



NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

January 7, 2013

The Township of Manitouwadge
1 Mississauga Drive
Manitouwadge, ON P0T 2C0

Attn: Mayor MacEachern

Re: Adaptive Phased Management Initial Screening – The Township of Manitouwadge

Dear Mayor MacEachern,

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

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

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

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

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

Sincerely,



Kathryn Shaver,
Vice President, APM Engagement and Site Selection

Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel

Township of Manitouwadge, Ontario

Revision: 0 (Final)

Prepared for:
Nuclear Waste Management Organization
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EXECUTIVE SUMMARY

On September 12, 2012, the Township of Manitouwadge expressed interest in learning more about the Nuclear Waste Management Organization (NWMO) site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report summarizes the findings of an initial screening, conducted by Geofirma Engineering Ltd., to evaluate the potential suitability of the Township of Manitouwadge against five screening criteria using readily-available information. The purpose of the initial screening is to identify whether there are any obvious conditions that would exclude the Township of Manitouwadge from further consideration in the site selection process. The initial screening focused on the Township of Manitouwadge and its periphery, which are referred to as the "Manitouwadge area" in this report.

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

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Township of Manitouwadge from further consideration in the NWMO site selection process. The initial screening indicates that the Manitouwadge area contains large portions of land with geological units that are potentially suitable for hosting a deep geological repository. Examples of these units include the metasedimentary rocks of the Quetico Subprovince, the Black-Pic Batholith and other smaller granitic intrusions including the Fourbay, Rawluk Lake and Everest Lake plutons.

It is important to note that at this early stage of the site selection process, the intent of this initial screening was not to confirm the suitability of the Manitouwadge area to host a deep geological repository, but rather to identify whether there are any obvious conditions that would exclude it from the site selection process. Should the Township of Manitouwadge remain interested in continuing with the site selection process, more detailed studies would be required to confirm and demonstrate whether the Manitouwadge area contains sites that can safely contain and isolate used nuclear fuel. The process for identifying an informed and willing host community for a deep geological repository for Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future.

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

Availability of Land

The review of available mapping and satellite imagery indicates that the Manitouwadge area contains sufficient land to accommodate the surface and underground facilities associated with the repository and could be accessible for construction and field investigation activities. Developed areas and large water bodies occupy only a small portion of the Manitouwadge area and no obvious topographic features that would prevent the safe construction of surface facilities were identified.

Protected Areas, Heritage Sites, Provincial Parks and National Parks

The Manitouwadge area contains sufficient land outside of protected areas, heritage sites, provincial parks and national parks to accommodate the repository's facilities. There are no protected areas in the Township of Manitouwadge. At the periphery of the Township there is only one conservation reserve, which occupies a small portion of the available land. There is only one localized, known archaeological site in the Manitouwadge area. There are no National Historic Sites. The absence of protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

Absence of Known Groundwater Resources at the Repository Depth

The review of available information did not identify any known groundwater resources at repository depth (approximately 500 m) for the Manitouwadge area. The Ontario Ministry of the Environment Water Well Information System database does not identify any potable water supply wells exploiting aquifers at typical repository depths in the Manitouwadge area or anywhere else in Northern Ontario. Water wells in the Manitouwadge area source water from overburden or shallow bedrock aquifers at depths of 49 m or less. Based on experience in similar crystalline rock settings in the Canadian Shield, the likelihood that exploitable aquifers are present at typical repository depth is low in the Manitouwadge area. The absence of groundwater resources at repository depth would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

Absence of Economically Exploitable Natural Resources as Known Today

Based on the review of readily-available information, the Manitouwadge area contains sufficient areas, free of known economically exploitable natural resources, to accommodate the required repository facilities. The potential for mineral resources is largely limited to the rocks of the Manitouwadge Greenstone Belt. The granitic intrusions, and metasedimentary and migmatized rocks in the Manitouwadge area have a generally low potential to host economic mineralization. Potential for non-metallic mineral extraction exists within the Manitouwadge area; however, the risk that these resources would pose for future human intrusion to a deep geological repository is negligible, as quarrying operations would be limited to very shallow depths.

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

Based on the review of readily available geoscientific information, the Manitouwadge area contains portions of land that do not contain known unsafe geological and hydrogeological conditions. There are a number of geological units with geoscientific characteristics that are potentially suitable for hosting a deep geological repository. Examples of these units include the metasedimentary rocks of the Quetico Subprovince, the Black-Pic Batholith and other smaller granitic intrusions including the Fourbay, Rawluk Lake and Everest Lake plutons.

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1 INTRODUCTION

On September 12, 2012, the Township of Manitouwadge expressed interest in learning more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report presents the results of an initial screening, conducted by Geofirma Engineering Ltd., as part of Step 2 in the site selection process to evaluate the potential suitability of the Township of Manitouwadge against five screening criteria using readily available information. The initial screening focused on the Township of Manitouwadge and its periphery, which are referred to as the "Manitouwadge area" in this report.

1.1 Background

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

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

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

1.2 Objectives and Approach for Conducting Initial Screenings

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

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

- 2) This available land must be outside of protected areas, heritage sites, provincial parks and national parks.
- 3) This available land must not contain known groundwater resources at the repository depth, such that the repository site is unlikely to be disturbed by future generations.
- 4) This available land must not contain economically exploitable natural resources as known today, such that the repository site is unlikely to be disturbed by future generations.
- 5) This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the safety factors outlined in Section 6 of the Site Selection Document (NWMO, 2010).

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

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

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

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

2 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Manitouwadge is located 60 km northeast of Lake Superior (Figure 2.1), at the northern end of Highway 614, approximately 50 km north of Highway 17 (Trans Canada Highway). By road, the Township of Manitouwadge is 400 km east of Thunder Bay, and 400 km north of Sault Ste. Marie (Index Map in Figure 2.1). The Township of Manitouwadge has an area of 352 km², and the Manitouwadge area is 2,371 km² (Figure 2.1).

The two closest municipalities to the Township of Manitouwadge are the Town of Marathon, which is approximately 100 km to the southwest by road, and the Township of White River, which is approximately 100 km to the southeast.

Figure 2.2 shows the satellite imagery for the Manitouwadge area. The settlement area of Manitouwadge is on the southern shore of Manitouwadge Lake. The satellite image in Figure 2.2 also shows Caramat Industrial Road running west out of the Township of Manitouwadge, then turning north, where it eventually intersects Highway 11.

2.2 Topography

The Township of Manitouwadge is located in the Precambrian Canadian Shield physiographic region, a low-relief, dome-like, gently undulating land surface. Figure 2.3 shows the general physiographic regions of Ontario (Thurston, 1991), including the subdivision of the Canadian Shield physiographic region into separate regions.

The Manitouwadge area lies in the Abitibi Uplands, a broadly rolling surface of Canadian Shield bedrock that occupies most of north-central Ontario (Natural Resources Canada, 2011). Within this area, bedrock is typically either exposed at surface or thinly covered with Quaternary glacial deposits or post-glacial organic soils (Thurston, 1991). Figure 2.2 shows areas of bedrock exposure as light grey areas, north of the Township of Manitouwadge, in the upland areas between the lakes.

The topography of the Manitouwadge area is presented in Figure 2.4. The land surface ranges from around 485 metres above sea level (masl) just north of the settlement area of Manitouwadge, down to approximately 195 masl in the Pic River valley west of the Township. The area north of the Township of Manitouwadge is generally rugged terrain, while the Black River and Pic River valleys contain relatively flat-lying areas.

2.3 Drainage

The Manitouwadge area is located in the Great Lakes Drainage Basin. The drainage in the Manitouwadge area is generally from the north to the south (Figure 2.5), towards Lake Superior. The Pic and the Black Rivers are the two primary rivers in the Manitouwadge area and both of them flow from north to south, almost parallel to each other. The Pic River runs northwest of the Township and has numerous tributaries including White Otter River and Nama Creek. The Black River meanders down the eastern part of the Manitouwadge area eventually discharging into the Pic River approximately 2 km upstream from where the Pic River discharges into Lake Superior, near Marathon, Ontario (Figure 2.5). Both the Black River and Pic River are located along faults, which is also the

case with some of the smaller watercourses such as Nama Creek (Williams and Breaks, 1996).

2.4 Protected Areas

2.4.1 Parks and Reserves

Figure 2.1 shows the location of parks and reserves in the Manitouwadge area. There is only one protected area in the Manitouwadge area, the Isko Dewabo Lake Complex Conservation Reserve approximately 10 km southwest of the Township. The conservation reserve has a total area of 29.67 km², of which only 7.3 km² lie within the Manitouwadge area. The conservation reserve consists of moderately broken ground moraine with mixed conifer, sparse forest, and with a cut-and-burn section that is less than 20 years old.

2.4.2 Heritage Sites

The cultural heritage screening examined known National Historic Sites and archaeological sites for the Manitouwadge area using the Ontario Archaeological Sites Database (Ontario Ministry of Tourism and Culture, 2012). There are no registered National Historic Sites in the Manitouwadge area.

There is one known archaeological site within the Manitouwadge area. The site is located approximately 15 km northeast of the settlement area of Manitouwadge, outside the Township boundary. There is potential for other archaeological and historical sites in the Manitouwadge area given the site already documented, and the length of time the region has been inhabited by First Nation communities. Locations of known archaeological sites are not shown in maps within this report to comply with the Ministry of Tourism and Culture publication guidelines.

The absence of archaeological and heritage sites would need to be further confirmed in discussion with the community and Aboriginal peoples in the area, if the community remains interested in continuing with the site selection process.

3 GEOLOGY AND SEISMICITY

3.1 Regional Bedrock Geology

The geology of the Manitouwadge area consists of unconsolidated Quaternary deposits overlying 3 to 2.7 billion year old bedrock of the Canadian Shield – a stable craton that forms the core of the North American continent. The Canadian Shield is an assemblage of Archean-aged plates and accreted juvenile arc terranes, and sedimentary basins of Proterozoic age that were progressively amalgamated over geologic time scales.

As shown in Figure 3.1, the Manitouwadge area is situated within the Superior Province of the Canadian Shield. The Superior Province covers an area of approximately 1,500,000 km² stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extends south through to Minnesota and the northeastern part of South Dakota.

The Superior Province has been divided into various subprovinces based on lithology, age, genesis and metamorphism (Thurston, 1991; Stott et al., 2010). These subprovinces are shown in Figure 3.1. The Manitouwadge area straddles the boundary between the Quetico and the Wawa Subprovinces, with the boundary between the two subprovinces approximately 6 km north of the Township of Manitouwadge (Figure 3.2).

The Quetico Subprovince is approximately 1,000 km long by 75 km wide and extends from Minnesota in the United States to northeastern Ontario (Figure 3.1), where it is truncated by the Kapuskasing Structural Zone that separates the Quetico Subprovince from the Abitibi Subprovince. The Quetico Subprovince is bounded to the north by the Wabigoon Subprovince and to the south by the Wawa Subprovince.

Figure 3.2 shows the Quetico Subprovince is mainly composed of clastic metasedimentary rocks that are 2.700 to 2.688 billion years old (Percival 1989; Zaleski et al., 1999), which account for roughly 80 to 90% of the area of the Quetico Subprovince (Williams, 1991). There are also 2.70 to 2.65 billion year old granitic intrusions and sporadic mafic and ultramafic intrusions in the subprovince (Williams, 1989), as well as young Early Archean intrusions and several swarms of Late Proterozoic diabase dykes (Stott and Josey, 2009).

The Wawa Subprovince is approximately 900 km long and 150 km wide, extending from central Minnesota in the United States to the Kapuskasing area in northeastern Ontario (Figure 3.1). It is bounded to the north by the Quetico Subprovince, and to the south by Proterozoic-aged (1.9 to 1.1 billion-year old) rocks of both the Southern Province including rocks associated with the Midcontinent Rift system. To the east, the Wawa Subprovince is truncated by the Kapuskasing Structural Zone. The Wawa Subprovince is composed primarily of Archean greenstone belts and granitic intrusions, with smaller mafic intrusive rocks locally present. As in many areas of the Superior Province, the Wawa Subprovince contains diabase dykes “swarms”, largely of Proterozoic age (Figure 3.2).

3.2 Local Bedrock Geology of the Manitouwadge Area

3.2.1 Lithologies

As mentioned in Section 3.1 the bedrock geology of the Manitouwadge area, shown in Figure 3.1, includes rocks of both the Quetico and the Wawa Subprovinces, in the northern and southern sectors of the area, respectively.

The bedrock geology in the central part of the Township of Manitouwadge is dominated by rocks of the Manitouwadge Greenstone Belt, which extends to the east beyond the Township boundary. The southern half of the Township is primarily underlain by felsic rocks of the Black-Pic Batholith, which extends well beyond the Township boundaries and the Manitouwadge area, to the south, east and west. Other smaller felsic intrusions within the Township include portions of the Nama Creek and Loken Lake plutons, in the northwestern and northeastern parts of the Township respectively. In the northeastern part of the Township there is a tonalite intrusion that surrounds the Loken Lake Pluton and extends east beyond the Township boundary. Along the northern boundary of the Township there are migmatized rocks, which are part of a broader belt running in a northeast direction immediately north of the Township.

The Black-Pic Batholith occupies approximately 35% of the Manitouwadge area, extending mostly over the central and southern sectors (Figure 3.3). Other felsic intrusive bodies of the Wawa Subprovince in the Manitouwadge area include the Fourbay Pluton, Dotted Lake Pluton and Rawluk Lake Pluton, which are southwest, southeast and east of the Township respectively. Additionally, northwest of the Township is the Everest Lake Pluton and an adjacent granodiorite formation. The Faries-Moshkinabi Intrusion is the only significant mafic intrusion and is east of the Township. Most of the northern part of the Manitouwadge area is underlain by metasedimentary rocks of the Quetico Subprovince, occupying about 25% of the area, and a granitic intrusion located about 16 km northwest of the Township in the Quetico Subprovince.

Figures 3.4 to 3.6 show the geophysical data available for the Manitouwadge area. Gravity data, shown in Figure 3.4, indicate the relative densities of the basement rocks. Since mafic rocks (e.g., basalt and gabbro) are rich in heavier elements (e.g., magnesium and iron), they generally exhibit a positive gravity response. In contrast, felsic rocks such as granite are rich in lighter elements (e.g., silicon, oxygen) and exhibit a negative gravity response. The gravity results from the Manitouwadge area show that all of the gravity results are relatively low (-39 Gal and less), indicating a dominance of light elements, which is expected given the dominance of felsic and metasedimentary rocks mapped in the area (Figure 3.2). There is a trend of decreasing gravity anomaly responses from north to south. This may be due to thicker geological units in the Quetico Subprovince or the presence of small amounts of ironstone (Williams, 1991) or magnetite (Williams and Breaks, 1996) in the metasedimentary rocks of the Quetico Subprovince.

Figure 3.5 shows the residual total magnetic field results, which reflect the variations in magnetism caused by the presence of magnetic minerals (mainly magnetite and pyrrhotite). Airborne magnetic surveys are useful tools for ore body detection, and enhanced lithological and structural mapping of bedrock geology. There are numerous east-west trending magnetic highs in the metasedimentary rocks in the Quetico Subprovince, which may be due to the presence of ironstone and ultramafic wacke (Williams, 1991) or magnetite and thin mafic sheets and lenses in the rock (Williams and

Breaks, 1996). Similarly there are high magnetic responses in the migmatized supracrustal rocks and in the intruded tonalite suite that surrounds the Loken Lake Pluton. The causes for the response in the migmatized supracrustal rocks are not known, but the responses in the tonalite are likely due to iron minerals including biotite and magnetite that were emplaced by hydrothermal events (Zaleski and Peterson, 1995; Zaleski et al., 1999). There are also strong responses from the Fourbay Pluton, which is likely due to the presence of significant amounts of pyroxene and amphibole in the granitic pluton (Williams and Breaks, 1996). There is also a magnetic high in the southern part of the Manitouwadge Greenstone Belt, which is due to iron (Williams and Breaks, 1996). The magnetic response of the Black-Pic Batholith is low due to the low iron content of the rocks, although dykes are clearly visible with northwest and northeast trends.

Airborne radiometric data for the Manitouwadge area, presented as parts per million of equivalent uranium, are provided in Figure 3.6. The gamma-ray spectrometry parameters (potassium, uranium and thorium) are often elevated in potassium-rich granitic rocks and rocks containing uranium and thorium. The overall results in the Manitouwadge area showed low equivalent uranium content with the maximum values reaching 1.3 parts per million, which is low compared to areas where there is active exploration for uranium or thorium. Due to these low equivalent uranium values, it is likely the relatively high responses shown in Figure 3.6 are due to high potassium content of the felsic rocks in the Manitouwadge Greenstone Belt, near the Fourbay Pluton, east of the Loken Lake Pluton and in the Everest Lake Pluton. The relatively low equivalent uranium values for the Black-Pic Batholith, Loken Lake Pluton and the Rawluk Lake Pluton (Figure 3.6) are due to the high tonalite composition of these rocks. Tonalite has plagioclase feldspar that is rich in calcium and sodium, where granites are typically rich in alkali feldspar that has potassium. The lack of potassium in tonalite will lead to a lower equivalent uranium concentration.

The main geological units present in the Manitouwadge area are further described below.

Quetico Subprovince – Metasedimentary Rocks and Granitic Intrusions

Metasedimentary rocks of the Quetico Subprovince extend over the northernmost part of the Manitouwadge area, approximately 6 km north of the Township. These are clastic 2.700 to 2.688 billion year old metasedimentary rocks that have undergone various degrees of metamorphism (Percival 1989; Zaleski et al., 1999).

