NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

TOWNSHIP OF MANITOUWADGE, ONTARIO

APM-REP-06144-0076

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Phase 1 Geoscientific Desktop Preliminary Assessment Terrain and Remote Sensing Study
Township of Manitouwadge, Ontario

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Executive Summary

On March 27, 2013, the Township of Manitouwadge expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process, and requested that a preliminary assessment be conducted to assess the potential suitability of the Manitouwadge area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2014). The objective of the desktop geoscientific preliminary assessment is to determine whether the Manitouwadge area and its periphery, referred to as the "Manitouwadge area", contains general siting areas that have the potential to meet NWMO's site evaluation factors.

This report presents the findings of a terrain and remote sensing study completed as part of the desktop geoscientific preliminary assessment of the Manitouwadge area (AECOM, 2013). The main information sources used include the Provincial and Canadian Digital Elevation Data (CDED) elevation models, remotely sensed imagery, and maps, reports and databases available from the federal and provincial governments. The study addresses the following seven objectives:

- Evaluate the nature, areal extent and depth of overburden materials;
- Delineate the areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;
- Determine and/or confirm watershed and sub-catchment boundaries;
- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

The Manitouwadge area is dominated by land where bedrock is at or near surface. Over the majority of the area the Precambrian bedrock is thinly covered by a discontinuous veneer of glacial sediments, dominantly ground moraine (till). Deposits of thicker drift, primarily consisting of glaciofluvial and glaciolacustrine sediments, are present in bedrock valleys and areas of lower elevation. The area is generally well-drained by a network of lakes and rivers that are present in four tertiary watersheds, two of which flow southward to Lake Superior and two northward to James/Hudson Bay.

Groundwater flow within drift deposits and in shallow bedrock aquifers in the Manitouwadge area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into creeks, rivers, lakes and wetlands.

Conclusive identification of features indicative of paleo-seismic events and reactivation of ancient bedrock structures due to cycles of glacial loading and unloading cannot be identified using currently available sources of information. Field investigations would be required to identify any such features.

Main roads provide access to the central and western portions of the Manitouwadge area. Augmenting these is an extensive network of secondary roads and trails, mainly developed to support forestry activities throughout the area. The construction of new access routes, or other types of infrastructure, could be developed to any part of the Manitouwadge area using construction techniques commonly employed in the Canadian Shield.

Table of Contents

Statement of Qualifications and Limitations
Executive Summary

List of Tables

List of Figures (in order following text)

1. Introduction

On March 27, 2013, the Township of Manitouwadge expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Manitouwadge area for safely hosting a deep geological repository (Step 3). The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability; engineering; transportation; environment and safety; as well as social, economic and cultural considerations (NWMO 2014).

This report presents the findings of a terrain and remote sensing study completed as part of the desktop geoscientific preliminary assessment of the Manitouwadge area. The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Manitouwadge and its periphery, referred to as the “Manitouwadge area” contains general areas that have the potential to meet NWMO’s geoscientific site evaluation factors (NWMO, 2010).

1.1 Objectives

A review and interpretation of remotely sensed data was conducted as part of the Phase 1 Desktop Geoscientific Preliminary Assessment of Potential Suitability for the Township of Manitouwadge (AECOM, 2014) to provide information on surficial materials and terrain conditions present in the Manitouwadge area. The work completed as part of this project adds to and expands upon the knowledge of surficial conditions provided in the Initial Screening report of the area (Geofirma Engineering Ltd., 2013).

This study makes use of remote sensing and geoscientific information sources to address the following seven objectives:

- Evaluate the nature, areal extent and depth of overburden materials;
- Delineate the areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;
- Determine and/or confirm watershed and sub-catchment boundaries;
- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

1.2 Manitouwadge Area

The Manitouwadge area is located northeast of Lake Superior approximately 265 km northeast of Thunder Bay, and 310 km north-northwest of Sault Ste. Marie. The area covered by this report, referred to herein as the Manitouwadge area, is 4,016 square kilometres (km^2) in size, with approximate dimensions of 70 km east-west and 57.4 km north-south (Figure 1). Within the Manitouwadge area, the Township of Manitouwadge occupies 373 km^2 in the southwest quadrant and includes the settlement area of Manitouwadge. The hamlet of Hillsport is located in the northeast corner. Other nearby towns located outside the area are Marathon, 60 km to the southwest, and White River, 70 km to the southeast.

1.3 Data and Methods

1.3.1 Source Data

Data for the Manitouwadge terrain and remote sensing study was collected from a variety of sources, including government organizations, such as Natural Resources Canada (NRCan) and the Ontario Geological Survey (OGS).

Existing surficial and bedrock geology mapping, topographic mapping and literature were reviewed as part of the terrain mapping process in order to gain familiarity with the area, its Quaternary history, and the surficial materials present.

1.3.1.1 Topographic Mapping

Topographic mapping of the area, with a contour interval of 20 m, was obtained from the Ontario Ministry of Natural Resources (MNR, 2013) and digital topographic data in raster format were obtained from Geobase (NRCan, 2009). The digital topographic data had a grid resolution of between 8 and 23 m.

1.3.1.2 Canadian Digital Elevation Data (CDED)

The CDED topography data for the Manitouwadge area, including a buffer zone extending in all directions outside the area, is available in 24 DEM format individual tiles, each tile covering approximately 1,200 km^2. The tile identifiers are listed in Table 1.

Table 1. Summary of CDED tiles for the Manitouwadge Area

042c13_0100_deme	042f03_0100_deme
042c13_0100_demw	042f03_0100_demw
042c14_0100_deme	042f04_0100_deme
042c14_0100_demw	042f04_0100_demw
042d16_0100_deme	042f05_0100_deme
042d16_0100_demw	042f05_0100_demw
042e01_0100_deme	042f06_0100_deme
042e01_0100_demw	042f06_0100_demw
042e08_0100_deme	042f11_0100_deme
042e08_0100_demw	042f11_0100_demw
042e09_0100_deme	042f12_0100_deme
042e09_0100_demw	042f12_0100_demw

These files have an accuracy of < 5 m and a resolution of 0.75 arc seconds, which is equivalent to approximately 16 to 23 m in the Manitouwadge area. The 24 individual tiles were merged, levelled, and a colour mosaic, shaded digital elevation model was created in ErMapper (SRK, 2013).

The digital elevation model (DEM) used for this study was constructed by the Ontario Ministry of Natural Resources' Water Resources Information Program (WRIP). The best available DEM in the Manitouwadge area of northern Ontario is generated from 1:20,000 source data acquired through the Ontario Base Mapping (OBM) program. Several OBM data sets were used in the DEM creation including, contours, spot heights, lake elevations derived from spot heights, water features and the WRIP stream network.

Surface analyses were performed on the digital elevation model in order to characterize slope and relief. Slope was calculated using the standard grid-based method employed in ArcGIS, which involves fitting a plane to the elevation values of a three by three neighbourhood centred on the processing cell. Slope is defined as the maximum slope of that plane, which can also be thought of as the dip of the plane, and aspect is equivalent to the dip direction. Relief was calculated in two ways. The first was by subtracting the average elevation within a radius from the elevation value in the processing cell; this was completed for two radii. The second was defined as the range in elevation within a circular window. The second relief calculation represents a high pass filter. The density of steep slopes was calculated as the number of points with a slope of at least 6° within a 2 km radius. The threshold of 6° was established as it serves to distinguish rugged bedrock-controlled areas and those with gentler slopes. Less overburden cover is expected in the former areas and greater amounts in the latter. Areas with a higher density of steeper slopes also present greater challenges to construction.

1.3.1.3 Satellite Imagery

Systeme Pour l'Observation de la Terre (SPOT) and Landsat Imagery

The SPOT 4/5 Geobase OrthoImages for the Manitouwadge area, and surrounding buffer zone, are available as six individual tiles. Each tile contains five Geotiff images representing spectral bands B1, B2, B3, MIR, and a panchromatic band, and covers approximately 8,400 km^2. Multispectral bands have a resolution of 20 m, and the panchromatic band has a resolution of 10 m. The tiles that cover the area are listed in Table 2.

Table 2. Summary of SPOT imagery scenes

s4_08622_4925_20080909_m20_utm16
s5_08456_4925_20060911_m20_utm16
s5_08509_4857_20060911_m20_utm16
s5_08539_4925_20070503_m20_utm16
s5_08551_4857_20060901_m20_utm16
s5_08632_4857_20080813_m20_utm16

For quality control, Natural Resources Canada (NRCan) provides images that have a maximum of 5% snow and ice cover, 5% cloud cover and a maximum viewing angle of 15°. NRCan orthorectified the SPOT images using three data sources: 1:50,000 scale Canadian Digital Elevation Data (CDED), National Road Network (NRN), and Landsat 7 orthoimagery. The orthoimages are provided in GeoTIFF format, projected using Universal Transverse Mercator (UTM) projection referenced to the North American Datum 1983 (NAD83).

The Landsat 7 Orthorectified imagery for the Manitouwadge area is available as a single tile (023026_0100_001010_l7), which covers approximately 75,000 km^2 in area. The tile contains 10 Geotiff images representing spectral bands 1 through 8 (two versions of band 6) and a multispectral image with bands 7, 4 and 3 combined. Multispectral bands have a resolution of 30 m.

1.3.1.4 Geological Mapping

Surficial geology mapping from the OGS was acquired at a scale of 1:1,000,000 (OGS, 1997). Larger scale 1:100,000 mapping from the Northern Ontario Engineering Geology Terrain Study (NOEGTS) series covers the entire area and provides a greater detail on the distribution of surficial materials in addition to information on landforms, relief and drainage. Each NOEGTS map is accompanied by a report describing the landscape and surficial materials in the area, as well as a description of how the terrain may influence engineering decisions.

The majority of the area is covered by NOEGTS Study 45 - Obakamiga Lake (Gartner and McQuay, 1980a). NOEGTS Study 61 - White River (Gartner and McQuay, 1980b), Study 44 – Steel Lake (Gartner, 1979) and Study 29 - Taradale (Gartner and McQuay, 1980c) cover small portions of the southern, western and northern parts of the area, respectively. A digital compilation of the NOEGTS map data is also available (OGS and MNR, 2005).

The Quaternary geology of the southwest quadrant of the Manitouwadge area, surrounding the Township of Manitouwadge, has been mapped at a scale of 1:50,000 by Kristjansson and Geddes (1986, 2009), (Geddes and Bajc, 1985, 2009) and Kettles and Way Nee (1998). This mapping, while in general agreement with the NOEGTS maps of the area, provides a greater level of detail on the distribution of glacial and post-glacial materials and features.

In addition to the above mapping products, literature describing surficial materials and the regional Quaternary history where also reviewed (e.g., Boissonneau, 1966; Prest, 1970; Zoltai, 1967; Geddes, 1986; Sado and Carswell, 1987; Barnett, 1992). A prime objective of the review was to confirm areas of thicker overburden cover that may obscure the surface expression of lineaments in the Manitouwadge area, and to assess the degree to which variation in drift thickness occurs over relatively short distances. Attention was also paid to areas of glaciofluvial and glaciolacustrine deposits, and poorly drained wetland areas as these offer insights into drainage conditions within the area.

1.3.1.5 Aerial Photography

Aerial photographic coverage of the study area, at a scale of approximately 1:54,000, was acquired from the archives of the Ontario Geological Survey. These photos were used for the terrain interpretation and mapping completed as part of the NOEGTS program (Gartner, 1979; Gartner and McQuay; 1980a, 1980b, 1980c). The review of these photographs provided an improved understanding of how the surficial materials, landforms and topography were classified during the NOEGTS mapping.

1.3.1.6 Drill Holes and Water Wells

There is limited information on groundwater resources in the Manitouwadge area with the Ontario Ministry of Environment Water Well Information System Database (2013) containing records of 52 wells. The majority of the water wells are located within the Township of Manitouwadge, with three wells located in the north-central portion of the Manitouwadge area. Two of the northern wells are positioned along the CNR railway. Fourteen of the wells contain data on the depth to bedrock, which ranged from 0 to 29.6 m.

The drill hole database maintained by the Ministry of Northern Development and Mines (2013) contains records of 516 diamond drill holes in the Manitouwadge area. The holes were completed as part of mineral exploration programs, most commonly for precious and base metals. For this reason, the majority of the drill holes are located within the Manitouwadge-Hornepayne greenstone belt (herein referred to as the Manitouwadge greenstone belt) or immediately adjacent to its boundaries. The majority of drill holes are located within the Township of Manitouwadge with other concentrations on the western border of the township and over fragments of greenstone to the east. A cluster of drill holes is also present approximately 5 km northeast of the township in an area of Quetico metasediments.

Positional information for the majority of the drill holes in the database is generally good; however, the listed location for a small percentage of the drill holes must be considered as approximate. Caution must be exercised when viewing the overburden thickness as reported in the database; this is because the majority of the holes were advanced at an angle to vertical, thus artificially increasing the overburden thickness. When the angle is reported, a simple projection to vertical is required.

2. Summary of Geology

2.1 Bedrock Geology

The Manitouwadge area occurs within the Archean Wawa and Quetico subprovinces of the Superior Province which developed 3.0 to 2.6 billion years ago (Ga) (Figure 2). The Wawa Subprovince is composed of well-defined greenstone belts of metamorphosed komatiite, basalt, dacite and rhyolite, and associated metasedimentary rocks, separated by granitoid plutons and batholiths. The metasedimentary rocks include turbiditic wacke, minor conglomerate and iron formation. Stratigraphic and structural relationships between these units of volcanic and sedimentary rocks are usually unclear and commonly masked by later shearing (Williams *et al*., 1991). The granitoids that separate the greenstone belts comprise 20 to 30 percent of the landmass and consist of massive, foliated and gneissic tonalite-granodiorite, which is cut by massive to foliated granodiorite and granite. The majority of the granitoids were intruded during or after the deposition of the greenstone belts with which they are associated (Williams *et al*., 1991).

The Quetico Subprovince, occurring in the northern portion of the area (Figure 2), consists of migmatitic metasedimentary rocks (Zaleski *et al.,* 1995). Granitic intrusions are widely present throughout the Quetico Subprovince, while mafic to ultramafic intrusions occur sporadically (Williams, 1989; Sutcliffe, 1991).

Within the Wawa Subprovince there are two semi-linear zones of greenstone belts, the northern of which includes the Shebandowan, Schreiber-Hemlo, Manitouwadge, Dayohessarah and Kabinakagami greenstone belts. The southern zone comprises the Michipicoten, Mishibishu and Gamitagama greenstone belts which are located west of the Kapuskasing structural zone, well southeast of the Manitouwadge area. The Manitouwadge greenstone belt is a northeast- to east-trending, variably dipping, highly deformed and metamorphosed belt of supracrustal rocks. In the Manitouwadge area the greenstone belt forms a 1 to 2 km thick, east- to northeast-trending synform of metavolcanic and subordinate metasedimentary rocks, in addition to layered gabbro-anorthosite intrusions (Milne, 1968; Williams and Breaks, 1989; Williams *et al.*, 1991; Zaleski *et al.*, 1995; Williams and Breaks, 1996). The greenstone belt is bounded on the south side by the Black-Pic batholith and on the north by the metasedimentary rocks of the Quetico Subprovince (Figure 2).

In the Wawa Subprovince large granitoid bodies, commonly composed of tonalite to granodiorite, surround the greenstone belts and occur as intrusions within them. Such bodies in the Manitouwadge area include the Black-Pic batholith and several smaller plutons. Granitoid intrusions also occur in the Quetico Subprovince (Figure 2). Several generations of Paleoproterozoic diabase dyke swarms, ranging in age from 2.473 to 2.101 Ga, (Hamilton *et al*., 2002; Buchan and Ernst, 2004; Halls *et al*., 2006) cut all bedrock units in the Manitouwadge area.

Published bedrock geological maps (e.g., Zaleski and Peterson, 2001; Johns and McIlraith, 2003) of the region surrounding Manitouwadge indicate a number of faults that range in length from a few kilometres to several tens of kilometres (Figure 2). The largest of these is the Gravel River fault, located approximately 17 km to the northwest of the Manitouwadge area. There are also several mapped northwest-, and northeast-trending faults which appear to coincide with the orientations of distinct Paleoproterozoic dykes that transect the Manitouwadge area. In addition, an east-trending fault is mapped in the Quetico Subprovince immediately north of the east-trending Wawa-Quetico Subprovince boundary (Figure 2).

Faulting in the Manitouwadge area occurred over a protracted period of time. Faulting began during the formation of the greenstone belts and continued to be active until after the accretion of the Wawa and the Quetico subprovinces (i.e., ~2.7 to 2.68 Ga, Williams *et al.*, 1991; Corfu and Stott, 1996). Tectonic forces active during the accretion process produced a zone of highly sheared rocks that extends approximately 15 km either side of the subprovince boundary (Williams, 1991). It is possible that fault reactivation may have occurred during Proterozoic events such as development of the ca. 1.9 Ga Kapuskasing structural zone (e.g., Percival and West, 1994) or the ca. 1.1 Ga Midcontinent rifting event (Van Schmus, 1992), as evidenced by offsets of dykes which occupy some faults (SRK, 2014). Additional fault movement may also have occurred as a result of Phanerozoic tectonism; however, no tectonic activity attributed to this event is evident in the area.

2.1.1 Metasedimentary Rocks of the Quetico Subprovince

Metasedimentary rocks of the Quetico Subprovince occupy the northern third of the Manitouwadge area and have a southern boundary approximately 6 km north of the Township (Figure 2). These 2.700 to 2.688 Ga clastic metasedimentary rocks have undergone various degrees of metamorphism (Percival, 1989; Zaleski *et al*., 1999). The Quetico Subprovince is understood to be an accretionary prism of an Archean volcanic island-arc system, which developed where the Wawa and Wabigoon belts form converging arcs (Percival and Williams, 1989). The timing of the Quetico-Wawa belt accretion has been constrained to between 2.689 Ga and 2.684 Ga (Percival, 1989).

Metasedimentary wacke-pelite-arenite rocks of the Quetico belt (Williams and Breaks, 1996; Zaleski *et al.,* 1999) were interpreted by Stott *et al.* (2010) as having been formed in a basin setting. Small amounts of ironstone, conglomerate, ultramafic wacke and siltstone are present locally (Williams *et al.*, 1991). The arenite, pelite and wacke are layered; however, no occurrences of bedding, unequivocal grain size grading or syn-sedimentary features, such as cross-stratification or dewatering structures, have been documented in the area (Williams and Breaks, 1996).

The metasedimentary rocks of the Quetico belt display evidence of variable deformation and metamorphism, and transformation into gneisses and migmatites. The rocks show a strong compositional layering, numerous small-scale folds, shearing, and sporadically distributed, narrow (<1 m) concordant, boudinaged and folded amphibolite layers (Williams and Breaks, 1996). The metasedimentary rocks display various states of migmatization; Williams and Breaks (1996) classified the metasedimentary rocks in the Manitouwadge area primarily as metatexite with a banded or stromatic structure. Metagreywacke in the Quetico Subprovince contains abundant migmatitic segregations comprising pegmatitic and tonalitic leucosomes, locally with garnet and cordierite (Zaleski *et al.,* 1999).

