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

TOWNSHIP OF HORNEPAYNE, ONTARIO

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PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

TERRAIN AND REMOTE SENSING STUDY

TOWNSHIP OF HORNEPAYNE, ONTARIO

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EXECUTIVE SUMMARY

In December, 2011, the Township of Hornepayne, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess the potential suitability of the Hornepayne area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Hornepayne and its periphery, referred to as the "Hornepayne area", contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of a terrain and remote sensing assessment completed as part of the desktop geoscientific preliminary assessment of the Hornepayne area (Geofirma, 2013). The main information sources used include the Canadian Digital Elevation Data (CDED) elevation model, the multispectral SPOT satellite imagery and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS).

The assessment addresses the following seven objectives:

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

The report provides an overview of the bedrock and Quaternary geology within the Hornepayne area, including estimates of overburden thickness. Aside from the Arnott Moraine, an interlobate kame moraine, much of the northwest, northeast and southeast quadrants of the Hornepayne area represent low-lying areas underlain by thick overburden deposits. The most extensive area of thin

drift and good bedrock exposure is located within a highland in the southwest quadrant of the area, which is expected to be the main recharge area for shallow bedrock aquifers. Runoff and groundwater discharge from the bedrock highland are transmitted into lowland lakes, rivers, wetlands and overburden deposits.

Using the CDED surface model, drainage divides delineated in the provincial quaternary watershed file were confirmed and subdivided. Apart from a small area in the southwest corner of the Hornepayne area, all surface flow is directed to the northeast.

Highway 631 and a network of resource roads provide reasonably good access for site reconnaissance aimed at preliminary site characterization. However, the most extensive areas of thin drift are the least accessible using the existing road network.

TABLE OF CONTENTS

LIST OF FIGURES (in order following text)

LIST OF TABLES

1 INTRODUCTION

In December, 2011, the Township of Hornepayne, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Hornepayne area for safely hosting a deep geological repository (Step 3). The preliminary assessment is a multicomponent study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations (NWMO, 2013).

This report presents the findings of a terrain and remote sensing assessment completed as part of the geoscientific desktop preliminary assessment of the Township of Hornepayne and its periphery, referred to as the "Hornepayne area" (Geofirma, 2013). The objective of the geoscientific desktop preliminary assessment is to determine whether the Hornepayne area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

1.1 OBJECTIVES

This report presents an analysis of the terrain in the Hornepayne area using existing remote sensing and geoscientific information sources. The aim is to provide information that enhances and expands upon that presented in the initial screening report (Golder, 2011) prepared for the Nuclear Waste Management Organization (NWMO) as part of the Adaptive Phased Management (APM) project for the long term management of Canada's used nuclear fuel. The main information sources relied on in this study are the Canadian Digital Elevation Data (CDED) elevation model, the multispectral SPOT satellite imagery and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS).

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

- Evaluate the nature, areal extent and depth of overburden materials;
- Delineate areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;

- Determine and/or confirm watershed and sub-catchment boundaries;
- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

The objectives above were addressed for the Hornepayne area described in Section 1.2 using the data and methodology described in Section 1.3.

1.2 HORNEPAYNE AREA

The Hornepayne area is a rectangular area approximately 77.8 km by 62.1 km in size, encompassing an area of about 4,800 km^2 (Figure 1). The approximate western, northern, eastern and southern limits of the Hornepayne area are (UTM Zone 16, NAD83): 622574, 5489052, 700337, and 5426953 m. The settlement area of Hornepayne is located along Highway 631 at the intersection with the railway line.

1.3 DATA AND METHODS

This section summarizes the remote sensing and geoscientific data sources available for the Hornepayne area, including an evaluation of the quality of the data. The datasets are all publically available.

1.3.1 NOEGTS

Overburden deposits within the Hornepayne area were mapped as part of a program undertaken between 1977 and 1980 entitled the Northern Ontario Engineering Terrain Study (NOEGTS). These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. The terrain units were delineated by identifying landforms from black and white air photos taken in the late 1960s and early 1970s at a scale of approximately 1:54,000. Interpreted terrain units were checked against published and unpublished maps and reports that documented previous field visits and observations. A limited amount of fieldwork was undertaken in 1978, which involved observing terrain conditions from roads in order to corroborate the aerial photo interpretation. The results of the terrain studies were intended to provide a framework for regional planning and a database on which to conduct site studies. In many areas of northern Ontario, including the Hornepayne area, maps produced from this program currently represent the best level of detail available for surficial geology mapping and descriptions of terrain conditions.

The terrain conditions in the Hornepayne area are described in two main engineering geology terrain studies (Gartner and McQuay, 1980a, b) and two maps at a scale of 1:100,000 (McQuay, 1980a, b; see Figure 3). These reports provide background information on the bedrock and Quaternary geology, followed by descriptions of the occurrence and nature of the engineering geology terrain units outlined on the accompanying maps. The terrain reports include estimates of the distribution and thickness of overburden deposits. They discuss the influence of the terrain conditions on general construction (e.g., location and construction of highways, transmission lines, timber storage sites, town sites, work camp sites, waste disposal sites, cottage subdivisions, airfields), aggregate resource potential (e.g., asphalt aggregate, traffic gravel, base course and subbase for pavement structures) and groundwater resource potential.

Recently, the Ontario Geological Survey (OGS) digitized the NOEGTS maps and published the digital data in the form of a miscellaneous release of data (OGS, 2005a). For the current assessment, JDMA clipped part of the NOEGTS digital map layer and then transformed it from geographic coordinates into Universal Transverse Mercator (UTM) projection (Zone 16).

1.3.2 CDED

Canadian Digital Elevation Data (CDED), 1:50,000 scale, 0.75 arc second (20 m) elevation models (GeoBase, 2011a) served as important data sources for analyzing and interpreting the terrain in the Hornepayne area. The digital elevation model (DEM) used for this assessment was constructed by NRCan using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (OMNR). The data represented 1:20,000 source data acquired through the Ontario Base Mapping (OBM) program, which was a major photogrammetric program conducted across Ontario between 1978 and 1995. Four main OBM datasets were used: OBM contours, OBM spot heights, WRIP stream network, and lake elevations derived using the OBM spot heights and OBM water features. CDED datasets are provided in geographic coordinates, referenced horizontally using North American Datum 1983 (NAD83) and vertically based on the Canadian Geodetic Vertical Datum 1928 (CGVD28). Ground elevations are recorded in metres relative to mean sea level.

CDED generally provides a representation of the land surface that is reasonable for the scale of the data and the underlying photogrammetric method used to generate the elevation data. Relatively poor quality representation can be found in flat areas, where the elevation model is, in some instances, based on elevation values obtained from a single elevation contour, with large areas around the contour where elevation values must be interpolated. These areas display a distinct stair-step or terraced pattern in the DEM. Slope values are relatively steep along the margins of these steps, as the step represents an artificially abrupt shift in elevation.

JDMA converted the elevation matrices provided by GeoBase from geographic coordinates to UTM projection using bilinear resampling, which assigns a value to each output cell based on a weighted average of the four nearest cells in the input raster. Compared with cubic convolution, bilinear resampling can sometimes produce a noticeably smoother surface, whereas cubic convolution can produce a sharper image. However, the differences between the two methods are generally trivial and the selection of bilinear resampling made here was arbitrary. After projection, each file was assembled into a single-band mosaic with a 20 m cell size and 32-bit pixel type.

Surface analyses were performed on the digital elevation model in order to characterize slope and relief. Slope was calculated using the standard grid-based method employed in ArcGIS, which involves fitting a plane to the elevation values of a three by three neighbourhood centred on the processing cell. Slope is defined as the maximum slope of that plane, which can also be thought of as the dip of the plane, and aspect is equivalent to the dip direction. Relief was calculated in two ways. The first was by subtracting the average elevation within a radius from the elevation value in the processing cell. The second was defined as the range in elevation within a circular window. The second relief calculation represents a high pass filter. The density of steep slopes was calculated as the number of points with a slope of at least 6° within a 2 km radius. The threshold of 6° was found to be effective in distinguishing between the rugged bedrock-controlled areas and the areas of gentle slope associated with thicker overburden cover.

Section 4.1 describes the drainage basin analysis conducted in this assessment using the CDED elevation model as the representation of the landscape.

1.3.3 SPOT

SPOT multispectral orthoimagery at a resolution of 20 m formed an important information source for identifying areas of exposed bedrock within the Hornepayne area (GeoBase, 2011b). SPOT multispectral data consist of several bands, each recording reflected radiation within a particular spectral range. SPOT 5 images were acquired using the HRG sensor (Table 1). Each image covers a ground area of 60 km by 60 km. For quality control, NRCan provides images that have a maximum of 5% snow and ice cover, 5% cloud cover and a maximum viewing angle of 15°. NRCan orthorectified the SPOT images using three data sources: 1:50,000 scale Canadian Digital Elevation Data (CDED), National Road Network (NRN), and Landsat 7 orthoimagery. The orthoimages are provided in GeoTIFF format, projected using Universal Transverse Mercator (UTM) projection referenced to the North American Datum 1983 (NAD83).

Four SPOT images provided complete coverage for the Hornepayne area (Table 2). The scenes are from the SPOT 5 satellite with three images acquired in September 2006 and one in May 2007.

Table 1 Characteristics of SPOT 5 multispectral bands.

Satellite, sensor, band no.	Wavelength (μm)	Pixel size (m)
SPOT 5, HRG, B1	0.50-0.59 (Green)	20
SPOT 5, HRG, B2	0.61-0.68 (Red)	20
SPOT 5, HRG, B3	0.78-0.89 (Near-Infrared)	20
SPOT 5, HRG, B4	1.58-1.75 (Shortwave-Infrared)	20

Table 2 List of SPOT 5 multispectral images acquired in this study.

Scene ID	Satellite	Date of image
S5_08415_4925_20060901	SPOT 5	September 1, 2006
S5_08456_4925_20060911	SPOT 5	September 1, 2006
S5_08509_4857_20060911	SPOT 5	September 1, 2006
S5_08426_4857_20070503	SPOT 5	May 3, 2007

In order to assist with the interpretation of the location and extent of bedrock outcrops in the Hornepayne area, JDMA performed two types of multivariate analyses on the SPOT multispectral data: principal component analysis and unsupervised classification. Prior to performing these analyses, water bodies were removed from the SPOT images in order to maximize contrast in the dry areas. This was accomplished by removing values from the shortwave-infrared band (band 4) that were below a threshold. The shortwave band displays a bimodal histogram with one high-valued mode representing dry land surfaces that reflect shortwave radiation and a lower-valued mode for areas that largely absorb shortwave radiation. The latter generally represents water bodies, but can also represent dark forest areas or shadows in front of north-facing cliffs where sunlight is absorbed.

Principal component analysis based on all four SPOT bands was found to generate composite images that provided the best definition of the various land cover types thereby enabling optimal interpretation of the presence of bedrock exposures. For that purpose, principal component analysis generally produced composite images that were at least slightly superior to those produced by combining any of the raw SPOT bands. For each image, four components were generated and then the first three components were used to generate the composite image, referred to as the PCA composite image. Campbell (1987) provides more information on the use of principal component analysis in remote sensing.

An unsupervised classification aimed at mapping bedrock exposures was attempted, but was eventually abandoned and is only described below for reference. Unsupervised classification generates distinct unimodal groups from the four SPOT bands using an iterative self-organizing (ISO) cluster procedure employed within ArcGIS. The ISO cluster algorithm is an iterative process that computes the minimum Euclidean distance when assigning each candidate cell to a cluster. The first step that JDMA took in the unsupervised classification was to classify the four SPOT bands into fifteen classes and to interpret the fifteen classes in light of the features (e.g., bedrock outcrops, clearcuts) interpreted in the PCA composite image. If a set of the fifteen classes delineated the interpreted bedrock exposures exclusively, then this completed the classification and these classes were used to generate a map depicting bedrock exposures. However, in many cases the classes mapping bedrock exposures also mapped wetlands and clearcuts. The next step was to mask the four SPOT bands in order to exclude areas that were both distinctly unrelated to bedrock exposures and effectively delineated by a set of classes, such as areas with a high vegetation index. The cluster analysis was then performed a second time on the masked data.

After several attempts at the unsupervised classification, the only areas where this type of technique could be used in a straightforward way were in the areas undisturbed by the forest industry in recent decades. It is difficult to make an accurate appraisal of the extent of bedrock exposure within fresh clearcuts. Some of the exposed land within fresh clearcuts represents exposed mineral soil rather than bedrock. Even in the areas not disturbed by the forest industry, there remain challenges in using unsupervised classification to map the exposed bedrock accurately and reliably. For instance, certain parts of wetlands can exhibit similar spectral characteristics as exposed bedrock. Alluvial sediments exposed in creek valleys also display similar spectral properties. Additional issues contribute to the unreliability of this technique. As a result, the identification of bedrock exposure from SPOT imagery in this assessment (Section 5.2) has relied on the PCA composite images.

1.3.4 DRILL HOLES AND WATER WELLS

A preliminary review was made of data on overburden thickness obtained from databases compiled by the OGS and the Ontario Ministry of the Environment (MOE). Section 5.1 summarizes the results of the subsurface information reviewed. Additional subsurface information that could be available from the OGS Resident Geologist Program has not been reviewed.

Water well records from the Ministry of the Environment (MOE) Water Well Information System for the Hornepayne area were acquired (MOE, 2012). Out of the 71 well records in the Hornepayne area, thirty-three well records were found to contain data on depth to bedrock, most of which are located near the settlement of Hornepayne. The wells were drilled between 1959 and 1992.

The Ontario Drill Hole Database was compiled by the Ontario Geological Survey from assessment files, with the most recent official release of the database in December 2005 (OGS, 2005b). A preliminary analysis of the drill hole database was completed during this assessment.

OGS establishes the geographic coordinates of the drill holes using one of a variety of methods, including some approximate georeferencing methods, such as positioning the drill hole in the centre of a claim for lack of additional supporting information. As a result, the location of the drill holes can be off by hundreds of metres in some cases. This makes interpreting the depth to bedrock information in light of terrain conditions interpreted from SPOT imagery difficult, as a distance of 100 to 200 m can mean the difference between a hilltop location and a location between rock ridges where drift would be expected to be thicker.

