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

MUNICIPALITY OF CENTRAL HURON, ONTARIO

APM-REP-06144-0126

SEPTEMBER 2015

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Municipality of Central Huron

Revision: 0 (Final)

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Document ID: Central Huron_Final Main Report_R0
NWMO Report Number: APM-REP-06144-0126

September 2015

Title:	Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Municipality of Central Huron	
Client:	Nuclear Waste Management Organization	
Document ID:	Central Huron_Final Main Report_R0	
Revision Number:	0	Date: September 2015
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EXECUTIVE SUMMARY

In July 2014, the Municipality of Central Huron 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 the Municipality for safely hosting a deep geological repository (Step 3). This request followed successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment of the Municipality of Central Huron are reported in the integrated preliminary assessment report (NWMO, 2015).

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the Municipality contains 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 Municipality. Areas beyond the municipal boundaries of Central Huron were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Municipality and surrounding areas, referred to in this report as the "Central Huron area".

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 data;
- Interpretation of available borehole geophysical data and a selected 2D seismic reflection line 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, and 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 the geological setting in the Municipality of Central Huron has a number of favourable characteristics for hosting a deep geological repository for used nuclear fuel. 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 a minimum depth of 500 metres below ground surface (mBGS) would be preferred 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 the Municipality of Central Huron appears to contain large areas that have the potential to meet the geoscientific site evaluation factors outlined in the site selection process document.

While the Municipality of Central Huron appears 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 Municipality of Central Huron would need to be confirmed. Also, the impact of salt and hydrocarbon resource potential on repository siting and safety would need to be further assessed.

Should the Municipality of Central Huron 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.

TABLE OF CONTENTS

LIST OF FIGURES (IN ORDER FOLLOWING TEXT)

LIST OF TABLES

LIST OF APPENDICES

SUPPORTING DOCUMENTS

Terrain and Remote Sensing Study, Municipality of Central Huron (JDMA, 2015)

Processing and Interpretation of Geophysical Data, Municipality of Central Huron (PGW, 2015)

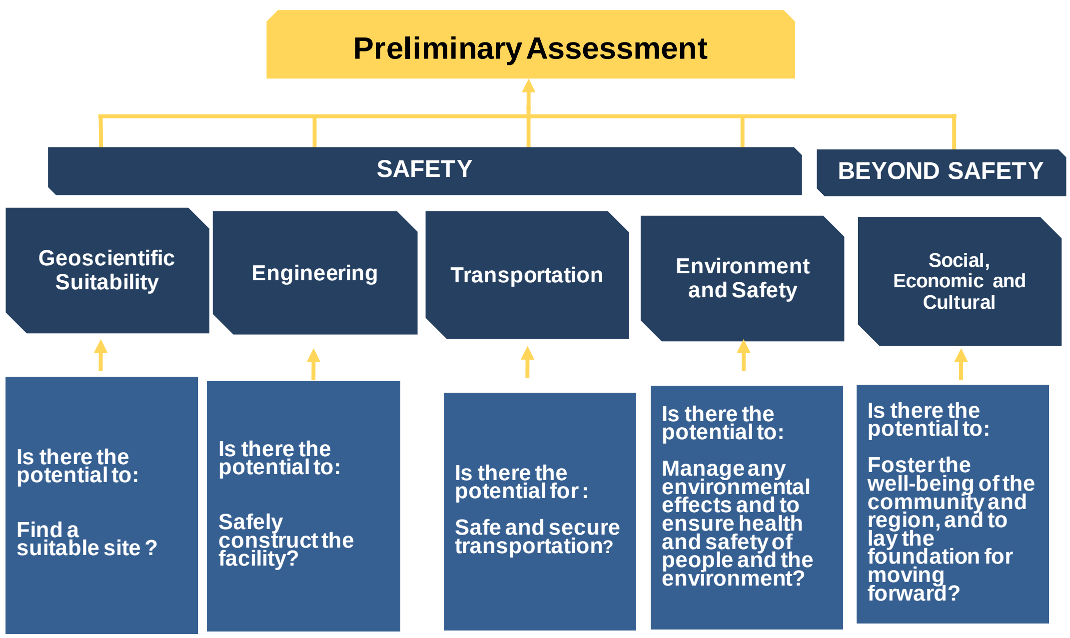
Processing and Interpretation of Borehole Geophysical Log and 2D Seismic Data, Municipality of Central Huron (Geofirma Engineering Ltd., 2015)

1 INTRODUCTION

1.1 Background

In July 2014, the Municipality of Central Huron 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 the Municipality of Central Huron for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (AECOM Canada Ltd., 2013).

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 assessment are documented in the integrated preliminary assessment report (NWMO, 2015).



The objective of the geoscientific preliminary assessment is to assess whether the Municipality of Central Huron contains 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 Municipality of Central Huron contains 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 general 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 screening (AECOM Canada Ltd., 2013). The identification of potentially suitable areas focused on the area within the boundaries of the Municipality of Central Huron. Areas beyond the municipal boundaries of Central Huron were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Municipality of Central Huron and surrounding areas, referred to in this report as the Central Huron area (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 data;
- Interpretation of available borehole geophysical data and a selected 2D seismic reflection line 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 exposure, accessibility constraints, watershed and subwatershed boundaries, and 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, 2015); geophysical interpretation (PGW, 2015); and borehole geophysical log and 2D seismic data interpretation (Geofirma Engineering Ltd., 2015). 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 Municipality 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 the safety functions outlined above (Section 7.3).

1.4 Available Geoscientific Information

Geoscientific information for the Central Huron area 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 Central Huron area.

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, 2014a), Ontario Geological Survey (OGS) digital bedrock geology of Ontario seamless coverage (OGS, 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 notewhorthy data assembly and interpretative reports reviewed include: the geotechnical feasibility assessment of the Bruce nuclear site (about 50 km north of the Central Huron area) 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 undertaken at a regional scale as part of a geosynthesis (NWMO, 2011) including several supporting technical reports, and undertaken at a 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 same package of sedimentary strata found within the Central Huron area. Based on available information on geoscientific characteristics of the sedimentary sequence in the region, including information from the detailed site characterization at the Bruce nuclear site, the Ordovician Cobourg Formation (argillaceous limestone) would be the preferred host rock for a used nuclear fuel deep geological repository in the Central Huron area (see Section 7.1). 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 (e.g., Geofirma Engineering Ltd., 2012; Golder Associates Ltd., 2013; Béland-Otis, 2014; Ministry of Northern Development and Mines, 2014a; 2014b; 2014c; Natural Resoures Canada, 2015a; 2015b; Carter et al., 2015a; 2015b; Hamilton, 2015).

The review of existing information identified that there is sufficient geoscientific information available to conduct the Phase 1 Geoscientific Desktop Preliminary Assessment to identify general potentially suitable areas within the Municipality of Central Huron.

1.4.1 Geology

Maps of subcropping bedrock in southwestern Ontario are available digitally from the OGS (2007). Overburden (Quaternary geology) mapping 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 is available from Barnett (1992), Karrow (1989, 1974), Peltier (2011) and JDMA (2015). Eyles (2012) and Hallet (2011) provide information on glacial erosion processes and rates in and near the Central Huron area.

Armstrong and Carter (2006, 2010) and Johnson et al. (1992) summarize the subsurface Paleozoic stratigraphy of southern Ontario. The stratigraphic nomenclature for the Paleozoic bedrock formations in Ontario varies for surface and subsurface characterization, 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 those 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 Central Huron area is also available from the Petroleum Wells Subsurface Database from the OGSRL (2014a); the three-dimensional interpretation of these data was 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, 1977). Bedrock geology maps at a 1:50,000 scale are available for the Central Huron area from the OGS (2007).

Detailed lithological and mineralogical information on the Paleozoic bedrock formations in the region 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 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 maps by Bailey Geological Services Ltd. and Cochrane. Information on fracture and joint mapping of Paleozoic bedrock outcrops in southern Ontario and near the Central Huron area 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 Central Huron area, is available from Brunton and Dodge (2008) and Worthington (2011).

Interpretation of the Precambrian basement underlying the Paleozoic bedrock within southern Ontario and the Central Huron area 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 Airborne/Ground Geophysics

The digital elevation model (DEM) data for the Central Huron area 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, 2013). The DEM data provided a good quality data set for quantifying ground slopes and relief, and for assessing regional surface water drainage and likely groundwater flow directions.

Table 1.1 Summary of DEM, Satellite and Geophysical Source Data Information for the Central Huron Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED);1:50,000 scale	Geobase, 2013	20 m	Entire Central Huron area	1978-1995	Hill-shaded used for mapping
Satellite Imagery	Spot4/5; Orthoimage, multispectral/ panchromatic	Geobase, 2010	10 m (panchromatic) 20 m (multispectral)	Entire Central Huron area	2006-2007	Good Coverage
Geophysics	Waterloo fixed wing magnetic survey	GSC, 2014	926m line spacing 305m sensor height	Eastern portion of Central Huron area	1986	Large overlap with newer survey to the south
	Lake Huron fixed wing magnetic survey	GSC, 2014	1,900m line spacing 305m sensor height	Western half of Central Huron area	1986	Low rsolution survey over Lake Huron
	Strathroy fixed wing magnetic survey	Spector, 1999	700 m x 700m m grid 450mASL sensor height	Western half of Central Huron area	1999	Higher resolution than GSC surveys. Terrain clearance varies from 130m to 275m
	Southern Ontario Radon Survey – Block 2	GSC, 2014	1000m line spacing 150m sensor height	Entire Central Huron area	2008	Low resolution survey, east-west flight lines
	Ground gravity measurements	GSC, 2014	6 km (onshore), 1.6 km x 18 km (offshore)/surface	Entire Central Huron area	1945-2007	Variable station spacing
	Ground gravity measurements	PGW, 2015	0.4 km x 2 km/ surface	Entire land portion of Central Huron area	1950s	Higher resolution than GSC coverage, variable station spacing

SPOT-5 satellite imagery for the Central Huron area (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 Central Huron area. Figure 2.1 shows the SPOT-5 panchromatic satellite imagery for the Central Huron area.

Low-resolution airborne magnetic data collected by the Geological Survey of Canada (GSC, 2014) provide complete coverage of the Central Huron area. These magnetic data were flown in 1986 in two different surveys, at 926 and 1,900 m flight line spacing and sensor heights of 305 m (Table 1.1). Medium-resolution magnetic data are also available covering a portion on the west side of the Central Huron area (Figure 1.2; see PGW, 2015). 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 provide low-resolution (1 km flight line spacing) data coverage over the entire Central Huron area (GSC, 2014). These data were flown in

2008 as part of the Southern Ontario Radon Survey (Table 1.1).

Gravity data from the GSC provide relatively sparse coverage for the Central Huron area (GSC, 2014). The data were acquired for the Central Huron area and the surrounding region and consist of an irregular distribution of station measurements on land and off shore in Lake Huron (Table 1.1). On land, the data consists of 58 station measurements within the Central Huron area comprising roughly a station every 3 to 6 km. Offshore, the data consists of 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 large portion of the Central Huron area (Figure 1.2; PGW, 2015). This proprietary gravity data set 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

One historical 2D seismic reflection line acquired for oil and gas exploration purposes in the 1970s within the Municipality of Central Huron was purchased for reprocessing and reinterpretation. Figure 1.2 shows the location of the interpreted 2D seismic line and Table 1.2 summarizes its characteristics.

Table 1.2 Summary Characteristics of the 2D Seismic Data Line Interpreted in the Municipality of Central Huron

Data Characteristic	***Line A000300528***
Location	Municipality of Central Huron
Source Spacing	20 m
Receiver Spacing	20 m
Line Length	9.9 km
Fold	24
Owner at Acquisition	Shell Canada
Current Data Owner	Shell Canada
Year Acquired	1977
Recording Instrumentation	DFS IV – 48 channel

The acquired seismic line A000300528 is located in the Municipality of Central Huron, and is oriented north-south (Figure 1.2). This line was selected for use in this study based mostly on its length (it was one of the longest lines available) and its location in the central portion of the Municipality, and in proximity to known pinnacle reefs. Based on the survey acquisition characteristics (Table 1.2), this seismic line is of relatively low quality and low spatial resolution compared to more modern seismic acquisition systems; the data for line A000300528 were acquired with 48 channel seismographs and 20 m station spacing. However, the overburden heterogeneity and thickness within the Municipality, which had a detrimental effect on data quality, is a limitation that is still valid today using modern equipment and collection methods and is a well known limitation of seismic methods for areas within southwestern Ontario north of Lambton County.

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 Central Huron area. Deep borehole data are available from oil and gas exploration activities and OGS geological investigations (OGSRL, 2014a), interpretations of those oil and gas borehole data (Bailey Geological Services Ltd. and Cochrane, 1990; OGS, 2011), 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 and Climate Change (MOECC, 2014a) Water Well Information System.

Deep borehole data from the OGSRL (2014a) 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. Only four wells out of 125 within the OGSRL database for the Central Huron area contain information from cored sections of boreholes.

Geoscientific data on the entire Paleozoic bedrock sequence are available from six continuously-cored deep boreholes at the Bruce nuclear site, located approximately 55 km north of the Central Huron area, and summarized by Intera Engineering Ltd. (2011). Available borehole data from these wells include geological information on formation depth, orientation, 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 Central Huron area are available principally from the Ontario Ministry of the Environment and Climate Change (MOECC) Water Well Information System database (MOECC, 2014a). This database contains simple hydrogeological and hydrogeochemical information on the overburden and shallow bedrock aquifers.

Interpretation 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*. Major interpretative studies available include: Huron County groundwater study (Golder Associates Ltd., 2003b), six conservation authorities FEFLOW groundwater modeling project (Waterloo Hydrogeologic Inc., 2007), and the Ausable Bayfield and Maitland Valley protection area assessment reports (Ausable Bayfield Maitland Valley Source Protection Region, 2011a; 2011b). 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, 2014a), and detailed site characterization studies at the Bruce nuclear site (Intera Engineering Ltd., 2011; Geofirma Engineering Ltd., 2012). 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. Carter et al. (2015b) have recently released static water level maps for deep bedrock formations in southern Ontario based on petroleum well records data.

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 (2015) provides a summary of groundwater hydrogeochemical data for shallow overburden and bedrock aquifers in southern Ontario based on 2007-2014 OGS sampling from water wells, including several located within the Central Huron area. Ontario Ministry of the Environment and Climate Change (MOECC, 2014b) 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 Central Huron area.

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, 2014a), recent interpretations of petroleum well records data (Carter et al, 2015a; Skuce et al., 2015), 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 and mineral resources potential for the Central Huron area 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, 2014a), reports in the Oil Gas and Salt Resources Library in London, Ontario, the Bruce DGR geosynthesis and DGSM studies (NWMO, 2011; Intera Engineering Ltd, 2011), and OGS studies evaluating the hydrocarbon and shale gas potential of Paleozoic rocks in southern Ontario (OGS, 2011; Béland-Otis, 2014; 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 60 km northeast of the Central Huron area.

Information on metallic mineral resources is available from the Abandoned Mines Information System (AMIS) database (MNDM, 2014c), the Mineral Deposit Inventory (MDI) database (OGS, 2014), the Assessment File Research Imaging (AFRI) database (MNDM, 2014a) and the CLAIMaps database (MNDM, 2014b). 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 mine 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 Huron County are summarized by 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 Central Huron area. Information on rock geomechanical properties, including rock strengths, rock quality, thermal conductivity and in situ stresses for Paleozoic rocks in the Central Huron area 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 near the Central Huron area 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 Central Huron area and the surrounding region. Information on earthquake occurrence in these areas is available from the National Earthquake Database maintained by Natural Resources Canada (2015a).

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., 2013) as part of an ongoing micro-seismic monitoring program around the Bruce nuclear site. The findings are also applicable to the Central Huron area.

Information on neotectonics in the Central Huron area is available from JDMA (2015) and Slattery (2011) as well as from earlier work by McFall (1993) and Karrow and White (2002) for the larger southern Ontario region.

2 PHYSICAL GEOGRAPHY

2.1 Location

The Central Huron area is shown in Figure 1.1, and includes parts of Huron County and a small portion of Perth County in the southeast corner (Figure 1.1, inset). The Municipality of Central Huron is located within Huron County. Figure 2.1 shows the location and extent of the Central Huron area on black-and-white 2006 SPOT-5 satellite imagery.

The Municipality of Central Huron borders Lake Huron, and is located between Goderich and Bayfield. It is approximately 456 km^2 in size. The largest settlement areas in the Municipality are shown in Figure 1.1 and include Clinton, where the municipal offices are located in the south central part; Holmesville in the central part; and Londesborough and Kinburn in the eastern part of the Municipality.

2.2 Physiography and Topography

A detailed terrain analysis was completed for the Central Huron area as part of the Phase 1 preliminary assessment (JDMA, 2015). This section presents a summary of that analysis. The landform and topography information for the Central Huron area is illustrated in 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 Central Huron area: Horseshoe moraines, Stratford till plain, Huron slope, Huron fringe, Dundalk till plain and Teeswater drumlin field, five of which are found within the Municipality (inset in 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 lists the areal extent of these physiographic regions within the Municipality of Central Huron (JDMA, 2015) and the following text describes their occurrence based on JDMA (2015).

Table 2.1 Areal Extent of Physiographic Regions within the Municipality of Central Huron

Physiographic Region	*Area (km^2)*	*Area (%)*
Teeswater drumlin field	0.053	0.01
Huron fringe	5.53	1.2
Huron slope	64.43	14.1
Stratford till plain	93.90	20.6
Horseshoe moraines	292.84	64.1

The Horseshoe moraines, covering 64.1% of the Municipality, represent an elaborate array of moraines and spillways extending north-south across the central part of the Central Huron area (Figure 2.2, inset). The moraines within this belt are part of the Port Huron moraine system. The belt is about 16 km wide within the Municipality. The western boundary of the Horseshoe moraines is marked by the low gravel beaches of glacial Lake Warren, whereas the eastern flank is marked largely by the Seaforth Moraine (Figure 2.2). The central part of the Horseshoe moraines in this area comprises the Wawanosh Moraine, the Wyoming Moraine and a network of adjacent spillways.

The Stratford till plain, covering the easternmost 20.6% of the Municipality, represents an area of low relief largely underlain by Rannoch Till and sporadic glaciolacustrine deposits. Within the Central Huron area, the Stratford till plain extends between the Mitchell and Seaforth moraines and is interrupted by the Dublin Moraine (Figure 2.2).

The Huron slope, covering 14.1% of the Municipality, occupies the section of land along the east shore of Lake Huron between the east edge of the Huron fringe and the west edge of the Wyoming Moraine. It covers a strip of land 2.7 to 5 km in width that extends along the western part of the Municipality (Figure 2.2, inset). The land slopes gently across this feature from about 180 to 245 m elevation. The area is characterized by a sand plain and bevelled till plain bounded to the east by the twin beaches of glacial Lake Warren. Below the Warren beach the till surface has been subdued by the deposition of a veneer of glaciolacustrine gravelly sand. Exposures of till occur at the surface in many locations where the sand and gravel are absent. The till sheet is formed of brown silt to silty clay (St. Joseph Till) and is generally only 2 to 3 m thick and rests on stratified clay of the same colour.

Outside the Central Huron area, the Huron fringe is characterized by wave-cut terraces of glacial Lake Algonquin and glacial Lake Nipissing, with their boulders, gravel bars and sand dunes located within a narrow fringe of land extending along the Lake Huron shoreline. However, in the Central Huron area recent shoreline erosion has destroyed most of the landforms and deposits associated with glacial lakes Algonquin and Nipissing. The Huron fringe in this area is typically only 200 to 400 m wide (Figure 2.2).

The Teeswater drumlin field is located in the northeast corner of the Central Huron area and occupies a very small part of the Municipality (Table 2.1). Within the Central Huron area the drumlins are weak and fade into an undulating till plain. The drumlin field is typically interrupted in a few places by the presence of kames and associated outwash.

The Dundalk till plain is not found within the Municipality, but is present along the eastern boundary of the Central Huron area (Figure 2.2, inset).

2.2.2 Topography and Ground Elevation

The large-scale topography in the Central Huron area 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 Central Huron area (Figure 2.3) controls the overall pattern of drainage and is itself largely controlled by the bedrock topography. The elevation gradient from west (Lake Huron) to east is from 176 to 366 m, with this elevation increase occurring over an approximate

35 km lateral distance. The elevation minimum is defined by the surface of Lake Huron, which has a chart datum of 176 m. The highest points in the area, with elevations of 366 m, are located along the Mitchell Moraine at the east edge of the Central Huron area (Figures 2.2 and 2.3). Steep slopes which are rare in the Central Huron area are associated with drumlins, river valleys, spillway margins, kames and till ridges, and raised shore bluffs.

The elevation of 245 m outlines the approximate extent of glacial Lake Warren in the Central Huron area about 12,500 years ago. Approximately 15% of the Municipality was below the level of glacial Lake Warren.

2.3 Drainage

JDMA (2015) provides a summary of the drainage features and characteristics of the Central Huron area and the following is a summary of that work. Section 2.3.1 provides information on the size, distribution and depth of lakes and wetlands in the Central Huron area. Section 2.3.2 describes the existing watershed map file, and Section 2.3.3 describes surface flow and drainage within the Central Huron area on a watershed basis.

2.3.1 Waterbodies and Wetlands

Apart from Lake Huron, the Central Huron area is devoid of large or even medium-sized lakes. Waterbodies cover 11.0 km^2 or 0.8% of the Central Huron area. Seven of the ten largest lakes in the Central Huron area are associated with the Hullett Marsh Complex (Figure 2.4) and are located within the Hullett Wildlife Management Area (Section 2.4 and Table 2.2). The largest lake is 1.3 km^2 in extent. None of the lakes in Table 2.2 have been assigned official names.

Table 2.2 Size of Ten Largest Lakes within the Central Huron Area

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

Lake Huron, the second largest of the Great Lakes, has a surface area of approximately 63,500 km^2 and a maximum depth of 229 m. Within the Central Huron area (Figure 2.4), the lowest elevation of the floor of Lake Huron reaches 162 m, equivalent to a maximum water depth of 14 m. Apart from Lake Huron, there is no information on the depths of other lakes within the map area.

Figure 2.4 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 Central Huron area include: the Saratoga Complex, Westfield Complex, Morris Creek Complex, Sunshine Tract, Blyth Brook Headwater Complex, Hullett Marsh Complex, Holmesville Creek Complex, and Tricks Creek Complex (Figure 2.4). Only the Hullett Marsh Complex, Tricks Creek Swamp and the Holmesville Creek Complex are within the Municipality. Several of the provincially significant wetlands are situated within spillways, such as the Tricks Creek Complex, Holmesville Creek Complex and Saratoga Complex, which are located within north-south trending spillways that extend along the axis of the Wyoming Moraine (Figure 2.2). It is likely that these spillway wetlands receive some of their source water from shallow surficial aquifers within the surrounding till and kame moraine ridges.

In total, wetlands cover 78.4 km^2 (5.6%) of the Central Huron area, while wooded areas cover 218.1 km^2 (15.6%). Within the Municipality wetlands cover about 8.8%. Note that there is significant overlap between the areas mapped as wetland and those mapped as forest (JDMA, 2015). Many of the wetlands and wooded areas are distributed along property boundaries, illustrating how their distribution is largely controlled artificially through various land uses. The absence of wetlands southeast of the Municipality appears distinctly artificial and, although it is possible that unmapped wetlands exist in that area, it is also possible the absence relates to drainage or filling of wetlands for agricultural or other land uses.

2.3.2 Watersheds

A watershed, also known as a catchment, basin or drainage area, includes all the land that is drained by a watercourse and its tributaries. The most detailed available watershed delineation for the Central Huron area is the quaternary watershed file produced by the MNR (LIO, 2014). The delineation of drainage divides can be useful for determining drainage directions and contributing to an initial understanding of the shallow groundwater flow system.

Figure 2.5 shows the divides that delineate the three tertiary-scale watersheds (Maitland, Ausable and Penetangore) associated with the main river systems in the Central Huron area, as well as the nine quaternary-scale watersheds that further compartmentalize surface drainage in the area. The Municipality of Central Huron lies within the southern portion of the Maitland watershed and the northern portion of the Ausable watershed (Figure 2.5).

2.3.3 Surface Flow and Drainage

The Central Huron area 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 Central Huron area flow towards Lake Huron.

Surface water flow over the Central Huron area is directed to the west into Lake Huron (Figure 2.5). Much of this flow into Lake Huron is accomplished by the Maitland and Bayfield rivers, and to a lesser extent by smaller rivers such as the South Maitland, Middle Maitland, McEwan, Blyth Brook, Hopkins, Sharpes, Naftel's, Bridgewater, Tricks and Bannockburn rivers or creeks.

2.3.3.1 Maitland Watershed

The Maitland watershed covers 69.4% of the Central Huron area, and the portion contained within this area has been divided into five quaternary watersheds (Figure 2.5). The Maitland River is the primary drainage feature in the watershed and drains into Lake Huron just north of the Municipality.

The Lower Maitland watershed (2FE-02) contains the lower reach of the Maitland River, which meanders through a deep, forested valley locally incised through bedrock. The Maitland River makes several sharp bends where it extends through the Wyoming Moraine, which, along with the Wawanosh Moraine, represents an important groundwater recharge area within the watershed (Waterloo Hydrogeologic Inc., 2007)

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

A small portion of the Middle Maitland watershed (2FE-04) extends north south along the eastern edge of the map area (Figure 2.5) and drains part of the Dundalk till plain, an area with abundant agriculture. A minor part of the Little Maitland watershed (2FE-05), which contains the Little Maitland River, a tributary of the Middle Maitland River, is contained in the northeast corner of the map area. These rivers drain part of the Teeswater drumlin field in the northeast corner of the map area, an area with extensive forest cover.

The South Shore watershed (2FE-01) is a small watershed extending between Lake Huron and the Wyoming Moraine (Figures 2.2 and 2.5) and occupying a highly dissected till and sand plain. The reason for the high density of streams is the low permeability of the St. Joseph Till and underlying glaciolacustrine silts and clays found along this slope. Within this small watershed and adjacent watersheds that drain the level slope west of the Wyoming Moraine (e.g., 2FD-07, 2FE-01, 2FF-06), seepage from the higher rolling terrain above the glacial Lake Warren beach or bluff has a tendency to collect and create swampy conditions (Chapman and Putnam, 2007).

2.3.3.2 Ausable Watershed

The Ausable watershed covers 26.1% of the Central Huron area (Figure 2.5), and the portion contained within this area has been divided into three quaternary watersheds. The Bayfield River is the primary drainage feature in this part of the watershed and drains into Lake Huron at the southern boundary of the Municipality.

The Main Bayfield watershed (2FF-07) extends east west along the southern part of the map area, draining land west of the Seaforth Moraine. The Bayfield River cuts through the Wyoming Moraine before emptying into Lake Huron. Recharge areas within this watershed include the Dublin, Seaforth, Wawanosh and Wyoming moraines (Figure 2.2).

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

2.3.3.3 Penetangore Watershed

The Penetangore watershed covers 4.5% of the Central Huron area (Figure 2.5, inset). The portion contained within the Central Huron area is represented by one quaternary watershed (2FD-07), where Allans Creek forms the main drainage feature. A very dense network of west trending creeks testifies to the poor drainage of the sand and till plain. Gully erosion is common where the creeks intersect the Lake Huron bluff. Seepage from granular layers within the bluffs along the Lake Huron shoreline also contributes to gully erosion in this area.

2.4 Land Use and Protected Areas

Figure 2.6 shows land disposition and ownership within the Central Huron area. Most of the land in the Central Huron area consists of private agricultural land, with several small parcels of provinical parks, conservation areas and reserves. Several small parcels of Crown leased land associated with water lots of the Bayfield and Maitland rivers and Lake Huron in the Central Huron area are too small to be seen in Figure 2.6.

2.4.1 Land Use

Land use within the Central Huron area consists mostly of wetlands, forested areas, agricultural lands and developed/built-up areas with residential, commercial and industrial land uses. Figure 2.6 shows the distribution of all mapped wetlands within the Central Huron area. As described in Section 2.3.1, wetlands and forested areas represent 5.6% and 15.6% respectively of the land area shown in 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, NGO Nature Reserves, Provincial Wildlife areas, Provincially Significant Wetlands, and earth science Areas of Natural Scientific Interest (ANSI) within the Central Huron area (LIO, 2014; ABCA, 2014). With the exception of earth science ANSIs and Provincial Wildlife areas, these land uses are considered within this report as protected areas. Table 2.3 lists the percentage of the Municipality covered by these different types of areas, and the following paragraphs summarize the available information on them within the Municipality. Because of overlapping of some of these aeras (e.g., Provincially Significant Wetlands and Wildlife Management Areas) the total combined protected areas and earth science ANSIs in Table 2.3 is less than the sum of the individual areas listed in the table.

Table 2.3 Summary of Protected Areas, Earth Science ANSIs and Wildlife Management Areas in the Municipality of Central Huron

Area as % of Municipality					
Provincial Parks	***Provincially Significant Wetlands***	***Conservation Areas***	***Reserves/Wildlife Management Areas***	***Earth Science ANSI***	***Total Combined Protected Areas and Earth Science ANSIs***
0	2.6	0.12	4.8	4.6	9.4

There are no national or provincial parks within the Municipality of Central Huron. There are two conservation areas within the Municipality of Central Huron: the Naftel's Creek and Black's Point conservation areas located in the northwestern part of the Municipality proximal to Lake Huron and Highway 21 (Figure 2.6). These conservation areas cover a combined area of about 0.5 km^2 or about 0.12% of the Municipality.

There is also a NGO nature reserve (GG Newton Reserve) located west of Holmesville, and the Hullet Wildlife Management Area encompassing the Hullet Marsh and surrounding lands (Figure 2.6). These lands cover approximately another 4.8% of the Municipality, with a combined area of approximately 22.1 km^2.

There are three designated Provincially Significant Wetlands within the Municipality of Central Huron comprising the Hullett Marsh Complex, the Holmesville Creek Complex and the Trick's Creek Swamp (Figure 2.6). These wetlands have a combined area of approximately 12 km^2, comprising 2.6% of the Municipality. Two large earth science Areas of Natural Scientific Interest (ANSI) are present within the Municipality: the Seaforth-West Wawanosh moraines located between Clinton and Kinburn south of the Hullett Marsh; and the Holmesville Area situated north of Holmesville (Figure 2.6). These features cover approximately another 4.6% of the Municipality with a combined area of approximately 21.2 km^2. These ANSIs represent prominent glacial geological features that support unique habitats and protect groundwater infiltration and recharge functions. These combined protected areas and earth science ANSIs occupy approximately 9.4% of the Municipality of Central Huron.

The presence and function of other natural features and areas, such as significant woodlands, significant valley lands or significant wildlife habitats (Provincial Policy Statement, 2014) 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.

2.4.3 Heritage Sites

The assessment of cultural heritage examined known archaeological and historic sites in the Municipality of Central Huron. Information on archaeological sites in Ontario is provided by the Ontario Ministry of Tourism, Culture and Sport, through their Archaeological Sites Database (Ontario Ministry of Tourism, Culture and Sport, 2015).

There are 20 registered archaeological sites in the Municipality of Central Huron (von Bitter, 2013). Of the 20 archaeological sites, ten are recorded as being early (Pre-Contact) campsites or findspots for which no cultural affiliation or time period can be established. Four archaeological sites have been identified as Middle or Late Woodland sites; three are campsites and one is a Late Woodland village. Two archaeological sites have more than one occupational time period (historic Euro-Canadian and Pre-Contact) and one site is identified as a historic Euro-Canadian homestead. No information was given for the three remaining sites.

The potential for archaeological sites within the Municipality of Central Huron 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 no National Historic Sites in the Municipality (Parks Canada, 2015). There are 17 properties designated as municipal or provincial heritage sites within the Municipality of Central Huron (Ontario Minisitry of Tourism, Culture and Sport, 2015). Of these 17 designated heritage properties, 14 are located within the Town of Clinton. The remaining properties include the Ball Chapel and private cemetery, located on Balls Line, and Ball's Bridge, located off County Road 8. Additionally, there are no conservation easements or heritage districts currently administered by the Ontario Heritage Trust in the Central Huron area (Ontario Heritage Trust, 2015).

The presence of locally protected areas and heritage sites would need to be further confirmed in discussion with the community and First Nation and Métis communities in the vicinity during subsequent evaluation stages, if the Municipality 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 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 modelling considering surface water flow and overland flow to surface water. Two IPZs are potentially defined for each surface water source.

For groundwater supplies, the source water protection areas are defined as Well Head Protection Areas (WHPAs) based on simple geometrical factors and hydrogeological modelling 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.

Table 2.4 lists the public surface water and groundwater drinking water supplies that create source water protection areas in the Municipality of Central Huron. Figure 2.7 shows the extents of the IPZs and WHPAs for these drinking water supplies and others outside the Municipality within the Central Huron area, based on Assessment Reports completed by Ausable Bayfield Maitland Valley Source Protection Region (2011a, 2011b).

Figure 2.7 shows grouping of WHPAs into three categories: A, B and C; D; and E. Table 2.4 and Figure 2.7 also include the IPZs for the Goderich Drinking Water System in the Town of Goderich that has a land-based IPZ that extends into the Municipality of Central Huron. Figure 2.7 also shows: the WHPA for the Benmiller Well Supply located in the Township of Ashfield-Colborne-Wawanosh that extends into the Municipality of Central Huron; and the WHPA-E associated with the Century Heights well supply that runs along the northern boundary of the Municipality. Although the Auburn Well Supply is located within the Municipality of Central Huron, almost all its WHPA is within the Township of North Huron. Table 2.4 and Figure 2.7 show there are 10 source water protection areas in the Municipality of Central Huron, consisting of 9 WHPAs to protect groundwater (GW) supplies and one IPZ to protect surface water (SW) supplies. Table 2.4 also identifies that all the municipal groundwater supplies are sourced from bedrock aquifers (GW-B).

Table 2.4 Summary of Source Water Protection Areas in the Municipality of Central Huron

Source Protection Area	***Drinking Water System***	***Supply Type (GW-B or SW)***
Ausable Bayfield	Carraige Lane Well Supply	GW-B
	Clinton Well Supply (Wells 1, 2 and 3)	GW-B
	Harbour Lights Well Supply	GW-B
	SAM Well Supply	GW-B
	Vanderwetering Well Supply	GW-B
Maitland Valley	Auburn Well Supply	GW-B
	Benmiller Well Supply	GW-B
	Kelly Well Supply	GW-B
	McClinchey Well Supply	GW-B
	Goderich Intake – Lake Huron	SW

Note: GW-B = bedrock groundwater supply; SW = surface water supply

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 bedrock formations present in the Central Huron area (Table 3.1) based on regional geological understanding. It should be noted that the Paleozoic stratigraphic nomenclature in southern Ontario 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.

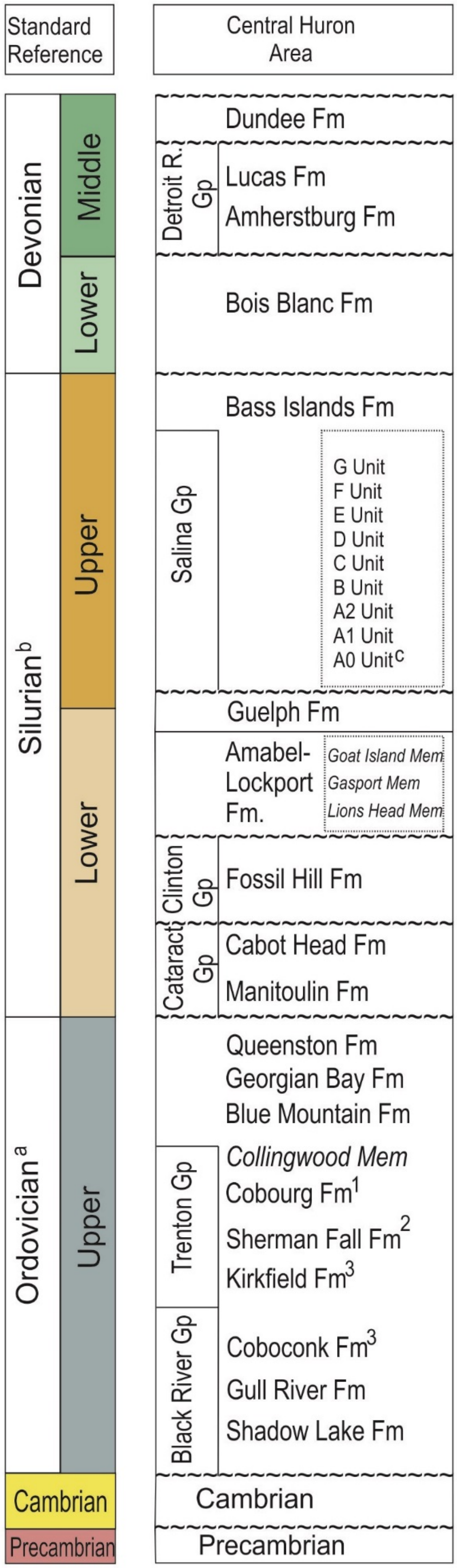
This section also provides overview descriptions of the current understanding regarding Paleozoic faults, diagenesis, karst and paleokarst distribution, glacial history and associated erosion for southern Ontario, as well as a discussion of the subsidence history of the Michigan Basin.

3.1.1 Geological Setting

The bedrock geology of southern Ontario, including the Central Huron area, consists of a thick Paleozoic sequence of sedimentary rocks ranging in age from Cambrian to Mississippian deposited between approximately 540 million and 323 million years ago (Johnson et al., 1992). This sedimentary sequence rests unconformably on the Precambrian crystalline basement rocks of the Grenville Province, which is the south-eastern most subdivision of the Canadian Shield. The Grenville Province comprises approximately 2,690 million to 990 million year old metamorphic rocks deformed during orogenic events approximately 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 Figures 3.1 and 3.2, after Armstrong and Carter (2010) and Johnson 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 in Figure 3.1) structural depression, define a regional basement high beneath southern Ontario that extends

Table 3.1 Stratigraphy of the Central Huron Area (after Armstrong and Carter, 2010)



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

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

~~ Unconformity ~~

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 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 Central Huron area was deposited within the Michigan Basin.

Within the Michigan Basin the Paleozoic rocks have a maximum thickness of about 4,800 m at the centre of the basin (Johnson et al., 1992); at the northeast corner of the Central Huron area the thickness is about 900 m (OGSRL, 2014a). 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 of southern Ontario and Figure 3.3 shows a vertically exaggerated regional cross-section, which runs north of the Central Huron area. The location of the cross-section is shown in Figure 3.2. The geological cross-section A-A’ (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 Central Huron area are almost flat lying, with dips of 1º or less. These slight west-southwesterly dips result in subcrop exposure of increasingly older sedimentary formations from west to east across southern Ontario, as shown in Figure 3.2.

3.1.2 Geological and Tectonic History

The structural and tectonic history of southern Ontario, including the Central Huron area, 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 approximately 1,210 to 970 million-year-old orogenic events, referred to generally as the Grenville Orogeny. The Grenville Orogeny is generally interpreted to have involved northwest-directed thrusting and imbrication of the entire crust, presumably as a result of 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 rifting prior to 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 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, defined based on aeromagnetic data, 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 within the Precambrian basement identified by Boyce and Morris (2002) and Wallach et al. (1998). However, there is some uncertainty over the tectonic significance 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 Central Huron area, is underlain by Precambrian crystalline basement of the Central Gneiss Belt and consists mainly of quartzofeldspathic gneissic rocks that have generally been metamorphosed to upper amphibolite facies, and locally to granulite facies. Most of these gneisses are believed to be plutonic in origin, with subordinate amounts of metasedimentary gneiss (Easton and Carter, 1995).

The Huron Domain, shown in 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). 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 (2015) for the Central Huron area. The Huron Domain underlies all the Central Huron area.

3.1.4 Paleozoic Stratigraphy

Table 3.1 illustrates the Paleozoic bedrock stratigraphy for much of southern Ontario, including the Central Huron area (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). The following descriptions are based on regional understanding and are considered to be generally representative of the Paleozoic stratigraphy underlying the Central Huron area.

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). Within the Central Huron area the Cambrian unit is interpreted to pinch out approximately 5 to 10 km east of Lake Huron (Bailey Geological Services Ltd. and Cochrane, 1984a), and thus is expected to be absent beneath the eastern and central parts of the

Central Huron area (see Section 3.2.2.2) . There are no surface exposures of the Cambrian unit in southern 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). 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 that consists of grey to green to maroon noncalcareous shales with minor sandstone and carbonate interbeds. Within the Central Huron area, the Cataract Group includes the Manitoulin and the Cabot Head formations. The Clinton Group is composed of thin- to medium-bedded, very fine- to coarse-grained fossiliferous dolostone. Within the Central Huron area, 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 Central Huron area, 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 Central Huron area, the Guelph Formation is characterized by facies deposited between the basinward pinnacle reef belt found along the eastern shore of Lake Huron, and the patch reefs found in the eastern parts of the Central Huron area (see also Section 3.2.2.3). The basin margin reef complex is located east of the Central Huron area (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 Amabel-Lockport Formation 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). 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., A1, A2, 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; 1977). The Salina Group A1, A2, B, D and F salt units are present in the Central Huron area (Sanford, 1977; Section 5.3.3).

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, which consists of the Amherstburg and Lucas formations, and the Dundee Formation. The Bois Blanc Formation consists of cherty, fossiliferous limestones and argillaceous dolostones that unconformably overlie Silurian strata. The Amherstburg Formation is a bituminous bioclastic fossiliferous limestone and dolostone. The Lucas Formation is fine-crystalline, fossiliferous dolostone and limestone. The Dundee Formation comprises sparsely fossiliferous limestones and minor dolostones that unconformably overly the Detroit River Group.

The Dundee Formation represents the subcropping bedrock throughout most of the Municipality of Central Huron (Figure 3.2). Small areas in the northern and eastern parts of the Municipality of Central Huron have Lucas Formation as subcropping bedrock (Figure 3.2). The Devonian carbonates crop out along the shoreline of Lake Huron and north shoreline of Lake Erie (Figure 3.2).

3.1.5 Fracturing of the Paleozoic Strata

Figure 3.2 shows basement-seated faults that displace the Paleozoic strata in southern Ontario. Faults of the Paleozoic strata in southern Ontario are generally thought to have formed by upward propagation of faults within the underlying Precambrian basement (Carter et al., 1996). Faults shown in Figure 3.2 were compiled from several sources by the Ontario Geological Survey (Armstrong and Carter, 2010) and assigned relative ages based on the youngest geological unit that they offset: i) Shadow Lake/Precambrian, ii) Trenton Group (Ordovician-aged) and iii) Rochester Formation (Silurian-aged; equivalent to the Lions Head Member of the Amabel-Lockport Formation in Table 3.1). 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 by 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 Central Huron area, faults are identified with a lower degree of confidence. As discussed in Section 3.2.2.4, there are no OGS OGS mapped faults within the Central Huron area.

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 Central Huron area, 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 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 in the Paleozoic rocks of 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., 2013).