Migmatitic veins and sheets of granitic material are ubiquitous in the Quetico Subprovince. The compositional layering differentiates two types: one type reflects a transposed or original layering upon which is superimposed a second type of layering resulting from the formation of leucocratic veins and elongate masses. The second type is a product of partial melting and segregation during high-grade metamorphism and includes lenses rich in hornblende-, diopside- and epidote that are commonly elongate along the layering in the enclosing migmatite (Williams and Breaks, 1996). In addition, metasedimentary rocks of the Quetico Subprovince are commonly intruded by tonalite and diorite along the Quetico-Wawa Subprovince boundary. The tonalite and diorite intrusions pre-date migmatization and exhibit low volumes of deformed leucosome. The leucosome is characteristic of the diatexite class of migmatite formation (Williams and Breaks, 1996).

2.1.2 Granite – Granodiorite of the Quetico Subprovince

A number of largely east-west-trending granite-granodiorite intrusions have been mapped in the Quetico Subprovince in the Manitouwadge area (Figure 2). The largest of these, located approximately 15 km north of the Township of Manitouwadge, is described by Coates (1970b) as migmatitic, and consisting of biotite-quartz-feldspar gneisses and hornblende-biotite-quartz-feldspar gneisses; Percival (1989) in turn described it as pink biotite leucogranite. In general, granitic rocks in the Quetico Subprovince are typically medium- to coarse-grained and massive to rarely foliated (Percival, 1989). Information on the depth or age of the intrusions in the Manitouwadge area is not available.

2.1.3 Black-Pic Batholith

The Black-Pic batholith is a large, regionally-extensive intrusion that encompasses an area of approximately 3,000 km^2 and forms the bedrock for the majority of the southern half of the Manitouwadge area (Figure 2). The Black-Pic batholith comprises a multi-phase suite that includes hornblende-biotite monzodiorite, foliated tonalite. and pegmatitic granite, with subordinate foliated diorite, granodiorite, granite and cross-cutting aplitic to pegmatitic dykes (Williams and Breaks, 1989; Zaleski and Peterson, 1993). The thickness of the batholith in the Manitouwadge area is not known but regional geologic models of the area (e.g., Lin and Beakhouse, 2013) suggest it may extend to a considerable depth.

The age of emplacement of the Black-Pic batholith has been constrained by U-Pb (zircon) dating of the oldest phase recognized, a tonalite at 2.720 Ga (Jackson *et al*., 1998). A younger monzodiorite phase has been dated at 2.689 Ga (Zaleski *et al*., 1999). No readily available information regarding the thickness of the batholith was found.

The Black-Pic batholith is interpreted to be a domal structure with slightly dipping foliations radiating outward from its centre (Williams *et al*., 1991). Within the batholith, Williams and Breaks (1989) found that structurally deeper levels of the tonalite suite are strongly foliated with a subhorizontal planar fabric and a weak, north-trending mineral elongation lineation. Upper levels of the tonalite are frequently cut by granitic sheets of pegmatite and aplite and are generally more massive (Williams and Breaks, 1989). Within the Black-Pic batholith, zones of migmatized sedimentary rocks and zones of massive granodiorite to granite are also present. The contact between these rocks and the tonalitic rocks of the batholith is gradational and associated with extensive sheeting of the tonalitic unit (Williams and Breaks, 1989; Williams *et al*., 1991).

Published compilation maps of the Manitouwadge area (Johns and McIlraith, 2003; Johns *et al*., 2003) include an east-trending belt of migmatized rocks occurring north and northwest of the Manitouwadge synform along the Quetico subprovince boundary (Figure 2). Milne *et al*. (1972) described these rocks as migmatized felsic igneous and metamorphic rocks; however, other information on this rock complex, including thickness and age, does not appear to be available within the public domain. While the Black-Pic batholith is generally considered to be monzodioritic, tonalitic and granitic, sporadic borehole data southeast of the Manitouwadge area toward the Township of White River indicate the presence of basalt and gabbro at depth within the Black-Pic batholith. As such, there may be local lithological variations in the Black-Pic batholith resulting in some uncertainty regarding the predominant composition of the batholith.

Within the Black-Pic batholith, magmatic features are destroyed or equivocal and metamorphic textures and mineralogies prevail. Inclusions of relatively melanocratic members of the suite occur as foliated inclusions within later, leucocratic members (Williams and Breaks, 1989; 1996). These intrusions include a pluton termed the Everest Lake pluton by Zaleski and Peterson (2001; not outlined on Figure 2), and another mapped, but unsubstantiated pluton toward the east of the Manitouwadge area (Figure 2). The Everest Lake pluton lies along the western side of the Wawa-Quetico boundary north of the Manitouwadge greenstone belt and comprises weakly to moderately foliated, hornblende-clinopyroxene-biotite monzodiorite to diorite. The S_2 tectonic fabric is concordant to the east-west trends and steep dips typical of the Quetico subprovince boundary (Zaleski *et al*., 1999).

In the Quetico Subprovince conformable sheets of composition equivalent to the Everest Lake pluton are interleaved with migmatitic paragneiss. While coarse igneous textures are preserved in enclaves, the Everest Lake pluton is pervaded by diffuse leucocratic patches that suggest local anatexis. Zaleski *et al*. (1999) estimated the age of the Everest Lake pluton to be 2.679 ± 2 Ga.

The existence of an unnamed, northeast-trending granite-granodiorite pluton located along the eastern side of the Manitouwadge area, south of the Manitouwadge greenstone belt could not be confirmed (outlined, but not labeled on

Figure 2). Although depicted on a compilation map of the area (Johns and McIlraith, 2003), field geologic mapping of the area by Giguere (1972) could not confirm its existence.

2.1.4 Loken Lake Pluton

The Loken Lake pluton extends eastward from the northeastern portion of the Township of Manitouwadge and occupies the innermost area of the Manitouwadge synform (Figure 2). The surficial expression of the pluton, dated at 2.687 Ga (Jackson *et al.,* 1998), forms an ellipse approximately 16.5 km across and 4 km wide. The Loken Lake pluton is described as foliated to massive granite to granodiorite, characterized by K-feldspar megacrysts, 5 to 15 cm in length, which vary in abundance from near zero to 25 percent, and by a relatively low abundance of mafic minerals (Zaleski *et al*., 1999). Locally, the Loken Lake pluton is cut by minor intrusions of foliated biotite granite. Information on the depth of the Loken Lake pluton is limited to a seismic survey which indicates the intrusion extends to at least 0.7 km (Roberts *et al.*, 1997).

2.1.5 Foliated Tonalite Suite

A foliated tonalite intrusion that surrounds the Loken Lake pluton, between the arms of the Manitouwadge greenstone belt (Figure 2), is interpreted to be synvolcanic with the Manitouwadge greenstone belt, and has been dated at 2.72 Ga (Zaleski *et al*., 1999). The surficial expression of the intrusion spans approximately 50 km east-west and 6 km north-south. The tonalite is foliated with minor amounts of biotite and magnetite, and becomes more granite-like as it approaches the metavolcanic rocks (Zaleski and Peterson, 1995). Data collected as part of a seismic survey indicates the intrusion extends to a depth of at least 1.5 km (Roberts *et al.*, 1997).

2.1.6 Nama Creek Pluton

The Nama Creek pluton is located within the northwest quadrant of the Township of Manitouwadge (Figure 2). It is considered a distinct phase of the Black-Pic batholith and forms an approximately 33 km long and typically less than 1 km wide sinuous body along the contact with the Manitouwadge greenstone belt (Zaleski *et al*., 1999). It consists of foliated biotite-hornblende monzonite to monzodiorite, characterized by 1 to 5 cm K-feldspar phenocrysts. Compositionally, the Nama Creek pluton is similar to the Loken Lake pluton, albeit with a greater abundance of mafic minerals and less quartz. The pluton has been dated by Zaleski *et al.* (1999) at 2.680 Ga. There is no readily available information on its depth. The foliated Nama Creek pluton is antiformally folded (Zaleski *et al*., 1999) likely during the D_2 to D_4 deformation events.

2.1.7 Fourbay Lake Pluton

The Fourbay Lake pluton is located in the southwest corner of the Manitouwadge area (Figure 2). The pluton is described by Milne (1968) as consisting of pyroxene-hornblende-biotite granodiorite and by Beakhouse (2001) as a massive, uniform hornblende–biotite (± clinopyroxene) quartz monzodiorite with a medium-grained granular texture. The elliptically shaped pluton, covers approximately 64 km^2 (in the Manitouwadge area), is located entirely within the Black-Pic batholith and is distinguished from the Black-Pic batholith by a prominent aeromagnetic anomaly with clearly defined boundaries. Relatively abundant Fe and Fe-Ti oxides (~1-2 percent) likely account for the aeromagnetic signature of the pluton (Williams and Breaks, 1996). Dioritic enclaves are a minor component in several outcrops but their abundance is less than 1 percent overall (Beakhouse, 2001). The thickness of the pluton is not known but it is expected to be well beyond the planned repository depth (~500 m) based on the interpretation of regional gravity data (PGW, 2014) and the regional geological model for the area (Santaguida, 2002; Muir, 2003).

The Fourbay Lake pluton has a U-Pb (zircon) age of 2.678 Ga (Beakhouse, 2001), and Williams and Breaks (1996) considered it to be one of a series of late stage, likely post-tectonic plutons situated along the central axis of the Black-Pic batholith. No information is available on the depth of the Fourbay Lake intrusion.

2.1.8 Dotted Lake Batholith

The Dotted Lake batholith lies within the southeast corner of the Manitouwadge area (Figure 2). The surficial expression of the batholith is approximately 20 km long and 15 km wide, however only a small portion (approximately 8 km^2) lies within the Manitouwadge area. The pluton is a massive to weakly foliated, compositionally homogeneous leucogranodiorite to leucotonalite with an age of 2.697 Ga (Beakhouse, 2001). Enclaves or inclusions of any sort are not known to occur and leucogranitic pegmatite dykes are rare (Beakhouse, 2001).

The texture and mineralogy of the Dotted Lake batholith is extremely uniform across the batholith and straddles the granodiorite-tonalite field boundary (Beakhouse, 2001). Accessory and trace primary minerals include sphene, opaque oxides, epidote, apatite and zircon. Except where overprinted by intense deformational fabric, development of the batholith displays a coarse grained equigranular texture (Beakhouse, 2001).

The margin of the Dotted Lake batholith is highly strained with a well-developed penetrative fabric parallel to both the contact and penetrative fabrics in the adjacent mafic metavolcanic rocks. Localized narrow zones of high strain also occur in the interior of the pluton associated with narrow, brittle-ductile shear zones (Beakhouse, 2001). The batholith was emplaced prior to the development of the regional (S_2) deformational fabric (Jackson *et al*., 1998). The depth of the pluton is unknown.

2.1.9 The Manitouwadge Greenstone Belt

The Manitouwadge greenstone belt, together with the Faries-Moshkinabi intrusion (Williams and Breaks, 1990; 1996), is part of a semi-continuous supracrustal and mafic intrusive suite (Manitouwadge–Hornepayne assemblage, Williams *et al*., 1991) situated along the northern margin of the volcano-plutonic Wawa Subprovince (Figure 2).

The Manitouwadge greenstone belt comprises metasedimentary and metavolcanic rocks, the majority of which can be found interweaving along both strike and dip in a synform (Milne, 1969). The metasedimentary rocks within the synform comprise predominantly grey to buff psammite and pelite (Williams and Breaks, 1996). Bedding is rarely recognizable as strain and metamorphic recrystallization have produced a transposed layering (Zaleski *et al*., 1999). Most major minerals—mostly quartz, andesine, biotite, garnet, and microcline—are aligned parallel with the mineral foliation; garnet is also locally elongated along this planar anisotropy (Pye, 1960).

Mafic to felsic volcanic successions in the Manitouwadge greenstone belt includes iron formation and associated volcanogenic massive sulphide deposits. Along the southern limb of the Manitouwadge synform, metavolcanic rocks transition from mafic to felsic rocks toward a central belt of metagreywacke. A trondhjemite unit is present within the centre of the Manitouwadge synform, such that orthoamphibole-cordierite-garnet gneiss closely follows the mafic-felsic contact and the margin of this trondhjemite (Zaleski and Peterson, 1995). Similar orthoamphibole-bearing rocks are present in mafic rocks near the northern contact of the volcanic belt with felsic rocks and metagreywacke. Additionally, within the volcanic belt, sillimanite-muscovite-quartz schist and quartzose schist are present close to massive sulphide deposits and, in some cases, envelop ore bodies (Zaleski *et al*., 1999).

2.1.10 Gabbroic Intrusion

Three separate gabbroic intrusions are present within the southeast quadrant of the Manitouwadge area. All intrusions are limited in size and are largely surrounded by the Black Pic batholith.

2.1.10.1 Faries-Moshkinabi Intrusion

The Faries-Moshkinabi intrusion lies approximately 11 km to the east of the Township of Manitouwadge (Figure 2). The intrusion is a series of semi-continuous units of homogenous to interlayered mafic rocks, comprising websterite, hornblendite, metagabbro, gabbro, anorthositic gabbro, gabbroic anorthosite and anorthosite that have been delineated to the northwest, east and southeast of the Manitouwadge synform. The two largest bodies are the Faries Lake and Moshkinabi Lake plutons. Williams and Breaks (1996) suggested that the Faries Lake and Moshkinabi Lake plutons may have originally been part of one larger pluton and as such, they are here described together, including aspects of their composition and deformation. Together, these intrusions form an approximately 30 km long and typically less than 2 km thick elongate intrusion. No data are available on the age of this intrusion.

The Faries-Moshkinabi intrusion is a layered pluton with a maximum thickness of 700 m (Williams and Breaks, 1996). Preservation of primary textures can be observed; however, variable strain and alteration have commonly destroyed primary textures through recrystallization, grain size reduction and neoblastesis in much of the intrusion (Williams and Breaks, 1996). Compositional layering, defined by regular alternation of plagioclase-rich and plagioclase-poor layers in relatively undeformed peridotite, gabbro and leucogabbro to anorthosite, occurs over thicknesses of several tens of metres as part of cyclic successions. In the Faries and Moshkinabi lakes portions of the intrusion, hornblendic and anorthositic veins and sheets occur as layers and discordant plutons within both ultramafic and gabbroic rock types (Williams and Breaks, 1996).

Anorthositic rocks associated with the Faries-Moshkinabi intrusion overlie and underlie mafic to felsic metavolcanic rocks of the Manitouwadge greenstone belt (Williams and Breaks, 1996). The contact between the Faries-Moshkinabi intrusion and the Black-Pic batholith is a thrust-modified, tectonic breccia, composed of centimetre- to metre-scale blocks of anorthosite, metawacke and granitic rocks (Williams and Breaks, 1996). Near the lower, western contact of the intrusion, rocks are typically gneissic and show L > S fabrics. Contacts with the dioritic rocks west of Moshkinabi Lake are highly strained and sporadically mylonitic. In general, plagioclase-rich members of the suite are highly deformed, forming gneisses and mylonitic rocks that have subsequently been intruded by tonalites to form enclaves and breccias (Williams and Breaks, 1996). The Faries-Moshkinabi intrusion is marked by a moderate magnetic intensity that strikes northeastward (PGW, 2014).

2.1.10.2 Rawluk Lake Intrusion

The Rawluk Lake pluton is a small, 3 km by >6 km north-south trending elliptical intrusion located east of the Township of Manitouwadge boundary and west of the Faries-Moshkinabi intrusion (Figure 2). The pluton varies from a biotite-hornblende quartz diorite to tonalite, is slightly foliated, moderately to strongly lineated and is interpreted as a late tectonic magmatic intrusion (Williams and Breaks, 1996). A northward oriented magnetic signature of moderate intensity is present over the Rawluk Lake intrusion (PGW, 2014).

2.1.10.3 Bulldozer Lake Intrusion (informal name)

The informally named Bulldozer Lake intrusion is an approximately 15 km by 10 km ellipsoid gabbroic intrusion in the southeast corner of the Manitouwadge area (Figure 2). The extent of the intrusion is defined by the boundary of a magnetic anomaly observed in an OGS shaded relief total magnetic survey (as seen in OGS Map 2666; Santaguida, 2001). No additional information on this pluton, including its depth, was documented in the reviewed literature.

2.1.11 Mafic Dykes

Three distinct suites of diabase dykes crosscut the Manitouwadge area (Figure 2), including:

- Northwest-trending Matachewan dykes (ca. 2.473 Ga; Buchan and Ernst, 2004). This dyke swarm is one of the largest in the Canadian Shield. Individual dykes are generally up to 10 m wide, and have vertical to subvertical dips. The Matachewan dykes comprise mainly quartz diabase dominated by plagioclase, augite and quartz (Osmani, 1991);

- North-trending Marathon dykes (ca. 2.121 Ga; Buchan *et al*., 1996; Hamilton *et al*., 2002). These form a fan-shaped distribution pattern around the northern, eastern, and western flanks of Lake Superior. A greater density of Marathon dykes is observed north of a nondescript east-west boundary within the Quetico Subprovince (Figure 2). This is a result of the combination of various datasets within the OGS database and does not reflect a geological boundary. The dykes vary in orientation from northwest to northeast, and occur as steep to subvertical sheets, typically a few metres to tens of metres thick, but occasionally up to 75 m thick (Hamilton *et al*., 2002). The Marathon dykes comprise quartz diabase (Osmani, 1991) dominated by equigranular to subophitic clinopyroxene and plagioclase;
- Northeast-trending Biscotasing dykes (ca. 2.167 Ga; Hamilton *et al*., 2002). Locally, Marathon dykes also trend northeast and cannot be separated with confidence from the Biscotasing Suite dykes. On occasion, Biscotasing dykes appear to deflect at intersections with Matachewan-aged dykes; this is thought to be due to a rheological contrast between the Matachewan-aged dykes and the surrounding country rock.

2.1.12 Faults

In the Manitouwadge area, several faults are indicated on public domain geological maps. These faults display four dominant orientations: north, northeast, northwest, and east. Despite the interpretation of multiple faults, few of these structures are named. Named structures include the north-trending Cadawaja, Slim Lake and Fox Creek faults that offset folded stratigraphy in the hinge of the Manitouwadge synform (Figure 2). The northwest-trending Mose Lake fault also offsets stratigraphy near the hinge of the Manitouwadge synform. East-trending structures, including the Agam Lake and Rabbitskin faults, mimic the outline of the Manitouwadge synform and are typically offset by the north-trending faults. However, Chown (1957) indicated that the north-trending Slim Lake fault is truncated by an east-west-trending fault. Mapping, and interpretation of aeromagnetic data (e.g., Miles, 1998), indicates that these faults offset the regional fabric throughout the Manitouwadge area.