Drill holes near the Hornepayne area are generally located in the central portion of the area, within the metasedimentary and migmatitic rocks of the Quetico Subprovince. All of the drill holes are inclined, with the dip angles of the drill holes ranging from 38 to 79°. As a result, the vertical depth to bedrock had to be calculated from the recorded dip angle and length of drill hole to bedrock.

Data on depth to bedrock obtained from the Ontario Drill Hole Database must be interpreted carefully. Drilling often is carried out in areas where extensive stripping of the overburden has taken place, and some drill sites might be preferentially located in areas of thin overburden, biasing the drift thickness data to low values.

2 SUMMARY OF GEOLOGY

The Hornepayne area, shown in Figure 1, is underlain by a patchy to continuous cover of glacial soils and the approximately 3.0 to 2.6 billion year old bedrock of the Superior Province of the Canadian Shield – a stable craton that forms the core of the North American continent (Figure 2). The Canadian Shield is an assemblage of Archean-age plates and accreted juvenile arc terranes and sedimentary basins of Proterozoic age that were progressively amalgamated over geologic time scales.

The Hornepayne area straddles the boundary between the Quetico and Wawa subprovinces of the Superior Province. The Quetico Subprovince has mainly gneissic and migmatized metasedimentary rocks and the Wawa Subprovince is composed primarily of Archean greenstone belts and granitic intrusions, with smaller mafic intrusive rocks locally present. Mafic metavolcanic rocks are irregularly distributed across the Hornepayne area (Figure 2), including thin east-trending slivers proximal to the subprovince boundary, and a larger body that extends southeastwards beyond the southeastern corner of the area. Diabase dykes, largely of Proterozoic age, occur in "swarms" in the entire Superior Province and in the Hornepayne area (Figure 2).

2.1 BEDROCK GEOLOGY

The bedrock geology of the Hornepayne area is described in detail in Geofirma (2013) and the following is a summary of that information. Most of the Hornepayne area has only been subject to reconnaissance level bedrock geological mapping (Geofirma, 2013).

The Superior Province has been divided into various subprovinces based on lithology, age, genesis and metamorphism (Thurston, 1992; Stott et al., 2010). The Hornepayne area straddles the boundary of the Quetico and the Wawa subprovinces, with the north half of the Hornepayne area being situated in the Quetico Subprovince (Figure 2). About 150 km to the east, the Quetico and Wawa subprovinces are truncated by the Kapuskasing structural zone that separates these subprovinces from the Abitibi Subprovince (and is sometimes referred to as the Abitibi-Wawa belt).

Figure 2 shows the general bedrock geology and main structural features of the Hornepayne area. The Wawa-Quetico subprovince boundary crosscuts the Hornepayne area and separates the metasedimentary and granitic rocks of the Quetico Subprovince to the north from the Black-Pic batholith of the Wawa Subprovince to the south. Thin slivers of metavolcanic rocks of the

Manitouwadge-Hornepayne greenstone belt are mapped within the Black-Pic batholith and along the subprovince boundary. Paleoproterozoic diabase dykes are abundant in the Hornepayne area and include the dominant northwest-trending Matachewan swarm, and the subordinate northeast-trending dykes of Biscotasing and Marathon/Kapuskasing suites.

The initial screening report for the Hornepayne area (Golder, 2011), identified several potentially suitable geologic units within the Hornepayne area. These geologic units include the metasedimentary rocks and granitic-granodioritic intrusions of the Quetico Subprovince, and the Black-Pic batholith of the Wawa Subprovince. These potentially suitable geologic units are shown on Figure 2.

2.1.1 METASEDIMENTARY ROCKS OF THE QUETICO SUBPROVINCE

Much of the bedrock of the Quetico Subprovince in the northern half of the Hornepayne area is variably exposed and has only been mapped at a reconnaissance level. In the Hornepayne area bedrock in the Quetico Subprovince is dominated by highly metamorphosed and migmatized clastic sedimentary rocks, including also tonalitic gneiss, slivers of mafic metavolcanic rock, granodiorite of uncertain origin, and granitic rocks derived from partial melting of the sedimentary rocks.

The precursor sedimentary rocks were typically composed of turbidite successions derived from the erosion of adjacent volcanic arcs (granite-greenstone terranes) either adjacent to the Quetico Subprovince or conceivably derived from other granite-greenstone terranes hundreds of kilometres away. The deposition of the original sedimentary rocks in the southern Quetico Subprovince was initiated approximately 2.698 billion years ago, and its termination is constrained to approximately 2.688 billion years ago (Zaleski et al., 1999).

The thickness of the Quetico Subprovince metasedimentary rocks is estimated to be at least 7.5 km (Percival, 1989), although the thickness is interpreted to decrease along the boundary between the Quetico and Wawa subprovinces, where the metasedimentary rocks are thought to be underlain by rocks of the Wawa Subprovince (Percival, 1989).

2.1.2 GRANITIC-GRANODIORITIC INTRUSIONS OF THE QUETICO SUBPROVINCE

Approximately 10 and 20 km to the north of the Township of Hornepayne are two large east-trending, muscovite-bearing, granitic intrusions (Figure 2), each approximately 7 km by 30 km in size and likely derived from partial melting of the metasedimentary rocks (Percival, 1989;

Williams et al., 1992). Similar, though smaller, bodies are mapped approximately 20 km to the east of the Township. No information regarding the thickness of these bodies was found in the available literature. There is some uncertainty whether these bodies are the end point of in situ migmitization of the metasedimentary rocks or true intrusions.

2.1.3 BLACK-PIC BATHOLITH OF THE WAWA SUBPROVINCE

The Black-Pic batholith is a regionally-extensive intrusion that roughly encompasses an area of 3,000 km^2 covering the southern half of the Hornepayne area and extending west and south beyond the Hornepayne area (Figure 2; Fenwick, 1967; Stott, 1999). It is mostly composed of well foliated to gneissic granodiorite to tonalite (Milne, 1968), with phases of hornblende-biotite, monzodiorite and pegmatitic granite largely restricted to the margins of the batholith. Within the Hornepayne area, the Black-Pic batholith is described as a gneissic tonalite that locally includes biotite and/or amphibole-bearing tonalite (Williams and Breaks, 1996; Johns and McIlraith, 2003).

The age of emplacement of the Black-Pic batholith is poorly constrained. The oldest phase of this batholith has been dated at approximately 2.720 billion years old (Jackson et al., 1998, whereas the youngest phase is estaimted to be approximately 2.689 billion years old (Zaleski et al., 1999). No information on the thickness of the batholith was found in available literature.

The Black-Pic batholith is interpreted to be a domal structure, with slightly dipping foliations radiating outwards from its centre. 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 by granitic sheets of pegmatite and aplite and are generally more massive (Williams and Breaks, 1989).

Zones of migmatized sedimentary rocks and zones of massive granodiorite to granite exist within the batholith. The contact between these rocks and the tonalitic rocks is relatively gradational with extensive sheeting of the tonalitic unit apparent (Williams and Breaks, 1989; Williams et al., 1992). Of note in the Black-Pic batholith is a massive to foliated granitic to granodioritic intrusion located in the southeastern part of the Hornepayne area.

2.1.4 MAFIC DYKES

Paleoproterozoic diabase dykes are abundant across the Hornepayne area, dominated by the northwest-trending Matachewan swarm that was emplaced approximately 2.45 billion years ago

(Heaman, 1997). The northeast-trending dykes comprise two suites: the approximately 2.17 billion year old Biscotasing suite and the approximately 2.11 billion year old Marathon/Kapuskasing suite (Halls et al., 2008). Both sets of diabase dykes cross-cut all other rock types in the Hornepayne area, including the metasedimentary rocks, greenstone belts, and granitoid plutons of the Quetico and Wawa subprovinces. The density of diabase dykes in this area tends to mask the magnetic signatures of the surrounding Archean bedrock lithologies. A further, more detailed subdivision of the dyke swarms north of 49° 30' was interpreted from aeromagnetic data by Stott and Josey (2009) based on orientation and previous work by Halls and others (Halls et al., 2008; Halls and Davis, 2004; Ernst and Halls, 1983). This dyke mapping was extended southwards for the revised Bedrock Geology of Ontario compilation map (OGS, 2011).

2.1.5 Faults

The east- west trending Quetico-Wawa subprovince boundary, which cross-cuts the Hornepayne area (Figure 2), is characterized as a major shear zone. Evidence for faulting along the subprovince boundary is generally not well documented. Inferred faults on the compilation map of Johns and McIlraith (2003) are based on earlier mapping, typically derived from air photo lineament interpretations. West of the Hornepayne area, mapping by Zaleski and Peterson (2001) has recorded no evidence of faulting along the subprovince boundary, either from lack of geophysical offsets or insufficient bedrock exposure. Similarly, other sections along the Quetico-Wawa boundary show little or no evidence of faulting (Williams et al., 1992).

There is one east-trending fault, and numerous northeast- and northwest-trending smaller-scale faults mapped (OGS, 1991) within the Hornepayne area (Figure 2). The east-trending fault runs along the Wawa-Quetico subprovince boundary in the western half of the Hornepayne area, extending well beyond it. The mapped northwest- and northeast-trending faults parallel Paleoproterozoic diabase dykes of the Matachewan swarm and the Biscotasing - Marathon/Kapuskasing suite.

2.1.6 Metamorphism

In general, there is limited local preservation of pre-Neoarchean metamorphism within the Canadian Shield (e.g., Breaks and Bartlett, 1991; Percival and Skulski, 2000). The Superior Province largely preserves low pressure – low to high temperature Neoarchean metamorphism, from ca. 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002; Berman et al., 2005).

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the lithologic composition of the subprovinces (Easton, 2000; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest, Neoarchean metamorphism of lower greenschist to amphibolite facies in volcano-sedimentary assemblages and synvolcanic to syntectonic plutons. Both metasedimentary and associated migmatite-dominated subprovinces, such as the English River and Quetico subprovinces, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River Subprovince, display younger, syntectonic middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al., 1995).

Sub-greenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993). Most late orogenic shear zones in the Superior Province experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through 40Ar/39Ar dating to ca. 2.5 billion years ago, the value of which remains unclear (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic eons. In northwestern Ontario, the concurrent post-Archean effects, are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al., 1990 and references therein).

In northeastern Ontario, the Kapuskasing structural zone, east of the Hornepayne area, documents a preservation of ca. 1.9 billion years ago thrust-uplifted, westward tilted Archean crust exposing greenschist facies rocks from <10 km depth in the west near the settlement area of Wawa to granulite facies metamorphism in the east side of the zone through erosion up to 30 km depth (Percival and West, 1994). Approximately 1 billion years ago far-field reactivation of faults by compression from the Grenville orogeny caused potential but poorly documented lower greenschist metamorphism along pre-existing faults are largely restricted to the vicinity of Lake Nipigon and near Lake Superior (Manson and Halls, 1994).

Overall, most of the Canadian Shield, outside of unmetamorphosed, late tectonic plutons, contains a complex episodic history of metamorphism largely of Neoarchean age with broad tectonothermal overprints of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville orogeny ca. 0.95 billion years ago.

2.2 GEOLOGICAL AND STRUCTURAL HISTORY

Direct information on the geological and structural history of the Hornepayne area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown in Figure 2, drawing particularly on information from the area around the Township of Manitouwadge, west of the Hornepayne area. It is understood that there are potential problems in applying a regional Dx numbering system into a local geological history. Nonetheless, the summary below represents an initial preliminary interpretation for the Hornepayne area, which may be modified after site-specific information has been collected.

The geological and structural history of the Hornepayne area described below can be summarized as a tectonic succession of events following one major episode of volcanism on the northern margin of the Wawa Subprovince, concurrent with and followed by clastic sedimentation and iron formation deposition dominantly within the Quetico Subprovince (Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001; Williams and Breaks, 1996).

Synvolcanic plutons are spatially associated with volcanic rocks and subsequently highly metamorphosed and deformed remnants of volcanic and metasedimentary host rocks (Zaleski et al., 1999; Zaleski and Peterson, 2001). Syn-orogenic activity included the exhumation and erosion of the Wawa Subprovince, deposition of sediments into the approximately 2.698 to 2.688 billion year ago Quetico basin (Zaleski et al., 1999), and emplacement of the approximately 2.689 billion year old Black-Pic batholith and granitic and gabbroic plutons and stocks (Zaleski et al., 1999). This later emplacement pre-dates and post-dates major collisional folding and refolding during transpressional deformation across the Wawa – Quetico subprovince boundary.

Uplift and cooling of major plutonic bodies was followed by brittle fractures formed during residual late orogenic stress. Three and possibly four Proterozoic diabase dyke swarms intruded this region with the most prominent being the northwest-trending Paleoproterozoic Matachewan dykes (approximately 2.444 billion years ago) and the less frequent northeast-trending dykes of the approximately 2.17 billion year old Biscotasing suite and the approximately 2.11 billion year old Marathon/Kapuskasing suite (Halls et al., 2008; Stott and Josey, 2009). Proterozoic reactivation of Archean faults is suspected based on thermal resetting of biotite radiometric ages to Paleoproterozoic ages in this region (Manson and Halls, 1997) relatable to the uplift of the Kapuskasing structural zone to the east.

The relative sequence of Archean faulting across the Hornepayne area (Williams and Breaks, 1989; Peterman and Day, 1989; Percival and Peterman, 1994) indicates that the oldest faults tend to be more ductile and east-trending, concurrent with or followed by northwest- and northeast-trending ductile to brittle-ductile faults, followed by late, brittle north-trending faults. Subsequent brittle faulting of uncertain age occurs along each of these trends.