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 shoreline of Lake Huron near the Bruce nuclear site, approximately 50 km north of the Central Huron area. 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 occur within 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 have formed 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 and systematically 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 indicate 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 is estimated to have been eroded from the Paleozoic succession during and after the late Paleozoic and early Mesozoic periods at the Bruce nuclear site, approximately 50 km north of the Central Huron area (NWMO, 2011).

The 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 (approximately 450 to 250 million years ago), and or corresponding to maximum burial compaction (see Section 3.1.6). 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 the 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 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 text provides 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, within or proximate to the Central Huron area (Figure 3.5). 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;
- 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 in Figure 3.5, there are no known occurrences of near-surface karst within the Municipality of Central Huron. Brunton and Dodge (2008) and Ausable Bayfield Maitland Source Protection Region (2011b) document the occurrence of significant near-surface karst features immediately south of the Municipality and west of the Municipality near Brussels within the Central Huron area. Figure 3.5 also shows that all the Municipality of Central Huron includes areas of inferred 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 southern 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 define regional erosional unconformities (e.g., Silurian - Devonian boundary).

Worthington (2011) summarizes the potential for karst and paleokarst at 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 there is an absence of high-permeability karstic pathways between the Ordovician carbonates and the surface. Comparable conclusions would be expected for the Municipality of Central Huron, particularly for the Upper Ordovician carbonates; Upper Ordovician limestones in the Municipality are expected to have similarly extremely low hydraulic conductivities (see Section 4.2) and are found at depths greater than at the Bruce nuclear site.

3.1.9 Glaciations and Glacial Erosion

The North American continent has been subject to nine glacial events in the last million years (Peltier, 2003). 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 Central Huron area uplift rates approach 0.5 mm/year (Mainville and Craymer, 2006). Conversely, subsidence occurs to the south of the Great Lakes Basin, 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 basin 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 (2015) 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 Central Huron area. The study by Hallet (2011) concluded that although uncertainties remain in ice sheet reconstructions and estimates of erosion by ice and meltwater, 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 Central Huron area. 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 the geomorphology 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. Regional buried bedrock valleys proximate to the Central Huron area include the Walkerton trough located east and west of Walkerton that extends northwest to Lake Huron, the Wingham – Milverton valley that extends from Wellesley, through Milverton to Wingham, and the Mount Forest valley that extends from Drayton to Mount Forest. These regional buried bedrock valleys are located north and east of the Central Huron area. Gao (2011a; 2011b) mapped one buried bedrock valley that extends south from Wingham into the northeast corner of the Central Huron area (Figure 3.6), and refers to this buried bedrock valley as the Hutton Heights valley. JDMA (2015) present drift thickness mapping and discuss buried bedrock valleys within the Central Huron area. For example, a north-trending linear zone of thicker overburden occurs in the southeast corner of the Central Huron area (Figure 3.20) that does not correspond with a positive surficial landform (Figure 2.2). This feature could be a buried valley not identified by Gao (2011b).

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 Central Huron area 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, 2015; Geofirma Engineering Ltd., 2015; JDMA, 2015) to provide insight on the characteristics of the Paleozoic Upper Ordovician shale and limestone units identified as potentially suitable in the initial screening (AECOM Canada Ltd., 2013).

The presentation of the local bedrock and Quaternary geology in this section is focused on the Central Huron area. Figure 3.7 shows the bedrock geology, oil and gas wells, and acquired 2D seismic data in the Central Huron area. Figure 3.8 shows the bedrock geology, oil and gas wells, distribution of the Cambrian unit and the acquired 2D seismic data, as well as the location of geological cross-sections constructed through the Municipality of Central Huron as part of this assessment. Figure 3.8 is presented at a slightly larger scale to accommodate wells used in the construction of the geological cross-sections that are located outside the Central Huron area.

3.2.1 Precambrian Geology

3.2.1.1 Lithotectonic Domains

As described in Section 3.1.3, the Huron Domain of the Precambrian Central Gneiss Belt in the Grenville Province underlies the entire Central Huron area (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, about 50 km north of the Central Huron area, identified the Precambrian basement as pink to grey, fine- to medium-crystalline 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, 2015), the available magnetic and gravity data were interpreted in the Central Huron area. Figures 3.9 to 3.11 show the distribution of magnetic and gravity features located within the Central Huron area. Both the magnetic data (Figures 3.9 and 3.10), and gravity data (Figure 3.11) for the Central Huron area are based on merging of data sets with differing resolutions (PGW, 2015), resulting in linear and irregularly-shaped features along the data set boundaries. For example, the north-trending linear feature in the magnetic data that extends through the Municipality of Central Huron west of Londesborough (Figure 3.9) represents the boundary between the Strathroy and the Waterloo data sets.

In the Central Huron area, 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).

In the Central Huron area, 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, 2015). 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 Central Huron area (Easton, 1992). Based on subtle variability of character and pattern of the magnetic data observed in and beyond the Central Huron area, the Precambrian basement has been subdivided into domains that may reflect changes in basement lithology or lithotectonic domains (Figure 3.9; PGW, 2015).

In the western and central portions of the Central Huron area, and underlying most of the Municipality, Domain A consists of several curvilinear magnetic features that trend west to west–northwest. The eastern most boundary of Domain A is largely defined by a change in the magnetic character to a more north-northeast oriented pattern. Where similar rock units are exposed north of the Central Huron area, several mapped domains similarly show northwest-trending fold structures (Easton, 1992), and are observable in the regional magnetic data for southern Ontario (Gupta, 1991).

In the eastern portion of the Central Huron area, Domain B shows a predominant north to northeastern trend (PGW, 2015). The resulting magnetic features appear as distinct wavy curvilinear to elliptical magnetic anomalies. These anomalies were also identified by Boyce and Morris (2002) in this region of southern Ontario. Easton and Carter (1995) suggest these elliptical magnetic features may represent metamorphosed plutons, where the trend variability corresponds to gneissosity, foliation, folds and shear zones preserved within the Precambrian basement rock near the north-northeast trending Grenville Front Tectonic Zone.

A complex northeast trending anomaly has previously been interpreted over Lake Huron as having a strong magnetic intensity that parallels the Grenville Front Tectonic Zone (O'Hara and Hinze, 1980; Boyce and Morris, 2002). Although outside the Central Huron area, this anomaly has been interpreted to represent the boundary between the Grenville and Superior provinces of the Canadian Shield (Figure 3.4b).

The observed Bouguer gravity data over the Central Huron area exhibit mainly broad responses that are attributed to spatial variability in lithology of the Precambrian basement (PGW, 2015). 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 Central Huron area below Lake Huron (Figure 3.11). 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 eastern portion of the Central Huron area 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, which may correspond to ductile patterns of the Precambrian basement rocks (PGW, 2015). A north-northeast trending gravity feature in the eastern part of the Central Huron area is coincident with a magnetic anomaly that generally marks the boundary between the magnetic Domains A and B (Figures 3.9 and 3.11).

3.2.1.2 Faults

Boyce and Morris (2002) mapped aeromagnetic and gravity lineaments in southern Ontario, including the Central Huron area. These authors interpreted the identified lineaments as zones of potential shearing and faulting in the Precambrian basement underlying the Paleozoic sedimentary sequence in southern Ontario. The lineament interpretation of Boyce and Morris (2002) has been reviewed as part of this assessment based on the newly purchased higher resolution aeromagnetic and gravimetric data covering a portion of the Central Huron area (see Section 1.4.2, and PGW, 2015). Figure 3.9 shows the pole-reduced, first vertical derivative of total magnetic intensity for the Central Huron area. Figure 3.10 shows the aeromagnetic data together with the Boyce and Morris (2002) aeromagnetic lineaments. Figure 3.11 shows the first vertical derivative of Bouguer gravity data within the Central

Huron area (PGW, 2015).

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 Central Huron area. This lack of coincidence is largely due to the differences in interpretation scale between the Boyce and Morris (2002) study compared with 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 Central Huron area, they predominantly comprise curved to circular features that appear to align with highs in the aeromagnetic data used for this assessment (Figure 3.10). These magnetic features are interpreted as most likely lithologically-related magnetic anomalies, and are reflective of the ductile fabric of the Precambrian basement (PGW, 2015), as opposed to cross-cutting brittle fault structures.

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 they offset. There are no OGS mapped faults in the Central Huron area.

3.2.2 Paleozoic Geology

3.2.2.1 Formation Descriptions

Detailed lithological descriptions of the Paleozoic formations within the Central Huron area are not available from the OGSRL Petroleum Wells Database (OGSRL, 2014a) 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 Central Huron area. 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 Central Huron area is mostly based on borehole data and 2D seismic data interpretation work (Geofirma Engineering Ltd., 2015) carried out as part of this preliminary assessment. One of the main objectives of Geofirma Engineering Ltd. (2015) 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., 2015), based on the following:

- Ability to interpret formation tops using borehole geophysical data and to consistently trace them throughout the Central Huron area 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, 2015).

Gamma ray and/or neutron logs available from 111 wells in the Central Huron area and surrounding region were assessed to reinterpret key formation tops. In the Municipality of Central Huron there are 20 wells with useful borehole geophysical data. 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 are available. Geofirma Engineering Ltd. (2015) 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 two geological cross-sections through the Municipality of Central Huron (Figures 3.12 and 3.13) to better illustrate the depths and thicknesses of the key Paleozoic stratigraphic packages (Geofirma Engineering Ltd., 2015). The Cambrian sandstone was not defined as a key formation in Geofirma Engineering Ltd. (2015), given that it cannot be identified with confidence on borehole geophysical logs; however, its interpreted subsurface distribution is shown in Figures 3.12 and 3.13, based on formation top depth information obtained from the OGSRL database (OGSR, 2014) and distribution of Cambrian units interpreted by Bailey and Cochrane (1984a) (Figures 3.8 and 3.17).

Figure 3.8 shows the location of the two 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 Central Huron area. 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. It is also worth noting that only five wells in the Central Huron area, three of which are within the Municipality, extend through the entire Paleozoic sequence.

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 3.12 and 3.13 also show the bedrock surface from Gao et al. (2006), the DEM ground surface, gamma ray logs where available, and the extent of the Municipality of Central Huron (Geofirma Engineering Ltd., 2015).

Figures 3.12 and 3.13 show that the Upper Ordovician shale and limestone packages are laterally continuous and 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 Central Huron area. The interpretation of 2D seismic data generally supports the interpretation of lateral continuity and uniformity of the thickness of the Paleozoic formation packages (see Section 3.2.2.4); however, these data are recognized to be of poor quality (Geofirma Engineering Ltd., 2015b). The Silurian formation package shows some variability in total thickness, most likely due to the following:

- 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 Central Huron area.

Paleozoic formations in the Central Huron area are known to dip uniformly to the southwest at between 0.23° and 1° (e.g., Watts et al., 2009; Intera Engineering Ltd., 2011; Armstrong and Carter, 2010). The inflections in the dips of key formation tops observed in the cross-sections (Figures 3.12 and 3.13) 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.

The cross-sections presented in Figures 3.12 and 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 both cross-sections constructed during this preliminary 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 a selected number of representative deep wells that provide spatial coverage within the Municipality of Central Huron, 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 for the Central Huron area and surrounding region (Geofirma Engineering Ltd., 2015). This updated database was also used to generate contour maps for the top of the Coboconk, Cobourg and Queenston formations, as shown in Figures 3.14 to 3.16.

Formation tops contour maps shown in Figures 3.14 to 3.16 were created using the iterative minimum curvature gridding method with a grid cell size of 500 m (Geosoft, 2012), with the exception of the Cobourg Formation surface. The Cobourg Formation surface was computed with a grid cell size of 1,000 m. The larger cell size used for this surface is based on the fewer number of boreholes that intersect the surface. 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. It is worth noting that information on depth to the top of the Coboconk and Cobourg formations within the Central Huron area is available from only three and five wells, respectively, mostly located in the western portion of the area. Well control for the construction of these contour maps was also provided by wells from the region surrounding the Central Huron area.

The depth contour maps shown in Figures 3.14 to 3.16 illustrate depth variations of the Paleozoic Upper Ordovician units in the Central Huron area. Figure 3.14 shows that the depth to the top of the Coboconk Formation (i.e., top of Black River Group) is estimated to range from approximately 900 mBGS to about 1,040 mBGS in the Municipality of Central Huron. Information from well T006364

Table 3.3 Summary of Bedrock Formation Top Depths within the Municipality of Central Huron (in mBGS)

		OGSRL Well ID	**F011965**	**F011970**	**F011974**	**F011975**	**F011976**	**F011978**	**F011982**	**F011986**	**F011987**	**F011989**
		Date Drilled	1958	1939	1955	1953	1953	1956	1941	1953	1958	1956
		Total Depth (mBGS)	618.2	1075.7	1128.4	566.6	563.3	517.6	551.4	549.0	611.1	569.7
Standard Reference		**Geological Unit**										
Devonian	Middle	Dundee Formation	26.2	35.98	51.2	28.39	29.3	11.6	14.6	25.3	21	30.2
		Lucas Formation	38.4	64.93	68	55.79	63.7	28.4	16.2	34.1	30.8	51.2
		Amherstburg Formation	-	-	-	-	-	-	-	-	-	-
	Lower	Bois Blanc Formation	132.6	-	174.7	-	-	-	119.8	-	146.3	-
Silurian	Upper	Bass Islands*	215.2	212.76	261.5	226.49	225	190.2	176.2	205.7	210.3	221.3
		Salina G Unit*	264.8	269.1	296.6	276.79	275.9	232.4	223.4	255.4	262.4	264.4
		Salina F Unit*	273.7		304.2		281.3	239.4			271.4	272.4
		Salina E Unit	337.4	-	356.9	318.79	308.5	287.4	261.5	289.3	321	317.9
		Salina D Unit	361.2	-	386.2	-	-	-	-	-	346.9	-
		Salina C Unit	370.4	-	393.5	344.99	342.9	309.1	295.1	324.9	352.7	340.2
		Salina B Unit	398.1	371.3	420	384.69	369.1	329.2	327.1	348.1	386.8	362.7
		Salina A2 Unit	474.6	445.9	493.2	435.89	433.4	350.8	378.9	419.7	458.7	439.2
		Salina A1 Unit	538.6	494.7	555.7	492.59	484	369.1	416.4	469.4	524.6	492
		Guelph Formation	579.4	535.8	598.3	534.59	528.8	391.1	458.4	510.9	568.2	532.8
	Lower	Goat Island Formation	-	-	-	-	-	-	-	-	-	-
		Gasport Formation	-	-	-	-	-	-	-	-	-	-
		Rochester Formation	603.8	-	623.9	557.19	552.6	495.6	485.6	538.6	588	558.1
		Reynales / Fossil Hill Formation	606.9	-	627.3	561.09	555.7	499.6	488.3	540.7	591	559.9
		Cabot Head Formation*	610.5	566.3	630.3	564.79	563	505.7	496.2	548.3	605.9	566.3
		Manitoulin Formation	-	-	659.6	-	-	-	516	-	-	-
Ordovician	Upper	Queenston Formation*	-	602.9	669.4	-	-	-	526.4	-	-	-
		Georgian Bay / Blue Mtn Formation	-	682.2	747.4	-	-	-	-	-	-	-
		Cobourg Formation - Collingwood Member*	-	828.5	885.8	-	-	-	-	-	-	-
		Sherman Fall Formation	-	-	-	-	-	-	-	-	-	-
		Kirkfield Formation	-	-	-	-	-	-	-	-	-	-
		Coboconk Formation*	-	-	-	-	-	-	-	-	-	-
		Gull River Formation	-	-	-	-	-	-	-	-	-	-
		Shadow Lake Formation	-	1060.1	-	-	-	-	-	-	-	-
Cambrian		Cambrian Sandstone	-	-	1115	-	-	-	-	-	-	-
Precambrian		Precambrian*		1062.2	1123.8	-	-	-	-	-	-	-

*Note: * and shading indicate Key Formations*

Table 3.3 Summary of Bedrock Formation Top Depths within the Municipality of Central Huron (in mBGS) (Continued)

		OGSRL Well ID	T001092	T003632A	T005326	T006251	T006341	T006346	T006364	T007179	T008843	T011960
		Date Drilled	1961	1973	1980	1983	1983	1983	1983	1987	1999	2009
		Total Depth (mBGS)	523.4	535.3	599.8	622.6	630.8	646.0	1132.0	596.5	621.7	567.0
Standard Reference		**Geological Unit**										
Devonian	Middle	Dundee Formation	18	25	24.8	39.8	22.8	66.7	57.8	47.9	58.5	73.3
		Lucas Formation	25	45.7	39.8	58.8	40.8	88.2	87	58.5	74.2	84.3
		Amherstburg Formation	-	120.4	118.8	111.8	111.5	168.3	162	137.2	131.7	84.3
	Lower	Bois Blanc Formation	147	193	195.3	156.8	143.3	200.4	206	174.2	188	213.3
Silurian	Upper	Bass Islands*	189.6	211.8	222	226.8	220.3	286.2	255	234	255.2	292.3
		Salina G Unit*	242.7	260.3	266.3	275.8	271.5	336	348.5	283.7	303	357.3
		Salina F Unit*	-	268.8	278.8	283.8	279	344	355	291.3	310.9	367.3
		Salina E Unit	-	303.6	312.4	343.8	312.4	391.6	409.7	335.2	344	402.3
		Salina D Unit	-	330.1	347.4	368.8	364.5	-	-	358.3	379.4	430.3
		Salina C Unit	326.2	338	362.3	383.8	375.3	428.1	446.8	373	392.1	430.3
		Salina B Unit	340.5	355.7	380.2	400.8	394.5	436.6	453	390.3	411.8	
		Salina A2 Unit	401.8	431	463.2	487.3	478.5	451.3	477	485.5	494.5	459.3
		Salina A1 Unit	442.3	483.7	518.8	549.8	542.5	477.2	514.1	532.5	554.6	
		Guelph Formation	495	520.9	556.8	591.8	580.3	495.6	524.4	571.3	594.3	485.3
	Lower	Goat Island Formation	-	525.2	-	598.8	589.7	614	589.3	578.6	600.2	-
		Gasport Formation	-	-	-	609.8	600.6	623	598.7	587.8	607.2	-
		Rochester Formation	521.6	-	-	613.8	605.5	627.2	613	592.5	611.7	-
		Reynales / Fossil Hill Formation	-	-	-	620.8	608.7	630.5	629.3	-	614.7	-
		Cabot Head Formation*	-	-	587.8	620.8	611.8	632	636.2	-	619.7	-
		Manitoulin Formation	-	-	-	-	614.7	-	657.7	-	-	-
Ordovician	Upper	Queenston Formation*	-	-	-	-	617.4	-	666.6	-	-	-
		Georgian Bay / Blue Mtn Formation	-	-	-	-	-	-	760.7	-	-	-
		Cobourg Formation - Collingwood Member*	-	-	-	-	-	-	883.5	-	-	-
		Sherman Fall Formation	-	-	-	-	-	-	939	-	-	-
		Kirkfield Formation	-	-	-	-	-	-	984	-	-	-
		Coboconk Formation*	-	-	-	-	-	-	1027.3	-	-	-
		Gull River Formation	-	-	-	-	-	-	1051.6	-	-	-
		Shadow Lake Formation	-	-	-	-	-	-	1117.4	-	-	-
Cambrian		Cambrian Sandstone	-	-	-	-	-	-		-	-	-
Precambrian		Precambrian*	-	-	-	-	-	-	1124	-	-	-

*Note: * and shading indicate Key Formations* within the Municipality indicates a thickness of the Black River Group of about 97 m, which is consistent with data from two boreholes outside the Municipality (i.e., F001893 and F012018) showing thicknesses of 90 and 97 m, respectively. Depth to the top of the Cobourg Formation is estimated to range from about 750 mBGS in the eastern corner of the Municipality to approximately 885 mBGS in the western part of the Municipality (well F0011974 in Table 3.3; Figure 3.15). Thickness of the Trenton Group based on data from three wells in the Central Huron area (T006364, F011893 and F012018) is also relatively uniform and on the order of 126 to 155 m. Within the Municipality, depth to the top of the Upper Ordovician shales (i.e., top of the Queenston Formation) ranges from approximately 530 mBGS to almost 650 mBGS (Figure 3.16), with a relatively uniform total thickness of the Upper Ordovician shale units ranging from approximately 216 m to 232 m based on information from three wells (F011970, T006364, F011974; OGSRL, 2014; Geofirma Engineering Ltd., 2015).

Erosion, pinnacle reef formation and salt bed dissolution introduce a certain degree of non-uniformity into the Paleozoic sequence in the Central Huron area, 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, the thicknesses of subcropping bedrock units will locally vary, as shown in the cross-sections in Figures 3.12 and 3.13. The Cambrian unit in the Central Huron area is generally interpreted to pinch out eastwards from the shores of Lake Huron and is expected to be absent beneath most of the Municipality (Figures 3.8 and 3.17; Section 3.1.4.1).). It should be noted that the Cambrian sandstone reported in the OGSRL borehole log for borehole F011970, located at the intersection of cross-section A-A' and B-B' and east of the pinch out line shown in Figures 3.8 and 3.17, is actually interpreted as the Shadow Lake Formation based on the small thickness reported and to be consistent with Bailey and Cochrane's interpreted distribution. Therefore, borehole F011970 does not show any interpreted Cambrian sandstone in Figures 3.12 and 3.13.

As described in Sections 3.1.4.3 and 3.2.2.3, 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. As shown in Figure 3.17, there are three known pinnacle reefs within the Municipality of Central Huron. Figure 3.17 also shows the plan extents of the Salina Group salt beds in the Central Huron area. The A1, A2, B, D and F Unit salts are present in the Municipality of Central Huron thinning out towards the east. Where salt dissolution occurred in the Municipality (e.g., D and F Unit salts – Sanford, 1977), there is the potential to have collapse structures in the overlying formations (Sanford, 1993).

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, where the Municipality of Central Huron is located (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 10s of hectares up to 120 hectares or approximately 1,000 m in maximum diameter (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011).

The Central Huron area lies in portions of the pinnacle to patch to barrier reef zones of the Guelph Formation. Known locations of pinnacle reefs (OGS, 2011) in the Central Huron area are shown in Figure 3.17. The locations of such known reefs are defined based on thickening of the Guelph Formation from borehole observations. As described in Section 5.1, pinnacle reefs in the Guelph Formation often host hydrocarbon pools in southern Ontario. There are five known pinnacle reefs identified in the Central Huron area (OGS, 2011), three of which lie within the Municipality (Figure 3.17). The two pinnacle reefs in the western portion of the Municipality, and those that lie immediately south of the Municipality are active or former hydrocarbon pools (see Section 5.1.2).

It was not possible to identify any additional pinnacle reefs that were not already identified in the OGSRL database within the Central Huron area using the cross-sections constructed as part of this assessment (Section 3.2.2.2; Geofirma Engineering Ltd., 2015), 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, while it is possible that the interpreted 2D seismic line crosses the edge of the Tipperary Pool reef structure, the poor quality and limited lateral resolution of the seismic data did not allow for the interpretation of any reefal structure.

As part of the interpretation of geophysical data, PGW (2015) completed an evaluation of the gravity data within the Central Huron area in an attempt to identify locations of known pinnacle reefs, and to also identify the potential presence of unknown pinnacle reefs. Gravity data have been used throughout southern Ontario to locate pinnacle reefs for exploration programs (Pohly, 1966). In particular, to assess coincidence, the locations of the known pinnacle reefs in the Central Huron area were compared to the responses from the observed Bouguer gravity and its first vertical derivative data. The results of this comparison (PGW, 2015) show there are several point anomalies in the first vertical derivative of the Bouguer gravity data in the Central Huron area that correlate well with most of the locations of known pinnacle reefs within the Paleozoic sedimentary sequence. However, there are many other positive gravity anomalies that appear comparable and some of these could be pinnacle reefs.

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 modelled and subsequently stripped from the Bouguer gravity data (PGW, 2015). However, the process of removing modelled gravity effect does not appear to significantly enhance the locations of the known pinnacle reef structures within the Central Huron area. Similar to the observed Bouguer gravity, it is assumed that, although a small amount of this resulting response may be attributed to the Paleozoic layers, the majority of the signal is derived from the lithological variability within the Precambrian basement rocks.

3.2.2.4 Fracturing of the Paleozoic Strata in the Central Huron Area

Information on the location and relative age of potential faults within the Paleozoic bedrock sequence in the Central Huron area 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 a 2D seismic line completed as part of this assessment (Geofirma Engineering Ltd., 2015).

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 Central Huron area 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 3.2 shows that there are no mapped subsurface faults in the Municipality of Central Huron or in the Central Huron area.

Figure 3.18 shows the results of the reprocessing and interpretation of seismic line A000300528, which runs north-south in the western portion of the Municipality of Central Huron (shown in Figure 3.8). Figure 3.18 shows the processed seismic data in a time versus line length plot, with interpreted major reflectors. Major reflectors include: Dundee, 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, Coboconk and Precambrian, and are noted on the data plot. No faults were interpreted based on this 2D seismic data, possibly due in part to the poor quality of the data.

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 Inverhuron Provincial Park, and for other areas of exposed Devonian and Silurian bedrock including the southern part of the Bruce peninsula (NWMO and AECOM Canada Ltd., 2011). Outcrop mapping in these locations, more than 50 km north of the Central Huron area, 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-centred 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 Central Huron area is described in detail in the Terrain and Remote Sensing Study Report (JDMA, 2015), 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 Central Huron area were formed and deposited by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet during the Late Wisconsinan 23,000 to 10,000 years ago (JDMA, 2015). 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 Central Huron area, the nature and distribution of surficial aquifers, groundwater discharge and recharge areas and sand and gravel deposits. Seamless mapping of surficial geology in the Central

Huron area is provided in Figure 3.19 (OGS, 2010).

A summary of glacial periods and Quaternary deposits in the Central Huron area is presented in Table 3.4 after JDMA (2015) and Barnett (1992). The surficial deposits of the Central Huron area have been mapped at the scale of 1:50,000 by Cooper and Fitzgerald (1977), Cooper et al., (1977) and Cowan et al. (1986).

Table 3.4 Summary of Quaternary Deposits and Events in the Central Huron Area

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	Warren beaches and bluffs
		St. Joseph Till	Wyoming Moraine
14,000 – 13,000	Mackinaw Interstade	Glaciolacustrine deposits	Clay plains
15,200 – 13,800	Port Bruce Stade	Glaciofluvial deposits	Outwash and ice-contact landforms
		Rannoch Till	Wawanosh Moraine, Startford till plain
		Elma Till	Teeswater and Dundalk drumlin fields, Wawanosh Moraine
16,500 – 15,500	Erie Interstade	Glaciolacustrine deposits	Buried
23,000 – 18,000	Nissouri Stade	Catfish Creek Till	Buried

Overburden thickness in the Central Huron area is shown in Figure 3.20 based on the data release of Gao et al. (2006) that involved quality assurance checking to remove erroneous water well information from the MOECC Water Well Information System. Overburden thickness in the Central Huron area ranges from zero up to about 91 m, with an average thickness of 28 m. Within the Municipality of Central Huron the overburden thickness ranges from zero to 80 m with an average of 31 m. The thickest overburden in the Central Huron area is associated with areas of high relief and elevation, and with till moraines and kame moraines, particularly the Wyoming Moraine and the northeast extension of the Wawanosh Moraine (Figure 3.19). The thinnest drift occurs along the Maitland and South Maitland rivers, where bedrock is exposed locally in the channels. Overburden thickness generally increases from east to west across the Municipality.

Table 3.5 provides a summary in percentages of the areal extent of the different surficial deposits mapped within the Central Huron area and within the Municipality (Figure 3.19).

Table 3.5 Extent of Surficial Deposits within the Municipality of Central Huron and within the Central Huron Area

Area	*Primary genesis (expressed as % area)*						
	Fluvial	*Glacial Morainal*	*Glacio-fluvial*	*Glacio-lacustrine*	*Lacustrine*	*Organic*	*Bedrock*
Municipality of Central Huron	2.0	45.8	34.2	17.8	0.0	0.1	0.1
Central Huron area	2.4	53.4	26.3	17.0	0.1	0.7	0.1

Glacial morainal deposits occur extensively throughout the Central Huron area covering 53.4% of the area and consisting of, in decreasing order of abundance, the Rannoch Till, the St. Joseph Till and the Elma Till. Glaciofluvial deposits consisting primarily of sand or sand and gravel are exposed over 26.3% of the Central Huron area. These glaciofluvial deposits are associated with kames, eskers and outwash plains. Glaciolacustrine deposits are exposed over 17.0% of the Central Huron area, with about 79% of these deposits mapped as fine-grained sediments consisting of silts and clays and the remaining 21% as sand or sand and gravel. Other surficial deposits including fluvial, lacustrine, organic and bedrock are all relatively minor occurrences in the Central Huron area.

The eastern part of the Municipality is characterized by thin drift, low relief, high elevation and low permeability surficial deposits principally comprised of Rannoch Till of the Stratford till plain. The central part of the Municipality is dominated by a very hummocky and irregular area of topography underlain largely by glaciofluvial deposits associated with the Wawanosh Moraine. Ice-contact deposits of sand and gravel are abundant in this area. The ice-contact deposits in the Wawanosh Moraine overlie Elma Till and locally underlie Rannoch Till. The Wyoming Moraine represents a north-south trending band of hummocky topography about 5 to 6 km wide located in the western part of the Municipality. A network of meltwater channels extends between the Wawanosh and Wyoming moraines and in the valleys of the Maitland and Bayfield rivers (Figure 3.19). The westernmost part of the Municipality along Lake Huron is characterized by a bevelled till plain with shallow deposits of permeable sand overlying several metres of silt and clay.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Central Huron area 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 3.21 presents the location of earthquakes with a moment magnitude (m_W) 3 or greater that are known to have occurred in Canada from 1627 until 2012 (Natural Resources Canada, 2015b). Figure 3.21 shows that no seismic events exceeding a magnitude of 6 m_w have been recorded within 300 km of the Central Huron area.

Figure 3.22 shows the recent (1985 to 2014) record of seismic events for southern Ontario using the Nuttli Magnitude (m_N) as contained within the National Earthquake Database (Natural Resources Canada, 2015a). Earthquake magnitude resolution in Figure 3.22 was improved to <1 m_N for the Central Huron area 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 geologic repository (DGR) for low and intermediate level waste project (University of Western Ontario, 2008), and to magnitude 2 m_N for the remainder of southern Ontario based on an expanded POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigation Seismicity) network established in 2002. As shown in Figure 3.22 there have been no recorded earthquakes within the Municipality of Central Huron since 1985, with the closest recorded earthquakes located just offshore in Lake Huron about 25 km southwest of the Municipality. The maximum magnitude of these events was of 2.4 m_N. A 4.3 m_N earthquake was recorded in 2005 northeast of Owen Sound within Georgian Bay at a distance of 135 km from the centre of the Municipality of Central Huron (Hayek et al., 2013).

Hayek et al. (2013) note that there is limited accurate information on the depth of earthquakes in the vicinity of the Bruce nuclear site and, by extension, of the Central Huron area, due to the lack of large enough earthquakes to reliably calculate depths. The reported depths of earthquakes by Hayek et al. (2013) 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 (AMEC Geomatrix, 2011). This PSHA 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 Municipality of Central Huron is 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 and glacial forces acting in the North American plate.

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 Central Huron area is typical of many areas of southern Ontario, which have been subjected to nine glacial cycles during the last million years (Peltier, 2003). 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 Central Huron area 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 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 reasonably well with the postglacial rebound models, indicating present day rebound rates in the Central Huron area approaching 0.5 mm/yr. 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 Central Huron area.

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, and maps), 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 area immediately north of the Central Huron area. No conclusive geomorphological or sedimentological evidence of post-glacial neotectonic activity was identified within the area studied (Slattery, 2011).

The Terrain and Remote Sensing Study (JDMA, 2015) did not identify any neotectonic features in the Central Huron area and concluded it would be very difficult 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 Central Huron area. For the purpose of this report, aquifers located in overburden and shallow bedrock are usually understood to be layers, formations or units that yield sufficient quantities of groundwater for water supply needs. For deeper bedrock, aquifers are understood to be formations or units that yield sufficient water for groundwater sampling.

Information on physiographic and terrain features (Figure 2.2), surficial and Quaternary geology (Figure 3.19), and subsurface overburden occurrence from MOECC water well records have been compiled and interpreted to broadly map the spatial distribution of overburden aquifers and aquitards within the Central Huron area. This work has been completed principally in support of Provincial Source Water Protection initiatives (Ausable Bayfield Maitland Valley Source Protection Region, 2011a; 2011b).

Information on bedrock aquifers, aquitards and aquicludes in the Central Huron area 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 MOECC 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 Municipality. Deep bedrock hydrogeological information is available from detailed drilling and testing investigations at the Bruce nuclear site, from regional compilations completed as part of a geosynthesis report (NWMO, 2011), and from interpretations of deep oil and gas drilling records maintained by the OGSR Library (e.g., Carter and Fortner, 2011; Carter et al, 2015a; 2015b; Skuce et al., 2015). Extrapolation of these deep bedrock hydrogeologic data to the Municipality of Central Huron is based on the known lateral traceability and predictability of the deep bedrock conditions within the Central Huron area, but would need to be confirmed during subsequent site evaluation stages.

4.1 Groundwater Use

Information concerning groundwater use in the Central Huron area was obtained principally from the Ontario Ministry of the Environment and Climate Change (MOECC) Water Well Information System (WWIS) database (MOECC, 2014a), 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 Central Huron area are shown in Figure 4.1, which shows all known MOECC water wells plotted by type – overburden or bedrock - on a background of surficial geology.

The WWIS database contains a total of 4,260 water well records for the Central Huron area. Not all these water well records are complete and not all these records provide useful hydrogeological information that can be plotted in Figure 4.1. Of the 3,194 wells shown in Figure 4.1 for the Central Huron area, 299 have been reliably identified as overburden wells, and 2,895 as bedrock wells. The well type was uncertain for the remaining 1,066 wells, and these wells are not shown in Figure 4.1.

Figure 4.1 also shows the location of six monitoring wells (five bedrock, one overburden) within the Central Huron area that are part of the Provincial Groundwater Monitoring Network (PGMN) (MOECC, 2014b). These wells are regularly monitored for water level and groundwater quality by the Province. Two of these wells (one bedrock, one overburden) are located within the Municipality of Central Huron (see Figure 4.1) between the Wyoming and Wawanosh moraines.

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 the Municipality of Central Huron. 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 overburden wells represent approximately 8% of the wells within the Municipality of Central Huron.

Table 4.1 Water Well Record Summary for the Municipality of Central Huron

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 Central Huron (Total 1,117 Well Records)								
Overburden	90	1.2	134.1	0.3	33.5	7.6	75.7	30.4
Bedrock	1,027	7.0	275.0	0.3	96.0	3.8	700	47.8

The Municipality of Central Huron relies 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, all eight of the public and municipal groundwater supply wells in the Municipality of Central Huron obtain water from shallow bedrock aquifers.

4.1.1 Overburden Aquifers

Overburden wells in the Central Huron area are generally 10 to 100 m deep and have well yields of 10 to 70 L/min (MOECC, 2014a). 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 local overburden aquifers. In contrast, silt and clay of clay plains, till plains, till moraines, lacustrine and glaciolacustrine deposits are commonly associated with local overburden aquitards.

Figures 2.2 and 3.19, and the Terrain and Remote Sensing Study (JDMA, 2015), show overburden deposits within the Municipality can be divided into four zones extending from west to east, and be used to infer presence of local overburden aquifers and aquitards. The westernmost zone is characterized by a discontinuous high permeability sand veneer forming an unconfined aquifer draped over low permeability deposits of St. Joseph Till overlying glaciolacustrine silts and clays. The next zone eastward consists of the Wyoming Moraine and adjacent spillways. This zone of very thick drift

(40 to 91 m) consists of low permeability St. Joseph Till forming till ridges and other topographic highs, while high permeability sand and gravel outwash deposits exist in spillways and other topographic lows forming localized unconfined aquifers. The third zone consists of the Wawanosh Moraine and adjacent spillways. In this zone, highly permeable and locally very thick ice-contact sand and gravel forms kames and other topographic highs, while outwash sand and gravel is exposed in spillways and other topographic lows that form local unconfined aquifers. Low permeability Rannoch Till has been deposited over some of the ice-contact and outwash deposits, rendering some of the sand and gravel deposits as confined aquifers. The easternmost zone, which exhibits the highest elevations of the four zones, is represented by the Stratford till plain. This is the largest area of low relief and thin drift (Figure 3.20) within the Municipality, an area underlain largely by Rannoch Till and sporadic deposits of glaciolacustrine silts and clays.

Consistent with the above description of overburden, noteworthy overburden aquifers within the Municipality of Central Huron identified by Ausable Bayfield Maitland Valley Source Protection Region (2011a; 2011b) include the following:

- the unconfined sand Lake Warrren Shoreline Aquifer forming a narrow band of glacioclacustrine deposits running north-south inland and parallel to Lake Huron;
- the unconfined sand and gravel Lake Huron Beach Aquifer situated along the present day shoreline of Lake Huron;
- the unconfined sand and gravel Wawanosh Kame Moraine Aquifer situated in the central part of the Municipality;
- the unconfined sand and gravel Holmesville Outwash Aquifer located between the Wyoming and Wawanosh moraines; and
- the unconfined Seaforth Moraine Aquifer located within and on the flanks of the north-south trending Seaforth Moraine situated immediately west of the Hullet Marsh.

Source water protection assessment reports (Ausable Bayfield Maitland Source Protection Region, 2011a; 2011b) also provide the location of significant groundwater recharge areas within the Central Huron area. 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 Central Huron area. Significant groundwater recharge occurs throughout the Municipality 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 depths of 500 mBGS or greater. There are 2,895 water well records in the Central Huron area that can be confidently assigned to shallow bedrock aquifers. Shallow bedrock hydrogeological information is available primarily to depths of 100 -150 m from the MOECC well records (MOECC, 2014a) based on regional use of this shallow bedrock aquifer as a source of drinking water, although some wells are shallower and some are deeper than this general depth range. Shallow bedrock is the most important source of drinking water in the Municipality of Central Huron, and is the primary source of all the public and municipal water supplies located inland from

Lake Huron. Shallow bedrock aquifers within the Municipality are composed of an aggregate of the upper few metres to over 100 m of the different shallow bedrock formations present, which typically include Middle Devonian Dundee Formation limestone and Lucas Formation dolostone and limestone (Figure 3.7). Water quantity and quality within the shallow bedrock aquifer can vary dramatically across the Municipality of Central Huron as a consequence of the different chemical and physical characteristics of the individual bedrock formations.

In most parts of the Central Huron area, 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 (Ausable Bayfield Maitland Source Protection Region, 2011a; 2011b) map the areas of shallow bedrock aquifer vulnerability to surface sources of contamination within the Central Huron area. 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 Central Huron area. In accordance with provincial guidance, aquifer vulnerability is not calculated in well head protection areas and land-based intake protection zones and these areas appear as white in Figure 4.2. 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.

Throughout the Municipality and the Central Huron area, the shallow bedrock aquifer, consisting of the Dundee Formation limestone and to a lesser extent the Lucas Formation dolostone and limestone, is confined by overlying layers of clay and silt till. Near the contact of the Lucas Formation with the overlying Dundee Formation about 9 km northeast of the Municipality, the Lucas limestone has been associated with localized karst (i.e., sinkhole) development (Figure 3.5; Ausable Bayfield Maitland Source Protection Region, 2011b). Karst is also known to occur immediately south of the Municipality (Figure 3.5). Such areas of karst and sinkhole development in the Lucas and Dundee formations provide high quality, high yielding aquifers extensively used as sources of drinking water. Areas that drain into sinkholes are Significant Groundwater Recharge Areas under Ontario's *Clean Water Act*.

4.1.3 Shallow Groundwater Regime

The shallow groundwater regime includes overburden aquifers that provide drinking water supplies to residences and shallow confined bedrock aquifers that provide water supplies to both communities and residences (Waterloo Hydrogeologic Inc., 2007). The shallow groundwater regime typically extends to depths of less than 60 m. Groundwater flow directions within shallow systems often mimic surface water flow directions with the groundwater table generally present as a subdued reflection of topography. Shallow groundwater flow will be directed from areas of higher hydraulic head, such as highlands and drainage divides, to areas of lower hydraulic head such as valleys, depressions, and surface waters. The extent of such shallow flow systems will be defined by local, topography-controlled, drainage divides across which groundwater flow will not readily occur. Generally, for such shallow systems, groundwater divides will coincide with surface water drainage divides.

Information on the shallow overburden and bedrock groundwater flow systems within the Central Huron area is provided in the Provincial Source Water Protection Assessment Reports (Ausable Bayfield Maitland Source Protection Region, 2011a; 2011b). Information on surficial deposits (Figure

3.19) and landforms (Figure 2.2), and subsurface overburden and bedrock occurrence from MOECC water well records have been compiled and interpreted in these studies to broadly map the spatial distribution of overburden aquifers and aquitards within the Central Huron area. This information has been compiled and incorporated into watershed-scale, calibrated 3-D groundwater flow models for the purposes of addressing Provincial Source Water Protection needs (Waterloo Hydrogeologic Inc., 2007).

Contour maps of the groundwater table surface within the overburden deposits and shallow bedrock aquifers of the Central Huron area have been prepared in the Provincial Source Water Protection Assessment Reports and in the hydrogeologic modelling report based on the large number of water wells that access the overburden and shallow bedrock for water supply (Waterloo Hydrogeologic Inc., 2007). These potentiometric surface maps show that both overburden and shallow bedrock groundwater within the Municipality flows broadly to the west from the highland areas along the eastern edge of the area (Figure 2.3) towards Lake Huron, similar to surface water flow within the Ausable and Maitland Valley watersheds (Figure 2.5). The potentiometric surface for the shallow bedrock is within the overlying tills confirming the hydrogeological confinement of the shallow bedrock aquifer.

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 the Municipality of Central Huron, 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, 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 [Hydrostratigraphic (HS) Unit 6 in Figure 4.3a), 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 Municipality of Central Huron is reviewed below, although the presence of the associated geological formations has already been discussed in Section 3.2.2.2.

Based in Figure 3.16, the top of HS Unit 5 (Ordovician shale aquiclude) is expected to be found at depths of about 530 to 650 mBGS in the Municipality of Central Huron, with an estimated thickness of

210 to 230 m. Based in Figure 3.15, the top of very low hydraulic conductivity HS Unit6 (Ordovician limestone aquiclude) is interpreted to be at depths of about 750 to 885 mBGS in the Municipality of Central Huron.