The Agam Lake fault strikes east and occurs within the metasedimentary rocks on the southern limb of the Manitouwadge synform. It forms a pronounced topographic lineament, and is primarily a brittle strike-slip fault (Chown, 1957), that in part follows the volcanic-sedimentary contact and locally may have experienced ductile shear (Peterson and Zaleski, 1999).

Miles (1998) interpreted the Cadajwa, Slim Lake, and Fox Creek faults to be sinistral strike-slip faults with the Fox Creek fault displaying a sinistral strike-separation of the Geco VMS deposit by 60 m with a minor east side up vertical displacement. The Cadawaja fault cuts the outer hinge zone of the Manitouwadge synform and offsets the southern limb of the fold by 500 m (Miles, 1998). Miles (1998) noted that the southern limb to the east of the fault has significantly higher magnetic intensity and a more continuous anomaly pattern, and suggested that there may also be some vertical displacement along this fault. The northwest-trending faults are subparallel and adjacent to the similarly oriented Matachewan dykes. A complex history of brittle deformation is evidenced, in part, by offset of the Matachewan dykes by younger episodes of faulting (e.g., Miles, 1998).

Within the Quetico metasedimentary rocks a number of northeast-trending faults are indicated on the geological maps of the Manitouwadge area (Zaleski and Peterson, 2001; Johns and McIlraith, 2003; OGS, 2011). These faults are of modest length, ranging from approximately 5 to 20 km (Figure 2).

2.2 Quaternary Geology

The Manitouwadge area is within the Abitibi upland physiographic region of Thurston (1991) who subdivided the extensive James Region physiographic region of Bostock (1970). The region is characterized by bedrock outcrop with shallow drift cover and a rolling to moderately rugged surface, scattered with lakes.

The Quaternary sediments, commonly referred to as drift, soil or overburden, are glacial and post-glacial materials which overlie the bedrock in the Manitouwadge area (Figure 3). The distribution, thickness and physical characteristics of these deposits have an important influence on several aspects of the current investigation. Areas of thicker drift can hinder the interpretation of lineaments by masking their surface expression or muting the response obtained from geophysical surveys. Coarser grained surficial sediments typically have a moderate to high transmissivity and can serve as local aquifers as well as being a potential source of mineral aggregates for use in building and road construction.

The most recent major geological event in the geologic history of northern Ontario was an extended period of glacial activity that shaped the landscape and resulted in the deposition of the majority of the surficial materials that overlie the bedrock of the area (Barnett, 1992). Large ice sheets are believed to have repeatedly advanced and retreated across this part of Ontario during the Quaternary Period, which is defined as occurring between 1.8 million years and 10,000 years ago.

The last glacial stage affecting the Manitouwadge area, termed the Wisconsinan, is deemed to have begun approximately 115,000 years ago and resulted in extensive and prolonged ice cover. The Wisconsinan Stage is commonly divided into three phases: Early – 115,000 to 60,000 years ago; Middle – 60,000 to 30,000 year ago; and Late – 30,000 to 10,000 years ago (Barnett, 1992).

The Early Wisconsinan corresponds to global cooling and the growth of the Laurentide Ice Sheet, the Middle Wisconsinan was a slightly warmer period, during which southern Ontario and perhaps parts of northern Ontario were ice-free, while the Late Wisconsinan saw the return of ice cover. The Late Wisconsinan glacial ice cover peaked at approximately 20,000 years ago with the glacial ice mass extending across all of Ontario and into the northern United States.

All glacial landforms and related materials within the Manitouwadge area are associated with the Late Wisconsinan. Quaternary deposits and landforms in the area are thought to have formed during the latter stages of ice cover. The Quaternary (i.e., surficial) geology of the area has been mapped at a regional scale (>1:100,000) by several authors, including Boissonneau (1965), Zoltai (1965), Sado and Carswell (1987), and Barnett *et al.* (1991). Mapping at a scale of 1:100,000 (Figure 3) was completed by Gartner (1979) and Gartner and McQuay (1980a, 1980b, 1980c) as part of the NOEGTS program. The area covered by the Manitouwadge, White Lake and Vein Lake NTS map sheets has been mapped at a scale of 1:50,000 by Kristjansson and Geddes (1986, 2009), (Geddes and Bajc, 1985, 2009) and Kettles and Way Nee (1998), respectively. The area covered by this detailed mapping is shown on Figure 4.

The principle difference between the 1:50,000 scale and the NOEGTS mapping is the former delineates areas of bedrock outcrop as opposed to including these in broader areas of thin drift. The detailed mapping also outlines modest sized pockets of till and glaciolacustrine deposits not identified in the coarser-scale mapping. The till is likely a veneer of modest thickness (1 to 3 m) while the fine-grained deposits may be of greater depth, especially where they occupy bedrock controlled valleys. The additional detail in the 1:50,000 mapping is also evidenced by the delineation of narrow glaciofluvial complexes west and southeast of the Township of Manitouwadge.

Kristjansson and Geddes (1986) report that glacial striae in the Manitouwadge area indicate the last direction of glacial movement was toward the south-southwest with little deviation from a general orientation of 210° to 220°. Geddes and Bajc (1985) note that in the southern portion of the area a weakly developed, presumed older, striation direction is recognized that reflects a more southerly direction of ice flow. For the large parts of the Manitouwadge area, drift thickness over bedrock is limited and the ground surface reflects the bedrock topography Kristjansson and Geddes (1986). Over the majority of the area bedrock outcrops are common and the terrain is classified, for surficial purposes, as a bedrock-drift complex; i.e., thin drift cover that only locally achieves thicknesses that mask or subdue the bedrock topography (Figure 3). Valleys and lowland areas typically have extensive and thicker surficial deposits that frequently have a linear outline.

Near White Otter Lake in the north-central part of the Manitouwadge area, a series of kames have been inferred as a recessional moraine (Boissonneau, 1965; Gartner and McQuay, 1980a). In that these features form part of an extensive esker-outwash complex, it is questionable whether they represent an ice marginal position.

The glaciolacustrine sediments found in the river valleys and lowland areas in the Manitouwadge area were deposited in glacial lakes which occupied the Lake Superior basin; glacial lakes present in the area were a series of sequentially lower levels that existed after glacial Lake Minong (i.e., referred to as Post-Minong levels) followed by glacial Lake Houghton. As the glacier receded northward, these glacial lakes expanded and connected with glacial Lake Barlow-Ojibway through the Pic-White Otter river valley (Prest, 1970). Deposition of sediments directly related to glacial activity is thought to have ended by 9,000 years ago.

3. Topography

3.1 Elevation

The elevation difference within the Manitouwadge area is moderate with a maximum range of approximately 287 masl (Figure 5). The highest point of land within the area, 482 masl, occurs approximately 5 km west of the settlement area of Manitouwadge, and the lowest point (195 masl) is in the Nama Creek valley where it intersects the western project area boundary. Notable variations in elevation caused by bedrock knobs and ridges are prevalent in parts of the Manitouwadge area.

Across large parts of the area, the elevation of knobs and intervening valleys is commonly between 320 and 380 m (Figure 5). Localized areas of higher elevation are present in the central portion of the Township of Manitouwadge, as well as in the east-central and southeast corners of the Manitouwadge area (Figure 5, inset map). These areas are underlain by the Manitouwadge greenstone belt, Quetico metasediments and the Black Pic batholith, respectively. Elevations in these areas commonly range between 380 to 440 m.
Elevations of 280 to 320 m are found in the northeastern portion of the Manitouwadge area and immediately flanking the Pic and White Otter rivers, as well as a northeast trending band running from where Highway 614 crosses the southern boundary of the area, to the east of the Township of Manitouwadge (Figure 5). These areas generally correspond to the distribution of glaciolacustrine and glaciofluvial deposits, and, to a lesser degree, ground moraine.

The Pic and White Otter river valleys, and some of their tributaries, have elevations less than 280 m over the majority of their length. Located in the west-central and northwest portions of the Manitouwadge area, the river valleys are narrow and are floored with glaciolacustrine sediments. These valleys are highlighted in blue on the inset map of Figure 5.

3.2 Relief

Relief maps of the Manitouwadge area are useful in outlining zones of thin drift located in bedrock controlled upland areas. Within the Manitouwadge area the upland regions, consisting of knobby bedrock hills, are characterized by moderate relief (approximately 60 m) over distances of hundreds of metres to a few kilometres. These uplands are scattered throughout the area and are the dominant terrain type. Glaciolacustrine and, to a lesser degree, glaciofluvial deposits and areas of ground moraine, represent areas of limited relief, although many of these deposits are characterized by protrusions of bedrock knobs. The glaciolacustrine deposits in the northeastern corner of the area and those within and around the Township of Manitouwadge display relief in the range of 20 to 40 m over the majority of their surface area. However, relief within the glaciolacustrine deposits of the Pic-White river and the Nama and Fourbay creek systems ranges 20 to 60 m due, in part, to erosion (Figure 5).

Relief was calculated using different approaches to highlight different aspects of the topography. These different representations of relief are presented in Figures 6 to 8. Figures 6 and 7 display relief calculated through subtracting the average elevation within a pre-defined radius (20 km and 2 km, respectively) from the elevation value in the processing cell, resulting in a value depicting the departure of a given point from the average surrounding elevation.

The use of a 20 km averaging radius (Figure 6) highlights the presence of broadly higher and lower ground within the Manitouwadge area. In Figure 6, the area of greatest positive departure from the average elevation is located in the immediate vicinity of the settlement area of Manitouwadge. Several large areas of positive relief are found throughout the Manitouwadge area as illustrated in the inset map of Figure 6, which highlights the areas with elevation departures of 16 m or higher than the surrounding average.

The Pic- White Otter river system, which trends westward across the northern part of the area prior to arching southwest along the western boundary of the area, appears as a feature with strong negative departure on Figure 6. In the southern and southeastern portions of the area, Black River and Gum River valleys are other notable features that are also defined as negative departures.

The use of a 2 km averaging radius for depicting the departure of a given point from the average surrounding elevation highlights locally prominent positive or negative landforms in the Manitouwadge area (Figure 7). This calculation of relief again illustrates the upland areas, but enables the recognition of linear features (valleys) separating bedrock knobs. The upland area in the Township of Manitouwadge is again evident, as are numerous other highlands, throughout the area. The bedrock knobs shown on Figure 7 are circular to rectangular in shape and are of 1 to 3 km in length with widths usually in the 1 to 1.5 km range. Bedrock and river valleys appear as negatives on Figure 7, the most pronounced of which is the Pic-White Otter river system.

The inset map on Figure 7 displays areas that are at least 10 m higher than the surrounding average elevation, and further emphasizes the dominance of knob and ridge terrain within the area. On the inset map, knobs (high ground) are displayed in red. Of note is the general decrease in knobby terrain towards the northeast corner of the area (Figure 7, inset map). There does not, however, appear to be any obvious correlation between topographic relief and the bedrock geology based on mapping available for the area.

The areas of positive relief shown in Figure 6 and Figure 7 are largely indicative of zones of thinner overburden within which the bedrock may be more easily characterized by surface mapping. Conversely, areas of strong negative relief are more likely to have a thicker overburden cover making observation of the bedrock surface difficult. The trend of the areas negative relief may reflect the orientation and/or presence of underlying bedrock structures.

Figure 8 displays the range in elevations within a 250 m radius of a given point in the area. Using this approach, the maximum amount of relief calculated over this short distance is approximately 145 m. Figure 8 once again illustrates the knobby surface of the Manitouwadge area and highlights relief in the area north of the Town of Manitouwadge and along the Pic and White Otter rivers. Lower relief is displayed in the northeastern and northwestern corners of the area. The inset map on Figure 8 differentiates between areas of high local relief (>20 m).

3.3 Slope

In the region surrounding Manitouwadge, approximately 13 percent of the area is represented by slopes greater than 6 degrees (Figure 9). These steep slopes are generally associated with topography in areas of bedrock terrain, with the only notable exception being the Pic-White Otter river system. Not surprisingly, the steep slopes associated with bedrock are concentrated in areas of higher relief, including the northern half of the Township of Manitouwadge, the southwestern corner of the area and a defuse zone in the east-central portion of the area.

The knobby nature of the terrain over much of the area is illustrated by the circular or ovoid pattern of steep slopes on Figure 9; however, linear ridges can also be identified, particularly in the region along the southern boundary. The tops of the knobs and ridges frequently have lower slopes than the surrounding terrain. The steep slopes associated with the Pic-White Otter river system, and a number of its tributaries, are narrow but continuous for much of the system's length. The northern third of the Manitouwadge area has a paucity of steep slopes as do pockets of land in the central and south-central portions of the area.

Assuming that areas with steep slopes are indicative of areas with no or limited overburden, and areas displaying gentler slopes may be indicative of somewhat thicker overburden, a map showing the density of slopes greater than 6 degrees was generated (Figure 10). Areas of low slope density on this figure highlight potential areas of thicker overburden that may obscure the surface expression of lineaments, or introduce uncertainty to the mapping and geologic interpretation of the area.

A high density of steep slopes occurs over the nose of the Manitouwadge greenstone belt, in the southwest corner of the area, along the Nama Creek and segments of the Pic River. Broad areas of higher slope density, >340 points/km^2, are present over the remainder of the area, except in the northeastern and northwestern corners, and restricted pockets in the south-central parts of the area.

In the Manitouwadge area the use of slope density mapping (Figure 10) as an indicator of potential thick drift is best done by interpreting the data in conjunction with the surficial geology (Figures 3 and 4). The general good correlation between areas of low density of steep slopes and areas with overburden gives confidence in the quality of the surficial geology mapping.

4. Drainage

The distribution of surface water and surface water drainage in the Manitouwadge area are important factors to consider in the preliminary assessment. Larger lakes can completely or partially conceal the surface expression of geological structures thus adding uncertainty to the results of a lineament interpretation comparing surficial and geophysical data sets (SRK, 2013).

The Manitouwadge area is largely within the Atlantic-Great Lakes watershed with waters draining southward toward Lake Superior. Relatively small pockets of land along the northern boundary and a strip of land along most of the eastern side fall within the Arctic watershed and drain northeastward via rivers of the James/Hudson Bay system. Surface water flow patterns are also a useful surrogate for shallow groundwater flow.

4.1 Waterbodies and Wetlands

The numerous lakes within the study area occupy approximately 4.5 percent (181.8 km^2) of the land surface and occur with an even distribution (Figure 11). As a generalization, it may be stated that lakes present in bedrock dominated areas (i.e., thin drift cover) are linear in outline, while those floored by glaciolacustrine deposits are more ovoid in shape. Many of the lakes within the glaciofluvial complexes are smaller and are elongate, parallel to the orientation of the hosting feature.

In general, the lakes are of a modest size with the majority having a surface area of less than 1.0 km^2. The larger water bodies (>1.5 km^2) in the Manitouwadge area are listed in Table 3.

A lake sediment sampling survey conducted by the GSC recorded lake depths at approximately 478 locations in the Manitouwadge area (Friske *et al.*, 1991a, 1991b). While it was the intent of this survey to sample the deepest part of the lakes, this cannot be confirmed. Nevertheless, the lake sediment survey data do provide a general picture of minimum lake depths (Figure 11). Bathometric surveys have been conducted by the MNR for 67 lakes in the Manitouwadge area; however, the accuracy of these surveys is questionable (C. Bolton, written comm., 2013).

Table 3. Size of lakes larger than or equal to 1.5 km^2 in the Manitouwadge area.

Lake	Area (km^2)	Perimeter (km)
Garnham Lake	4.8	27.9
White Otter Lake	4.7	22.6
Jembi Lake	3.4	21.4
Wowun Lake	2.5	12.9
Barehead Lake	2.2	11.6
Flanders Lake	2.1	21.5
Everest Lake	1.7	8.1
Macutagon Lake	1.7	15.1
Upper Flanders Lake	1.6	13.3
Agonzon Lake	1.5	12.5

Table 4 indicates that approximately 56 percent of the sample sites measured by Friske *et al.* (1991a, 1991b) have a water depth of less than 5 m and nearly 88 percent are less than 10 m deep. Lakes deeper than 20 m account for only 1.0 percent of the sites sampled.

Table 4. Lake depth data in the Manitouwadge area (from Friske *et al.*, 1991a, 1991b).

Lake Depth (m)	Number of Lake Sites	Percentage
<5.0	267	55.9
5.1 – 10.0	152	31.8
10.1 – 15.0	42	8.8
15.1 – 20.0	12	2.5
>20.1	5	1.0

Lakes with a smaller surface area tend to be shallower, but there is only a weak correlation between lake depth and lake size, and no overall relationship between these parameters can be concluded. Lakes occur with near equal consistency over both granitic, greenstone and metasedimentary terrain. While the bedrock geology does not appear to be a significant factor in controlling the depth or size of lakes in the area, there is an indication that lakes over the northern half of the Quetico metasediments may be shallower. This could be a reflection of the fact that a number of the lakes are floored by glaciolacustrine deposits.

Wetlands are developed at scattered locations along water courses in the area and in rock floored basins (Figure 3). Organic deposits associated with the wetlands are expected to have a limited thickness based on surficial mapping conducted in the area (Kettles and Way Nee, 1998; Kristjansson and Geddes, 2009; Geddes and Bajc, 2009), and other areas of the Canadian Shield.

4.2 Watersheds

A watershed, also known as a catchment, includes all of the land that is drained by a watercourse and its tributaries. Watershed boundaries are defined by heights of land and are set where a height of land causes water to flow away from the topographic high (MNR, 2013). The delineation of drainage divides are therefore useful for determining surface flow directions and also contribute to an initial understanding of the shallow groundwater flow system.

The Manitouwadge area straddles the Atlantic and Arctic watersheds, which drain via the Lake Superior/Great Lakes/St. Lawrence River and James/Hudson Bay water systems, respectively. The Arctic watershed is represented in the area by two tertiary level watersheds, the Negagami and the Upper Kenogami, which drain pockets of land across the northern edge and along the eastern edge of the area respectively (Figure 12, inset map). Drainage to Lake Superior is through the Pic and White tertiary watersheds which cover approximately 85 percent of the land in the Manitouwadge area. Tertiary watersheds, as defined by MNR, are generally the equivalent of the sub-sub-division of drainage areas as defined by the Water Survey of Canada.

The boundaries of the quaternary watersheds for the Manitouwadge area were created using the Spatial Analyst Extension of ESRI's ArcGIS to compute the flow direction from a DEM and then employing the watershed function to determine contributing area. This analysis produced watershed boundaries that are generally consistent with the quaternary watershed boundaries developed by the MNR (MNR, 2013). The analysis conducted as part of this study delineated drainage divides at a finer level than completed by MNR (Figure 12). Further subdivision of the watersheds is possible as each of the many lakes in the area represents a distinct catchment area. Given the scale of the area and the scope of the current study, such a detailed delineation was not undertaken.

The horizontal positional accuracy of the watershed boundaries is variable depending on the nature and spatial distribution of the raw DEM information, and thus cannot be quantified without onsite investigation and verification. In general, positional accuracy in northern Ontario is within 400 m, but there is no statistical level of confidence available.