The structural style across the Quetico – Wawa subprovince boundary is well characterized by structural mapping conducted over the years from Minnesota (Schultz-Ela and Hudleston, 1991) to the Shebandowan greenstone belt, west of Thunder Bay (Stott and Schwerdtner, 1981; Williams et al., 1992) and the Manitouwadge belt (Peterson and Zaleski, 1999; Zaleski et al., 1999; and Zaleski and Peterson, 2001). In general, two major penetrative deformation events are observed along the length of the Quetico Subprovince and the adjacent boundary with the Wawa Subprovince. The first deformation event is pre- to syn-metamorphic. The second penetrative deformation event either refolds or overprints structures formed during the first event and is responsible for the widespread upright to moderately inclined and east-plunging folds defined by the lithologic layering at Manitouwadge and locally by iron-rich formations folded within the metasedimentary rocks of the Quetico Subprovince.

These large fold structures formed as a consequence of oblique, south-southeast directed collision between granite-greenstone subprovinces (terranes), following northward subduction of terranes evidenced from Lithoprobe studies in Ontario (e.g., Percival et al., 2006), during the final tectonic assembly of the Superior Province at around approximately 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 micro-continents to the north and south. Consequently, the more migmatitic matrix that dominates the Quetico Subprovince forms complex folds and refolds and some of the plutons appear to form metamorphosed, doubly-plunging domical structures (Peterson and Zaleski, 1999; Williams, 1992).

Table 3 provides a simplified summary of the geological history of the Hornepayne area.

Table 3 Summary of the geological and structural history of the Hornepayne area.

Time period (Ga)	Geological event
ca. 2.72	Oceanic arc to plume-generated volcanism and synvolcanic, trondhjemitic plutonism along the northern margin of the western Wawa-Abitibi terrane due to northward subduction of volcanic-dominated micro-continents (e.g., Wawa-Abitibi terrane) (White et al., 2003; Percival et al., 2006). Deposition of clastic sedimentary rocks in the Quetico basin. Emplacement of the oldest (tonalite) phase of the Black-Pic batholith (Jackson et al., 1998)
ca. 2.696 to 2.689	Commencement of the diachronous Shebandowanian Orogeny (approximately 2.695 to 2.677 billion years ago) involving collision of the Wawa-Abitibi micro-continental terrane with terranes to the north. (Percival et al., 2006; Peterson and Zaleski, 1999)
ca. 2.689 to 2.687	Emplacement of the monzodiorite phase (2.689 billion years old) of the Black-Pic batholith (Zaleski et al., 1999)
ca. 2.687 to 2.680	Regional D_2 deformation coeval with the peak amphibolite facies regional metamorphism, and local granulite facies and partial melting of clastic sedimentary rocks in the Quetico basin
ca. 2.680	Minimum age of regional D_2 deformation is defined by the 2.68 billion-year-old granite intrusion of the Loken Lake pluton in Township of Manitouwadge. Maximum age of regional D_3 deformation is defined by folding of the 2.68 billion-year-old Nama Creek pluton, also in Township of Manitouwadge
ca. 2.679 to 2.677	Regional D_3 deformation that produced the major east-northeast-trending upright folds in response to northwestward directed collisional transpression recorded across the Wawa-Abitibi terrane boundary with the Quetico metasedimentary gneisses to the north. (Percival et al., 2006). Late D_3 ductile faults (D_4 of Williams and Breaks, 1989) and kink folds (D_4 of Peterson and Zaleski, 1999) occurred during cooling across the terrane boundary, notably in the Quetico metasedimentary migmatites
ca. 2.679	The Everest Lake pluton, a sheet-like intrusion along the Quetico-Wawa contact near Manitouwadge, displays incipient migmatization and thereby constrains a period of metamorphism to be contemporaneous with D_3 deformation
ca. 2.677	Regional D_4 deformation defined by antiform folding of the Banana pluton in Township of Manitouwadge and by local interference of D_3 structures preserved locally within the Quetico metasedimentary rocks
ca. 2.673 to 2.671	Metamorphism (cooling?) of migmatized tonalite gneiss intruding migmatized Quetico metasedimentary basin north of Hornepayne, accompanied by muscovite-bearing granitic intrusions. Syn-orogenic granitic plutons and gabbroic intrusions occur across the Hornepayne area both in the Quetico basin and intruding the Black-Pic batholith. Late brittle (D_5) fault overprint
ca. 2.45	Intrusion of the northwest-trending Matachewan diabase dyke swarm
ca. 2.17	Intrusion of the northeast-trending Biscotasing diabase dyke swarm
ca. 2.126 to 2.101	Intrusion of the north- to northeast-trending Kapuskasing (Marathon) diabase dyke swarm (Halls et al., 2008)
ca. 1.947 to 1.9	Proterozoic brittle fault overprint and reactivation of regional-scale Archean faults (Peterman and Day, 1989; Percival and Peterman, 1994) collectively treated as D_6 events
ca. 1.1 to 1.0	Onset of development of Mid-Continent Rift and emplacement of northeast-trending Abitibi dykes south and southeast of the Hornepayne area

Six main regionally distinguishable deformation episodes (D_1-D_6) for the Manitouwadge area are inferred, based on the regional scale of the deformation, to have also overprinted the bedrock geological units of the Hornepayne area. The following sequence of tectonic deformation (D_x) events is based on detailed structural studies undertaken in the Manitouwadge area (Peterson and

Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001; Williams and Breaks, 1996) and is presented here as a general framework to understanding the likely tectonic history of the Hornepayne area.

- D_0 primary bedding and lithologic layering is locally preserved in strongly deformed sedimentary and volcanoclastic units.

- D_1 regional tectonic deformation is locally evident in Quetico metasedimentary rocks and as a ductile fault at Manitouwadge. S_1 foliations outline D_2 folds.

- D_2 defines the regional schistosity as an axial planar S_2 fabric within amphibolite grade volcanic and sedimentary rocks, migmatitic rocks and differentiated layering in tonalite. S_2 foliations dip northward and L_2 lineations plunge north to northeastward outside of the domain of D_3 deformation.

- D_3 deforms D_2 fabrics and produced major synform and antiform structures plunging shallowly westward or eastward, accompanied by late-stage east-trending and northwest-trending dextral shear zones and faults, and northeast-trending sinistral shear zones in the Manitouwadge – Hornepayne region. Z asymmetry of F_3 folds is characteristic and reflects northwest-directed transpressive deformation.

- Late D_3 ductile faults (D_4 of Williams and Breaks, 1989) and kink folds (D_4 of Peterson and Zaleski, 1999) occurred during cooling across the terrane boundary, notably in the Quetico metasedimentary migmatites.

- D_4 local refolding of D_3 structures occurs most typically but very locally preserved within Quetico metasedimentary rocks.

- D_5 applies to later brittle faults and fractures trending northwest, northeast and northward. These brittle structures mark a period of crustal cooling under residual stress and affect rocks of the narrow, dominantly amphibolitic supracrustal belts as well as synvolcanic and synorogenic plutons, gneisses and the Black-Pic batholith. Some faults and fractures may have been reactivated during later D_6 Proterozoic events.

- D_6 events are collectively potential Early Proterozoic faults and reactivation on Archean faults. Reactivation of Archean faults, coincident with thermal resetting of biotite radiometric ages in the Hornepayne region, would have developed during far-distant collision of the Trans-Hudson Orogen with the Superior Province as well as related uplift of the Kapuskasing structural zone to the east.

Little information is available for the geological history of Hornepayne area for the period following the onset of development of Mid-Continent Rift approximately 1.1 billion years ago. During the Paleozoic, much of the Superior Province was inundated by shallow seas and Paleozoic strata dating from the Ordovician to Devonian are preserved within the Hudson Bay and Michigan basins. The presence of a small outlier of Paleozoic strata known as the Temiskaming outlier in the New Liskeard area indicates that Paleozoic cover was formerly much more extensive and much of the present surface of the Canadian Shield lies close to an exhumed paleoplain interpreted to be of Ordovician age (Brown et al., 1995).

While there is a restricted area of Mesozoic strata within the Moose River Basin and there is evidence of Mesozoic-age emplacement of kimberlitic pipes and dykes elsewhere in northern Ontario, no post-Precambrian to pre-Quaternary rocks are known within the Hornepayne area. The contact between bedrock and the overlying unconsolidated Quaternary sediments represents an unconformity exceeding one billion years.

2.3 QUATERNARY GEOLOGY

Glacial, glaciofluvial and glaciolacustrine deposits that largely accumulated with the progressive retreat of the Laurentide Ice Sheet, during the late Wisconsinan glaciation, dominate the Quaternary geology of the Hornepayne area. This most recent period of glaciation began approximately 115,000 years ago and reached its greatest extent 20,000 years before present, at which time the ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992). Erosion during the late Wisconsinan glaciation has generally removed any earlier unconsolidated deposits in the area. Retreat of the ice mass from the Hornepayne area occurred approximately 9,000 years ago (Boissonneau, 1966).

The main direction of the most recent ice advance, as indicated by several eskers throughout the area (Figure 3), was from the north-northeast (Gartner and McQuay, 1980a; 1980b). This ice advance left thin and discontinuous deposits of sandy, bouldery till throughout the areas mapped as ‘bedrock’, with thicker, more extensive accumulations of till mapped as ‘ground moraine’ (Figure 3). The Arnott interlobate moraine is a prominent plateaux-like landform that was deposited in the north-central part of the Hornepayne area (Figure 3) during a minor readvance of the ice mass (Boissonneau, 1966). Its surface is marked by kettles and kames, with an esker complex extending along it western margin. In the Hornepayne area, the moraine rises 50 to 80 m above the surrounding glaciolacustrine plain.

Following withdrawal of the ice mass, glacial Lake Barlow-Ojibway occupied the low-lying parts of the Hornepayne area. At this time, flat-lying deposits of sand, silt and clay had accumulated at elevations below about 330 m, forming extensive, poorly drained clay plains. Wave-cut terraces around the receding shorelines of glacial Lake Barlow-Ojibway were etched into the side of the Arnott moraine and into extensive areas of ground moraine situated above the glaciolacustrine plain in the northeast part of the Hornepayne area, east and west of the Shekak River (Figure 3).

Along these abandoned shorelines, deposits of sand and gravel mark former beaches within nearshore zones of the proglacial lake (McQuay, 1980a).

Since the disappearance of the ice sheets and the gradual draining or drying up of proglacial lakes, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions. Examples of extensive alluvial deposits are found along the floodplains of the Shekak and Foch rivers (Figure 3). Organic deposits of peat and muck are found throughout the area, particularly in association with thicker, poorly drained overburden deposits.

Information on the thickness of overburden deposits in the Hornepayne area was obtained from water well records and diamond drill holes from a limited number of locations throughout the area (Figure 3). These data indicate overburden thickness values ranging from zero to 38.4 m (Section 5.1). Further information on overburden thickness within the different terrain types mapped on Figure 3 are provided in Section 5.2. In general, the thickest overburden deposits in the Hornepayne area are located at elevations less than about 330 m, with the largest area of thin drift situated at high elevation in the southwest quadrant of the area.

3 TOPOGRAPHY

Topography is an important aspect of the terrain, as it plays an important role in controlling surface and groundwater flow directions and can reveal much about the overburden deposits and geological structures in the Hornepayne area. The following descriptions of the topography rely heavily on the representation of the landscape by the CDED digital elevation model.

3.1 ELEVATION

Elevation ranges from about 263 m in the northeast to 483 m in the southwest of the area shown on Figure 4. The lowest elevation of 263 m in the Hornepayne area occurs where the Shekak River intersects the northern boundary of the area. The maximum elevation of 483 m occurs on a rock ridge between Gum and Granitehill lakes, 6 km west of Obakamiga Lake. The major elevation gradient in the Hornepayne area is established by the contrast provided by the rugged, bedrock-controlled highland in the southwest quadrant of the area and the lowland glaciolacustrine plain covering much of the other three quadrants (Figure 4). The broad upland within the southwest quadrant of the area is informally referred to here as the Obakamiga Upland, representing the only large continuous part of the Hornepayne area where elevations exceed about 345 m. The tops of local ridges within the upland exceed elevations of 400 m. In addition, near Rat Lake, Sawbill Lake, and Norton Lake there are a few residual areas of high elevation separated from the Obakamiga Upland (Figure 4).

3.2 RELIEF

Relief is a metric that can be defined in different ways, and the calculated value of relief depends on the horizontal dimension considered in the calculation. Relief was calculated in two ways. The first was by subtracting the average elevation within a certain radius from the elevation value in the processing cell (termed departure), providing an indication of the degree to which a point is expressed negatively or positively. Many of the areas of thin drift in the Hornepayne area are located on the tops of rock ridges of various sizes. As a result, relief departure maps (Figure 5, Figure 6) can be effective at delineating the areas of thin drift. The second was defined as the range in elevation within a circular window, providing an indication of the maximum relief, or roughness within the window.

A map of departures from average elevation within a 20 km radius (Figure 5) can define broad areas of high ground within the Hornepayne area. The inset map on Figure 5 shows the areas with at least 15 m of topographic prominence at this scale of calculation. Within the area delineated by the slope density contour of 350 points/km2, the blocks of high ground are generally quite fragmented, giving the impression of being cut by a dense network of geological structures. One of the largest areas is in Welsh Township, an elongate area about 10 km by 4 km in extent. Drew Township contains a northeast trending ridge about 2 km wide and 12 km long. The eastern half of Foch Township contains a complex of four topographically prominent areas dissected by a few linear depressions. In contrast to the areas described above, the two largest contiguous areas of high ground shown in the Figure 5 inset, which are located in Lessards Township and between Haig and Newlands townships, contain significantly less bedrock exposure.

Relief was also calculated as the negative or positive deviation in elevation of point locations with respect to the average elevation within a 2 km radius. This definition of relief produces a map highlighting locally prominent positive or negative landforms (Figure 6). The Obakamiga Upland contains the greatest concentration of positive relief landforms, with elevation changes of 30 to 60 m typically occurring over ground distances of 250 to 1,000 m, and some of the extreme knobs and ridges rising 100 m above the surrounding landscape over short ground distances. The flanks, and in some cases the tops, of many of the rock ridges display cliffs in the SPOT imagery. Most of the hills are less than 1 km long and less than 500 m wide, with a range of shapes displayed from compact and flat on top to elongate narrow ridges.

The areas of strong positive relief shown in Figure 5 and Figure 6 are probably indicative of relatively favourable rock mass conditions and thinner overburden, as compared with the areas of strong negative relief, which likely indicate the surface expression of damage zones in the bedrock associated with geological structures.