4.3 Hydrogeochemistry

Information on overburden and shallow bedrock groundwater geochemistry in southwestern Ontario, including the Central Huron area, is presented by the Ontario Geological Survey (Hamilton, 2015) and by MOECC (2014b). Within the Central Huron area, Hamilton (2015) summarizes the groundwater geochemistry of 21 wells (8 overburden, 13 bedrock) to a maximum depth of 96 m sampled in 2007-2014; and MOECC (2014b) present water quality information for the six 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 Municipality of Central Huron. Figures 4.4 and 4.5 summarize the expected hydrogeochemistry of the shallow to deep Paleozoic and underlying Precambrian bedrock within the Central Huron area 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 of the Bruce nuclear site DGR Geosynthesis (NWMO, 2011; Hobbs et al., 2011), and by the Ontario Petroleum Institute (Carter and Fortner, 2011). Carter et al. (2015a) and Skuce et al. (2015) provide recent updates to these earlier compilations for individual deep bedrock formations based on Petroleum Well Records maintained by the OGSRL. 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. Where formations are permeable enough to allow conventional groundwater sampling, the regional data from sampling oil and gas wells confirm the suitiability of relying on Bruce nuclear site hydrogeochemical data as indicators of hydrogeochemistry of deep bedrock formations in the Municipality of Central Huron.

Figure 4.4a shows the profile of Total Dissolved Solids (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 $\delta^{18}O$ 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 0.5 g/L and oxidizing redox conditions. These overburden hydrogeochemical conditions are confirmed by recent sampling in the Central Huron area by Hamilton (2015).

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 ~0.5 g/L) near the top of the bedrock to brackish Ca-SO_4 water (TDS ~5 g/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 Central Huron area by Hamilton (2015), with fresh to slightly brackish groundwater reported. The deeper parts of HS Unit 2 including the Bass Islands Formation show a depleted $\delta^{18}O$ and δD signature, and ^{14}C ages indicative of a glacial meltwater component. Mixing and exchange of higher TDS $Ca\text{-}SO_4$ 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 $Ca\text{-}SO_4$ water (TDS ~10 g/L) near the top of the Unit (169.3 mBGS) to Na-Cl brine (TDS ~325 g/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 g/L at 328.5 mBGS to 370 g/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 g/L. The lower aquifer of the Guelph Formation contains Na-Cl brine with TDS of 370 g/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 g/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 g/L at the top of unit to about 230 g/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 (i.e. Cobokonk, Gull River, and Shadow Lake formations) 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 g/L at the top of Coboconk Formation to ~200 g/L in the top to middle of the Gull River Formation and then increases to ~230 g/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 to 235 g/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 Central Huron area, 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 g/L towards an estimated Precambrian Shield source brine of more than 350 g/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 are consistent with the regional scale understanding, and suggests a similar origin for brines in the Silurian and Ordovician rocks of the Central Huron area (Clark et al., 2013; Al et al., 2015). Clark et al, (2013) conclude the hypersaline porewater found in the deep Orodvician aquiclude originated at evaporated Silurian seawater and that authigenic helium within the halite minteralized aquiclude has been accumulating for over 260 milion years. Numerical simulations by Al et al. (2015) of the porewater profiles of Clark et al. (2013) support the interpretation that diffusion is the principal solute-transport process in the low permeability Plaeozoic rock over times scales on the order of several hundred million years. The relevance of these research results at the Bruce nuclear site to the Central Huron area 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. Because deep formation hydraulic pressures are in part associated with bedrock formation hydraulic properties, the regional lateral traceability and predictability of bedrock formation properties indicates that formation pressure data from the Bruce nuclear site can be broadly expected to occur in the Municpality of Central Huron, particularily for the low permeability HS Units 5 and 6.

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 densitycompensated 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 m expressed as environmental water head. Figure 4.6 shows the temporal evolution of these underpressures and that the formation pressures were not at equilibrium values and continued to decrease over measurement period. For example, Figure 4.6b shows the measured pressures and calculated environmental heads immediately after casing installation on April 28, 2009 and subsequently on June 6, 2009, August 24, 2009, November 15, 2009 and February 10, 2010 in borehole DGR-4 over a ten month monitoring period.

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 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).

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 Central Huron area 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 Central Huron area in this report broadly include: petroleum resources (conventional and unconventional oil and gas); metallic mineral resources; and non-metallic mineral resources (sand and gravel, bedrock resources and salt).

Based on mapping of the occurrence of fresh water and salty/sulphurous water within the regionally important Guelph Formation aquifer by Carter and Fortner (2011), deep fresh groundwater resources do not occur within the Central Huron area.

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 (2014a).

The main hydrocarbon play types in southern Ontario are listed in Table 5.1 after Carter (1990a), Sanford (1993), Mazurek (2004), Lazurek and Carter (2008), Hamblin (2008) 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 the 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 focused 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).

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 0.827 million m^3 of oil and 863 million m^3 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)

Note: Modified from Mazurek (2004), Sanford (1993), Carter (Ed.) (1990a), 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 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 3.67 milliom m^3 of oil and 1200 million m^3 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. 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). As of 2010, cumulative production from this type of play in southern Ontario was 0.008 milliom m^3 of oil and 13,046 million m^3 of gas (Carter, 2010).

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 A1 and A2 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 2.32 million m^3 and 20,600 million m^3, 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 6,680 million m^3 (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 7.07 million m^3.

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 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 was completed by Béland-Otis (2014) (Section 5.1.2). No economically exploitable shale gas accumulations have been discovered in southern Ontario to date.

5.1.2 Local Hydrocarbon Potential

As shown in Figure 5.2, there are four oil and gas pools in the Central Huron area. They include the Tipperary and Tipperary South pools within the Municipality of Central Huron, and the Tuckersmith 30-III-SHR and Bayfield pools located immediately south of the Municipality.

Table 5.2 lists the available information on the four petroleum pools located within the Central Huron area, as well as other known pools in close proximity to the Central Huron area (i.e, 20-25 km from the Municipality; Figure 5.1). All four pools within the Central Huron area are gas pools within pinnacle reefs of the Upper Silurian Guelph Formation (see Section 5.1.1) at a depth of approximately 490 to 570 m (OGSRL, 2014a). In plan view, these gas pools range in size from 7 to 35 ha (OGS, 2011). The 2D seismic line interpreted as part of this assessment (Geofirma Engineering Ltd., 2015), runs immediately east of the Tipperary pool; however, given the poor quality and limited lateral resolution of the seismic data, the reef structure was not identified. As of the end of 2013, cumulative gas production from the four pools in the Central Huron area was 100.5 million m^3. Both the Tipperary and Tipperary South pools within the Municipality are depleted and currently used for natural gas storage (OGSRL, 2014b). Similarly, the Bayfield Pool south of the Municiaplity is no longer in production and presently being considered for natural gas storage (Tribute Resources Inc., 2015).

The hydrocarbon pools in the vicinity of the Central Huron area listed in Table 5.2 and shown in Figure 5.1 are also gas pools in pinnacle reefs of the Guelph Formation. Cumulative gas production from these six pools to end of 2013 was 111.3 million m^3. They are all currently producing, except the Stanley 4-7-XI Pool south of the Municipality, which is suspended and being considered for potential gas storage (Tribute Resources Inc., 2015). The most recent gas pool developed in the vicinity of the Central Huron area is the West Wawanosh 1-25-XII Pool located about 20 km north of the Municipality and discovered by Northern Cross Energy Limited in 2007 (OGSRL, 2014a).

In addition to the pinnacle reefs associated with the Tipperary, Tipperary South, Tuckersmith 30-III-SHR and Bayfield pools, there is one additional known pinnacle reef in the Central Huron area. Drilling in 1956 through this pinnacle reef, which is located in the eastern part of the Municipality (Figure 5.2),

Table 5.2 Petroleum Pools Identified in the Central Huron Area 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)
Tuckersmith 30-III SHR Pool	Gas Pool	Active	Silurian - Salina-Guelph	74,129.8	Tuckersmith	10/61998	490	Guelph	4,036.96	0.0
Tipperary Pool	Gas Pool	Active (Non-Producing	Silurian - Salina-Guelph	352,104.4	Goderich	8/9/1969	571	Guelph	14,716.0	1,273.7
Tipperary South Pool	Gas Pool	Active (Non-Producing)	Silurian - Salina-Guelph	339,439.5	Goderich	11/17/1979	537	Guelph	13,151.9	168.0
Bayfield Pool	Gas Pool	Suspended	Silurian - Salina-Guelph	250,427.9	Stanley	10/8/1956	530	Guelph	68,585.92	0.0
Ashfield 5-IX WD Pool	Gas Pool	Active	Silurian - Salina-Guelph	320,867.6	Ashfield	2/28/1979	556	Guelph	12,810.83	0.0
West Wawanosh 1 25-XII Pool	Gas Pool	Active	Silurian - Salina-Guelph	--	West Wawanosh	11/09/2007	485	Guelph	687.79	0.0
Dungannon Pool	Gas Pool	Active	Silurian - Salina-Guelph	621,129.7	West Wawanosh	8/29/1958	510	Guelph	43,770.76	0.0
Ashfield 7-1-III ED Pool	Gas Pool	Active	Silurian - Salina-Guelph	230,759.3	Ashfield	3/5/1979	582	Guelph	27,655.24	0.0
West Wawanosh 26-X Pool	Gas Pool	Active	Silurian - Salina-Guelph	183,530.0	West Wawanosh	10/4/1968	509	Guelph	5,527.31	0.0
Stanley 4-7-XI Pool	Gas Pool	Suspended	Silurian - Salina-Guelph	450,000	Stanley	8/30/1982	543	Guelph	20,895.6	0.0
								2013 Cumulative Petroleum Production Totals:	**211,838.31**	**1,441.7**

Notes: Compiled from OGSR Library (2014a, 2014b) datasets.
-- not available

did not encounter economical accumulations of hydrocarbons. Similarly, wells drilled in the Municipality outside known pools resulted in either dry holes or minor gas shows (Figure 3.7; OGSRL, 2014a). 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, 2015; Geofirma Engineering Ltd., 2015), did not identify any additional pinnacle reefs in the Guelph Formation, or any other potential oil and gas plays in the Central Huron area.

Lower Silurian hydrocarbon plays are not expected to occur in the Central Huron area, as the Paleozoic formations that form the reservoirs in these types of plays (i.e., Whirlpool, Grimsby and Thorold formations; Section 5.1.1) are not present. Similarly, Devonian plays are not expected in the Central Huron area due to a lack of the necessary geological conditions; namely, presence of cap rocks and coincidence of Dundee and Detroit River Group with salt dissolution areas (OGSRL, 2014a). Cambrian sandstones in the Central Huron area are generally relatively thin and limited to the area along the shores of Lake Huron (Figure 3.17). No faults are mapped in the Central Huron area, and presence of Upper Ordovician hydrothermal dolomites has not been recognized. No evidence of economical hydrocarbon accumulations below the Upper Ordovician shales was found in the few deep boreholes in the Central Huron area (OGSRL, 2014a). However, given the lack of data in the Central Huron area, more work would be required to better understand the potential for structurally-controlled hydrothermal dolomite (Upper Ordovician carbonates) and Cambrian plays in this area.

As described in Section 5.1.1, the Ontario Geological Survey is currently assessing the potential for shale gas in southern Ontario. In 2011, the OGS drilled a 496.5 m deep well about 65 km northeast of the Central Huron area (i.e., in Wellington North County) to evaluate shale gas potential of the Upper Ordovician Georgian Bay Formation, Blue Mountain Formation (Rouge River Member) and Collingwood Member of the Cobourg Formation (Béland-Otis, 2012; 2014). Core samples of these shale units from depths of 304 to 488 mBGS were tested for total organic carbon (TOC), gas content, composition and isotopes. In 2012, some previously drilled cores and drill cuttings from 11 wells were sampled and analyzed throughout southern and eastern Ontario. The results from this work (Béland Otis, 2014) 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. Béland-Otis (2014) reported a TOC of 4.68% from a discrete cm-scale zone at the top of the Collingwood Member, and a TOC of 1.8% for the Rouge River Member in the borehole drilled northeast of the Central Huron area. TOC values from core samples and drill cuttings at a regional scale (Béland-Otis, 2014) range from less than 1% up to 9.87% for these two Ordovician shale units. Methane isotopes measured on methane in porewater as part of the detailed site characterization at the Bruce nuclear site indicate the methane within the Blue Mountain Formation and Collingwood Member were derived from biogenic processes and not thermocatalytically (Intera Engineering Ltd., 2011). In the well drilled by the OGS northeast of the Central Huron area, samples for methane isotopes collected throughout the Ordovician shales support a thermogenic origin. Upper Ordovician shales beneath the Bruce nuclear site only barely reached the oil window in terms of hydrocarbon maturation (Intera Engineering Ltd., 2011). Béland-Otis (2014) obtained similar results.

Given the lack of data in the Central Huron area, more work would be required to better understand hydrocarbon generation in the Paleozoic Upper Ordovician shales.

The potential for petroleum resources, including hydrocarbon generation potential in low permeability formations, in the Central Huron area 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 Municipality of Central Huron, as evidenced by the lack of active mining claims (MNDM, 2014b) and the lack of metallic mineral occurrences (Figure 5.2; OGS, 2014). The Abandoned Mines Information System (MNDM, 2014c) and Mineral Deposits Inventory (OGS, 2014) show that there are no currently or past producing metallic mineral mines within the Central Huron area.

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 near Clifford, about 40 km northeast of the Municipality of Central Huron (The Wellington Advertiser, 2007). 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, 2014a) indicates three wells (T011771, T011772 and T011773) 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 of 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 in the Central Huron area is considered low.

5.3 Non-Metallic Mineral Resources

5.3.1 Surficial Sand and Gravel

Sand and gravel pits are operating in the Municipality of Central Huron. Most of these pits are shallow (<8 m depth) and located within esker, glaciofluvial outwash, ice contact and glaciolacustrine beach deposits. The Ontario Aggregate Resources Inventory for Huron County (OGS, 2004) provides additional information on aggregate production and significance of areas for sand and gravel resources. The Ontario Aggregate Resources Inventory for Huron County assigns primary, secondary and tertiary significance to sand and gravel resources based on quality and potential volume.

Five areas within the Municipality of Central Huron were assigned a primary significance. The first of these areas comprises the currently operating pits that are located in a north-south oriented band through the centre of the Municipality, corresponding to the glaciofluvial outwash channel deposits between the Wyoming and Wawanosh Moraines (Figures 2.2 and 3.19). Pits are also present in the area associated with ice-contact sediments near the southeastern boundary of the Municipality, in the area characterized by esker deposits in the eastern portion of the Municipality, and along the northeastern boundary of the Municipality where kame deposits comprise the aggregate resource (Figure 3.19). An additional resource of primary significance was identified along the northern boundary of the Municipality, on the eastern bank of the Maitland River, and corresponds to glaciofluvial outwash deposits, and a single pit is present on the Municipality border at this location.

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

5.3.2 Bedrock Resources

Many of the Paleozoic rocks found at surface or under the overburden within the Central Huron area 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 5.3 summarizes information on economic bedrock resources in southern Ontario near the Central Huron area, including aggregate and other economic resources.

Current quarrying activities in the region surrounding the Central Huron area 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, northeast of the Central Huron area.

There are no known licensed bedrock quarries or commercial bedrock mining operations within the Municipality of Central Huron, presumably due to the presence of thick overburden (e.g., average thickness of 31 m in Municipality; Figure 3.20).

As shown in Figure 5.2, discretionary mineral occurrences of salt and gypsum have been reported within the Central Huron area. The one discretionary mineral occurrences of gypsum is located outside the Muncipalty in the southeast corner of the Central Huron area. Salt resources are discussed in more detail in Section 5.3.3 below.

Table 5.3 Summary of Economic Bedrock Units in Southern Ontario Near the Central Huron Area (after NWMO, 2011)

Age	*Group/Formation*	*Type*	*Potential Usage*	*Location*
U. Silurian	Salina Group	Evaporite	Salt, brine	Southwestern ON: Windsor, Goderich, Sarnia, North Wellington City. Only in subsurface.
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.
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)

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 immediately north of the Muncipality of Central Huron.

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). At the Goderich Mine, the Salina A2 and B salts are mined through underground mining and solution mining, respectively (Hewitt, 1962; Carter, 2009b).

Figure 5.2 shows the predicted lateral extent of the Salina B Unit salt bed, which is the most extensive and thickest of the Salina Group salt beds, and Figure 3.17 shows the lateral extent of the different salt units present in the Central Huron area (Salina A2, B, D and F units). A geological cross-section B-B' illustrating the Silurian to Devonian stratigraphy extending eastward from Goderich in the Central Huron area is shown in Figure 5.3 (Sanford, 1977). The location of the cross section is also shown in Figure 3.2. As illustrated in this cross-section, the salt beds quickly thin out east of the Municipality, with the Salina B unit being the only salt bed that underlies the entire Municipality. The Salina Group salt beds extend significantly to the west offshore under Lake Huron and to the south down to Sarnia along the eastern shore of Lake Huron. The estimated amount of salt present within the Sarnia-Goderich region is 2.0×10^{12} tonnes (Hewitt, 1962).

The Salina B Unit salt is found below all the Muncipality, typically at depths of about 320 to 490 mBGS (OGSRL, 2014a). Thickness of this salt bed within the Municipality ranges from approximately 40 to 80 m (Figure 5.4). The A2 Unit salt, which occurs below about 75% of the Municipality, is typically found at depths of 320 to 485 m (OGSRL, 2014a), and with a thickness of up to approximately 20 m (Figure 5.5).

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

5.4 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 Central Huron area. 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. There are only three wells within the Municipality of Central Huron drilled below the Silurian formations.

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 Municipality of Central Huron. However, geomechanical property data are available from detailed drilling and testing investigations at the Bruce nuclear site (Intera Engineering Ltd., 2011, Golder Associates Ltd., 2013a), 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 Municipality of Central Huron. Thermal property data are available from detailed drilling and testing investigations at the 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 Municipality of Central Huron 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 Municipality of Central Huron 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 in 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 UCS estimated mean values 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 compressive 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 with 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 (e.g., width or aperture, mineral fill, evidence of relative displacement) 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 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 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 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 6.2.

Information on the orientation of fractures logged in deep boreholes drilled at the Bruce nuclear site and comparison of those orientations with 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 Municipality of Central Huron. However, the effect that the approximately 100-to-200 m increased depth of the potentially suitable formations in the Municipality versus the Bruce nuclear site 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 Central Huron area. However, information on the state of in-situ stress likely to exist in the Paleozoic rocks of the Central Huron area 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 modelling 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 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 modelling (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 Municipality of Central Huron 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 Central Huron area 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 than 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 MUNICIPALITY OF CENTRAL HURON

7.1 Approach

The objective of the Phase 1 geoscientific desktop preliminary assessment is to assess whether the Municipality of Central Huron contains 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, 2015). 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 screening of the Municipality of Central Huron (AECOM Canada Ltd., 2013) identified the Upper Ordovician shale and limestone units as potentially suitable host rock formations. As described in Section 3.2.2, the Paleozoic bedrock sequence within the Municipality of Central Huron is approximately 1,025 to 1,075 m thick. As shown in Figure 3.7 and Table 3.1, within the Municipality the stratigraphy with depth includes: Devonian limestone and dolostone; Silurian dolostones, shales and evaporites; Upper Ordovician shales and limestones; and occasionally Cambrian sandstone overlying Precambrian basement.

  Based on available information on the geoscientific characteristics of the sedimentary sequence beneath the Municipality and surrounding region, including the Bruce nuclear site about 50 km north of the Central Huron area, the Ordovician Cobourg Formation (argillaceous limestone) would be the preferred host rock for a used nuclear fuel deep geological repository. The natural geological setting of this formation would provide the most favourable geoscientific characteristics for ensuring safety. As described in Sections 3.2, 4.2 and 6, the Cobourg Formation underlies the Municipality of Central Huron in sufficient thickness and volume. It has very low hydraulic conductivity and high geomechanical strength (Figures 4.3b and 6.1a). These 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.

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; Figure 6.1a). 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). There are no mapped (interpreted) subsurface faults within the Municipality of Central Huron (Figure 3.7), and the interpretation of a 2D seismic line within the Municipality did not identify any fault within the Paleozoic sedimentary sequence. The potential for faults in the Paleozoic sequence within the Municipality of Central Huron 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 Municipality of Central Huron, it was determined that a minimum depth of 500 metres below ground surface (mBGS) would be preferred to maintain the integrity of a repository within the Cobourg Formation. This preferred depth would also protect the overlying 200 m thick Upper 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 Municipality of Central Huron were excluded from further consideration. These include Conservation Areas, NGO Nature Reserves, and Provincially Significant Wetlands.

- ***Source Water Protection Areas:*** Land-based water protection zones (IPZs, Intake Protection Zones) 1 and 2, and groundwater protection areas (WHPAs, Well Head Protection Areas) A, B, C and E were excluded from further consideration. The consideration of WHPAs D would need to be further assessed in collaboration with the Municipality in future studies.

- ***Natural Resources:*** The potential for natural resources in the Central Huron area is shown in Figure 5.2. There are three known pinnacle reefs of the Silurian Guelph Formation in the Municipality of Central Huron, two of which were exploited for gas in the past and are currently being used for natural gas storage (i.e., Tipperary and Tipperary South pools; Figures 5.1 and 7.1). Salt beds of the Silurian Salina Group are known to be present beneath the entire Municipality of Central Huron. At this stage of the assessment, other than the location of the known historical pools, the presence of hydrocarbons and salts within the Municipality is not considered as preventing siting the repository within the Municipality. However, the impact of salt and hydrocarbon resource potential on repository siting and safety would need to be further assessed for specific sites.

- ***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 Municipality of Central Huron were not found to be siting constraints at this stage. Overburden cover is extensive and locally thick within the Municipality, and wetlands cover 8.8% of the Municipality. Water bodies cover a relatively small area.

Figure 7.1 shows the key geoscientific characteristics and constraints used to assess whether the Municipality of Central Huron contains areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. The figure shows protected areas; earth science ANSIs; wildlife management areas; source water protection areas; built-up areas; and the potential for natural resources. The legend of the figure also includes a 2 km by 3 km box to illustrate the approximate extent of the footprint that would be needed for a repository.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the key geoscientific characteristics and constraints discussed above revealed that the Municipality of Central Huron contains large areas that have the potential to satisfy NWMO's geoscientific evaluation factors. However, as discussed below, the assessment identified a number of uncertainties that would need to be addressed during subsequent evaluation stages. These include the impact of salt and hydrocarbon resource potential on repository siting and safety. Also, the assumption of transferability of geoscientific characteristics and understanding based on regional data and data from the Bruce nuclear site to the Municipality of Central Huron would need to be confirmed. At this early stage of the assessment, the boundaries of these general potentially suitable areas are not yet defined. The location and extent of these areas would be further refined during subsequent site evaluation stages.

The Municipality of Central Huron is underlain by a predictable, laterally extensive, near horizontally bedded Paleozoic sedimentary sequence. Based on information from three wells that were drilled to the Precambrian basement (T006364, F011970, F011974) within the Municipality (Table 3.3; Figure 3.7), the thickness of the Paleozoic sequence in this area is approximately 1,025 to 1,075 m.

Depth contour mapping (Figure 3.15) shows the preferred Cobourg Formation is found at depths greater than the preferred minimum depth (500 mBGS) under the entire Municipality. The depth to the top of the Cobourg Formation varies from about 750 mBGS in the eastern corner of the Municipality to approximately 885 mBGS (well F011974; Figure 3.15) towards the western part of the Municipality. Based on information from well T006364, the Cobourg Formation is interpreted to be approximately 55 m thick within the Municipality. The thickness of the overlying Upper Ordovician shale formations is estimated to be relatively uniform and more than 200 m (Figure 3.19; Section 3.2.2.2). No faults have been mapped within the Paleozoic sedimentary sequence in the Municipality of Central Huron (Figure 3.7), and the interpretation of a 2D seismic line within the Municipality did not identify any subsurface fault.

Known potential for economically exploitable natural resources in the Municipality of Central Huron is associated with hydrocarbons in the Silurian Guelph Formation and salt resources of the Salina Group.

There are two known historical hydrocarbon pools within the Municipality, the Tipperary and Tipperary South pools (Figure 7.1), which historically produced gas from pinnacle reefs of the Guelph Formation. These depleted pools are currently being used for natural gas storage (Section 5.1.2). Immediately south of the southern municipal boundary, the historic Bayfield gas pool is also being considered for gas storage, and the Tuckersmith 30-III-SHR pool is actively producing gas from a pinnacle reef of the Guelph Formation. The pinnacle reefs associated with all these hydrocarbon pools were recognized as positive gravity anomalies during the interpretation of available geophysical data (PGW, 2015). Similar gravity anomalies exist in the Municipality, but it is unknown if these anomalies reflect the existence of additional reefs. In any case, their stratigraphic occurrence is approximately 300 m above the preferred Cobourg Formation. At this stage, other than the location of the known historical pools, the presence of hydrocarbons within the Municipality is not considered as preventing siting a repository within the Municipality. However, the impact of hydrocarbon resource potential on repository siting and safety would need to be further assessed for specific sites.

Salt beds of the Silurian Salina Group are known to exist beneath the entire Municipality, extending significantly in the surrounding region to the south and west, including beneath Lake Huron. The Salina salt beds thin towards the east (Figure 5.3). The Salina B and A2 salt beds, mined at Goderich, are the thickest. The thickness of the Salina B salt ranges from approximately 80 m in the western portion of the Municipality, to about 40 m towards the east (Figure 5.4). The Salina A2 salt is approximately 20 m thick towards the western portion of the Municipality, pinching out towards its eastern portion (Figure 5.5). At this stage of the assessment, the presence of salt beds is not considered as a constraint. The Salina Group salt beds occur more than 330 m above the top of the preferred Cobourg Formation (Table 8). If salt were to be mined above the repository location, the vertical distance between the salt and the Cobourg Formation is likely to isolate and maintain the integrity of a repository. The impact of salt resource potential on repository siting and safety would need to be further assessed.

The largest built-up area in the Municipality is that associated with the settlement area of Clinton. Smaller built-up areas are found in Holmesville, Londesborough, Kinburn, and along and close to the Lake Huron shoreline (Figure 7.1).

There are three designated provincially significant wetlands in the Municipality of Central Huron: the Hullet Marsh Complex in the southwestern portion of the Municipality, and the Holmesville Creek Complex and Trick's Creek Swamp south of Holmesville in the central part of the Municipality. The Hullet Wildlife Management Area encompasses the Hullet Marsh Complex and surrounding lands. In the northwestern portion of the Municipality there are two conservation areas and one NGO nature reserve, all relatively small in size (Figure 7.1). There are two earth science ANSIs located in the central and southeastern parts of the Municipality (Figure 7.1).

The wellhead protection area, zones A to C, associated with the Clinton well supply system extends northeast of the settlement area of Clinton, in the central portion of the Municipality. Smaller wellhead protection areas (zones A to C) are found along the Lake Huron shoreline (Figure 7.1). WHPA-E associated with the Century Heights well supply, straddles part of the northern boundary of the Municipality. Part of the Goderich surface water intake protection zone occupies a small portion of the northwestern corner of the Municipality.

Accessibility throughout the Municipality of Central Huron is easy via the existing road network (Figure 7.1). Topography is relatively flat, although relatively distinct topographic features are identified associated with the Maitland and Bayfield rivers, as well as with smaller rivers and the Wyoming moraine (Figure 2.3). There are also small, non-designated wetlands and extensive overburden deposits with thicknesses of up to approximately 80 m locally (Section 3.2.3). At this early stage of the assessment, topographic features, wetlands outside protected areas and overburden thickness are not considered as key constraints for the identification of general potentially suitable areas.

In summary, the assessment of the above geoscientific characteristics and constraints indicates that the Municipality of Central Huron contains large potentially suitable areas, outside protected areas, source water protection zones and built-up areas (Figure 7.1). The depth to the top of the preferred Cobourg Formation beneath the Municipality ranges from about 750 to 885 mBGS, which is greater than the preferred minimum depth of 500 mBGS.

While the general potentially suitable areas within the Municipality of Central Huron appear to have favourable geoscientific characteristics for hosting a deep geological repository, there remain a number of uncertainties that would need to be addressed during subsequent stages of the site evaluation process. These include the impact of salt and hydrocarbon resource potential on repository siting and safety. Also, the assumption of transferability of geoscientific characteristics and understanding based on regional data and data from the Bruce nuclear site to the Municipality of Central Huron would need to be confirmed.

7.3 Evaluation of the General Potentially Suitable Areas in the Communities

This section briefly describes how the identified potentially suitable 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. An evaluation of the general potentially suitable areas in the Municipality of Central Huron 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 the following:

- 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 Municipality of Central Huron is consistent with the regional geological framework. The Municipality is entirely underlain by a predictable and laterally extensive Paleozoic sedimentary sequence that was deposited approximately 540 to 359 million years ago.

Given the predictability of the Paleozoic bedrock stratigraphy in the region, the Cobourg Formation, which is considered the preferred host rock in this assessment (Section 7.1), is interpreted to extend laterally beneath the general potentially suitable areas identified within the Municipality. Based on information from historic oil and gas wells (Figure 3.15), the top of the Cobourg Formation within the potentially suitable areas is interpreted to be at depths greater than the minumum 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 well T006364 within the Municipality indicate that the Cobourg Formation in the potentially suitable areas identified is expected to be about 55 m thick. 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 general potentially suitable areas, it is expected that they will be similar to the characteristics of the Cobourg Formation beneath the Bruce nuclear site, approximately 50 km north of the Central Huron area. 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 general potentially suitable areas is overlain by approximately 200 m of very low permeability Upper Ordovician shale formations that would provide multiple natural barriers for repository isolation.

Given the regional predictability of the Paleozoic bedrock sequence, the hydrogeological and hydrogeochemical conditions beneath the general potentially suitable areas in the Municipality of Central Huron 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 no interpreted or OGS mapped faults within the identified general potentially suitable areas (Figure 3.7). 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 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 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 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 the following:

- 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 collected and analyzed through detailed surface and subsurface investigations. The assessment would include understanding how the site has responded to past glacial cycles and geological processes, and would entail a wide range of 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 general potentially suitable areas identified in the Municipality of Central Huron. The remainder of this section provides preliminary assessment of the four factors listed above.

The Paleozoic sedimentary sequence in the Central Huron area, including the identified general 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). As described in Section 3.3.1 and shown in Figure 3.22 there have been no recorded earthquakes within the Municipality of Central Huron since 1985, with the closest recorded earthquakes located just offshore in Lake Huron about 25 km southwest of the Municipality. The maximum magnitude of these events was of 2.4 Nuttli Magnitude. In addition, there are no mapped subsurface faults extending into the sedimentary sequence of the Central Huron area, and interpretation of a 2D seismic line within the Municipality did not identify the presence of any potential fault (Geofirma Engineering Ltd., 2015).

The geology of the Central Huron area is typical of many areas of southern Ontario, which have been subjected to nine glacial cycles during the last million years (Peltier, 2003). 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 the deep subsurface Paleozoic sedimentary formations have remained largely unaffected by past perturbations such as glaciations (Sections 3 and 4).

Land in the Central Huron area 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 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 Central Huron area approaches 0.5 mm/yr.

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, providing coverage of the area immediately north of the Central Huron area, and concluded 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 general potentially suitable areas identified in the Municipality of Central Huron. The study concluded potential future glacial erosion rates in the area would be limited, with a conservative estimate of erosion of 100 m per 1 million years, which would not affect the integrity of a deep geological repository located at a depth of 500 mBGS or more.

In summary, available information indicates the identified general potentially suitable areas in the Municipality of Central Huron 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 potentially suitable areas 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 the following:

- 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 general potentially suitable areas identified in the Municipality of Central Huron. The general potentially suitable areas are characterized by a relatively flat topography with limited obvious topographic features, and they contain enough surface land outside protected areas, source water protection zones, 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 Municipality of Central Huron, there is abundant information from other locations in southern Ontario that could provide insight into what would be expected for the area. Available information on strength and in-situ stresses in the region suggests the Upper Ordovician Cobourg Formation has favourable 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 that 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). Given the greater depth of the Cobourg Formation in the Municipality of Central Huron, there is potential for higher in-situ stresses for a proposed DGR in this formation.

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 in the Municipality of Central Huron. 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 potentially suitable areas is extensive, with overburden thickness typically ranging from zero to about 80 m locally. However, at this early stage of the evaluation, it is anticipated that overburden cover is not a limiting factor for the construction and operation of a potential repository in the area.

In summary, the 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 the following:

- 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 general potentially suitable areas is limited to local extraction of sand and gravel. These extraction activities are limited to very shallow depths and would not have an effect on a deep geological repository hosted in the Cobourg Formation. The potential for shallow bedrock resources in the general potentially suitable areas is limited presumably due to the presence of thick overburden (Section 5.3.2).

The salt beds of the Salina Group are known to occur beneath the general potentially suitable areas identified in the Municipality of Central Huron (Section 5.3.3 and Figure 7.1), and extend significantly in the surrounding region to the south and west of the Municipality, including beneath Lake Huron. The Salina B and A2 salt beds, which are mined at Goderich, are up to approximately 80 m and 20 m thick, respectively, within the Municipality. The Salina Group salt beds occur more than 330 m above the top of the preferred Cobourg Formation (Table 8), and if salt were to be mined in the future within the general potentially suitable areas, the vertical distance between the salt beds and the Cobourg Formation would likely provide a sufficient buffer to isolate and maintain the long-term integrity of the repository. However, the impact of salt resource potential on repository siting and safety would need to be further assessed during future stages of the site evaluation process as more site specific data is collected.

There are two historical gas pools in the general potentially suitable areas identified within the Municipality. These pools yield gas from pinnacle reefs extending vertical upward from the Guelph Formation, approximately 300 m above the preferred Cobourg Formation. Currently they are being used for natural gas storage. No evidence of economical hydrocarbon accumulations in the Upper Ordovician shales or underlying carbonates is known from the few deep boreholes in the Central Huron area (OGSRL, 2014a). However, the potential for petroleum resources in the Central Huron area and their impact on repository siting and safety would need to be further assessed during future evaluation stages.

The review of available hydrogeological information did not identify any known groundwater resources within the Upper Ordovician sedimentary shale and limestone formations, including the Cobourg Formation within the identified general potentially suitable areas. All known water wells within the Municipality obtain water from overburden or shallow bedrock sources at depths ranging from 1.2 to 275 mBGS (Table 4.1).

As discussed in Section 4.2, the potential for groundwater resources within the Upper Ordovician limestone and shale units in the Central Huron area 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 there is no active deep groundwater system in the region 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 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 identified general potentially suitable areas is shallow and limited to the upper approximately 200 mBGS (Intera Engineering Ltd., 2011; Waterloo Hydrogeologic Inc., 2003).

In summary potential for the containment and isolation function of a repository in the general potentially suitable areas to be disrupted by future human activities would need to be further assessed.

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 Central Huron area is consistent with the regional geological framework for southern Ontario. The Paleozoic bedrock stratigraphy is characterized by a near horizontally bedded, undisturbed “layer cake” geometry that is laterally extensive and traceable beneath southern Ontario. Although subject to site-specific confirmation, current evidence strongly suggests transferability of geologic properties and attributes is possible within this predictable sedimentary sequence.

Quaternary overburden deposits within the general potentially suitable areas identified in the Municipality have thicknesses ranging from zero to 80 m locally (Section 3.2.3). Given the regional geological framework, the “layer cake” 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 general potentially suitable areas.

The general potentially suitable areas identified in the Municipality of Central Huron are accessible for site characterization activities using the existing road network.

In summary, evidence suggests that the sedimentary geologic setting and attributes beneath the general potentially suitable areas within the Municipality would be amenable to site characterization for the purpose of developing a repository safety case.

8 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the Municipality of Central Huron contains 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 and confirmed during subsequent site evaluation stages through more detailed studies and site-specific field investigations.

The preliminary geoscientific assessment built on the work previously conducted for the initial screening (AECOM Canada Ltd., 2013) and focused on the Central Huron area (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 Central Huron area. Where information for the Central Huron area 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 data;
- Interpretation of available borehole geophysical data and a selected 2D seismic reflection line 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, and 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 indicates the geological setting in the Municipality of Central Huron has a number of favourable characteristics for hosting a deep geological repository for used nuclear fuel. The assessment identified the Ordovician Cobourg Formation (limestone) as the preferred host rock formation for a used nuclear fuel deep geological repository. Beneath the Municipality the normally 55 m thick Cobourg Formation occurs below the minimum preferred repository depth of 500 metres below ground surface (mBGS) and is overlain by approximately 200 m of low permeability shales.

While the Municipality of Central Huron appears 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 Municipality of Central Huron would need to be confirmed. Also, the impact of salt and hydrocarbon resource potential on repository siting and safety would need to be further assessed.

Should the Municipality of Central Huron 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.

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REPORT SIGNATURE PAGE

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Principal

APPENDIX A

Geoscientific Evaluation Factors

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

Safety Functions	***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 Functions	***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 Central Huron Area

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 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
Ausable-Bayfield Conservation Lands	The database contains lands purchased by Ausable Bayfield Conservation Authority in the southern part of the Central Huron area. This database contains conservation lands that were not included in the Land Information Ontario database.	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 Data Base (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 Canada.	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
Petroleum Well Data	Ontario Oil, Gas and Salt Resources Library digital data set of petroleum well location, class, target, depth, status and operator name. Database also has digital data for petroleum pools in a GIS format and locations and wireline logs for geophysical surveys completed in boreholes in the database.	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
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 Central Huron Area

Product	***Source***	***Type***	***Line Spacing/ Sensor Height***	***Coverage***	***Date***	***Additional Comments***
Waterloo	Waterloo fixed wing magnetic survey	GSC, 2014	926m line spacing 305m sensor height	Eastern portion of Central Huron area	1986	Large overlap with newer survey to the south.
Lake Huron	Lake Huron fixed wing magnetic survey	GSC, 2014	1,900m line spacing 305m sensor height	Western half of Central Huron area	1986	Low resolution survey over Lake Huron
Strathroy	Strathroy fixed wing magnetic survey	Spector, 1999	700 m x 700m m grid 450mASL sensor height	Western half of Central Huron area	1999	Higher resolution than GSC surveys.
South Ontario Radon Survey – Block 2	Southern Ontario Block 2 radiometric survey	GSC, 2014	1000m line spacing 150m sensor height	Entire Central Huron area	2008	Low resolution survey, east-west flight lines
GSC Gravity	Ground gravity measurements	GSC, 2014	6 km (onshore), 1.6 km x 18 km (offshore)/surface	Entire Central Huron area	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	Ground gravity measurements	PGW, 2015	0.4 km x 2 km/ surface	Entire land portion of Central Huron area	1950s	Higher resolution than GSC coverage, variable station spacing

Table B.3 Summary of Geological Mapping Sources for the Central Huron Area

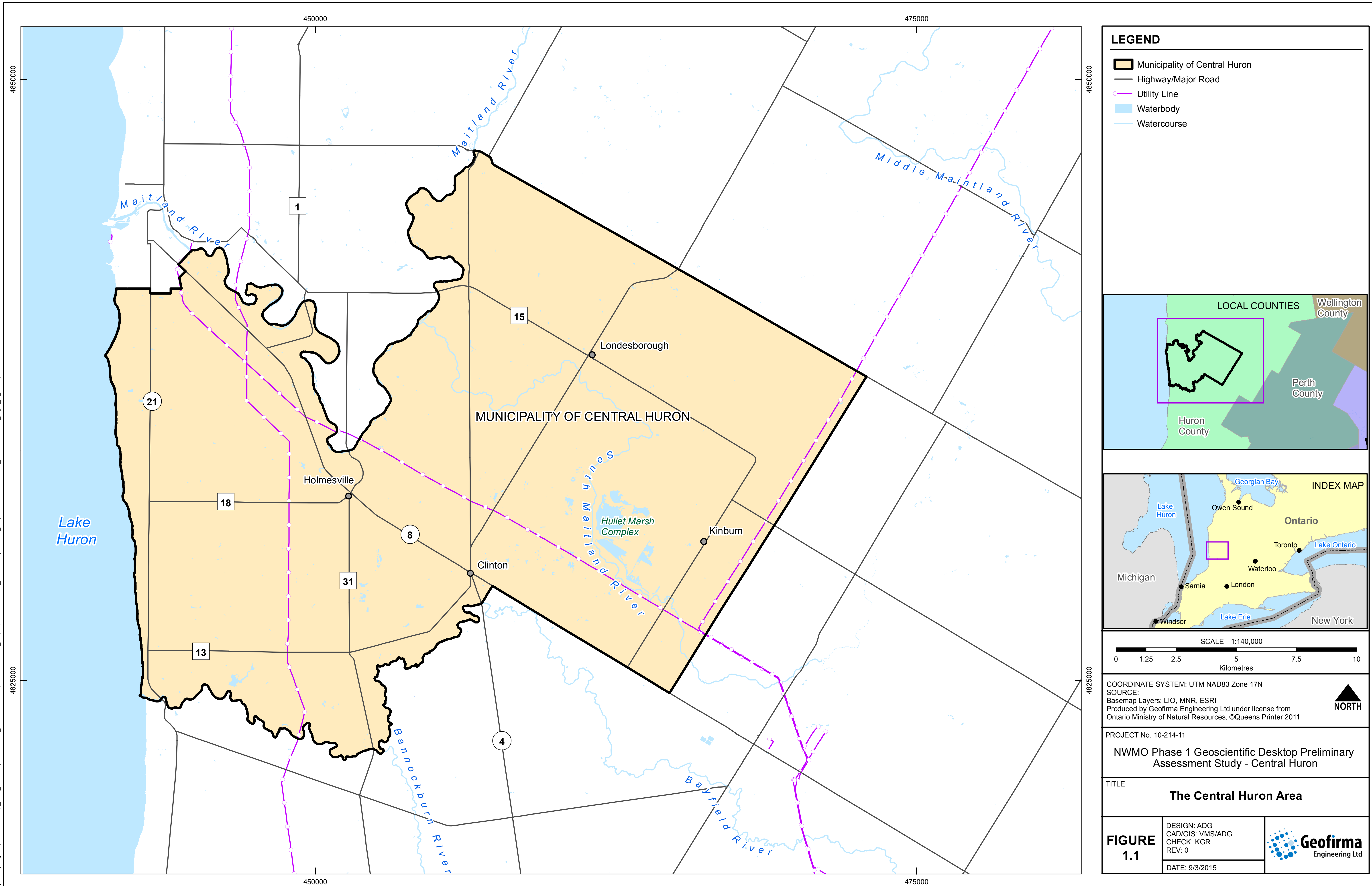
Map Product	*Title*	*Author*	*Date*	*Source*	*Scale*	*Coverage*	*Additional Comments*
EDS014	Quaternary Geology, Seamless Coverage of the Province of Ontario	Ontario Geological Survey	1997	OGS	1:1000000	Full	Includes geology and features such eskers, and moraines.
GRS 05	Karst of Southern Ontario and Manitoulin Island	F.R. Brunton and J.E.P. Dodge	2008	OGS	1:50000	Full	Digital data release of karst in Paleozoic rocks
M2225	Physiography of the Southwestern Portion of Southern Ontario	L.J. Chapman and D.F. Putnam	1972	OGS	1:253,440	Full	Preliminary map for Chapman and Putnam (2007)
M2544	Bedrock Geology of Ontario, Southern Sheet	Ontario Geological Survey	1991	OGS	1:1000000	Full	Regional-scale bedrock mapping
MRD-126 REV1	1:250 000 scale bedrock geology of Ontario	Ontario Geological Survey	2011	OGS	1:250000	Full	Bedrock mapping for the Province of Ontario
MRD-128 REV	Surficial geology of southern Ontario	Ontario Geological Survey	2010	OGS	1:50000	Full	Revised surficial geology mapping available in digital format
MRD-207	Bedrock Topography and Overburden Thickness Mapping, Southern Ontario	C. Gao, J. Shirota, R.I. Kelly, F.R. Brunton and S. van Haaften	2006	OGS	1:50000	Full	Bedrock elevation and drift thickness calculated from water well database
MRD-219	Paleozoic Geology of Southern Ontario	D.K. Armstrong and J.E.P. Dodge	2007	OGS	1:50000	Full	Attributed GIS-based Paleozoic geology
MRD-228	Physiography of southern Ontario	L.J. Chapman and D.F. Putnam	2007	OGS	1:50000	Full	Mapping of the physical structure including escarpments; dunes and landforms

