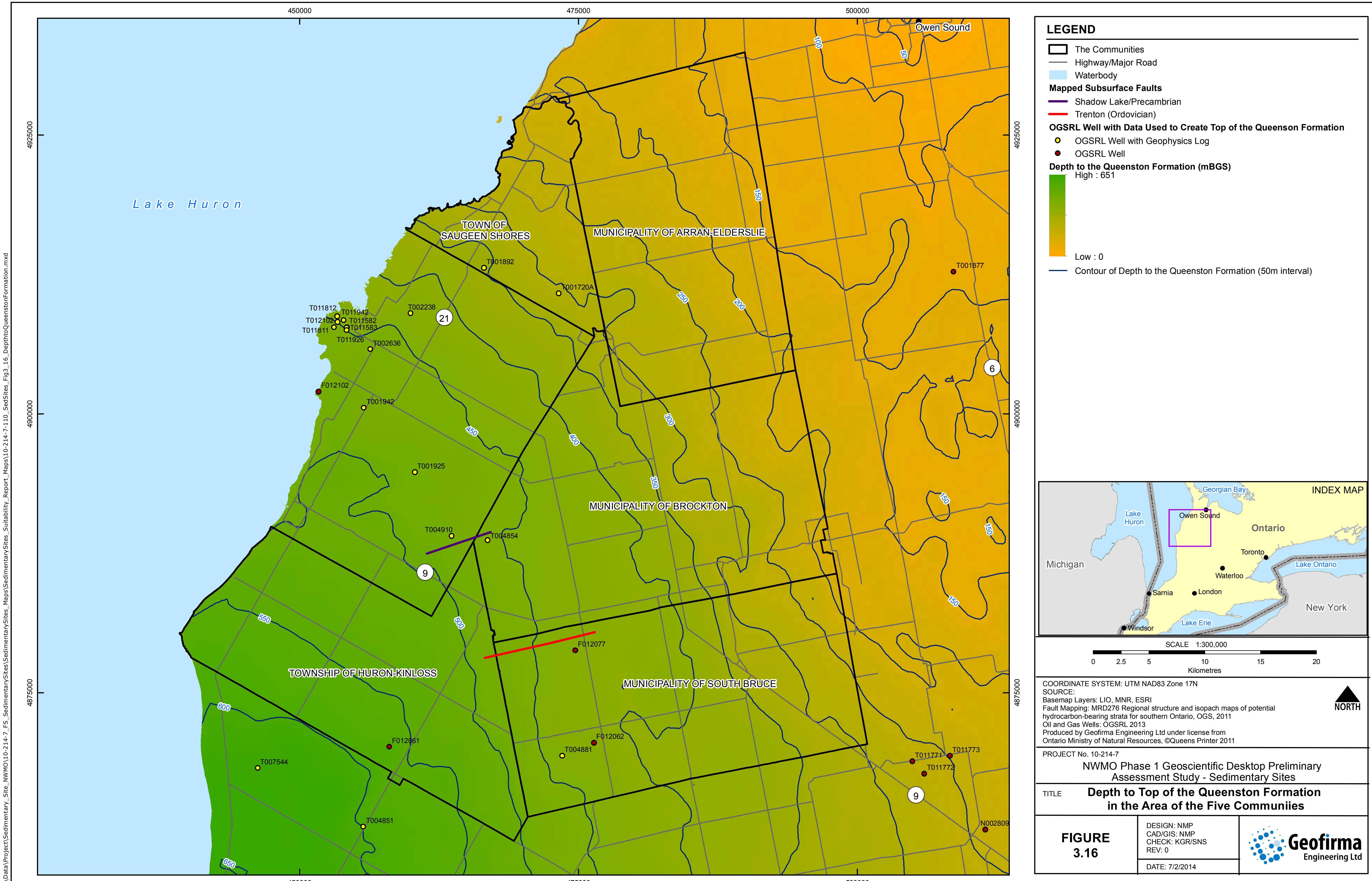

450000
475000
500000
4925000
4900000
4875000
Lake Huron
Owen Sound
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
MUNICIPALITY OF BROCKTON
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF SOUTH BRUCE
T001892
T001720A
T002238
T011812
T011942
T012102
T011582
T011811
T011583
T011926
T002636
F012102
T001942
T001925
T004910
T004854
F012077
F012061
T007544
T004881
F012062
T004851
T001877
T011771
T011773
T011772
N002809
21
6
9
100
50
150
250
200
300
400
450
350
500
550
600
650
LEGEND
The Communities
Highway/Major Road
Waterbody
Mapped Subsurface Faults
Shadow Lake/Precambrian
Trenton (Ordovician)
OGSRL Well with Data Used to Create Top of the Queenson Formation
OGSRL Well with Geophysics Log
OGSRL Well
Depth to the Queenston Formation (mBGS)
High : 651
Low : 0
Contour of Depth to the Queenston Formation (50m interval)
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Michigan
Toronto
Lake Ontario
Waterloo
Sarnia
London
New York
Lake Erie
Windsor
SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Fault Mapping: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
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NORTH
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites
TITLE
Depth to Top of the Queenston Formation in the Area of the Five Communiies
FIGURE 3.16
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 7/2/2014
Geofirma Engineering Ltd
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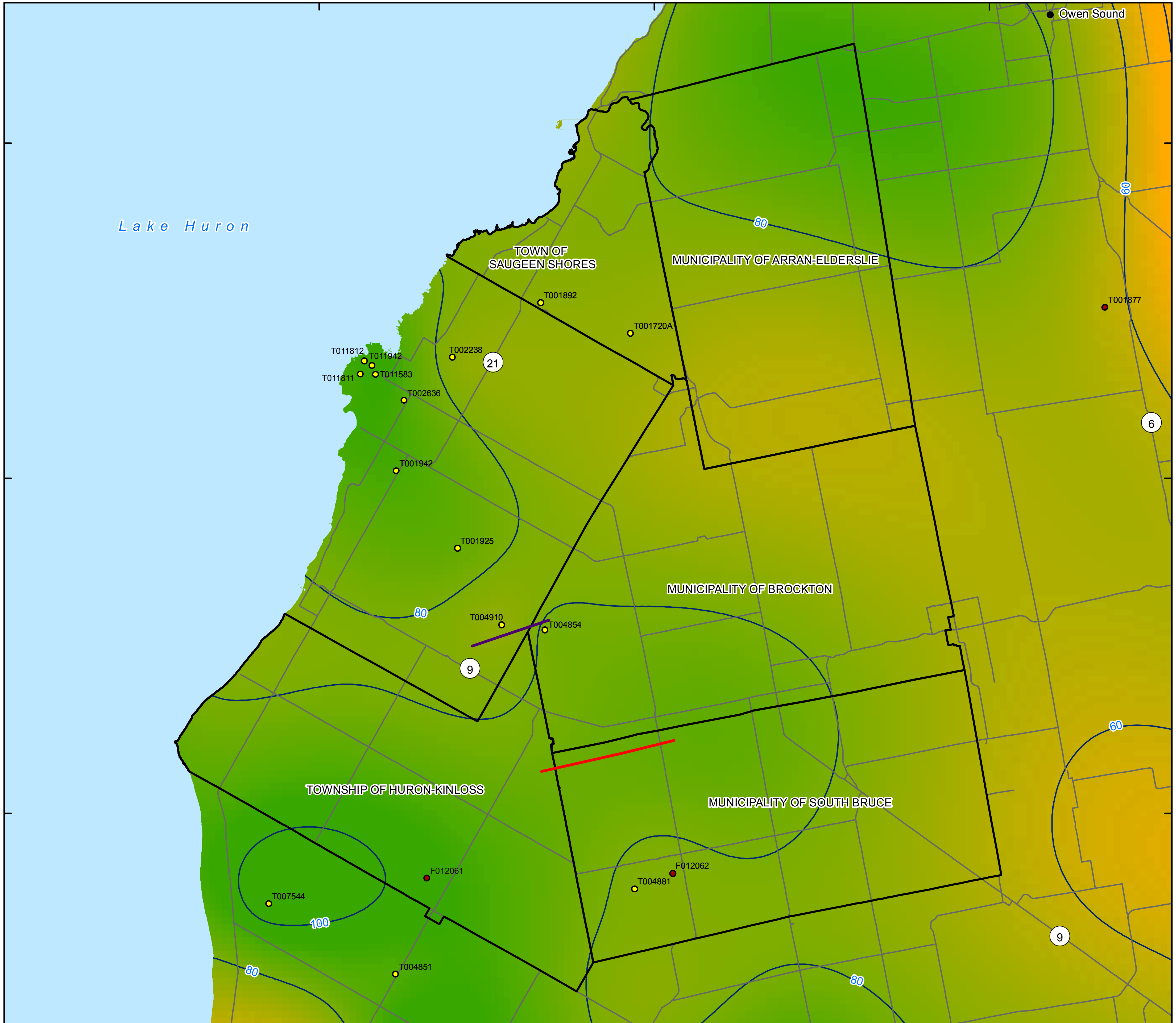

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

OGSRL Well with Data Used to Calculate Thickness of the Ordovician Black River Group

- OGSRL Well with Geophysics Log
- OGSRL Well

Black River Group Thickness (m)

116

33

- Contour of the Black River Group Thickness (20m interval)

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N

SOURCE:

Basemap Layers: LIO, MNR, ESRI

Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011

Oil and Gas Wells: OGSRL 2013

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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE **Thickness of the Ordovician Black River Group in the Area of the Five Communities**

FIGURE 3.17

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

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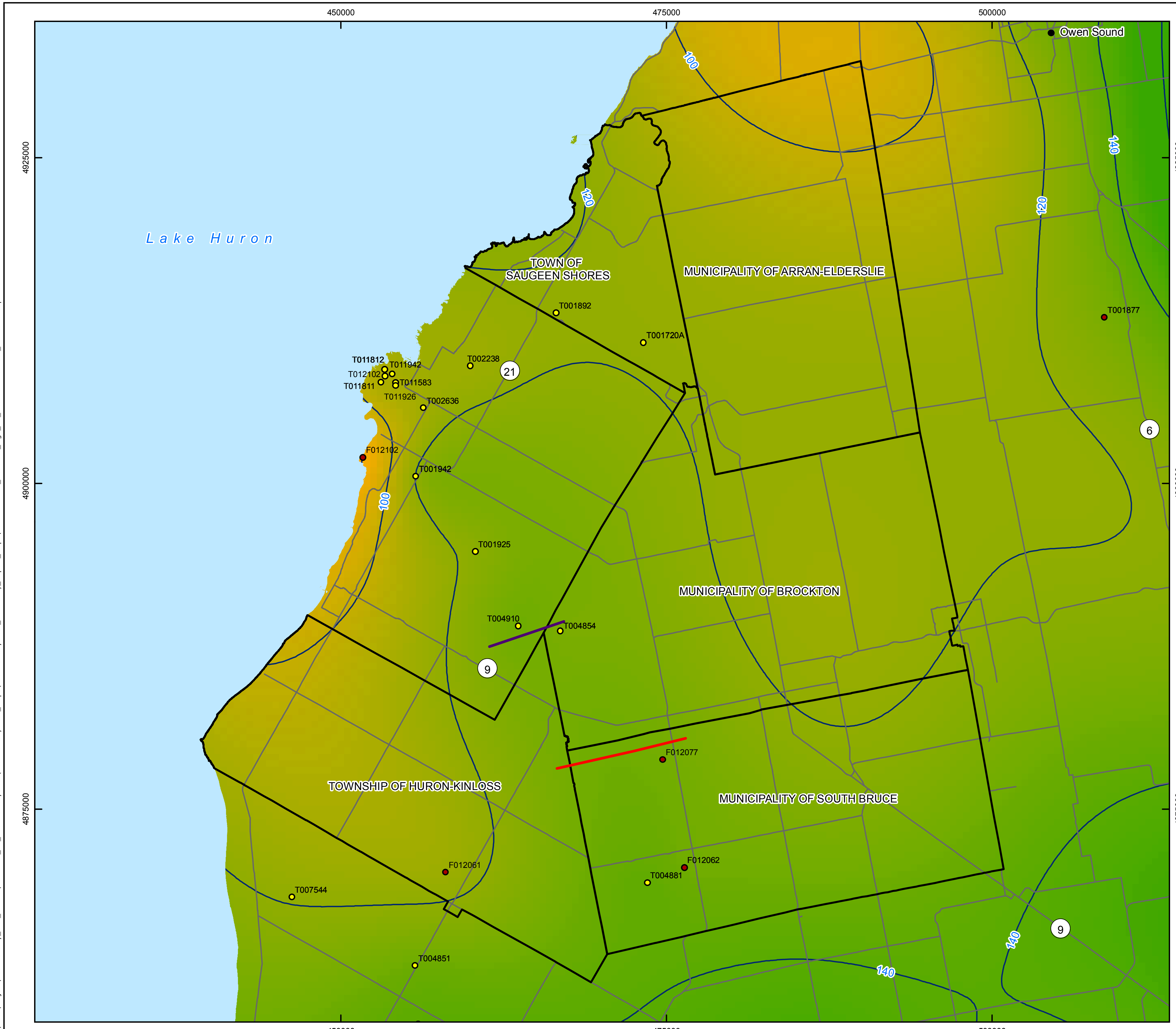

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

OGSRL Well with Data Used to Calculate Thickness of the Ordovician Trenton Group

- OGSRL Well with Geophysics Log
- OGSRL Well

Trenton Group Thickness (m)

162

76

- Contour of the Trenton Group Thickness (20m interval)