The original sediments of the metasedimentary rocks of the Quetico Subprovince are interpreted by Stott et al. (2010) as having been formed in a basin setting between subprovinces. These original sedimentary rocks consisted of pelite and wacke as graded and ungraded layers on a 10 cm to 1 m scale (Williams and Breaks, 1996), and were mapped as greywacke by Zaleski et al. (1991). Small amounts of ironstone, conglomerate, and ultramafic wacke and siltstone are also present locally (Williams, 1991). Variable, but generally low (<5 %) quantities of garnet, K-feldspar, orthopyroxene and magnetite may be present (Williams and Breaks, 1996). Along the Quetico-Wawa Subprovince border the metasedimentary rocks have mafic sheets and lenses on the order to 10 cm thick that have intruded the metasedimentary rocks (Williams and Breaks, 1996). Together, ironstone, ultramafic wacke, magnetite and mafic sheets and lenses are likely responsible for the magnetic anomalies of the Quetico Subprovince in Figure 3.5.

These metasedimentary rocks underwent variable deformation and metamorphic processes, and as a consequence were converted into gneisses and migmatites displaying a strong compositional layering, many small-scale folds, boudinage and shearing (Williams and Breaks, 1996). The migmatites formed by partial melting of the precursor sedimentary rocks at high-temperature and low-pressure and are comprised of two or more petrographically distinct components. Williams and Breaks (1996) classified the metasedimentary rocks in the Manitouwadge area primarily as metatexite. The metatexite consists of 10 to 30% of white-weathering leucosome (part of the rock that formed from segregated partial melting of the precursor rocks) embodied within a brown to blue-grey mesosome principally of greywacke.

The metasedimentary rocks of the Quetico Subprovince have an estimated thickness of at least 7.5 km (Percival, 1989). The thickness of these metasedimentary rocks along the Quetico-Wawa Subprovince border may be somewhat less, as the metasedimentary rocks are thought to be underlain by rocks of the Wawa Subprovince near the boundary (Percival, 1989).

Approximately 15 km north of the Township of Manitouwadge there is an east-west trending granite-granodiorite body (Figure 3.3) intruded in the metasedimentary rocks. The intrusion is approximately 40 km long and 5 km wide (Figure 3.2), although only part of it falls within the Manitouwadge area. Information on the depth or age of the intrusion was not readily available. The intrusion is mapped as a pink biotite leucogranite (Percival, 1989). Granitic rocks in the Quetico Subprovince are typically medium to coarse grained and massive to rarely foliated (Percival, 1989).

Manitouwadge Greenstone Belt

As shown in Figure 3.3., the Manitouwadge Greenstone Belt is found north of the settlement area of Manitouwadge and covers much of the central-northern part of the Township, extending to the east well beyond the Township boundaries (Figure 3.2).

The Manitouwadge Greenstone Belt is a mafic-to-felsic volcanic succession approximately 1-2 km thick (Williams and Breaks, 1996) that formed approximately 2.72 billion years ago (Zaleski et al., 1999). In the volcanic succession, tholeiitic basalts formed a substrate for subsequent felsic volcanism (Zaleski and Peterson, 1995). Felsic volcanic and subvolcanic activity led to the establishment of a seafloor hydrothermal system and metasomatic alteration accompanied by the precipitation of iron and sulphides (Zaleski and Peterson, 1995). Iron formations within the Greenstone Belt are responsible for the magnetic highs observed in Figure 3.5.

Deformation episodes within the Manitouwadge Greenstone Belt led to the development of the Manitouwadge Synform, a 'Z-shaped' folding phase that created the current shape of the Manitouwadge Greenstone Belt (Zaleski and Peterson, 1995) in the Manitouwadge area (Figure 3.3). Within the Synform, the Manitouwadge Greenstone Belt is up to approximately 14 km wide, but is as narrow as 1 km.

From southwest to northeast, the Manitouwadge Greenstone Belt transitions from mafic metavolcanic rocks to felsic metavolcanic rocks to metasedimentary rocks (described as meta-greywacke by Zaleski et al., 1999); at the inner margin of the synform there is a tonalite intrusion (Figure 3.3). The type of metamorphism (orthoamphibole-bearing) that is present in the inner part of the metavolcanic belt suggests that hydrothermal fluids were partly channelled in aquifers consisting of permeable

volcaniclastic deposits (Zaleski and Peterson, 1995).

The mafic volcanic rocks in the Manitouwadge Greenstone Belt are massive to foliated, rarely-pillowed amphibolite. Quartzo-feldspathic schist and gneiss containing combinations of biotite, hornblende, and garnet represent altered, metamorphosed and commonly strained equivalents of intermediate to felsic metavolcanic rocks and associated volcaniclastic sedimentary rock (Williams and Breaks, 1996). The mafic rocks are laminated due to extreme deformation of tuffaceous bedding or pillows (Zaleski and Peterson, 1995). Foliated gabbroic rocks are interlayered with fine-grained mafic schist and may have originated as massive flows, bases of flows, or subvolcanic sills.

The intermediate to felsic metavolcanic rocks in the Manitouwadge Greenstone Belt are layered and massive volcanic rocks, homogeneous schists, and quartzo-feldspathic breccias (Williams and Breaks, 1996). They typically contain magnetite porphyroblasts, minor muscovite and biotite, and highly variable amounts of microcline (Zaleski and Peterson 1995). In some areas, strong deformation has obscured the original features of the rock, which complicates the determination of the origin of the rocks (Williams and Breaks, 1996). There are finely to thickly layered rocks of fine grained quartz and plagioclase in the hanging wall strata of the Geco Quarry that appear to be produced by deformation of volcanic tuffs (Williams and Breaks, 1996).

Metasedimentary rocks have also been mapped within the Manitouwadge Synform. The rocks are mapped as highly metamorphosed greywacke and siltstone (Williams and Breaks, 1996; Zaleski et al., 1999). These metasedimentary rocks may represent a conformable transition from a depositional setting dominated by volcanism and chemical sedimentation, to a depositional setting dominated by clastic sedimentation (Williams et al., 1990), although mapping this transition in the highly metamorphosed rocks is difficult (Zaleski et al., 1999). In some cases the metasedimentary and metavolcanic rocks are interbedded together and grade laterally into one another (Williams and Breaks, 1996).

Faries-Moshkinabi Intrusion

The mafic Faries-Moshkinabi Intrusion lies approximately 11 km to the east of the Township of Manitouwadge. The intrusion is approximately 5 km long and less than 3 km wide, with a depth of 700 m (Williams and Breaks, 1996). This layered mafic pluton is considered to be the result of cooling and differentiation of mafic magma emplaced as concordant to sub-concordant sheets into or at the margins of mafic metavolcanic rocks (Williams and Breaks, 1996). No readily available information on the age of this intrusion was found.

The intrusion is comprised of anorthositic rocks that overlie and underlie mafic to felsic metavolcanic rocks of the Manitouwadge Greenstone Belt, with thrust-modified boundaries against the Black-Pic Batholith (Williams and Breaks, 1996). The actual contact between the Faries-Moshkinabi Intrusion and the Black-Pic Batholith is a tectonic breccia, greater than 15 m across, which is composed of centimetre to metre-scale blocks of anorthosite, metawacke and granitic rocks (Williams and Breaks, 1996).

The Black-Pic Batholith

The Black-Pic Batholith is a large, regionally-extensive intrusion that encompasses an area of roughly 3,000 km². Only part of the Black-Pic Batholith falls within the Manitouwadge area, covering most of the southern half (Figure 3.3). The predominant rock type of the Black-Pic Batholith was originally described by Milne (1968) as foliated biotite-granodiorite gneiss in his mapping of the Black River region. The Black-Pic Batholith is a multiphase intrusive unit that includes hornblende-biotite, monzodiorite, tonalite and pegmatitic granite.

The age of emplacement of the Black-Pic Batholith has been constrained by age-dating the tonalite phase, the oldest recognized phase of this Batholith, at 2.720 billion years old (Jackson et al., 1998), whereas a younger monzodiorite phase has been dated as 2.689 billion years old (Zaleski et al., 1999). There are also younger granitic phases of the Black-Pic Batholith. Accurate age dates for these younger rocks have not been obtained, although they are thought to be part of the regional suite of generally 2.660 billion years old, post-tectonic "Algoman" granites" (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 outwards from the center. Within the Batholith, Williams and Breaks (1989) found that deeper levels of the tonalite suite are strongly foliated with a sub-horizontal planar fabric. Upper levels of the tonalite are frequently cut with 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 exist, and the contact between these rocks and the tonalitic rocks of the Black-Pic Batholith is relatively gradational with extensive sheeting of the tonalitic unit (Williams and Breaks, 1989; Williams et al., 1991).

Other Felsic Intrusions

In addition to the Black-Pic Batholith there are seven relatively small felsic intrusions in the Manitouwadge area, including the Fourbay Pluton, Loken Lake Pluton, Nama Creek Pluton, Everest Lake Pluton, Rawluk Lake Pluton, Dotted Lake Pluton and the tonalite intrusion that surrounds the Loken Lake Pluton (Figure 3.3). The Fourbay Pluton, about 5 km southwest of the Township of Manitouwadge, is an elliptical pluton 15 km long and 7 km wide. The Fourbay Pluton is a massive, compositionally uniform quartz monzodiorite, with a preliminary U-Pb zircon age of 2.678 billion years (Beakhouse, 2001). No readily available information on the depth of this intrusion was found.

The Loken Lake Pluton partly underlies the northeastern corner of the Township of Manitouwadge and extends beyond the Township boundaries to the east. It is 15 km long and up to 5 km wide and was emplaced near 2.687 billion years ago (Jackson et al., 1998). This intrusion has been mapped as massive granodiorite to granite. There was no readily available information regarding the depth of the Pluton.

The Nama Creek Pluton, within the Township, is approximately 35 km long and less than 1 km wide in some places, and has been mapped as massive granodiorite to granite (Figure 3.3). Zaleski et al. (1999) obtained an absolute estimated age of 2.680 billion years for this intrusion. There was no readily available information regarding its depth.

The 2.679 billion years old (Zaleski et al., 1999) Everest Lake Pluton was mapped by Williams and Breaks (1990) as a melanocratic dioritic phase of the tonalite-granodiorite suite. The pluton is approximately 136 km long and up to 10 km wide, and emplaced just south of the subprovince boundary, northwest of the Township (Figure 3.3). There was no readily available information regarding the depth of the pluton. Both the Nama Creek Pluton and the Everest Lake Pluton show evidence of incipient migmatization, placing a time constraint on metamorphism in the Quetico Subprovince (Zaleski et al., 1999).

The Rawluk Lake Pluton is 4 km east of the Township and is 6 km long by 3 km wide. The elliptical intrusion ranges compositionally between biotite-hornblende quartz diorite to tonalite, is slightly foliated, and moderately to strongly lineated (Williams and Breaks, 1996). There was no readily available information regarding the depth of the pluton.

A small part of the Dotted Lake Pluton lies within the Manitouwadge Area, approximately 14 km southeast of the Township of Manitouwadge. The Dotted Lake Pluton is a massive to foliated, homogeneous leucogranodiorite to leucotonalite, with a U-Pb zircon age of 2.697 billion years (Beakhouse, 2001), with an irregular shape that is approximately 20 km long and 10 km wide (Figure 3.2). Localized narrow zones of high strain also occur in the interior of the pluton associated with narrow, brittle-ductile shear zones (Beakhouse, 2001). There was no readily available information regarding its depth.

The tonalite intrusion that surrounds the Loken Lake Pluton and adjacent to the Manitouwadge Greenstone Belt (Figure 3.3) is interpreted to be synvolcanic with the Manitouwadge Greenstone Belt, near 2.72 billion years ago (Zaleski et al., 1999). The intrusion has also been described as a trondhjemite by Zaleski et al. (1999), which is a type of tonalite. The tonalite is foliated with minor amounts of biotite and magnetite and becomes more granite-like as it approaches the metavolcanic rocks of the Manitouwadge Greenstone Belt (Zaleski and Peterson, 1995). No readily available information on the depth of this intrusion was found. The tonalite has inclusions of metavolcanic rocks from the Manitouwadge Greenstone belt within it and in some areas the tonalite was impacted by hydrothermal alteration (Zaleski and Peterson, 1995; Zaleski et al., 1999), which is identifiable by the magnetic responses in Figure 3.5.

Migmatized Supracrustal Rocks

North of the Manitouwadge Synform, is an east-trending belt of migmatized supracrustal rocks (Figure 3.3). Milne et al. (1972) described these rocks as migmatized felsic igneous and metamorphic rocks. Limited information was found on readily available documentation on the characteristics of these rocks, and their thickness and absolute age are unknown at this stage.

Diabase Dykes

All rock types in the Manitouwadge area are intruded by two main sets of diabase dykes (Figure 3.3). The northwest trending dykes belong to the Matachewan Swarm (Bates and Halls, 1991; West and Ernst, 1991; Phinney and Halls, 2001). The Matachewan dykes were emplaced around 2.47-2.45 billion years ago in the area between Lake Superior and James Bay, with subvertical dip and north-northwest to northwest (330-340°) strike, reaching up to 40 m in width (Phinney and Halls, 2001). These dykes display dark grey to brown weathering surfaces, and in the Manitouwadge area range in

width from ubiquitous millimetre-scale to linear masses several hundred metres wide (Williams and Breaks, 1996). The dykes have a spacing from less than 1 km up to approximately 8 km (Figure 3.3). All of the diabase dykes have chilled margins (Williams and Breaks, 1996).

A second set of dykes in the Manitouwadge area consists of subvertical, northeast trending dykes striking 30-50°. These dykes are generally mapped as part of the Biscotasing Dyke Swarm, which intruded approximately 2.17 billion years ago (Halls and Davis, 2004). Although some of the dykes may be related to the Kapuskasing Structural Zone uplift, as posed by Halls and Davis (2004), some of the dykes may be related to the Marathon Swarm (2.126-2.101 billion years old) (Halls et al., 2006).

3.2.2 Deformation and Metamorphism

The structural geology of the Manitouwadge area is complex, reflecting the overlapping events of volcanism, sedimentation and granitic intrusion, all related to the formation of the Canadian Shield between 3.1 and 2.6 billion years ago (Card and Poulsen, 1998).

The structural style across the Quetico – Wawa Subprovince boundary, which runs about 6 km north of the Township of Manitouwadge, is well characterized by structural mapping conducted over the years (Schultz-Ela and Hudleston, 1991; Stott and Schwerdtner 1981; Williams et al. 1991; Peterson and Zaleski, 1999, Zaleski et al., 1999, and Zaleski and Peterson, 2001). In general, two major penetrative deformations are observed along the length of the Quetico Subprovince and the adjacent boundary with the Wawa Subprovince. The second penetrative deformation phase either refolds or overprints the first and is responsible for the widespread upright to moderately inclined, east-plunging folds highlighted by the lithologic layering in the Manitouwadge area and surroundings and by iron formations folded within the metasedimentary rocks of the Quetico Subprovince. The Everest Lake Pluton has a tectonic foliation subparallel to these regional structural trends (Zaleski et al., 1999).

These large fold structures are interpreted as a consequence of oblique, south-southeast directed collision between the two subprovinces (terrane), following northward subduction of terranes (as evidenced from Lithoprobe studies in Ontario; e.g., Percival et al., 2006), during the final tectonic assembly of the Superior Province at around 2.7 to 2.6 billion years ago. This collisional history is reflected in the production of granitic intrusions and injections of partial melts into the sedimentary successions that comprise the Quetico Subprovince, which served as a collisional buffer between more rigid granite-greenstone microcontinents to the north and south. Consequently, the more migmatitic matrix that dominates the Quetico Subprovince shows complex folds and refolds and some of the plutons appear to form metamorphosed, doubly-plunging domal structures.

There have been at least four phases of ductile deformation in the Manitouwadge Greenstone Belt (Zaleski and Peterson, 1995; Zaleski et al., 1999), leading to the formation of the Manitouwadge Synform. Most or all of the deformation occurred after sedimentation occurred (Zaleski et al., 1999). The first phase, D₁, formed pre- to syn-metamorphic ductile faults from 2.716 to 2.690 billion years ago, which are recognized near the settlement area of Manitouwadge. The second phase, D₂, produced sheath folds, a dominant regional foliation, and mineral lineation parallel to the fold axes from 2.692 to 2.676 billion years ago. The third phase, D₃, produced the 'Z-shaped' pattern of the Manitouwadge Synform in response to dextral transpression beginning 2.682 billion years ago and ending near 2.670 billion years ago. The final stage of deformation, D₄, produced outcrop-scale kinks and crenulation cleavage, but the age range for this deformation is not known.

The tonalite intrusion adjacent to the Loken Lake Pluton was emplaced at the same time or slightly after the metavolcanic rocks of the Manitouwadge Greenstone Belt (Zaleski et al., 1999), and is highly deformed and metamorphosed. The Black-Pic Batholith shows foliation consistent with the D_2 deformation, but only in the areas near the Manitouwadge Greenstone Belt (Zaleski et al., 1999). The D_2 phase of deformation is clear in the Loken Lake Pluton that is folded by the D_3 Manitouwadge Synform and the Pluton is interpreted to be in the core of an anticline (Zaleski et al., 1999). The Nama Creek Pluton is also deformed by the formation of the Synform, though it may have also been deformed by late D_2 deformation. The Faries-Moshkinabi Intrusion shows a range of deformation, with some areas undergoing intense deformation and others with well preserved rocks (Williams and Breaks, 1996). Deformation of the Faries-Moshkinabi Intrusion may have been prior to its incorporation within the Black-Pic Batholith (Williams and Breaks, 1996).