4.3 Surface Flow

The orientation of the drainage network within the study area is largely controlled by bedrock structural features (faults and lineaments) and the irregular topography of the terrain. Due to this control, the majority of waterways, including lakes, have, in order of dominance, a northeast, north or northwest orientation. While the overall drainage in the Atlantic and Arctic watersheds are southwest and northeast, respectively, the catchment areas of individual lakes within the watersheds have stream segments with multiple flow directions (Figure 12).

The larger rivers draining the area's watersheds are fed by numerous smaller creeks and streams that effectively drain all parts of the Manitouwadge area. A higher density of streams is locally present along reaches of the Pic River and where Nama Creek enters the area along the western boundary. Here a number of short streams draining adjacent uplands have eroded thick glaciolacustrine deposits occupying bedrock valleys. In contrast, the northern

portion of the area has a lower stream density likely due to the fact that the surface relief is more subdued and drainage is not as well developed.
Typically, segments of the waterways in the Manitouwadge area are on the order of 3 to 10 km in length, as they flow into and out of lakes occurring along the drainage paths. Gradients of the watercourses vary; those of smaller streams are generally moderate, while longer waterways, such as the Pic and White Otter rivers and Macutagon Creek, have lower gradients. Rapids and small waterfalls are common in the area.

Periods of higher stream flow are related to the spring melt (March - May) and, to a lesser degree, increased autumn precipitation (October – November). While flows decrease in the summer months, regional data (no gauging stations are present in the area) from Environment Canada (2013) indicate that significant precipitation events during this part of the year can significantly increase flow for a short period of time. This is a reflection of rapid runoff from the bedrock terrain the area.

5. Terrain Characteristics

An understanding of the distribution and thickness of overburden within the Manitouwadge area is essential for interpreting the distribution of lineaments mapped from satellite imagery and topographic surface data (SRK Consulting, 2013), particularly with respect to lineament length and density. Thick drift deposits are able to mask the surface expression of lineaments. In areas of discontinuous surficial deposits, the drift can conceal minor lineaments, producing low apparent lineament density and can censor the lengths of major structures. In areas of thick and extensive overburden, major structures can remain undetected using only satellite imagery and/or aerial photographs, particularly if these areas also contain large lakes.

Areas of exposed bedrock or thin drift are more readily amenable to characterization. Thin drift terrain allows easier investigation of bedrock units through outcrop mapping, the identification of bedrock structures and preliminary rock mass characterization.

The following section provides information to enhance the understanding of overburden deposits in the Manitouwadge area. Sections 5.1 and 5.2 present reviews of the water well and drill hole data, respectively, and evaluate their contribution to the understanding of overburden thickness in the Manitouwadge area. Details on the expected composition, distribution and thickness of surficial deposits within the terrain units are presented in Section 5.3.

5.1 Water Well Data

Data on overburden thickness from water well records held by the Ontario Ministry of the Environment (MOE) were reviewed to supplement the information on overburden deposits outlined by the terrain mapping component of this study. There is limited depth of overburden information for the Manitouwadge area in the MOE's Water Well Information System (WWIS) (2013) as only 52 wells for the area are in the database, including two monitoring wells (Table 5).

The majority of the water wells are located within the Township of Manitouwadge with most of these in the immediate vicinity of Manitouwadge Lake. Outside of the township boundary a small number of water wells are located in the north-central part of the area and a single well occurs approximately 17 km to the east of the settlement area (Figure 3).

Thirty water well records contain data on the depth to bedrock. In these wells the bedrock surface was encountered at depths ranging from 0 to 29.6 m. The 20 wells confirmed to end in overburden had depths ranging from 4.6 to

30.2 m indicating that bedrock would be found at a greater depth. The wells which extract water from overburden aquifers are generally located in glaciolacustrine deposits and/or in bedrock controlled valleys.

Table 5. Ministry of Environment Water Well Data for the Manitouwadge Area

MOE Well ID	Depth of Well (mbgs)	Depth to Bedrock (mbgs)	Static Water Level (mbgs)	Water Well Type (aquifer)
1101872	73.2	21.6	3	Bedrock
6100067	25.9	25.6	1.2	Bedrock
6100068	29.9	29.6	0.9	Bedrock
6100099	5.2	4.9	0.6	Bedrock
6100161	18.3	18		Bedrock
6100163	2.7	2.4		Bedrock
6100164	5.5	5.2		Bedrock
6100165	1.8	1.5		Bedrock
6100166	3.7	3.4		Bedrock
6100167	8.2	7.9		Bedrock
6100168	4	3.7		Bedrock
6100171	20.4	20.1	5.5	Bedrock
6100172	21.9	21.6		Bedrock
6100173	17.1	16.8		Bedrock
6100174	11.9	11.6		Bedrock
6100531	19.8	15.8	7.6	Bedrock
6100532	30.5	5.5	3.7	Bedrock
6100607	48.8	1.8	6.7	Bedrock
6100732	26.8	5.2		Bedrock
6100734	28.7	0		Bedrock
6100981	7.3	7.3		Bedrock
6100982	25.6	25.6	4	Bedrock
6102668	23.5	23.5		Bedrock
6102669	119.2	5.2	10.7	Bedrock
6102671	45.7	20.7		Bedrock
6102672	14.3	13.7		Bedrock
6103146	76.2	8.5	3.4	Bedrock
6103277	46.3	9.1		Bedrock
6106444	42.7	6.1	5.2	Bedrock
7167492	56.4	18.9	1.8	Bedrock
6100069	30.2	NR	2.4	Overburden
6100160	24.4	NR	11	Overburden
6100162	11	NR		Overburden
6100169	24.4	NR	11	Overburden
6100170	27.7	NR	1.2	Overburden
6100513	15.2	NR	0.9	Overburden
6100514	12.5	NR	0.9	Overburden
6100515	14.9	NR	0.9	Overburden
6100611	14	NR	1.8	Overburden
6100612	13.7	NR	1.8	Overburden
6100983	25	NR	4.6	Overburden
6101372	25	NR	3	Overburden
6101373	23.5	NR	3.4	Overburden
6102670	25.3	NR		Overburden
6103147	8.8	NR	3.4	Overburden
6106445	18.3	NR		Overburden
6107608	4.6	NR		Overburden
7041659	8.2	NR		Overburden
7041660	5.2	NR		Overburden

Table 5. Ministry of Environment Water Well Data for the Manitouwadge Area

7152055	4.6	NR		Overburden
7178853				Monitoring Nest
7188321				Monitoring Nest

NR – Bedrock not reached; Blank Fields – data not reported

5.2 Ontario Drill Hole Database

The drill hole database maintained by the Ministry of Northern Development and Mines (2013) contains records of 516 mineral exploration holes in the Manitouwadge area. While the majority of these are located within the Manitouwadge greenstone belt (Figure 2) in areas mapped as bedrock dominated terrain, a significant number are located in areas mapped as containing thicker surficial deposits (Figure 3).

Drill holes located in bedrock dominated terrain generally have shallow depths of overburden although variation in overburden thickness of several metres is common over short lateral distances. Exceptionally, the depth of overburden may vary by over 10 m in closely spaced drill holes, illustrating the rugged nature of the buried bedrock surface. Drill holes collared in areas mapped as glaciofluvial and glaciolacustrine deposits to the east and west of the Township of Manitouwadge regularly encountered over 10 m of drift cover before reaching bedrock.

The average depth of overburden recorded in the drill logs is 6.8 m, with approximately 50 percent of the holes having <3.0 m of drift cover. In viewing the overburden thickness data contained in the MNDM database it must be noted that a large number of the drill holes were advanced at an angle. For those drill holes with a recorded depth of <5 m of overburden, the drill angle does not add appreciably to the indicated thickness of the surficial sediments. However, a large majority of the drill holes reporting greater than 5.0 m of drift were advanced at an angle to vertical, thus artificially increasing the overburden thickness more significantly. As an example, a hole drilled at a 45 degree angle reported 58.2 m of overburden; when corrected to horizontal the depth was reduced to 41.2 m.

When the drill hole depths are corrected for drill angle the average overburden thickness in the Manitouwadge area decreases to 5.4 m and approximately 62 percent of the holes have <3 m of overburden (Table 6).

Table 6. Overburden depth in diamond drill holes in the Manitouwadge area (MNDM, 2013). Depth is corrected for drill angle.

Depth of Overburden (m)	Number of Drill Holes	Percentage
<1.0	158	30.6
1.1 – 3.0	160	31.0
3.1 – 5.0	56	10.9
5.1 – 10.0	56	10.9
>10.1	86	16.6

5.3 Terrain Units

5.3.1 Morainal

The most common glacial deposit in the Manitouwadge area is ground moraine (till) which occurs as two main types (Geddes and Kristjansson, 1984; Geddes *et al.*, 1985). Dominant in the rocky upland areas is a moderately loose, stony, sandy till of local derivation that forms a discontinuous veneer over the bedrock. The second till type has calcareous, silt matrix and contains abundant non-local pebble lithologies derived from the James Bay Lowland. Two facies of this calcareous till are noted by Kristjansson and Geddes (1986); a moderately compact to loose, silty-sand melt-out variety, and a very dense, blocky and silty variety. In general, the calcareous till is most prevalent in areas situated on the lee-side (down ice) of major bedrock highs.

Till thickness in the Manitouwadge area is variable and while depths of several metres are present locally, thicknesses are typically less than 3 m (A. Bajc, pers. comm., 2013). In relatively restricted areas immediately west, south and southeast of the settlement area of Manitouwadge, the till forms a more continuous blanket over the bedrock that is, in places, gently fluted (Kristjansson and Geddes, 1986). In this area zones of lesser relief indicate the till thickness may be sufficient to subdue the bedrock topography, although bedrock outcrops occasionally protrude through the till cover.

More extensive ground moraine deposits are also located in the northwest and northeast corners of the area (Figure 3). The thickness of the till in these areas, based on air photo interpretation, is believed to be generally <3m, although the presence of drumlinoid features in the northeast quadrant suggests local thickening (Gartner and McQuay, 1980a, 1980b).

In areas where the ground moraine forms only a veneer over the bedrock, construction will often involve blasting, rock excavation and grading. In areas of thicker till, the clast-rich nature of the material requires equipment capable of moving and/or breaking-up boulders. While till is not suitable for use as aggregate due to its fines (i.e. silt and clay) content, it can be used as fill.

5.3.2 Glaciofluvial

Two types of glaciofluvial deposits are present in the Manitouwadge area, ice-contact stratified drift deposits (ICSD) and outwash deposits. The ICSDs deposits are associated with a number of esker and, kame terrace complexes (Gartner and McQuay, 1980a). Kristjansson and Geddes (1986) note that the orientation of the esker-kame complexes trend south and southwest (Figure 3) is similar to that of the major bedrock lineaments present in the area. Most of the esker complexes have defined, if discontinuous, central ridges flanked by kettled, kame terraces or younger glaciolacustrine deposits. The ICSDs consist primarily of stratified, well to poorly sorted, sand and gravel, locally boulder-rich, that can achieve thicknesses of up to 30 m (Kettles and Way Nee, 1998).

Glaciofluvial outwash deposits in the area have a restricted distribution with the largest deposits occurring to the east and southeast of the Township of Manitouwadge where they are associated with ICSD sequences (Figure 3). Locally the outwash plains are heavily kettled and pitted indicating the deposition of sediment over buried ice blocks. Deposits are generally well-sorted and consist predominantly of stratified sand, with a low clast content; however, locally they are coarser grained and gravel-rich (Kristjansson and Geddes, 1986). The thickness of the outwash deposits is likely to be variable, but may be substantial where they are proximal to ICSD features. For example, approximately 9 km east of the Township a south trending glaciofluvial complex is traversed by a series of diamond drill holes which have overburden depths ranging from 3.7 m to 64.6 m. Variability in the drift cover over short distances is illustrated by drill holes positioned 87 m apart having overburden thicknesses of 25.0 m and 40.2 m, and in another instance by two holes separated by 210 m having overburden depths of 8.2 m and 64.6 m.

In terms of engineering geology considerations, glaciofluvial deposits are suitable for most types of construction and/or development. Excavations should not encounter serious problems and material can generally be reused as fill and compacted with normal equipment; occasionally boulder-rich material may require screening or additional handling. Difficulties may arise in areas where bedrock is close to the surface and blasting may be required for excavations or in low lying areas where a shallow groundwater table may necessitate dewatering (Gartner and McQuay, 1980a, 1980b, 1980c). In the Manitouwadge region, most glaciofluvial deposits are of low to moderate relief and are well-drained Areas mapped as glaciofluvial deposits also frequently contain subordinate amounts of ground moraine, rock knobs and organic terrain; these areas may present additional engineering challenges.

5.3.3 Glaciolacustrine

Glaciolacustrine sediments in the area consist of stratified to laminated sand, silt and clay that were deposited during the incursion of glacial lakes post-Minong and Houghton into the Manitouwadge area (Prest, 1970; Gartner and McQuay, 1980a; Kettles and Way Nee, 1998). Northward expansion of the lakes allowed a connection with the waters of glacial Lake Barlow-Ojibway, via the Pic-White Otter river valleys.
Glaciolacustrine sediments occur across the area, with extensive deposits occurring on the eastern and western sides of the Township of Manitouwadge and in the northeast quadrant of the area (Figure 3). The highest glacial lake level in the Manitouwadge area was approximately 340 m (Kettles and Way Nee, 1998). The thickness of glaciolacustrine deposits is variable, ranging from several tens of metres to a relatively thin veneer over bedrock. Deposit thickness in the Pic and White Otter river valleys may attain 75 m (Kettles and Way Nee, 1998).

Glaciolacustrine deposits typically occur as low relief plains unless dissected by modern stream development, such as is the case in the Pic River valley. Drainage of the glaciolacustrine deposits is variable, ranging from good to poor. The fine-grained nature of the material has allowed the development of wetlands in shallow surface depressions, as well as the growth of a thin veneer of organic material over sizeable areas (Gartner and McQuay, 1980a).

The nature and engineering properties of glaciolacustrine materials, notably those with high percentages of silt and clay, may cause difficulties for construction. Potential problems include: low bearing strength for footings and foundations; slope instability and susceptibility to erosion and gullying; frost susceptible soils and difficulties with compaction of relocated material (Gartner and McQuay, 1980a). In addition, where the glaciolacustrine deposits are thin over rock, blasting may be required for deeper excavations.

5.3.4 Organic

Organic-rich alluvial deposits, consisting of sand, silt and clay, are present along water courses across the area (Figure 3). Bog and swamp deposits, developed on rock and glaciolacustrine floored basins, are also common with larger deposits containing bedrock knobs and minor outwash. These deposits tend to have a limited thickness, as determined by regional studies, and generally have a limited aerial extent.

The organic deposits in the area are characterized by poor drainage and high water tables, in addition to having poor engineering characteristics due to the fact they consist of compressible materials (Gartner and McQuay, 1980a,1980b, 1980c).

5.3.5 Eolian deposits

Eolian deposits formed in post-glacial time, consisting of fine to medium sand, are present as parabolic dunes developed on some glaciofluvial and glaciolacustrine deposits (Gartner and McQuay, 1980a; Kristjansson and Geddes, 1986; Kettles and Way Nee, 1998). The dune field present northeast of the town of Manitouwadge is now surrounded by organic deposits (Figure 3). Dunes have heights of only a few metres in the Manitouwadge area.

5.3.6 Anthropogenic Deposits

Historic mining activity immediately north of the town of Manitouwadge has resulted in the surface accumulation of waste rock and mine tailings. The area covered by these “man-made” deposits is small, covering less than 5 km^2 (Kristjansson and Geddes, 2009).

5.3.7 Bedrock

The majority of the Manitouwadge area consists of extensive tracts where bedrock is at or near surface (Figure 3). It is common in these areas of bedrock terrain for the rock to be overlain by a veneer, or in some instances a blanket, of overburden, most frequently ground moraine (till). The overburden is often in the range of 1 to 3 m in thickness; however, on the sides of some of the bedrock hills, and in the low areas between hills, the overburden can thicken to as much as 5 m. Areas mapped as bedrock by Gartner (1979), and Gartner and McQuay (1980a, 1980b, 1980c) contain 10 to 30 percent outcrop and frequently occur within what Geddes and Bajc (1985) and Kristjansson and Geddes (2009) termed bedrock-drift complex.

Mapping by Gartner and McQuay (1980a) indicates that bedrock knobs are the dominant landform in bedrock terrain and although drainage is usually good, organic deposits are commonly found in low, poorly drained areas between bedrock hills. Relief in bedrock terrain typically ranges between 40 to over 60 m, although locally it can exceed 100 m. Areas of higher relief associated with bedrock topography, are scattered throughout the southern two-thirds of the area, with the area around the Town of Manitouwadge containing particularly rugged topography. In the northern portion of the Manitouwadge area, the bedrock relief becomes slightly more subdued due to the presence of broad areas of overburden cover.

Engineering design and construction in areas of bedrock terrain is constrained by the irregular bedrock surface and, in instances, by high, steep bedrock slopes. Below-ground excavations will routinely require blasting and the placement of rock fill as part of site grading; however, footing conditions for supporting foundations are likely to be excellent. Route alignments for various types of infrastructure (e.g., roads, railways, pipelines) are likely to require cut-and-fill sections through bedrock (Gartner and McQuay, 1980a).

6. Groundwater

6.1 Groundwater Flow, Recharge and Discharge

The 20 water wells confirmed to be developed in overburden are largely within the glaciolacustrine deposits occupying the central portion of the Township of Manitouwadge. These wells, which draw water from overburden aquifers, generally have low pumping rates; however, yields are likely not reflective of aquifer capacity, as the wells primarily supply residences with limited demand. Recorded overburden well depths ranged from 4.6 to 30.2 m. Reported pumping test rates ranged from 68 to 2,795 L/min with static water levels ranging from 0.9 to 11.0 mbgs (MOE, 2013).

Within the Manitouwadge area 30 water wells are recorded as being developed in bedrock. These wells reach a maximum depth below ground surface of between 1.8 and 119.2 m. Reported pumping test rates ranged from 4.5 to 27 L/min with static water levels ranging from 0.6 to 10.7 mbgs (MOE, 2013).

The Manitouwadge area is characterized by significant areas where bedrock is at or near the surface. Groundwater recharge in these areas is through an interconnected fracture network present in the bedrock. Recharge via the fracture network can be rapid but is largely restricted to a near surface zone. Gartner and McQuay (1980a) note that groundwater resources within bedrock are limited to fractures, faults and fissures making the occurrence of bedrock aquifers unpredictable.

Groundwater flow off the uplands is to flanking valleys and depressions where the bulk of the groundwater discharges either directly to waterways or into surficial deposits occupying the lower ground. Surficial deposits on the highland bedrock areas, most commonly till, are usually thin (<3 m) and relatively coarse-grained allowing downward infiltration to the bedrock surface.

The sand-rich outwash deposits found along bedrock valleys in the Manitouwadge area are recharged by ground and surface flow from the bedrock highlands and direct precipitation (rain and snow). Groundwater discharge from these deposits is as baseflow to streams and rivers which transect them. The presence of a shallow water table in many of the valley outwash deposits is suggested by the fact that the elevation of the dissecting waterway is often within a few metres of the surrounding ground surface.