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

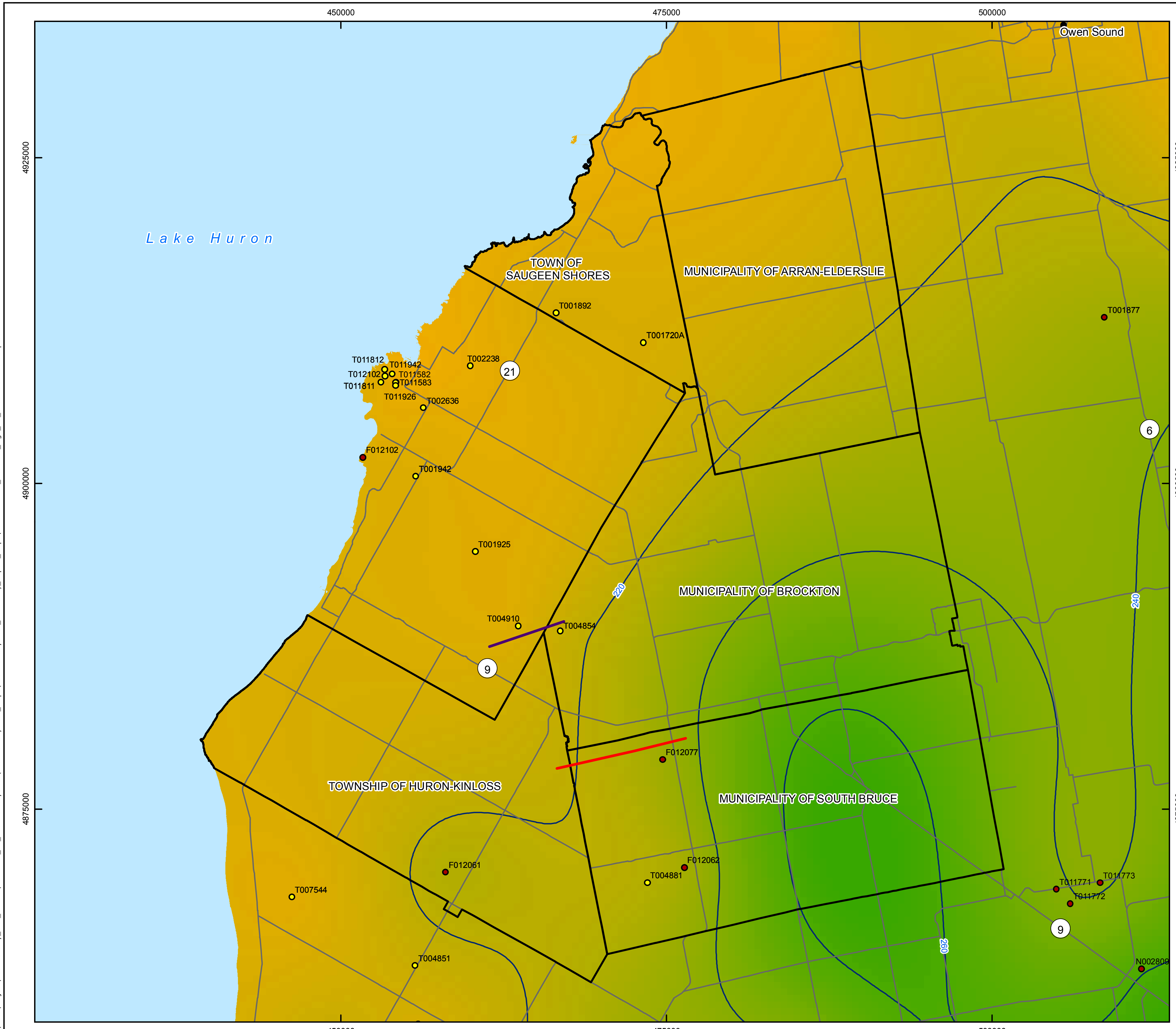
Thickness of the Ordovician Trenton Group in the Area of the Five Communities

FIGURE 3.18

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)

OGSRL Well with Data Used to Calculate Thickness of the Ordovician Shale Units

- OGSRL Well with Geophysics Log
- OGSRL Well

Ordovician Shale Thickness (m)

267

196

- Ordovician Shale Thickness Contour (20m interval)

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Oil and Gas Wells: OGSRL 2013
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE **Thickness of the Ordovician Shale Units in the Area of the Five Communities**

FIGURE 3.19

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

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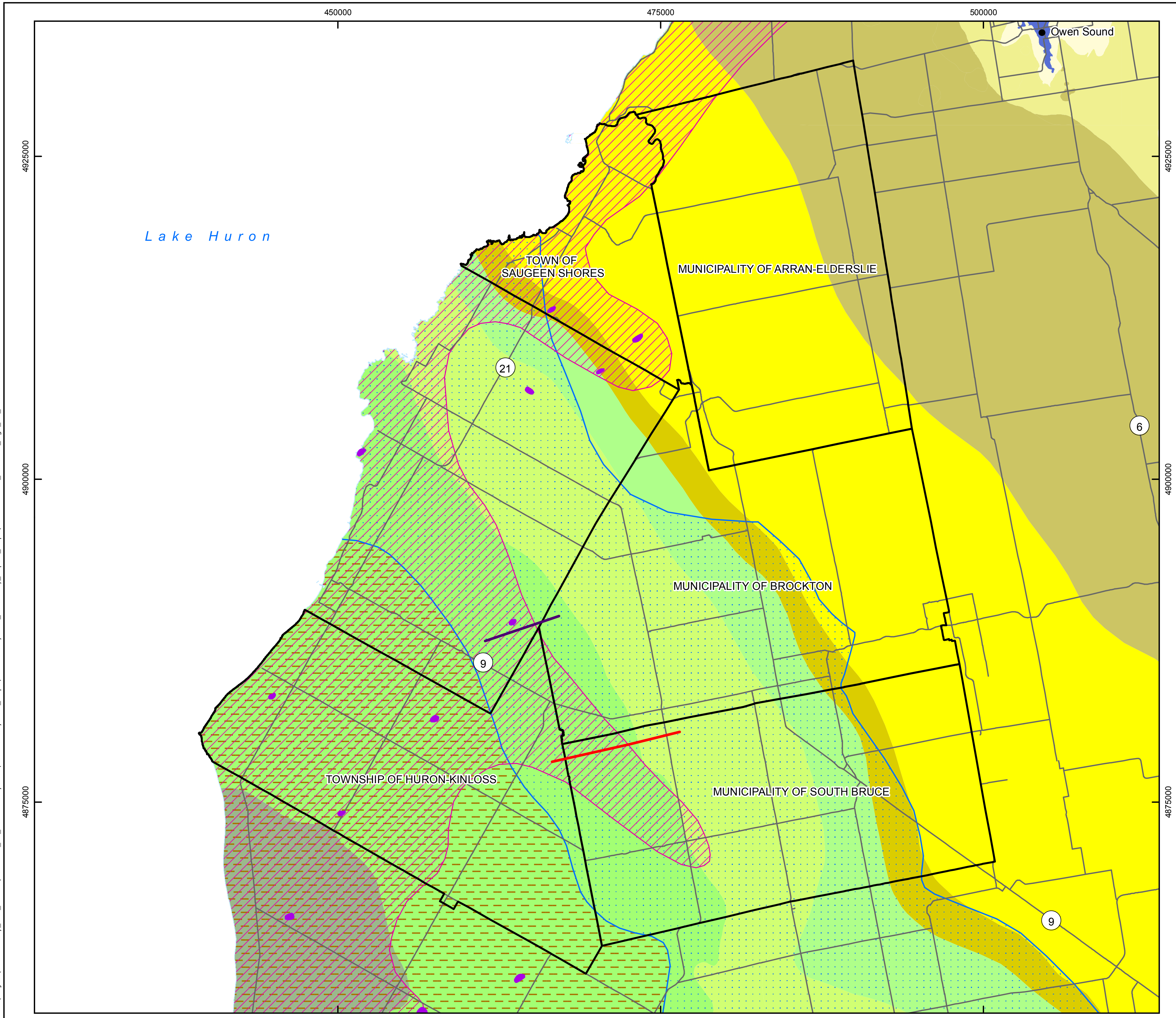

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

Mapped Subsurface Faults

- Shadow Lake/Precambrian
- Trenton (Ordovician)
- Area of Salt Occurrence
- Area of Salt Dissolution
- Cambrian Sandstone
- Pinnacle Reef

Bedrock Geology

Middle Devonian

- Dundee
- Lucas
- Amherstburg

Lower Devonian

- Bois Blanc

Upper Silurian

- Bass Islands
- Salina
- Guelph

Lower Silurian

- Amabel
- Clinton-Cataract Group

Upper Ordovician

- Queenston

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

NORTH

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Cambrian Sandstone: Bailey & Cochrane, 1990
Fault Mapping and Pinnacle Reefs: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Salt Occurrence & Salt Dissolution: Sanford, 1976
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PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Location of Pinnacle Reefs, Salt Occurrence and Dissolution, and Cambrian Sandstone in the Area of the Five Communities

FIGURE 3.20

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 6/26/2014

Geofirma Engineering Ltd

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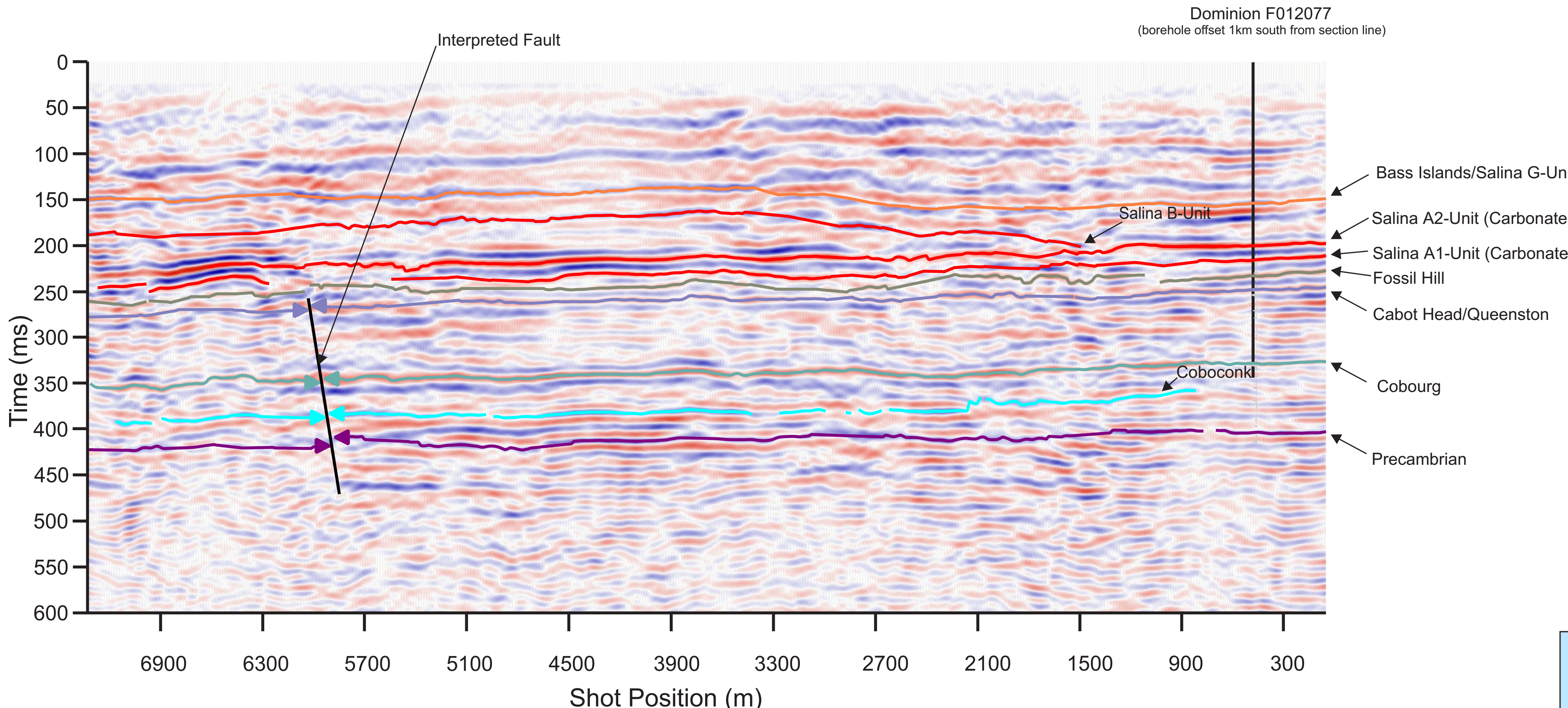
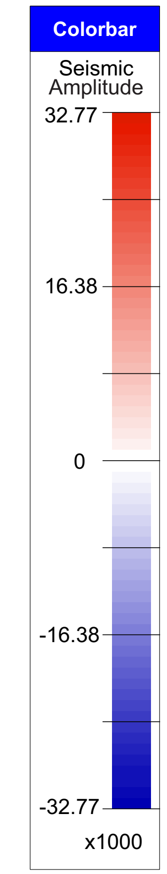
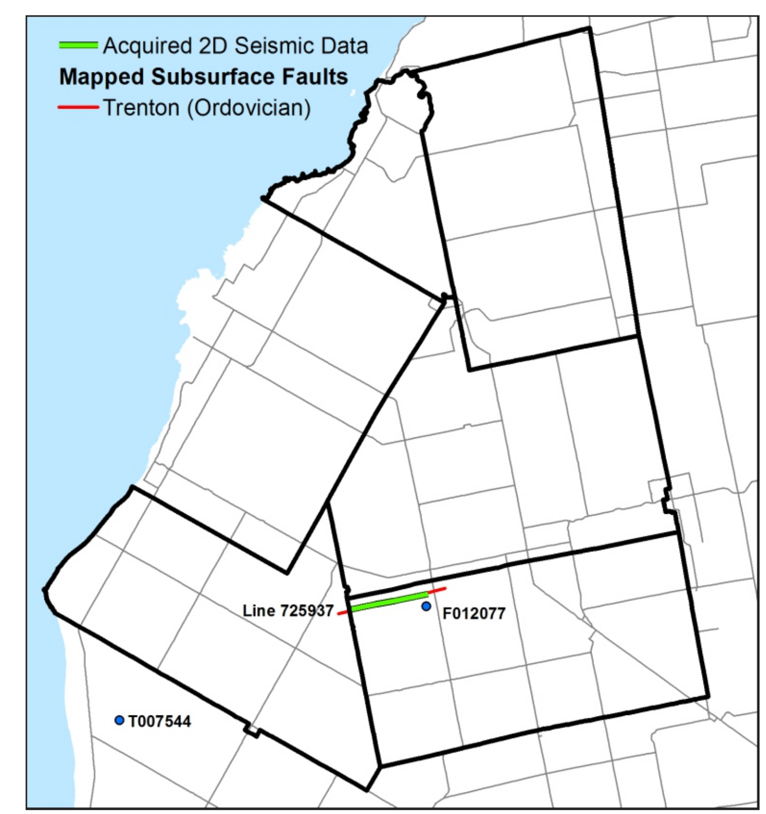