Map Product	Title	Author	Date	Source	Scale	Coverage	Additional Comments
MRD-276	Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario	Ontario Geological Survey	2010	OGS	1:100000 or 1:250000	Full	Digital mapping of Paleozoic hydrocarbon-bearing units including reefs and pools
OFM 0162	Extension of Grenville Basement Beneath Southwestern Ontario	R. M. Easton and T.R. Carter	1991	OGS	1:1013760	Full	Regional-scale basement mapping
Open File Report 401	Isopach of the Salina B Salt, Southwestern Ontario	B.V. Sanford	1977	GSC	1:250000	Partial	Geological mapping and cross sections
P0166	Palmerston sheet, bedrock topography series	P.F. Karrow L.L. Davies W.R. McClymont	1962	OGS	1:50000	Partial	Preliminary bedrock topography mapping of eastern part of the area
P0296	Bedrock topography series, Lucknow-Wingham sheet	P.F. Karrow I. Ben-Tahir D.B. Steele W.D. Morrison	1965	OGS	1:50000	Partial	Preliminary bedrock topography mapping of northern part of the area
P0297	Bedrock topography series, Goderich-Seaforth sheet	P.F. Karrow I. Ben-Tahir D.B. Steele W.D. Morrison	1965	OGS	1:50000	Partial	Preliminary bedrock topography mapping of southern half of the area
P1232	Quaternary geology, Goderich area, southern Ontario	A.J. Cooper W.D. Fitzgerald	1977	OGS	1:50000	Partial	Preliminary Quaternary geology mapping of the western part of the area

Map Product	*Title*	*Author*	*Date*	*Source*	*Scale*	*Coverage*	*Additional Comments*
P1233	Quaternary geology, Seaforth area, southern Ontario	A.J. Cooper W.D. Fitzgerald J. Clue	1977	OGS	1:50000	Partial	Preliminary Quaternary geology mapping of the eastern part of the area
P1974	Bedrock topography series, Goderich-Seaforth area, southern Ontario	A.J. Cooper	1978	OGS	1:50000	Partial	Preliminary bedrock topography mapping of the southern part of the area
P2450	Drift thickness of the Goderich and Seaforth areas, southern Ontario	A.J. Cooper L.P. Nicks	1981	OGS	1:50000	Partial	Preliminary drift thickness mapping of the southern half of the area
P2757	Petroleum resources map, structure, top pre-Hamilton, Devonian carbonates, Huron County, southern Ontario	Bailey Geological Services Ltd.	1985	OGS	1:100000	Full	Structural mapping based on borehole logs
P2812	Petroleum resources map, structure, top Devonian sulphur water-porosity, Huron County, southern Ontario	Bailey Geological Services Ltd.	1985	OGS	1:100000	Full	Structural mapping based on borehole logs
P2823	Petroleum resources map, isopach top Devonian carbonate to top sulphur water-porosity, Huron County, southern Ontario	Bailey Geological Services Ltd.	1985	OGS	1:100000	Full	Structural mapping based on borehole logs
P2895	Petroleum resources map, structure top Rochester Formation, Huron County, southern Ontario	Bailey Geological Services Ltd.	1985	OGS	1:100000	Full	Structural mapping based on borehole logs

Map Product	***Title***	***Author***	***Date***	***Source***	***Scale***	***Coverage***	***Additional Comments***
P2957	Quaternary geology, Wingham-Lucknow area, southern Ontario	W.R. Cowan A.J. Cooper J.J. Pinch	1986	OGS	1:50000	Partial	Preliminary Quaternary mapping of the northern part of study area
P3013	Petroleum resources map, isopach top Guelph to top Rochester, Huron County, southern Ontario	Bailey Geological Services Ltd., R.O. Cochrane	1986	OGS	1:100000	Full	Structural mapping based on borehole logs
P3201	Drift Thickness, Lucknow Area, Southern Ontario	R.I. Kelly and T.R. Carter	1993	OGS	1:50000	Partial	Contour mapping based on borehole logs
P3204	Drift Thickness, Wingham Area, Southern Ontario	R.I. Kelly and T.R. Carter	1993	OGS	1:50000	Partial	Preliminary drift thickness mapping northern part of study area
P3206	Bedrock Topography, Lucknow Area, Southern Ontario	R.I. Kelly and T.R. Carter	1993	OGS	1:50000	Partial	Preliminary bedrock topography mapping northern part of study area
P3209	Bedrock Topography, Wingham Area, Southern Ontario	R.I. Kelly and T.R. Carter	1993	OGS	1:50000	Partial	Preliminary bedrock topography mapping 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	1992	OGS	Numerous maps with a range of different scales	Full	Chapter 20 details the Paleozoic and Mesozoic geology of Ontario
SV 07	The Subsurface Paleozoic Stratigraphy of Southern Ontario	D.K. Armstrong and T.R. Carter	2010	OGS	Numerous maps with a range of different scales	Full	Reference document for describing Paleozoic rocks

FIGURES



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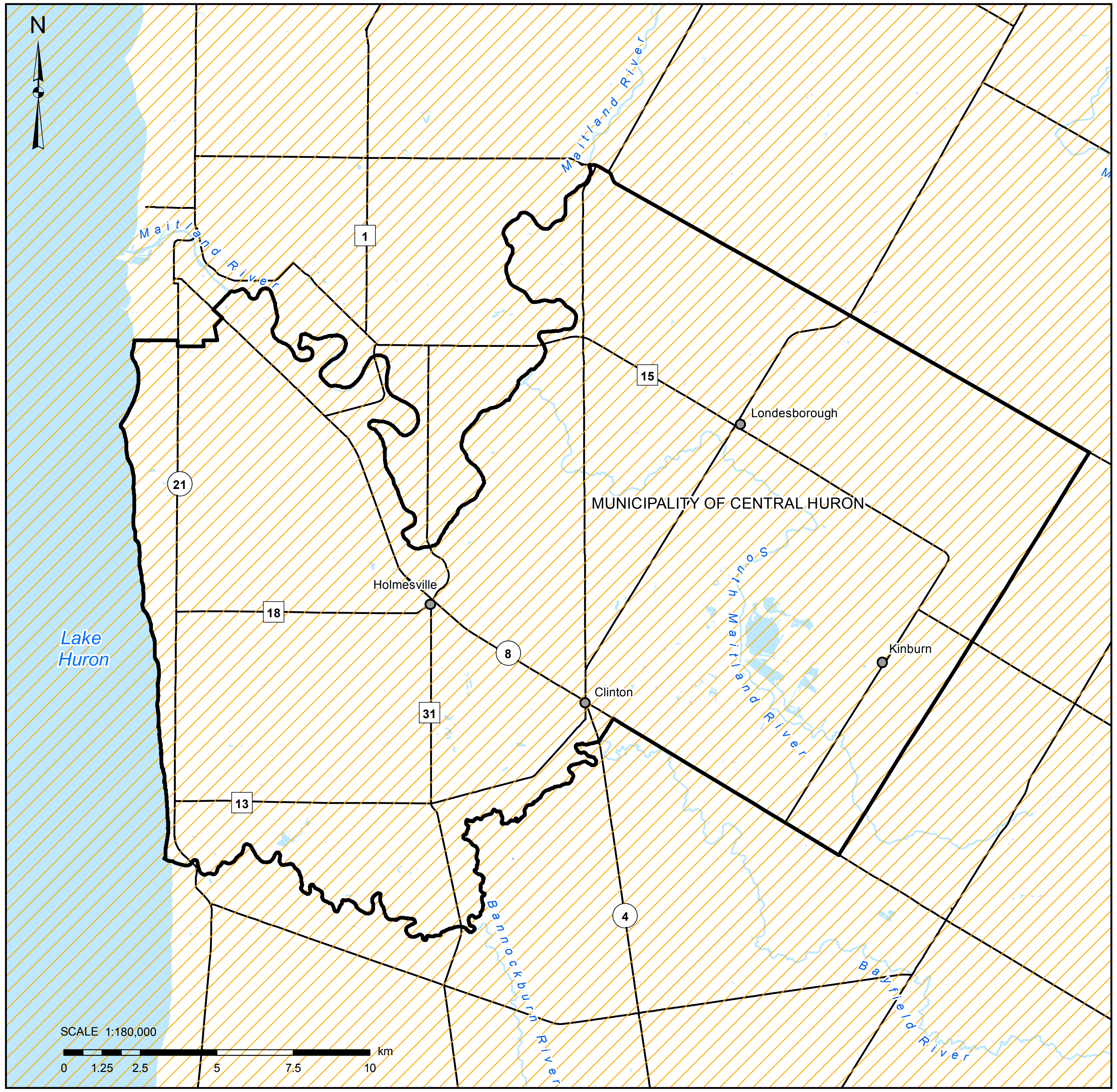
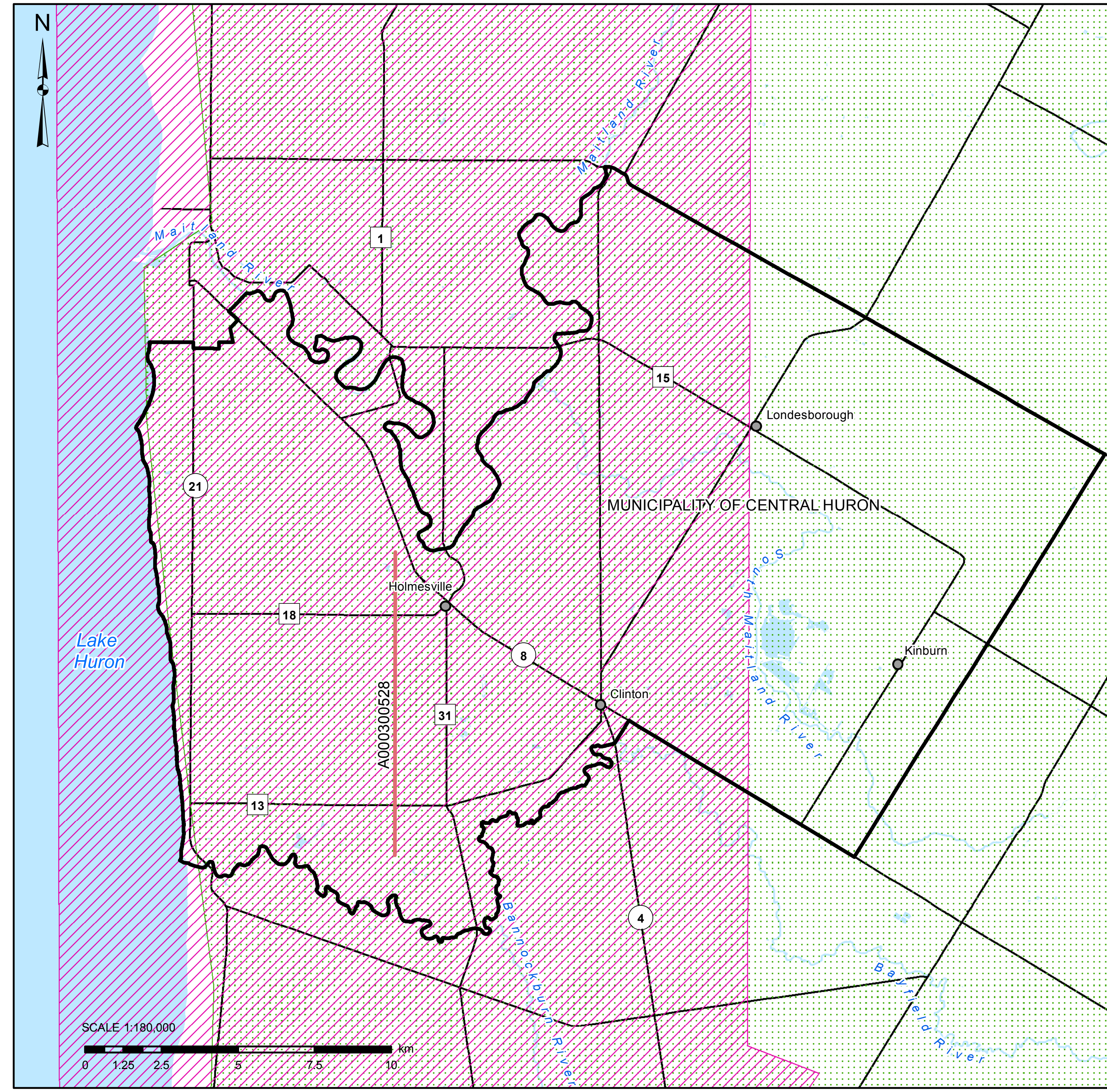
Geology Coverage



Geophysics Coverage



LEGEND

- Municipality of Central Huron
- Highway
- Water Area, Permanent
- Watercourse

Full Geology Coverage

Bedrock Geology Mapping
Armstrong and Carter (2010)
Brunton and Dodge (2008)
Gao et al. (2006)
Johnson et al. (1992)
OGS (2007)
OGS (2011)
Sanford (1977)

Quaternary Geology Mapping
Gao et al. (2006)
OGS (2010)
OGS (1997)

Full Geophysics Coverage

Magnetic, Gravity Data
Boyce & Morris (2002)

Gravity and Radiometric Data
GSC (2014)

Detailed Geophysical Extent
Acquired 2-D Seismic Data

Magnetic Data
GSC (2014) and Spector (1999)

Gravity Data
GSC (2014) and PGW (2015)

PROJECT No. 10-214-11
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE **Geoscience Mapping and Geophysical Coverage of the Central Huron Area**

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE: Basemap Layers: LIO MNR, obtained 2010-2013
Ontario Geological Survey, MNDM, PGW, 2013
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

FIGURE 1.2

DESIGN: NMP
CAD/GIS: VMS
CHECK: KGR
REV: 0
DATE: 9/3/2015

Geofirma Engineering Ltd

LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Imagery: SPOT 5, Geobase, 2010
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Satellite Imagery of the Central Huron Area

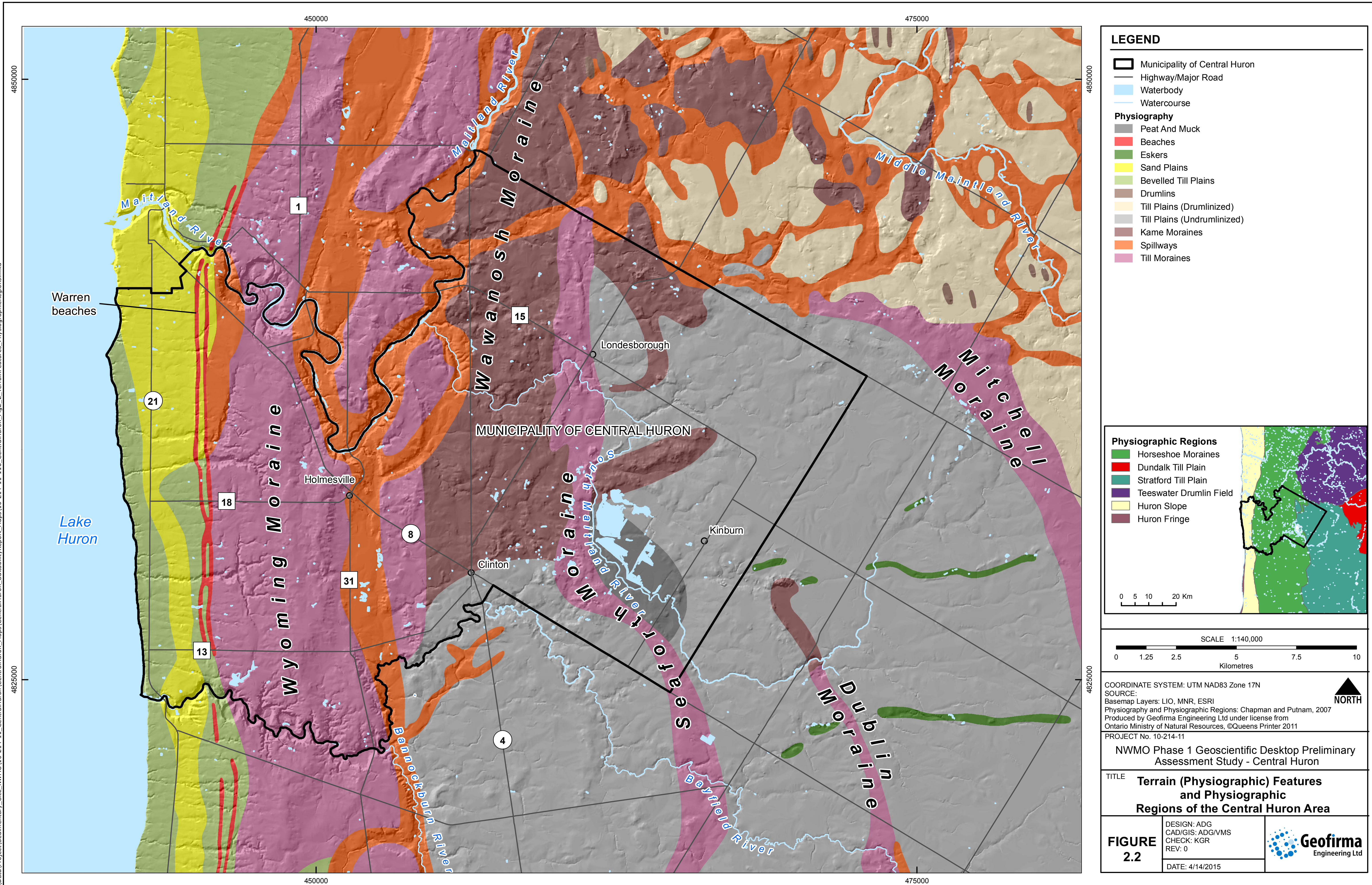
FIGURE 2.1

DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig2_1_SatelliteImagery.mxd



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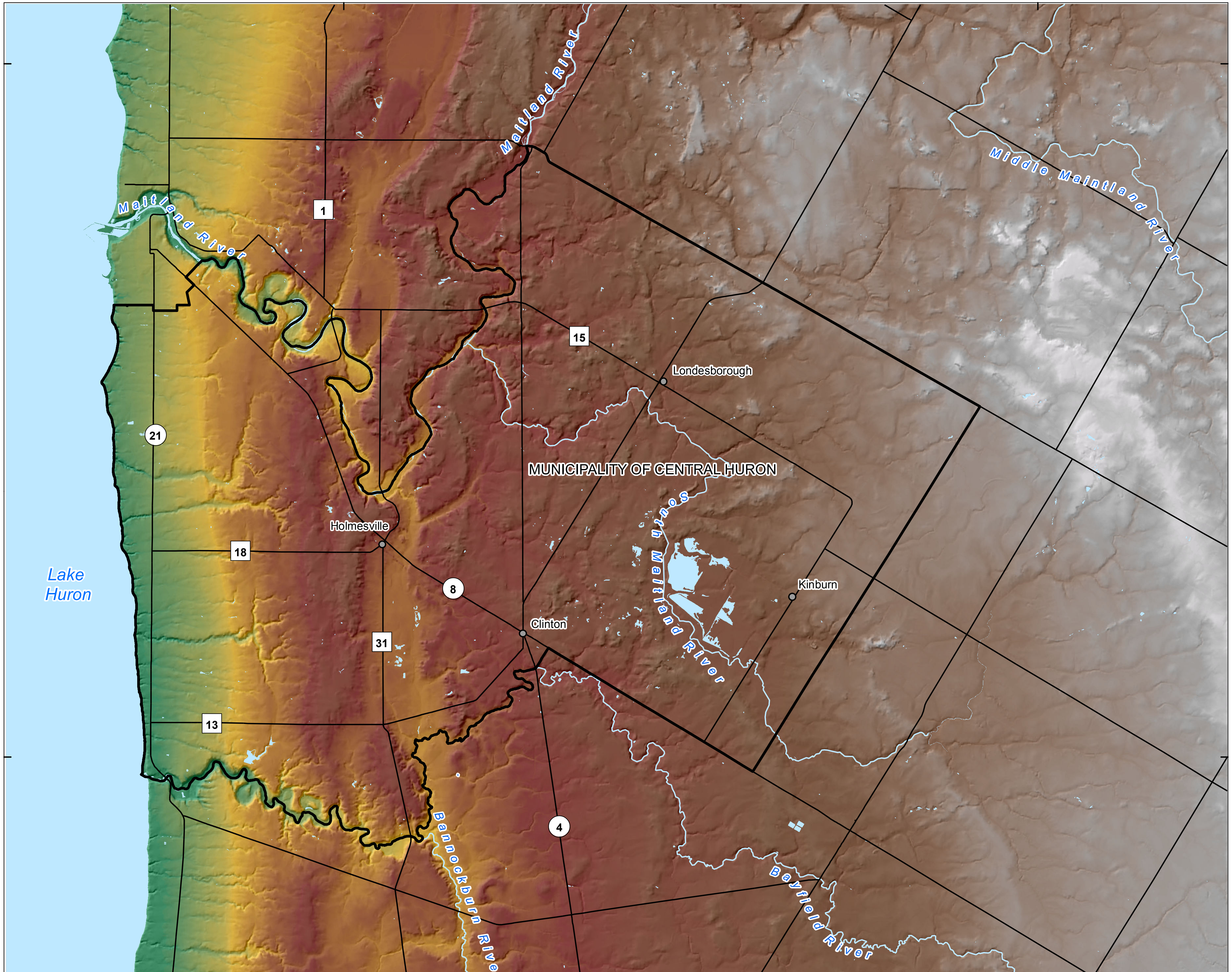

LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Watercourse

Digital Elevation Model (mASL)

High : 366

Low : 176

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Topography: DEM, Geobase, 2013
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Ground Surface Elevation of the Central Huron Area

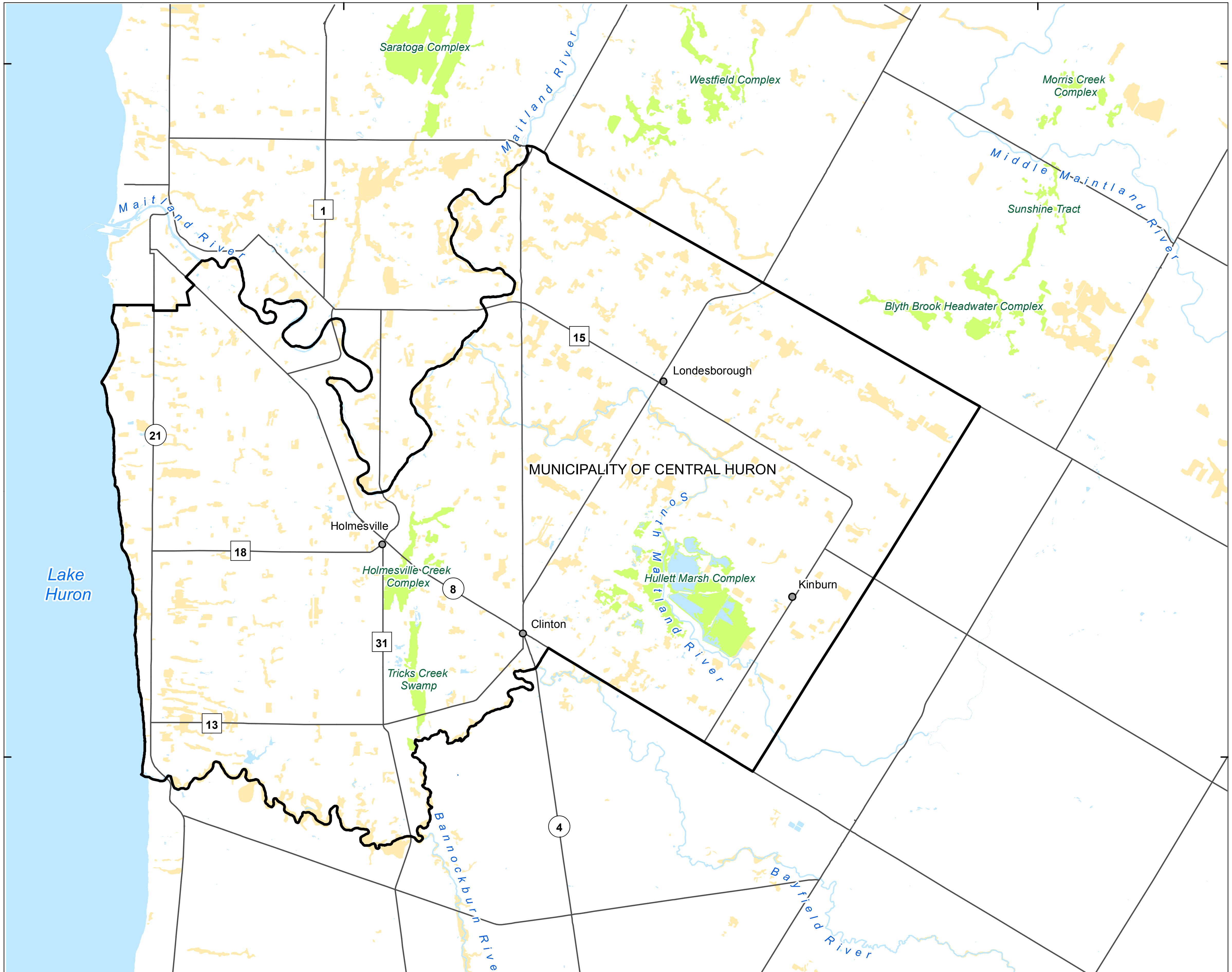
FIGURE 2.3

DESIGN: VMS
CAD/GIS: VMS, ADG
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig2_3_Elevation_MajorTopographic_Features.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Watercourse
- Other Wetlands
- Provincially Significant Wetland

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Wetlands: LIO, 2014; ABCA, 2014
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Waterbodies and Wetlands of the Central Huron Area

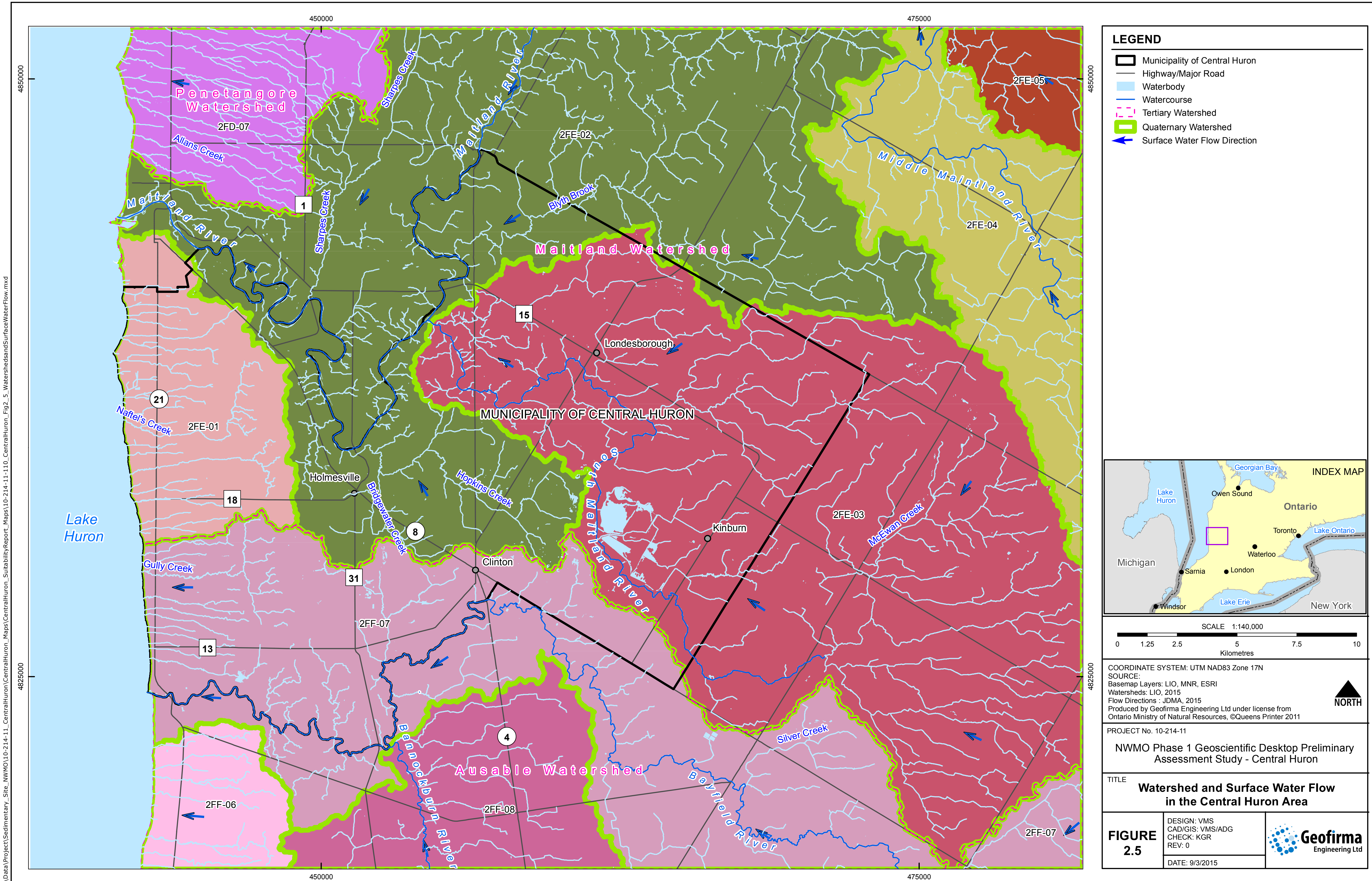
FIGURE 2.4

DESIGN: VMS
CAD/GIS: VMS
CHECK: KGR
REV: 0

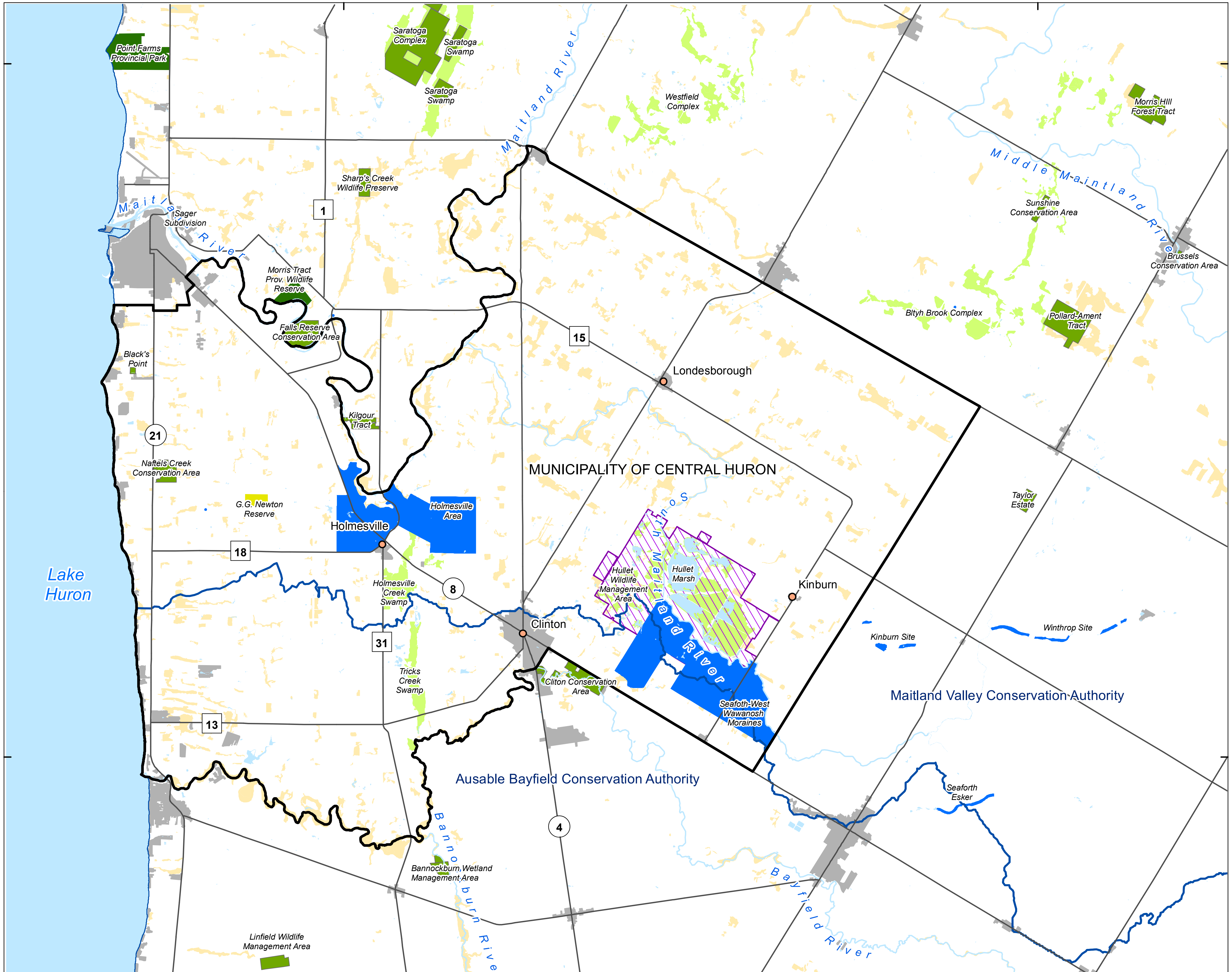
DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig2_4_LakesandWetlands.mxd



450000
475000
4850000
4825000
LEGEND
Municipality of Central Huron
Highway/Major Road
Waterbody
Watercourse
Tertiary Watershed
Quaternary Watershed
Surface Water Flow Direction
Penetangore Watershed
2FD-07
Allans Creek
Sharpes Creek
Maitland River
2FE-02
2FE-05
Middle Maintland River
2FE-04
Blyth Brook
Maitland Watershed
Lake Huron
2FE-01
Naftel's Creek
Holmesville
Bridgewater Creek
Hopkins Creek
Londesborough
MUNICIPALITY OF CENTRAL HURON
South Maitland River
Kinburn
2FE-03
McEwan Creek
Clinton
Gully Creek
2FF-07
Bannockburn River
Ausable Watershed
2FF-08
2FF-06
Silver Creek
Bayfield River
1
15
21
18
8
31
13
4
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Toronto
Lake Ontario
Waterloo
Michigan
Sarnia
London
Windsor
Lake Erie
New York
SCALE 1:140,000
0 1.25 2.5 5 7.5 10
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Watersheds: LIO, 2015
Flow Directions : JDMA, 2015
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-11
NWMO Phase 1 Geoscientific Desktop Preliminary
Assessment Study - Central Huron
TITLE
Watershed and Surface Water Flow
in the Central Huron Area
FIGURE
2.5
DESIGN: VMS
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0
DATE: 9/3/2015
Geofirma Engineering Ltd
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig2_5_WatershedsandSurfaceWaterFlow.mxd



LEGEND

Municipality of Central Huron
Highway/Major Road
Waterbody
Watercourse
Conservation Administration Area
ANSI (Earth Science)
Built-Up Area
Conservation Area/Reserve
NGO Nature Reserve

Provincia□0.5484 0 Td (a)Tj□□j□□0.3144 l 995.02767 289.91 l 99 (i)
Crown Leased Lands

SCALE 1:140,000

0 1.25 2.5 5 7.5 10
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Land Disposition and Ownership: Lio, 2014; ABCA, 2014
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Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Land Disposition and Ownership within the Central Huron Area

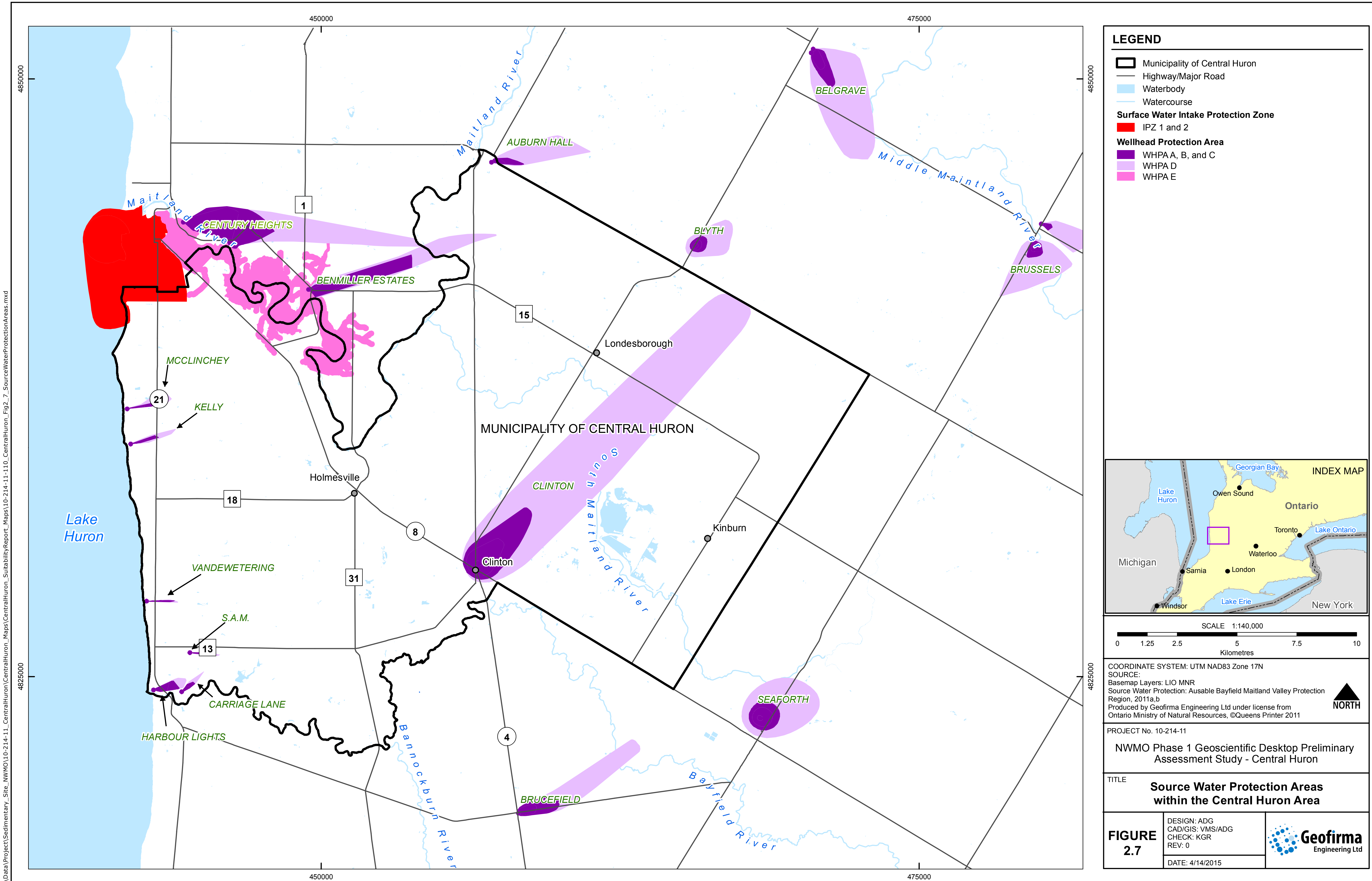
FIGURE 2.6

DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig2_6_LandDispositionOwnership.mxd



COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO MNR
Source Water Protection: Ausable Bayfield Maitland Valley Protection Region, 2011a,b
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PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