The large glaciofluvial (esker) deposits that trend south and southwest across the area are also zones of significant groundwater recharge. Creeks and streams are generally lacking over these glaciofluvial systems; however, the water level in kettle lakes associated with these features indicates a generally shallow water table. The influence of regional bedrock structures, such as the mapped faults in the area, on the rate and volume of groundwater flow is not known at present.

No information on groundwater flow at typical repository depths (approximately 500 m) was found during this study.

7. Neotectonic Features

The geology of the Manitouwadge area is typical of many areas of the Canadian Shield which have been subjected to numerous glacial cycles during the last million years, resulting in 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 Manitouwadge area would be of a somewhat greater magnitude, due to its closer proximity to the main centre of glaciation located over Hudson’s Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/a 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/a) 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, 2005). The current rate of isostatic uplift in the Manitouwadge area is not precisely known, although Lee and Southam (1994) estimate that the land is rising at a rate of 2.9 mm/a at Michipicoten, Ontario, some 150 km to the southeast.

The movement and interaction of tectonic plates also 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 Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

The stresses associated with cycles of ice loading and unloading, acting along with tectonic stresses, may result in seismic events related to displacements along ancient discontinuities in the bedrock. The study of neotectonic features in the Manitouwadge area may reveal the timing and magnitude of past seismic activity and deformations. Conclusive evidence of features indicative of reactivation of ancient bedrock structures could not be made using the information available in the current study. Field investigations would be required to identify such features since, under appropriate conditions; it may be possible to identify neotectonic features in bedrock and overburden, as discussed below.

7.1 Types of Bedrock Neotectonic Features

Existence of bedrock, neotectonic features can be used to extend the seismic record for a region well into the past. In the Manitouwadge area should any pop-up features be present, they may be recognized by their narrow, linear shape which could extend for hundreds of metres (White *et al.,* 1973). Such features would likely only be found in areas of bedrock outcrop or thin overburden cover (<1 to 2 m). It is possible that tree cover, typical of that found in the boreal forest, would assist in making their identification difficult when interpreting air photo or other remotely sensed imagery. Faults resulting from neotectonic activity may be equally challenging to discern from ancient features. Recent faults (i.e., post-glacial faults) may show evidence of displacement, fresh brecciation or an unhealed character suggestive of recent formation.

7.2 Types of Overburden Neotectonic Features

The most common neotectonic feature in glaciated terrain is faulting caused by movement of the bedrock which is reflected in the overlaying surficial sediments. Displaced (faulted) post-glacial beach ridges in the lower Great Lakes have provided evidence of movement and allowed a determination as to the post-glacial timing of the feature’s formation (McFall and Allam, 1990). Under the appropriate conditions, soft sediment deformation preserved in glacial sediments can also be an indication of post-depositional movement associated with paleo-seismic events. Doughty *et al.* (2013) suggest that deformation of glaciolacustrine and overlying post-glacial sediments in Lake Timiskaming, ~500 km to the southeast of Manitouwadge, are a reflection of neotectonic faulting associated with the Timiskaming graben.

In the Manitouwadge area neotectonic activity would best be recognized in stratified material such as fine-grained glaciolacustrine and glaciofluvial deposits. Disrupted or faulted bedding is more easily discerned in such materials as opposed to unsorted or coarse-grained deposits such as till and gravel. In the area, deposits most favourable for the preservation of neotectonic features are clay, silt and sand deposits occurring in: the larger river valleys (e.g., Pic and White Otter rivers, Macutagon Creek); the glaciolacustrine plain located northeast of the Township of Manitouwadge; and the northeast corner of the area (Figure 3). The sand-rich segments of the glaciofluvial outwash deposits found in bedrock controlled valleys across the Manitouwadge area could also possibly display such features.

The examination of natural and man-made exposures, such as those found in stream/river sections and excavations would provide the best opportunity to locate any evidence of recent movement. Sedimentological studies of the material would be required to separate recent soft-sediment deformation from that caused by processes active at the time of deposition, such as dewatering and faulting resulting from the melting of buried ice blocks or glaciotectonic movement (Slattery, 2011).

8. Accessibility Constraints

Access to the area is via Ontario Highway 614, which ends at Manitouwadge after trending northward approximately 50 km from Highway 17 (Trans Canada Highway). The Caramat Industrial Road exits the Township of Manitouwadge on its western side before heading north and then northwest, eventually connecting with Ontario Highway 11 (Figure 1). Access to the interior of the Manitouwadge area is provided by an extensive network of secondary roads and trails primarily developed during forestry operations which allows access to all parts of the area, including areas of thin drift. A rail line, operated by Canadian National Railways (CNR), cuts across the northeastern corner of the Manitouwadge area. An abandon railway right-of-way runs southward from the CNR line, through the Town of Manitouwadge and intersects the Canadian Pacific Railway trackage approximately 25 km south of the project area. An airport with a single, paved 1,050 m runway is located 5 km south of town.

The road access shown on Figure 13 is based on the Ministry of Natural Resources (MNR) road segment file obtained from Land Information Ontario. The MNR road segment file contains resource access roads constructed for and used by conventional (i.e., street legal) vehicles. Additional, but not all, forest access roads identified on satellite images of the Manitouwadge area have been added to Figure 13.
Secondary roads, primarily developed during forestry operations, may or may not be maintained following the completion of logging in an area. In some cases, culverts or river crossings have been removed, restricting access. Locally, trails of narrow width and short length have been developed; however, the condition and usability of these trails is highly variable.

All major geological bodies found in the Manitouwadge area are accessible by means of the existing road network. Roads are developed across the Black-Pic batholith and the Quetico Subprovince in addition to smaller intrusive bodies, including the Fourbay Lake, Loken Lake and Nama Creek plutons, as well as unnamed granitic bodies within the Quetico.

The principal constraint to developing access to most parts of the Manitouwadge area is the modest relief which, in places, is represented by steep slopes of varying heights. Significant slopes are most frequently located in areas of bedrock dominated terrain; however, steep embankments are also present along major water ways, such as the Pic River.

Throughout the area few natural constraints to development exist, other than topography and the position of lakes. As is the case for many of the existing roads in the Manitouwadge area, new roads can follow bedrock valleys as a means of reducing construction difficulties. The larger valleys are floored by either glaciofluvial or glaciolacustrine deposits that have a relatively level surface and can locally serve as a ready source of construction material.

Road and infrastructure development (e.g., power lines) can be achieved using standard construction techniques commonly used in the Canadian Shield.

The development of access corridors will need to deal with several issues and obstacles, the most notable of which are:

- Rugged, bedrock surfaces in highland areas;
- Numerous river and stream crossings; and
- The need to circumnavigate lakes.

9. Summary

The terrain and remote sensing study conducted as part of the Phase 1 Desktop Geoscientific Preliminary Assessment for the Township of Manitouwadge and surrounding area demonstrated that the region is dominated by land where bedrock is at or near surface. Over the majority of the area, the Precambrian bedrock is thinly covered by a discontinuous veneer of glacial sediments, the most common of which is ground moraine (till). Till thickness is commonly between 1 and 3 m; however, depths of >5 m are not uncommon. Laterally continuous and perhaps slightly thicker accumulations are found in the northeastern and northwestern quadrants of the area and locally in the vicinity of the Township of Manitouwadge.

Coarse-grained glaciofluvial deposits, occurring as large esker-outwash complexes, are present in some of the larger south and southwest trending valleys in the northern and eastern portions of the Manitouwadge area. Glaciolacustrine deposits occur in river valleys and lowland areas across the area with the most extensive and thickest occurring along the western side of the area within the Pic and White Otter river valleys, and in the northeast quadrant of the area. The depth of material present in areas mapped as glaciofluvial and glaciolacustrine deposits are commonly sufficient to mask the bedrock topography.

Elevation differences in areas mapped as bedrock terrain, typically on the order of 60 m, are more pronounced than in areas where either ground moraine, glaciofluvial or glaciolacustrine sediments are the surficial material; in these instances relief of 20 to 40 m is common. Post-glacial erosion of glaciolacustrine sediments in the Pic and White Otter rivers has, however, resulted in significant elevation changes over short distances.

Relief maps derived from the DEM of the Manitouwadge area are useful for interpreting the distribution of overburden thickness by dividing the area into zones of negative or positive relief. The zones of strong positive relief are more likely to contain thinner overburden that allows the bedrock to be characterized more easily. Conversely, zones of strong negative relief, notably those with a linear trend, can be indicative of bedrock structures and often contain thicker accumulations of glacial deposits.

The Manitouwadge area straddles the Atlantic-Arctic watershed boundary, with the vast majority of the land draining southward to Lake Superior. The area's drainage network is contained within four tertiary level watersheds, two of which flow towards Lake Superior with the others draining northward to James/Hudson Bay. Groundwater flow within drift deposits and in shallow bedrock aquifers in the Manitouwadge area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into creeks, rivers, lakes and wetlands. The Manitouwadge area has an abundance of lakes, streams and rivers that provide good drainage of all parts of the area; shallow groundwater flow systems recharge the waterways. The majority of recharge to the waterways is through direct runoff or a shallow, fracture-controlled groundwater system in bedrock. Information on shallow aquifers in the region is cursory and completely lacking for deep bedrock flow systems.

The area is tectonically stable with no known neotectonic activity, although isostatic recovery associated with the last glaciation continues in the region, albeit at a very low rate. Conclusive identification of features indicative of paleo-seismic events and reactivation of ancient bedrock structures due to cycles of glacial loading and unloading overprinted onto the tectonic stress field cannot be identified using currently available sources of information. Field investigations would be required to identify any such features

The main road network in the Manitouwadge area provides relatively good access to the western and northern parts of the area. Augmenting this network throughout the remainder of the area is a well-developed, interconnected series of forestry roads and trails. The construction of new access routes, or other infrastructure, could be developed to any part of the area using construction techniques commonly employed in the Canadian Shield. Given the knobby terrain in the bedrock dominated portions of the area, construction may involve considerable blasting and movement of rock.

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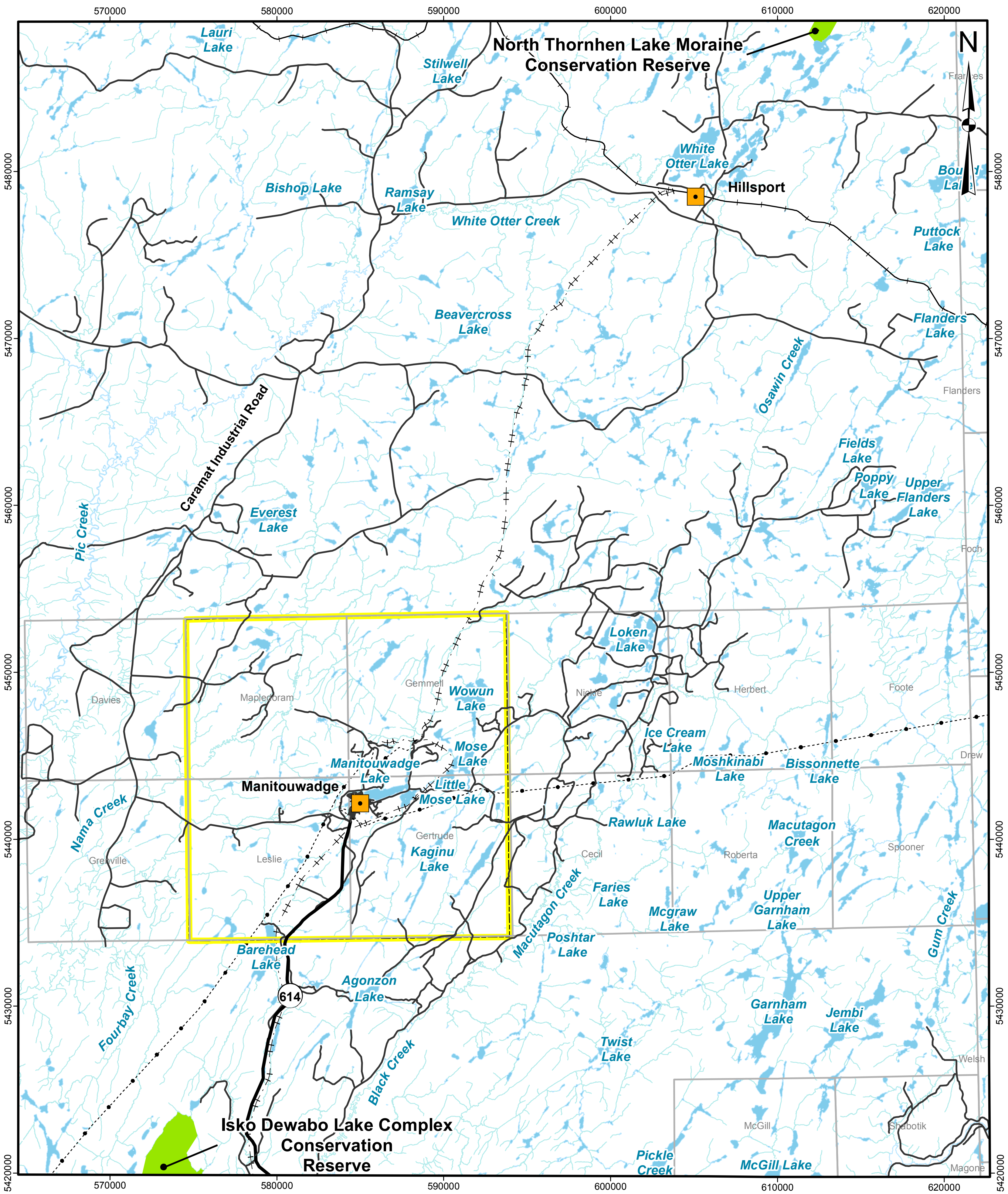
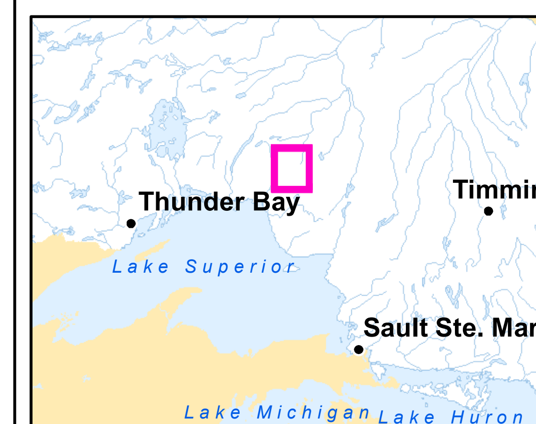


Legend

- Settlement
- Manitouwadge Municipal Boundary
- Township Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse

Protected Areas

- Conservation Reserve



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
- Cities/Towns: LIO Cities and Towns
- Road: LIO Road Segment
- Railway: LIO Railroad Segment
- Provincial Parks: LIO Provincial Parks
- Conservation Reserves: LIO Conservation Reserves
- Waterbody: LIO Waterbody
- Watercourse: LIO Watercourse
- Utility Lines: LIO Utility Lines
- Municipalities: LIO Upper, Single and Lower Tier

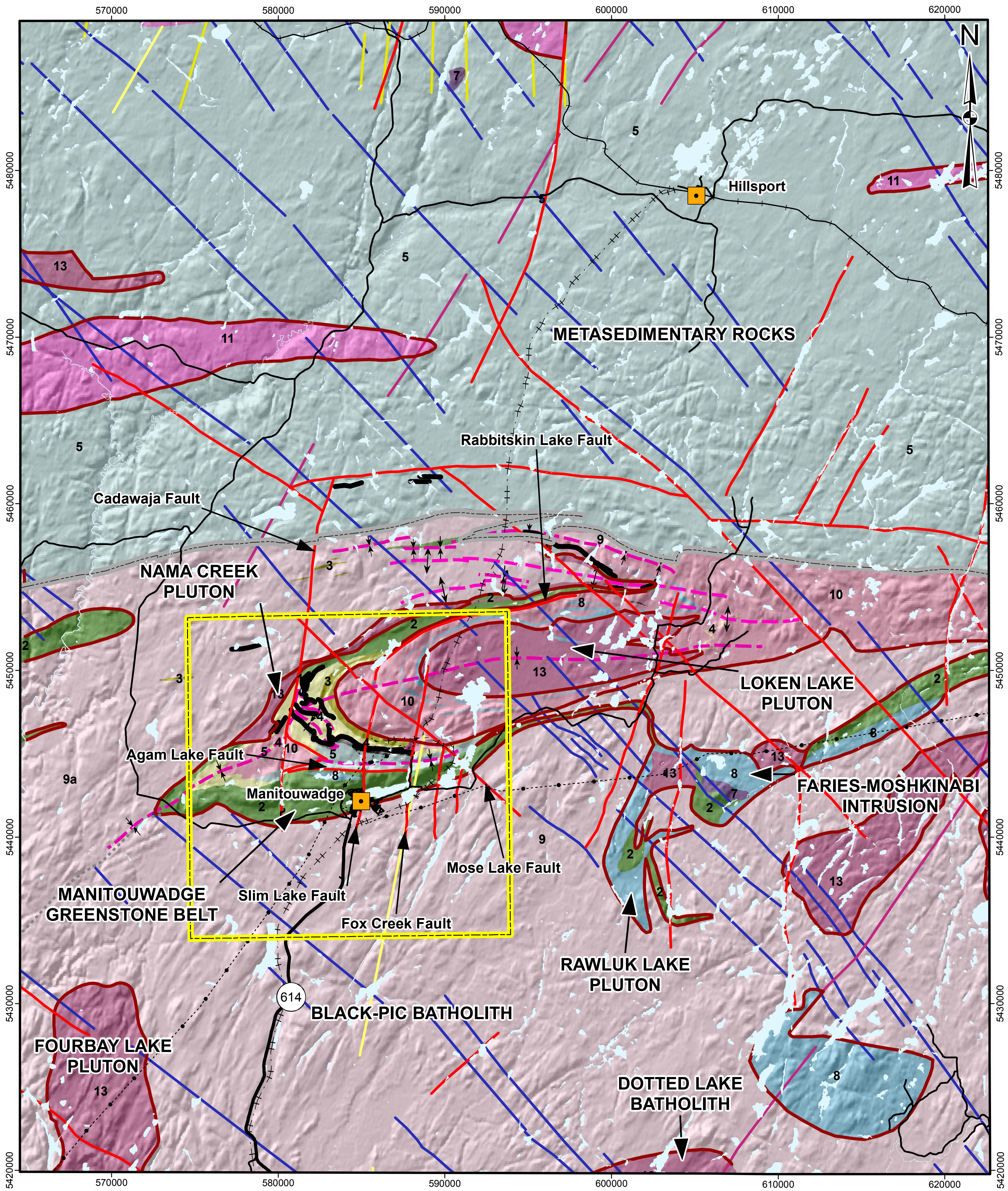
10 km

AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Township of Manitouwadge and Surrounding Area