Four main sets of faults have been mapped in the Manitouwadge area, striking northwest, north, northeast and east (Figure 3.3). Northwest trending faults in the Manitouwadge area are less than 30 km in length and are irregularly spaced. North trending faults, including the Cadawaja, Agam Lake and Fox Creek Faults within the Township of Manitouwadge (Figure 3.3), are less than 20 km in length and are spaced between 2 and 18 km apart. Northeast trending faults are up to approximately 15 km and there are too few northeast trending faults to adequately estimate fault spacing. The longest fault in the Manitouwadge area is an east-west striking fault, about 8 km north of the Township in the Quetico Subprovince that extends eastward for approximately 60 km (Figure 3.2). No available information has been found on the displacement and depths of any of these faults. Although absolute ages of these faults have not been found in readily-available literature, cross-cutting relationships in the Manitouwadge area indicate they are younger than 2.680 billion years old.

Regional metamorphic grade ranges from lower amphibolite facies in the Schreiber-Hemlo Greenstone Belt (Figure 3.2), through upper amphibolite facies at Manitouwadge, to upper amphibolite and granulite facies in the southern Quetico Subprovince (Williams and Breaks, 1989). There is a granulite domain in the southern margin of the Quetico Subprovince, north of the Township of Manitouwadge, which indicates that the rocks have undergone a high-temperature, low-pressure metamorphism as a result of crustal thickening and heating from magmatism (Pan et al., 1994). All mafic and felsic volcanic rocks and the tonalite intrusions are metamorphosed in the Manitouwadge Greenstone Belt (Zaleski and Peterson, 1995). The metamorphic grade increases from sillimanite-muscovite-quartz schist near the Geco Mine on the southern limb of the Manitouwadge Synform to sillimanite-microcline-quartz schist northwest of the Manitouwadge settlement area. Dominant D_2 fabrics are defined by high-grade minerals and folded by the D_3 Manitouwadge Synform indicating that peak metamorphism occurred with D_2 2.692 to 2.676 billion years ago (Zaleski et al., 1999).

3.2.3 Summary

In summary, the bedrock geology in the Manitouwadge area is comprised mostly of felsic intrusive rocks and metasedimentary rocks, with lesser amounts of metavolcanic and migmatitic rocks. All of these lithologic units are cross-cut by northwest and northeast trending dykes (Figure 3.3).

The central part of the Township of Manitouwadge is dominated by rocks of the Manitouwadge Greenstone Belt, which extends to the east beyond the Township boundaries. The rocks of the Manitouwadge Greenstone Belt are lithologically heterogeneous and have undergone several phases of deformation, including the formation of the Manitouwadge Synform. The metavolcanic rocks in the

Greenstone Belt are estimated to be approximately 1-2 km thick.

The southern half of the Township is underlain by granitic rocks of the Black-Pic Batholith, which extends well beyond the Township boundaries to the south, east and west. The Black-Pic Batholith is a multi-phase intrusive body that extends laterally over a large area. No information on the thickness of this intrusion was found in readily-available literature. Other smaller intrusions in the Manitouwadge area include the Nama Creek and Loken Lake plutons partly falling within the Township, the Faries-Moshkinabi Intrusion and the Fourbay, Dotted Lake, Rawluk Lake and Everest Lake plutons at the periphery of the Township (Figure 3.3). North of the Township there is also a relatively large granitic body intruding the metasedimentary rocks of the Quetico Subprovince.

Metasedimentary rocks of the Quetico Subprovince underlie the northernmost part of the Manitouwadge area. These are gneiss and migmatites that formed by metamorphism of sedimentary rocks. They have an estimated thickness of about 7.5 km (Percival, 1989), although thickness maybe somewhat less along the Quetico-Wawa subprovince boundary.

Along the northern boundary of the Township there is a strip of migmatized supracrustal rocks, which is part of a broader belt running in a northeast direction immediately north of the Township (Figure 3.3). Little information exists in readily-available literature on these migmatized felsic igneous and metamorphic rocks.

Four main sets of faults have been mapped in the Manitouwadge area, striking northwest, north, northeast and east (Figure 3.3). These mapped faults show variable lengths and spacings. The longest fault in the Manitouwadge area is an east-west striking fault, about 8 km north of the Township in the Quetico Subprovince that extends eastward for approximately 60 km (Figure 3.2). No available information has been found on the displacement and depths of any of these faults.

3.3 Quaternary Geology

Figure 3.7 illustrates the extent and type of Quaternary deposits in the Manitouwadge area from 1:1,000,000 scale mapping (Ontario Geological Survey, 2003) and the location of the wells from which information on overburden thickness was obtained. Most of the Manitouwadge area has exposed bedrock, and Quaternary deposits are predominantly located in bedrock controlled valleys and topographic lows. Additional mapping was conducted by Kristjansson and Geddes (2009) at a 1:50,000 scale in the Township of Manitouwadge and the area to the east (not shown on Figure 3.7).

Quaternary deposits within the Manitouwadge area were deposited during the Late Wisconsin by the Labrador sector of the Laurentide Ice Sheet. Bedrock striae mapped by Kristjansson and Geddes (2009) indicate there was one prominent direction for the ice retreat, towards the northeast.

Quaternary deposits in the Manitouwadge area include mostly glaciolacustrine and glaciofluvial deposits, as well as smaller amounts of till and organic deposits. Glaciolacustrine deposits are found in the Pic River and Black River valleys, as well as the valleys of the tributaries for these rivers (e.g. White Otter River and Nama Creek). Adjacent to some of the glaciolacustrine deposits are glaciofluvial deposits, including ice-contact deposits and outwash deposits. Kristjansson and Geddes (2009) show a 0.5 km esker with a northeast trend approximately 12 km northeast of the Manitouwadge settlement area. Figure 3.7 shows eight other eskers, all with a northeast trend and all

within the glaciofluvial ice-contact deposits. Till and organic deposits are mostly found in the central and eastern parts of the Manitouwadge area.

Information on overburden thickness was obtained from 438 diamond drill holes that had lithological data (Ontario Geological Survey, 2005) and 23 water wells (see Section 4). The diamond drillholes and water wells are located mostly within the Township of Manitouwadge and the area to the east (Figure 3.7). Based on information from these diamond drill holes and water wells overburden thickness ranges from 0 m to 71 m within the Manitouwadge area. These reported overburden thicknesses are from localized pockets of overburden that may not be evident at the 1:1,000,000 scale mapping shown in Figure 3.7.

3.4 Neotectonic Activity

Neotectonics refers to deformations, stresses, and displacements in the Earth's crust of recent age or which are still occurring. Neotectonics of the Manitouwadge area is typical of many areas of the stable craton of the Canadian Shield (Adams and Clague, 1993), which has been subjected to numerous glacial cycles during the last million years (Shackleton et al., 1990; Peltier, 2002). The neotectonic activity of the Manitouwadge area appears to be principally due to post-glacial isostatic rebound resulting from melting of the Laurentide Ice Sheet (Adams and Clague, 1993).

Post-glacial isostatic rebound began with the melting and retreat of the continental ice sheets and is still occurring across most of Ontario. The greatest rates of crustal rebound (approximately 12 mm/a) are recorded in the Hudson Bay region, where the thickest glacial ice occurred (Sella et al. 2007). As a result of the glacial unloading, horizontal stresses are created locally and culminate in natural stress release features including elongated compressional ridges or pop-ups such as those described in Karrow and White (2002) and McFall (1993).

Herget (1972), Herget and Arjang (1990), Arjang (1991) and Arjang and Herget (1997), based on stress testing and analyses completed at the nearby underground mines at Wawa, Elliot Lake and Sudbury, indicate pre-mining major horizontal compressional stress directions of about northeast-southwest. These regional horizontal stress results are similar to directions for other parts of the Canadian Shield in eastern North America, and have been interpreted by Herget (1972) as stable and preserved in relative magnitude for close to a billion years.

No identification and interpretation of neotectonic structures was found in the readily-available literature for the Manitouwadge area. It is therefore useful to review the findings of previous field studies involving fracture characterization and evolution as it may pertain to glacial unloading. McMurtry et al. (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks in Western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Early-formed fractures have tended to act as stress domain boundaries. Subsequent stresses, such as those caused by plate movement or by continental glaciation, generally have been relieved by reactivation along the existing zones of weakness rather than by the formation of large, new fracture zones.

3.5 Seismicity

The Manitouwadge area lies in the Superior Province of the Canadian Shield, where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Hayek et al. (2011) indicated that the Superior Province has experienced a number of low magnitude shallow seismic events.

Figure 3.8 presents the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada from 1627 until 2010 and Figure 3.9 shows the locations and magnitudes of earthquakes recorded in the National Earthquake Database (Natural Resources Canada, 2012) for the period between 1985 and 2012 in the Manitouwadge area and surroundings. These figures show that there have not been any earthquakes recorded in the Manitouwadge area over these periods. The closest earthquakes were recorded in June 2004 approximately 40 km north of the Township of Manitouwadge with magnitude 2.2 and 2.1. A 2.6 magnitude earthquake was measured in May 1990 approximately 45 km east of the Township, and a 2.2 magnitude earthquake was measured in January 2011 approximately 62 km southeast of the Township. Finally, a 2.1 magnitude earthquake was measured in October 1988 approximately 42 km south of the Township.

In summary, available literature and recorded seismic events indicate that the Manitouwadge area is located within a region of low seismicity.

4 HYDROGEOLOGY

Information concerning groundwater for the Manitouwadge area was obtained from the Ontario Ministry of the Environment (2010) Water Well Information System (WWIS) database and is shown in Figure 4.1. All but one of the water wells were drilled within the Township of Manitouwadge.

The WWIS database contains a total of 23 water well records for the Manitouwadge area (Figure 4.1). Of the 23 records, 22 records had information on lithology, 21 records had information on static water level and 10 records had information on well yield. Table 1 summarizes the water well record data for the Manitouwadge area. Two of the 23 water wells are part of the Manitouwadge municipal drinking water system. These two overburden wells are completed to depths of 24 and 25 metres below ground surface (mbgs).

Table 1 Water Well Record Details for the Manitouwadge Area

Water Well Type	Number of Wells	Total Well Depth (m)	Static Water Level (m below surface)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	13	8.8 - 30	3 - 36	57 – 1,514	-
Bedrock	9	5.2 - 49	2 - 22	15 - 38	0 - 30

4.1 Overburden Aquifers

Two municipal wells and 11 additional wells obtain groundwater from overburden aquifers in the Manitouwadge area. The thickest overburden encountered in water wells was 30 m. The yields reported for the municipal supply wells were both approximately 1,514 L/min, and yields for other overburden wells were between 57 and 946 L/min. These well yields reflect the maximum pumping rate of the pumps in the wells and do not necessarily reflect the maximum sustained yield that might be available from overburden aquifers. The static water levels in the overburden wells range from 3 to 36 mbgs. The review of the water well information indicates that the overburden is generally thin and discontinuous. However, suitable local thicknesses of sands and gravels are present for water supply.

4.2 Bedrock Aquifers

The review of available information did not identify any known groundwater resources at repository depth (approximately 500 m) in the Township of Manitouwadge. There are nine well records that can be confidently assigned to the shallow bedrock in the Manitouwadge area, ranging in depth from 5.2 to 49 m.

The Ontario Ministry of the Environment (2010) WWIS shows no potable water supply wells which exploit aquifers at typical repository depths in the Manitouwadge area. Experience from other areas in the Canadian Shield has shown that active groundwater flow is generally confined to shallow fractured localized systems. In these shallow regions, flow tends to be dependent on the secondary permeability created by fractures (Singer and Cheng, 2002). For example, in Manitoba's Lac du Bonnet Batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996).

The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry et al., 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth (Herget and Arjang, 1990) tend to close or prevent fractures, thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003).

4.3 Hydrogeochemistry

No information on groundwater hydrogeochemistry at repository depth was found for the Manitouwadge area. However, existing literature shows that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh groundwater flow system, and a deep, saline to brine groundwater flow system (Singer and Cheng, 2002).

Gascoyne et al. (1987) investigated the saline groundwater to brines found within several Precambrian plutons and identified a general chemical transition at around 300 m depth marked by a uniform, rapid rise in total dissolved solids and chloride. This was attributed to advective mixing above 300 m, with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths. In the deeper regions, where groundwater transport in unfractured or sparsely fractured rock tends to be very slow, long residence times on the order of a million years or more have been reported (Gascoyne et al., 1987; Gascoyne 2000; 2004).

Groundwater research carried out in AECL's Whiteshell Underground Rock Laboratory (URL) in Manitoba found that crystalline rocks from depths of 300 to 1,000 m have total dissolved solids values ranging from 3 to 90 g/L (Gascoyne 2000; 2004). However, total dissolved solids exceeding 250 g/L have been reported in some regions of the Canadian Shield at depths below 500 m (Frape and McNutt, 1984; Frape and Fritz, 1987).

5 ECONOMIC GEOLOGY

5.1 Petroleum Resources

The Manitouwadge area is located in a crystalline rock setting where the potential for petroleum resources is negligible. No hydrocarbon exploitation or exploration activities are known to occur in the Manitouwadge area.

5.2 Metallic Mineral Resources

Figure 5.1 shows the areas of active exploration and mining in the Manitouwadge area based on active mining claims and known mineral occurrences identified in the Ontario Geological Survey's Mineral Deposit Inventory (Ontario Geological Survey, 2011).

There are currently no active mines within the Manitouwadge area. There are, however, six past producing mines, all located within the Manitouwadge Greenstone Belt (Figure 5.1). Four of the past producing mines have remaining reserves and include the Will-Echo 1/2, Will-Echo 3, Willroy Zone 1, and the Willroy mines. The Geco and Big Nama mines are past producing mines without reserves. The Geco mine closed in November 1995 and was the most productive and last active mine in the area. Geco produced 55.9 million metric tons (Mt) with an overall grade of 1.9% copper, 3.8% zinc, and 46.9 g/t silver (Zaleski and Peterson, 1995). Combined production from the Willroy, Big Nama, and Will-Echo deposits, was 8.0 Mt with a grade of 0.9% copper, 4.9% zinc, and 50 g/t silver (Zaleski and Peterson, 1995).

Active metallic mineral exploration is currently focused in the rocks of the Manitouwadge Greenstone Belt and the tonalite suite surrounding the Loken Lake Pluton, where active mining claims and mineral occurrences are documented. Exploration in these areas is mainly focused on identifying targets at depth and along the folded extensions of the Manitouwadge Greenstone Belt (Zaleski and Peterson, 1995). Active mining claims are also documented near faults in the metasedimentary rocks of the Quetico Subprovince, Loken Lake Pluton, Rawluk Lake Pluton and in an area near the Dotted Lake Pluton (Figure 5.1). However, no economically exploitable resources appear to have been identified in these areas to date. There is low mineral potential and exploration activity in the Black-Pic Batholith, Fourbay Pluton, the migmatized supracrustal rocks and the Everest Lake Pluton.

5.2.1 Iron

There are a few iron mineral occurrences recorded in the Manitouwadge area. These are mainly located in the Manitouwadge Greenstone Belt, the Faries-Moshkinabi Intrusion, the Black-Pic Batholith and the southern part of the Quetico Subprovince (Figure 5.1). Occurrences in the Manitouwadge Greentone Belt, Faries-Moshkinabi Intrusion and Black-Pic Batholith are likely associated with the hydrothermal activity as described by Zaleski et al. (1999). Iron (pyrite) occurrences in the Quetico metasedimentary rocks may be in rock formations containing ironstone, ultramafic wacke or magnetite (Williams, 1991; Williams and Breaks, 1996), although hydrothermal sources cannot be dismissed.

There are also a couple of discretionary mineral occurrences for iron in the Everest Lake Pluton and in the granodiorite intrusion adjacent to the Everest Lake Pluton. There is no readily available information regarding the mineralization of these mineral occurrences.

Although there are mineral occurrences and discretionary occurrences of iron recorded in the Manitouwadge area, the economical potential of these occurrences has not been proven to date.

5.2.2 Base Metals

Base metal sulphides represent the dominant mineral potential in the Manitouwadge area and are associated with hydrothermal activity (Zaleski and Peterson, 1995). Mineral occurrences and discretionary mineral occurrences are commonly associated with mapped faults, dykes or at the boundary between two different lithologies.

In the Manitouwadge area most of the base metal mineral occurrences are recorded within the Manitouwadge Greenstone Belt and the tonalite rocks that surround the Loken Lake Pluton (Figure 5.1). A few base metal occurrences are also identified in the Rawluk Lake Pluton, the Black-Pic Batholith and in the metasediments of the Quetico Subprovince.

Potential for economical base metals mineralization in the Manitouwadge area has only been proven in the past within the rocks of the Manitouwadge Greenstone Belt. Mineral occurrences identified elsewhere in the Manitouwadge area have not been proven to be economical to date.

5.2.3 Gold

There are no mineral occurrences of gold recorded in the Manitouwadge area.

5.2.4 Uranium

There are no mineral occurrences of uranium or thorium recorded in the Manitouwadge area.

5.2.5 Rare Earth Metals

There are no mineral occurrences of rare earth metals recorded in the Manitouwadge area.

5.3 **Non-Metallic Mineral Resources**

5.3.1 Sand, Stone and Gravel

Kristjansson and Geddes (2009) mapped 12 sand and gravel pits near the Township of Manitouwadge. The gravel pits were primarily located in mapped glaciofluvial sediments. The size of these deposits was not discussed.

5.3.2 Diamonds

There are no mineral occurrences or discretionary occurrences of diamonds in the Manitouwadge area.