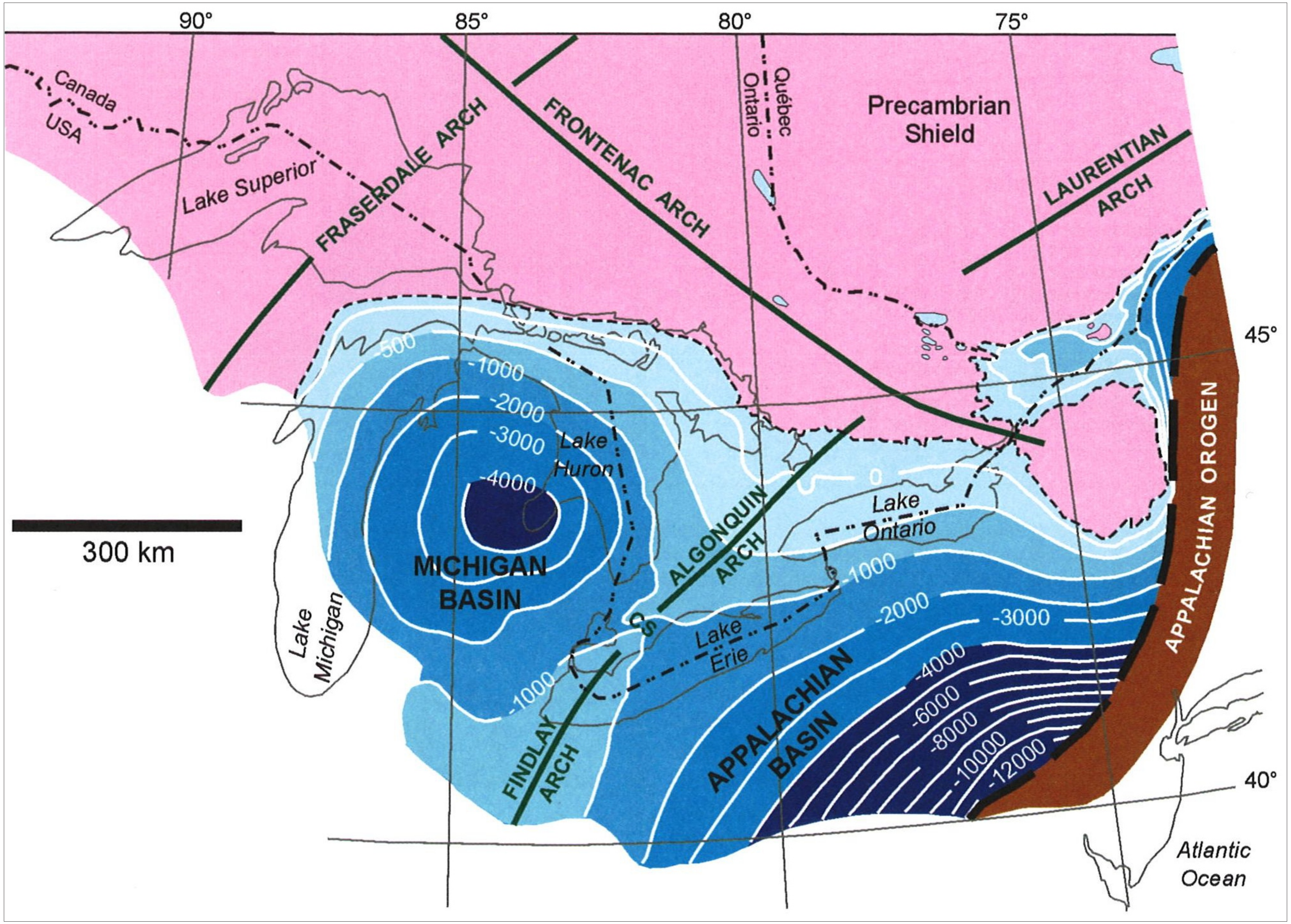
TITLE

Source Water Protection Areas within the Central Huron Area

FIGURE 2.7

DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0
DATE: 4/14/2015

Geofirma Engineering Ltd

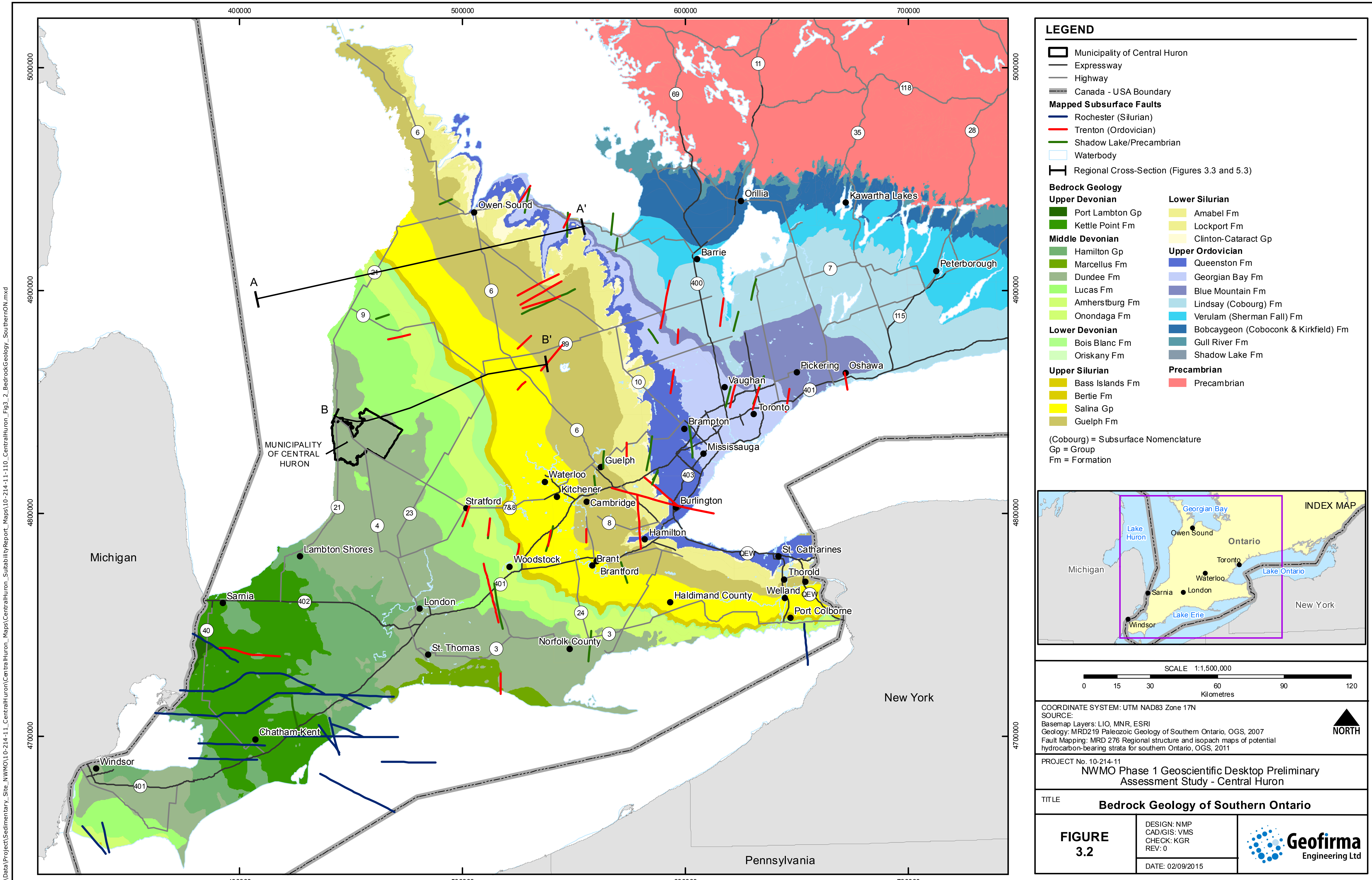


Data Source: Johnson et al. (1992); Armstrong and Carter (2010)

FIGURE 3.1 - Geological Features of Southern Ontario	Prepared by: VMS Reviewed by: KGR	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)
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	Date: 01/20/2015	

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\R0A\10-214-11-110_CentralHuron_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

PROJECT No. 10-214-11
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

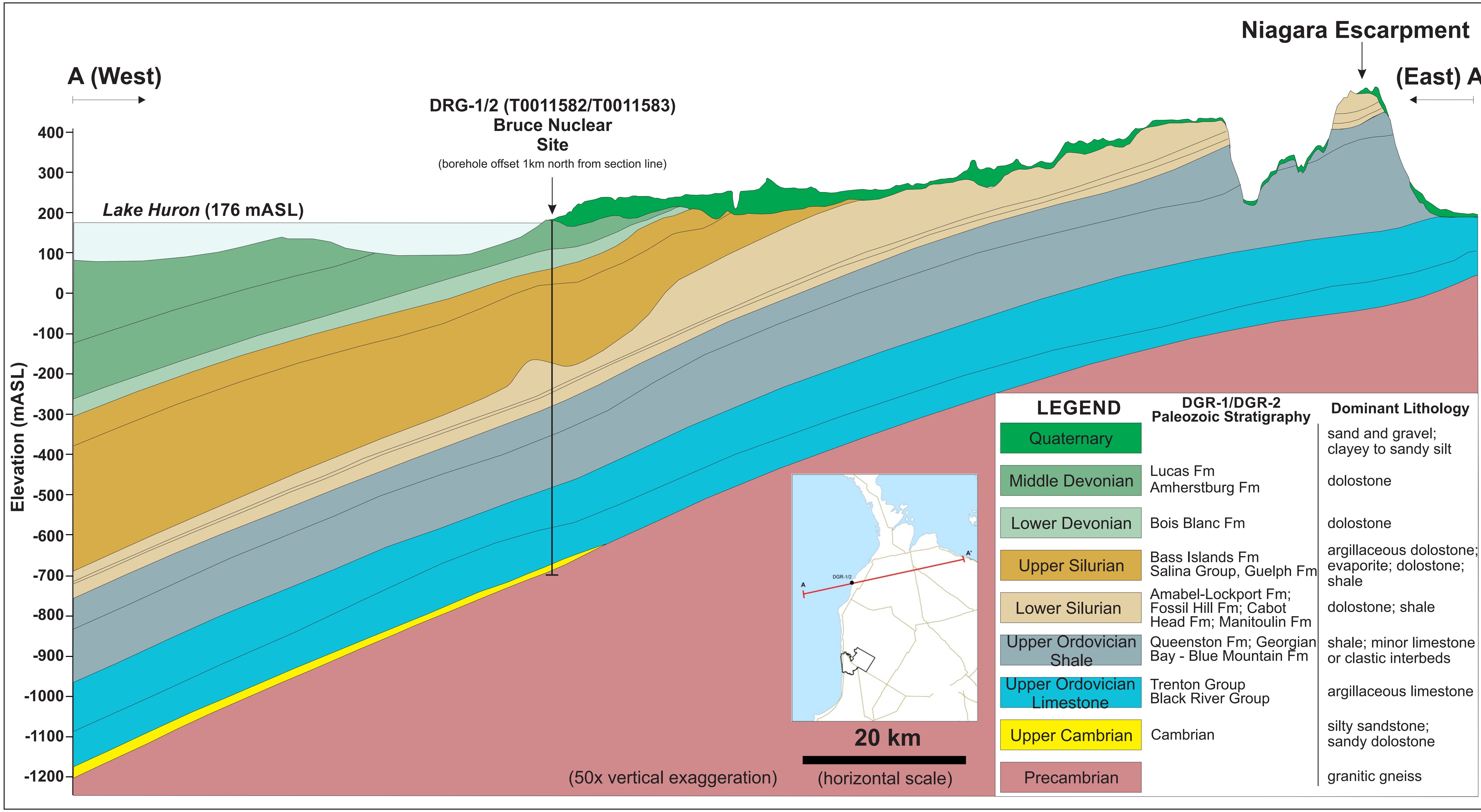
TITLE
Bedrock Geology of Southern Ontario

FIGURE 3.2

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

DATE: 02/09/2015

Geofirma Engineering Ltd



Data Source: after NWMO, 2011

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

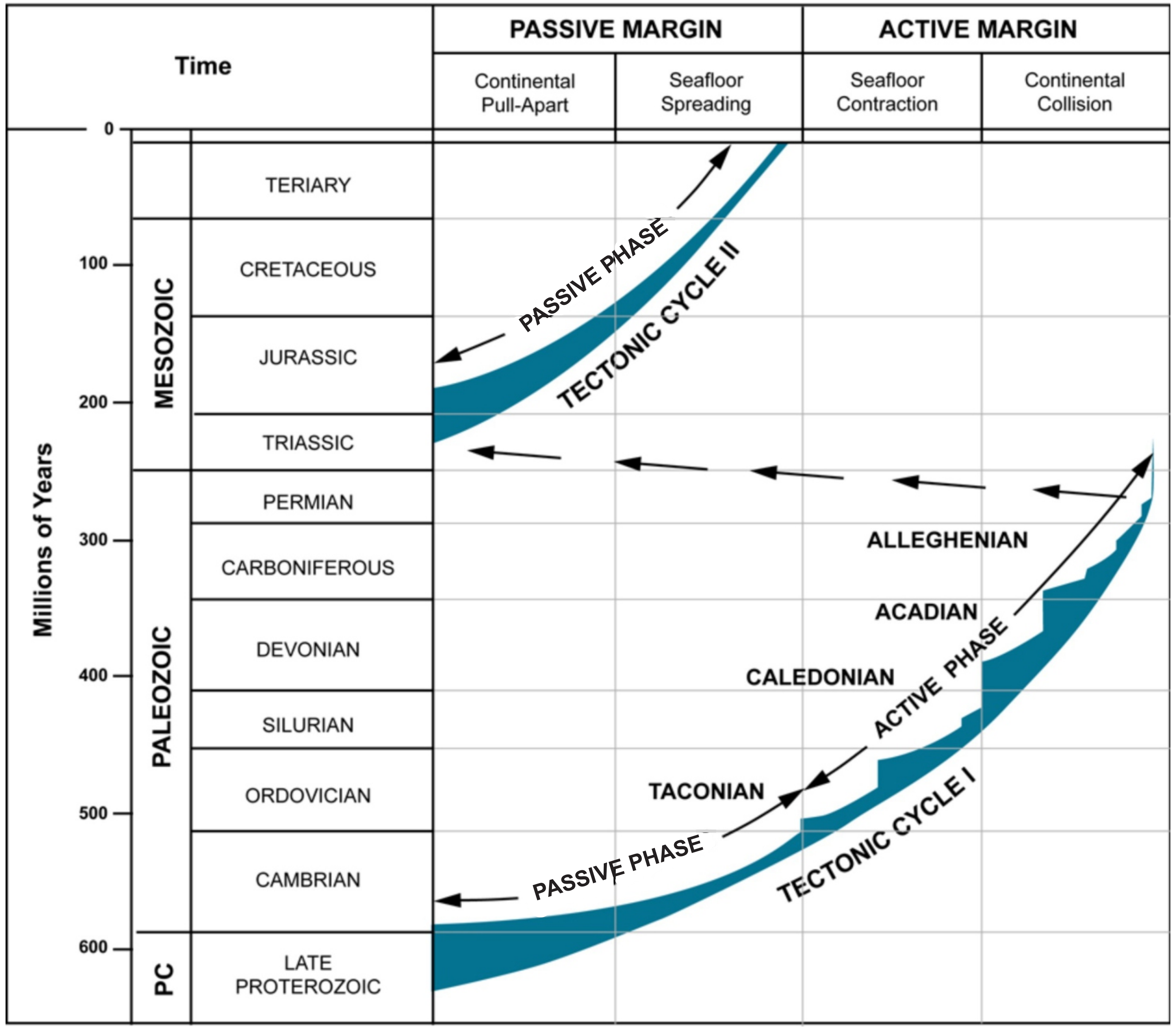
PROJECT No: 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

Prepared by: NMP/VMS
Reviewed by: KGR
Date: 01/20/2015

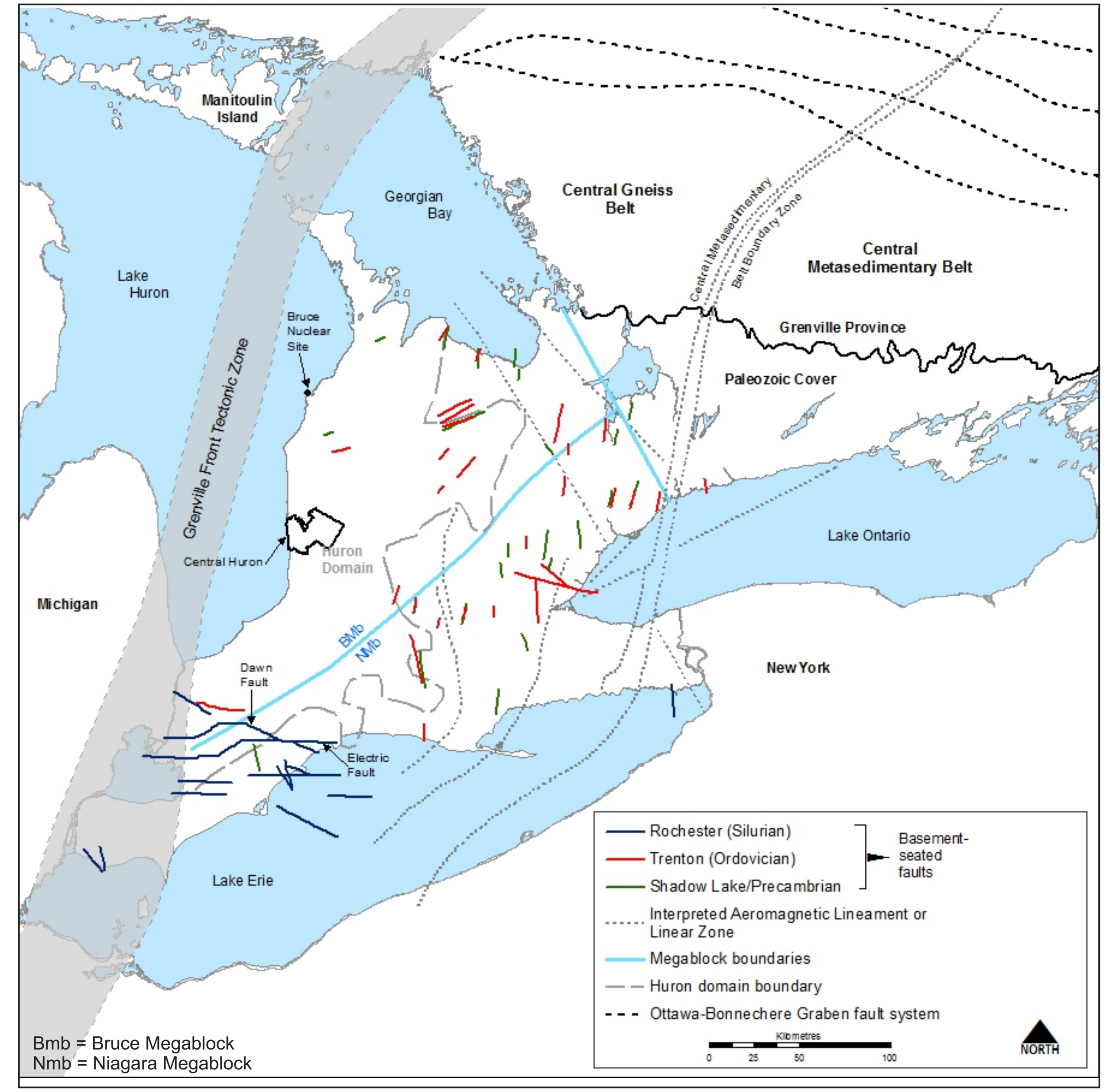
Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig3_3_Cross_Section_EasternFlankMichiganBasin.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 - Central Huron

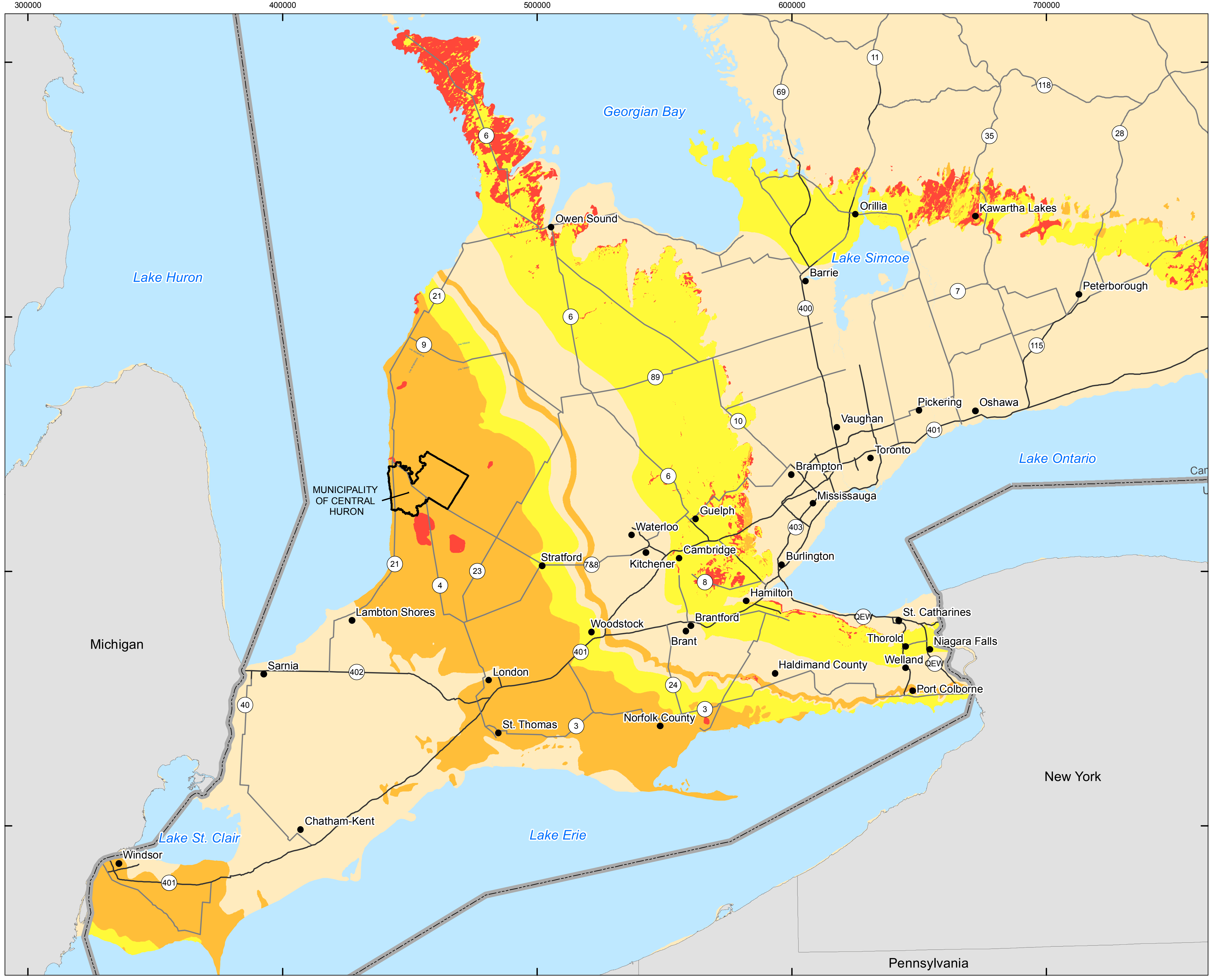
Prepared by: VMS/ADG

Reviewed by: KGR/SNS

Date: 14/03/2015

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig3_5_Tectonics.cdr"



LEGEND

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

Karst

- Known
- Inferred
- Potential

SCALE 1:1,500,000

0 10 20 40 60 80
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: Brunton and Dodge, 2008, Karst of Southern Ontario and Manitoulin Island, OGS Dataset GRS005
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NORTH

PROJECT No. 10-214-11

Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Karst Mapping of Southern Ontario

FIGURE 3.5

DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0

DATE: 4/14/2015

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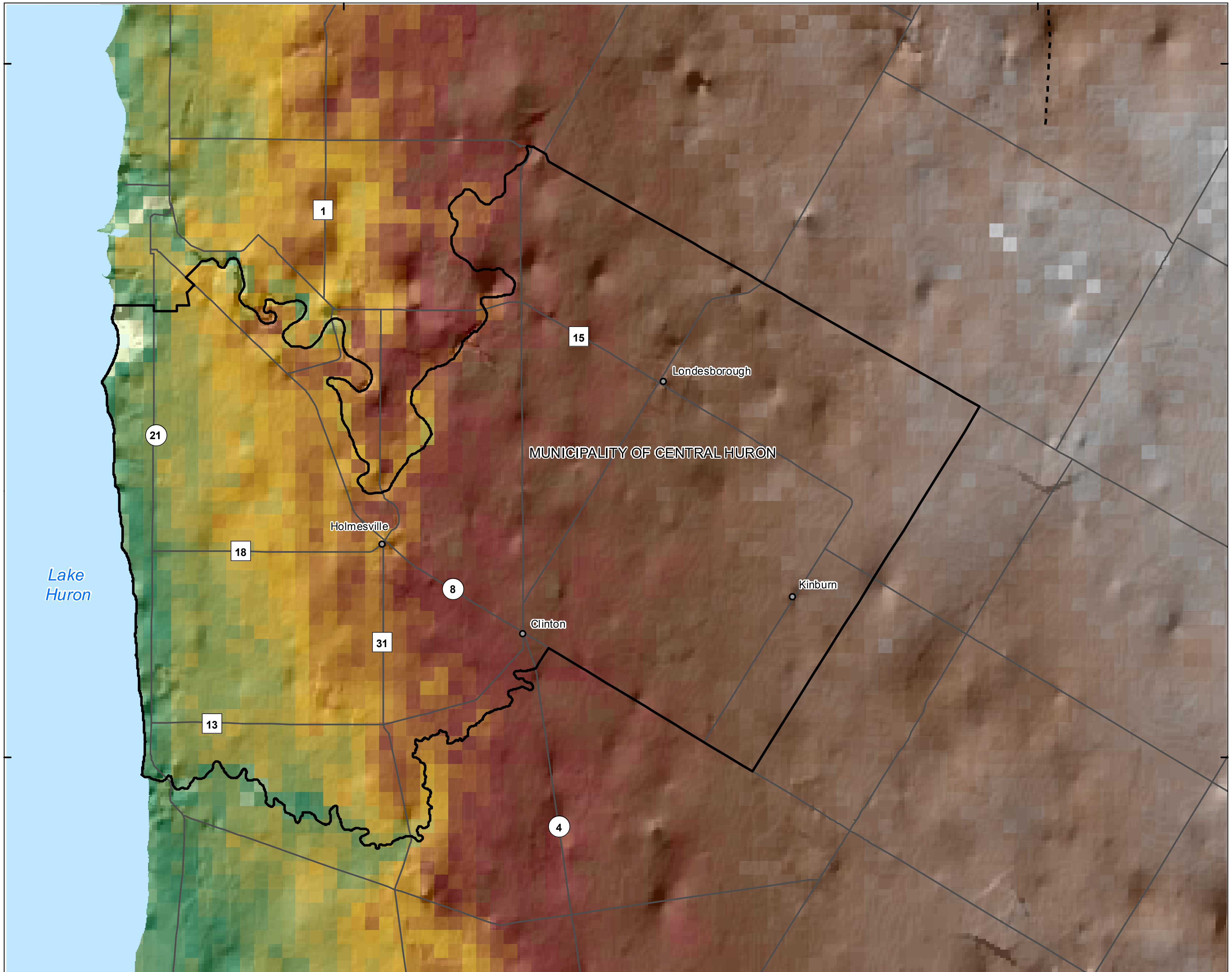
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_5_KarstMappingRegional.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Hutton Height Buried Bedrock Valley
- Waterbody

Bedrock Surface (mASL)

High : 350

Low : 95

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Buried Bedrock Valley: Gao, 2011a
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Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Bedrock Surface Topography in the Central Huron Area

FIGURE 3.6

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 02/09/2015

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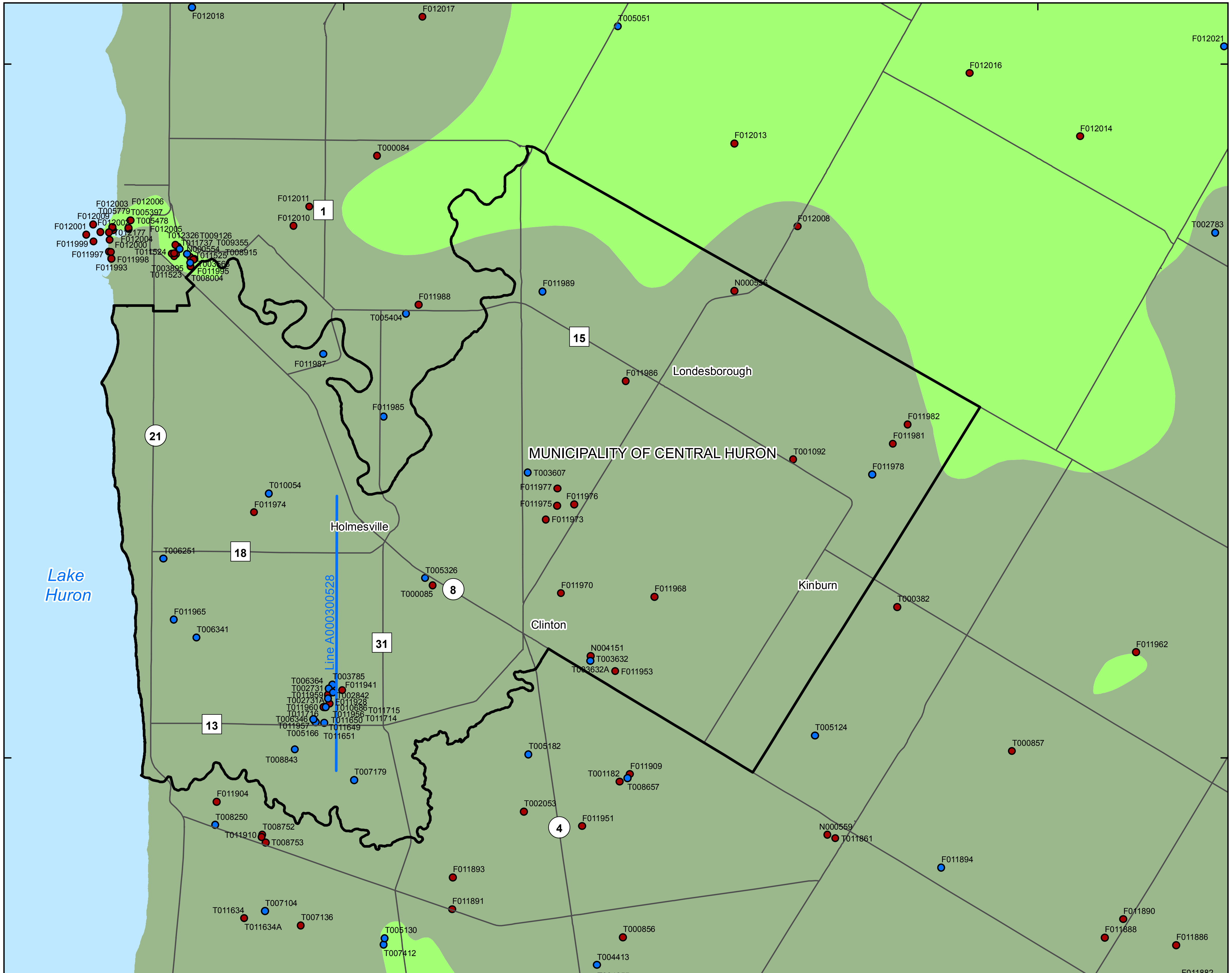
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_6_BedrockSurfaceTopography.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Acquired 2D Seismic Data
- OGSRL Well
- OGSRL Well with Geophysics Log

Bedrock Geology

Middle Devonian

- Dundee Fm
- Lucas Fm

Fm = Formation

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: OGS 2007
Wells: OGSRL 2014a
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Bedrock Geology, Oil and Gas Wells and 2D Seismic Line of the Central Huron Area

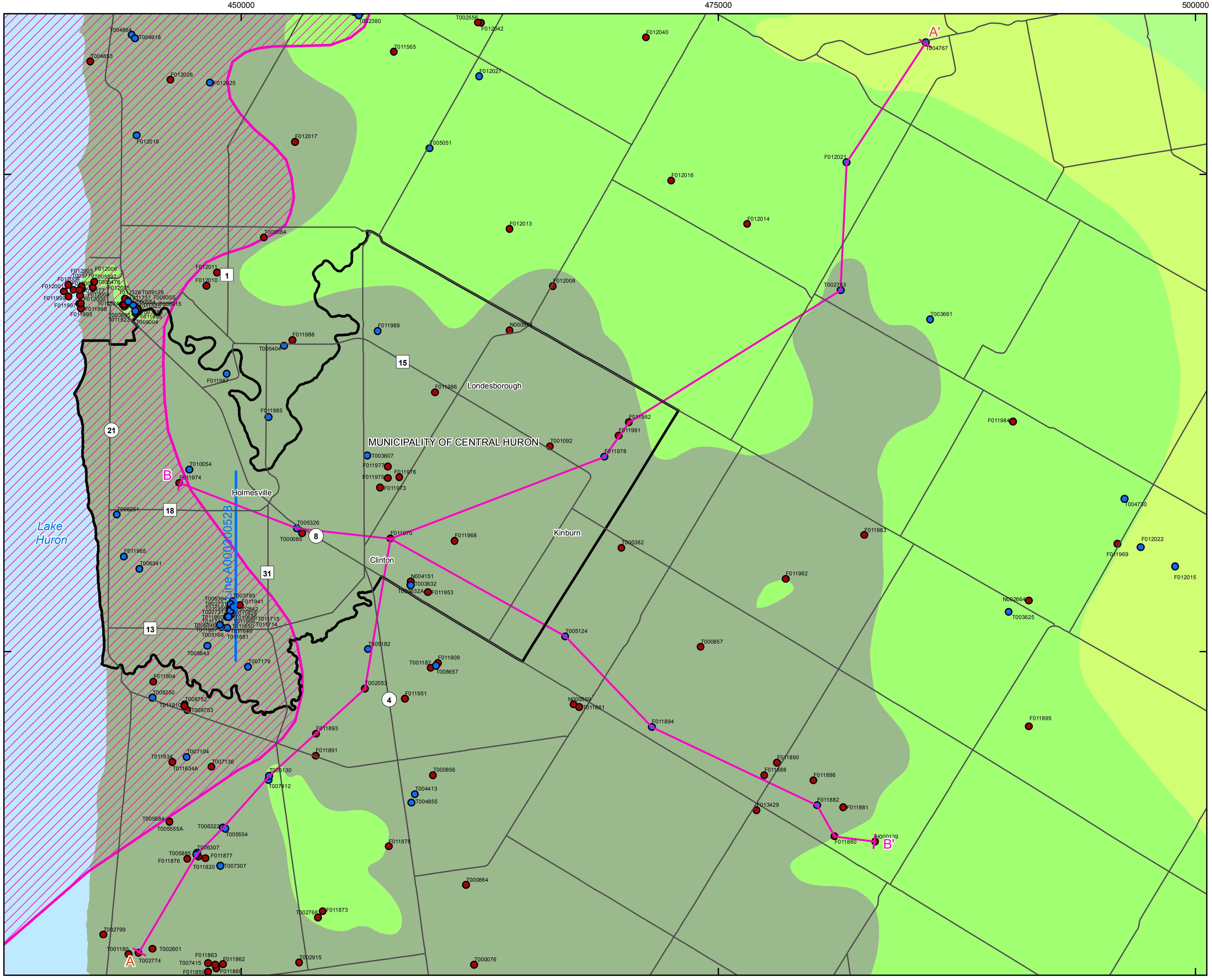
FIGURE 3.7

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 9/3/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron_SuitabilityReport_Maps\CentralHuron_Maps\CentralHuron_Fig3_7_BedrockGeologyOilGasWells.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Acquired 2D Seismic Data
- OGSRL Well
- OGSRL Well with Geophysics Log
- Cross-Section (see Figures 3.12 and 3.13)
- Cambrian Sandstone

Bedrock Geology

Middle Devonian

- Dundee Fm
- Lucas Fm
- Amherstburg Fm

Lower Devonian

- Bois Blanc Fm

Fm = Formation

SCALE 1:200,000

0 1 2 4 6 8

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Cambrian Sandstone: Bailey & Cochrane, 1984a
Geology: OGS 2007
Wells: OGSRL 2014a
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Sedimentary Sites

TITLE

Location of Cross-Sections and 2D Seismic Line

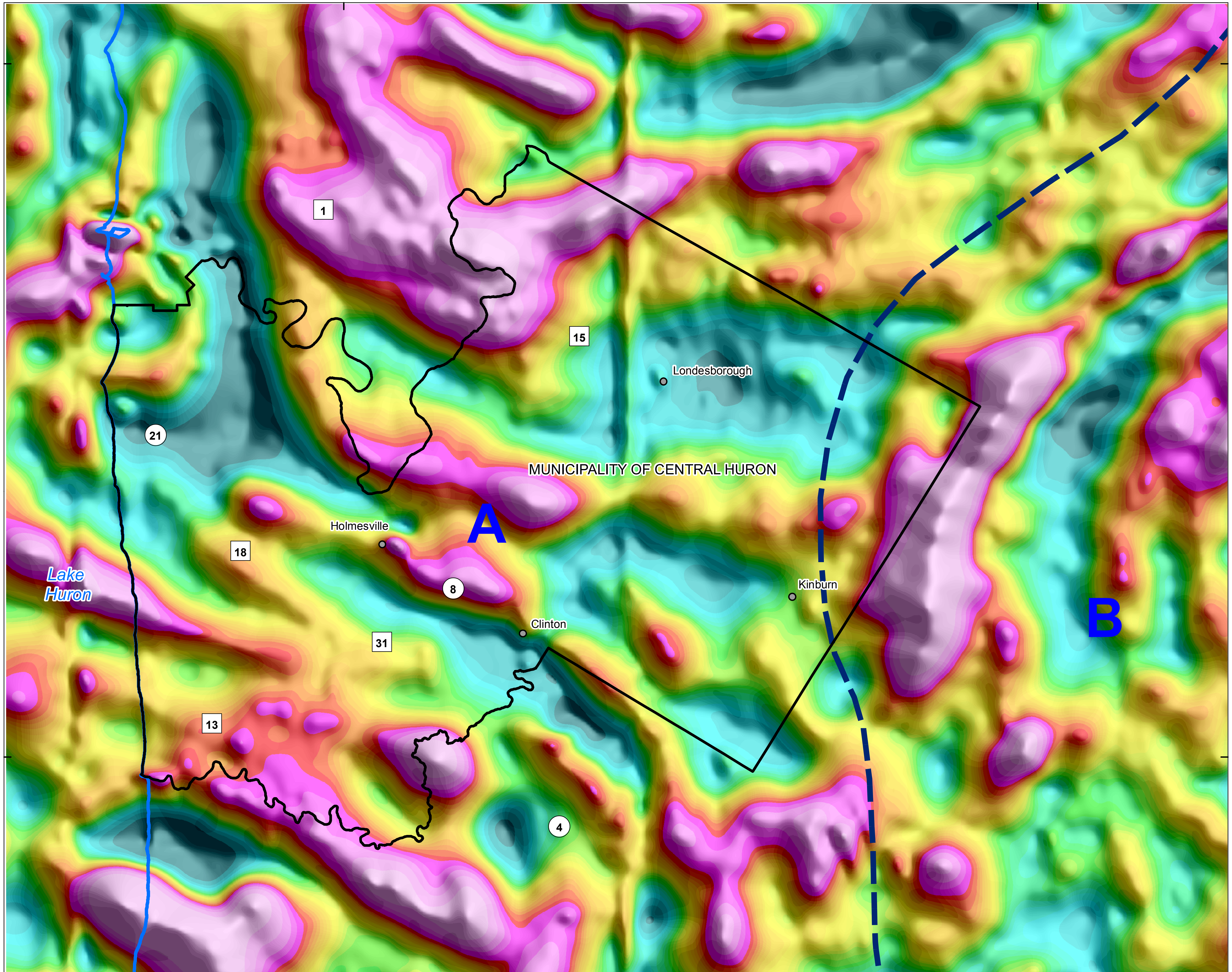
FIGURE 3.8

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 10/7/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_8_BedrockGeologyOilGasCrossSection.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Interpreted Magnetic Domains

First Vertical Derivative, Reduced to Pole, Magnetic Field

0.043
0.033
0.027
0.023
0.019
0.017
0.014
0.012
0.010
0.008
0.006
0.004
0.003
0.001
0.000
-0.002
-0.003
-0.005
-0.007
-0.008
-0.010
-0.013
-0.015
-0.018
-0.021
-0.026
-0.034

nT/m

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Interpreted Domains: PGW, 2015
Magnetic Data: GSC, 2014; Spector, 1999
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

First Vertical Derivative of the Pole Reduced Magnetic Field in the Central Huron Area

FIGURE 3.9

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

DATE: 4/14/2015

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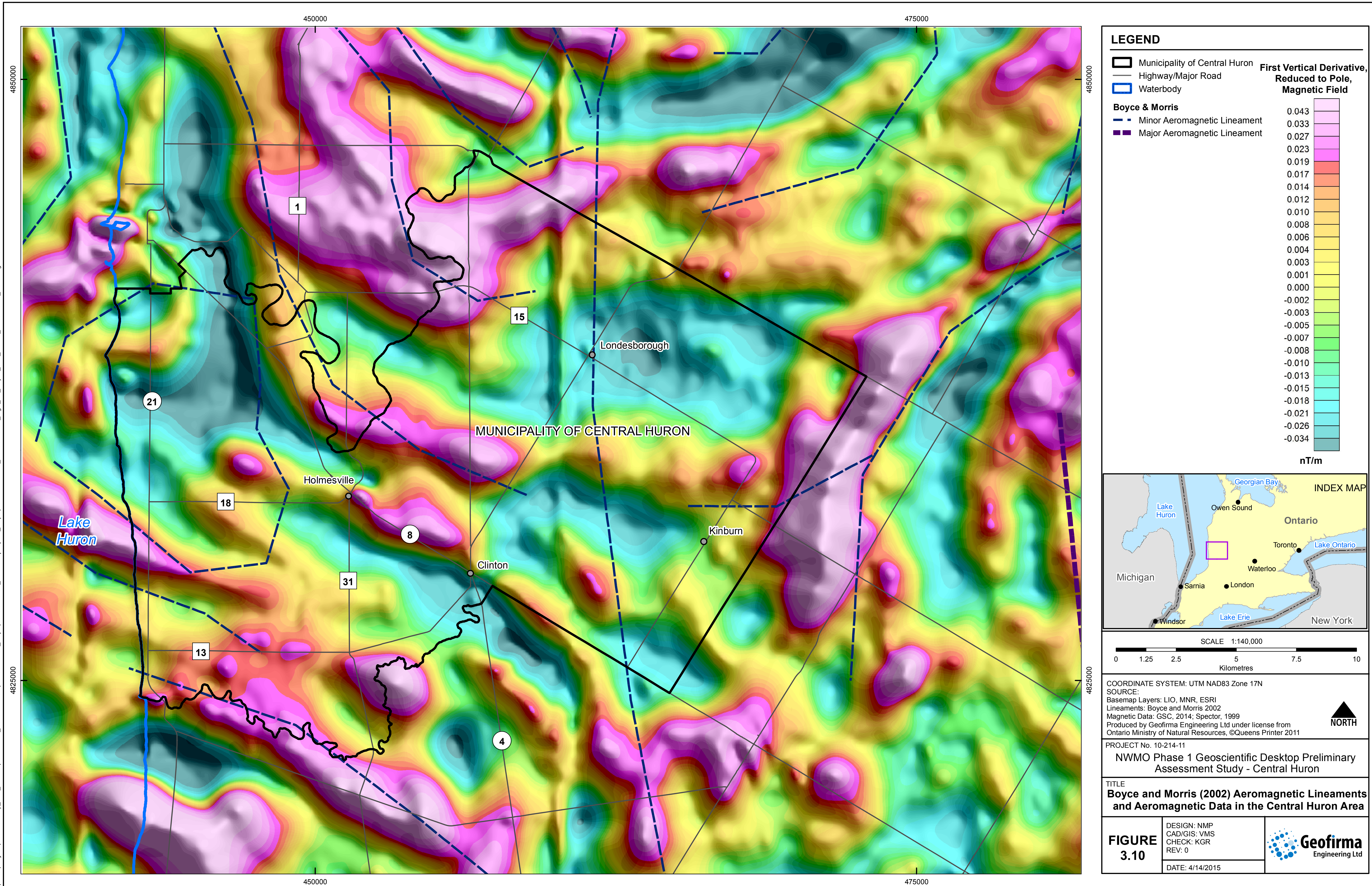
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_9_1VDPR_Magnetic_Field.mxd