A map showing the range in elevation within a 250 m radius (Figure 7) provides an indication of the location and extent of high and low relief areas. The upper limit of relief calculated at this scale is about 132 m. From Figure 7, it appears that the highest relief in the Hornepayne area is found in the Black-Pic batholith in the southwestern part of the Hornepayne area.

3.3 SLOPE

Areas of steep slope form the margins of many of the rugged landforms in the Hornepayne area, particularly rock ridges (Figure 8). As steep slopes in the Hornepayne area are often associated with bedrock topography, with some exceptions (e.g., Arnott Moraine, abandoned shorelines, modern river valleys), the presence of steep slopes in this landscape is generally indicative of minimal overburden cover. Many of the areas lacking steep slopes are relatively flat due to the presence of overburden filling the topographic lows. As a result, a map showing the density of steep (≥6°) slopes within a 2 km radius was prepared to provide a general indication of the areas where the thickness of overburden might be relatively low and conversely where the surficial deposits could be thicker (Figure 9).

The main part of the Obakamiga Upland is delineated by a steep slope density value of about 200 points/km^2 (Figure 9). Based on the appearance of bedrock structure in the digital elevation model and on the abundance of bedrock exposure displayed in the SPOT imagery, the density contour value of 350 points/km^2 appears to delineate the areas of thinnest drift in the Hornepayne area.

4 DRAINAGE

The distribution of surface water and surface water drainage are important factors to consider in the preliminary assessment. The direction of surface water flow is a useful surrogate for groundwater flow at shallow depth.

4.1 WATERBODIES AND WETLANDS

The Hornepayne area contains a large number of lakes of various sizes, with roughly 8.5% (404 km^2) of the area occupied by water bodies (Figure 10). Seven waterbodies within the Hornepayne area are larger than 10 km^2, five of which are larger than 20 km^2 (Table 4). The largest is Kabinakagami River (92.5 km^2), followed by Nagagami Lake (54.1 km^2), Obakamiga Lake (29.4 km^2), Nagagamisis Lake (25.0 km^2), and Cameron Lake (22.3 km^2). The vast majority of lakes in the area are very small in size (less than 1-2 km^2). There are concentrations of small lakes associated with the Arnott Moraine and the two eskers mapped about 10 km south of the Township of Hornepayne. To some extent, the larger lakes in the area must conceal the surface expression of geological structures. However, the larger lakes in the area display a mixture of circular shorelines formed in surficial materials and straight shorelines controlled by geological structures. The circular portion of a lakeshore is generally indicative of that portion of the lake resting over thicker overburden deposits.

Table 4 Size of waterbodies larger than 20 km^2 in the Hornepayne area.

Lake	Perimeter (km)	Area (km^2)
Cameron Lake	33.8	22.3
Nagagamisis Lake	70.6	25.0
Obakamiga Lake	136.5	29.4
Nagagami Lake	70.3	54.1
Kabinakagami River	283.8	92.5

[1]Metrics obtained from LIO OHN Waterbody file

Wetlands depicted on Figure 10 are from the Wetland Unit and FRI Wetland files produced by the MNR. The mapping coverage provided by these files provides a reasonable impression of the number and extent of wetlands in the Hornepayne area. However, many wetlands displayed in the

SPOT imagery are not included in these files. An obvious concentration of unmapped wetlands occurs in a 20 km radius around Nagagami Lake, including several larger features with extents of 0.5 to 1.0 km^2.

The larger wetlands in the Hornepayne area occur in association with the larger lakes, which reflects the distribution of the more extensive and thicker, poorly drained overburden deposits in the area. The area delineated by the slope density contour of 350 points/km^2 (see Section 3.3) contains the best example of wetlands, lakes and creeks occupying linear depressions associated with geological structures (Figure 10), a product of thin overburden cover.

The MNR completed depth surveys of selected lakes in the late 1960s and early 1970s (Figure 10). The resulting depth maps consist of contour plots based on soundings. The greatest known lake depth in the Hornepayne area is 27 m in Nagagami Lake (Table 5).

Table 5 Maximum and mean depths of lakes in the Hornepayne area.

Lake[1]	Max depth (m)	Mean depth (m)
Nagagami Lake	27	8
Nagagamisis Lake	12	4
Kabinakagami Lake	15	3

[1]Depth values obtained from margin of MNR depth maps

4.2 WATERSHEDS

A watershed, also known as a catchment, basin or drainage area, includes all of the land that is drained by a watercourse and its tributaries. JDMA conducted a drainage analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the MNR. The drainage divides assist with inferring regional and local groundwater flow directions.

The best available catchment delineation for the Hornepayne area is the quaternary watershed file produced by the MNR. According to the metadata for this file, a quaternary watershed is a polygon feature that identifies a subdivision of a tertiary watershed (MNR tertiary watersheds are generally equivalent to the sub-sub-division of drainage areas produced by the Water Survey of Canada). The boundaries of the quaternary watersheds were created based on the Provincial DEM and Enhanced Flow Direction products that the MNR released between 2006 and 2008. The watershed boundaries are generally consistent with the regional hydrology available for Ontario. The horizontal positional accuracy of the quaternary watershed boundaries is variable depending on the nature and spatial distribution of the raw DEM information, and thus cannot be quantified without onsite investigation and verification. In general, positional accuracy in northern Ontario is within 400 m, but there is no statistical level of confidence available.

JDMA modelled the movement of water over the landscape using the watershed analysis function in the program TNTmips with the CDED elevation model as the surface model. The CDED digital elevation model used for this study was created by NRCan using the same data on which the Provincial DEM was constructed. As a result, the DEM used here is comparable with that used by the MNR to construct the quaternary watersheds.

The procedure that JDMA followed in the drainage analysis was to confirm the boundaries in the quaternary watershed file and then to subdivide the quaternary watersheds where possible. It is important to note that the quaternary watersheds do not represent the smallest catchments that can be delineated in most areas, as local ridges and highland complexes are present within many of the quaternary watersheds that serve to divide surface flow directions within the basin. The drainage analysis was conducted with no a priori knowledge of the quaternary catchments. Rather, only the tertiary catchments were examined during the drainage analysis.

The result of the drainage analysis is a single set of lines and polygons, which represents a merged watershed file (Figure 11). Where drainage divides created by JDMA matched reasonably with the quaternary watershed boundaries, the procedure was to accept the existing quaternary watershed boundary. Newly delineated drainage divides were then used to subdivide the quaternary watersheds. In some instances, the quaternary watershed file contained a drainage divide that was not delineated by JDMA during the drainage analysis. JDMA made an effort to ensure that the newly delineated drainage divides honoured the existing watercourse map file.

4.3 SURFACE FLOW

The southwest corner of the Hornepayne area drains through the White River sub-sub drainage area towards northeastern Lake Superior (Figure 11). This includes flow from the narrow basin surrounding Gum Lake and the Gum River and the small basin containing Tocheri Creek. Aside from this corner of the area, surface flow elsewhere in the Hornepayne area is directed by the Nagagami and Upper Kabinakagami rivers into the Kenogami and Albany rivers and then into James Bay.

The Foch, Obakamiga and Shekak rivers are the main watercourses draining the upland in the southwest corner of the Hornepayne area. Many of the watersheds shown in Figure 11 display a northeast elongation reflecting the overall direction of flow within the Nagagami and Upper Kabinakagami sub-sub basins.

5 TERRAIN CHARACTERISTICS

An assessment of the distribution and thickness of overburden deposits is essential for interpreting the lineament investigation. Areas covered by thick overburden deposits are areas where the least amount of information is available on the presence of adverse geological structures and bedrock formations.

Another important reason for investigating the surficial deposits in the Hornepayne area is to delineate areas of exposed bedrock that would enable further investigation of the potentially favourable bedrock formation through outcrop mapping of bedrock structures and preliminary rock mass characterization.

The purpose of this section is to review the information on overburden deposits in the Hornepayne area generated through the NOEGTS mapping program, which was undertaken under the auspices of the Ontario Geological Survey in the late 1970s (Figure 3). Section 5.1 provides a review of the water well and drill hole data on overburden thickness. Details on the expected composition, distribution and thickness of surficial deposits within the terrain units are presented in Section 5.2.

5.1 DRILL HOLE AND WATER WELL DATA

Data on overburden thickness from water well records collected by the Ministry of the Environment (MOE) and from diamond drill holes compiled by the Ontario Geological Survey (OGS) have been included here to supplement the information on overburden deposits compiled from NOEGTS reports presented in Section 5.2.

5.1.1 WATER WELL INFORMATION SYSTEM

Water well records from the Ministry of the Environment (MOE, 2012) Water Well Information System for the Hornepayne area were acquired (Section 1.3.4). Of the 71 water wells in the Hornepayne area, 33 records contained information on depth to bedrock. These wells are clustered mostly around the settlement of Hornepayne. It appears that the shallow bedrock is the primary source of exploitable groundwater. Depth to bedrock in these wells ranges from zero to 38.4 m, with an average of about 6.6 m (Table 6).

Table 6 Ministry of the Environment water well data on drift thickness.

Well ID	Date	Elevation (m)	Depth to bedrock (m)
1101173	29/10/1959	319	8.5
1101167	01/09/1960	355	0.6
1101168	03/09/1960	343	2.1
1101171	07/09/1960	357	2.7
1101172	08/09/1960	360	1.5
1101175	29/09/1960	338	2.1
1101176	30/09/1960	338	1.2
1101177	10/12/1960	322	1.5
1100227	17/11/1961	308	10.7
1101170	25/10/1963	348	2.4
1100096	14/07/1964	284	5.5
1101174	27/08/1964	330	7.9
1101179	07/09/1967	342	3.0
1101196	23/10/1967	330	1.5
1101195	27/10/1967	353	1.5
1101197	30/10/1967	326	1.5
1101220	27/01/1968	317	25.9
1101237	12/10/1968	343	1.8
1101169	26/09/1969	352	0.6
1101454	29/08/1971	348	0.9
1101709	12/06/1973	326	1.5
1101944	20/09/1974	321	11.9
1101946	20/09/1974	322	11.9
1103047	12/09/1977	342	0.0
1102427	06/10/1978	348	2.1
1102607	26/09/1979	332	3.7
1102608	27/09/1979	330	19.2
1102606	02/10/1979	332	1.8
1102809	12/08/1980	349	13.1
1102785	13/08/1980	314	9.8
1102783	14/08/1980	313	13.7
1102986	12/08/1981	366	6.4
1105519	13/11/1992	350	38.4

5.1.2 ONTARIO DRILL HOLE DATABASE

The 31 drill holes in the Hornepayne area reviewed in this assessment (Section 1.3.4; Table 7) are located in three main areas (Figure 3). Six of the holes are located in bedrock terrain about 10 km northeast of Obakamiga Lake, where depth to bedrock was less than 5 m in the holes located on hills whereas the hole located in a depression along a lake shore recorded a depth to bedrock of about 18 m. Nine other drill holes are located about 7 km south of the southeast corner of the Township of Hornepayne, located within a complex of glaciolacustrine and esker deposits mapped in Figure 3. All of these holes record depths to bedrock less than or equal to 6 m. The remainder of the drill holes are located 28 km east of the Township of Hornepayne within a broad area mapped as a glaciolacustrine plain. Nine of these holes record depths to bedrock of less than 5 m and the greatest depth recorded was about 20 m. The extent to which any of the drill sites were stripped of overburden before drilling took place is unknown.

Table 7 Ontario Geological Survey diamond drill hole data on depth to bedrock.

		Drift thickness (m)		
AFRI FID[1]	Count	Min	Max	Mean
42F02SE0002	1	1.4	1.4	1.4
42F02SE0003	8	0	6.7	1.9
42F06SW0003	1	17.7	17.7	17.7
42F07SW0005	5	2.2	3.9	2.8
42F08SW0002	9	0	20.1	5.0
42F08SW2002	2	2.6	2.6	2.6
42F08SW2003	5	0	8.2	4.8
Summary	31	0	20.1	4.0

[1]Assessment File Research Image (AFRI) file number

5.2 NOEGTS TERRAIN UNITS

5.2.1 BEDROCK

The term “bedrock terrain” used in the NOEGTS maps and reports is somewhat misleading, and morainal veneer would be a more appropriate term. Many readers misinterpret the term bedrock terrain as meaning exposed bedrock. Exposed bedrock makes up rarely more than 10 to 20% of local zones within the broad areas mapped as bedrock terrain. Even in areas of thin overburden, dense vegetation can result in no bedrock exposure over large areas, especially in areas harvested by the forest industry.

All of the bedrock terrain mapped in the Hornepayne area has been mapped as bedrock knob terrain (Figure 3), with bedrock plateau, plain and ridge notably absent. Within bedrock terrain mapped in the Hornepayne area, Gartner and McQuay (1980a, 1980b) suggest that drift deposits consist of a discontinuous layer of ground moraine that is usually less than one metre thick. On the sides of some of the knobs and in the lows between the hills, the overburden can thicken to as much as 5 m, with swamps located in many of the low areas between rock knobs.

The outline of the largest contiguous area mapped as bedrock knob terrain (Figure 3) matches the outline of the steep slope density contour of 350 points/km^2. This area is expected to contain the best bedrock exposure and largest contiguous area of thin drift in the Hornepayne area, with the high ground northwest and southeast of Granitehill Lake, north of Obakamiga Lake, and in the northern half of Foch Township providing the best examples. Outside of this area, it is expected that the areas of thin drift are patchy and consist of either glaciolacustrine and morainal deposits.

Within bedrock terrain, bearing capacities are usually excellent, blasting is required for excavations, earth borrow is scarce, groundwater resources are unpredictable, and trafficability is poor (Gartner et al., 1981).

5.2.2 MORAINAL

Ground moraine covers almost all parts of the Hornepayne area, but areas shown as ground moraine on Figure 3 are places where a thicker cover of till exists over the bedrock. In these areas, Gartner and McQuay (1980b) suggest that the morainal deposits form a 2 to 5 m thick mantle of stony, cobbly and bouldery silty sand till overlying the bedrock. According to these authors, much of the ground moraine has been flooded by glacial lakes and meltwaters, resulting in a washed and modified surface, and producing layers of stratified sand, silt and sometimes gravel overlying and intermixed with the till. In areas mapped as ground moraine, the terrain is typically well drained, topography is undulating to knobby, and bedrock knobs and narrow ridges occur along the trend of other moraine-like features.