Geofirma Engineering Ltd

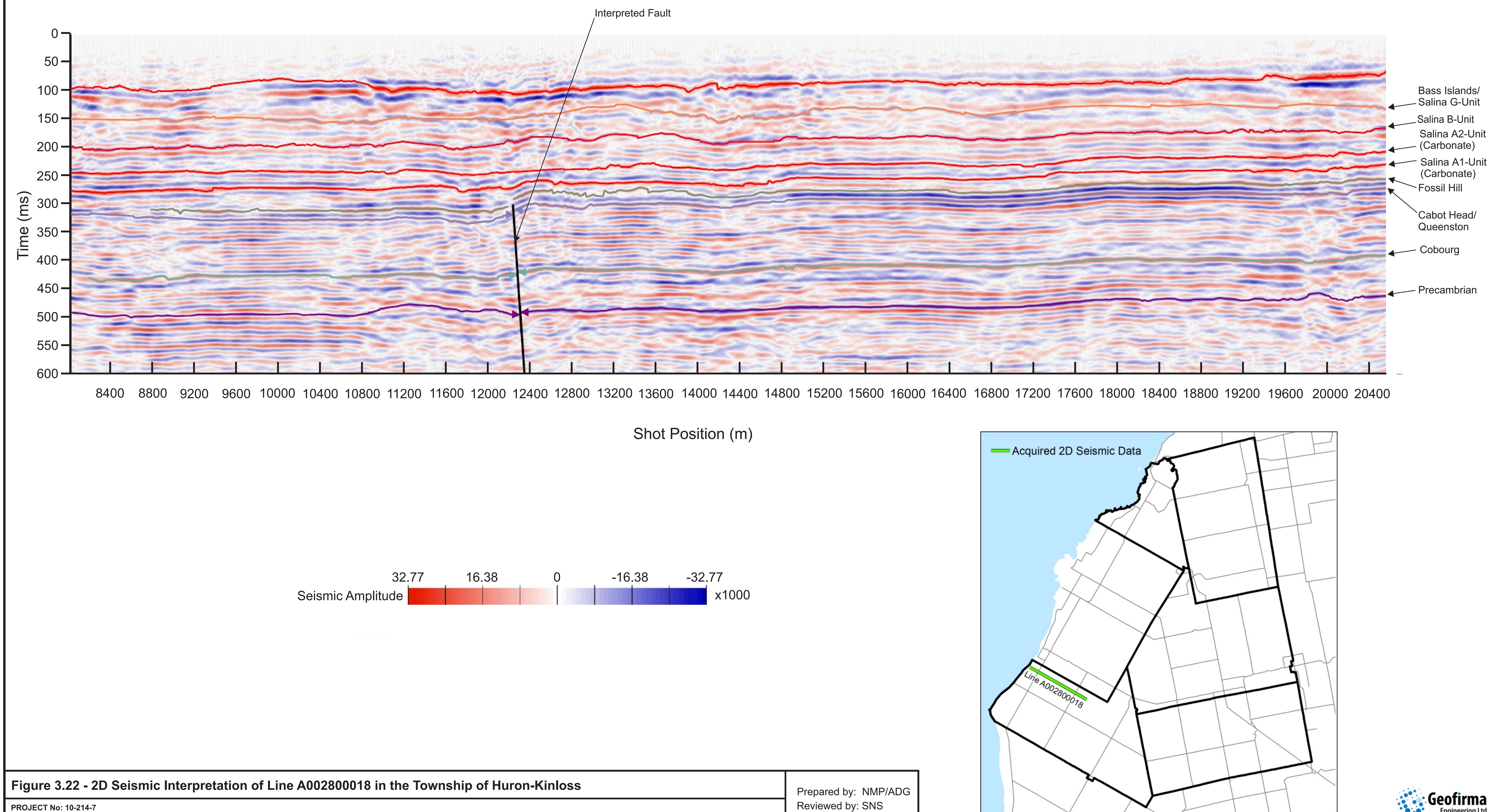
Figure 3.21 - 2D Seismic Interpretation of Line 725937 in the Municipality of South Bruce

PROJECT No: 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: SNS
Date: 26/06/2014

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig3_21_CrossSection_SeismicLine725937.cdr"



Geofirma Engineering Ltd

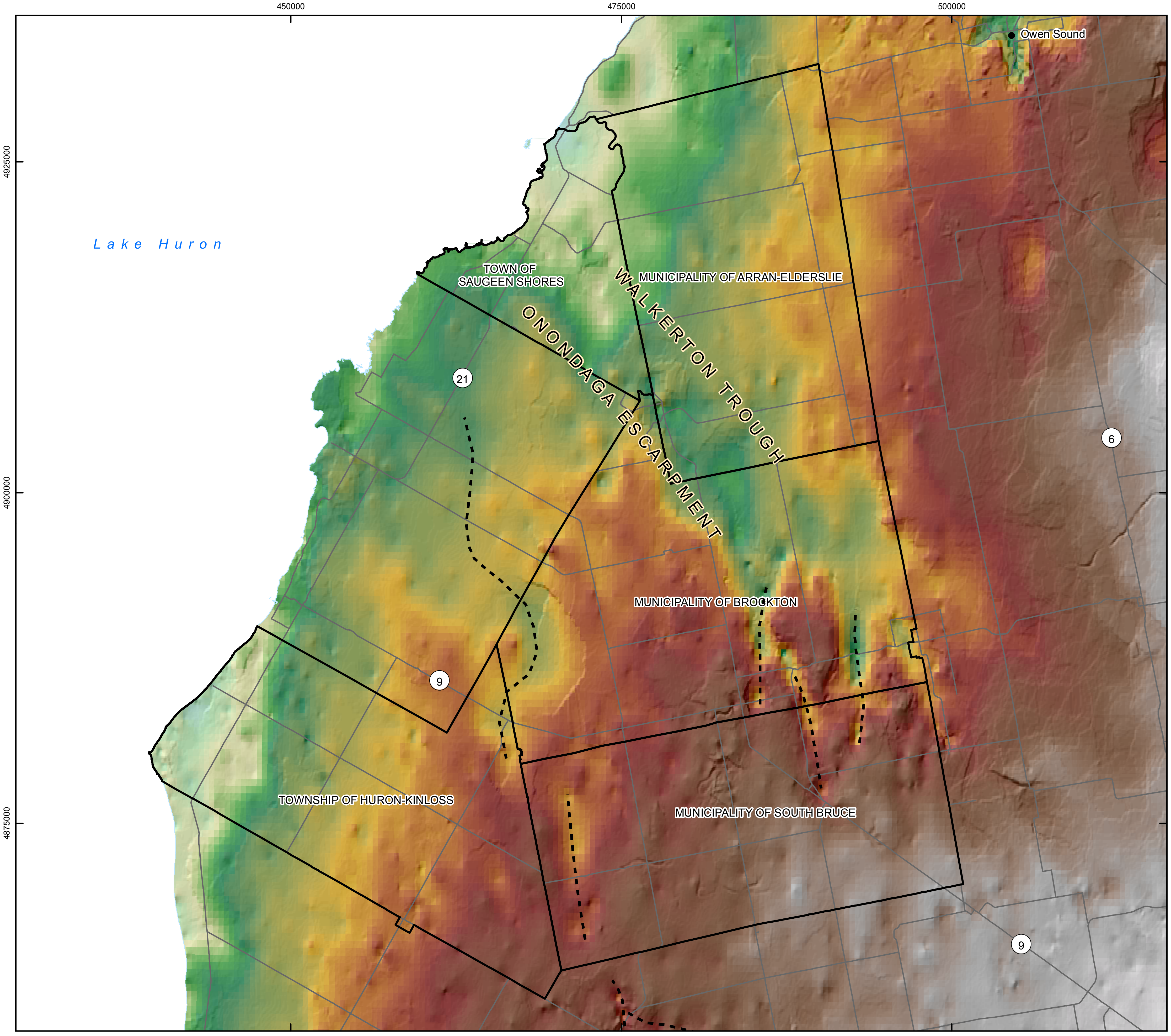
Figure 3.22 - 2D Seismic Interpretation of Line A002800018 in the Township of Huron-Kinloss

PROJECT No: 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: SNS
Date: 29/05/2014

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig3_22_CrossSection_SeismicLinesA002800018.cdr"



LEGEND

- The Communities
- Highway/Major Road
- Buried Bedrock Valley
- Waterbody

Bedrock Surface (mASL)

High : 397

Low : 95

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Buried Bedrock Valley: Gao, 2011a
Geology: MRD207 Bedrock Topography and Overburden Thickness Mapping, Southern Ontario, OGS, 2006
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Bedrock Surface Topography in the Area of the Five Communities

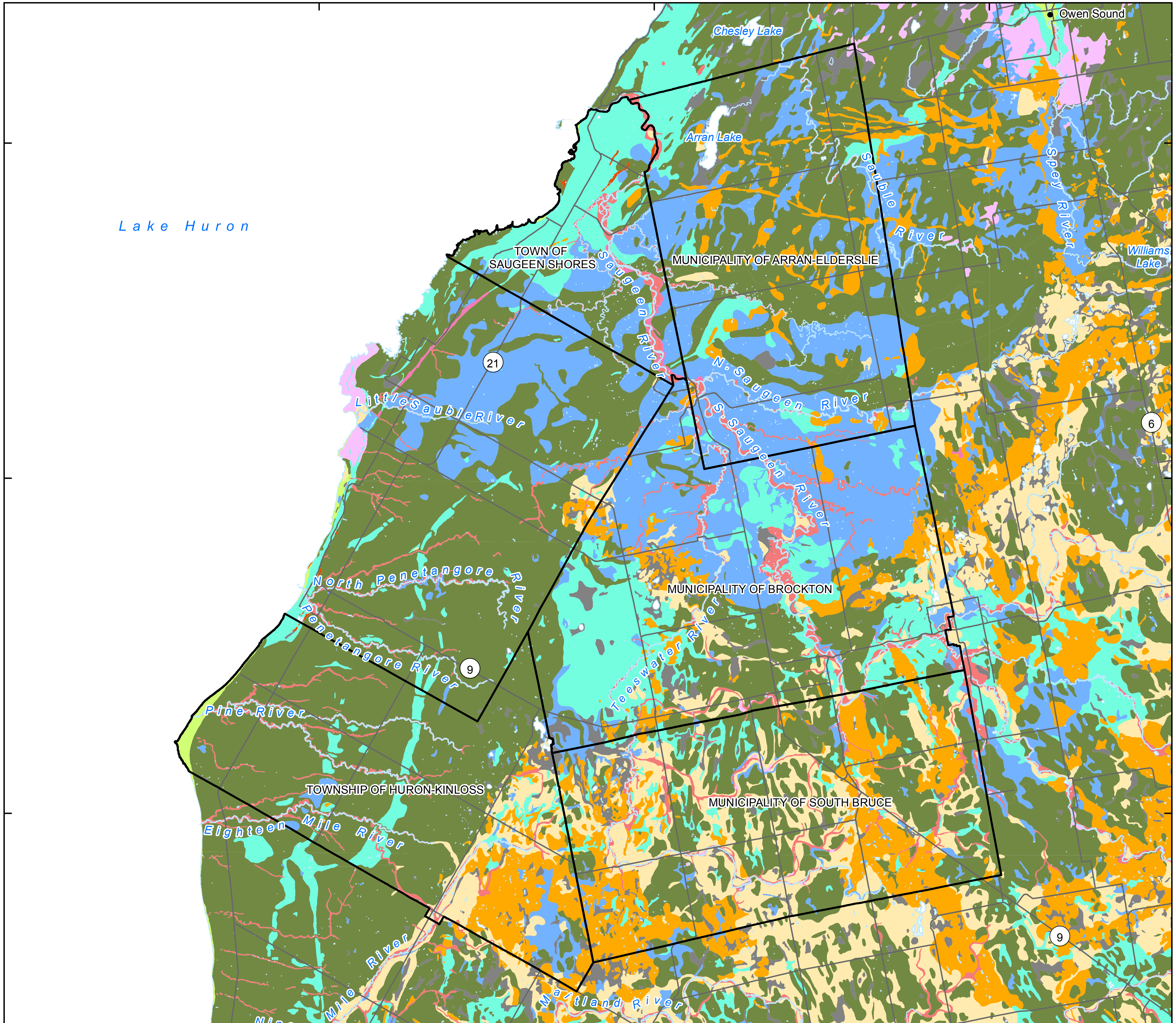
FIGURE 3.23

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 7/2/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig3_23_BedrockSurfaceTopography.mxd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse

Surficial Geology

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

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: OGS MRD128-REV Surficial Geology of Southern Ontario,1:50,000, 2010
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Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Surficial Geology of the Area of the Five Communities

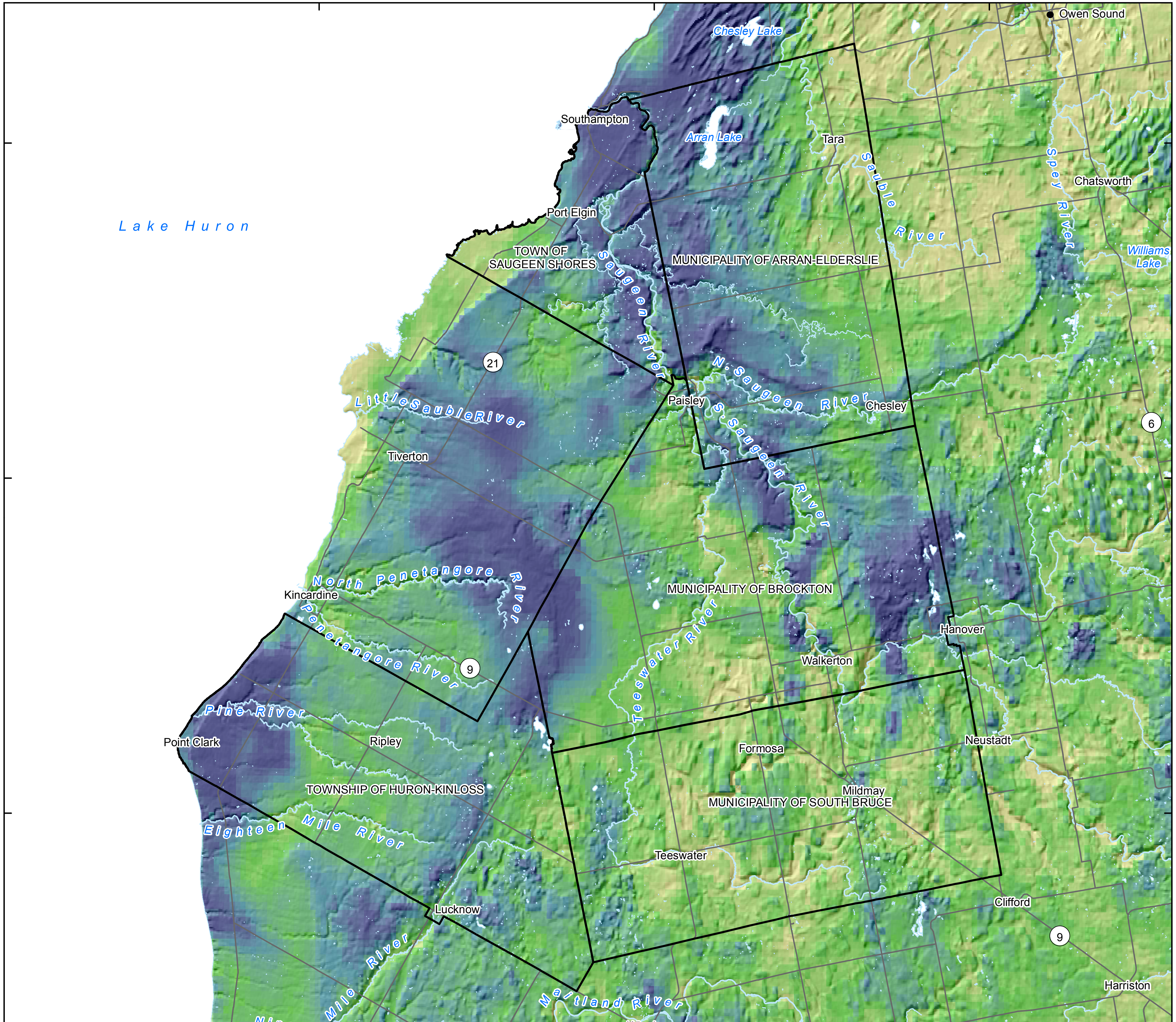
FIGURE 3.24

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 30/05/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig3_24_SurficialGeology_Community.mxd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse

Overburden Thickness (m)

High : 104

Low : 0

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: OGS MRD207 Bedrock topography and overburden thickness mapping, southern Ontario, 2006
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Overburden Thickness in the Area of the Five Communities

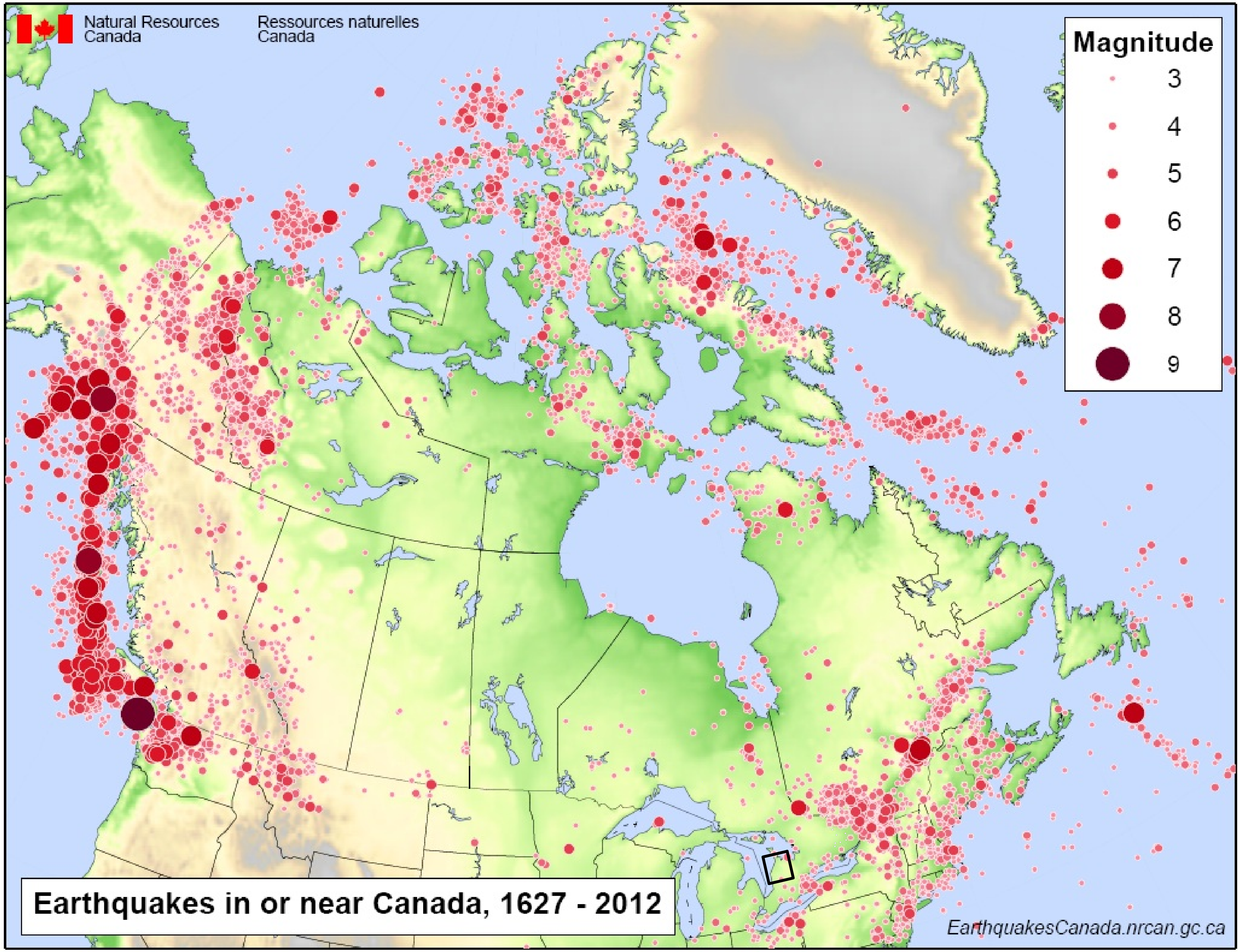
FIGURE 3.25

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 04/06/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig3_25_OBThickness_Community.mxd



LEGEND

Area of the Five Communities

COORDINATE SYSTEM: N/A
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Seismic: NRCAN. Earthquake Map of Canada 1627 -2012
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Ontario Ministry of Natural Resources, ©Queens Printer 2011

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PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Earthquakes Map of Canada 1627-2012

FIGURE 3.26

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 30/05/2014

Geofirma Engineering Ltd

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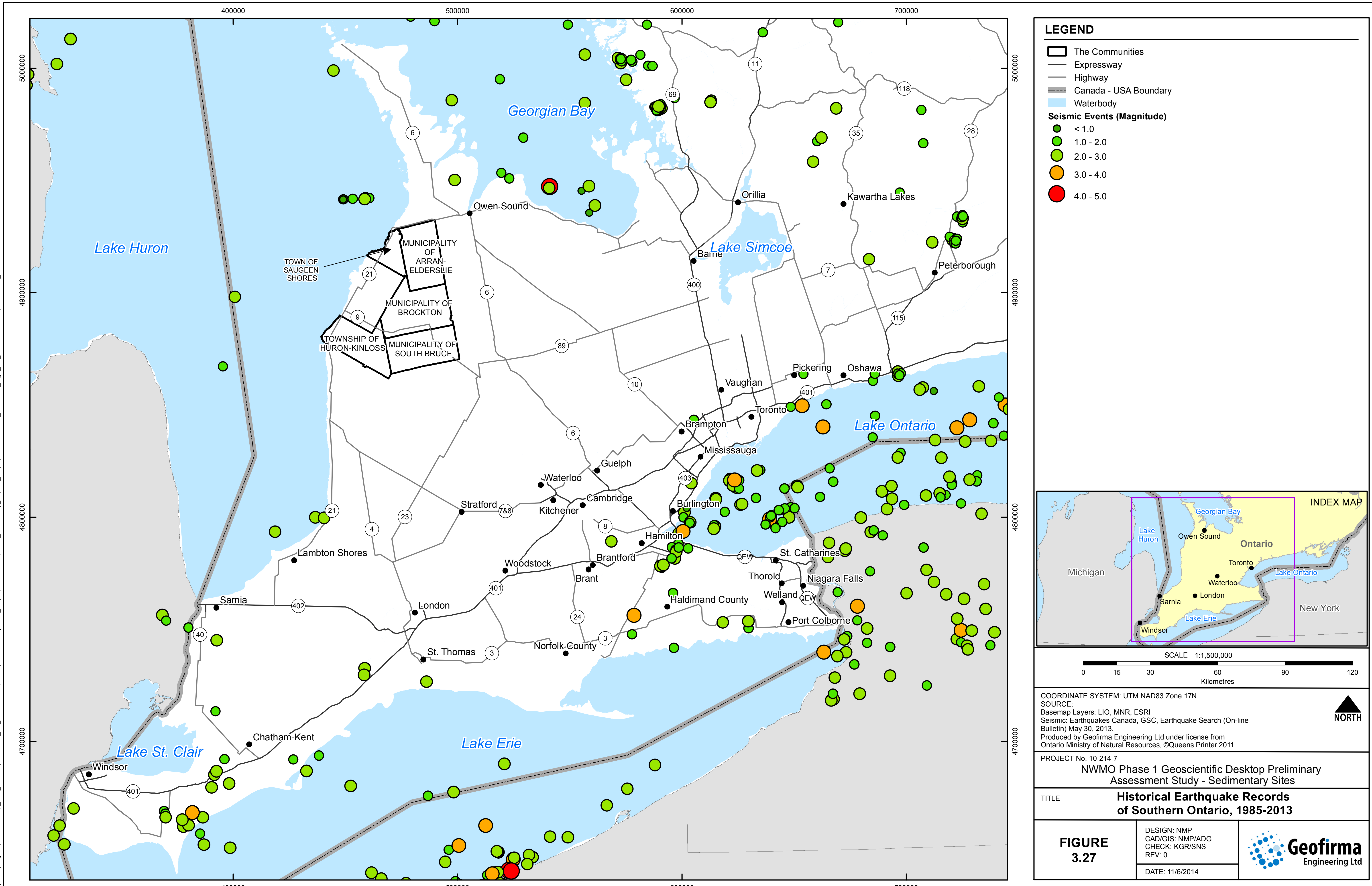
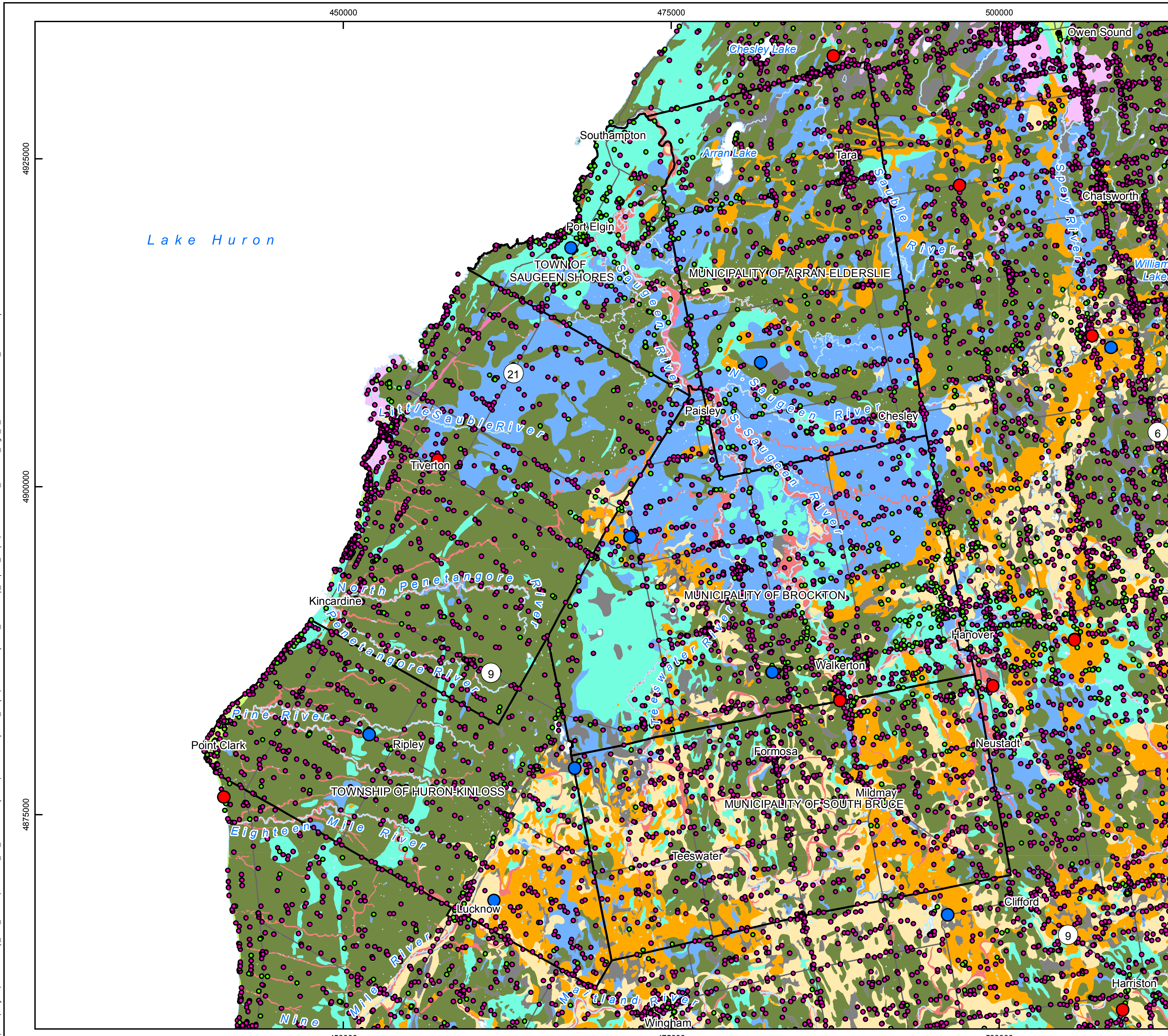