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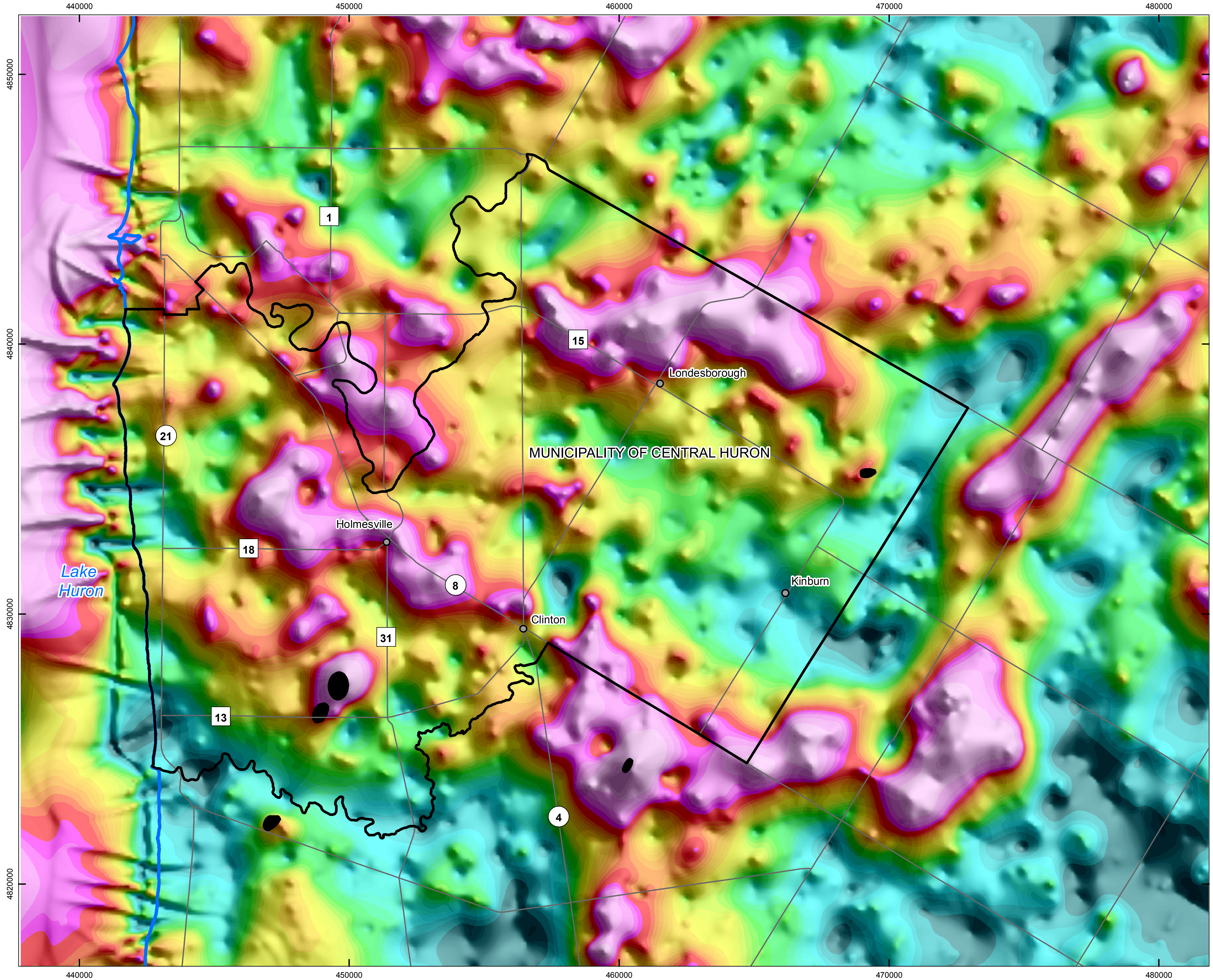

LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Pinnacle Reef

First Vertical Derivative of Bouguer Gravity

0.00075
0.00060
0.00050
0.00045
0.00040
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
-0.00005
-0.00010
-0.00015
-0.00020
-0.00025
-0.00030
-0.00035
-0.00045
-0.00050
-0.00055
-0.00065
-0.00075
-0.00085
-0.00100

mGal/m

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

NORTH

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Pinnacle Reefs: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Gravity Data: GSC, 2014; PGW, 2015
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PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

First Vertical Derivative of the Bouguer Gravity in the Central Huron Area

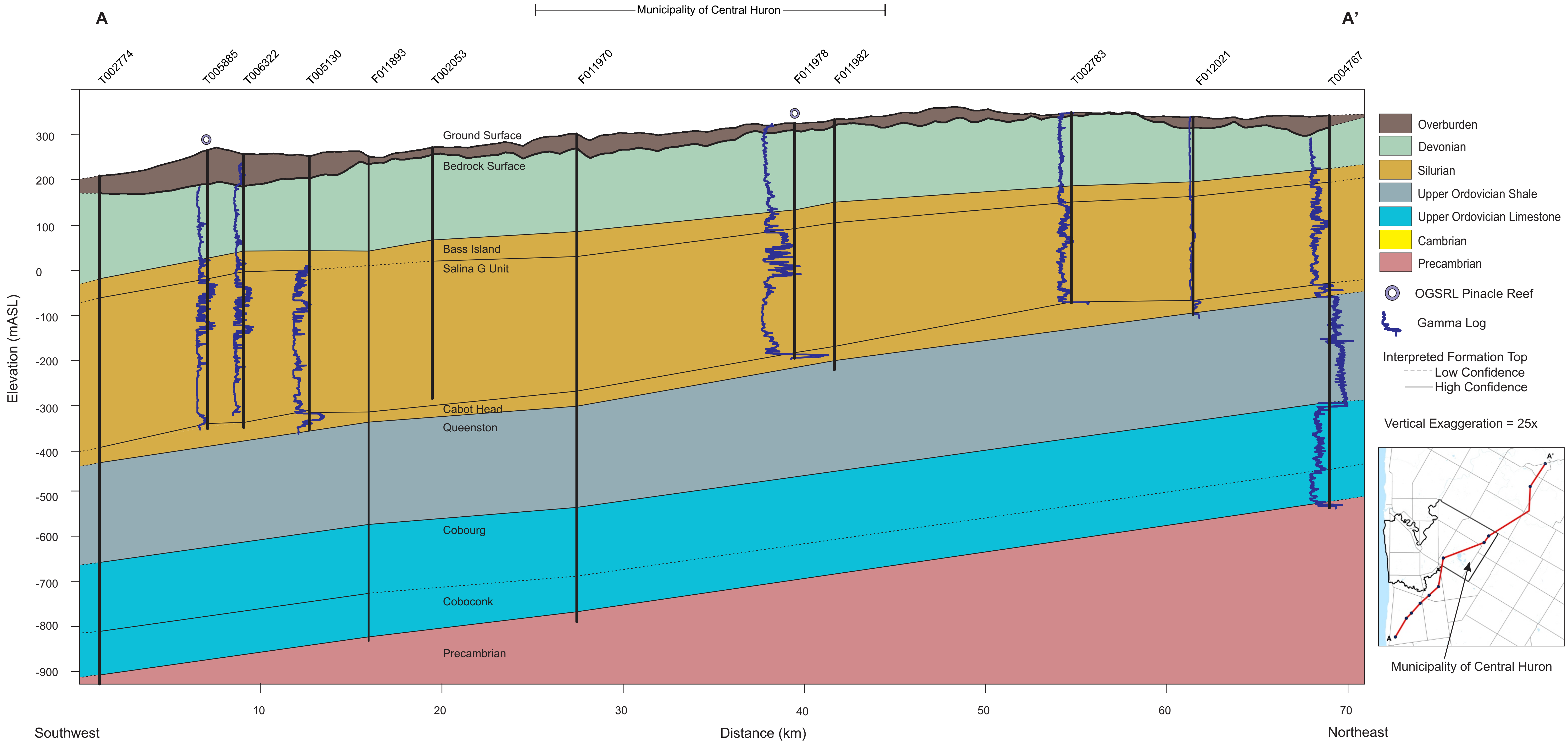
FIGURE 3.11

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

DATE: 10/7/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_11_1VDBouguerGravity.mxd



Cross Section A-A'

Geological Cross Section A-A'
NWMO Phase I Geoscientific Desktop Preliminary Assessment Study - Central Huron

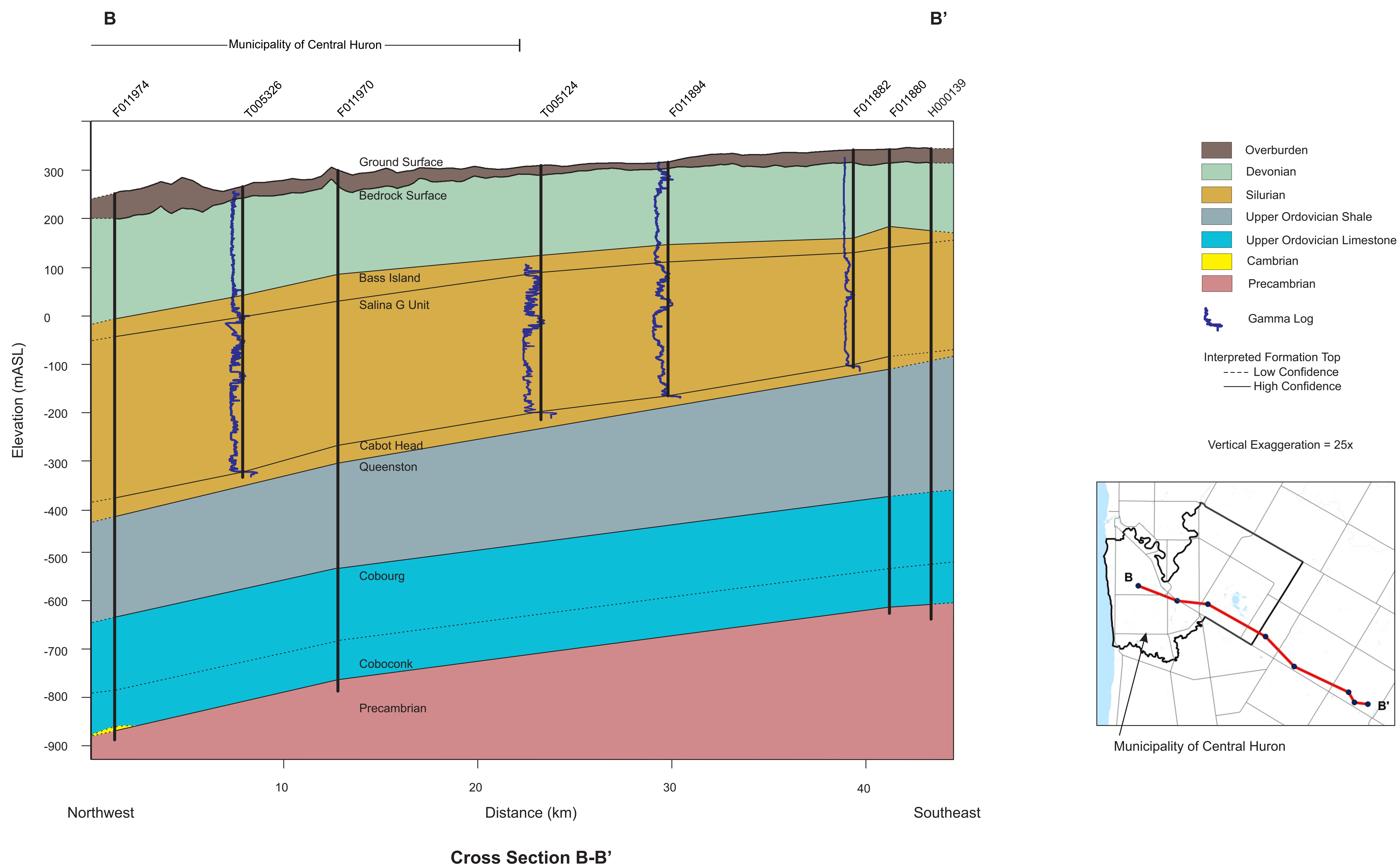
FIGURE 3.12

Doc. No.:10-214-11-110_CentralHuron_Fig3_12_CrossSectionA.cdr

Prepared by: NDR/ADG/NMP
Reviewed by: KGR/SNS
Date: Oct 7, 2015

SOURCE:
Wells: OGSRL, 2014a
Pinnacle Reef: OGS, 2011

Geofirma Engineering Ltd



Cross Section B-B'

Geological Cross Section B-B'
NWMO Phase I Geoscientific Desktop Preliminary Assessment Study - Central Huron

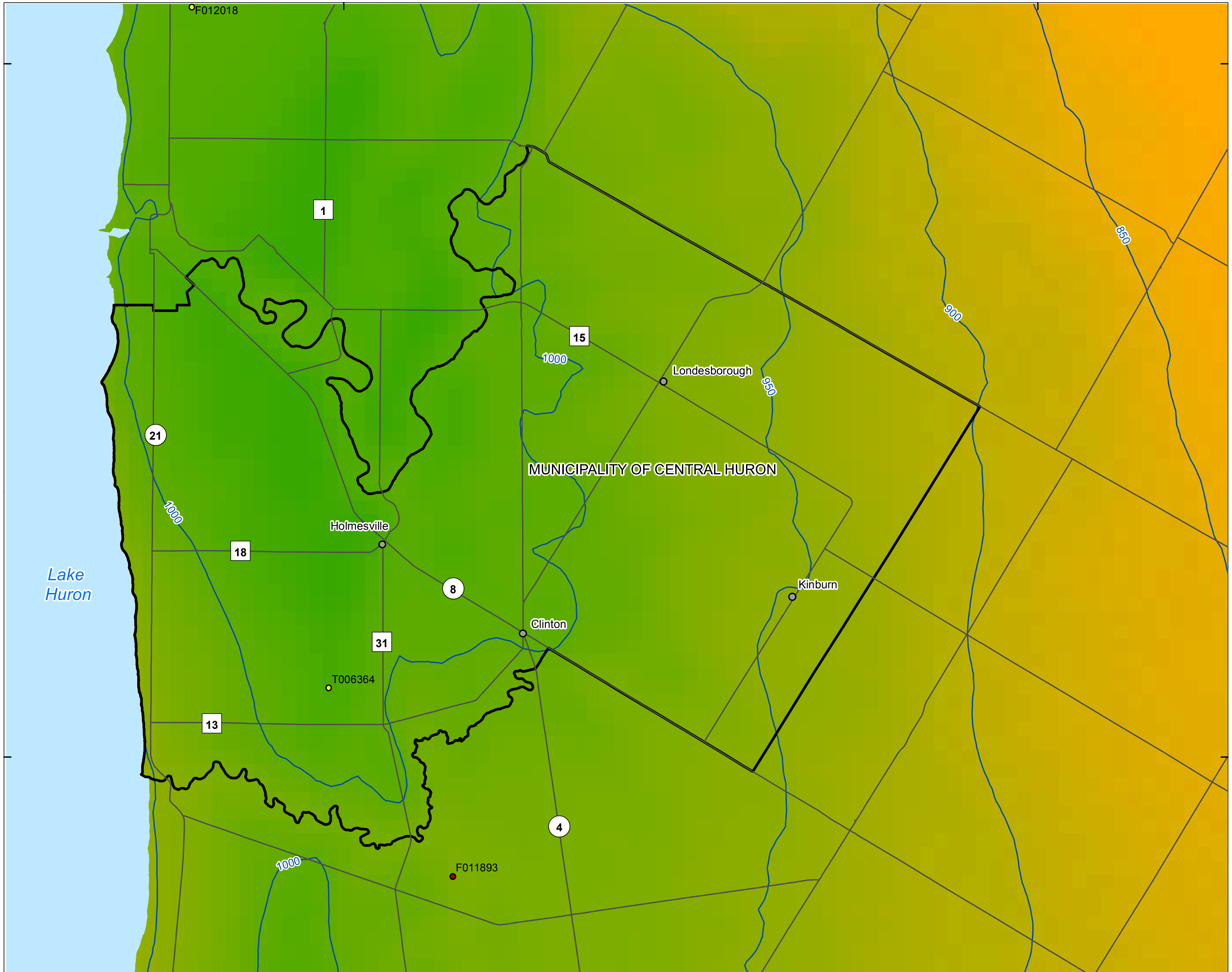
FIGURE 3.13

Doc. No.:10-214-11-110_CentralHuron_Fig3_13_CrossSection_B.cdr

Prepared by: NDR/ADG
Reviewed by: KGR/SNS
Date: Feb 4, 2015

SOURCE:
Wells: OGSRL, 2014a

Geofirma Engineering Ltd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody

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 : 1047

Low : 809

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

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Wells: OGSRL 2014a
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Depth to Top of the Coboconk Formation in the Central Huron Area

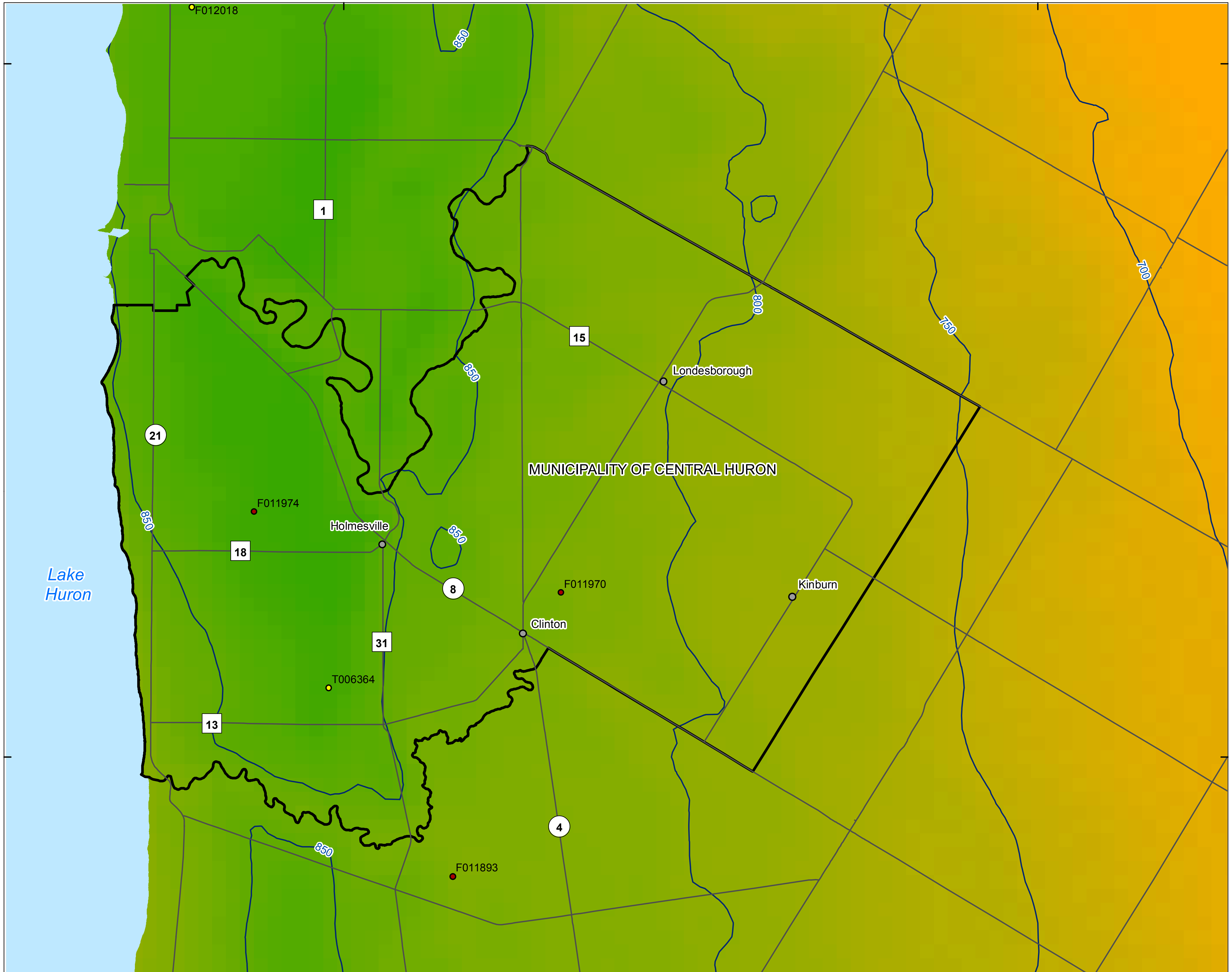
FIGURE 3.14

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_14_Depth_to_Coboconk.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody

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 : 898

Low : 662

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

SCALE 1:140,000

0 1.25 2.5 5 7.5 10
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Wells: OGSRL 2014a
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Depth to Top of the Cobourg Formation in the Central Huron Area

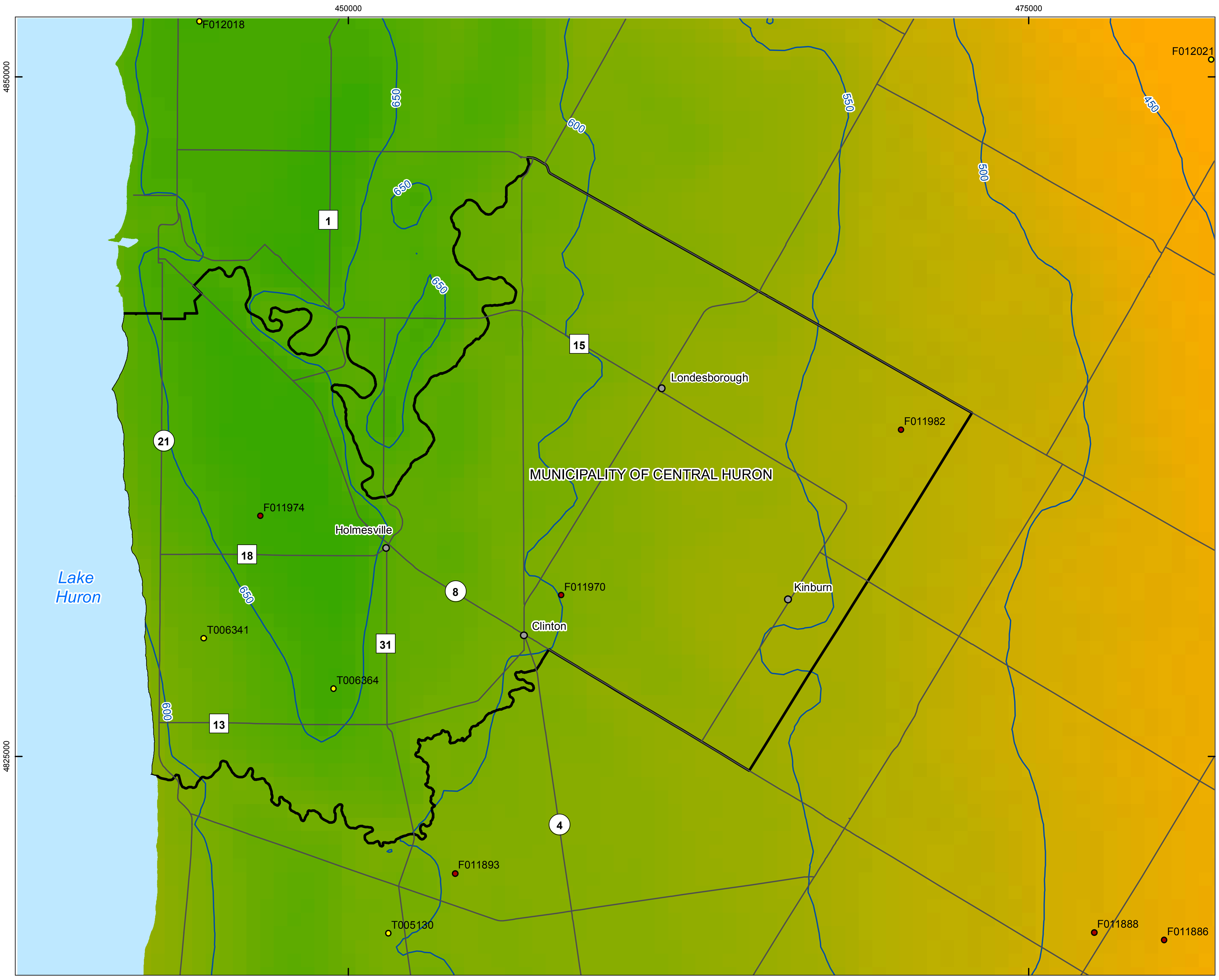
FIGURE 3.15

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_15_Depth_to_Cobourg.mxd



LEGEND

Municipality of Central Huron
Highway/Major Road
Waterbody

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

OGSRL Well with Geophysics Log
OGSRL Well

Depth to the Queenston Formation (mBGS)

High : 679

Low : 426

Contour of Depth to the Queenston Formation (50m interval)

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Wells: OGSRL 2014a
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NORTH

PROJECT No. 10-214-11

Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Depth to Top of the Queenston Formation in the Central Huron Area

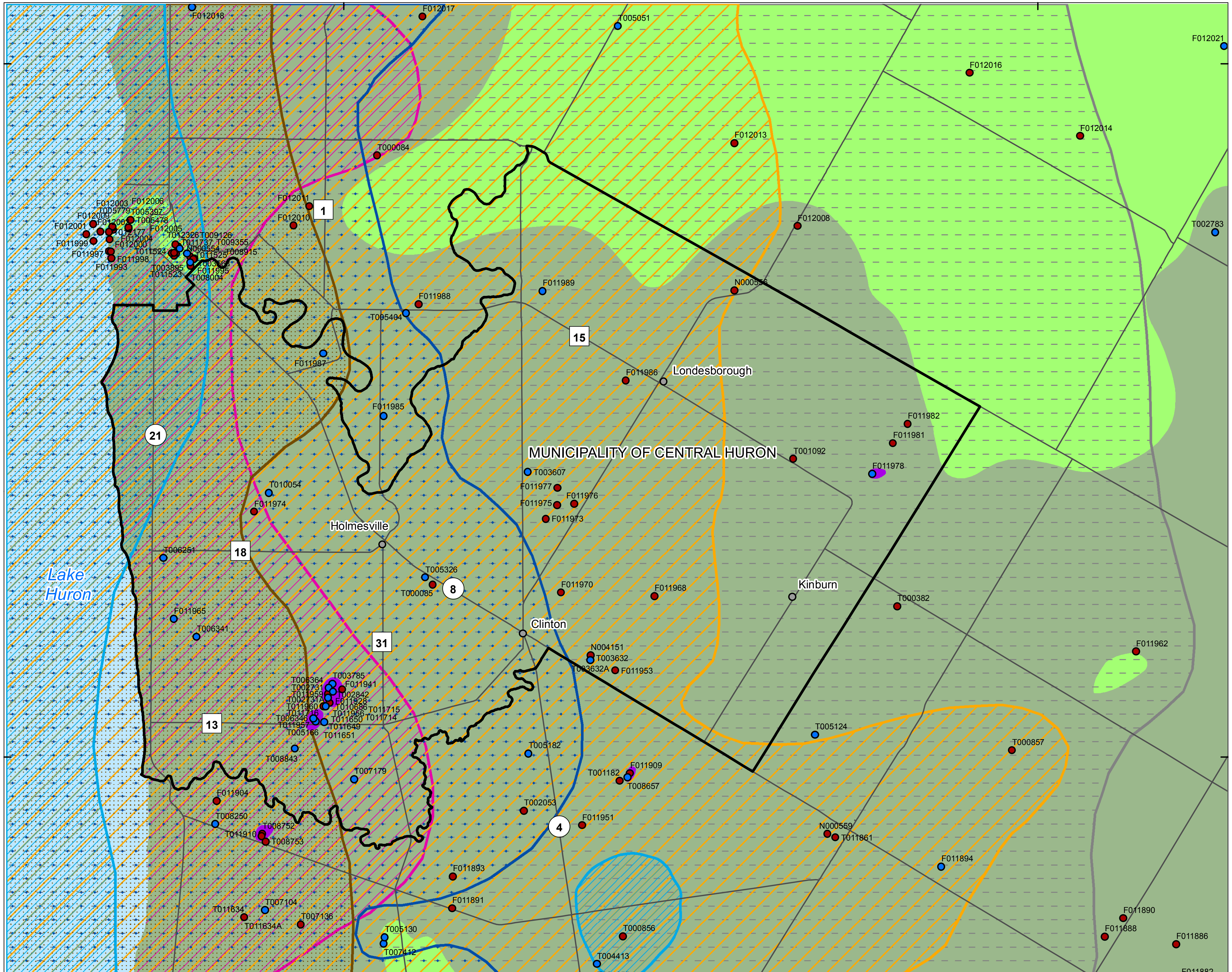
FIGURE 3.16

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_16_Depth_to_Queenston.mxd



LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- OGSRL Well
- OGSRL Well with Geophysics Log
- Salina F Salt
- Salina D Salt
- Salina B Salt
- Salina A2 Salt
- Salina A1 Salt
- Pinnacle Reef
- Cambrian Sandstone

Bedrock Geology

Middle Devonian

- Dundee Fm
- Lucas Fm

Fm = Formation

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

NORTH

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Cambrian Sandstone: Bailey & Cochrane, 1984a
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, 1977
Wells: OGSRL 2014a
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PROJECT No. 10-214-11

Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

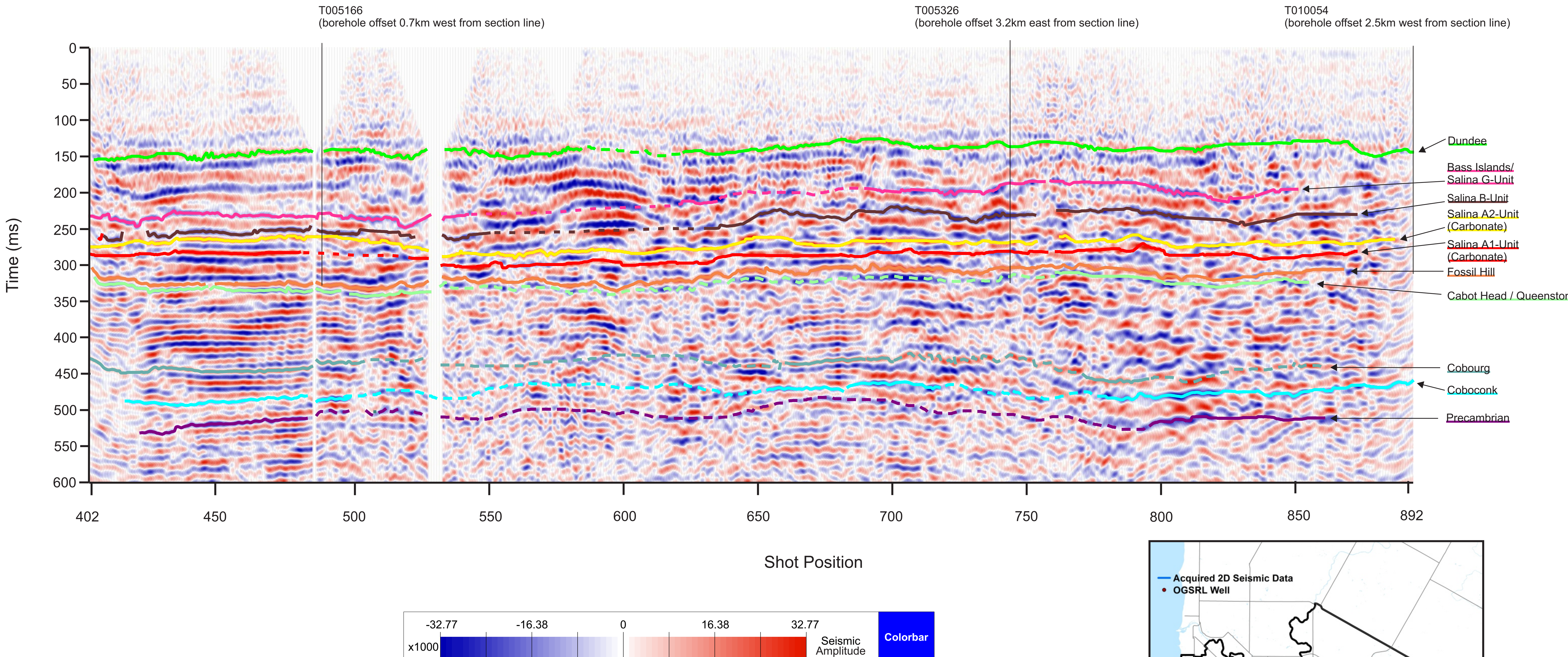
Location of Pinnacle Reefs, Salt Occurence, and Cambrian Sandstone in the Central Huron Area

FIGURE 3.17

DESIGN: ADG
CAD/GIS: VMS
CHECK: KGR
REV: 0

DATE: 10/7/2015

Geofirma Engineering Ltd



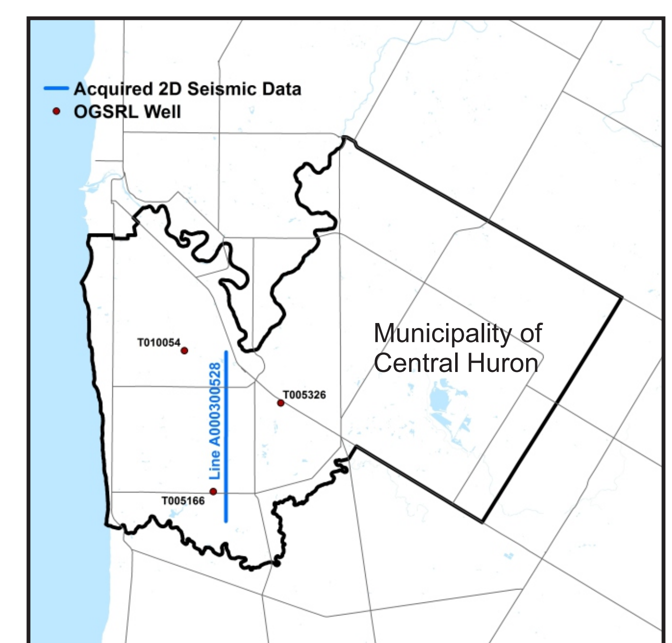


Figure 3.18 - 2D Seismic Interpretation of Line A00300528 in the Municipality of Central Huron

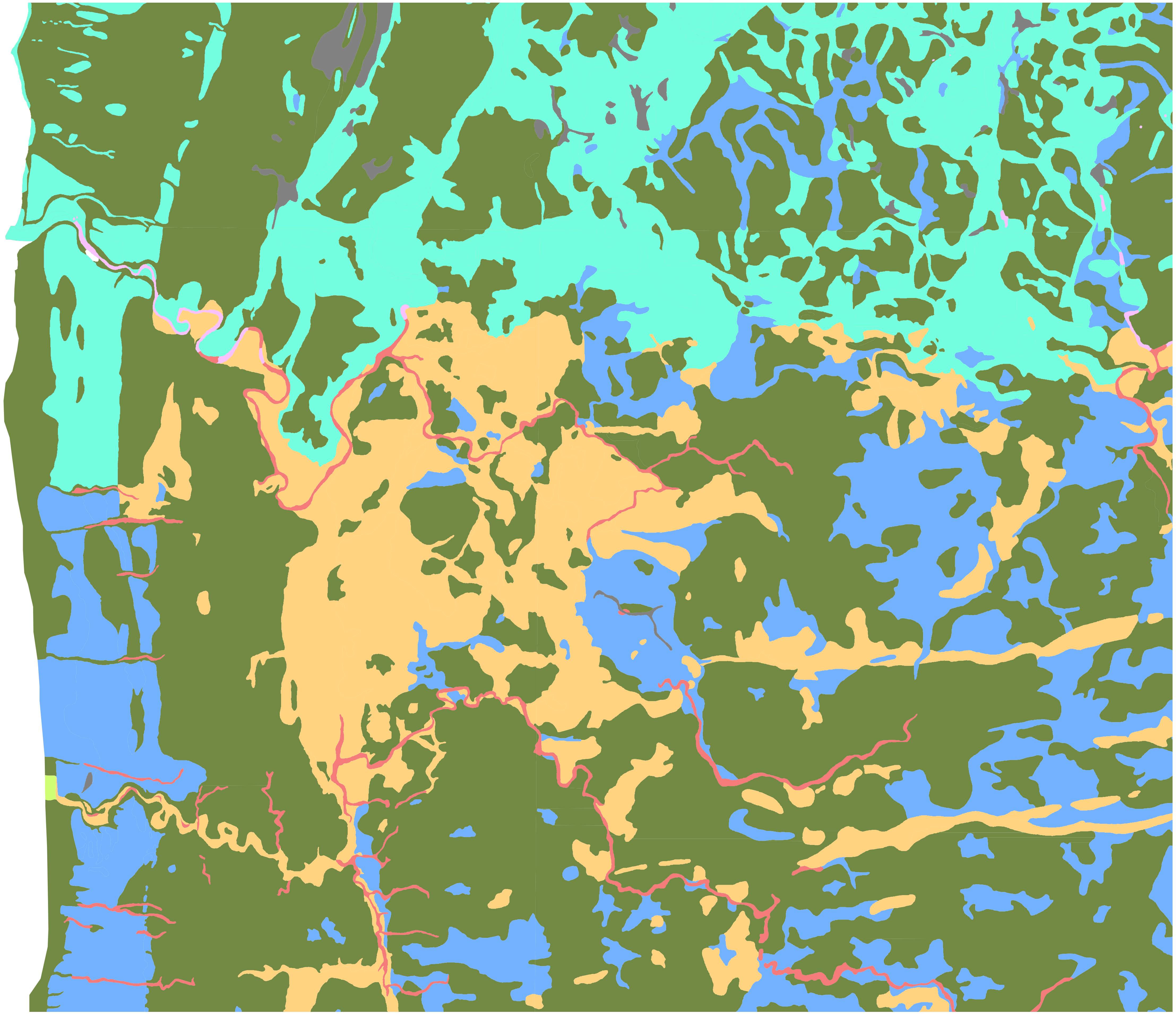
PROJECT No: 10-214-11

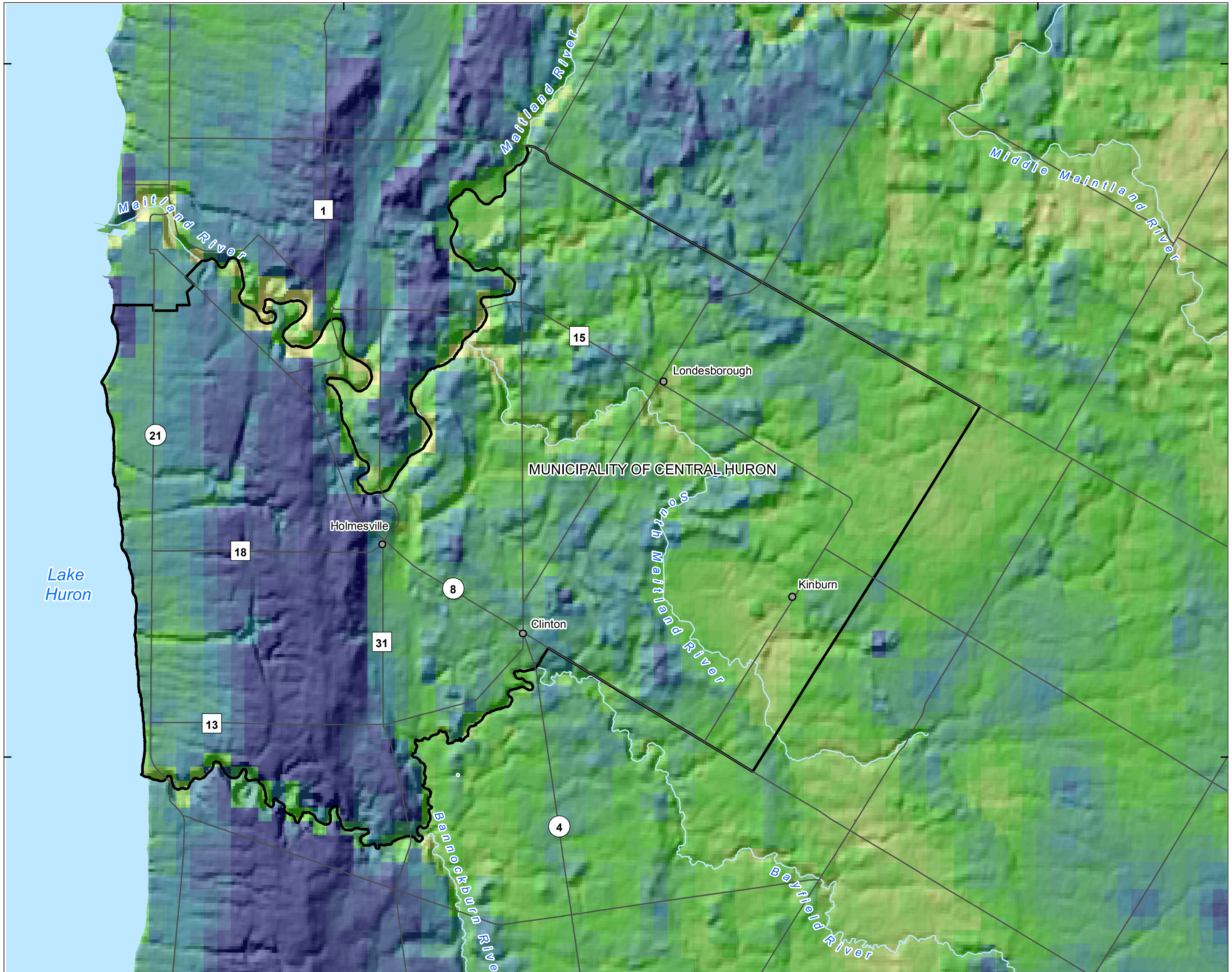
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

Prepared by: NMP/ADG
Reviewed by: SNS
Date: 16/04/2015

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig3_18_CrossSection_SeismicLine.cdr"





LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Waterbody
- Watercourse

Overburden Thickness (m)

High : 116

Low : 0

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Overburen Thickness: Gao, C., 2006
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Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Overburden Thickness in the Central Huron Area