The ground moraine deposits mapped on the highlands a short distance east and west of Hornepayne are discontinuous or patchy in extent, filling the lows between rock ridges and knobs (Figure 3). Within these areas, deciduous forest cover extends to the tops of many of the hills, with few bedrock exposures typically shown in the SPOT imagery. On the more rugged part of the Obakamiga Upland, there are very few ground moraine deposits mapped. In this area, many of the hills exhibit exposed bedrock.

Virtually no drumlins are shown in Figure 3. However, the ground moraine in the furthest northeast part of the Hornepayne area displays a north-northwest trending drumlin fabric that was mapped in the regional surficial geology file.

5.2.3 GLACIOFLUVIAL

The Arnott Moraine is an interlobate kame moraine (Boissonneau, 1966) that represents the major glaciofluvial landform mapped in the Hornepayne area (Figure 3). Sand and gravel are the primary material types present in the landform, but organic terrain and ground moraine are subordinate landforms associated with the moraine. Outwash and eskers have been mapped south of Hornepayne. Outwash deposits are not extensive in the Hornepayne area.

Larger glaciofluvial deposits have the potential to represent significant regional aggregate or groundwater supplies. The good foundation conditions and abundance of suitable borrow and granular materials make these landforms ideal for transportation routes, building sites, forest management staging areas, and airport locations.

5.2.4 GLACIOLACUSTRINE

All of the glaciolacustrine deposits in the Hornepayne area have been mapped as glaciolacustrine plains (Figure 3), with no nearshore or delta deposits mapped (McQuay, 1980a, 1980b). This is in contrast to the OGS Quaternary geology map, which shows nearshore glaciolacustrine deposits mapped typically at higher elevations than the deep-water plain deposits.

Within the glaciolacustrine plain in the northeast part of the Hornepayne area, there are local high areas where bedrock terrain has been mapped, and the SPOT imagery confirms that bedrock is exposed in some of these areas. Bedrock is also exposed along parts of the northeast facing abandoned shorelines mapped in this area.

According to Gartner and McQuay (1980a), the glaciolacustrine plains mapped in the northeast lowland part of the Hornepayne area consist of stratified silt, sand and clay, with varved silt and clay representing a common material type. Organic terrain and ground moraine are subordinate landforms associated with this terrain. These authors indicate that water well logs from the area reveal that the glaciolacustrine sediments vary in thickness from a little more than 1 m to about 8 m and either overlie sandy, bouldery tills or rest directly on the bedrock. The total thickness of overburden varies from 6 to 44 m.

At higher elevations within the Hornepayne area, the lake plain sediments form a thin mantle over the bedrock, perhaps up to 5 m thick, distributed amongst thin patches of organic terrain and ground moraine (Gartner and McQuay, 1980a). These are low-relief areas with mixed drainage conditions. Many logging roads extending through highland areas mapped as glaciolacustrine plain attempt to traverse along the local areas of ground moraine where possible to take advantage of better drainage conditions.

The geotechnical properties of the silts and clays associated with glaciolacustrine plains are usually poor, with low shear strengths that decrease with depth, poor bearing capacities, and high frost susceptibility (Gartner et al., 1981). These materials can have high moisture contents and can be difficult to handle and compact.

5.2.5 ORGANIC

Areas of organic terrain contain a mixture of peat and muck with stagnant drainage or wet surface conditions. Many organic areas consist of wet areas of mosses, grasses, sedges, and small herbaceous plants, often interspersed with small areas of open water. Others are treed areas consisting of dry or wet muskeg on which stunted trees occur as widely spaced individuals or in small groups.

Patchy organic deposits have been mapped throughout the Hornepayne area (Figure 3). One of the largest areas mapped as organic terrain fills the lowland south of Obakamiga Lake associated with an extensive glaciolacustrine plain. The provincial wetlands files (Section 4.1) provide additional information on the distribution of organic deposits within the Hornepayne area.

Exceptionally poor engineering characteristics can be found within areas mapped as organic terrain (Gartner et al., 1981). Peat and muck have very low shear strength and high compressibility. Groundwater tables are at or near the surface in organic terrain. Flooding is common in organic terrain, and this forms a significant constraint on most types of development. Although peat and muck deposits usually occur as relatively thin surficial layers, in places, these organic materials can be several metres thick, and the thickness can change drastically over very short distances. The deposits are generally thin where they overlie flat mineral soil terrain such as outwash and glaciolacustrine plains, whereas they are thicker in high relief till deposits and where they fill bedrock depressions and deep kettle holes. The locations of deeper pockets of organic material are difficult to predict reliably without test drilling.

6 GROUNDWATER

A detailed discussion of the hydrogeology of the Hornepayne area is provided by Geofirma (2013). Only a brief summary of likely groundwater recharge and discharge conditions and local and regional groundwater flows is provided here.

Bedrock aquifers are likely shallow with recharge occurring through discontinuities such as joints and fractures. Gartner and McQuay (1980a, 1980b) suggests that groundwater occurs in fractures and along fault zones in the bedrock terrain, but this terrain unit is considered to have only poor to fair potential for groundwater supplies. A large proportion of the groundwater in the bedrock terrain is likely confined to fractures, with permeability varying from impermeable to highly permeable, depending on the spacing, depth and aperture of discontinuities in the bedrock.

Regional groundwater flow in the Hornepayne area was assessed using surface water elevations, surface drainage directions and ground surface elevations based on the expectation that the regional groundwater table will be a subdued reflection of topography. Due to the large amount of exposed bedrock in the southwest quadrant of the Hornepayne area, the groundwater table in that area will be present within the bedrock, likely within several metres of the ground surface. Exceptions to this assumption will occur in the areas of thicker overburden in the other three quadrants of the Hornepayne area, where the groundwater table will be present within the overburden. Around the margins of highlands and in bedrock valleys, especially in the Shekak River valley, the overburden will act as a local discharge area for bedrock groundwater. In the local highland areas with overburden cover (e.g., Arnott Moraine) the overburden will serve as a groundwater recharge area to the underlying bedrock and adjoining overburden deposits.

Based on the available topographic and drainage information, groundwater is conceptualized as being recharged in the bedrock highlands in the southwest quadrant of the Hornepayne area and flows predominantly northward and eastward via local discharge to lakes and river valleys to the regional discharge locations of the Nagagami-Nagagamisis lakes and the Shekak River. Groundwater flow in areas south and east of the Shekak River is from the bedrock highlands north and northwest to the Shekak River valley and other drainage courses. These estimates of regional groundwater flow conditions in the bedrock will be locally affected by the presence of faults and major structural and lithological discontinuities that have hydraulic properties different from that of the bulk bedrock.

7 NEOTECTONIC FEATURES

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

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major horizontal principal stress orientation in central North America, based on the World Stress Map (Zoback, 1992) is northeast (063° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Zoback, 1992; Baird and McKinnon, 2007), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973) which has likely persisted since the most recent Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

Repeated cycles of glaciation and deglaciation throughout the Quaternary have induced stresses by sequentially loading and unloading the Earth's crust. The loads associated with glaciation are sufficient to depress the crust by hundreds of metres. Crustal rebound takes place once the weight of the ice is removed and rebound continues to occur today in this area, albeit slowly. The greatest rates of rebound typically occur near the ice-centres, such as around the margins of Hudson Bay.

The stresses associated with cycles of ice loading and unloading, acting along with the tectonic stresses, may result in seismic events related to displacements along ancient discontinuities in the bedrock. In addition, the advance of glacial ice may also exert stresses near the bedrock surface during its motion across the landscape. For instance, the glacier can thrust itself against topographic barriers and this can damage the rock and may cause movement along existing discontinuities.

The assessment of neotectonic features in the area may reveal the timing and magnitude of glacially-induced seismic activity and deformations. Conclusive identification of features indicative of reactivation of ancient bedrock structures due to cycles of glacial loading and unloading could not be made using the information sources available in the current assessment. Field investigation would be required to identify such features. Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity in situations where the materials were deposited over lineaments that have been reactivated post-glacially.

8 ACCESSIBILITY CONSTRAINTS

Highway 631 is the main access road into the Hornepayne area. It provides north-south access to the central part of the Hornepayne area, including good access to areas of favourable bedrock and somewhat favourable surficial geology in Beaton, Larkin, and Hornepayne townships (Figure 1). The terrain in these townships is mapped as patchy areas of bedrock terrain interspersed with sporadic to locally extensive areas of ground moraine, organic terrain, glaciolacustrine plain, and glaciofluvial deposits.

The areas of thinnest overburden cover and best bedrock exposure in the Hornepayne area are located 20 to 40 km west of Highway 631. The most favourable areas in terms of thin drift cover are located in Welsh, Drew, and Foch townships, with Lessard and Chelsea townships displaying less favourable conditions roughly equivalent to those found along Highway 631. Cholette Township contains an abundance of lakes, wetlands and creeks, which limit the available land and complicate access.

The MNR road segment file is used in Figure 1 to illustrate the distribution of resource roads in the Hornepayne area. This file contains resource access roads constructed for and used by conventional street legal vehicles, it includes winter roads, and it contains roads not under the jurisdiction of the MNR (municipal roads and provincial highways) that are sourced from the Ontario Road Network. Recreation trails and short-term forest operation roads (skidder trails) or forest fire management roads (e.g., rehabilitated fire trail) are not included in the MNR road segment file. An evaluation of this file revealed that it contains many of the resource roads visible in the Hornepayne area from the SPOT imagery, but that there are still some roads not included in the MNR road segment file. JDMA mapped some additional roads from the satellite imagery, which are shown on Figure 1.

Some of the townships with the best bedrock exposure are currently the least accessible with the existing road network. This includes Welsh Township, the south half of Drew Township, and the northwest corner of Foch Township. Welsh and Drew townships contain some of the most impressive topography in the Hornepayne area, with several north-northwest trending narrow lakes, and cliff-bounded trenches and ridges forming constraints to the development of new roads into this area of particularly good bedrock exposure. The northeast corner of Foch Township lacks roads, but the slightly less rugged topography is relatively favourable for routing new roads as compared with the latter two townships.

9 SUMMARY

This report presents an analysis of the terrain in the Hornepayne area using available remote sensing and geoscientific information sources. The aim is to provide information that enhances and expands upon that presented in the initial screening report (Golder, 2011). The main information sources relied on in this study are the Canadian Digital Elevation Data (CDED) elevation model, the multispectral SPOT satellite imagery and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS).

Expectations about the nature, distribution and thickness of Quaternary deposits were generated based on 1:100,000 scale NOEGTS mapping and on interpretation of CDED and SPOT imagery. The Arnott Moraine, an interlobate kame moraine, is present in the north central part of the area. Much of the northwest, northeast and southeast quadrants of the Hornepayne area are underlain by thick overburden deposits consisting of ground moraine, glaciolacustrine sediments, and organic deposits. The most extensive area of thin drift and good bedrock exposure is located within a highland in the southwest quadrant of the Hornepayne area, which formed a topographic barrier to glacial Lake Barlow-Ojibway, precluding deposition of extensive glaciolacustrine deposits above an elevation of about 330 m.

The distribution of bedrock exposures was interpreted from multispectral SPOT imagery. A composite image was created based on principal component analysis, which effectively distinguishes between many of the land cover types present in the Hornepayne area (e.g., bedrock outcrops, conifer forest, and wetland). The SPOT images confirm our expectation from the digital elevation models and the NOEGTS reports that the thinnest drift and best bedrock exposure are associated with positive relief features, such as rock ridges and hills.

Relief maps produced from the CDED digital elevation model consistently dividing the area into zones of negative or positive relief are believed to be one of the more useful datasets available for interpreting the distribution of overburden thickness across the Hornepayne area. The areas of strong positive relief are probably indicative of relatively favourable rock mass conditions and thinner overburden, as compared with the areas of strong negative relief, which likely indicate the surface expression of damage zones in the bedrock associated with geological structures. Several areas of positive relief were delineated and discussed. Many of the rock ridges in the area are less than 1 km long and 500 m wide. The small size of these features is likely related to the presence of a dense network of geological structures including faults and dykes.

Drainage divides delineated in the provincial quaternary watershed file produced by the Ministry of Natural Resources were confirmed using the CDED surface model. In some instances, the quaternary watersheds were subdivided based on the presence of continuous highlands dividing flow within the watersheds. An updated watershed file was produced that specifies the drainage divides delineated in this assessment not present in the quaternary watershed file. Apart from a small area in the southwest corner of the Hornepayne area, all surface flow is directed to the northeast towards James Bay.

The directions of regional groundwater flow and areas of recharge and discharge were interpreted based on topography, on the directions of surface drainage, and on the distribution of overburden deposits. Shallow groundwater flow is expected largely to mimic surface drainage patterns and bedrock aquifers are expected to be shallow, with permeability dependent on the aperture, spacing and persistence of discontinuities. The major bedrock recharge area is the highland in the southwest quadrant of the Hornepayne area. Groundwater from these highland bedrock aquifers will discharge into lowland lakes, creeks, wetlands and overburden deposits.

Conclusive identification of features indicative of reactivation of ancient bedrock structures due to cycles of glacial loading and unloading cannot be identified using the information sources available in the current assessment. Field investigation would be required to identify such features. One type of feature that could be targeted during field reconnaissance is deformed glaciolacustrine deposits filling the trenches forming the surface expression of lineaments. Investigation of such features would likely require excavation with a backhoe to enable a large enough exposure of bedded silt and clay to be inspected for deformation structures recording post-glacial displacements along the lineament.

Accessibility constraints were evaluated by considering the location of the main areas of thin drift and good bedrock exposure in relation to the existing road network as depicted in the Ministry of Natural Resources road segment file and identification of additional roads through inspection of the SPOT imagery. The main highway corridor is generally characterized by drift-veneered bedrock knobs scattered between patchy ground moraine, organic and glaciolacustrine deposits, with a few of the bedrock knobs displaying good outcrop exposure. The most extensive area of thin drift and good bedrock exposure is located 20 to 40 km west of Highway 631, generally accessible by the dense network of resource roads, but the best areas of bedrock exposure in the west are the least accessible using the existing road network.