5.3.3 Industrial Minerals

There is one mineral occurrence of carbon in the metasedimentary rocks of the Quetico Subprovince. and one discretionary mineral occurrence of garnet in the tonalite intrusion surrounding the Loken Lake Pluton (Figure 5.1). The economical potential of these occurrences has not been proven.

6 INITIAL SCREENING EVALUATION

This section provides an evaluation of each of the five initial screening criteria (NWMO, 2010) for the Manitouwadge area based on the readily available information presented in Sections 2 to 5. The intent of this evaluation is not to conduct a detailed analysis of all available information or identify specific potentially suitable sites, but rather to identify any obvious conditions that would exclude the Township of Manitouwadge from further consideration in the site selection process.

Initial screening criteria (NWMO, 2010) require that:

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

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

6.1 Screening Criterion 1: Land Availability

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

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

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

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

The review of available mapping and satellite imagery shows that the Township of Manitouwadge contains limited constraints that would prevent the development of repository surface facilities (Figures 2.1 and 2.2). These include permanent water bodies such as the Manitouwadge, Wowun and Rabbitskin lakes, which account for less than 1% of the Township area. Also, residential and industrial infrastructure covers a very small portion of the Township, with developments limited to roadways and the settlement area of Manitouwadge (Figure 2.1). The area at the periphery of the Township is largely undeveloped, with few natural or physical constraints such as large water bodies or major infrastructure.

Although the Manitouwadge area has a range in topographic elevations between approximately 195 and 485 masl, most of the Manitouwadge area is unconstrained by topography (Figure 2.4).

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

Based on the review of readily-available information, the Manitouwadge area contains sufficient land to accommodate the repository's surface and underground facilities.

6.2 Screening Criterion 2: Protected Areas

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

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

The Manitouwadge area was screened for federal, provincial and municipal parks, conservation areas, nature reserves, national wildlife areas and archaeological and historic sites using available data from the Ontario Ministries of Natural Resources (Crown Land Use Policy Atlas) and Tourism and Culture. There is only one protected area within the Manitouwadge area, the Isko Dewabo Lake Complex Conservation Reserve, which is located approximately 10 km southwest of the Township and occupies less than 1% of the Manitouwadge area (Figure 2.1).

As discussed in Section 2.4, most of the land in the Manitouwadge area is free of known heritage constraints. There is only one known archaeological site in the Manitouwadge area. The site is localized and small in size and located approximately 15 km northeast of the settlement area of Manitouwadge, outside of the Township boundary. There are no known National Historic Sites in the

Manitouwadge area.

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

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

6.3 Screening Criterion 3: Known Groundwater Resources at Repository Depth

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

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

The review of available information did not identify any known groundwater resources at repository depth for the Manitouwadge area. As discussed in Sections 4.1 and 4.2, the Ontario Ministry of the Environment Water Well Information System database shows that all water wells known within the Manitouwadge area obtain water from overburden or shallow bedrock sources at depths of up to 49 m below ground surface.

Experience from other similar areas in the Canadian Shield has shown that active groundwater flow is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). For example, in Manitoba's Lac du Bonnet Batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and interconnected (Stevenson et al., 1996; McMurry et al., 2003).

The Ontario Ministry of the Environment Water Well Information System database indicates no potable water supply wells are known to exploit aquifers at typical repository depths in the Manitouwadge area or anywhere else in Northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits the potential yield, even if suitable water quality were to be found.

The absence of groundwater resources at repository depth in the Manitouwadge area would, however, need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

The review of available information did not identify any known groundwater resources at repository depth for the Manitouwadge area. Experience in similar geological settings suggests that the potential for deep groundwater resources at repository depth is low throughout the Manitouwadge area. The absence of groundwater resources at repository depth would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

6.4 Screening Criterion 4: Known Natural Resources

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

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

The review indicates that there is no evidence of past or present exploration or development activities associated with hydrocarbon resources in the Manitouwadge area. Given the geological setting (i.e. crystalline rock), the potential for activities associated with these resources in the Manitouwadge area is negligible.

There are currently no active mines within the Manitouwadge area. There are, however, six past producing mines, four of which have mineral reserves remaining (Figure 5.1). These mines exploited base metals and are all located in the Manitouwadge Greenstone Belt within the Township of Manitouwadge. Base metal mineral occurrences in the Manitouwadge area are recorded primarily within the Manitouwadge Greenstone Belt and the tonalite intrusion surrounding the Loken Lake Pluton, where active exploration is ongoing (Figure 5.1).

Active exploration is also ongoing in the Faries-Moshkinabi Intrusion, where an iron formation is documented. Limited iron mineral occurrences have also been recorded in the metasedimentary rocks of the Quetico Subprovince. These occurrences are associated with faults and dykes and their economical viability has not been proven to date. The mineral potential of the metasedimentary rocks of the Quetico Subprovince is generally low. The mineral potential of the migmatized supracrustal rocks and the granitic intrusions in the Manitouwadge area, including the Black-Pic Batholith, Fourbay Pluton, Everest Lake Pluton, and the granitic intrusion of the Quetico Subprovince is also considered low.

Extraction of sand and gravel in the Manitouwadge area has occurred in the past and continues today. However, the risk that these resources pose for future human intrusion is negligible, as operations are typically limited to very shallow depths.

Based on the review of readily-available information, the Manitouwadge area contains sufficient lands, free of known economically exploitable natural resources, to accommodate the required repository facilities. The absence of natural resources would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

6.5 Screening Criterion 5: Unsafe Geological or Hydrogeological Features

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

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

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

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

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

6.5.1 Safe Containment and Isolation

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

As described in Section 3.2, the bedrock geology in the central part of the Township of Manitouwadge is dominated by rocks of the Manitouwadge Greenstone Belt, which extends to the east beyond the Township boundaries. Other bedrock units in the northern part of the Township include portions of the Nama Creek and Loken Lake plutons, as well as a strip of migmatized supracrustal rocks which is part of a broader belt running in a northeast direction immediately north of the Township. The southern half of the Township is underlain by granitic rocks of the Black-Pic Batholith, which extends well beyond the Township boundaries and dominates the bedrock geology in the southern part of the Manitouwadge area (Figure 3.3).

Other smaller intrusions in the Manitouwadge area include the Faries-Moshkinabi Intrusion and the Fourbay, Dotted Lake, Rawluk Lake and Everest Lake plutons at the periphery of the Township (Figure 3.3). North of the Township there is also a relatively large granitic body intruding the metasedimentary rocks of the Quetico Subprovince. Metasedimentary rocks of the Quetico Subprovince underlie the northernmost part of the Manitouwadge area.

The Manitouwadge Greenstone Belt comprises a series of heterogeneous metavolcanic and metasedimentary rocks that have undergone several phases of deformation, including the formation of the Manitouwadge Synform. While the greenstone belt may have sufficient thickness and lateral extent, it is unlikely to be suitable for hosting a deep geological repository due to structural complexity and lithological heterogeneity, as well as to its potential for natural resources (see Criterion 4). The Nama Creek Pluton and the Faries-Moshkinabi Intrusion within and to the east of the Township respectively would also be likely unsuitable due to insufficient rock volume (i.e. insufficient lateral extent). Similarly, the portion of the Dotted Lake Pluton that falls within the Manitouwadge area has insufficient lateral extent to potentially host the repository's facilities.

The Black-Pic Batholith is a multi-phase, granodiorite gneiss to gneissic tonalite intrusive body that extends laterally over a large area. The granitic rocks of this intrusion appear to have favourable geological characteristics. While no information on its thickness was found in readily-available literature, the rocks of the Black-Pic Batholith warrant further consideration as potential host-rocks for a deep geological repository. The other granitic intrusions in the Manitouwadge area, including the Loken Lake, Fourbay, Rawluk Lake and Everest Lake plutons, as well as the intrusion of the Quetico Subprovince north of the Township, have significant lateral extents and may be lithologically relatively homogeneous. Although no information was found regarding the thickness of these intrusions, they also warrant further consideration as potentially suitable host rocks.

The belt of migmatized supracrustal rocks that runs immediately north of the Township and covers part of the Township comprises felsic igneous and metamorphic rocks. Although little information exists in the readily-available information on this bedrock unit in the Manitouwadge area, these rocks

may have favourable geological characteristics and sufficient volume to potentially host a deep geological repository.

The metasedimentary rocks of the Quetico Subprovince in the northern part of the Manitouwadge area are laterally extensive, with an estimated thickness of 7.5 km. While there is no information on the degree of homogeneity of these metasedimentary rocks at repository depth, the high degree of metamorphism and partial melting they have experienced in the past would suggest that their physical characteristics could mimic those of granitic rock. Therefore, the metasedimentary rocks of the Quetico Subprovince warrant further consideration as potential host-rocks for a deep geological repository.

There are four main sets of faults that have been mapped in the Manitouwadge area, striking northwest, north, northeast and east (Figure 3.3). There are two sets of dykes that cross-cut the bedrock geologic units within the Manitouwadge area. The extent to which these faults and dykes extend to depth, their frequency of occurrence, and their potential impact on siting the repository would need to be evaluated during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

From a hydrogeologic point of view, the review of readily-available information did not reveal the existence of known deep fracture systems or deep aquifers in the Manitouwadge area (see Section 4.2). The presence of active deep groundwater flow systems in crystalline formations is controlled by the frequency and interconnectivity of fractures at depth. Experience from similar areas in the Canadian Shield, particularly for granitic intrusions (plutons and batholiths), indicates that active groundwater flow tends to be generally limited to shallow fractured systems, typically less than 300 m. In deeper rock, fractures are less common and less likely to be interconnected, leading to very slow groundwater movement with residence times that could reach a million years or more (McMurry et al., 2003; Gascoyne, 2000; 2004).

In summary, the review indicates that the Manitouwadge area contains areas with no known obvious geological and hydrogeological conditions that would fail the containment and isolation requirements. The bedrock geology in these areas is comprised of granitic rocks of the large Black-Pic Batholith and other smaller intrusions, migmatized supracrustal rocks and metasedimentary rocks of the Quetico Subprovince.

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

6.5.2 Long-Term Stability

A suitable site for hosting a repository is a site that would remain stable over the very long term in a manner that will ensure that the performance of the repository will not be substantially altered by future geological and climate change processes, such as earthquakes or glaciation. A full assessment of this geoscientific factor requires detailed site specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the

site has responded to past glaciations and geological processes and would entail a wide range of studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change.

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

The Manitouwadge area lies in the Superior Province and the Southern Province of the Canadian Shield, where large parts have remained tectonically stable for the last 1.75 billion years (Wetherill et al., 1960). As discussed in Sections 3.2.2 and 3.4, faults have been mapped in the Manitouwadge area; however, there is no evidence to suggest that these faults have been tectonically active within the past billion years. As discussed in Section 3.5, no earthquakes of magnitude 3 or greater have been recorded in the Manitouwadge area.

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. Glaciation is a significant past perturbation that could occur in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline formations, particularly the plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004), indicated that the evolution of the groundwater flow system was characterized by periods of long-term hydrogeological and hydrogeochemical stability. Furthermore, there is evidence that only the upper 300 m have been affected by glaciation within the last million years. McMurtry et al. (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks of Western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Subsequent geological processes such as plate movement and continental glaciation have caused reactivation of existing zones of weakness rather than the formation of large, new zones of fractures.

In summary, the review did not identify any obvious geological or hydrogeological conditions that would clearly fail to meet the long-term stability requirement for a potential repository in the Manitouwadge area. As mentioned above, the long-term stability factor would need to be further assessed through detailed multidisciplinary geoscientific and climate change site investigations, if the community remains interested in continuing in the site selection process.

6.5.3 Potential for Human Intrusion

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

This factor has already been addressed in Sections 6.3 and 6.4, which concluded that the potential for groundwater resources at repository depths is low throughout the Manitouwadge area, and that the potential for economically exploitable mineral resources is mostly limited to the rocks of the Manitouwadge Greenstone Belt and adjacent tonalite intrusion.

6.5.4 Amenability to Construction and Site Characterization

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

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and in-situ stresses for the Manitouwadge area. However, there is abundant information at other locations of the Canadian Shield that could provide insight into what should be expected for the Manitouwadge area in general. Available information suggests that crystalline rocks within the Canadian Shield, particularly plutonic intrusions, generally possess geomechanical characteristics that are good to very good and amenable to the type of excavation activities involved in the development of deep geological repository for used nuclear fuel (McMurry et al., 2003; Chandler et al., 2004; Arjang and Herget, 1997; Everitt, 1999).

The review of readily-available information on the bedrock geology and Quaternary geology (Sections 3.4 and 3.5) did not indicate any obvious conditions which could make the rocks of the Manitouwadge area difficult to characterize, except those of the structurally complex and heterogeneous Manitouwadge Greenstone Belt. Conditions such as thick overburden cover may exist in localized areas. The degree to which factors such as geologic variability and overburden thickness might affect the characterization and data interpretation of the granitoid intrusions and metasedimentary rocks is unknown at this stage and would require further assessment during subsequent site evaluation stages of the site selection process, provided the community remains interested in continuing in the site selection process.

Based on the review of available geological and hydrogeological information, the Manitouwadge area includes portions of land that do not contain obvious known geological and hydrogeological conditions that would make the area unsuitable for hosting a deep geological repository.

7 INITIAL SCREENING FINDINGS

This report presents the results of an initial screening to assess the potential suitability of the Manitouwadge area against five initial screening criteria using readily available information. The initial screening focused on the Township of Manitouwadge and its periphery, which are referred to as the "Manitouwadge area" in this report.

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

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Township of Manitouwadge from further consideration in the NWMO site selection process. The initial screening indicates that the Manitouwadge area contains large portions of land with geological units that are potentially suitable for hosting a deep geological repository. Examples of these units include the metasedimentary rocks of the Quetico Subprovince, the Black-Pic Batholith and other smaller granitic intrusions including the Fourbay, Rawluk Lake and Everest Lake plutons.

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

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

8 REFERENCES

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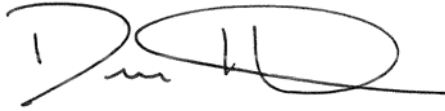
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9 REPORT SIGNATURE PAGE

Respectfully submitted,
Geofirma Engineering Ltd.



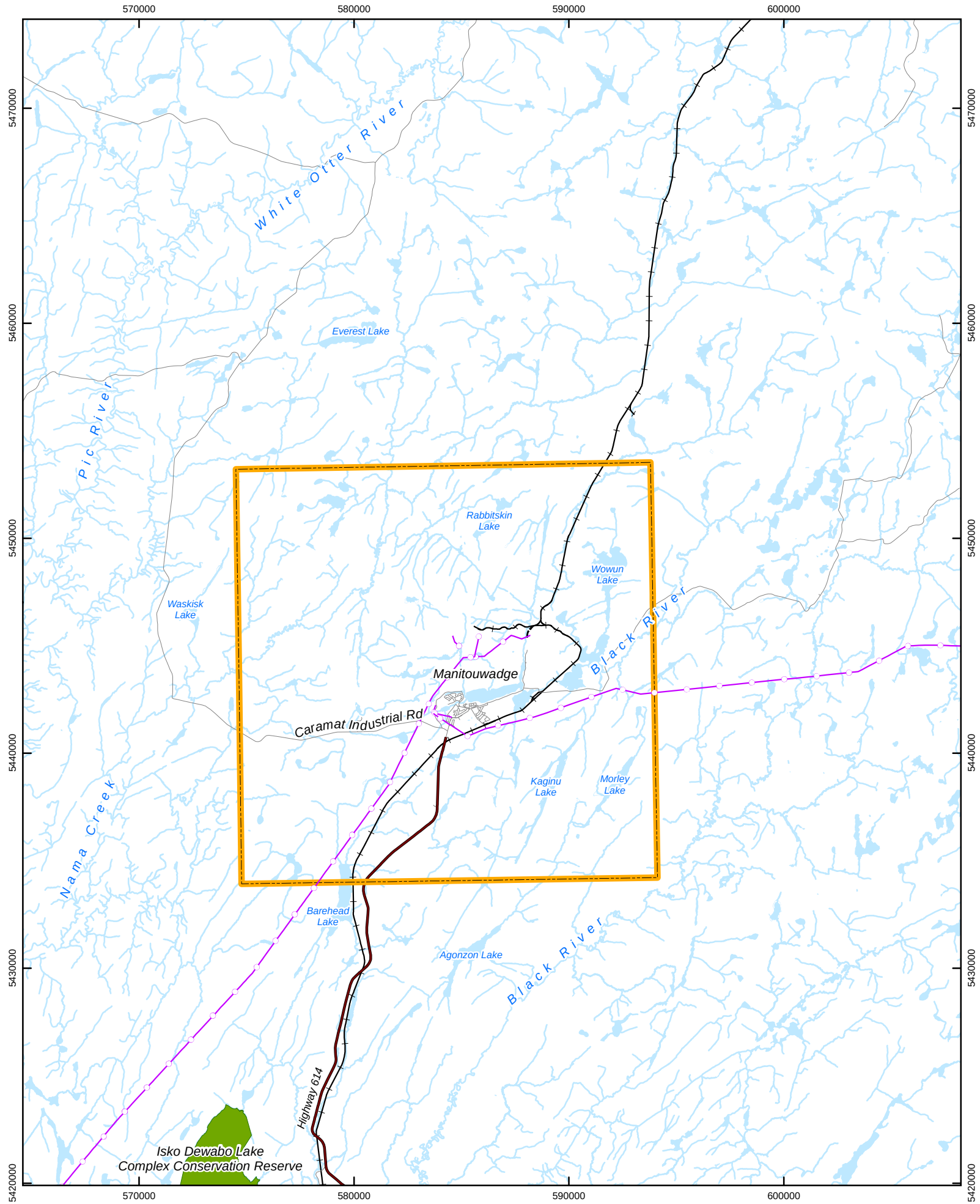
Dru Heagle, Ph.D., P.Geo.
Senior Hydrogeologist