DESIGN	KR	14 JUN 2013	Figure 1	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000



Legend

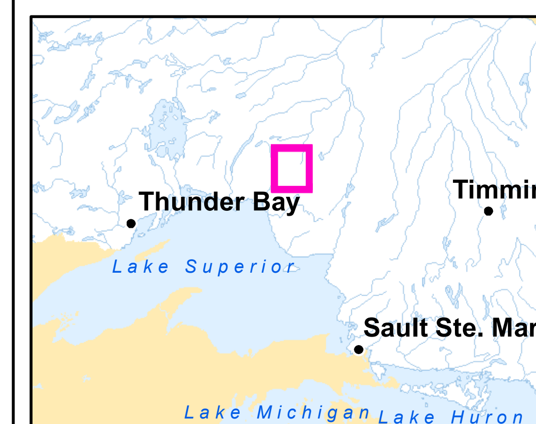
- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Faults
- Syncline (Approximate)
- Anticline (Approximate)
- Iron Formation
- Bedrock Unit Subdivision
- Bedrock Geology Contact
- Quetico-Wawa Subprovince Boundary

Mapped Dykes

- Biscotasing mafic dyke
- Marathon mafic dyke
- Marathon, Kapuskasing or Biscotasing mafic dyke
- Matachewan mafic dyke

Bedrock Geology

- 13: Granite-granodiorite
- 11: Granite-granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 9a: migmatized supracrustal rocks
- 8: Gabbro
- 7: Ultramafic plutonic rocks
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic rocks



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011; M2668, 2003; GSC 1917A, 2001
Dykes: OGS MRD 126-REV1, 2011
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

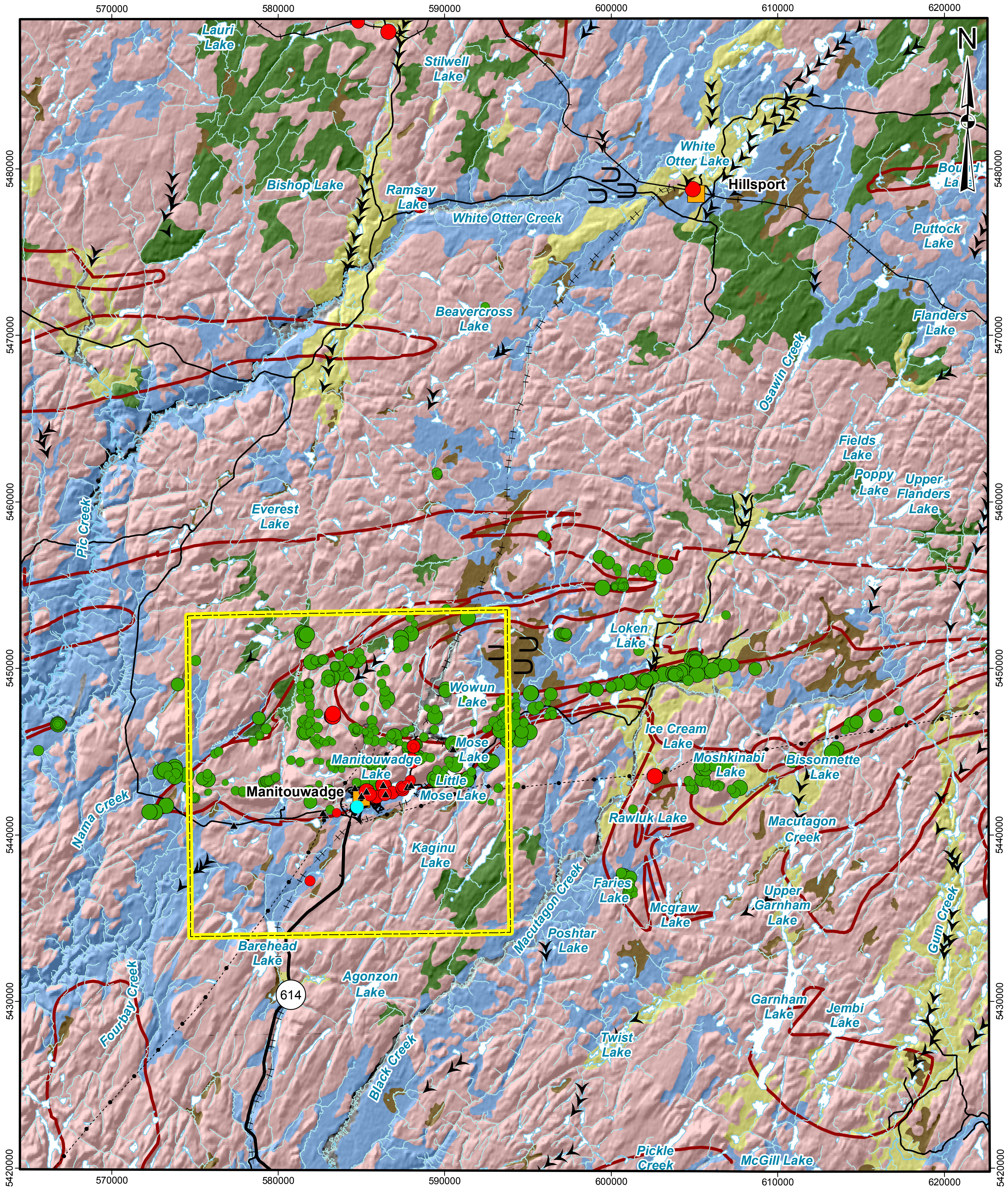
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Bedrock Geology of the Manitouwadge Area

DESIGN	KR	14 JUN 2013	Figure 2	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig2 Bedrock Geology of the Manitouwadge Area.mxd



Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse
- Bedrock Geology Contact
- Sand Dunes
- Eskers

Water Well (MOE)

Depth to Bedrock (m)

- Depth Unknown
- <1
- 1.1 - 3.0
- 3.1 - 5.0
- 5.1 - 10.0
- >10.1

Drill Hole (MNDM)

Depth to Bedrock (m)

- < 1
- 1.1 - 3.0
- 3.1 - 5.0
- 5.1 - 10.0
- >10.1

Surficial Geology

- Morainal Terrain
- Glaciofluvial Terrain
- Glaciolacustrine Terrain
- Bedrock Terrain
- Organic Terrain

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Overburden: OGS MRD-160, NOEGTS 2006
Water Well: MOE Water Well Information System
Drill Hole: MNDM Drill Hole Database
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

AECOM

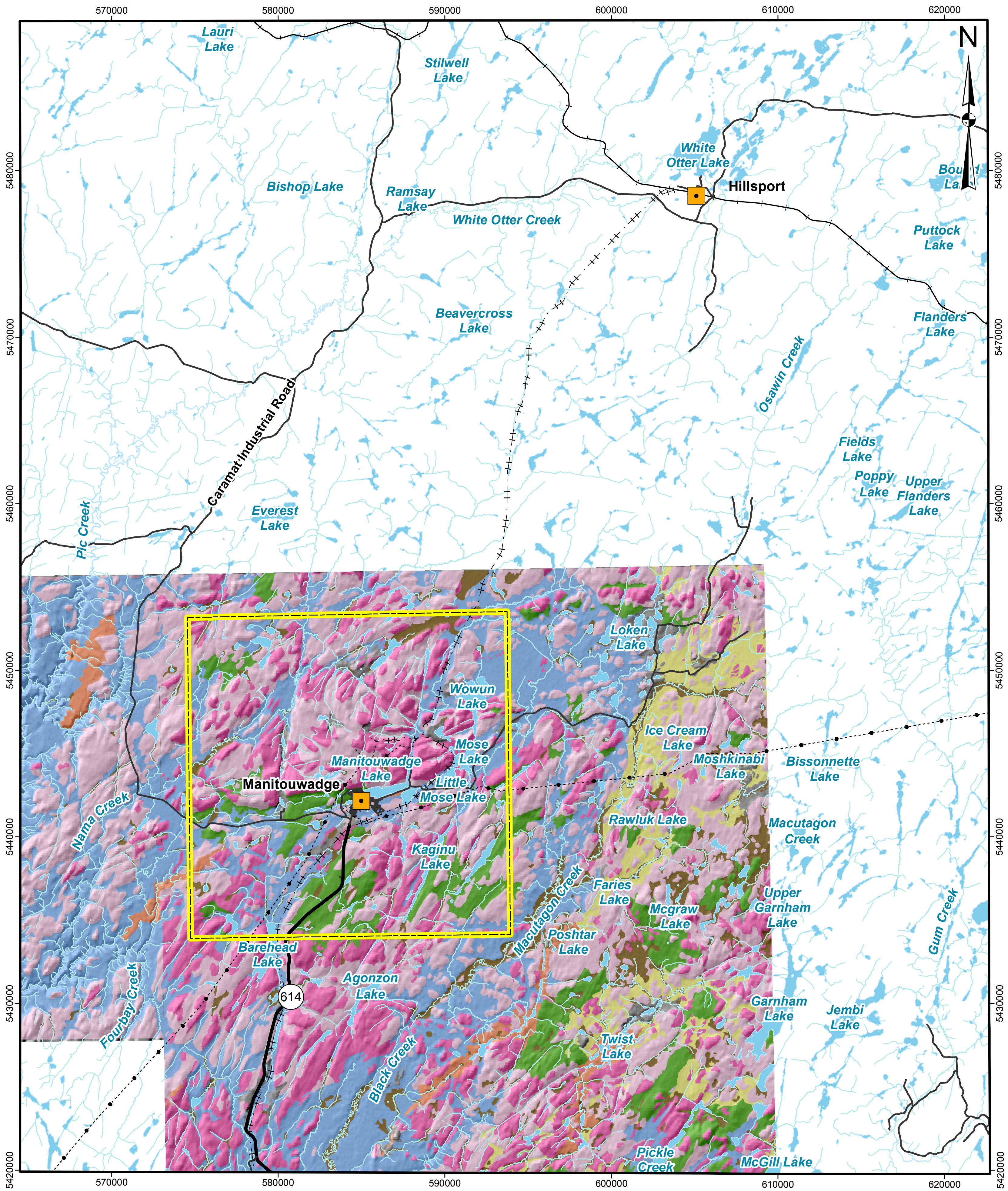
PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Surficial Geology of the Manitouwadge Area

DESIGN	KR	14 JUN 2013	Figure 3	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig3 Surficial Geology of the Manitouwadge Area.mxd

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig4 Area of 1-50000 Scale Surfical Mapping of the Manitouwadge Study Area.mxd

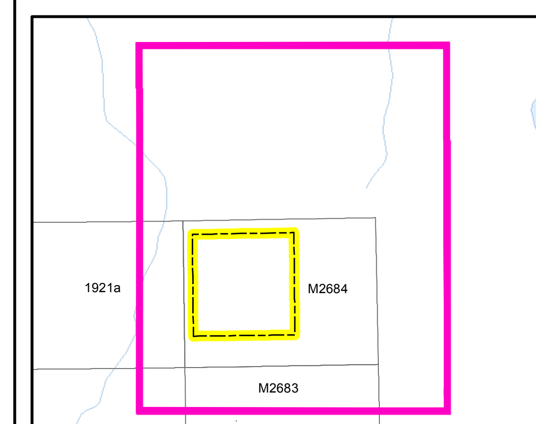


Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse

Surficial Geology

- Swamp and Alluvium Deposits
- Glaciolacustrine Deposits
- Glaciofluvial Outwash Deposits
- Glaciofluvial Ice-Contact Deposits
- Till
- Bedrock Drift Complex
- Precambrian Bedrock



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Geology: OGS M2683, 2009; M2684, 2009; GSC 1921a, 1998
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

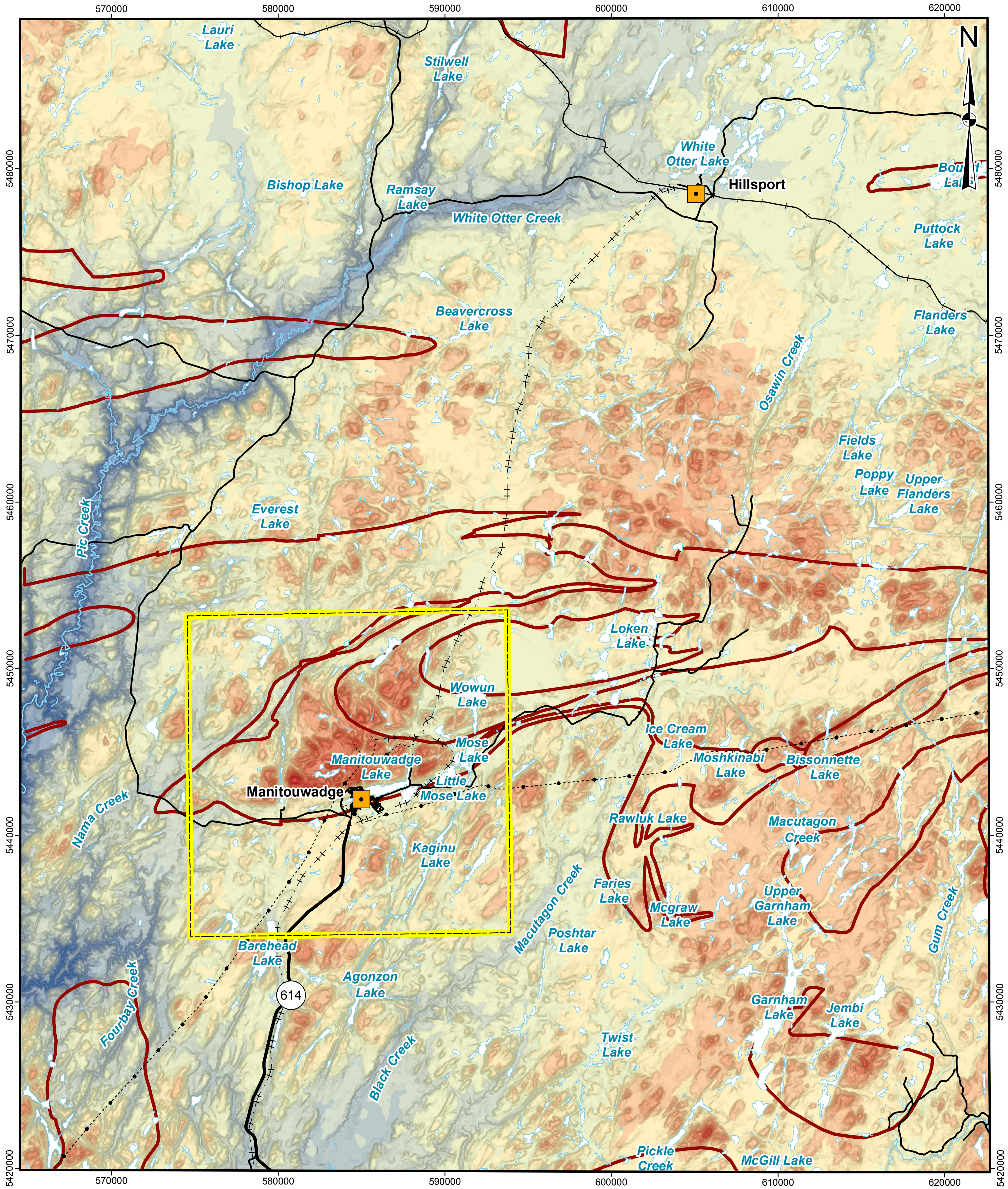
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Area of 1:50,000 Scale Surficial Mapping

DESIGN	GF	20 AUG 2013	**Figure 4**	REVISION 1
GIS	GF	20 AUG 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig5 Elevation and Major Topographical Features of the Manitouwadge Area.mxd



Legend

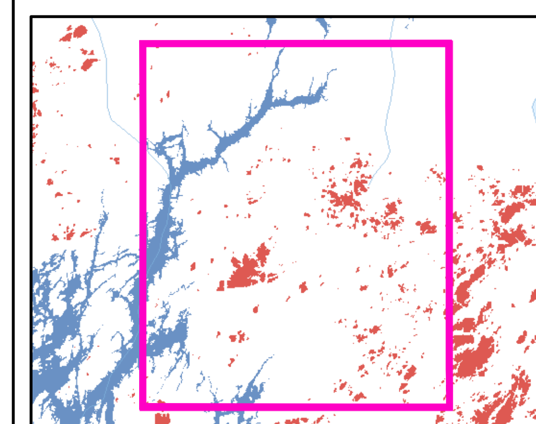
- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Bedrock Geology Contact

Elevation (m)

- 195 - 219
- 220 - 243
- 244 - 267
- 268 - 291
- 292 - 315
- 316 - 339
- 340 - 363
- 364 - 387
- 388 - 411
- 412 - 435
- 436 - 459
- 460 - 483

Slope (°)

- 0 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 83.1



Elevation (m)

195 - 291 | 292 - 387 | 388 - 483

Data Sources:
Base Data: MNR LIO, 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

10 km

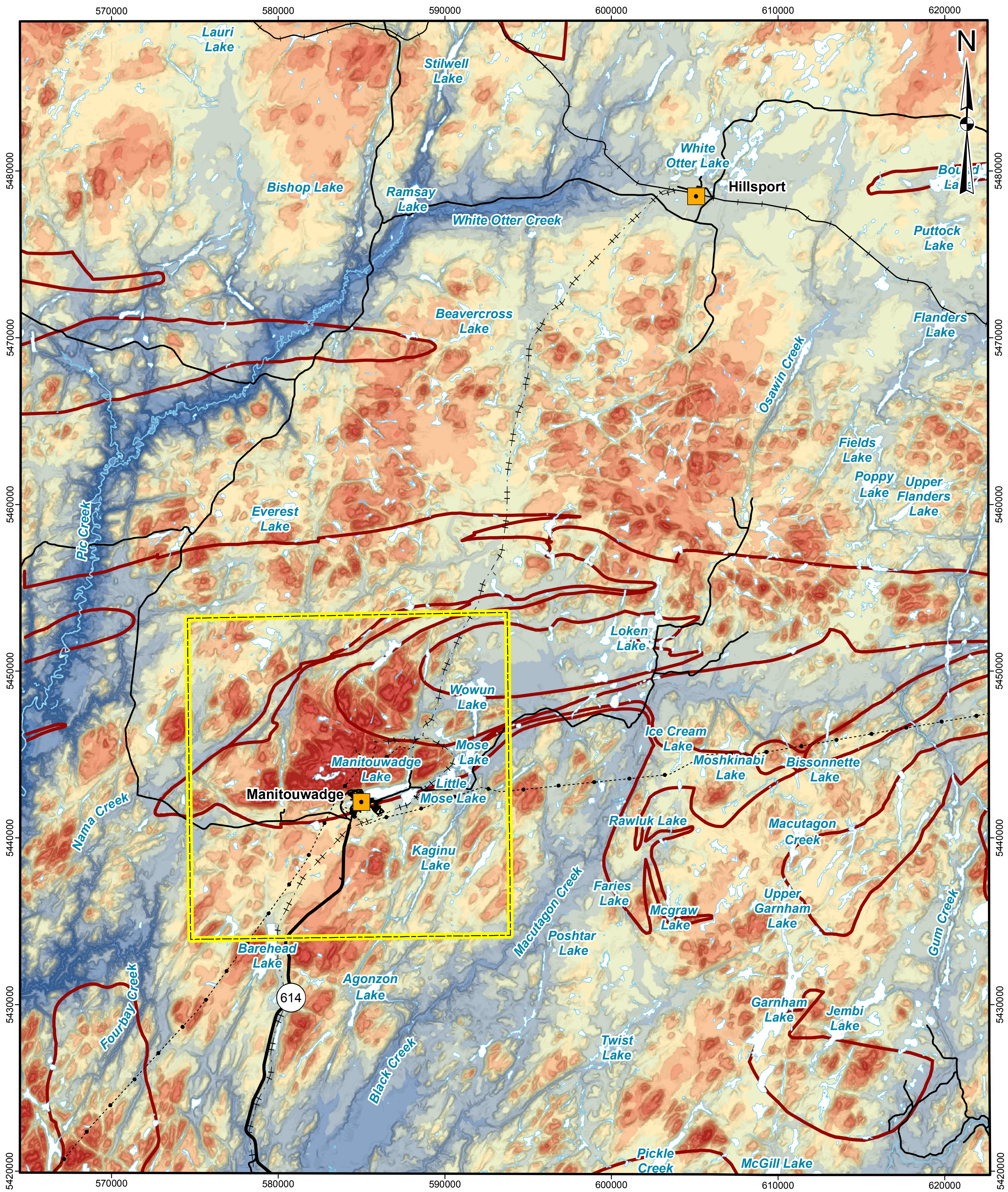
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Elevation and Major Topographic Features