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REPORT SIGNATURE PAGE

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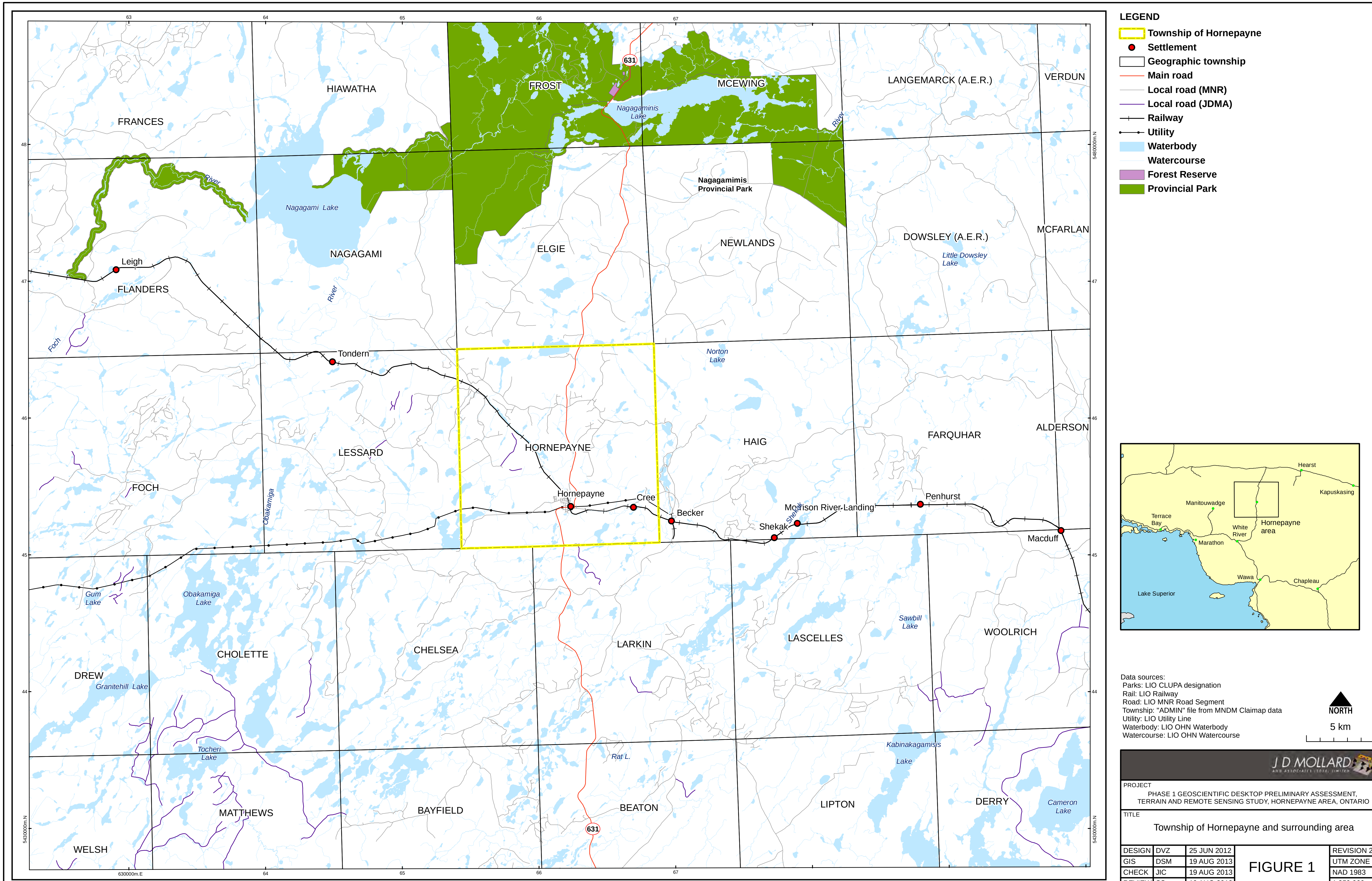
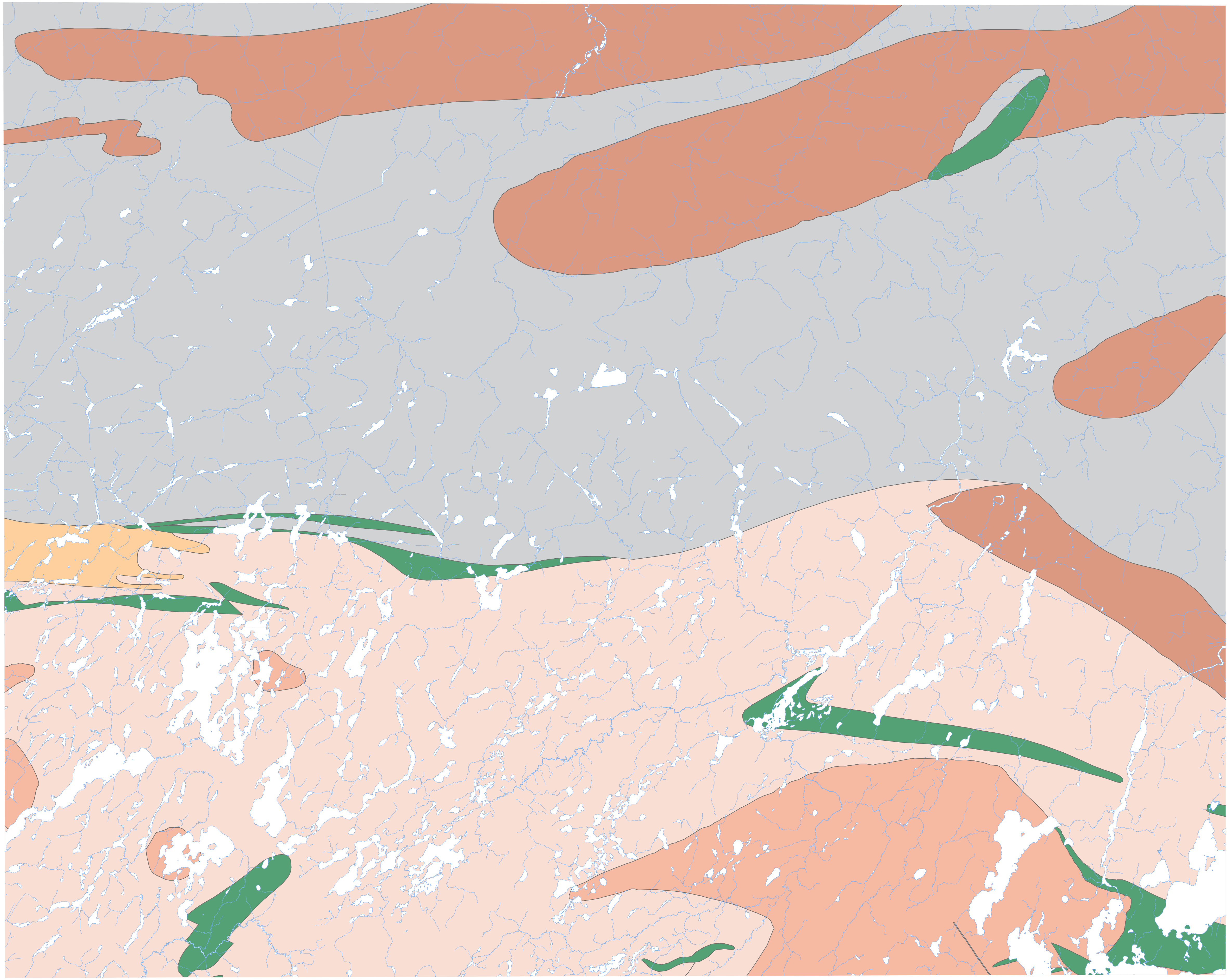
David van Zeyl, M.Sc.

Lynden Penner, M.Sc., P.Eng., P.Geo.

FIGURES



FRANCES
HIAWATHA
FROST
MCEWING
LANGEMARCK (A.E.R.)
VERDUN
Nagagaminis Lake
Nagagamimis Provincial Park
Nagagami Lake
River
NAGAGAMI
ELGIE
NEWLANDS
DOWSLEY (A.E.R.)
Little Dowsley Lake
MCFARLAN
Leigh
FLANDERS
Foch
Tondern
Norton Lake
HORNEPAYNE
HAIG
FARQUHAR
ALDERSON
LESSARD
FOCH
Obakamiga
Hornepayne
Cree
Becker
Morrison River Landing
Penhurst
Shekak
Macduff
Gum Lake
Obakamiga Lake
CHOLETTE
CHELSEA
LARKIN
LASCELLES
Sawbill Lake
WOOLRICH
DREW
Granitehill Lake
Tocheri Lake
Rat L.
Kabinakagamisis Lake
MATTHEWS
BAYFIELD
BEATON
LIPTON
DERRY
Cameron Lake
WELSH
631
630000m.E
5480000m.N
5430000m.N
LEGEND
Township of Hornepayne
Settlement
Geographic township
Main road
Local road (MNR)
Local road (JDMA)
Railway
Utility
Waterbody
Watercourse
Forest Reserve
Provincial Park
Hearst
Kapuskasing
Manitouwadge
Terrace Bay
White River
Hornepayne area
Marathon
Wawa
Chapleau
Lake Superior
Data sources:
Parks: LIO CLUPA designation
Rail: LIO Railway
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Utility: LIO Utility Line
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
NORTH
5 km
J D MOLLARD
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, HORNEPAYNE AREA, ONTARIO
TITLE
Township of Hornepayne and surrounding area
DESIGN DVZ 25 JUN 2012
GIS DSM 19 AUG 2013
CHECK JIC 19 AUG 2013
REVIEW SS 19 AUG 2013
FIGURE 1
REVISION 2
UTM ZONE 16
NAD 1983
1:250,000



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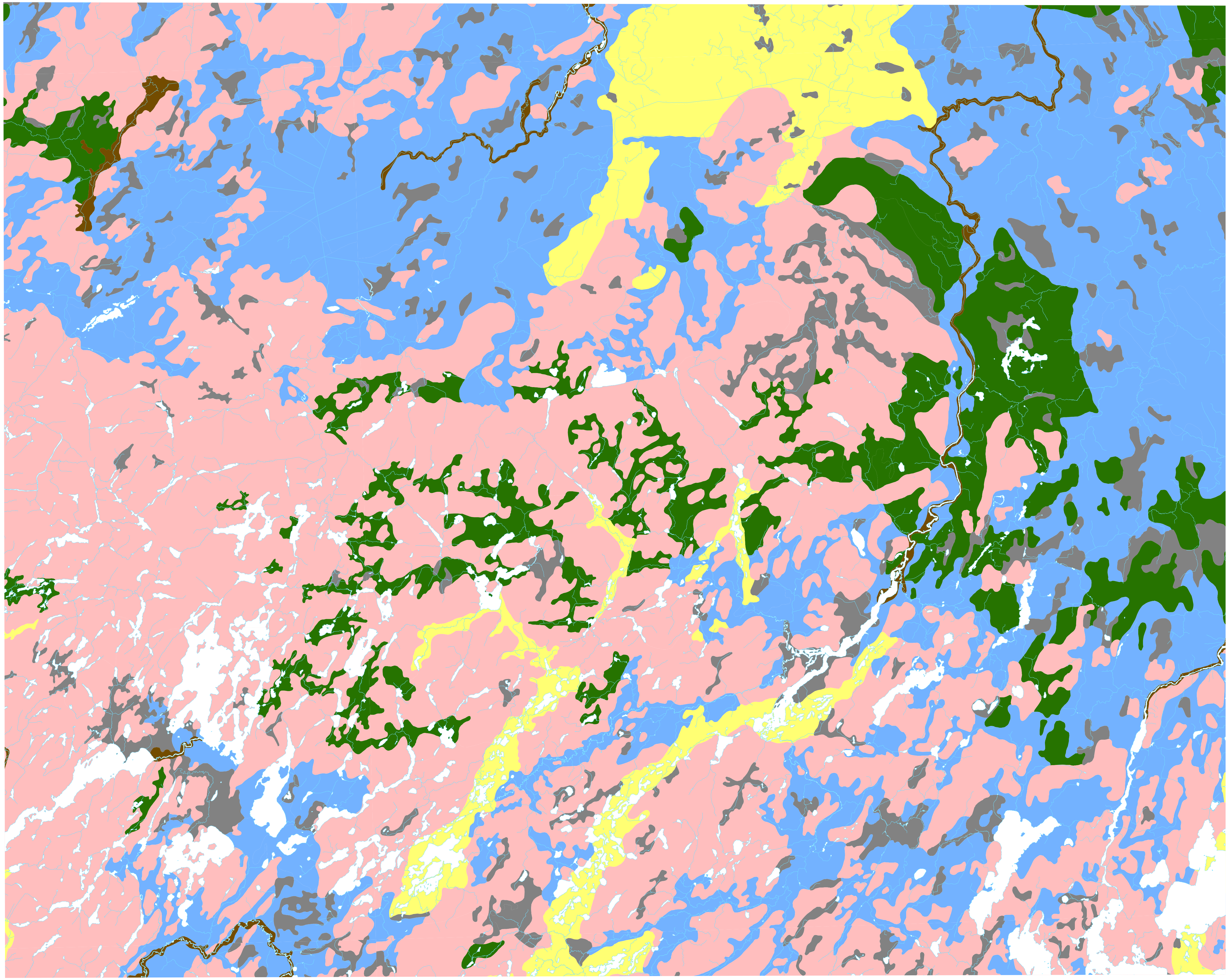