LEGEND
The Communities
Expressway
Highway
Canada - USA Boundary
Waterbody
Seismic Events (Magnitude)
< 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Michigan
Toronto
Lake Ontario
Waterloo
London
Sarnia
Lake Erie
Windsor
New York
SCALE 1:1,500,000
0 15 30 60 90 120
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Seismic: Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin) May 30, 2013.
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites
TITLE
Historical Earthquake Records of Southern Ontario, 1985-2013
FIGURE 3.27
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 11/6/2014
Geofirma Engineering Ltd
Georgian Bay
Lake Huron
Lake Simcoe
Lake Ontario
Lake Erie
Lake St. Clair
Owen Sound
Orillia
Kawartha Lakes
Barrie
Peterborough
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
MUNICIPALITY OF BROCKTON
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF SOUTH BRUCE
Pickering
Oshawa
Vaughan
Toronto
Brampton
Mississauga
Guelph
Waterloo
Cambridge
Kitchener
Stratford
Burlington
Hamilton
Lambton Shores
Woodstock
Brantford
Brant
St. Catharines
Thorold
Niagara Falls
Welland
Haldimand County
Port Colborne
Sarnia
London
St. Thomas
Norfolk County
Chatham-Kent
Windsor
400000
500000
600000
700000
5000000
4900000
4800000
4700000
G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig3_27_HistoricalEarthquake1985_2013.mxd



LEGEND

The Communities
Highway/Major Road
Waterbody
Watercourse

PGMN Wells
- Bedrock
- Overburden

MOE Water Wells
- Bedrock
- Overburden

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

SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: OGS MRD128 Surficial Geology of Southern Ontario,1:50,000, 2003
Groundwater Wells: Water Wells Information System, MOE, 2013
PGMN Wells: MOE, 2013
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NORTH

PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

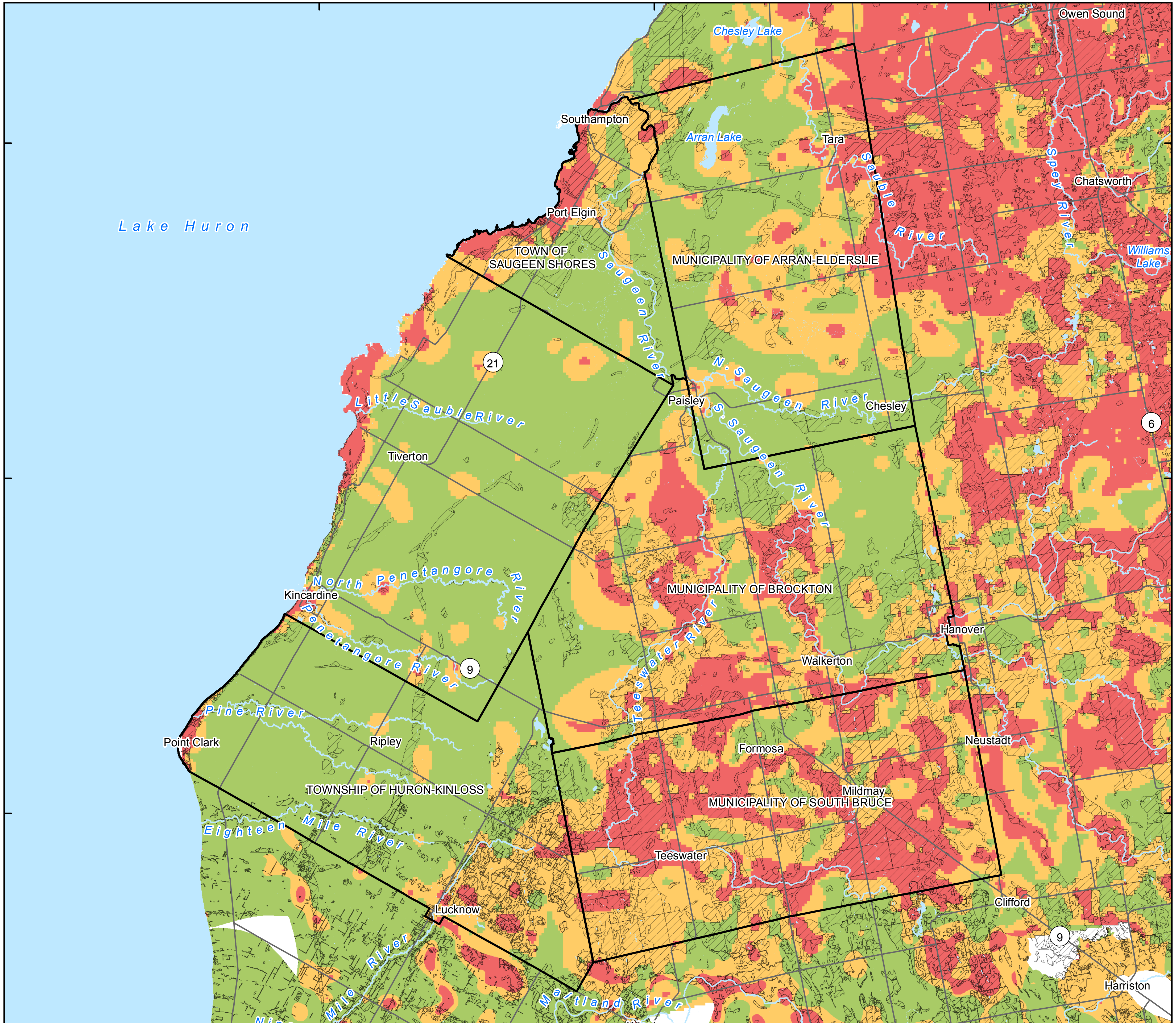
TITLE
Groundwater Wells within the Area of the Five Communities

FIGURE 4.1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 04/06/2014

Geofirma Engineering Ltd



LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse
- Significant Groundwater Recharge Area

Intrinsic Susceptibility Index

- High
- Medium
- Low

Note: Areas without Intrinsic Susceptibility Index results are Well Head Protection Areas. Aquifer Vulnerability for these areas was calculated separately by Ausable Bayfield Maitland Valley Source Water Protection Region.

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO MNR
ISI & SGRA: Source Water Protection Conservation Authorities, 2013
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NORTH

PROJECT No. 10-214-7

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Aquifer Vulnerability and Significant Groundwater Recharge Areas in the Area of the Five Communities

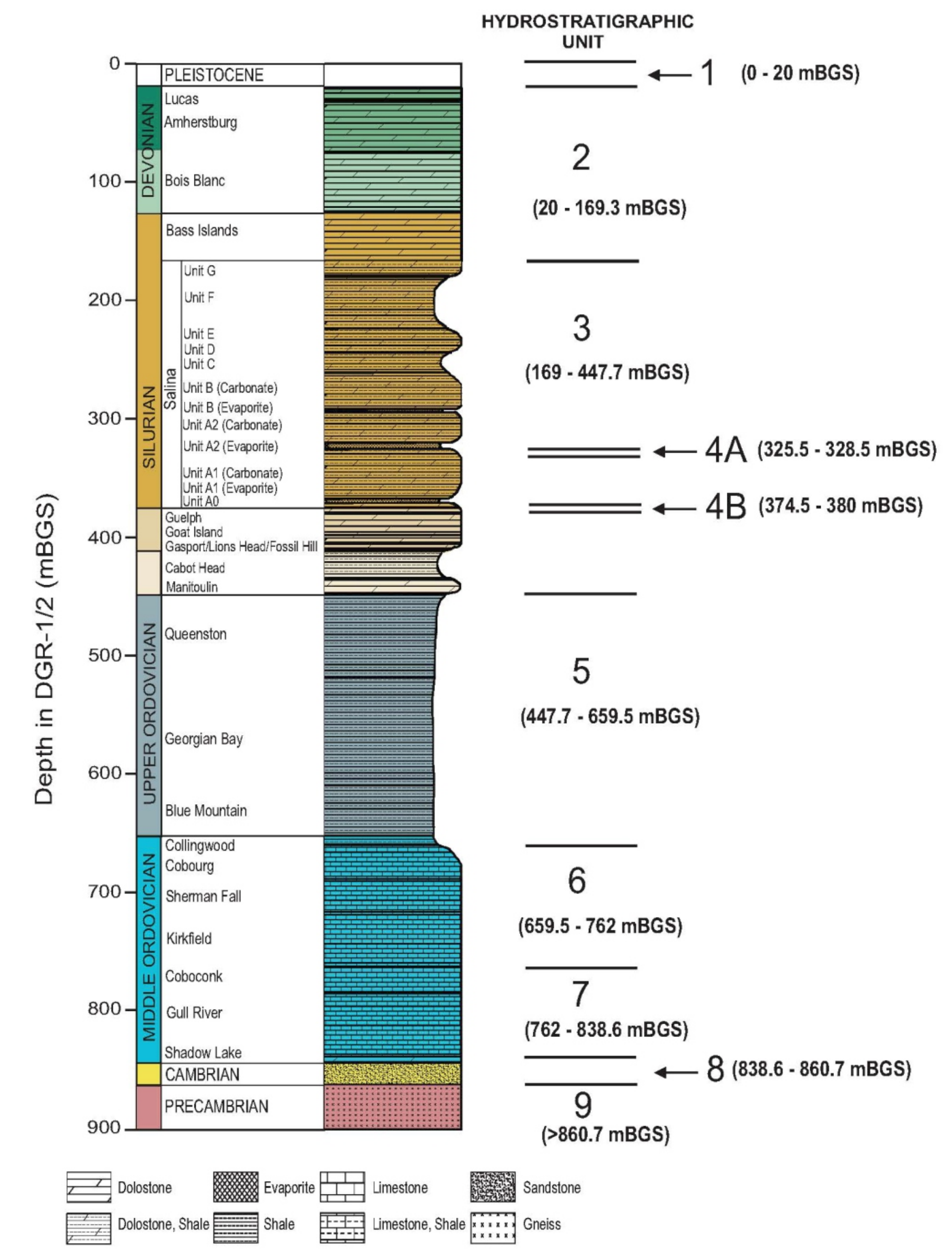
FIGURE 4.2

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/DJH
REV: 0

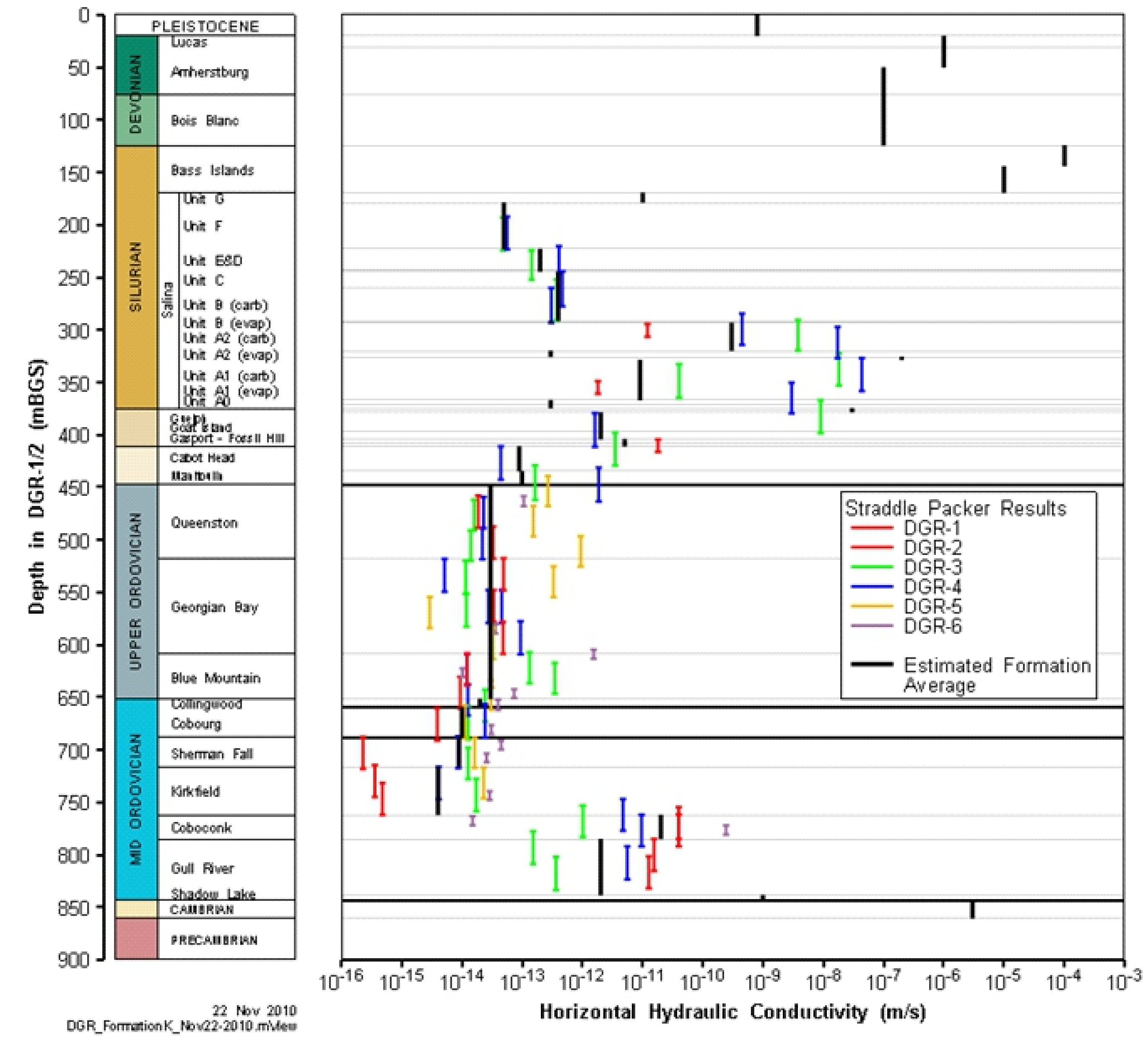
DATE: 04/06/2014

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-7_FS_SedimentarySites\SedimentarySites_Maps\SedimentarySites_Suitability_Report_Maps\10-214-7-110_SedSites_Fig4_2_AquiferVulnerability_SGRA_Community.mxd



a. Reference Stratigraphic Column and Hydrostratigraphic Units
(after Intera Engineering Ltd., 2011)