Kenneth Raven, P. Eng., P.Geo.
Principal

APPENDIX A
Report Figures

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LEGEND

- Township of Manitouwadge
- Conservation Reserve
- Highway
- Local Road
- Railway
- Utility Line
- Water Area, Permanent
- Watercourse

INDEX MAP

SCALE 1:215,000
0 2 4 8 12 16
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR obtained 2012
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ? Queens Printer 2011

PROJECT No. 10-214-4
NWMO Desktop Level Initial Site Screening

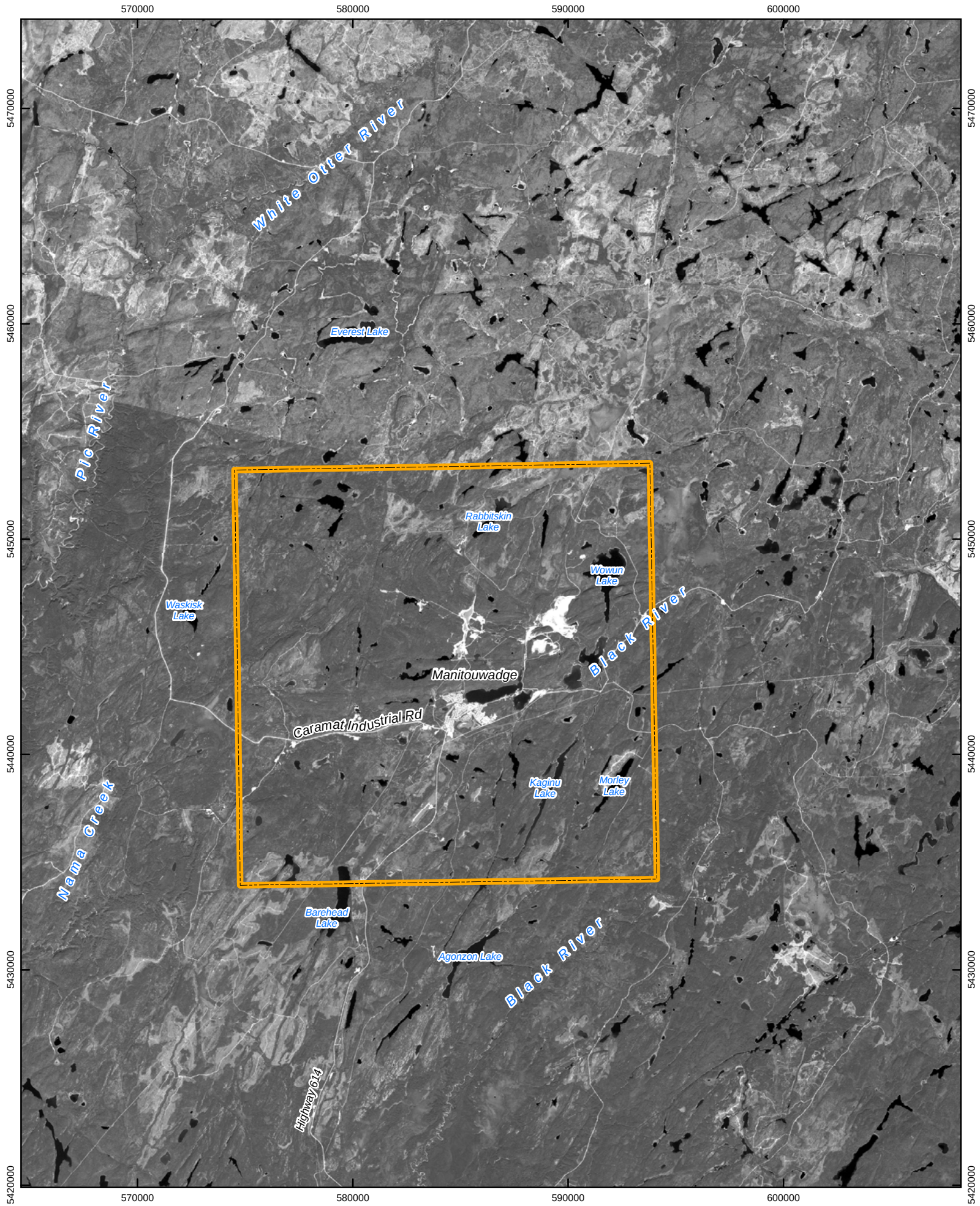
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Manitouwadge Area

FIGURE 2.1

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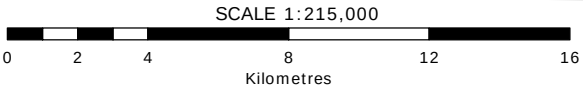
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LEGEND

 Township of Manitouwadge



PROJECTION: UTM NAD83 Zone 16N
SOURCE: Spot 4 and 5, Obtained from Geobase 2012
(data 2005-2010, 10m resolution)
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ? Queens Printer 2011

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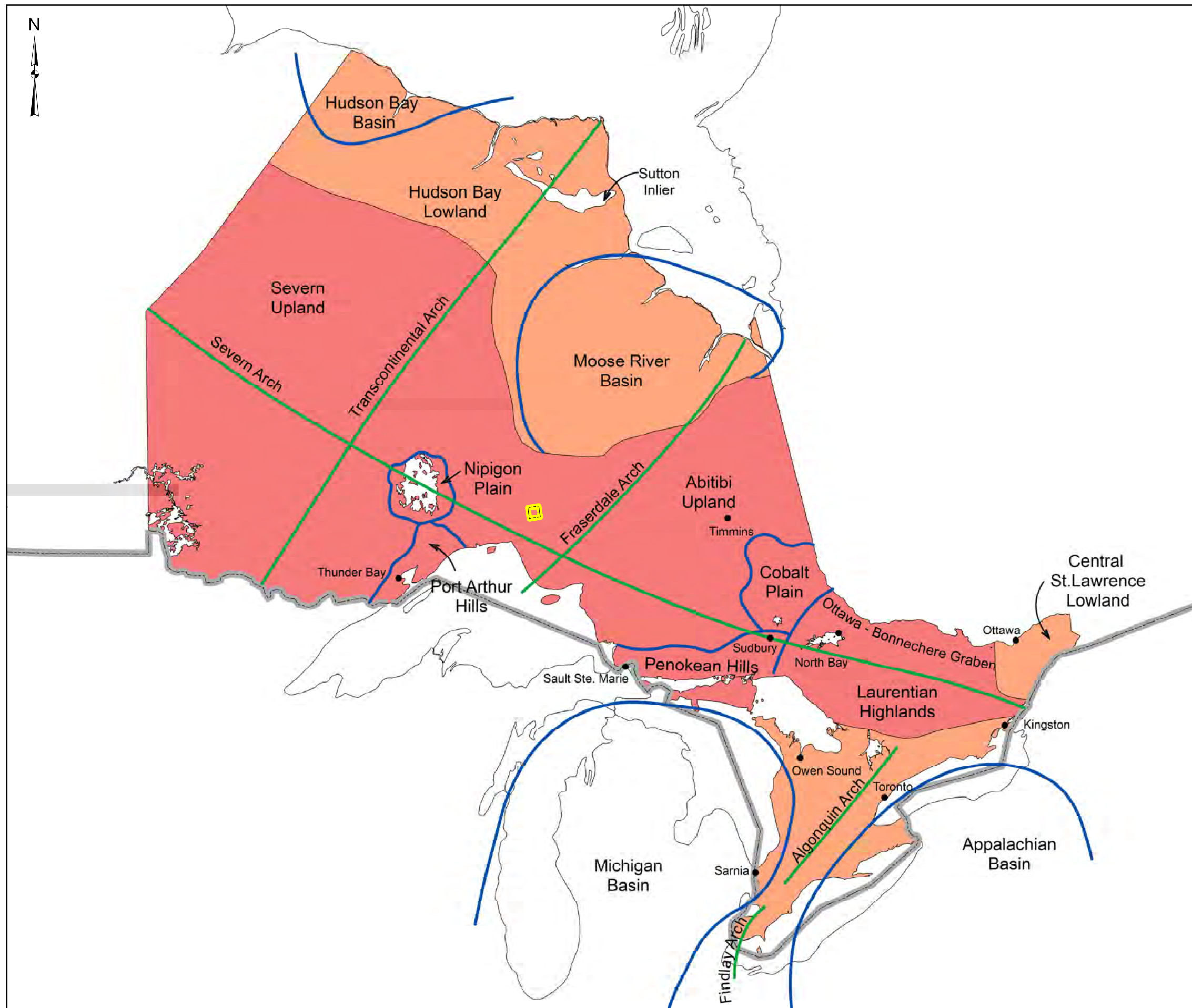
TITLE
Satellite Imagery
of the Manitouwadge Area

FIGURE
2.2

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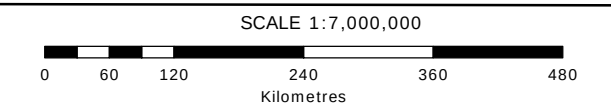


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LEGEND

- Township of Manitouowadge
- International Boundary
- Phanerozoic Borderlands
- Precambrian Canadian Shield



PROJECTION: Lambert Conformal Conic
SOURCE: NRCAN, ESRI Canada
Physiography: Physiographic regions in Ontario based on Bostock (1970) (from Thurston et al. 1991)

PROJECT No. 10-214-6
NWMO Desktop Level Initial Site Screening

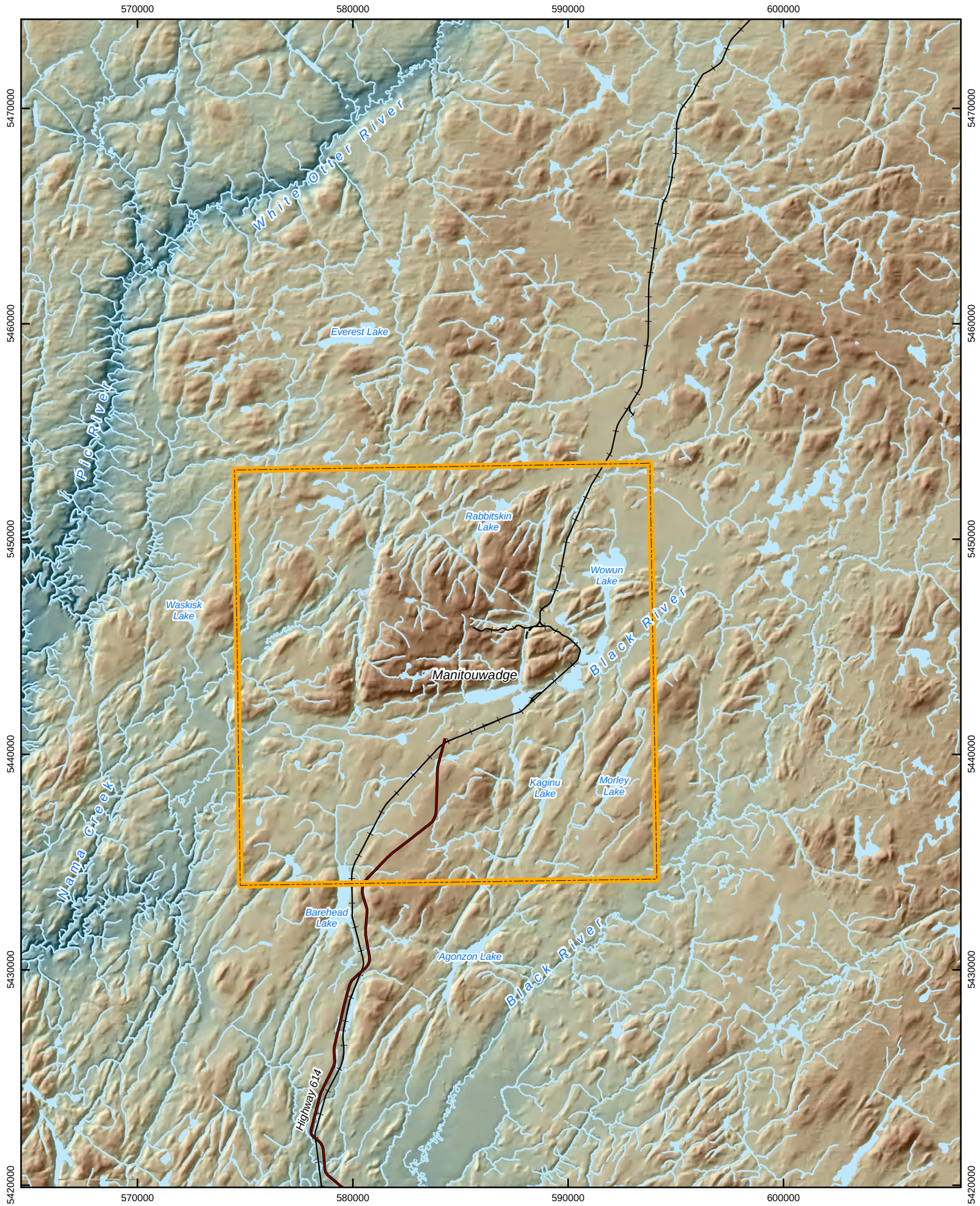
TITLE
Physiographic Regions of Ontario

FIGURE
2.3

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REV: 0
DATE: 04/01/2013



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LEGEND

Township of Manitouwadge

Highway

Railway

Water Area, Permanent

Watercourse, Permanent

Elevation (mASL)

485

465

435

395

365

335

305

275

245

215

195

INDEX MAP

0 2 4 8 12 16

Kilometres

SCALE 1:215,000

PROJECTION: UTM NAD83 Zone 16N
SOURCE: DEM; MNR, obtained 2012
Produced by Geofirma Engineering Ltd under license from
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PROJECT No. 10-214-4

NWMO Desktop Level Initial Site Screening

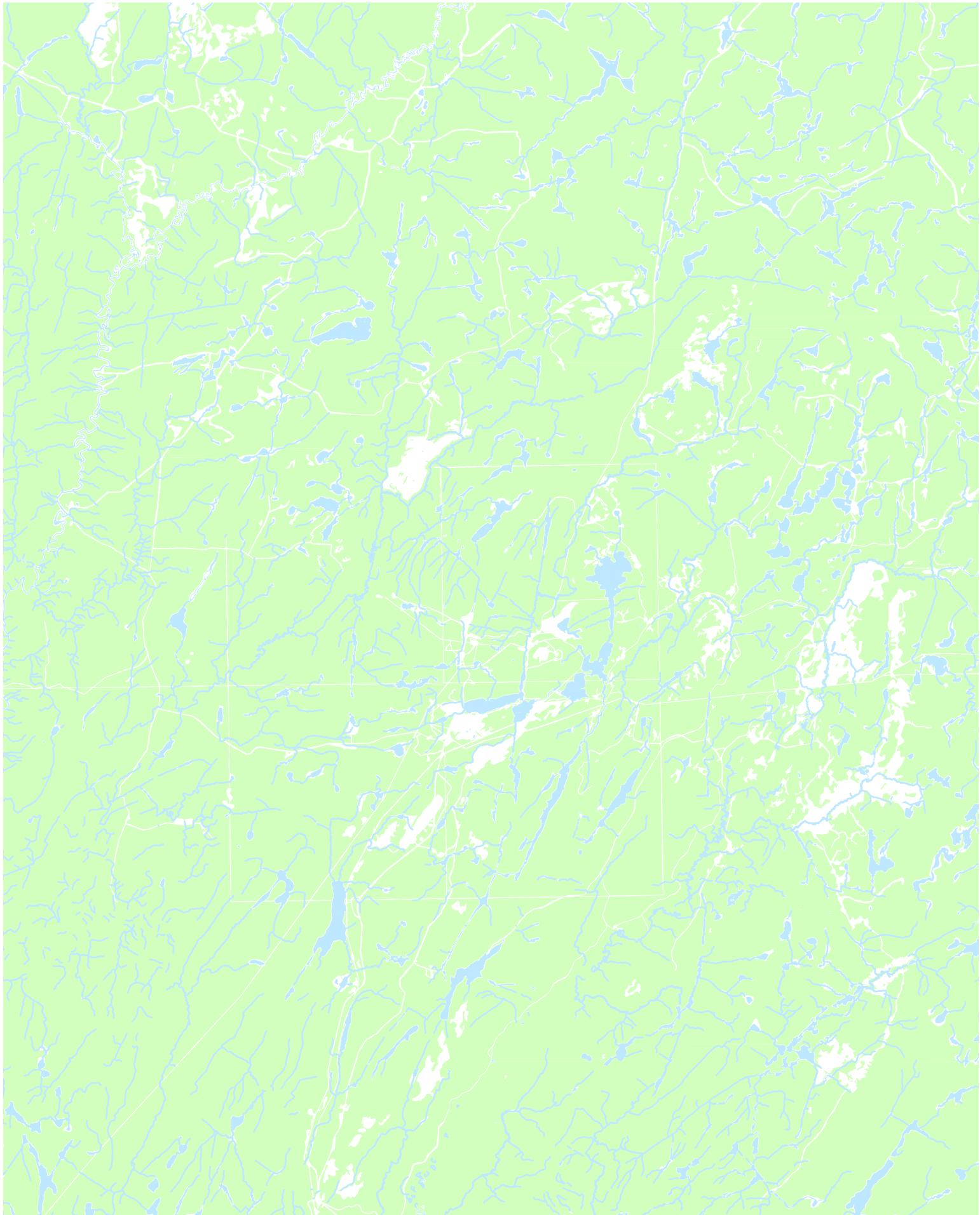
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Digital Elevation Model (DEM)
of the Manitouwadge Area