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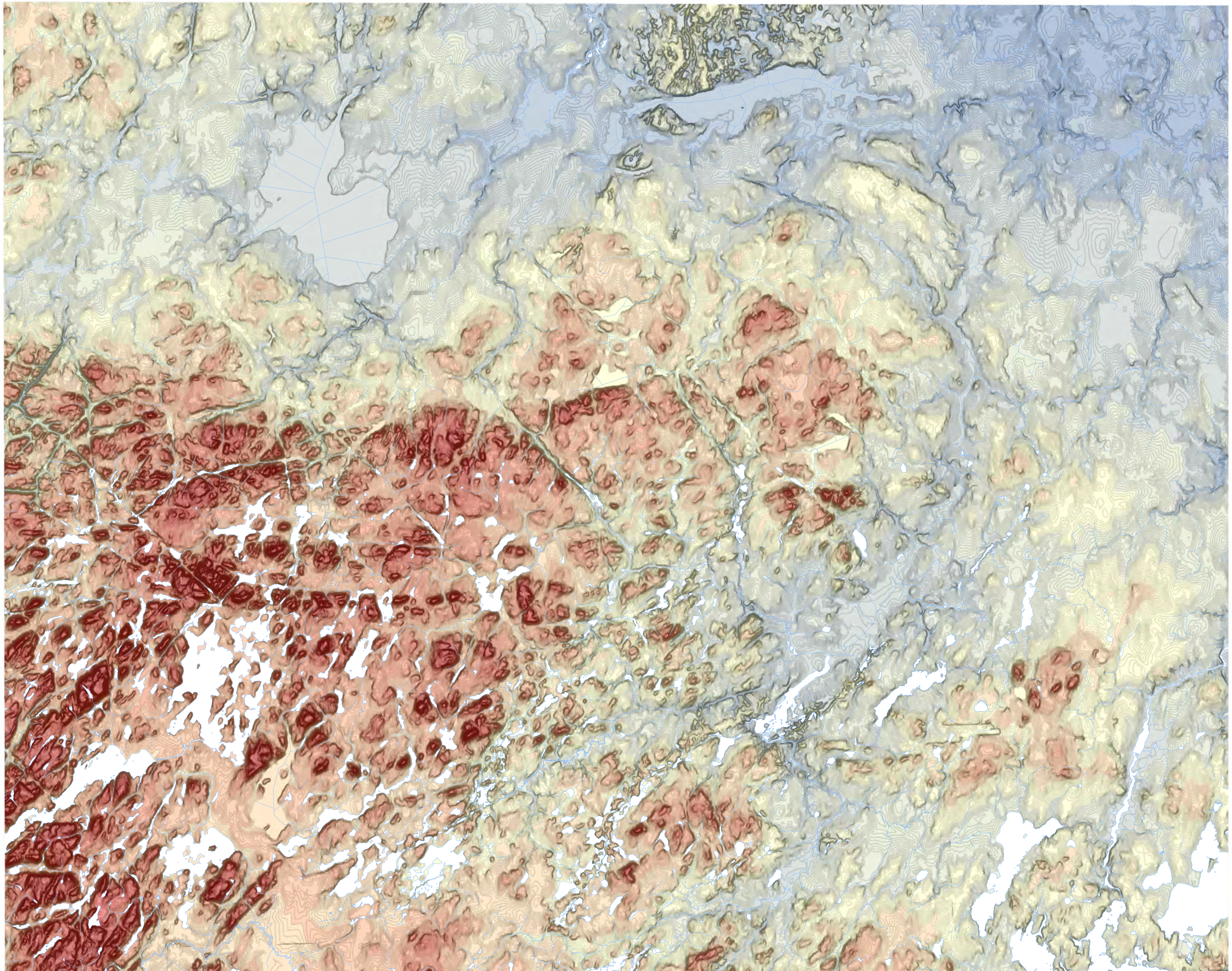

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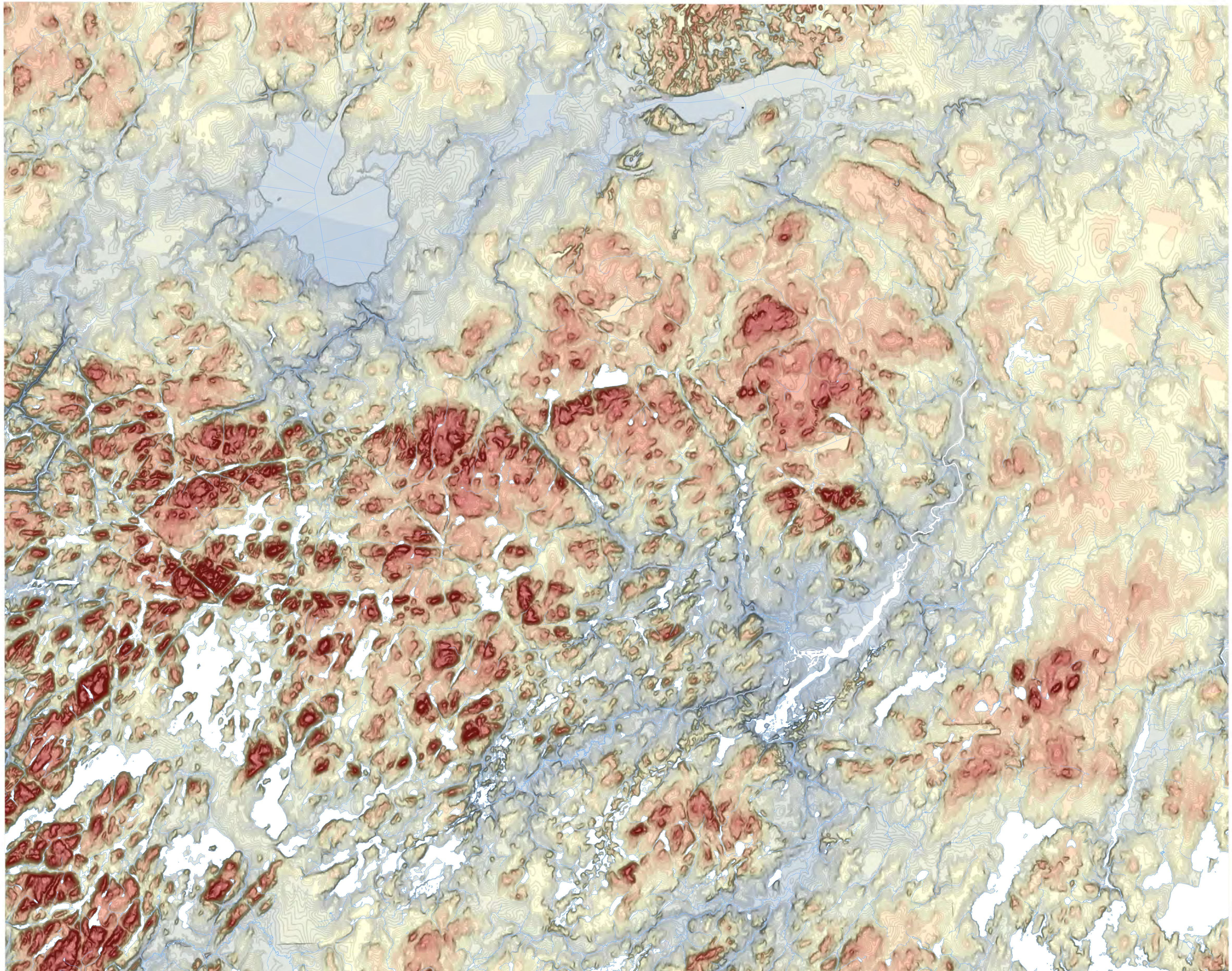

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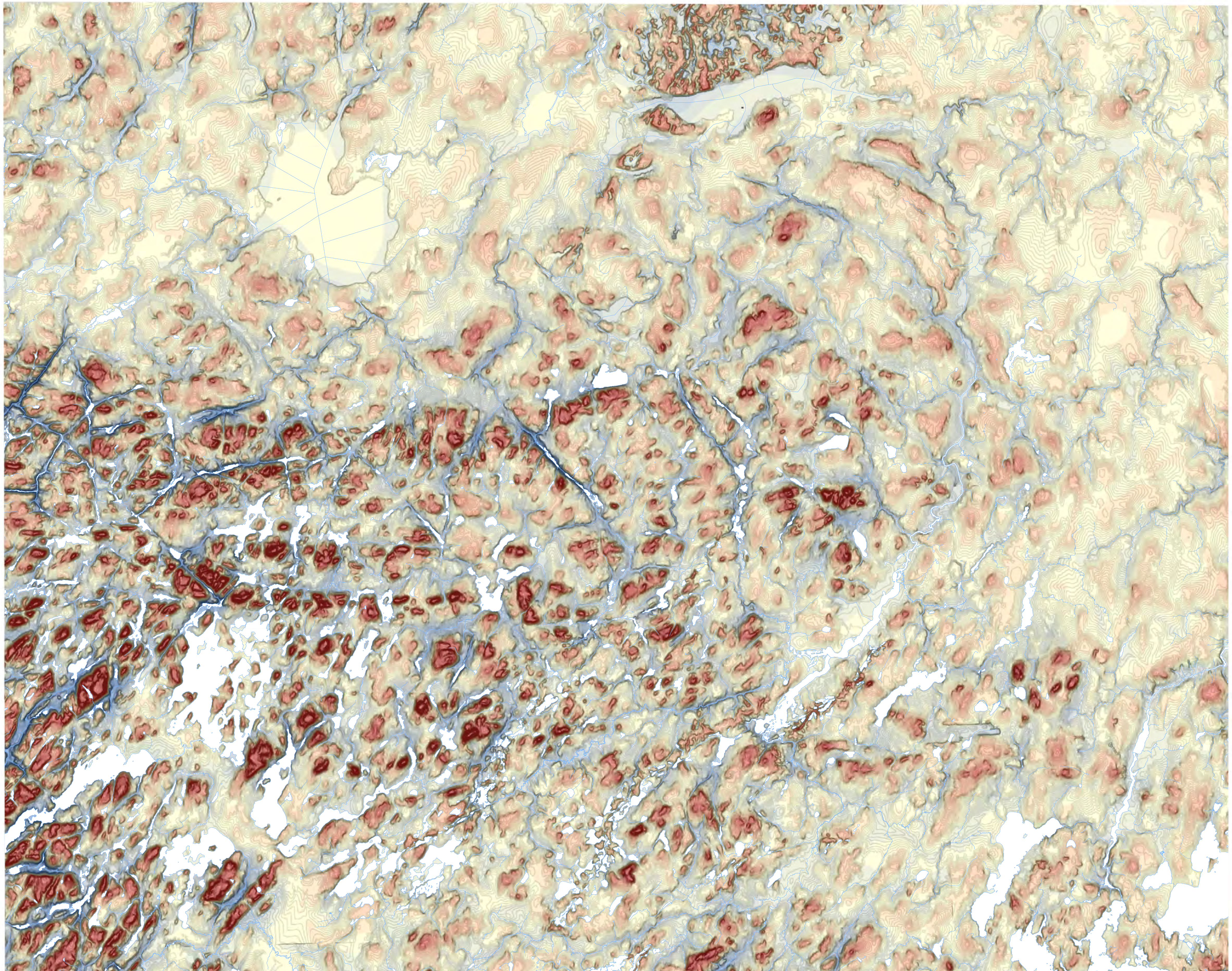

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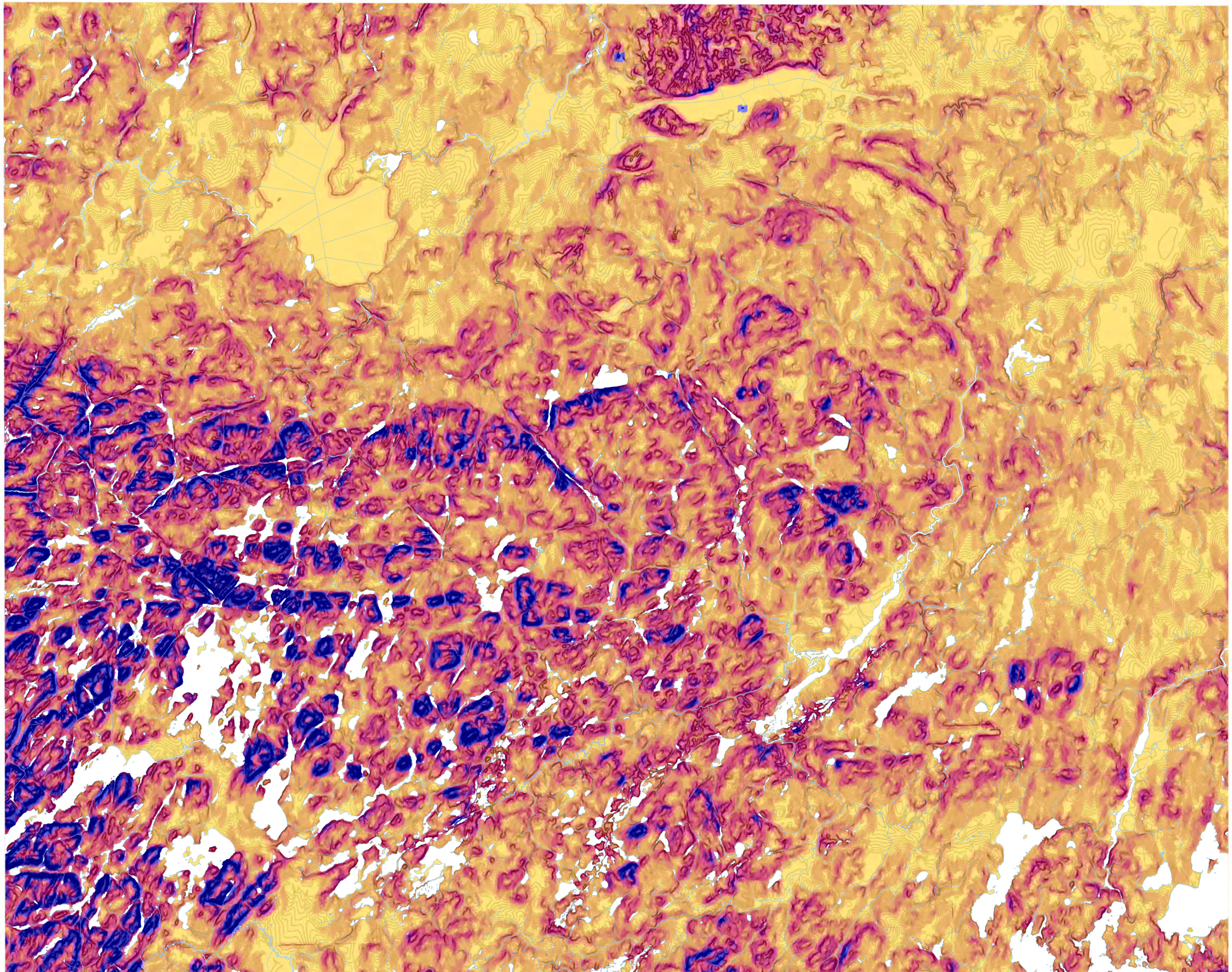