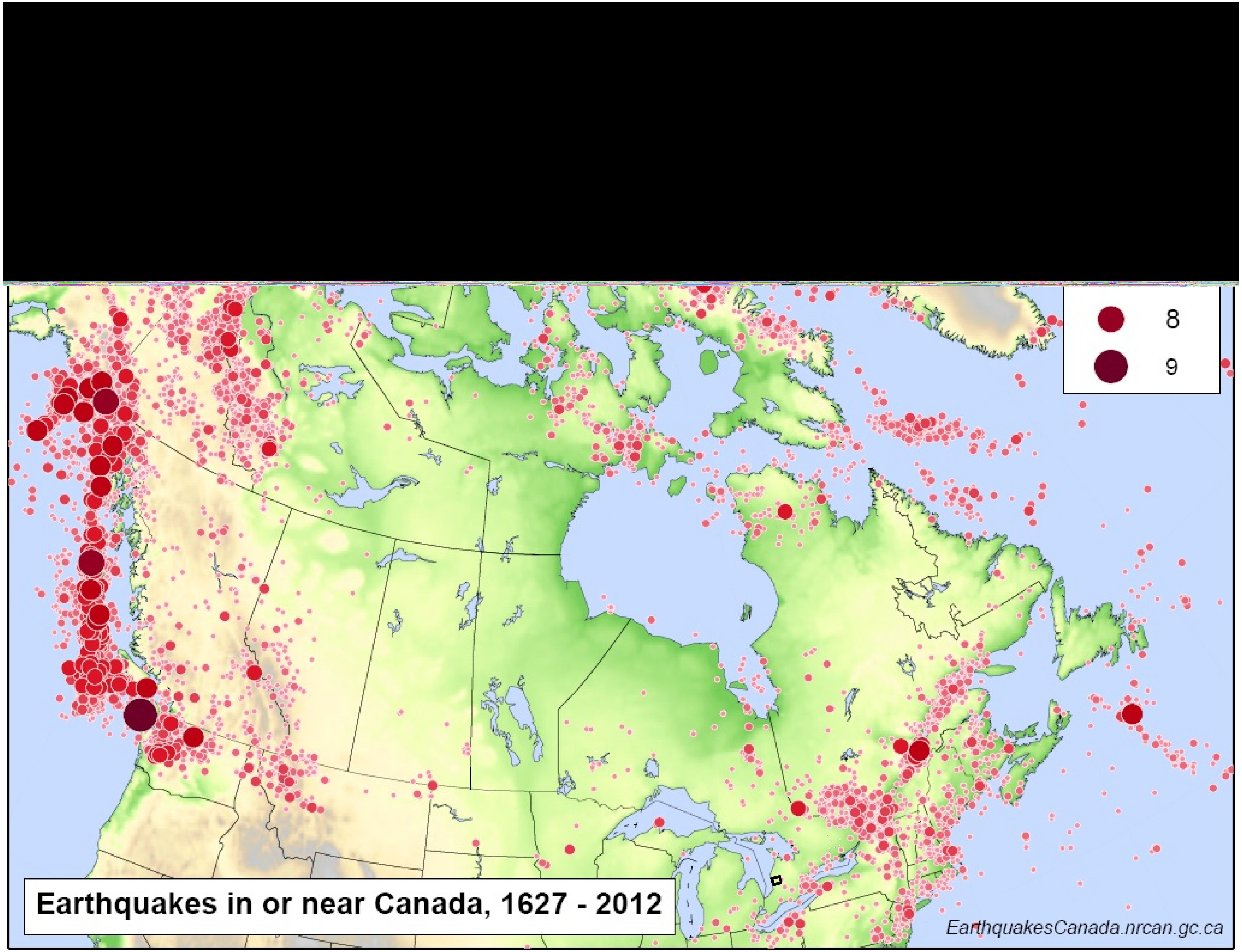
FIGURE 3.20

DESIGN: ADG
CAD/GIS: ADG/VMS
CHECK: KGR
REV: 0

DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_20_OverburdenThickness.mxd



LEGEND

Municipality of Central Huron

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

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Earthquakes Map of Canada 1627-2012

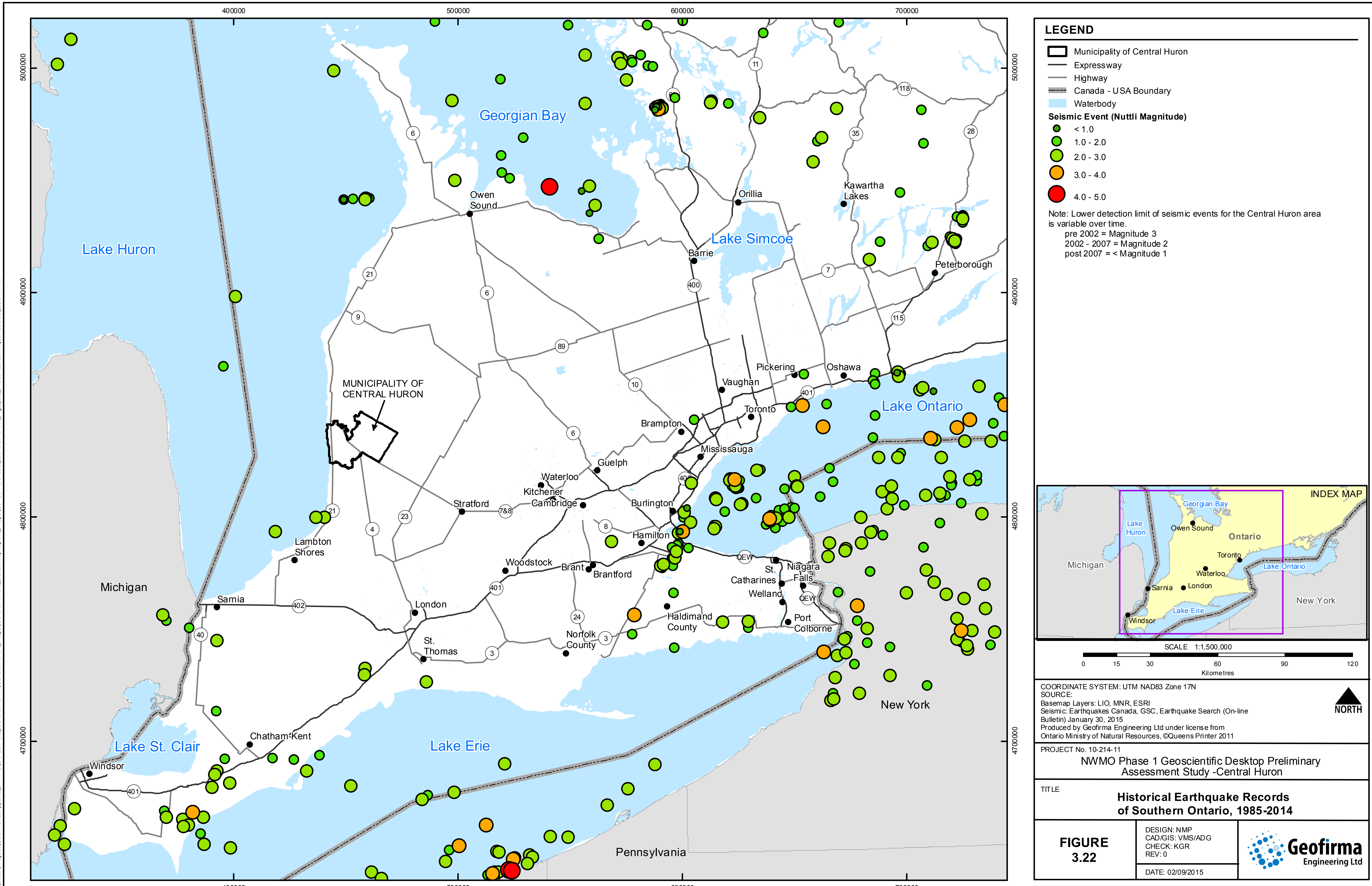
FIGURE 3.21

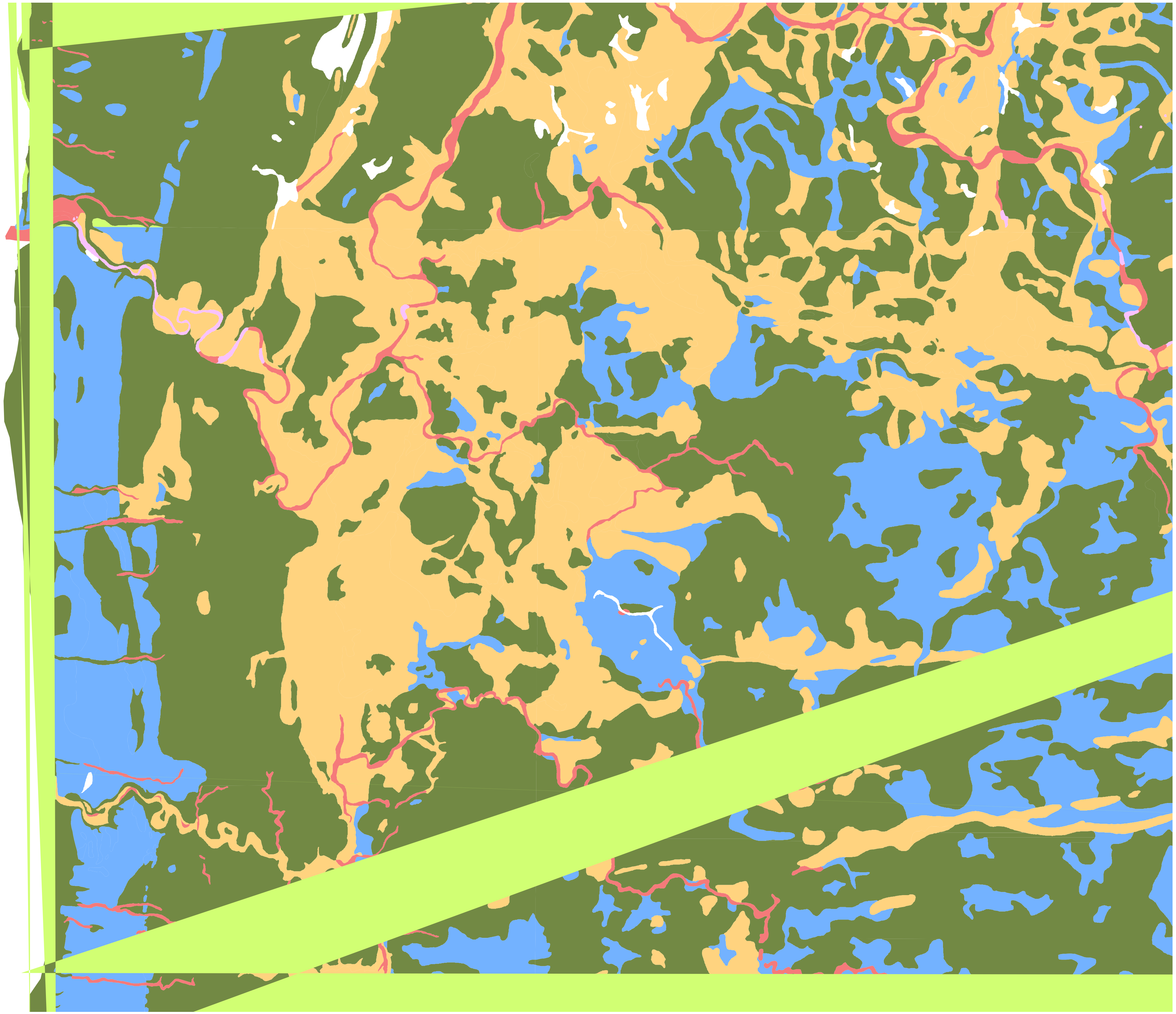
DESIGN: VMS
CAD/GIS: VMS
CHECK: KGR
REV: 0

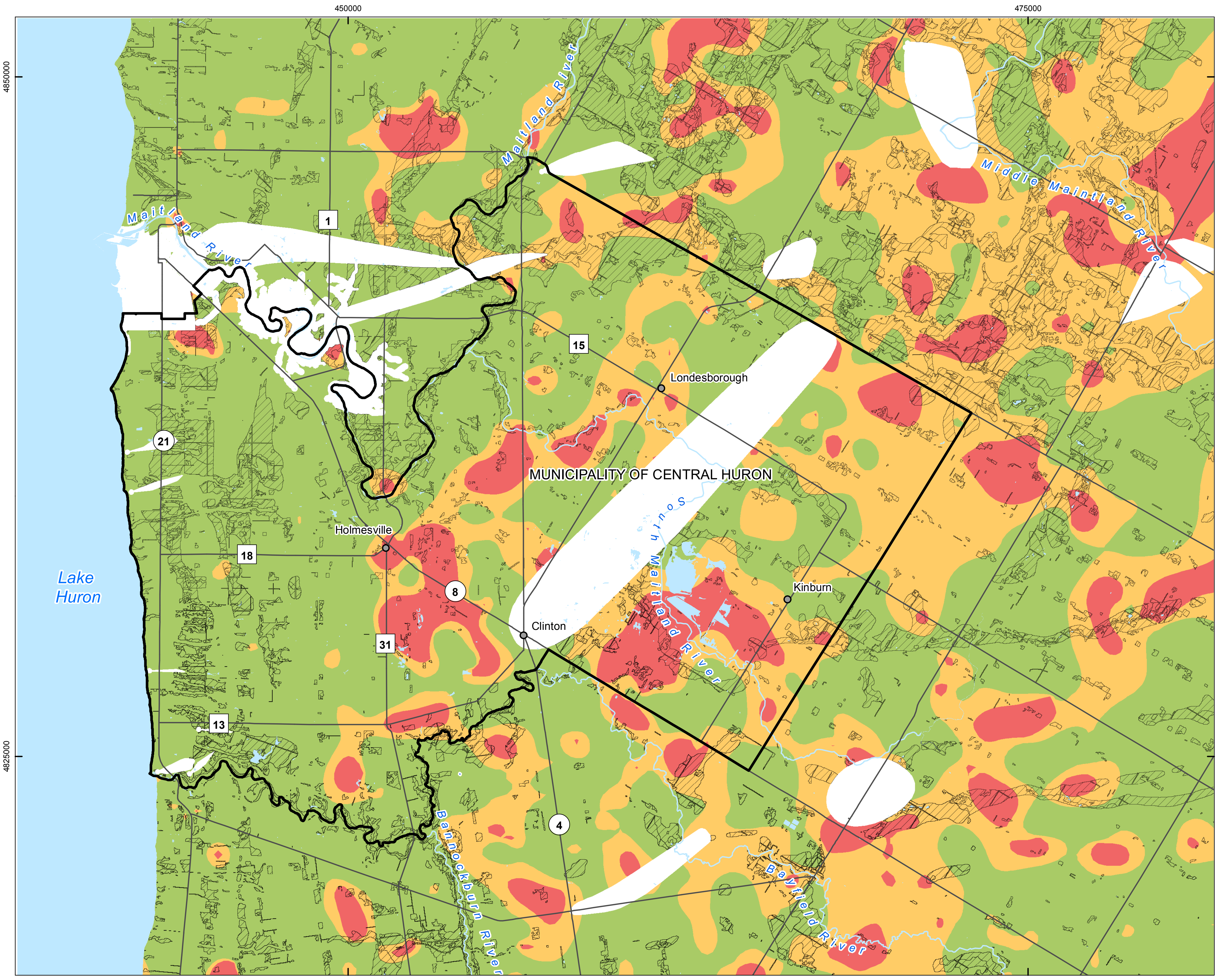
DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_21_EarthquakesMapofCanada1627-2012.mxd


LEGEND
Municipality of Central Huron
Expressway
Highway
Canada - USA Boundary
Waterbody
Seismic Event (Nuttli Magnitude)
< 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
Note: Lower detection limit of seismic events for the Central Huron area is variable over time.
pre 2002 = Magnitude 3
2002 - 2007 = Magnitude 2
post 2007 = < Magnitude 1
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Toronto
Waterloo
Lake Ontario
Michigan
Sarnia
London
New York
Lake Erie
Windsor
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) January 30, 2015
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-11
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study -Central Huron
TITLE
Historical Earthquake Records of Southern Ontario, 1985-2014
FIGURE 3.22
DESIGN: NMP
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0
DATE: 02/09/2015
Geofirma Engineering Ltd
400000
500000
600000
700000
5000000
4900000
4800000
4700000
Georgian Bay
Lake Huron
Lake Simcoe
Lake Ontario
Lake St. Clair
Lake Erie
Michigan
New York
Pennsylvania
MUNICIPALITY OF CENTRAL HURON
Owen Sound
Orillia
Kawartha Lakes
Barrie
Peterborough
Pickering
Oshawa
Vaughan
Toronto
Brampton
Mississauga
Guelph
Waterloo
Kitchener
Cambridge
Stratford
Burlington
Hamilton
Lambton Shores
Woodstock
Brant
Brantford
St. Catharines
Niagara Falls
Welland
Sarnia
London
Haldimand County
Port Colborne
St. Thomas
Norfolk County
Chatham-Kent
Windsor
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig3_22_HistoricalEarthquake1985_2014.mxd





LEGEND

- Municipality of Central Huron
- 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 1:140,000

0 1.25 2.5 5 7.5 10 Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO MNR
ISI & SGRA: Ausable Bayfield Maitland Valley Protection Region, 2011a,b
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NORTH

PROJECT No. 10-214-11

Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

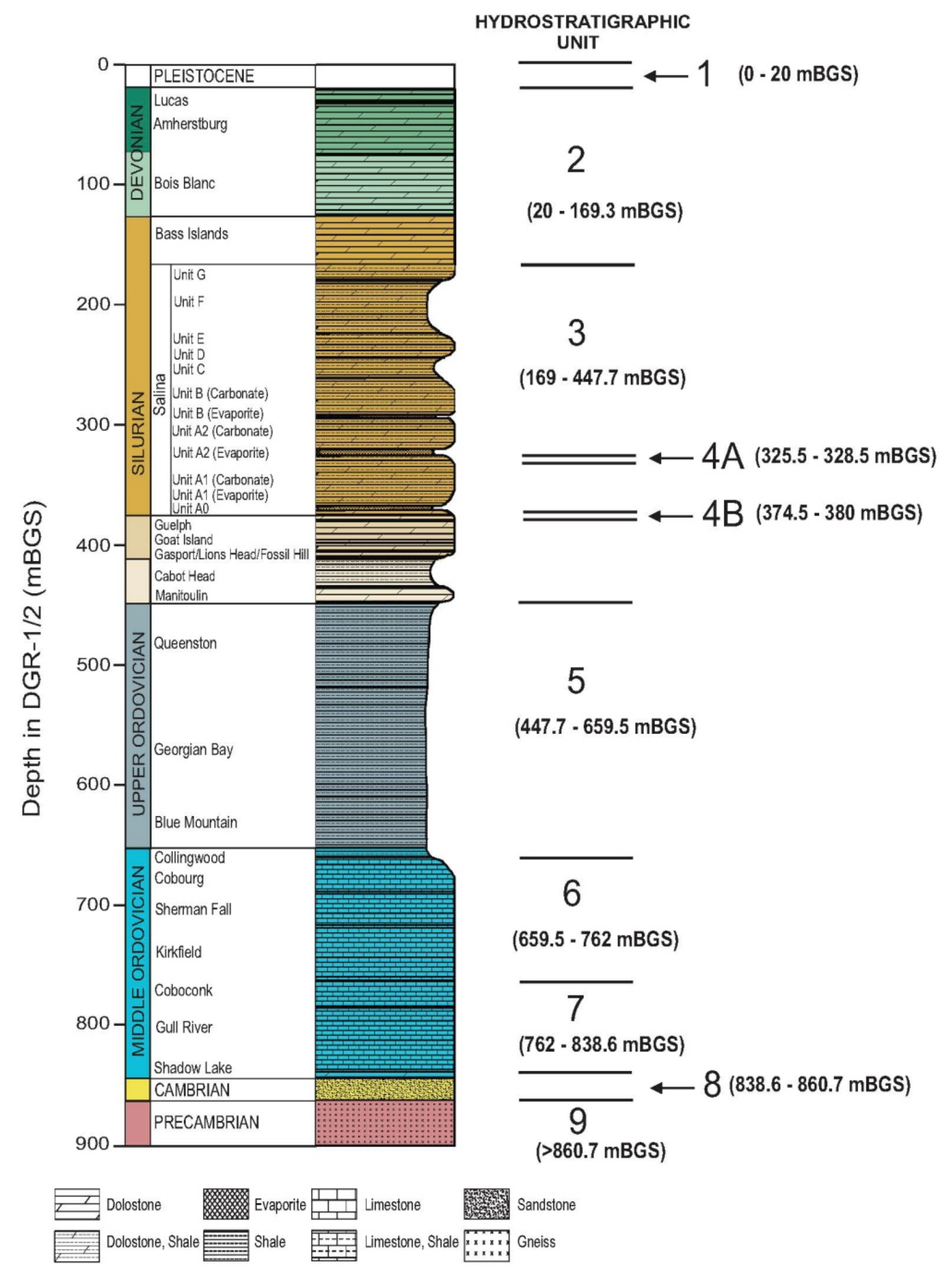
Aquifer Vulnerability and Significant Groundwater Recharge Areas in the Central Huron Area

FIGURE 4.2

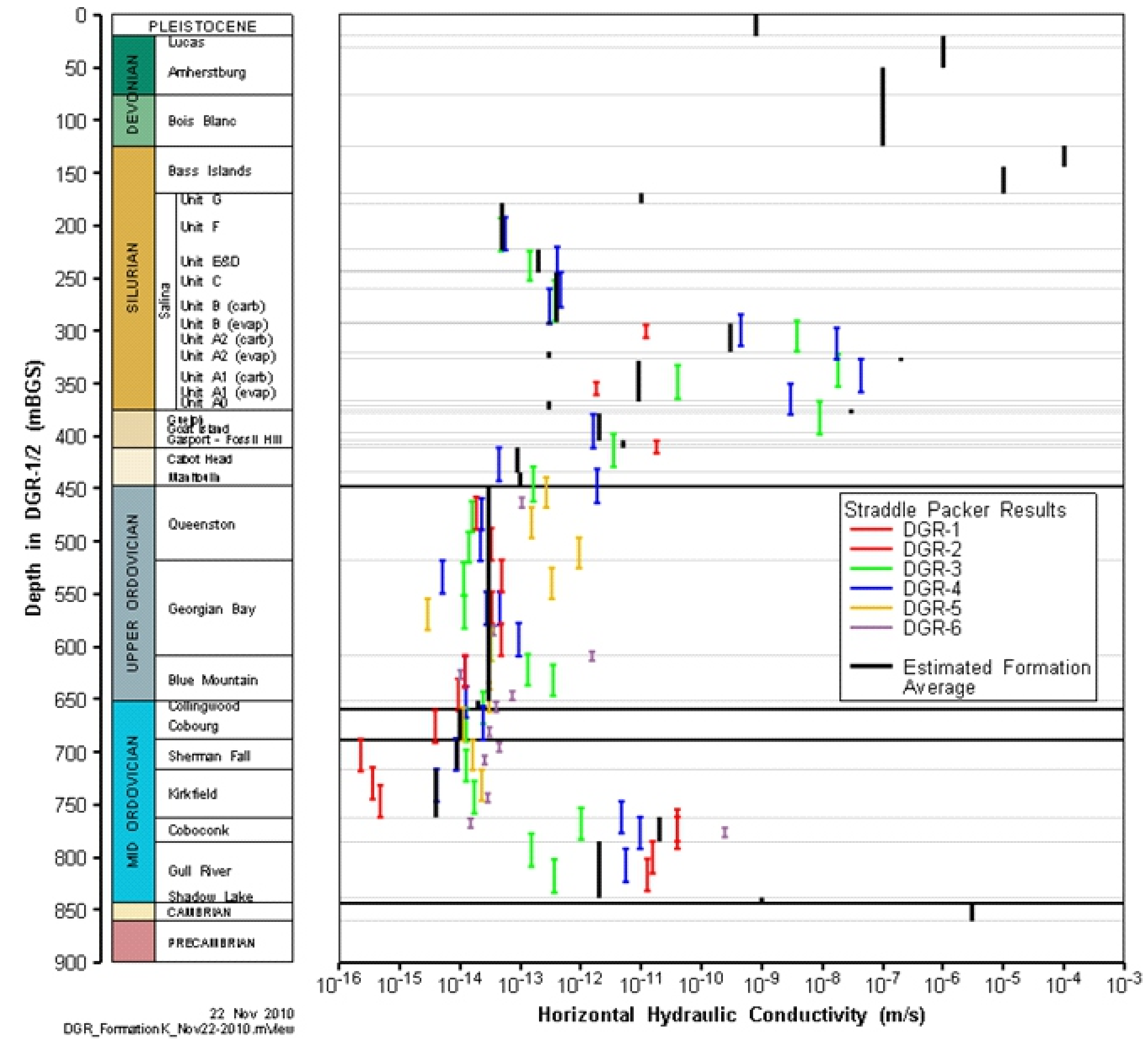
DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0
DATE: 4/14/2015

Geofirma Engineering Ltd

G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig4_2_AquiferVulnerability_SGRA_Community.mxd



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



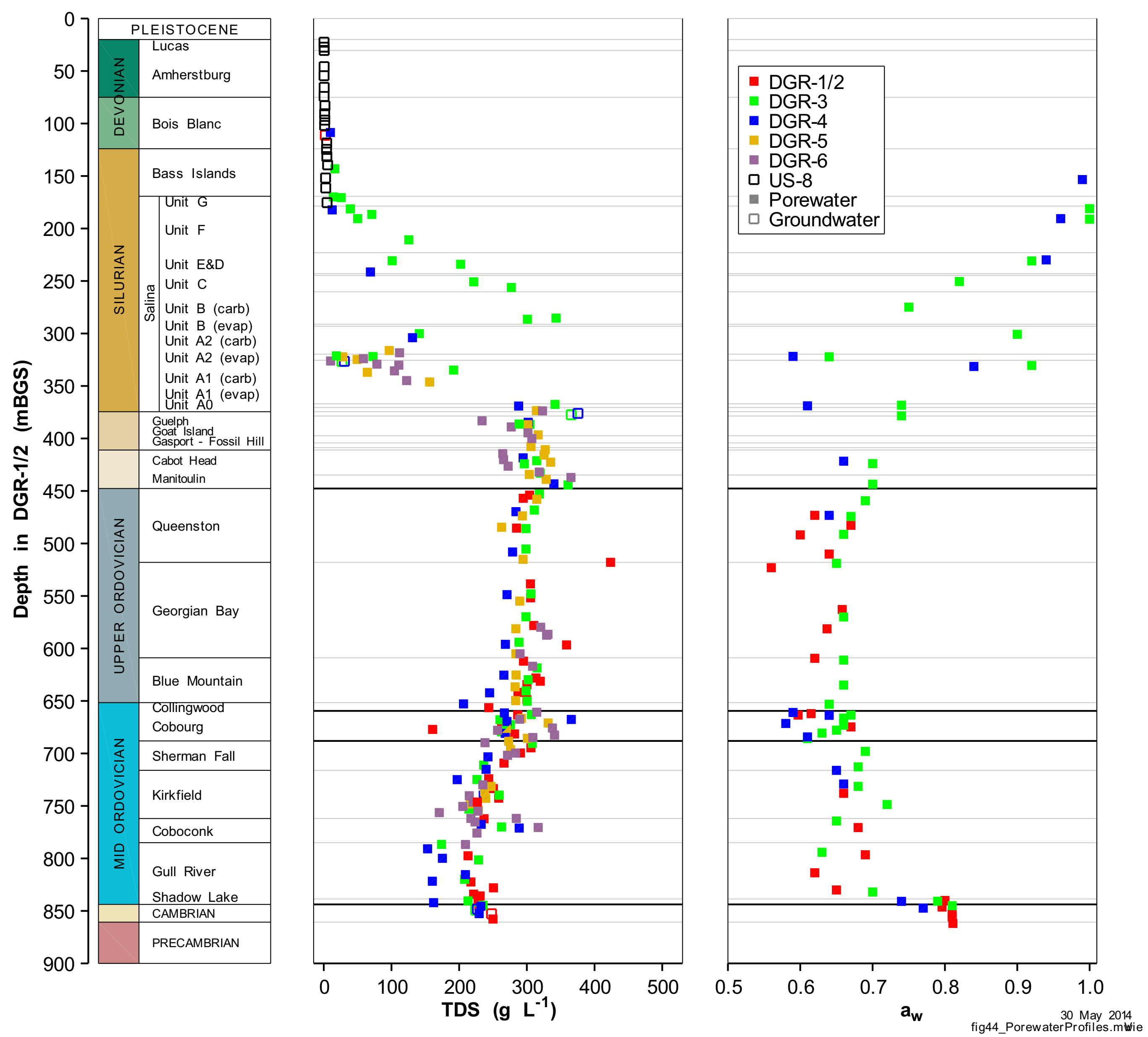
b. Results of Straddle-Packer Hydraulic Testing
(after Walsh, 2011)

FIGURE 4.3 - Hydrostratigraphic Units and Results of Hydraulic Testing at the Bruce Nuclear Site	Prepared by: VMS/ECK Reviewed by: KGR Date: 20/01/2015
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	

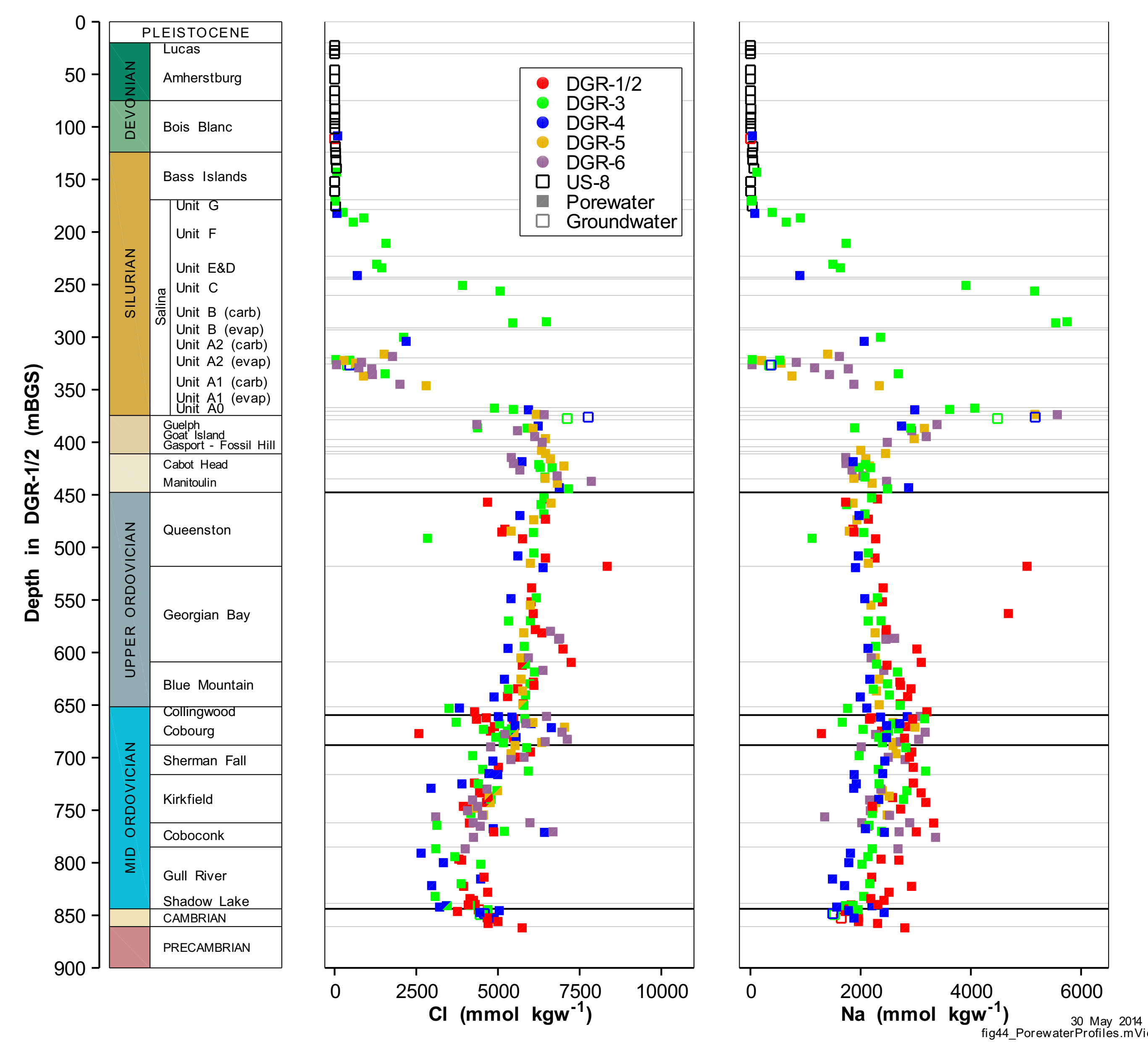
Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig4_3_HydraulicTestingResults.cdr"



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



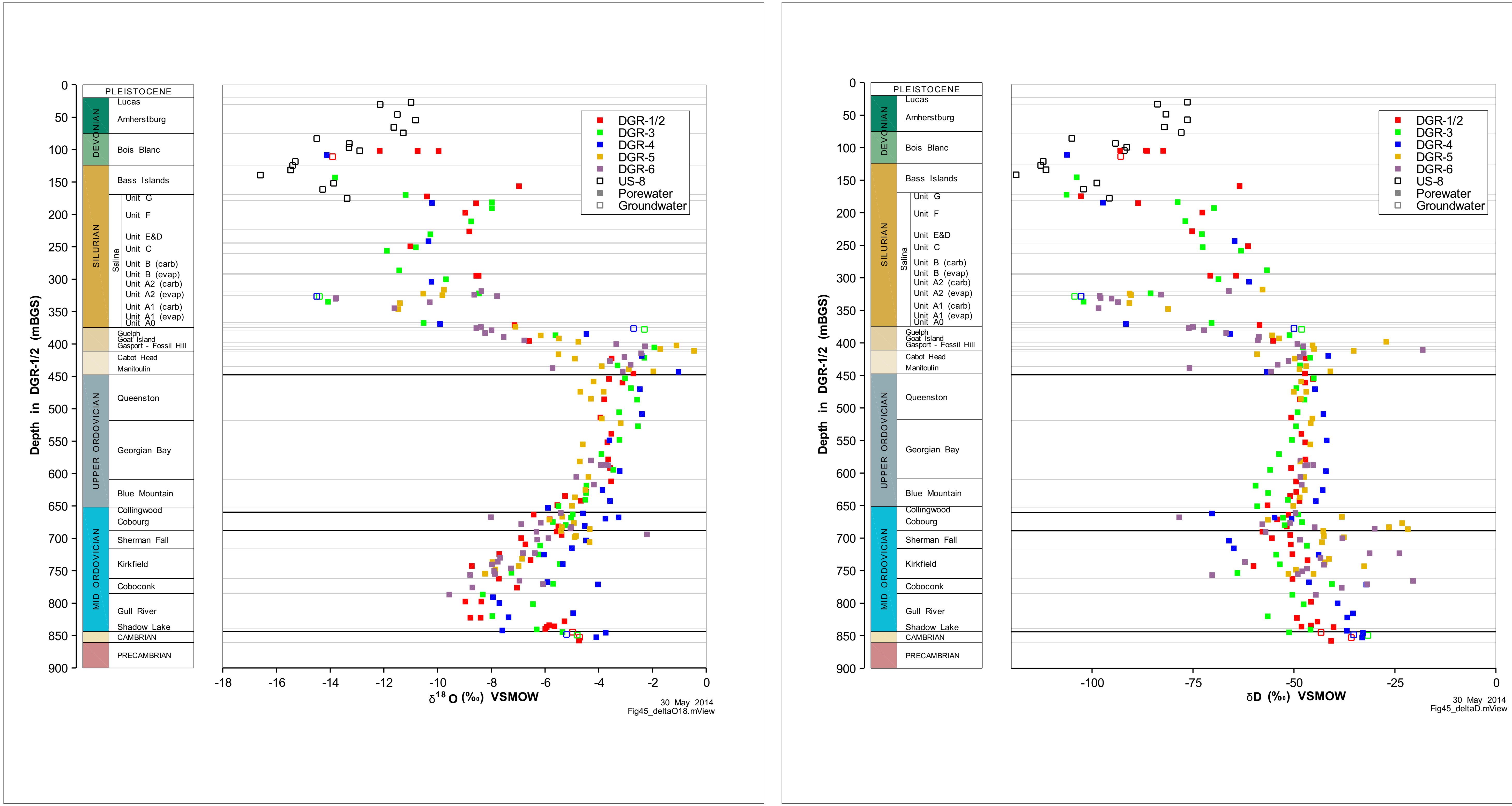
b. Chloride and Sodium
(after Intera Engineering Ltd., 2011)

FIGURE 4.4 - Profiles of Major Ion Chemistry of Porewater and Groundwater at the Bruce Nuclear Site	Prepared by: VMS/ADG Reviewed by: KGR Date: 20/01/2015
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	

Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig4_4_ProfilesMajIonChem.cdr"



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

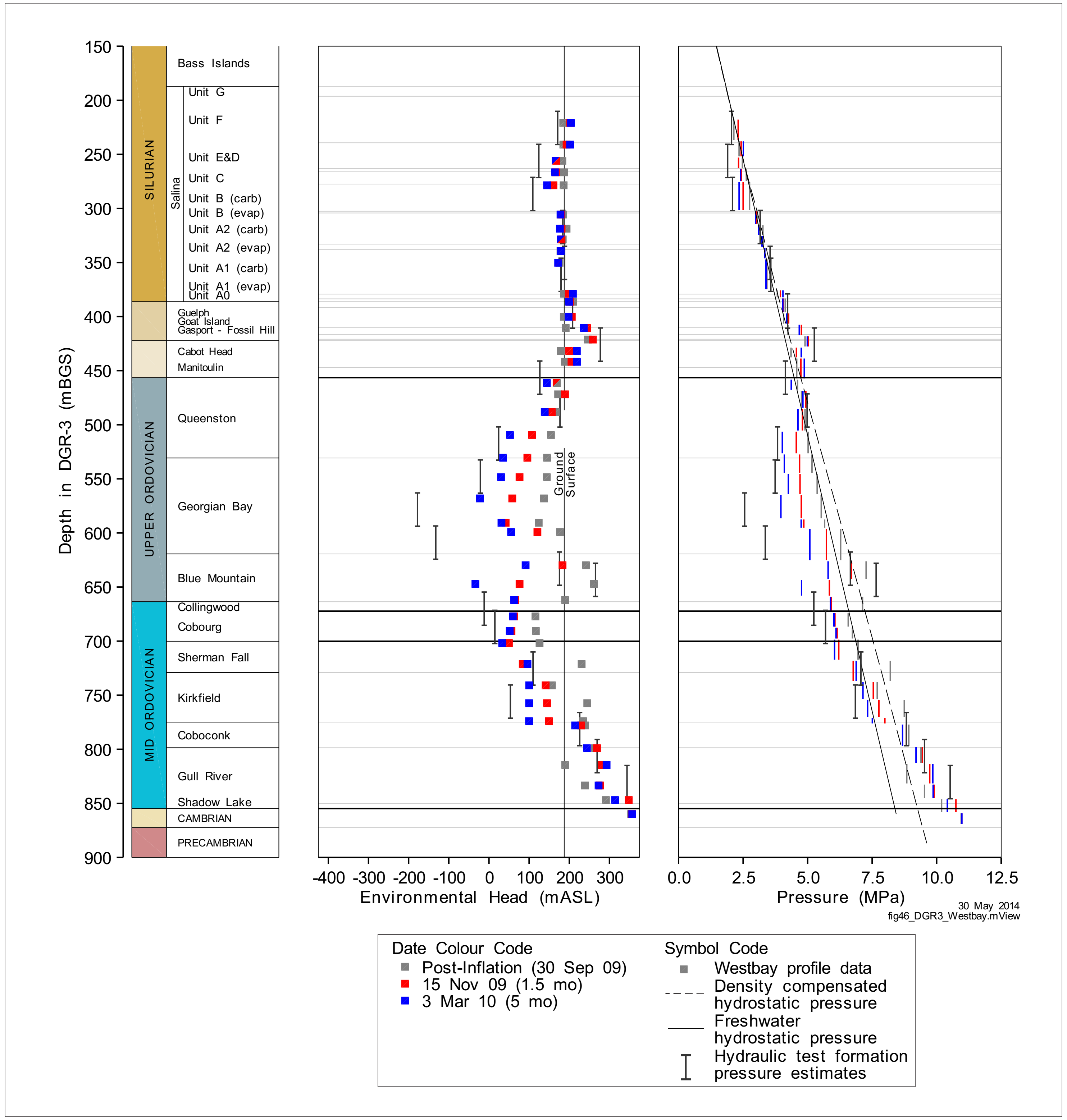
b. Deuterium
(after Intera Engineering Ltd., 2011)

FIGURE 4.5 - Profiles of Environmental Isotopes in Porewater and Groundwater at the Bruce Nuclear Site	Prepared by: VMS/ADG Reviewed by: KGR/SNS
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	Date: 20/01/2015

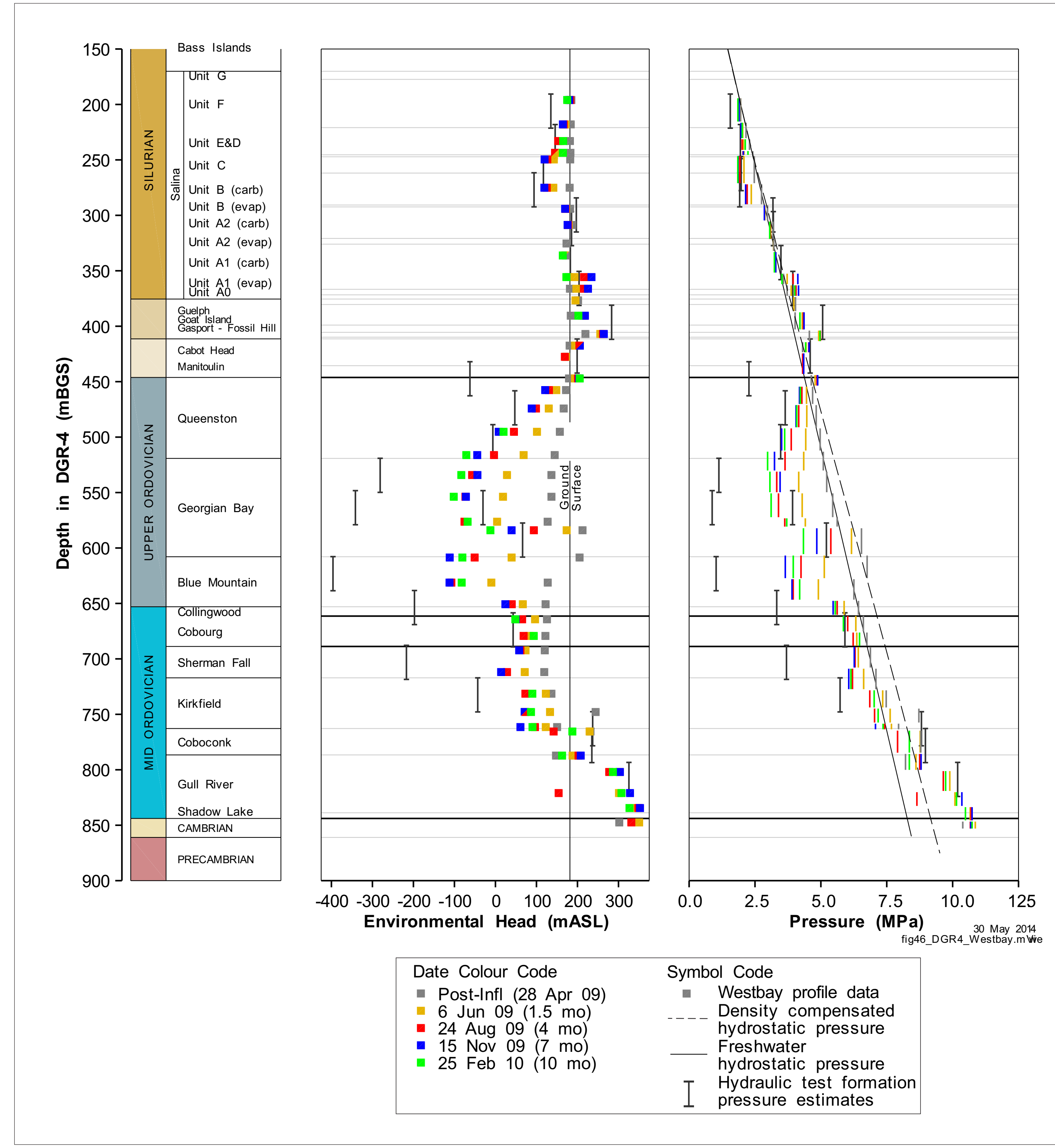
Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

Geofirma Engineering Ltd

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig4_5_ProfilesEnvIsotopes.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

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

Prepared by: VMS/ADG
Reviewed by: KGR/SNS
Date: 20/01/2015

Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig4_6_ProfilesFormPres_EnvHead.cdr

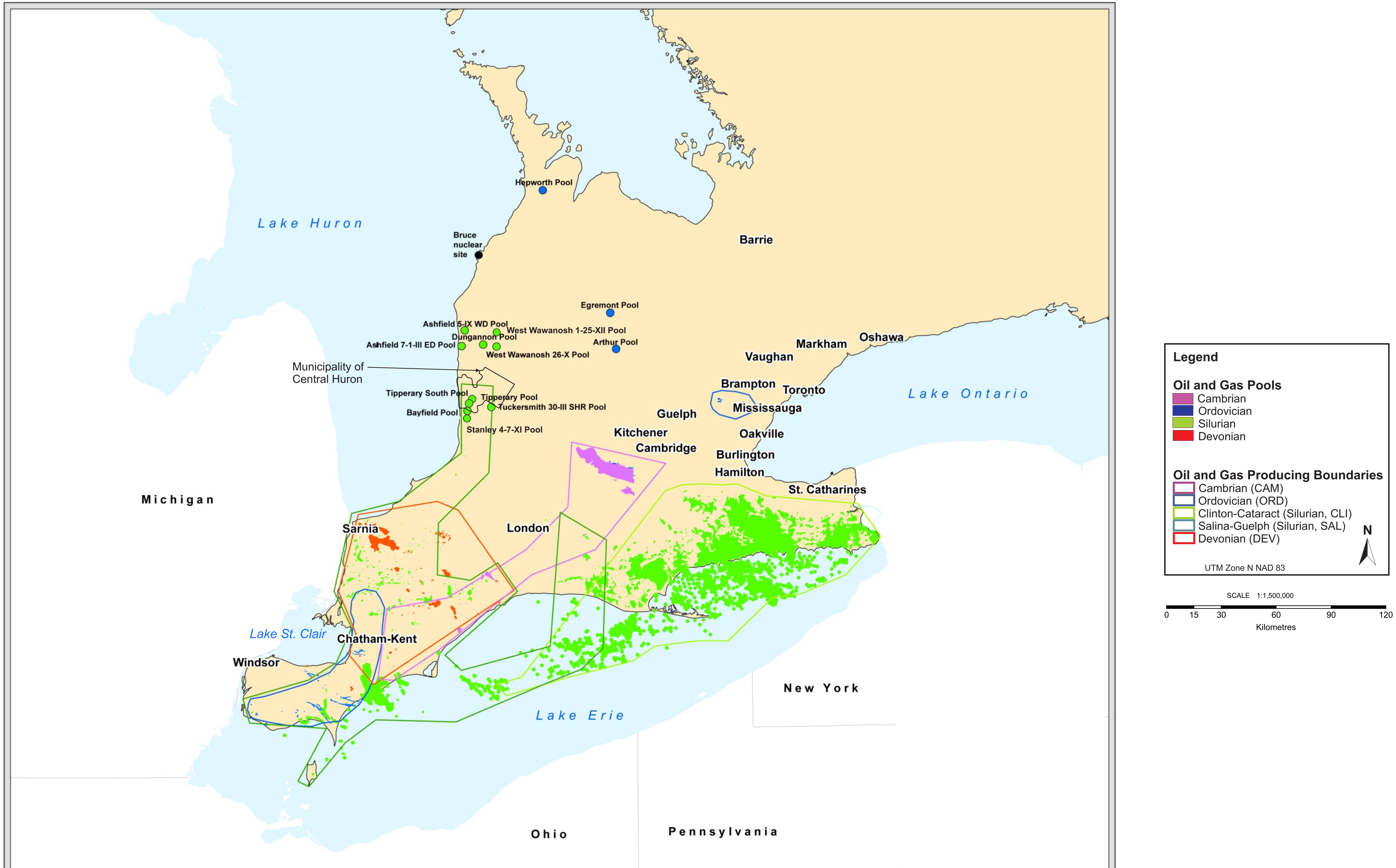


FIGURE 5.1 - Principal Oil and Natural Gas Producing Regions and Pools in Southern Ontario

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

Prepared by: ECK/ADG

Reviewed by: KGR/SNS

Date: 14/04/2015

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).