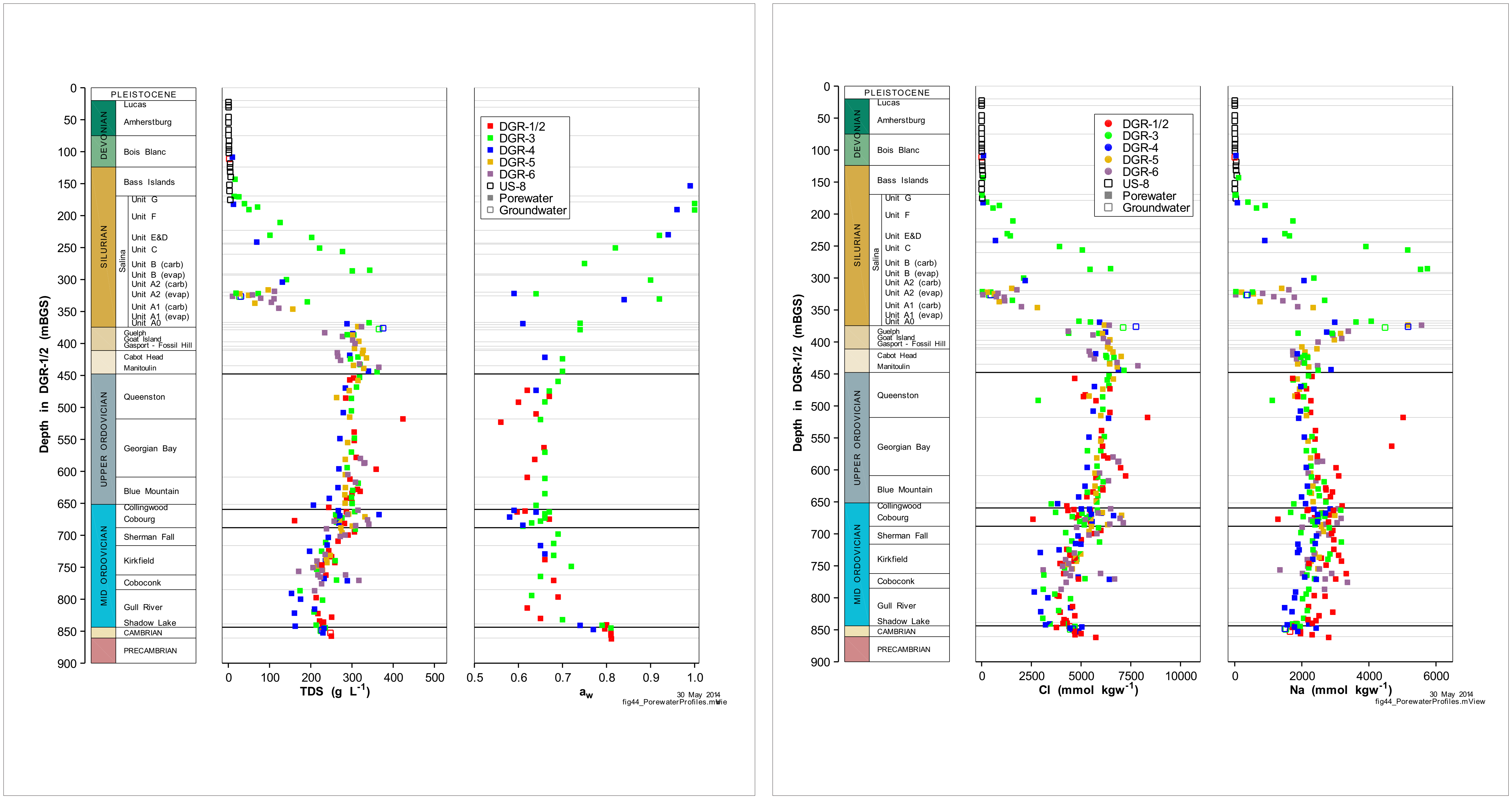


b. Results of Straddle-Packer Hydraulic Testing
(after Walsh, 2011)

FIGURE 4.3 - Hydrostratigraphic Units and Results of Hydraulic Testing at the Bruce Nuclear Site	Prepared by: ECK Reviewed by: KGR/SNS Date: 27/06/2014
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites	

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig4_3_HydraulicTestingResults_R0B.cdr"



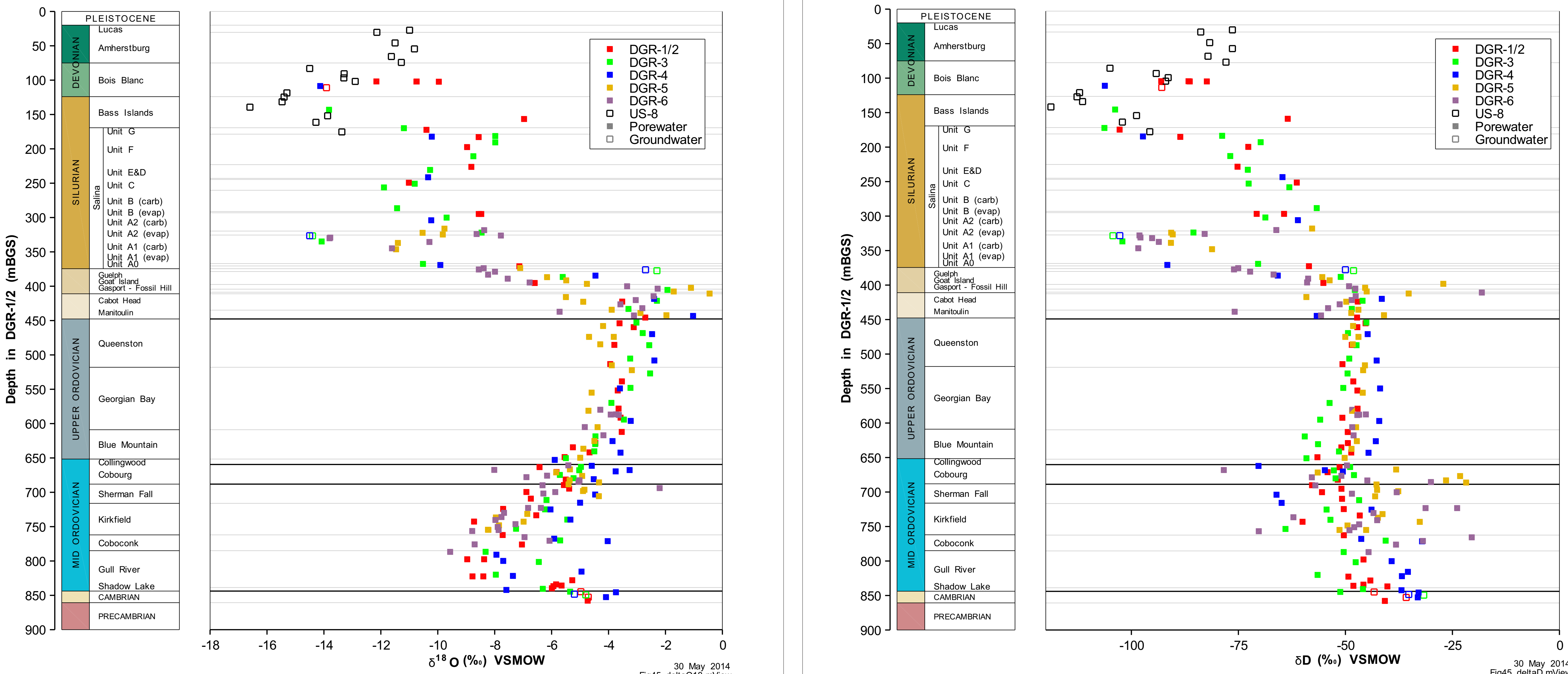
a. Total Dissolved Solids and Water Activity
(after Intera Engineering Ltd., 2011)

b. Chloride and Sodium
(after Intera Engineering Ltd., 2011)

FIGURE 4.4 - Profiles of Major Ion Chemistry of Porewater and Groundwater at the Bruce Nuclear Site	Prepared by: ADG Reviewed by: KGR/SNS
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites	Date: 13/02/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig4_4_ProfilesMajIonChem_R0B.cdr"



a. Oxygen-18
(after Intera Engineering Ltd., 2011)

b. Deuterium
(after Intera Engineering Ltd., 2011)

FIGURE 4.5 - Profiles of Environmental Isotopes in Porewater and Groundwater at the Bruce Nuclear Site

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

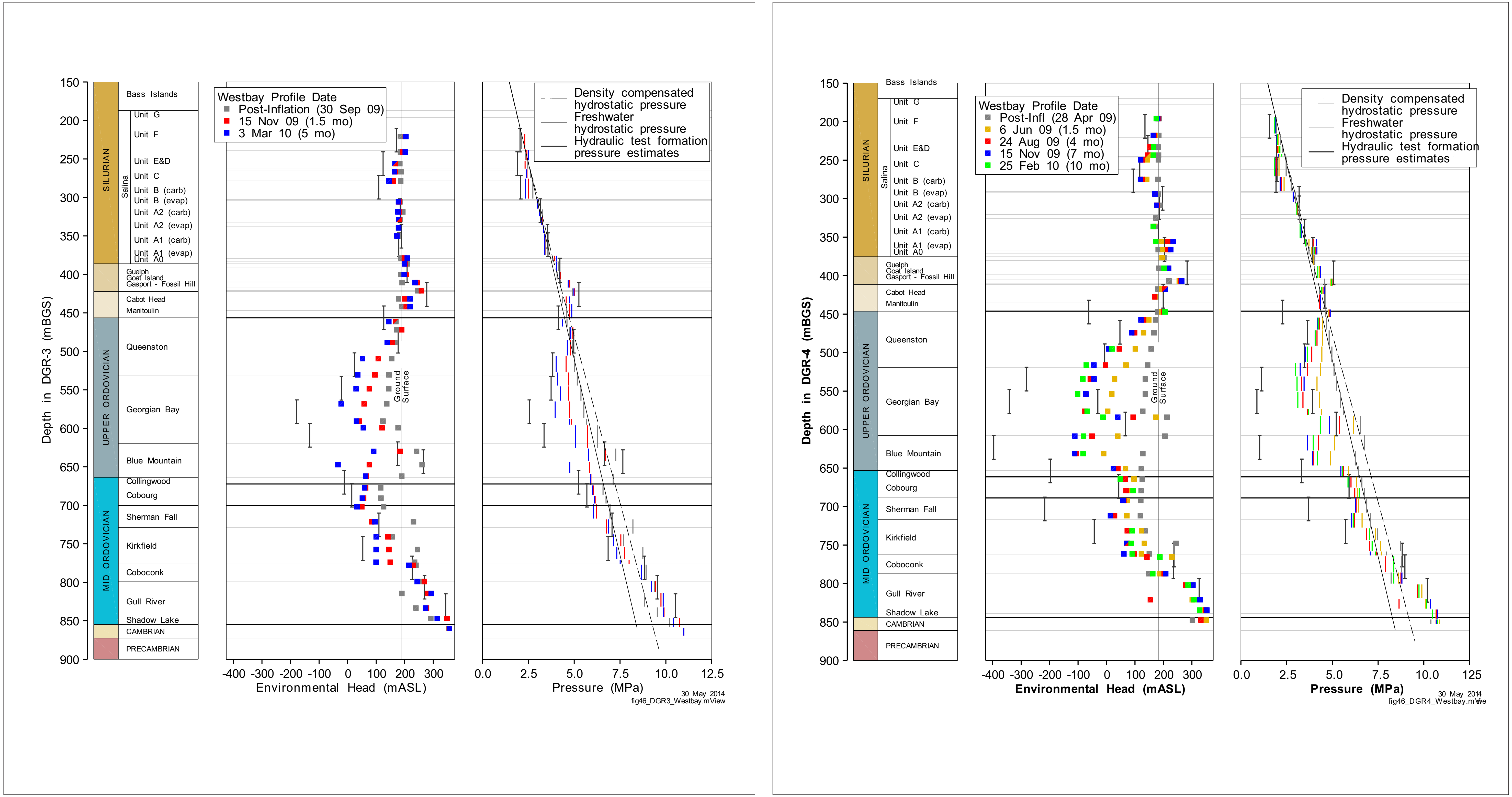
Prepared by: ADG

Reviewed by: KGR/SNS

Date: 14/02/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig4_5_ProfilesEnvIsotopes_R0B.cdr"



a. DGR-3
(after Intera Engineering Ltd., 2011)

b. DGR-4
(after Intera Engineering Ltd., 2011)

FIGURE 4.6 - Profiles of Formation Pressures and Environmental Heads in Deep Boreholes at the Bruce Nuclear Site	Prepared by: ADG Reviewed by: KGR/SNS
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites	Date: 14/02/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig4_6_ProfilesFormPres_EnvHead.cdr"

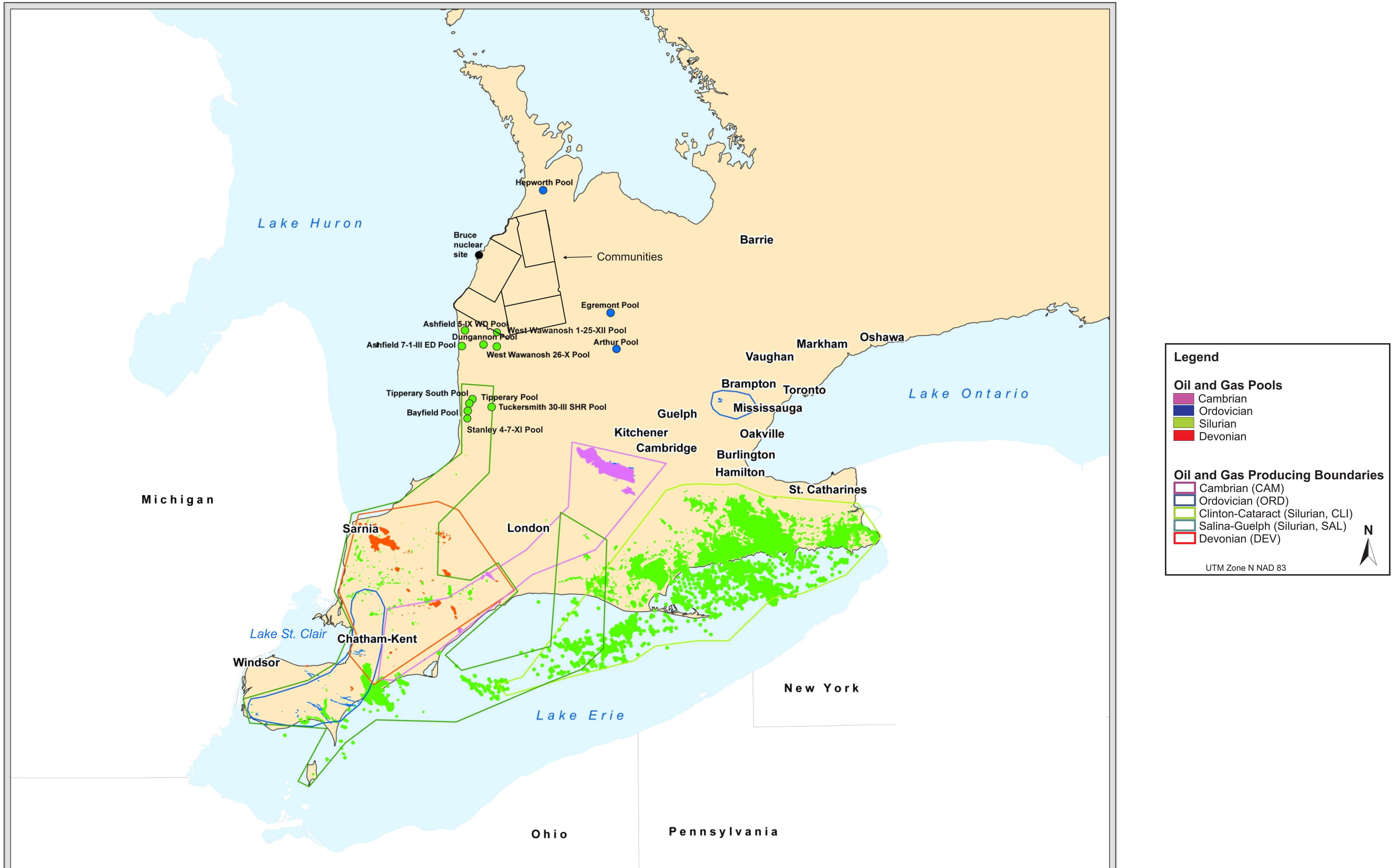


FIGURE 5.1 - Principal Oil and Natural Gas Producing Regions and Storage Pools in Southern Ontario