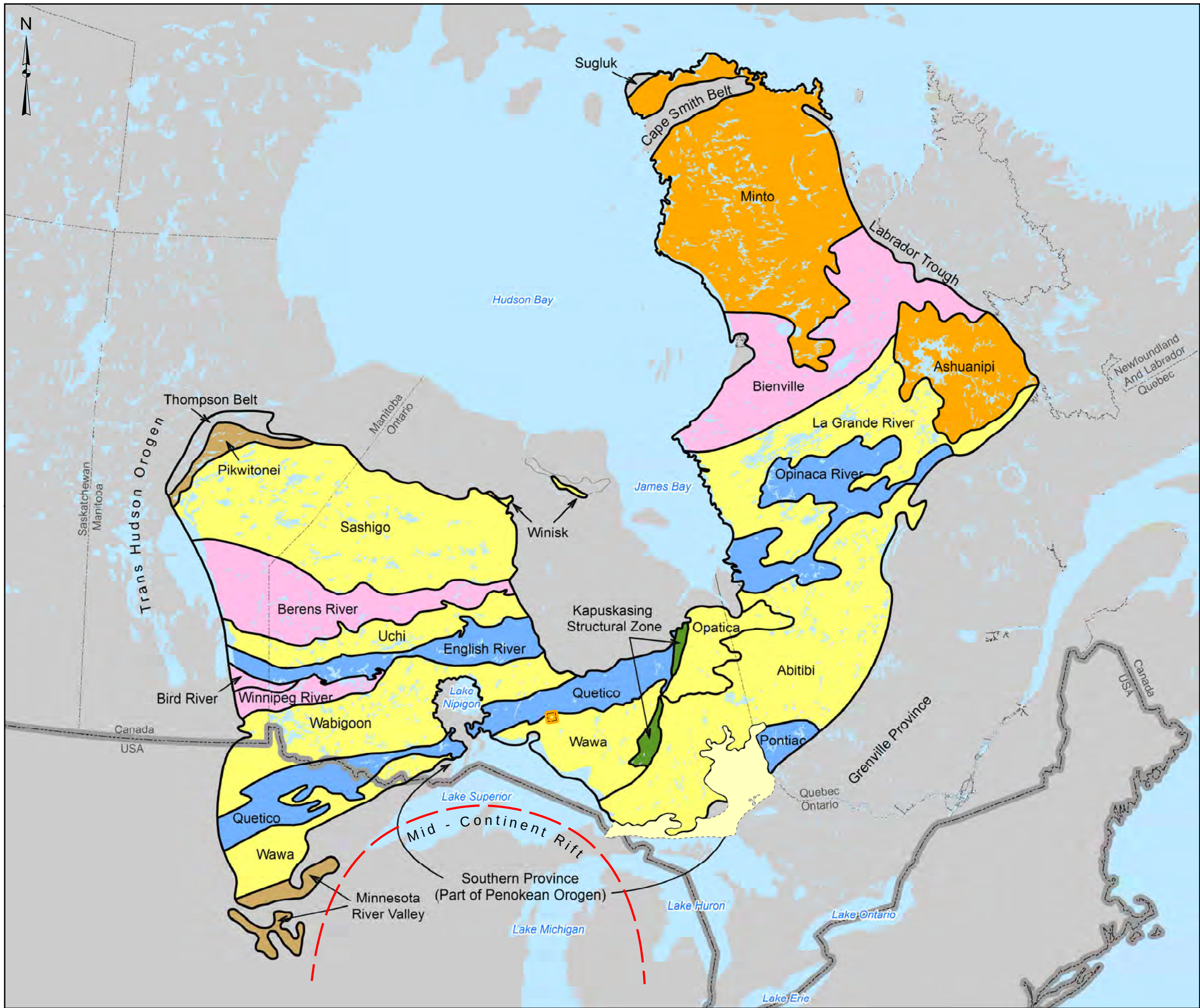
FIGURE
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DATE: 04/01/2013

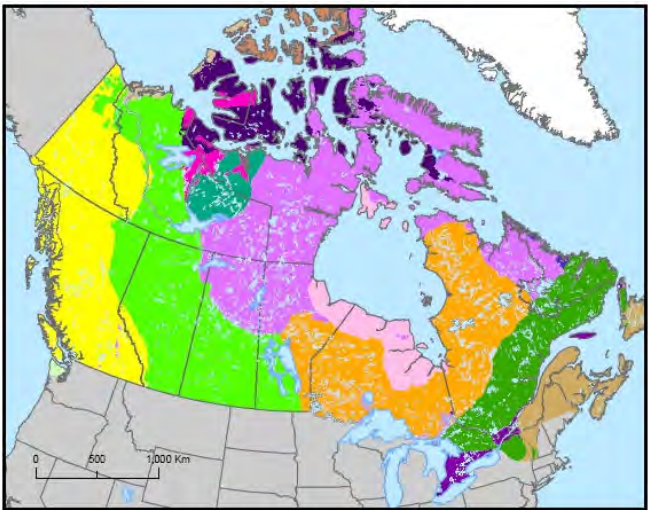


G:\Data\Project\Manitouwadge\10-214-6_NWMO_InitialSiteScreening_Manitouwadge\Figure_3.1_SubdivisionoftheSuperiorProvinceoftheCanadianShield_R0.mxd



LEGEND

- Township of Manitouwadge
- Provincial Boundary
- International Boundary
- Limit of Exposed Archean Rock



Geological Regions of Canada

- | | |
|----------------------------|---------------------------|
| Appalachian Orogen | Innuitian Orogen |
| Arctic Continental Shelf | Interior Platform |
| Arctic Platform | Nain Province |
| Atlantic Continental Shelf | Pacific Continental Shelf |
| Bear Province | Slave Province |
| Churchill Province | Southern Province |
| Cordilleran Orogen | St. Lawrence Platform |
| Grenville Province | Superior Province |
| Hudson Bay Lowlands | Oceanic crust |

SCALE 1:9,500,000



PROJECTION: NAD 1983 Canada Atlas Lambert

SOURCE: MNR, ESRI Canada

Geology of Ontario: Subprovinces of the Superior Province

Canadian Shield, Modified from Card and Ciesieski, 1986

Geology: Geological Map of Canada 1996, Map D1860A

Produced by Geofirma Engineering Ltd under license from

Ontario Ministry of Natural Resources, ? Queens Printer 2011

PROJECT No. 10-214-6

NWMO Desktop Level Initial Site Screening

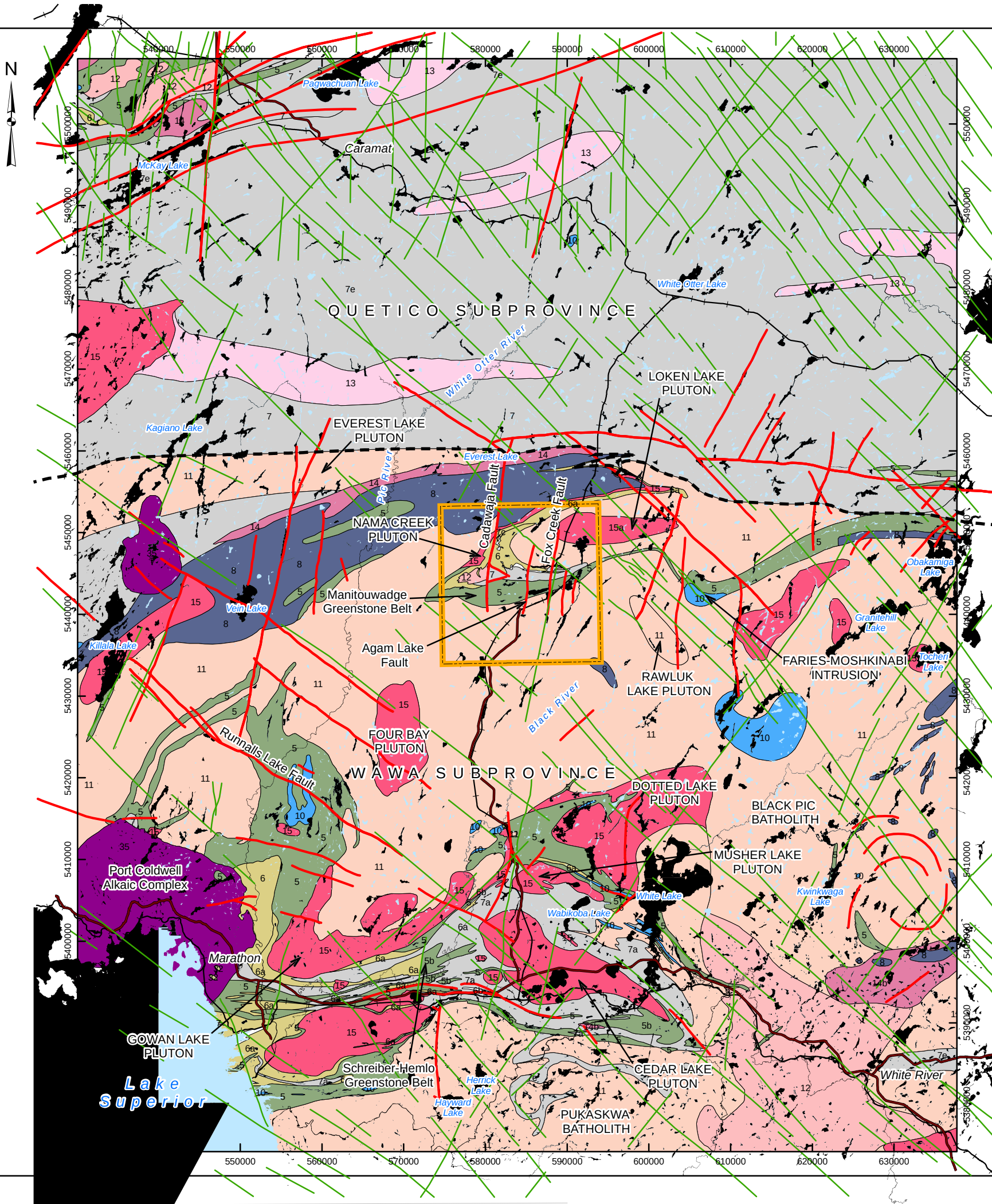
TITLE Subdivision of the Superior Province of the Canadian Shield

FIGURE 3.1

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

DATE: 04/01/2013





LEGEND

- Township of Manitouwadge
 - Highway
 - Railway
 - Water Area, Permanent
 - Subprovince Boundary
 - Geological Fault
 - Dyke
- Bedrock Geology
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
 - 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
 - 15 Massive granodiorite to granite
 - 15a Potassium feldspar megacrystic units
 - 14-Diorite-monzodiorite-granodiorite suite
 - 14b Granodiorite, granite
 - 13 Granite-granodiorite
 - 12 Foliated tonalite suite
 - 11 Gneissic tonalite suite
 - 10 Mafic and ultramafic rocks
 - 8 Migmatized supracrustal rocks
 - 7 Metasedimentary rocks
 - 7a Paragneisses and migmatites
 - 7c Marble, chert, iron formation, minor metavolcanic rocks
 - 7e Paragneiss and migmatites
 - 6 Felsic to intermediate metavolcanic rocks
 - 6a Dacitic and Andesitic flows, tuffs and breccias
 - 5 Mafic to intermediate metavolcanic rocks
 - 5b Basaltic and andesitic flows, tuffs and breccias



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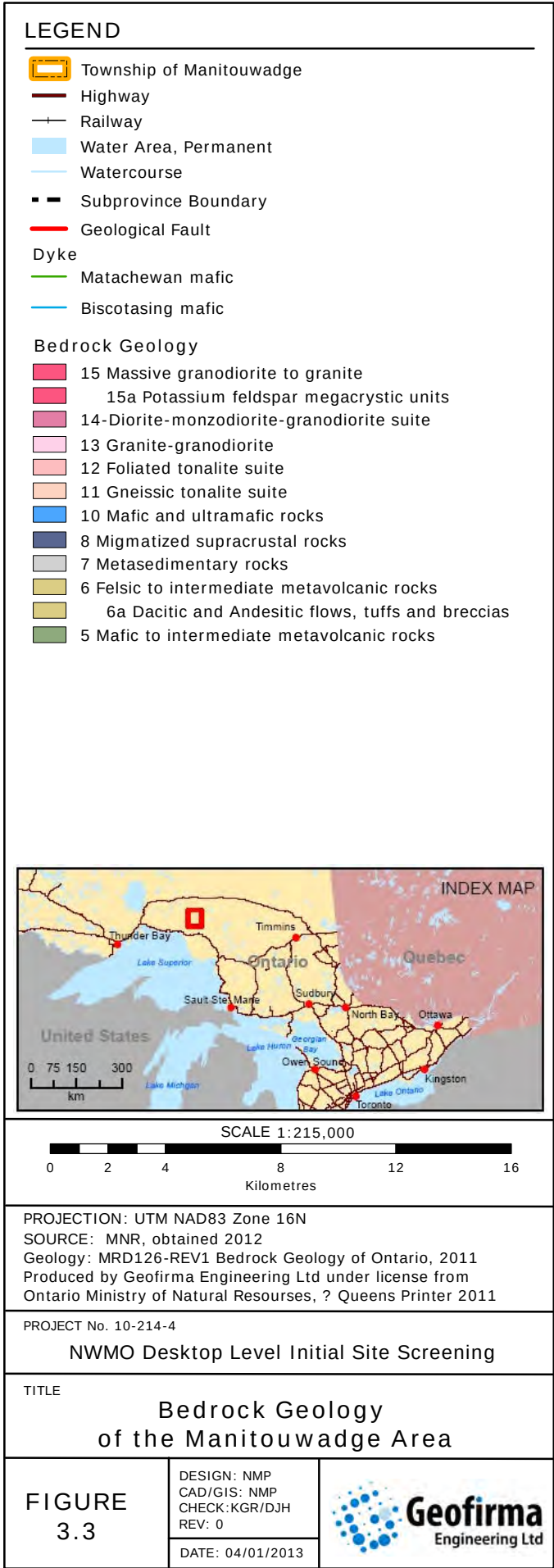
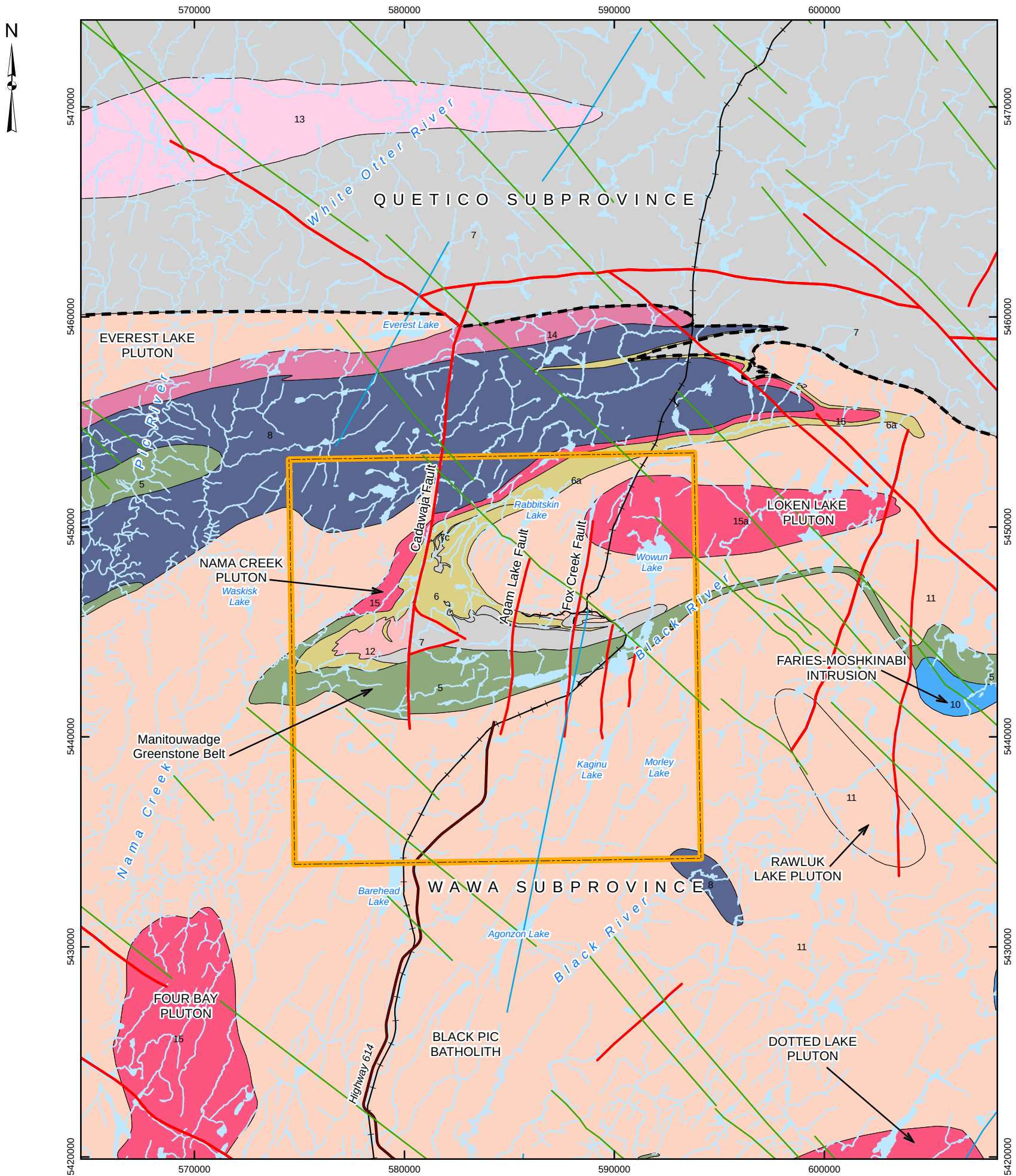
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NWMO Desktop Level Initial Site Screening