DESIGN	KR	14 JUN 2013	**Figure 5**	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig6 Departure from Average Elevation within a 20km radius of the Manitouwadge Area.mxd



Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Bedrock Geology Contact

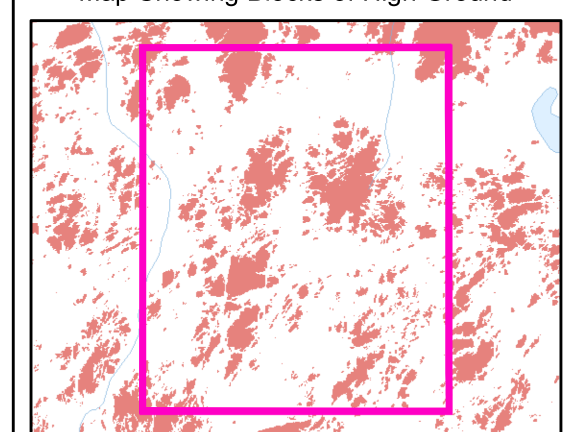
Relief (m)

- -121 - -66
- -65 - -39
- -38 - -22
- -21 - -10
- -9 - 2
- 3 - 14
- 15 - 28
- 29 - 46
- 47 - 73
- 74 - 155

Slope (°)

- 0 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 83.1

Map Showing Blocks of High Ground



Relief (m)

- -121 - 16
- 17 - 155

Data Sources:
Base Data: MNR LIO, 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

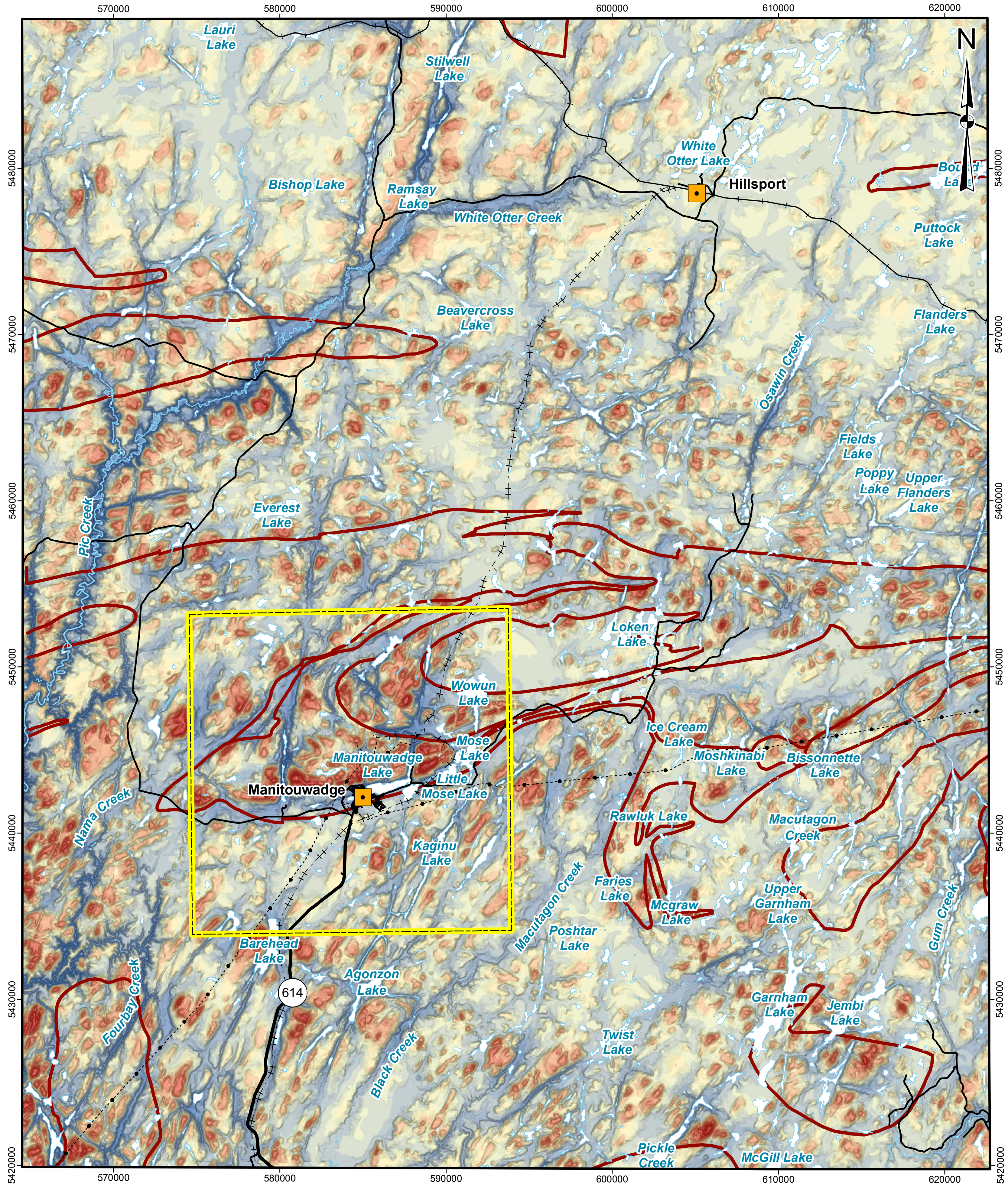
10 km

AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Departure from Average Elevation within a 20 km Radius

DESIGN	KR	14 JUN 2013	**Figure 6**	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000



Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Bedrock Geology Contact

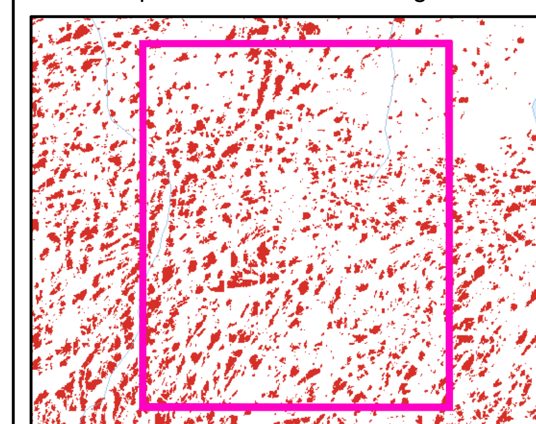
Relief (m)

- -68 - -35
- -34 - -21
- -20 - -12
- -11 - -6
- -5 - 0
- 1 - 6
- 7 - 13
- 14 - 21
- 22 - 30
- 31 - 42
- 43 - 58
- 59 - 101

Slope (°)

- 0 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 83.1

Map of local knobs and ridges



Relief (m)

- -68 - 10
- 11 - 101

Data Sources:
Base Data: MNR LIO, 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

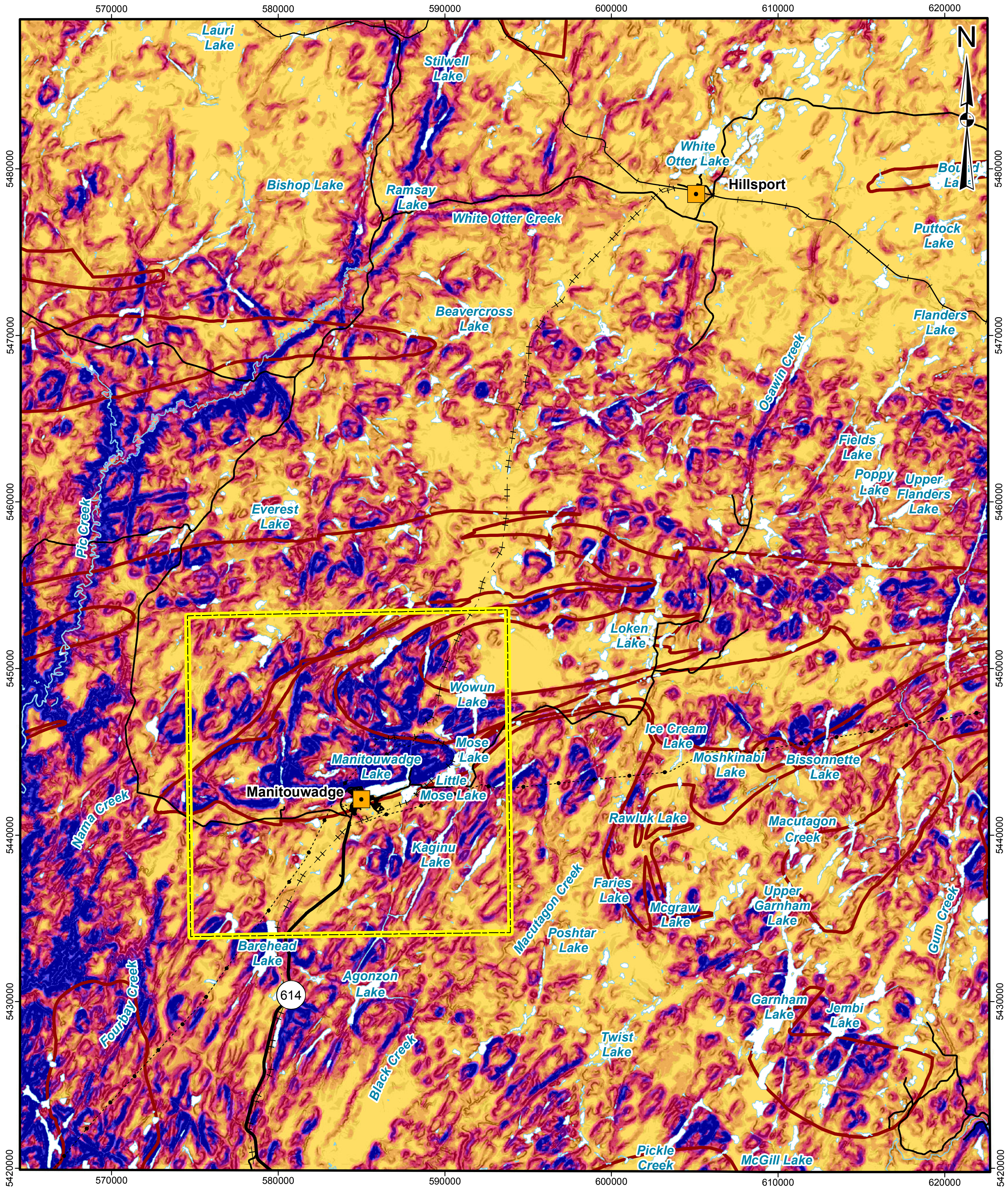
10 km

AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Departure from Average Elevation within a 2 km Radius

DESIGN	KR	14 JUN 2013	**Figure 7**	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000



Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Bedrock Geology Contact

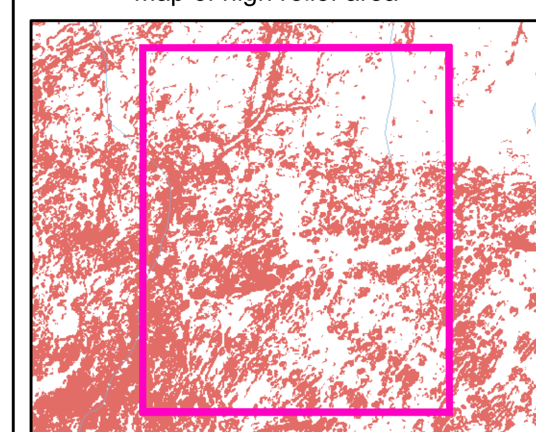
Relief (m)

- 0 - 10
- 11 - 16
- 17 - 21
- 22 - 28
- 29 - 32
- 33 - 35
- 36 - 43
- 44 - 145

Slope (°)

- 0 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 83.1

Map of high relief area



Relief (m)

- 0 - 20
- 21 - 145

Data Sources:
Base Data: MNR LIO, 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

10 km

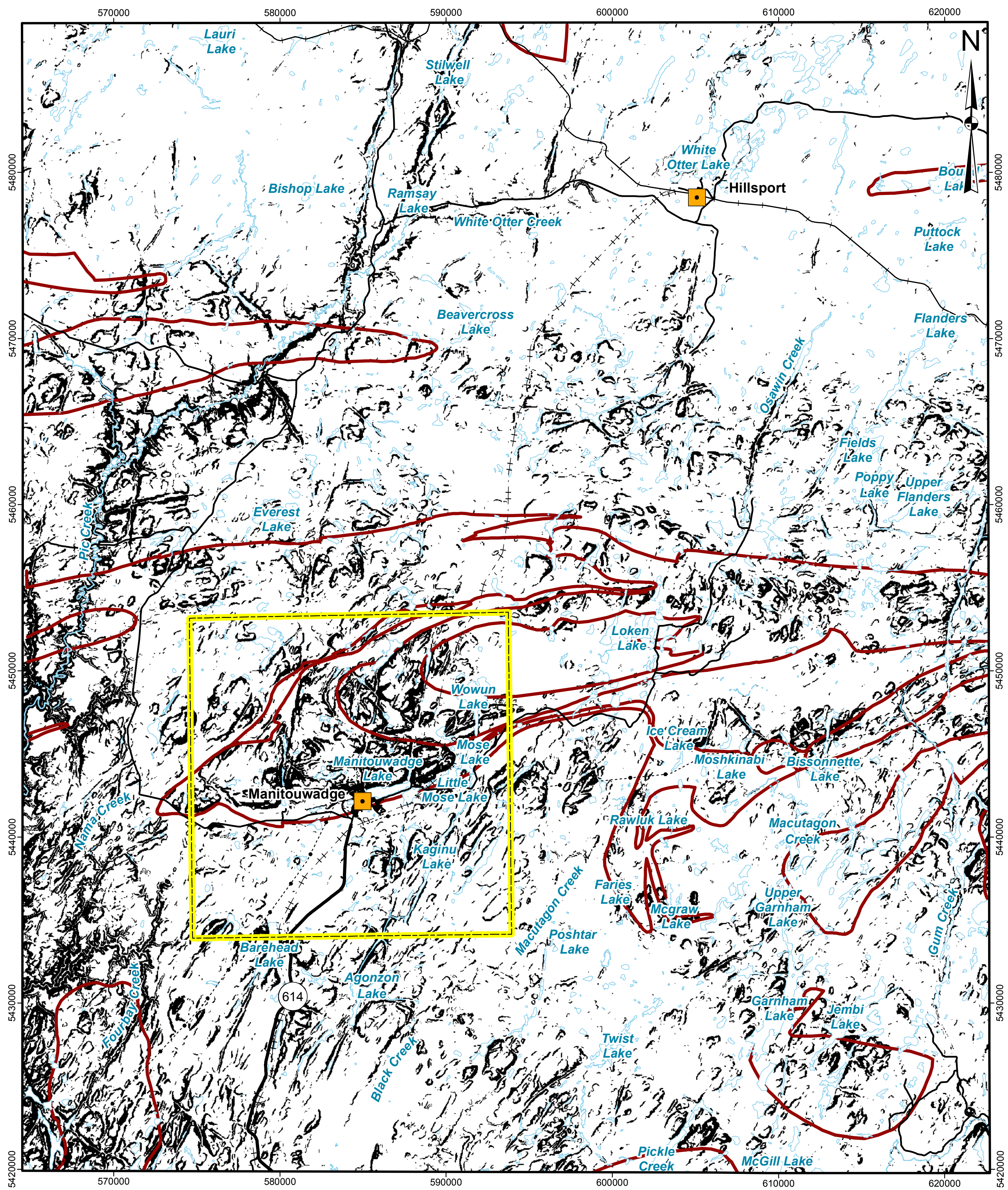
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Departure from Average Elevation within a 250 m Radius

DESIGN	KR	14 JUN 2013	Figure 8	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig8 Range in Elevation within 250 m Radius of the Manitouwadge Area.mxd



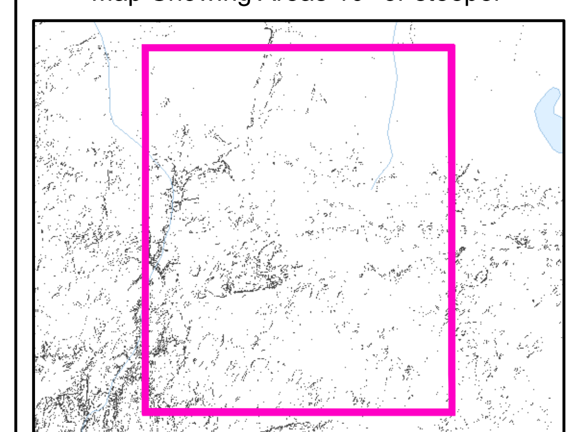
Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Bedrock Geology Contact

Slope (°)

- 0 - 6
- 6.01 - 83.1

Map Showing Areas 10° or steeper



Slope (°)

- 0 - 10
- 10.01 - 83.1

Data Sources:
Base Data: MNR LIO, 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