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: ECK

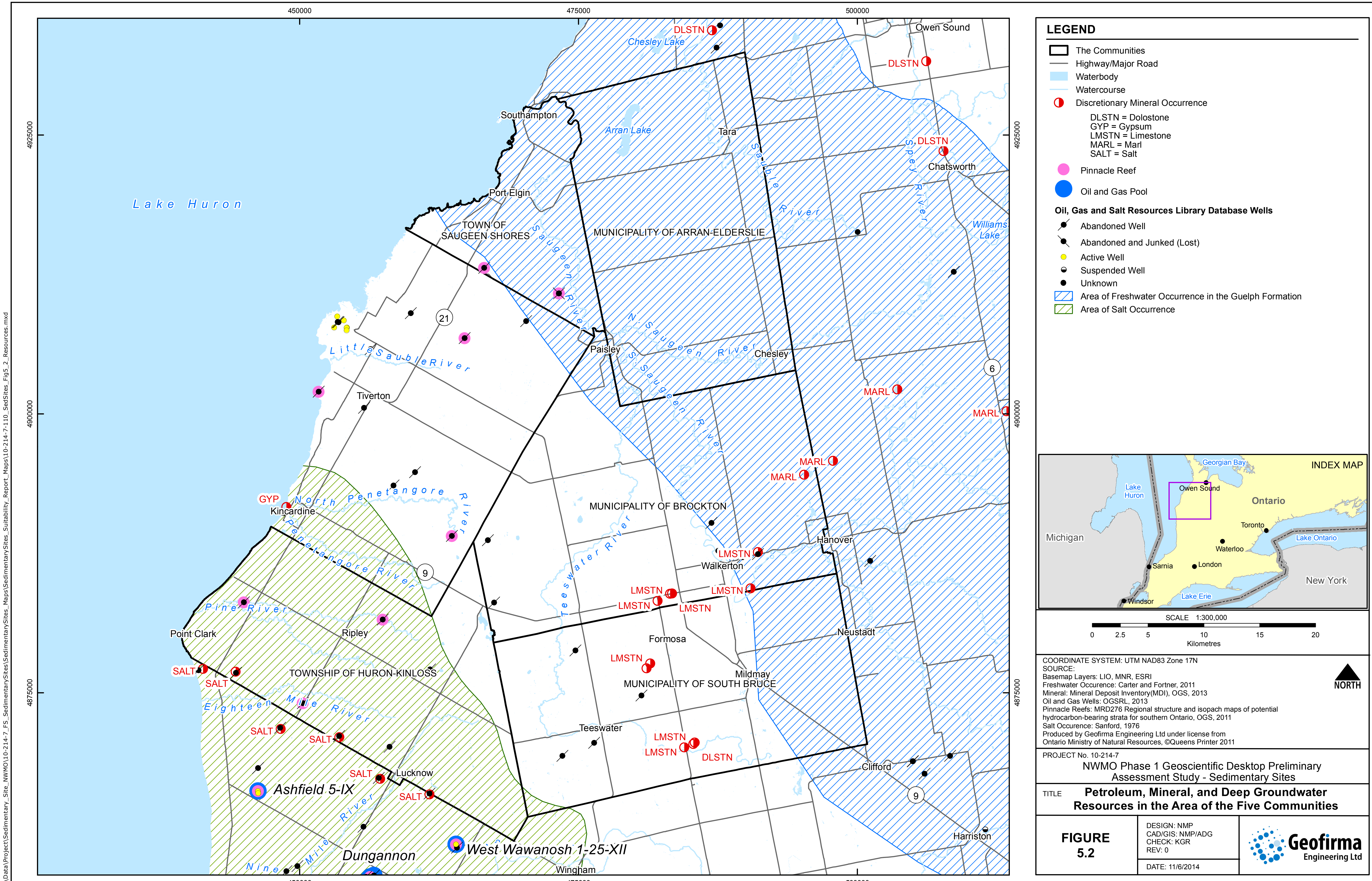
Reviewed by: KGR/SNS

Date: 13/02/2014

Notes: Base map is from Ontario Ministry of Natural Resources Pool data supplied by the Oil. Gas and Salt Resources Library and the Ontario Ministry of Natural Resources. All pool boundaries are accurate as of October 2012. Pool boundaries are interpretive and approximate. Dots represent pools which have boundaries too small to see on figure. Production boundaries are modified from Carter (1990).

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig5_1_OilGasRegions_R0B.cdr"



Lake Huron
Southampton
Port Elgin
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
Arran Lake
Tara
Chesley Lake
Owen Sound
Chatsworth
Williams Lake
Paisley
Chesley
Tiverton
Kincardine
Point Clark
Ripley
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF BROCKTON
Hanover
Walkerton
Neustadt
Formosa
Mildmay
MUNICIPALITY OF SOUTH BRUCE
Teeswater
Lucknow
Clifford
Harriston
Wingham
Dungannon
Ashfield 5-IX
West Wawanosh 1-25-XII
Saugeen River
N. Saugeen River
S. Saugeen River
Sauble River
Spey River
Little Sauble River
North Penetangore River
Penetangore River
Teeswater River
Pine River
Eighteen Mile River
Nine Mile River
DLSTN
GYP
LMSTN
MARL
SALT
21
9
6
450000
475000
500000
4925000
4900000
4875000
LEGEND
The Communities
Highway/Major Road
Waterbody
Watercourse
Discretionary Mineral Occurrence
DLSTN = Dolostone
GYP = Gypsum
LMSTN = Limestone
MARL = Marl
SALT = Salt
Pinnacle Reef
Oil and Gas Pool
Oil, Gas and Salt Resources Library Database Wells
Abandoned Well
Abandoned and Junked (Lost)
Active Well
Suspended Well
Unknown
Area of Freshwater Occurrence in the Guelph Formation
Area of Salt Occurrence
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Michigan
Toronto
Lake Ontario
Waterloo
Sarnia
London
New York
Windsor
Lake Erie
SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Freshwater Occurence: Carter and Fortner, 2011
Mineral: Mineral Deposit Inventory(MDI), OGS, 2013
Oil and Gas Wells: OGSRL, 2013
Pinnacle Reefs: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Salt Occurence: Sanford, 1976
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-7
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites
TITLE
Petroleum, Mineral, and Deep Groundwater Resources in the Area of the Five Communities
FIGURE 5.2
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR
REV: 0
DATE: 11/6/2014
Geofirma Engineering Ltd
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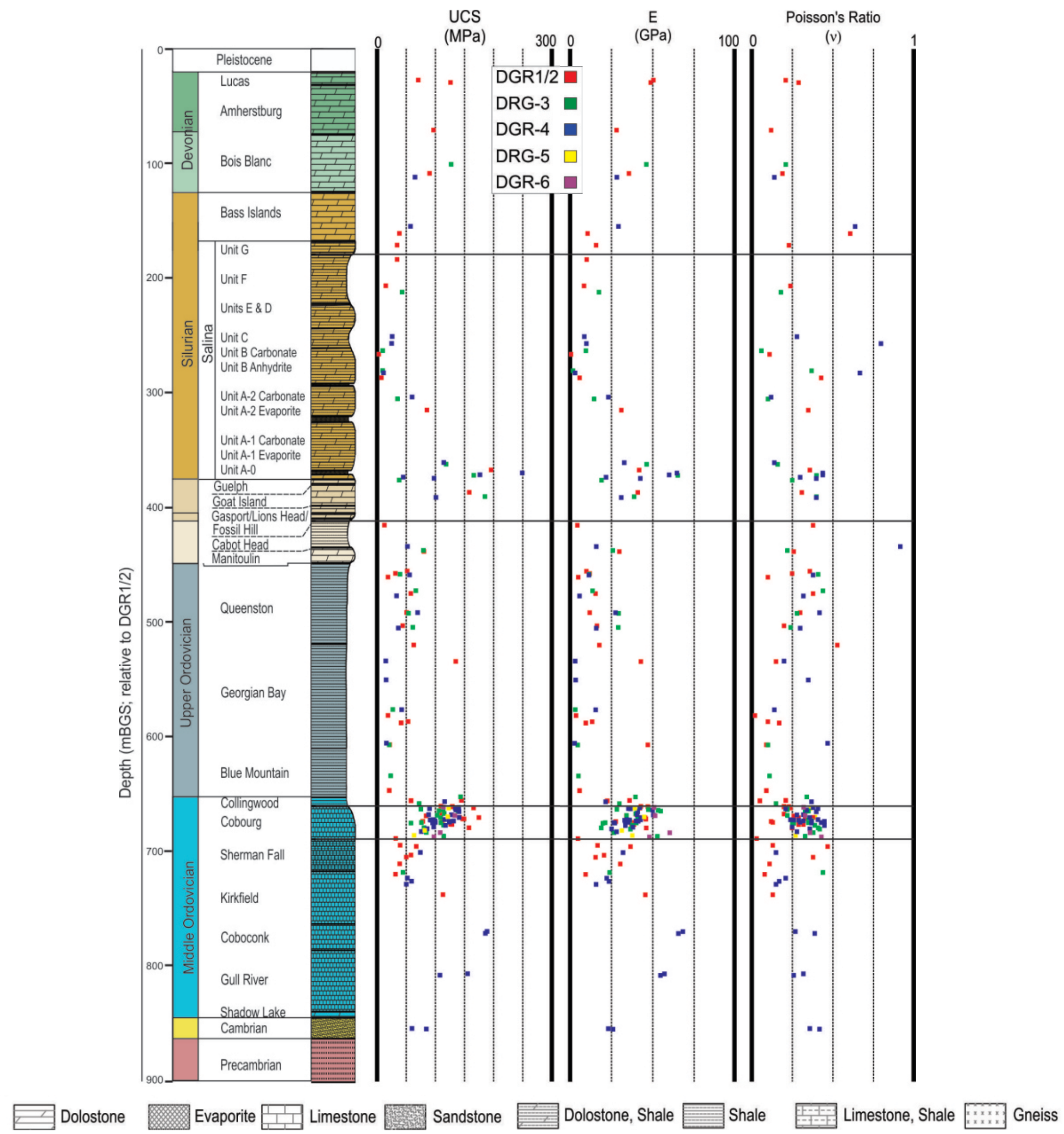
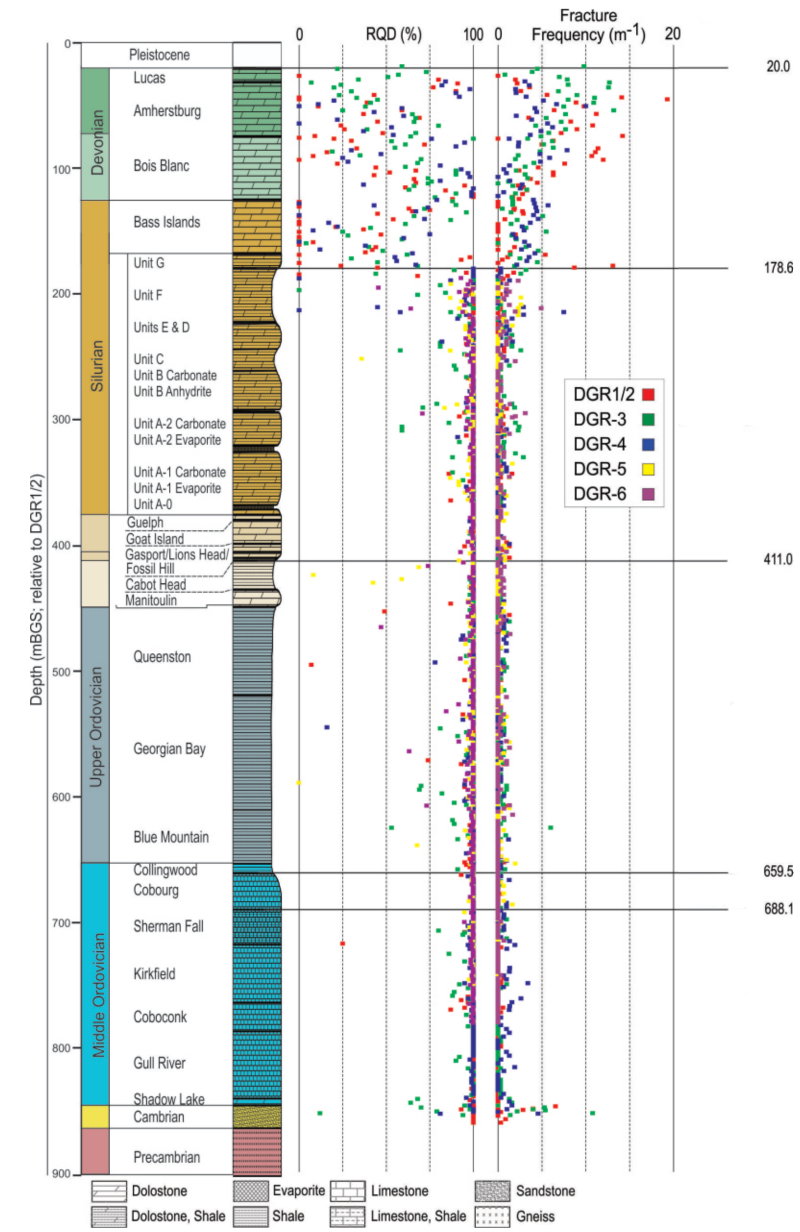


a. Uniaxial Compression Test Results
(after NWMO, 2011)



b. Reference Stratigraphic Column, MS Units, RQD and Fracture Frequency
(after NWMO, 2011)