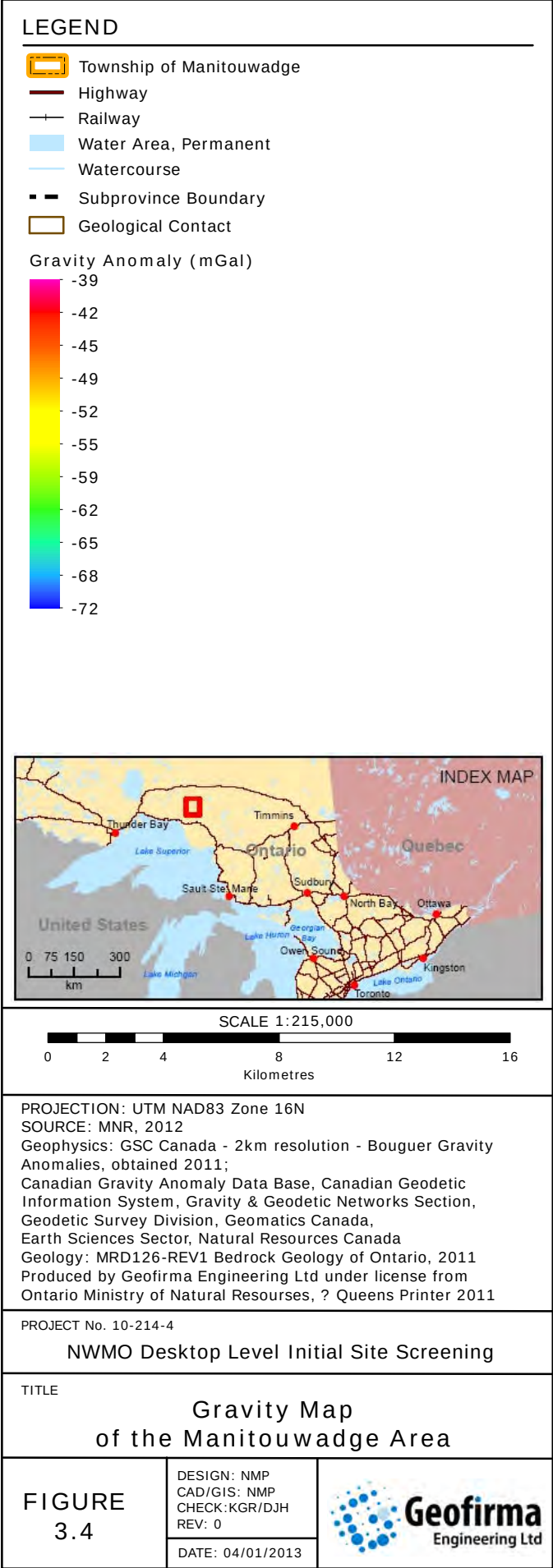
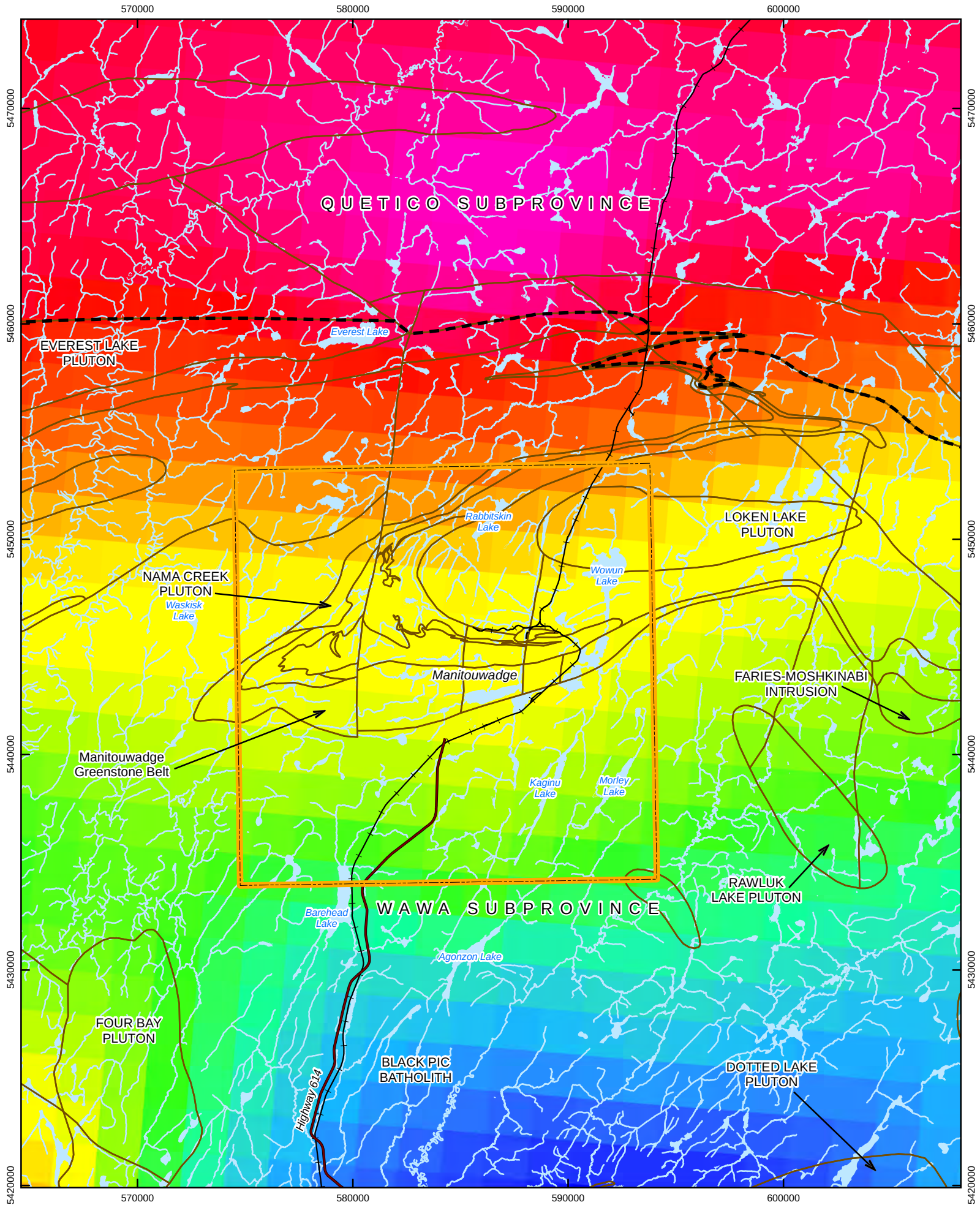
TITLE
Regional Geology of the Manitouwadge Area

FIGURE 3.2	DESIGN: NMP CAD/GIS: NMP CHECK: KGR/DJH REV: 0	
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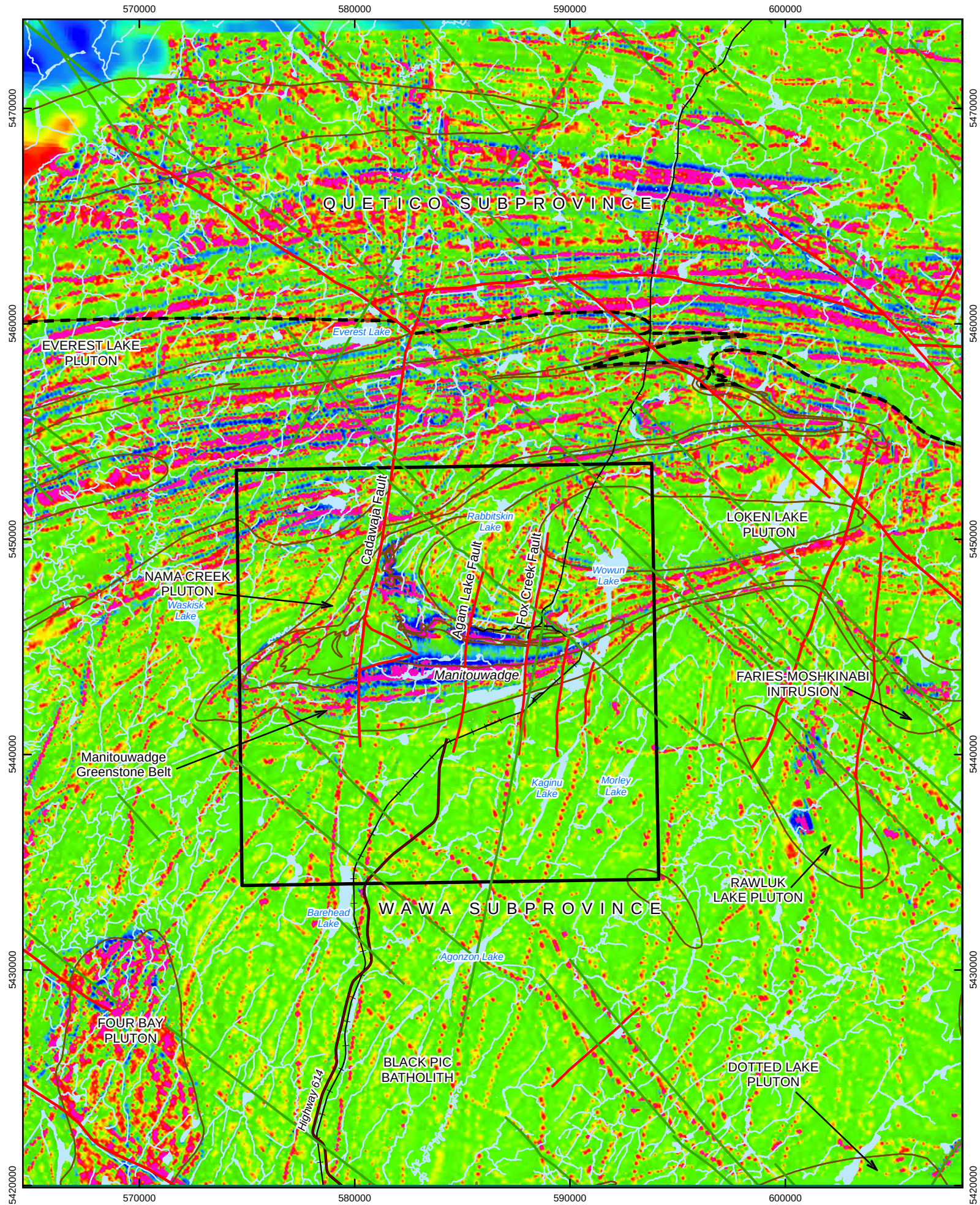
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LEGEND

- Township of Manitouwadge
- Highway
- Railway
- Water Area, Permanent
- Watercourse
- Subprovince Boundary
- Geological Fault
- Dyke
- Geological Contact

Residual Total Magnetic Field (nT)

54.8

0

-30.2

INDEX MAP

0 75 150 300 km

SCALE 1:215,000

0 2 4 8 12 16 Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2012
Geophysics: Geophysical Data Set 1205;
Total Magnetic Field 30m, obtained 2012; Ontario Geological Survey, Ministry of Northern Development and Mines.
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ? Queens Printer 2011

PROJECT No. 10-214-4

NWMO Desktop Level Initial Site Screening

TITLE

Residual Total Magnetic Field
of the Manitouwadge Area

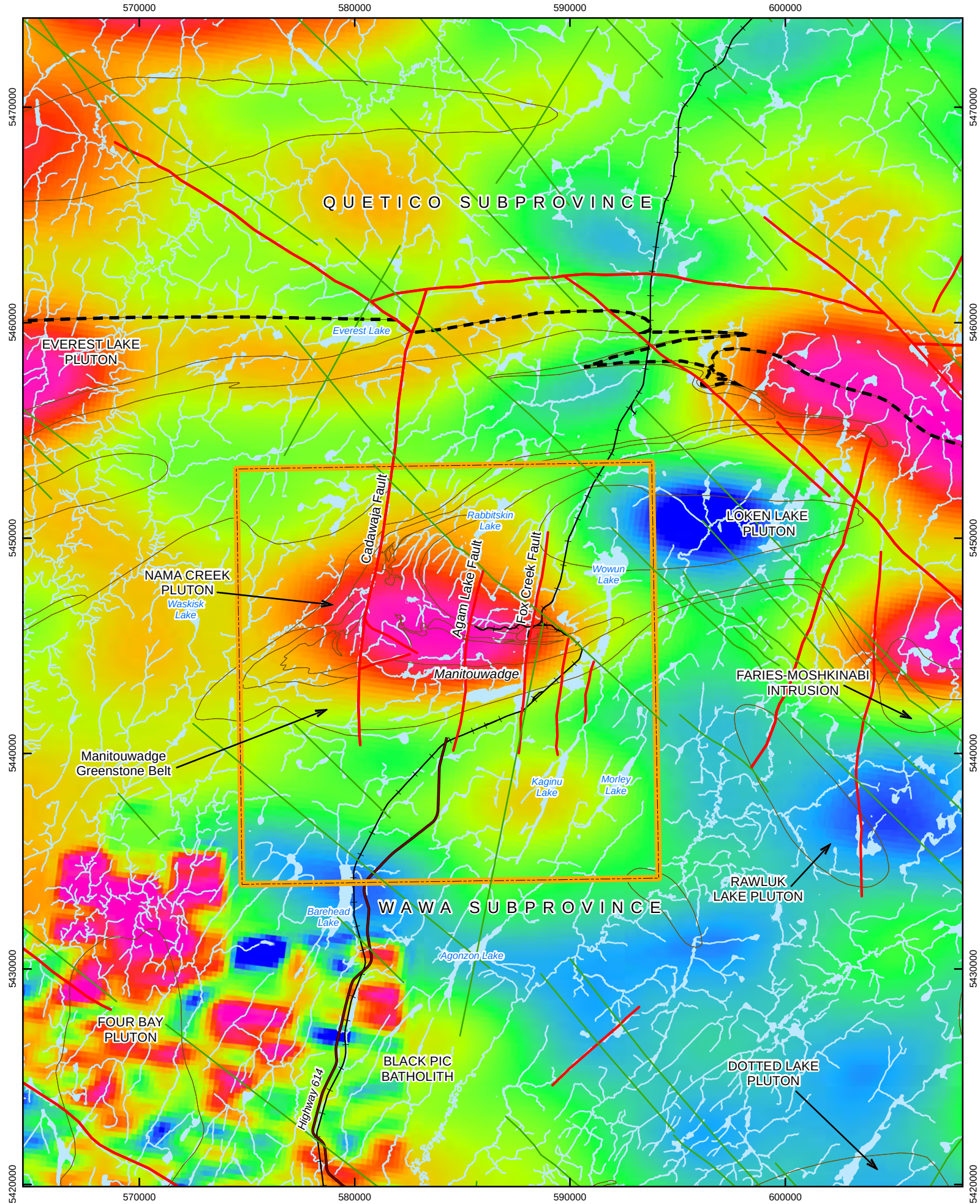
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3.5

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REV: 0

DATE: 04/01/2013

Geofirma
Engineering Ltd

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LEGEND

- Township of Manitouwadge
- Highway
- Railway
- Water Area, Permanent
- Watercourse
- Subprovince Boundary
- Geological Fault
- Dyke
- Geological Contact

Equivalent Uranium (ppm)

1.30
1.16
1.00
0.90
0.76
0.63
0.50
0.36
0.23
0.10
0

INDEX MAP

SCALE 1:215,000

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2012
Geophysics:
Radiometrics: GSC Canada - 250m -Equivalent Uranium, obtained 2012; National Gamma-Ray Spectrometry Program Data Base, Airborne Geophysics Section,GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ? Queens Printer 2011