10 km

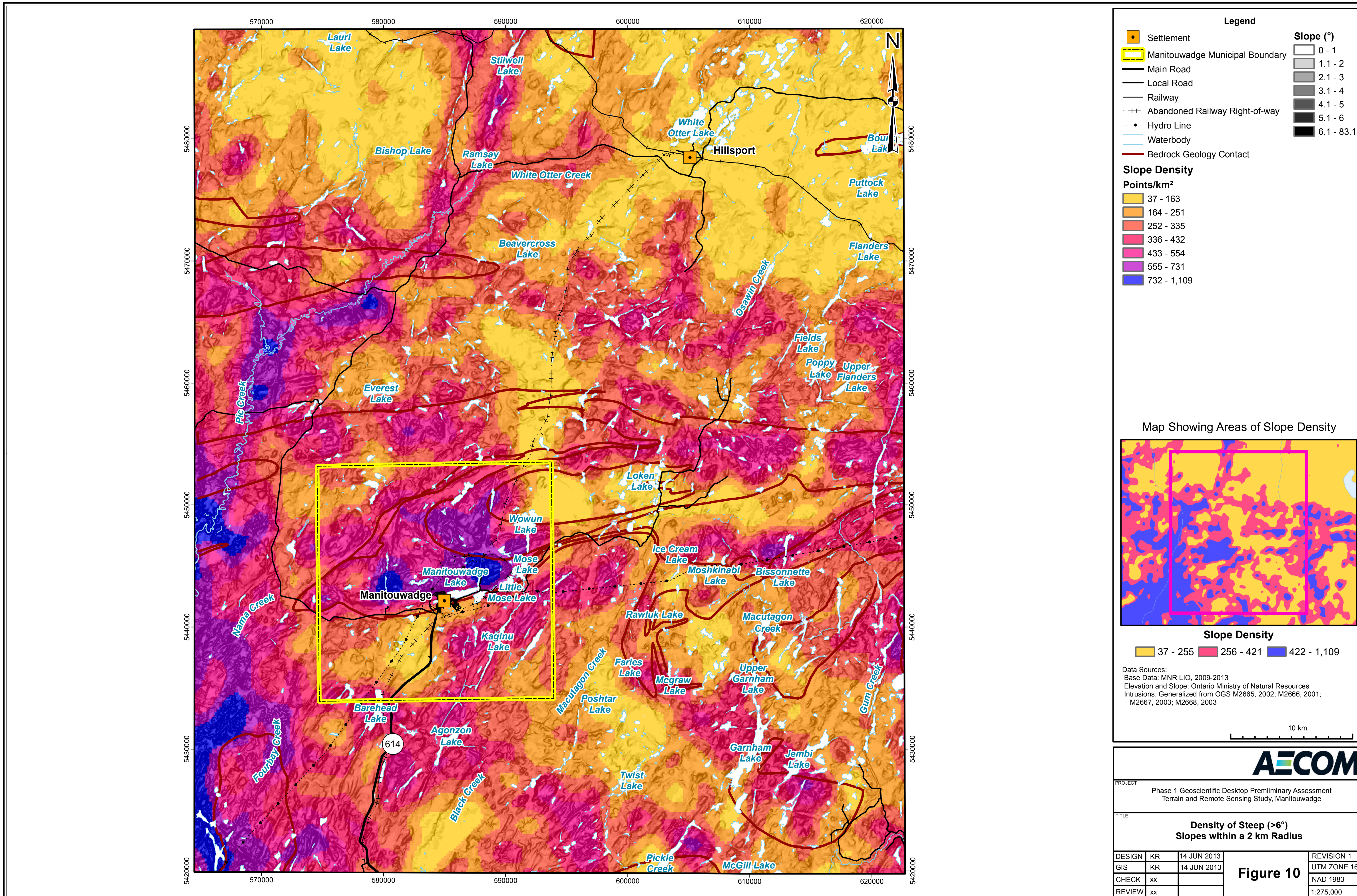
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

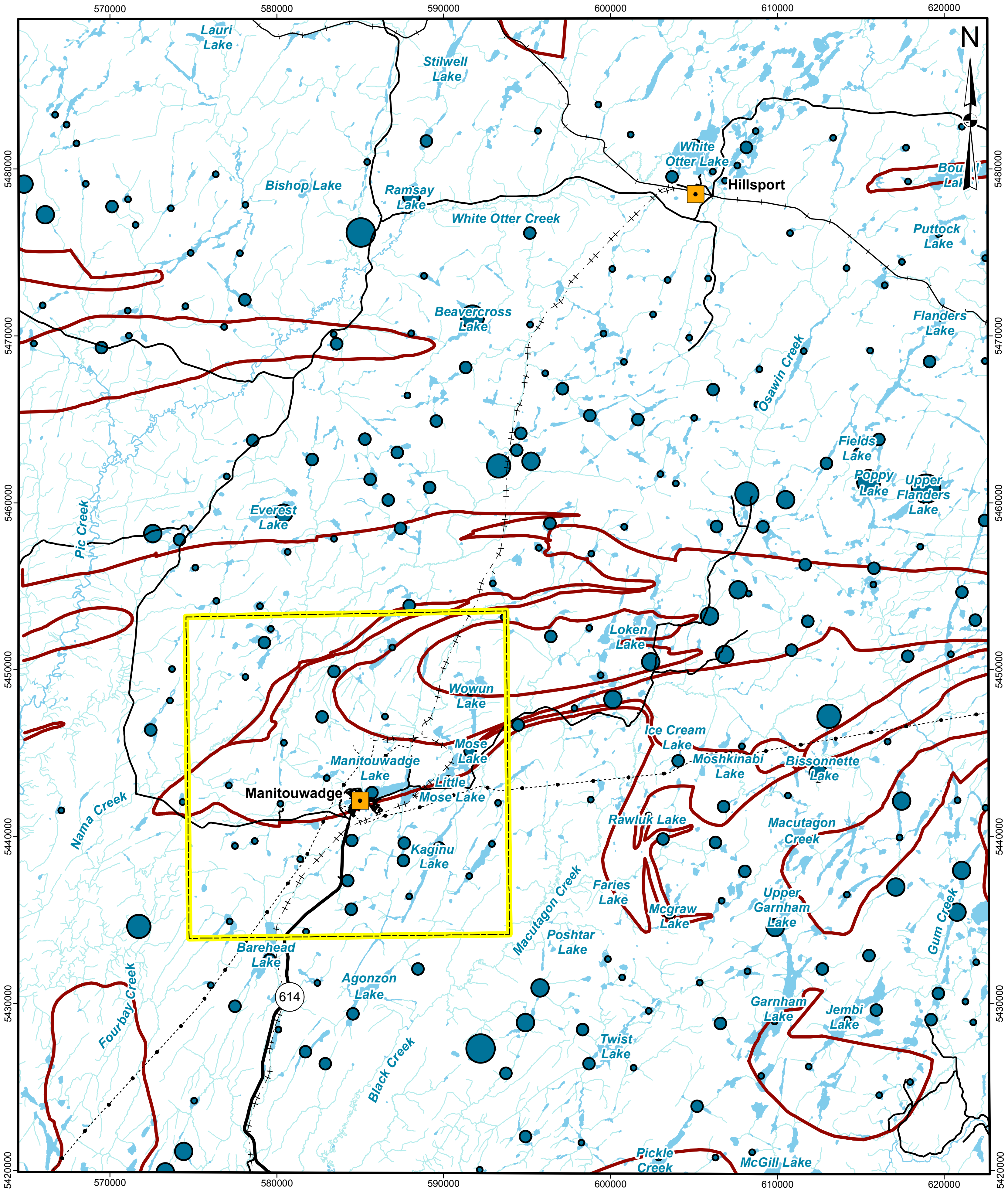
TITLE
Areas of 6° or Steeper Slope in the Manitouwadge Area

DESIGN	KR	14 JUN 2013	Figure 9	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig9 Areas of 6 degrees or Steeper Slopes within the Manitouwadge Area.mxd



Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig10 Density of Steep Slopes within a 2 km radius of the Manitouwadge Area.mxd

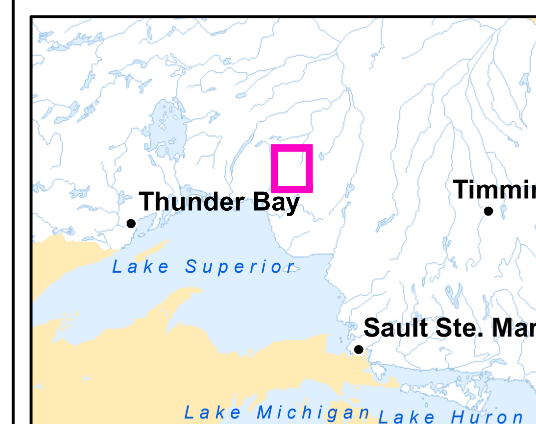


Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse
- Bedrock Geology Contact

Lake Depth (m)

- < 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- >20.1



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Lake Depth: GSC, Open File 2362
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

10 km

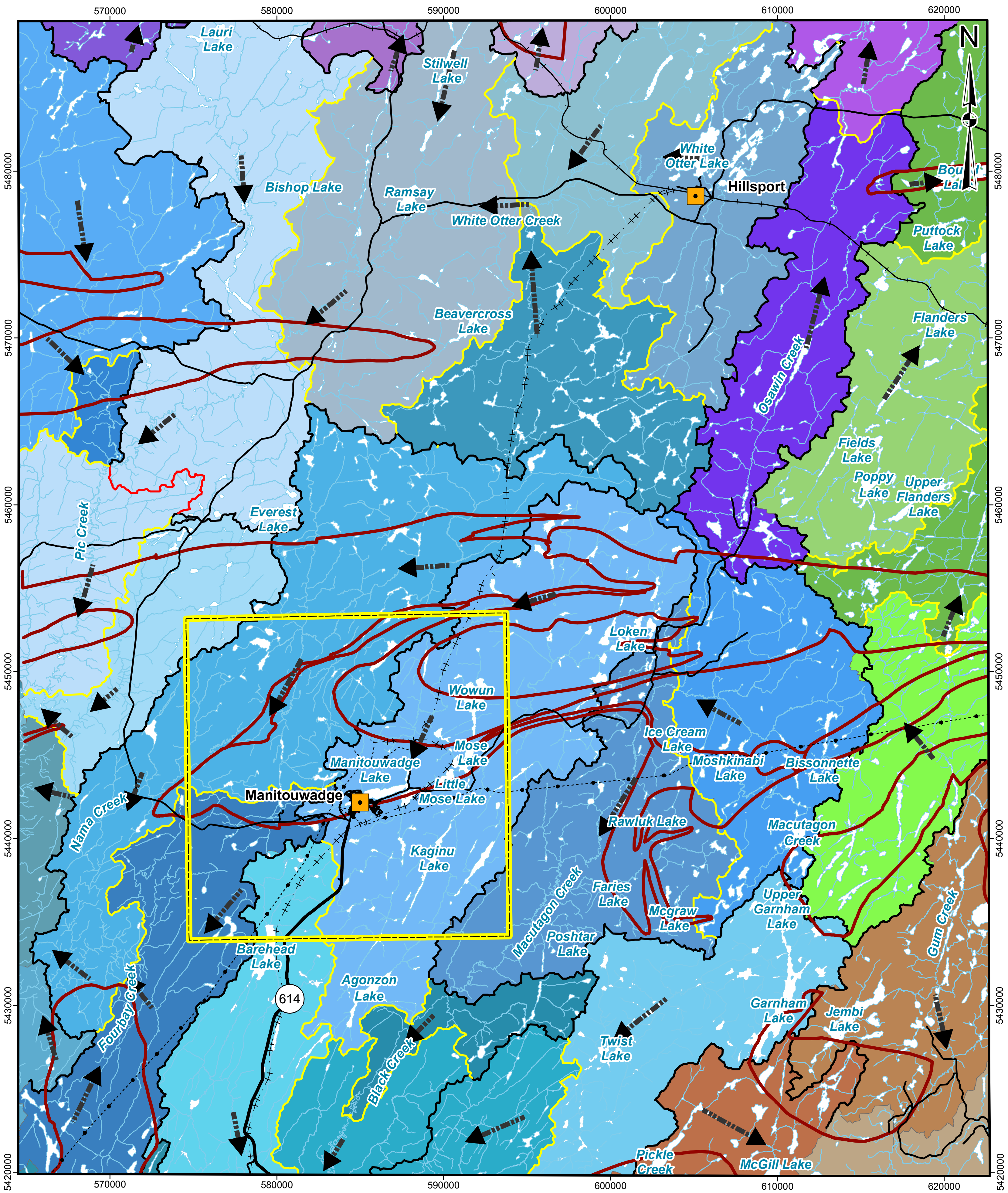
AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Surface Drainage Features of the Manitouwadge Area

DESIGN	KR	14 JUN 2013	Figure 11	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig11_Surface Drainage Features of the Manitouwadge Area.mxd



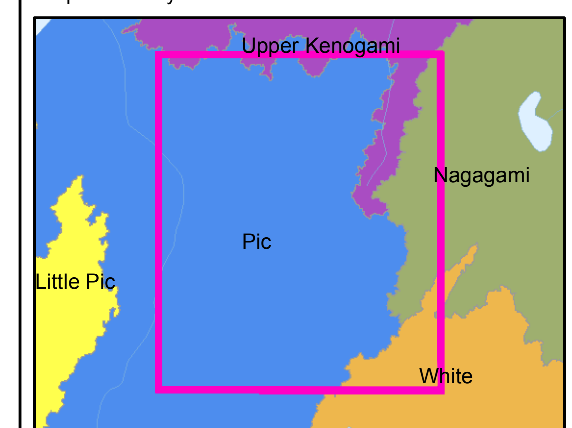
Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse
- Bedrock Geology Contact

Quaternary Level Drainage Divides

- AECOM
- MNR
- MNR/AECOM
- Surface Flow Direction (Interpreted By AECOM)

Map of Tertiary Watersheds



Tertiary Watershed

Little Pic | Pic | White | Nagagami | Upper Kenogami

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003
Watersheds: MNR Quaternary, Tertiary Watersheds

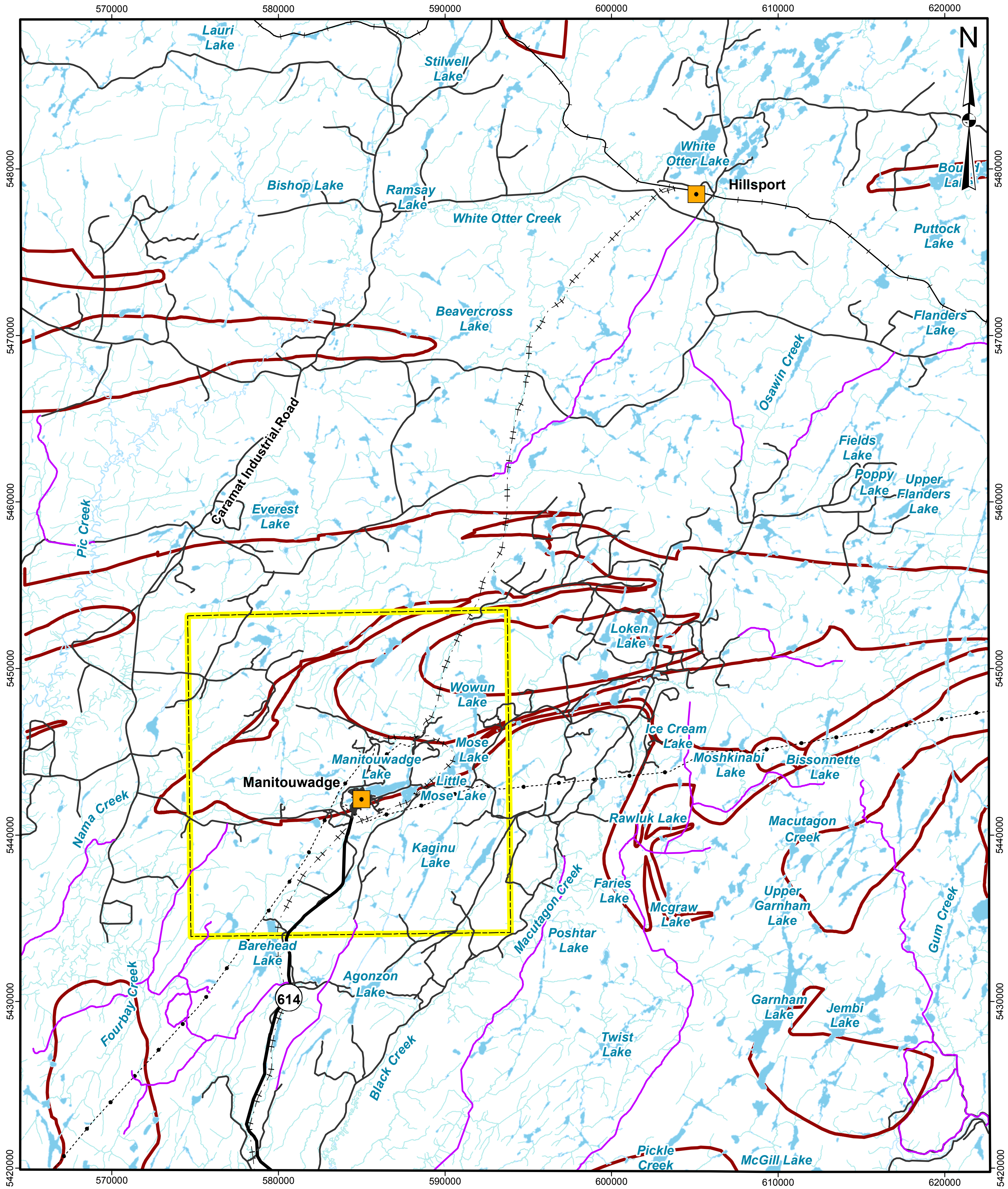
10 km

AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

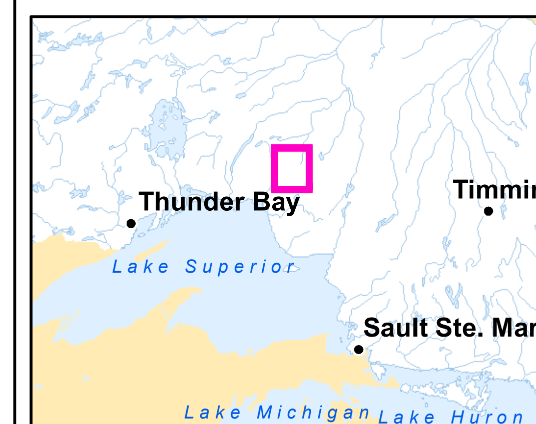
TITLE
Watersheds within the Manitouwadge Area

DESIGN	KR	14 JUN 2013	**Figure 12**	REVISION 1
GIS	GF	4 SEPT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000



Legend

- Settlement
- Manitouwadge Municipal Boundary
- Main Road
- Local Road
- AECOM added roads (approximated)
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Watercourse
- Bedrock Geology Contact



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2665, 2002; M2666, 2001; M2667, 2003; M2668, 2003

10 km

AECOM

PROJECT
Phase 1 Geoscientific Desktop Premliminary Assessment
Terrain and Remote Sensing Study, Manitouwadge

TITLE
Road Network of the Manitouwadge Area

DESIGN	KR	14 JUN 2013	**Figure 13**	REVISION 1
GIS	KR	14 JUN 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:275,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Remote Sensing Report\ReportMXDs\Revision 2 - Manitouwadge\60297733_Fig13 Road Network of the Manitouwadge Area.mxd