FIGURE 6.1 - Geomechanical Properties of Paleozoic Rocks at the Bruce Nuclear Site

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: ECK

Reviewed by: KGR/SNS

Date: 12/02/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig6_1_MS_RQD_UCS_R0B.cdr"

a. Manitoulin Formation Dolostone
480.75 - 483.79 mBGS
in DGR-5

b. Queenston Formation Shale
475.73 - 478.78 mBGS
in DGR-3

c. Blue Mountain Formation Shale
619.08 - 622.13 mBGS
in DGR-4

d. Cobourg Formation Limestone
677.03 - 680.08 mBGS
in DGR-3

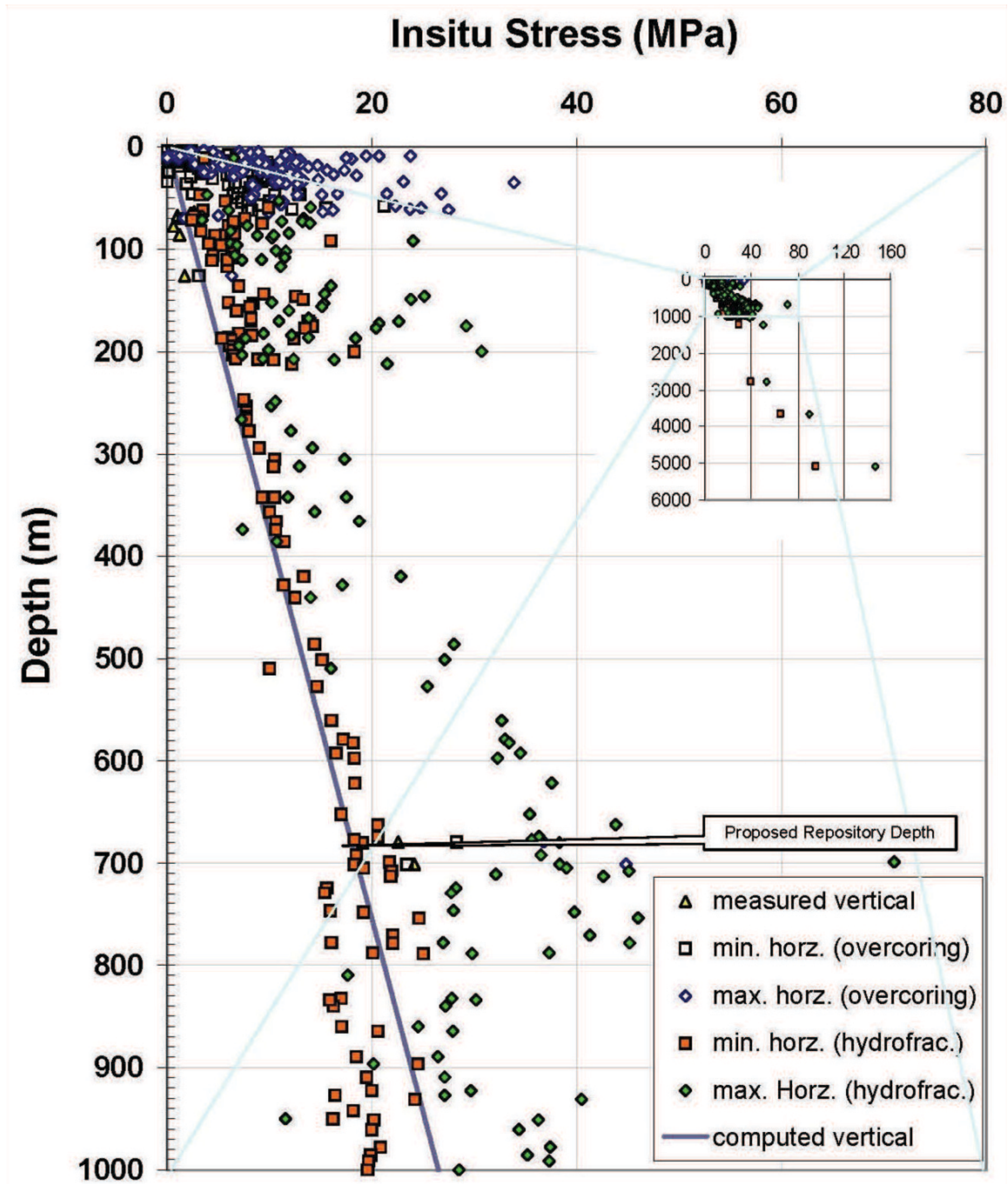
FIGURE 6.2 - Intact Core Runs of Paleozoic Formations at the Bruce Nuclear Site

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

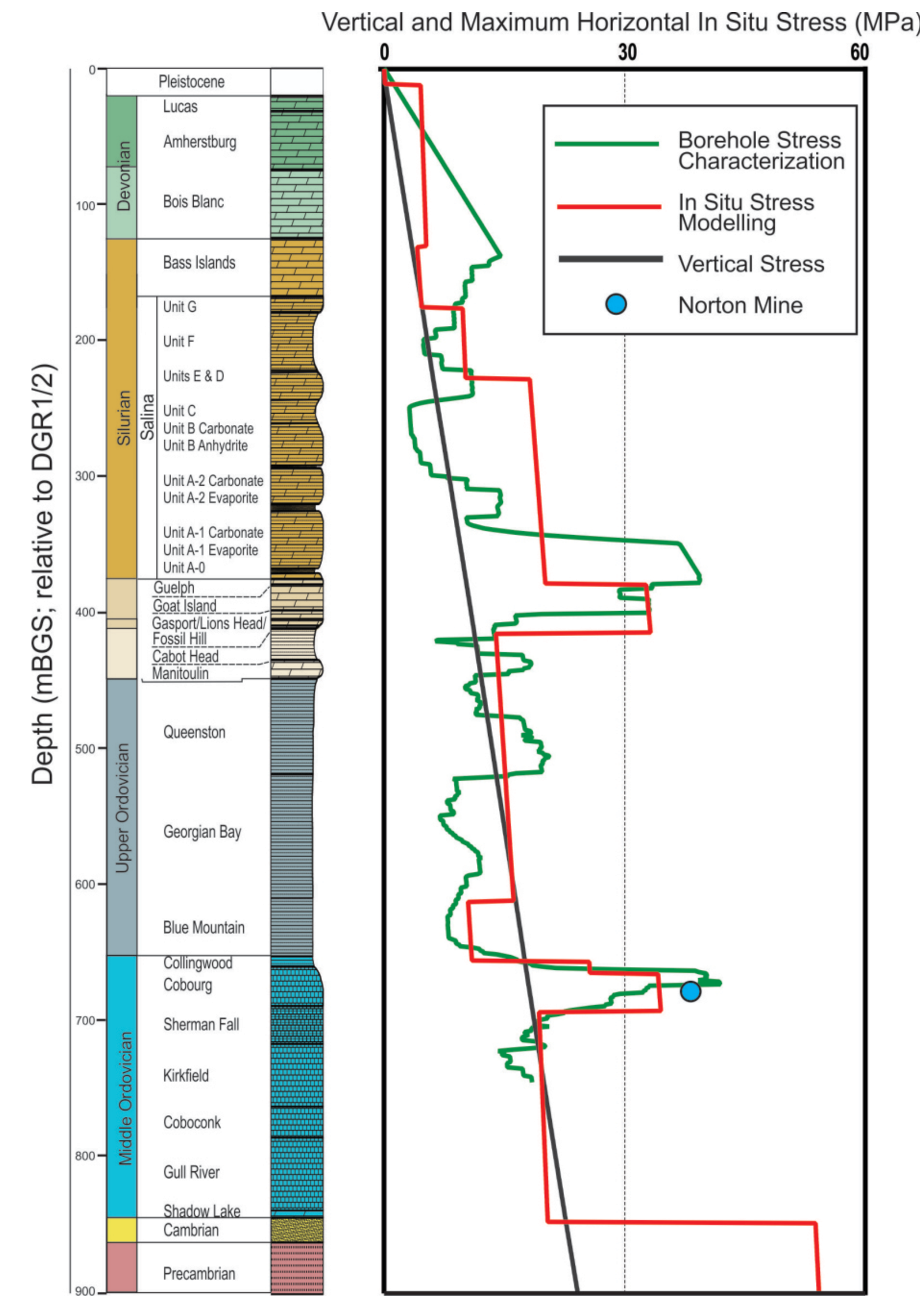
Prepared by: ECK
Reviewed by: KGR/SNS
Date: 12/02/2014

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig6_2_CoreRunPhotos_R0B.cdr"



a. Distribution of Principal Stress with Depth in the Appalachian and Michigan Basins
(*after: NWMO and AECOM Canada Ltd., 2011*)



b. Calculated Maximum Horizontal Stress Profiles at the Bruce Nuclear Site
(*after: NWMO, 2011*)

FIGURE 6.3 - Distribution of Principal Stress with Depth in the Appalachian and Michigan Basins and Calculated Maximum Horizontal Stress Profiles at the Bruce Nuclear Site

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

Prepared by: ECK
Reviewed by: KGR/SNS
Date: 12/02/2014

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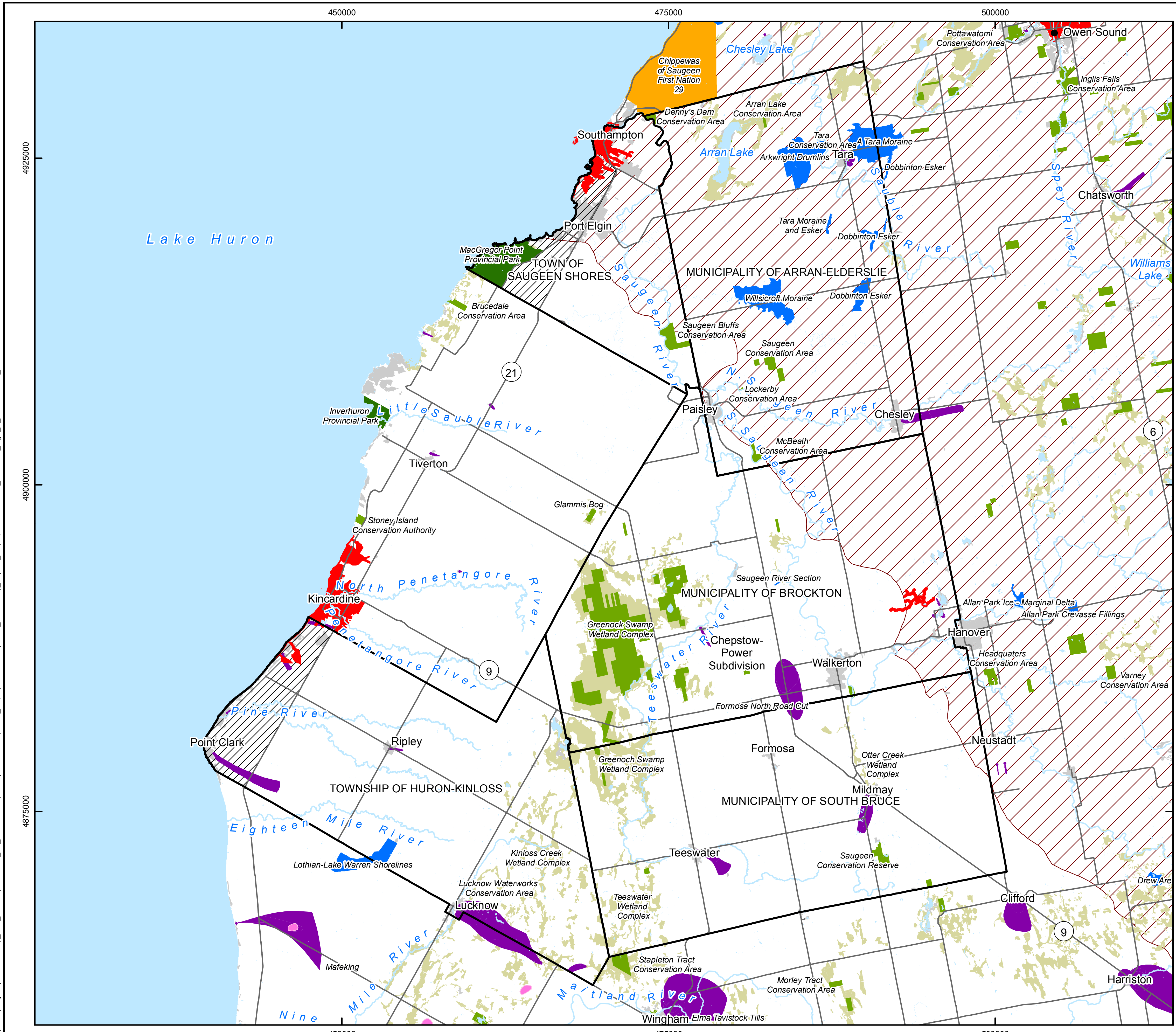
"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-7 Sedimentary Sites FS\110 Reporting\110.10 Suitability Report\Figures\WorkingFiles\10-214-7-110_SedSites_Fig6_3_Stress_R0B.cdr"



LEGEND

- The Communities
- Highway/Major Road
- Watercourse
- Waterbody
- Oil and Gas Pool
- ANSI (Earth Science)
- Area reserved by Municipality (or Town/Township) for future expansion
- Built-Up Area
- Conservation Area/Reserve
- First Nation Reserve
- Provincial Park
- Provincially Significant Wetland
- Depth to Cobourg Formation <500m
- Surface Water Intake Protetction Zone (IPZ) 1 and 2
- Wellhead Protection Area (WHPA) A, B, and C

Approximate Size of Repository Footprint

2 Km

3 Km

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Oil and Gas Pools: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Protected Areas: LIO, MNR, 2013
Source Water Protection, 2013
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NORTH

PROJECT No. 10-214-7

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TITLE

Characteristics and Constraints in the Area of the Five Communities

FIGURE 7.1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 7/3/2014

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