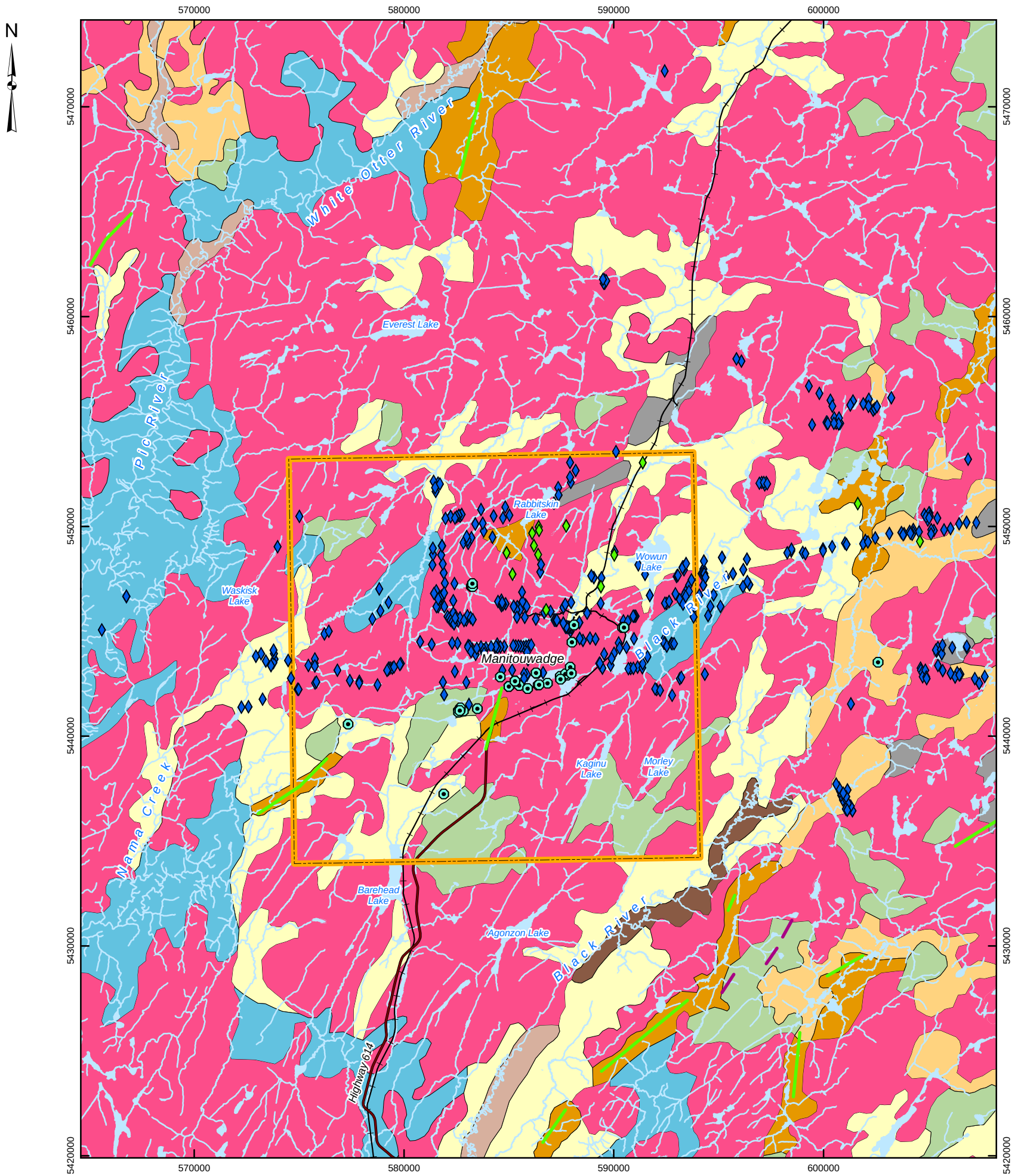
PROJECT No. 10-214-4

NWMO Desktop Level Initial Site Screening

FIGURE 3.6	DESIGN: NMP CAD/GIS: NMP CHECK: KGR/DJH REV: 0	
	DATE: 04/01/2013	

TITLE

**Equivalent Uranium
of the Manitouwadge Area**

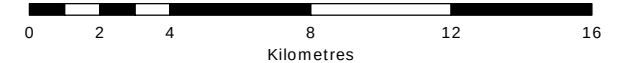


LEGEND

- Township of Manitouwadge
 - Highway
 - Railway
 - Water Area, Permanent
 - Watercourse, Permanent
 - MOE Well
 - Diamond Drillhole
 - Drumlin or Area of Drumlins
 - Esker or Area of Eskers;
Direction of Flow Known or Assumed
- Geology**
- 1: Bedrock
 - 18: Till
 - 22: Glaciofluvial Ice-contact Deposits
 - 23: Glaciofluvial Outwash Deposits
 - 24: Glaciolacustrine Deposits
 - 25: Glaciolacustrine Deposits
 - 28: Fluvial Deposits on Abandoned Flood Plains,
Terrace Remnants
 - 31: Fluvial Deposits on Modern Flood Plains
 - 32: Organic Deposits



SCALE 1:215,000



PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, 2012
Geology: EDS014-Surficial Geology of Ontario 1:1,000,000, 1988
Wells: Ministry of the Environment, 2012
Diamond Drillhole: MRD-126 Bedrock Geology of Ontario 2007
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ? Queens Printer 2011

PROJECT No. 10-214-4

NWMO Desktop Level Initial Site Screening

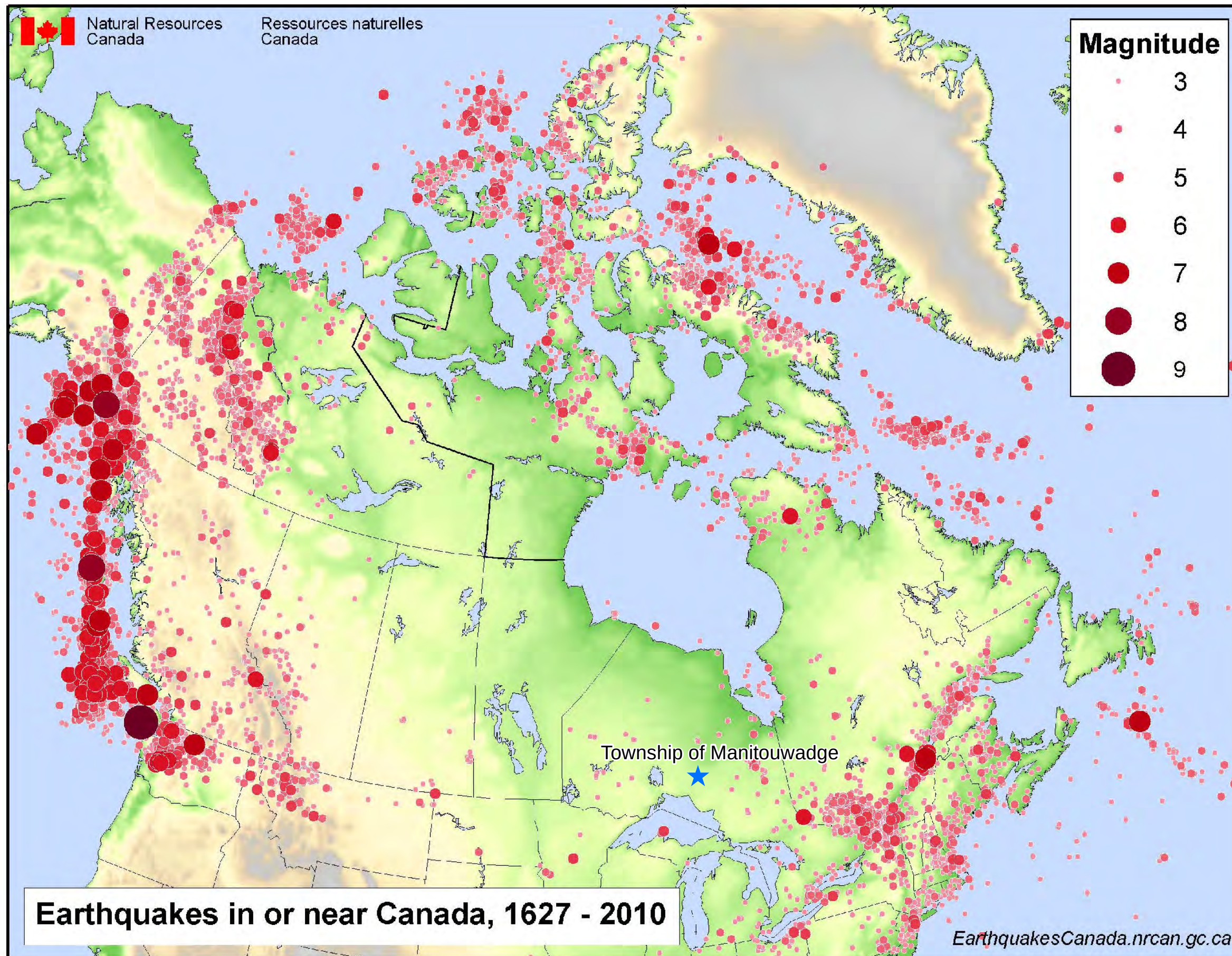
TITLE
**Quaternary Geology
of the Manitouwadge Area**

**FIGURE
3.7**

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/DJH
REV: 0
DATE: 04/01/2013



G:\Data\Project\Manitouwadge\10-214-6_NWMO_InitialSiteScreening_Manitouwadge\Maps\10-214-6_NWMO_InitialSiteScreening_Manitouwadge\MapOfCanada1627-2010_R0.mxd



LEGEND

★ Township of Manitouwadge

Not to Scale

PROJECTION: NA
SOURCE: Seismic: NRCAN, Earthquake Map of Canada 1627-2010

PROJECT No. 10-214-6

NWMO Desktop Level Initial Site Screening

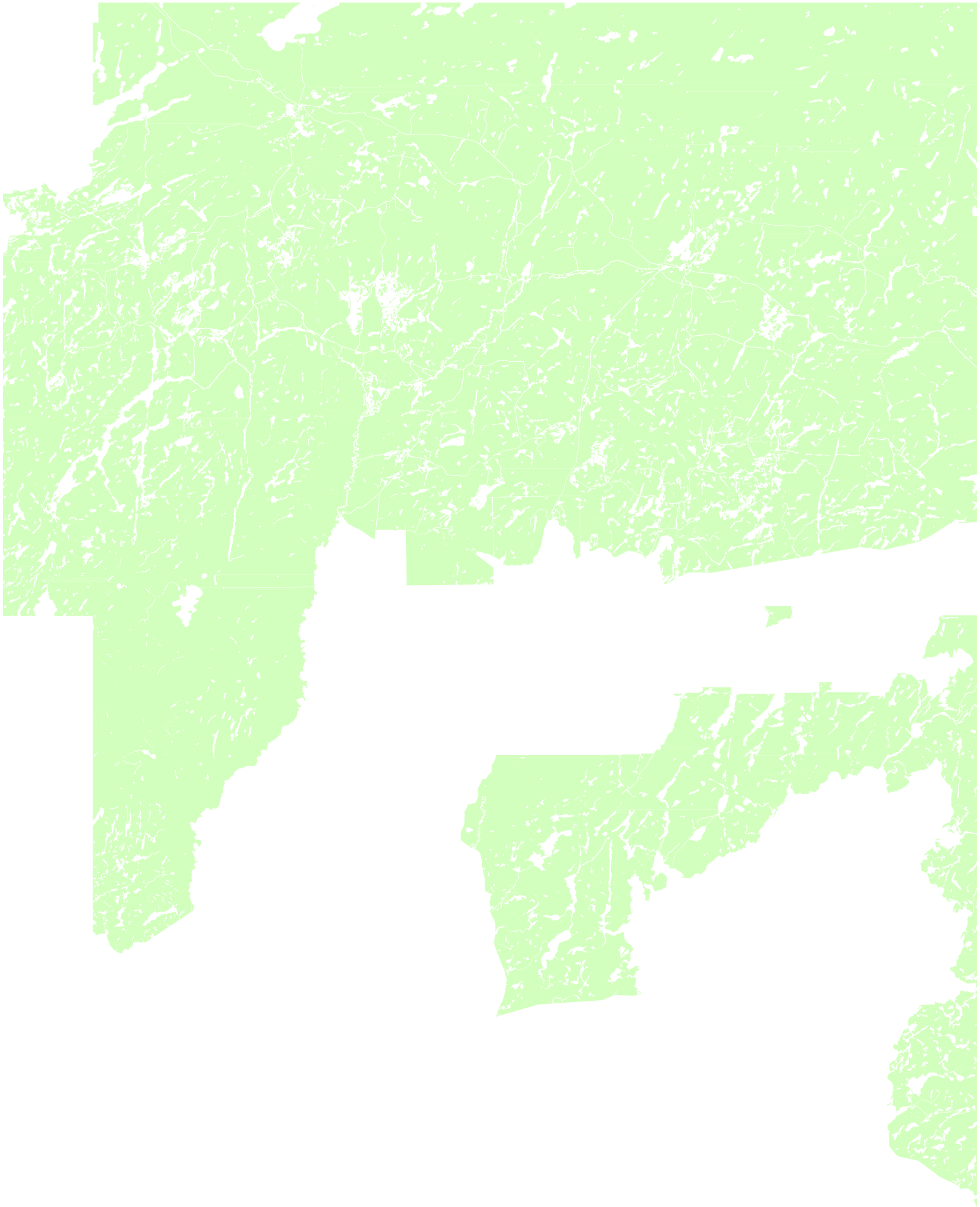
TITLE

Earthquake Map of Canada 1627-2010

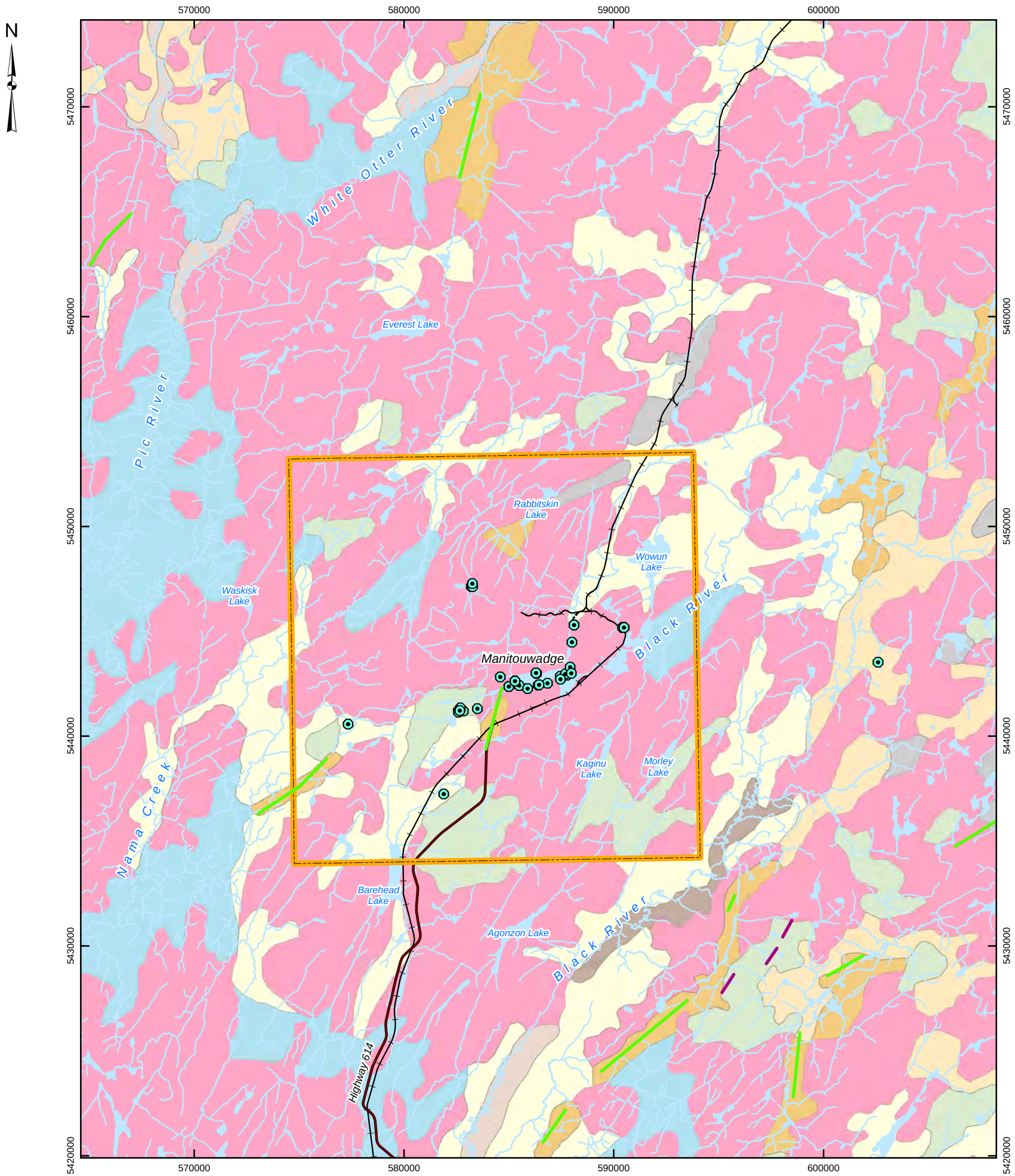
FIGURE
3.8

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/DJH
REV: 0
DATE: 04/01/2013





G:\Data\Project\Manitouwadge\10-214-6_NWMO_InitialSiteScreening_Manitouwadge\Maps\10-214-6_NWMO_InitialSiteScreening_Manitouwadge_Figure_4.1_WaterWellRecords_R0.mxd



LEGEND

Township of Manitouwadge

Highway

Railway

Water Area, Permanent

Watercourse, Permanent

MOE Well

Drumlin or Area of Drumlins

Esker or Area of Eskers;
Direction of Flow Known or Assumed

Geology

1: Bedrock

18: Till

22: Glaciofluvial Ice-contact Deposits

23: Glaciofluvial Outwash Deposits

24: Glaciolacustrine Deposits

25: Glaciolacustrine Deposits

28: Fluvial Deposits on Abandoned Flood Plains,
Terrace Remnants

31: Fluvial Deposits on Modern Flood Plains

32: Organic Deposits

INDEX MAP

SCALE 1:215,000

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2012
Geology: EDS014-Surficial Geology of Ontario 1:1,000,000, 1988
Wells: Ministry of the Environment, 2012
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ? Queens Printer 2011

PROJECT No. 10-214-4

NWMO Desktop Level Initial Site Screening

TITLE		
Water Well Records of the Manitouwadge Area		
FIGURE 4.1	DESIGN: NMP CAD/GIS: NMP CHECK: KGR/DJH REV: 0	
	DATE: 04/01/2013	