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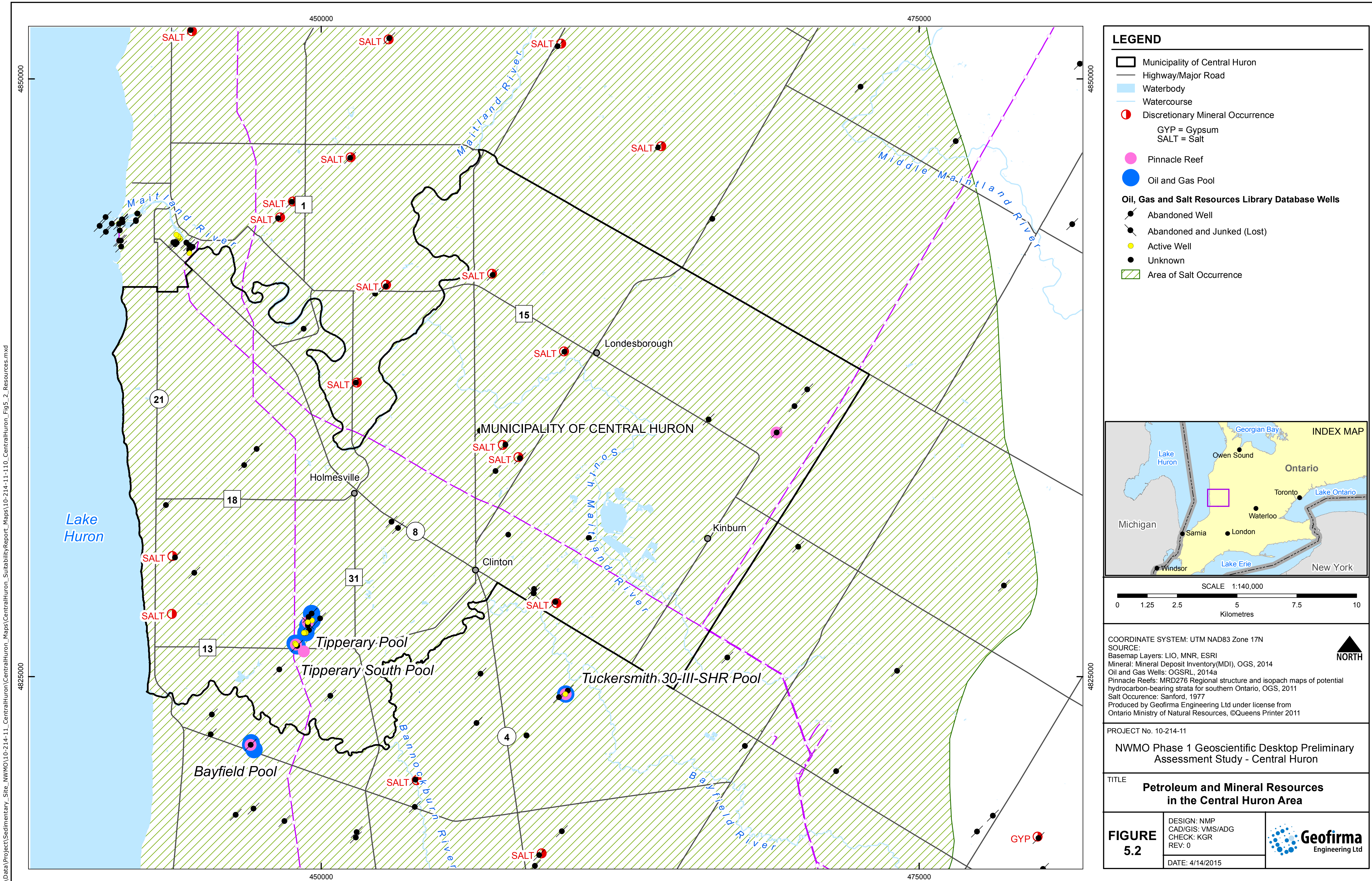
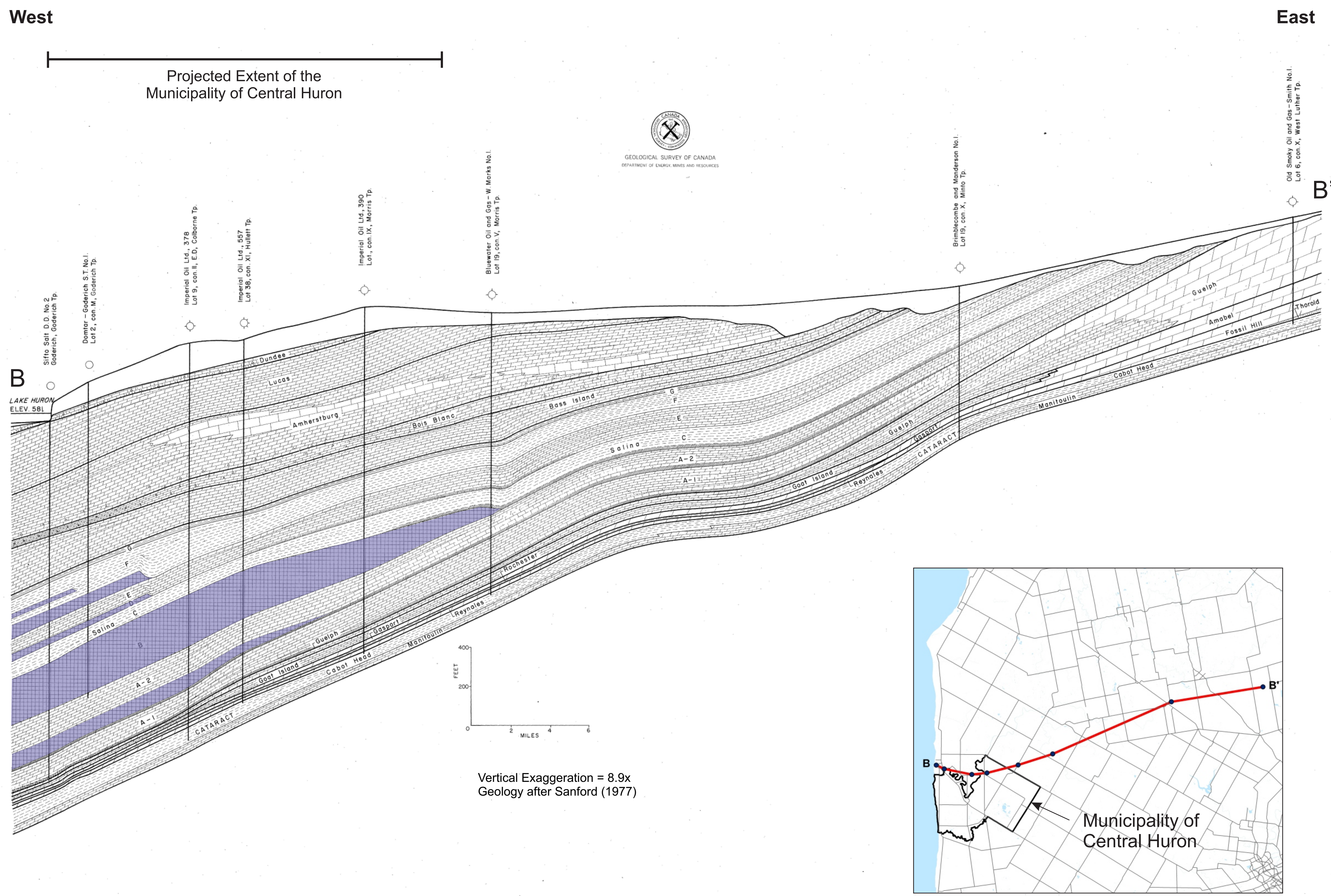
"P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig5_1_OilGasRegions.cdr"



LEGEND
Municipality of Central Huron
Highway/Major Road
Waterbody
Watercourse
Discretionary Mineral Occurrence
GYP = Gypsum
SALT = Salt
Pinnacle Reef
Oil and Gas Pool
Oil, Gas and Salt Resources Library Database Wells
Abandoned Well
Abandoned and Junked (Lost)
Active Well
Unknown
Area of Salt Occurrence
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Toronto
Lake Ontario
Waterloo
Michigan
Sarnia
London
Windsor
Lake Erie
New York
SCALE 1:140,000
0 1.25 2.5 5 7.5 10
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Mineral: Mineral Deposit Inventory(MDI), OGS, 2014
Oil and Gas Wells: OGSRL, 2014a
Pinnacle Reefs: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
Salt Occurence: Sanford, 1977
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-11
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron
TITLE
Petroleum and Mineral Resources in the Central Huron Area
FIGURE 5.2
DESIGN: NMP
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0
DATE: 4/14/2015
Geofirma Engineering Ltd
450000
475000
4850000
4825000
Lake Huron
Maitland River
Middle Maitland River
South Maitland River
Bannockburn River
Bayfield River
MUNICIPALITY OF CENTRAL HURON
Londesborough
Holmesville
Clinton
Kinburn
1
15
21
18
8
31
13
4
Tipperary Pool
Tipperary South Pool
Tuckersmith 30-III-SHR Pool
Bayfield Pool
SALT
GYP
G:\Data\Project\Sedimentary_Site_NWMO\10-214-11_CentralHuron\CentralHuron_Maps\CentralHuron_SuitabilityReport_Maps\10-214-11-110_CentralHuron_Fig5_2_Resources.mxd



Note: The Rochester Fm and Reynales Fm are Southwestern Ontario - Lake Erie equivalents of the Lion's Head Member (Amabel Fm) and Fossil Hill Fm, shown in Table 3.1

LEGEND

Dominant Lithology

- Salt
- Shale
- Limestone
- Dolostone

PROJECT No. 10-214-11.20

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

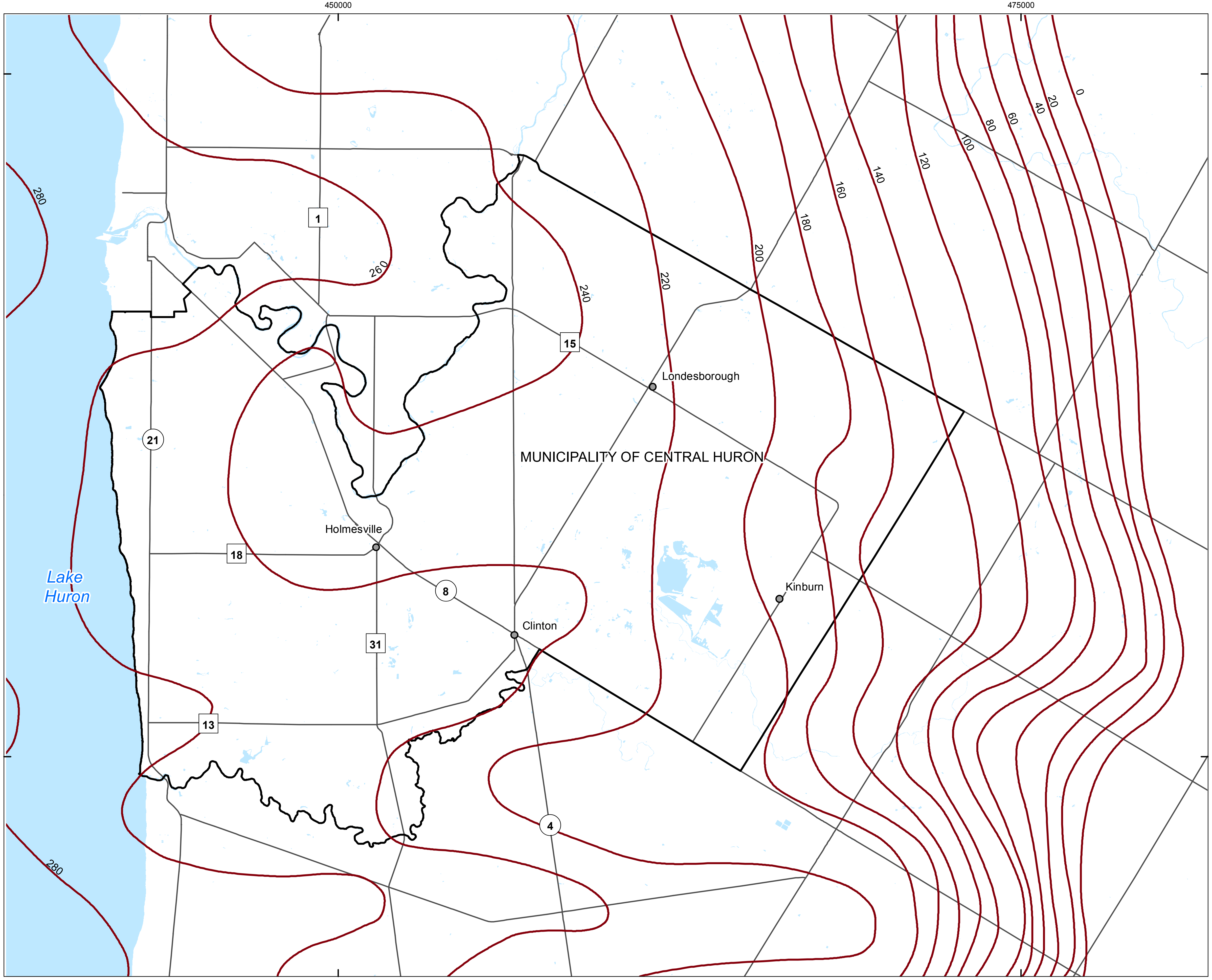
TITLE

Regional Geological Cross-Section of the Silurian and Devonian Rocks of Southwestern Ontario

FIGURE 5.3

DESIGN: ADG
Corel/GIS: ADG
CHECK: KGR
REV: 0
DATE: 2/27/2015

Geofirma Engineering Ltd



LEGEND

- Municipality of Central Huron
- Waterbody
- Highway/Major Road
- 100 Salina B Unit Salt Isopach (ft)

SCALE 1:140,000

0 1.25 2.5 5 7.5 10
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Salt Occurence: Sanford, 1977
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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

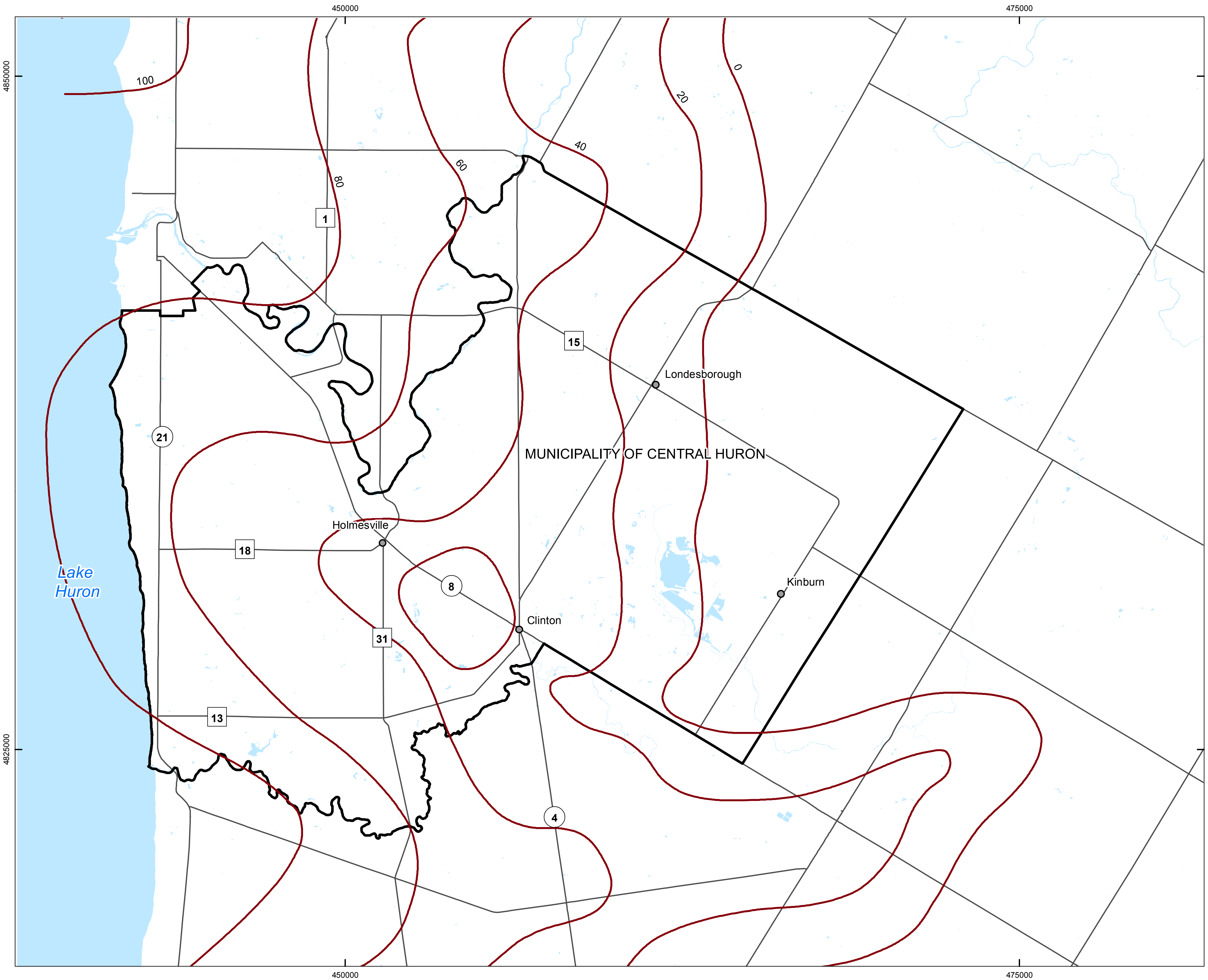
Thickness of Salina B Unit Salt in the Central Huron Area

FIGURE 5.4

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

DATE: 10/7/2015

Geofirma Engineering Ltd



LEGEND

- Municipality of Central Huron
- Waterbody
- Highway/Major Road
- 40 Salina A2 Unit Salt Isopach (ft)

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Salt Occurence: Sanford, 1977
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Thickness of Salina A-2 Unit Salt in the Central Huron Area

FIGURE 5.5

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

DATE: 10/7/2015

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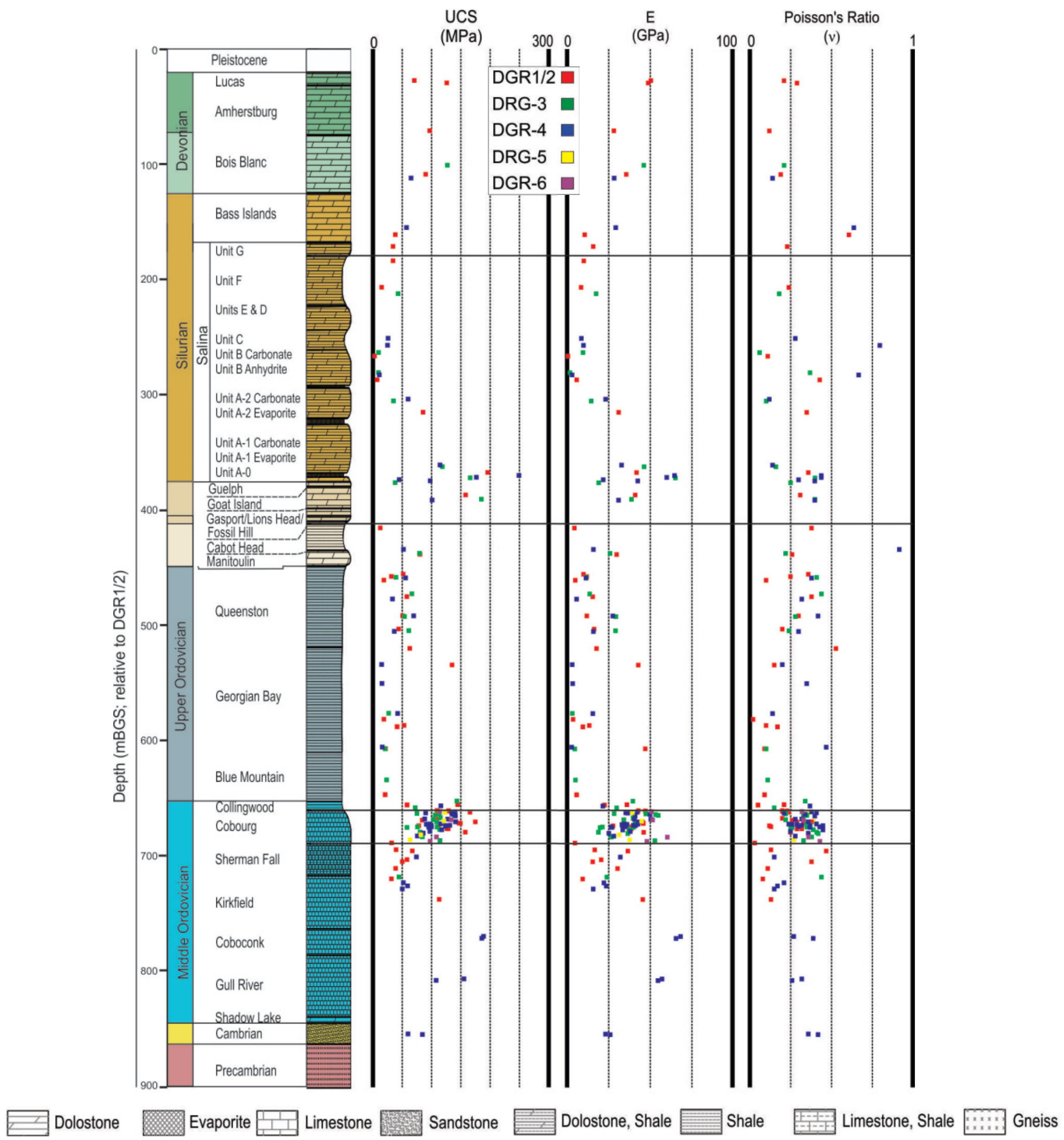
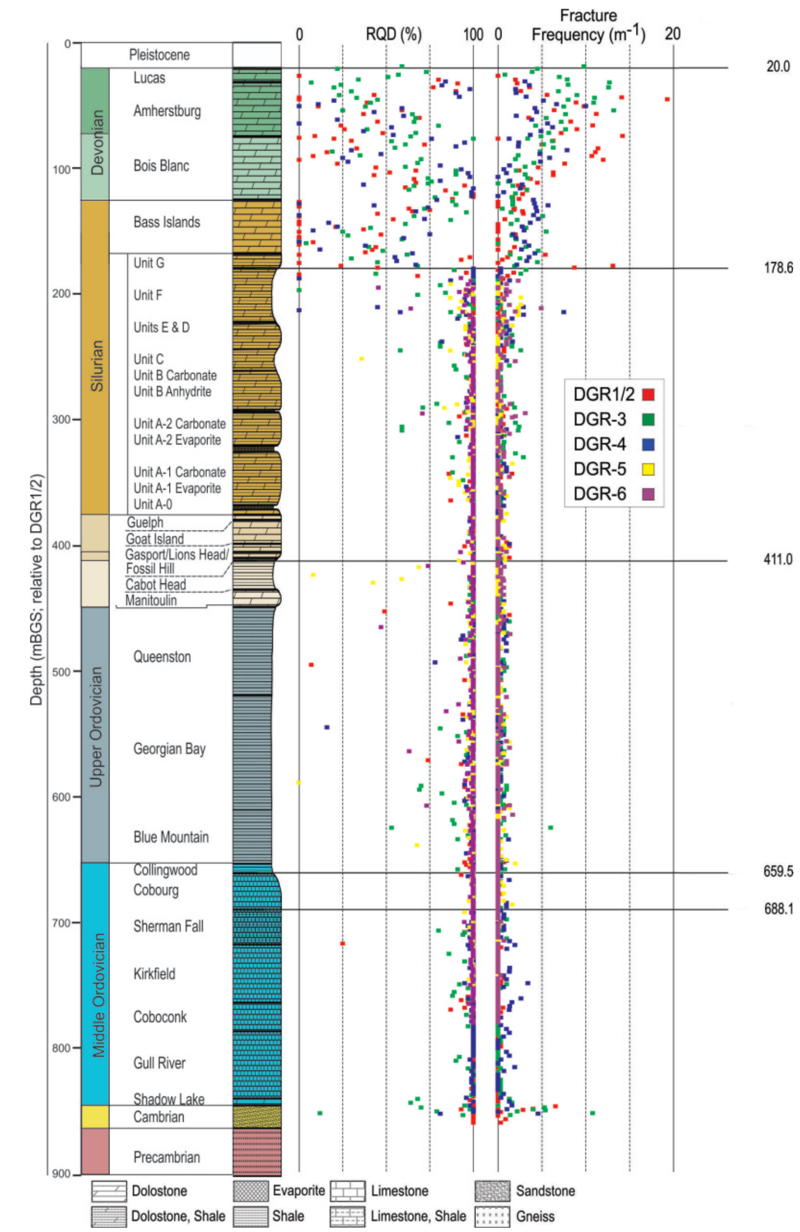


a. Uniaxial Compression Test Results
(after NWMO, 2011)



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

FIGURE 6.1 - Geomechanical Properties of Paleozoic Rocks at the Bruce Nuclear Site	Prepared by: VMS/ECK Reviewed by: KGR
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	Date: 20/01/2015

Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

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P:\Projects\2010\10-214 NWMO APM Site Screening\10-214-11 Central Huron\50 Reporting and Deliverables\Figures\Working Files\10-214-11-110_CentralHuron_Fig6_1_MS_RQD_UCS.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	Prepared by: VMS/ECK Reviewed by: KGR
NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron	Date: 20/01/2015

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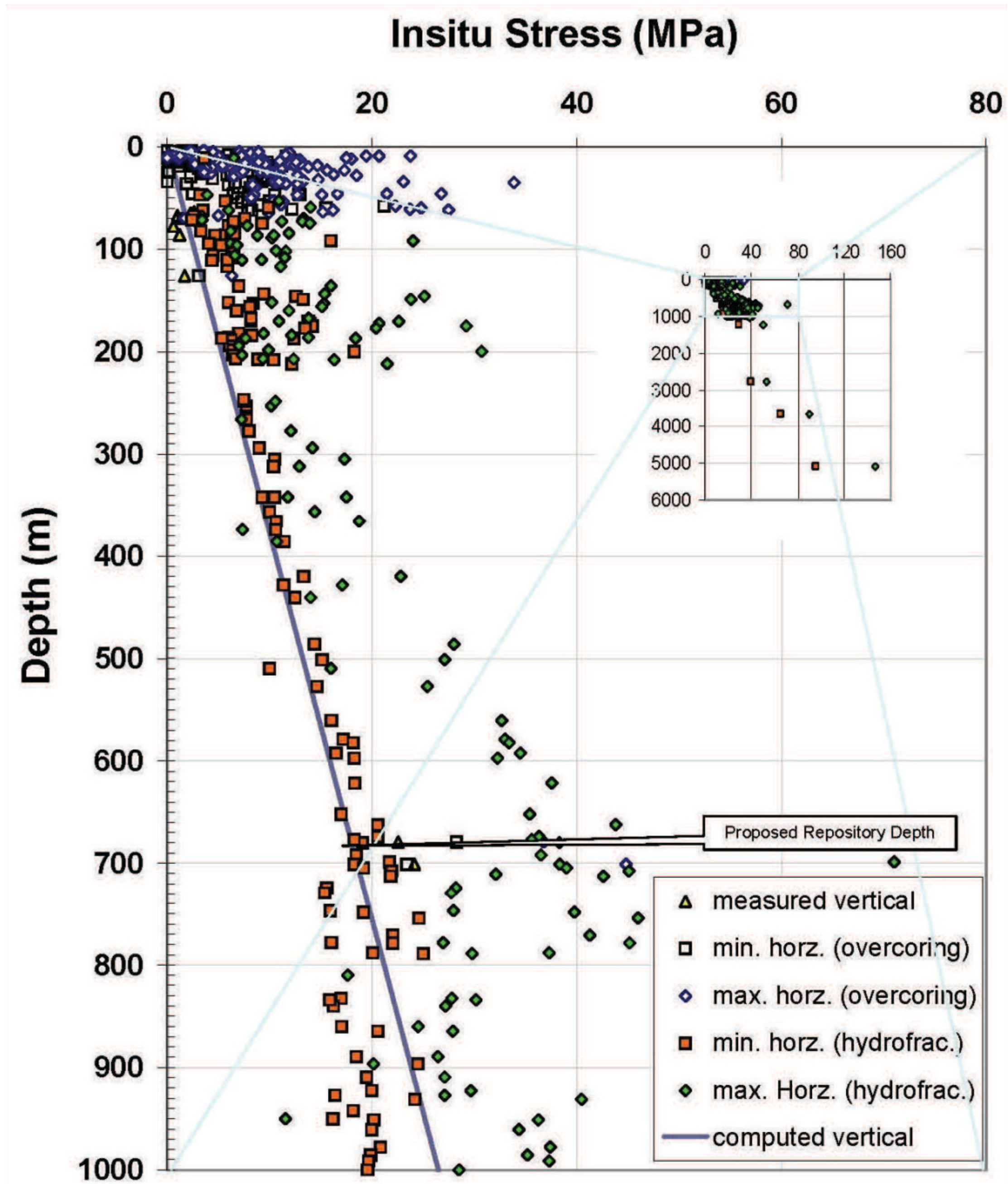
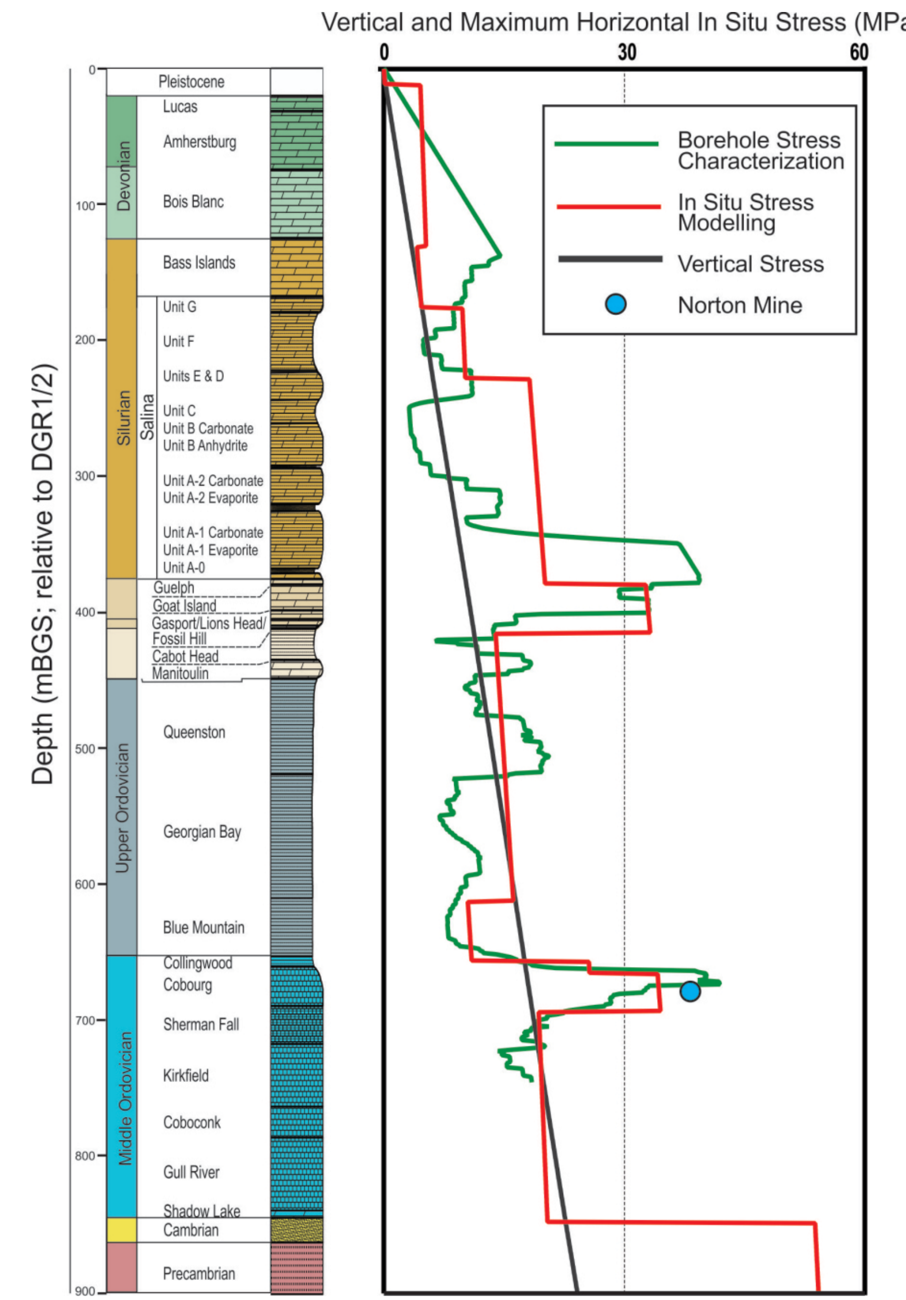


a. Distribution of Principal Stress with Depth in the Appalachian and Michigan Basins
(*after: NWMO and AECOM Canada Ltd., 2011*)



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

Prepared by: VMS/ECK
Reviewed by: KGR
Date: 20/01/2015

Note: Stratigraphic nomenclature shown on figures predates Armstrong and Carter (2010), see Table 3.1 for current nomenclature

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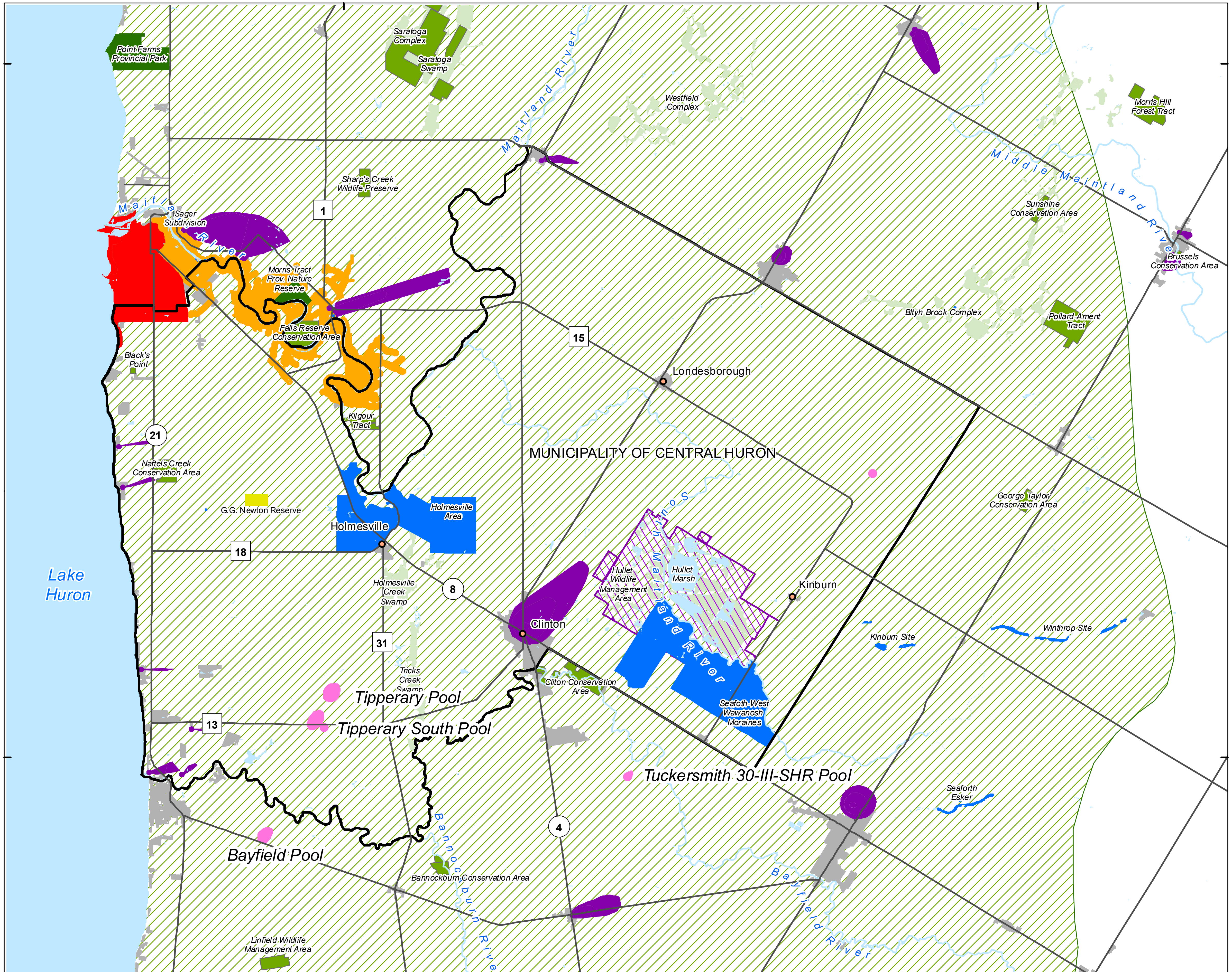

LEGEND

- Municipality of Central Huron
- Highway/Major Road
- Watercourse
- Waterbody
- Oil and Gas Pools and Pinnacle Reefs (see Fig 5.3)
- ANSI (Earth Science)
- Built-Up Area
- Conservation Area/Reserve
- NGO Nature Reserve
- Provincial Park
- Provincial Wildlife Area
- Provincially Significant Wetland
- Surface Water Intake Protetction Zone (IPZ) 1 and 2
- Wellhead Protection Area (WHPA) A, B, and C
- Wellhead Protection Area (WHPA) E
- Area of Salt Occurrence

Entire Study Area is >500m above the Cobourg Formation

Approximate Size of Repository Footprint

2 Km

3 Km

Extent of figure frame

SCALE 1:140,000

0 1.25 2.5 5 7.5 10

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N

SOURCE:

Basemap Layers: LIO, MNR, ESRI

Oil and Gas Pools and Pinnacle Reefs: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for Southern Ontario, OGS, 2011

Protected Areas: LIO, 2014; ABCA, 2014

Salt Occurence: Sanford, 1977

Source Water Protection: Ausable Bayfield Maitland Valley Protection Region, 2011a,b

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NORTH

PROJECT No. 10-214-11

NWMO Phase 1 Geoscientific Desktop Preliminary Assessment Study - Central Huron

TITLE

Characteristics and Contstraints in the Central Huron Area

FIGURE 7.1

DESIGN: ADG
CAD/GIS: VMS/ADG
CHECK: KGR
REV: 0

DATE: 05/10/2015

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