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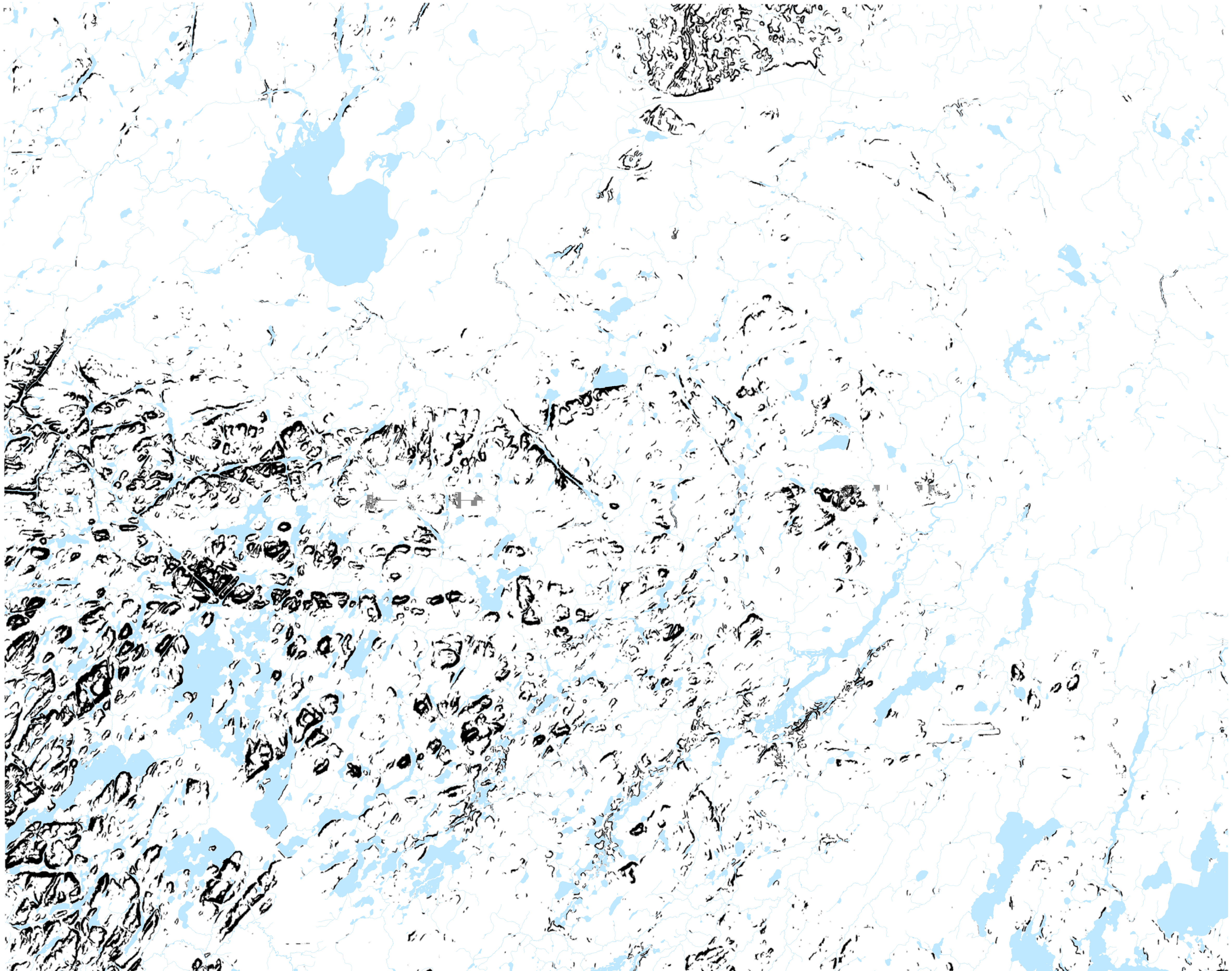

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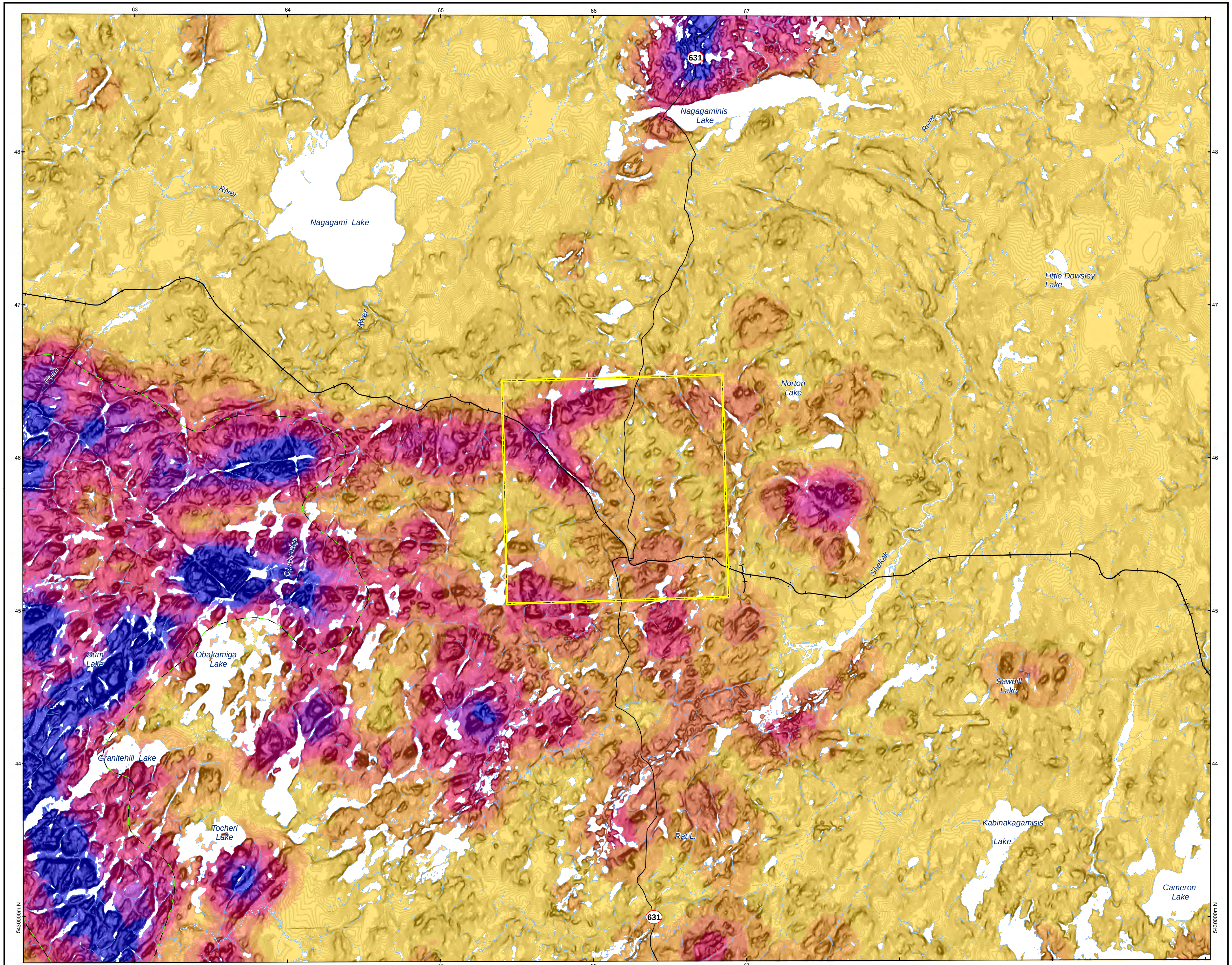


LEGEND

- Township of Hornepayne
- Main road
- Railway
- Slope density 350 p\km2
- Waterbody
- Watercourse

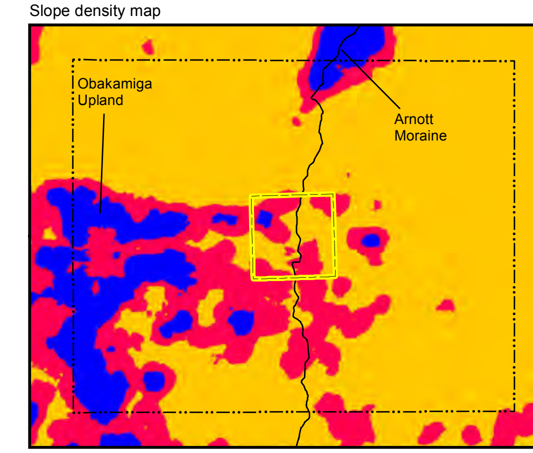
Slope density
Points\km^2

- 0 - 80
- 80.1 - 172.2
- 172.3 - 264.3
- 264.4 - 356.5
- 356.6 - 448.7
- 448.8 - 540.8
- 540.9 - 633
- 633.1 - 1,192

Slope (°)

- 0 - 0
- 0.1 - 1.1
- 1.2 - 2.1
- 2.2 - 3.2
- 3.3 - 4.3
- 4.4 - 5.3
- 5.4 - 6.4
- 6.5 - 71

Slope density map



- Township of Hornepayne
- Main road

Slope density

- 0 - 140
- 141 - 421
- 422 - 1,192

Data sources:
DEM: CDED (1:50,000)
Road: Selected from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

5 km

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PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, HORNEPAYNE AREA, ONTARIO

TITLE
Density of steep (≥6°) slopes within 2 km radius

DESIGN	DVZ	25 JUN 2012	FIGURE 9	REVISION 2
GIS	DSM	19 AUG 2013		UTM ZONE 16
CHECK	JIC	19 AUG 2013		NAD 1983
REVIEW	SS	19 AUG 2013		1:250,000

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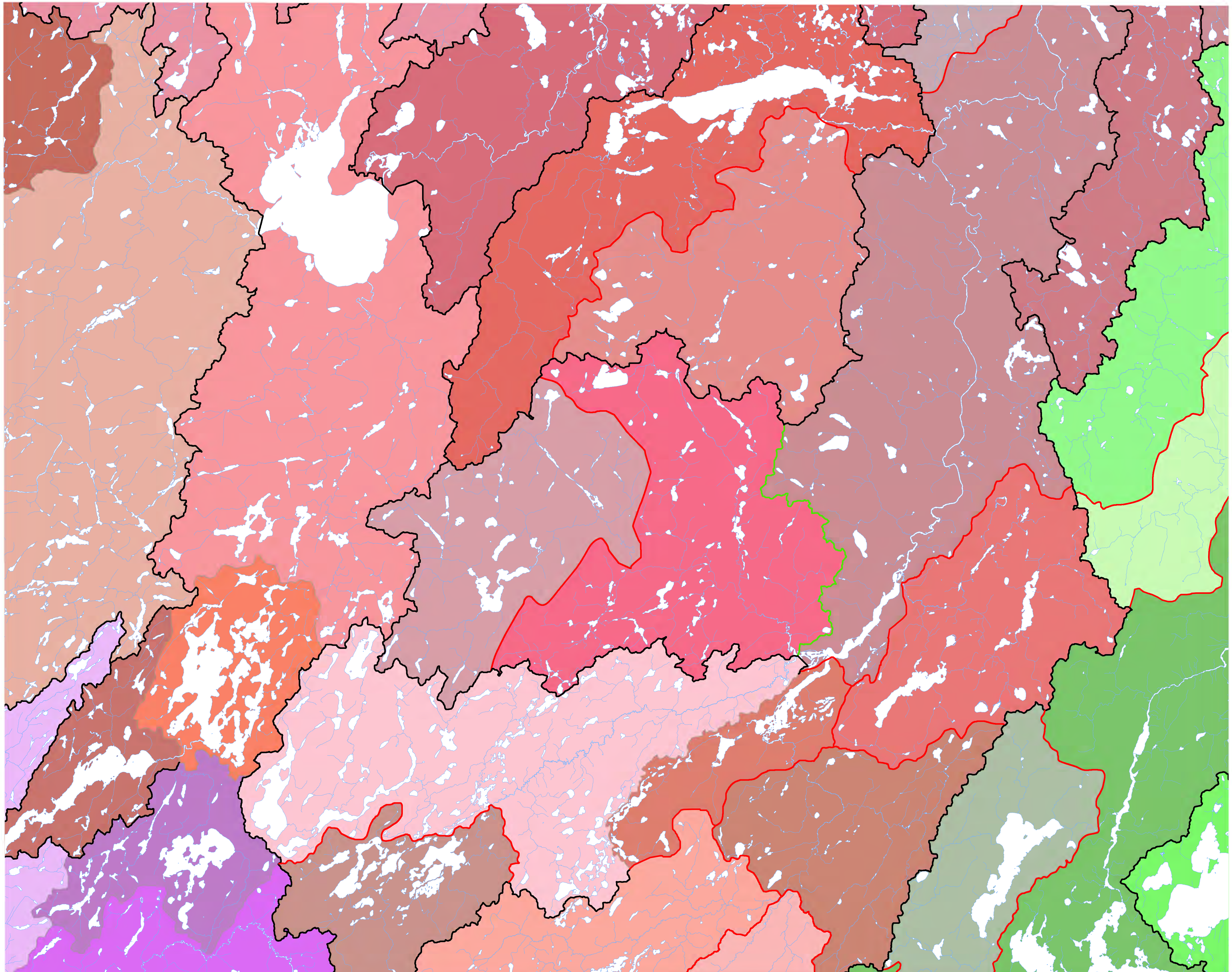

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